NANOTECHNOLOGY: UNDERSTANDING HOW SMALL SOLUTIONS DRIVE BIG INNOVATIONS

HEARING

BEFORE THE

SUBCOMMITTEE ON COMMERCE, MANUFACTURING, AND TRADE

OF THE

COMMITTEE ON ENERGY AND COMMERCE

HOUSE OF REPRESENTATIVES

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[1] Mr. Tour did not respond to submitted questions for the record.
[2] Mr. Mrksich did not respond to submitted questions for the record.
[3] Mr. Phillips did not respond to submitted questions for the record.

NANOTECHNOLOGY: UNDERSTANDING HOW SMALL SOLUTIONS DRIVE BIG

TUESDAY, JULY 29, 2014

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON COMMERCE, MANUFACTURING, AND TRADE,
COMMITTEE ON ENERGY AND COMMERCE,
Washington, DC.

The subcommittee met, pursuant to call, at 10:20 a.m., in room 2322 of the Rayburn House Office Building, Hon. Lee Terry (chairman of the subcommittee) presiding.

Members present: Representatives Terry, Lance, Harper, Olson, Bilirakis, Johnson, Long, Schakowsky, Sarbanes, and Barrow.

Staff present: Leighton Brown, Press Assistant; Graham Dufault, Policy Coordinator, Commerce, Manufacturing, and Trade; Melissa Froelich, Counsel, Commerce, Manufacturing, and Trade; Kirby Howard, Legislative Clerk; Paul Nagle, Chief Counsel, Commerce, Manufacturing, and Trade; Michelle Ash, Democratic Chief Counsel; Carol Kando, Democratic Counsel; and Will Wallace, Democratic Professional Staff Member.

OPENING STATEMENT OF HON. LEE TERRY, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF NEBRASKA

Mr. TERRY. Welcome all to our rock and roll hearing that is in a series of hearings called Nation of Builders where we explore American technology and its impact on job creation and manufacturing. I want to thank all of you here today. Now I feel like I am giving a speech on the National Mall. So while they are trying to fix it, I will continue to talk and be the guinea pig.

So just as electricity, telecommunications, and the combustion engine fundamentally altered American economics in the "second industrial revolution," nanotechnology is poised to drive the next surge of economic growth across all sectors.

Nanotechnology refers to the ability to manipulate matter between 1 and 100 billionths of a meter, an endeavor that is no small feat. Pun intended. This capability is helping solve long intractable problems. For example, as computers get smaller, the problem of heat generation becomes more and more severe, and nanotech could hold the solution.

Currently, there are natural barriers to making transistors, semiconductors, and computers any smaller because the heat generated during use destroys the material if that material is below a certain size. The ability to harness the inertia of an electron could one day allow a computer to operate on its own recycled waste heat. This capability is called spintronics, and it would allow electronic computer parts to break through that size barrier.

Dr. Binek, who is here from the University of Nebraska, probably off of the Big 10 media days in Chicago, will expand on the idea of spintronics and describe his excellent work in this area of nanotechnology.

Advances in nanotech don't just mean we can make things smaller. It is the ability to harness matter at the nanometer level, which has applications across many industries. In medicine, nanotech research has revealed that advanced nerve regeneration and cancer detection, diagnosis, and treatment methods could be just around the corner. In manufacturing, nanotech research has allowed us simply to make better materials. For example, nanocomposites can be used to decrease the weight of the bumper on a car, while enhancing its resistance to dents and scratches. And with three teenage boys, that is appreciated. And wires used to transmit electricity made from carbon nanotubes could one day eliminate much of the electricity loss that occurs in transmission.

Today we seek to learn more about what obstacles stand in the way of nanotech research, but also any barriers that exist between the research and development stage and full-scale commercialization.

There is no question that the U.S. is a leader in nanotech researching, but as U.S. researchers make new discoveries and the applications are revealed, I am concerned that other countries are doing more to facilitate nanotech development than we are. Nanotech is a true science race between the nations, and we could be encouraging the transition from research breakthroughs to commercial development.

I believe the U.S. should excel in this area. Historically we have a great track record on generating startups, which is fueled by our entrepreneurial spirit in this country. However, for the first time since the Census Bureau started measuring this statistic, more businesses are failing than starting in the United States. Four hundred thousand businesses are born annually nationwide, while 470,000 are failing. That is a disturbing statistic.

Accordingly, I am curious as to whether, given this hostile business climate, there are regulatory obstacles to adoption of nanotechnology in the commercial context.

As Dr. Binek notes in his testimony, Moore's Law tells us that the performance-to-cost ratio of computing power doubles every 18 months or so. I believe we ought to be careful not to slow down the progress described by "Moore's Law" with "more laws."

Again, I thank our witnesses, and introductions will be right after the ranking member's opening statement. Yield to the ranking member, Jan Schakowsky, for her statement.

[The prepared statement of Mr. Terry follows:]

PREPARED STATEMENT OF HON. LEE TERRY

Thank you all for joining us today to discuss nanotechnology-a catalyst that I believe could play a leading role in the next wave of economic growth.

Just as electricity, telecommunications and the combustion engine fundamentally altered American economics in the "second industrial revolution," nanotechnology is poised to drive the next surge of economic growth across all sectors.

Nanotechnology refers to the ability to manipulate matter between 1 and 100 billionths of a meter-an endeavor that is no small feat.

This capability is helping solve long-intractable problems.

For example, as computers get smaller, the problem of heat generation becomes more and more severe, and nanotech could hold the solution.

Currently, there are natural barriers to making transistors, semiconductors and computers any smaller because the heat generated during use destroys the material if that material is below a certain size.

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As Dr. Binek notes in his testimony, Moore's Law tells us that the performance-to-cost ratio of computing power doubles every 18 months or so.

I believe we ought to be careful not to slow down the progress described by "Moore's Law" with "more laws."

Again, I thank the witnesses for being here today and look forward to their testimony.

OPENING STATEMENT OF HON. JANICE D. SCHAKOWSKY, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF ILLINOIS

Ms. SCHAKOWSKY. Well, it looks like our macrotechnology might have been fixed. I am not sure. Is this working, this on here? OK.

So I want to thank you, Chairman Terry, for holding this important hearing on the issue of nanotechnology. I look forward to hearing from each of our accomplished witnesses about this exciting field. I was about to ask you all for some help here. I figured maybe the scientists know.

But I would like to take this opportunity to introduce one of the witnesses today. Dr. Milan Mrksich is a professor at my hometown school of Northwestern University and a leader in the field of nanotechnology. Dr. Mrksich has focused his research on biomedical advances that would not be possible without the development of nanotechnology. He has been involved in research that has made Chicago one of the premiere destinations around the world for nanotechnology, from research and development on Northwestern's campus to the commercialization at the nearby Illinois Science and Technology Park, and other sites. So I look forward to getting his valuable perspective on this.

From real-time monitoring of critical infrastructure to water purification to more effective treatment of cancer, nanotechnology has the potential to solve some of the world's most important challenges. Few fields of scientific research have as much breadth or potential.

That being said, nanotechnology's impact on public health and our environment is not yet well understood. Certain studies have indicated potential hazards. For example, titanium dioxide nanoparticles, which are used in sunscreen to block UV light can also kill microbes used to treat municipal water supplies. That is why we need to be careful to ensure that federal regulators responsible for public health and chemical exposure, from EPA to FDA to CPSC, coordinate efforts to better understand any possible toxicity of nano materials and protect the public from harmful impacts, while enabling their beneficial use.

The United States recognized the promise of nanotechnology early on, and the National Nanotechnology Initiative has benefitted from nearly $20 billion in federal investment since 2000. Other world leaders have followed suit, and more than $70 billion in global investment in nanotechnology over the same period.

The Federal Government must continue to play a lead role in supporting nano research and development. Last year, Congress appropriated $1.5 billion for nanotechnology, more than 10 percent below the Administration's request, however. According to the GAO, some other nations may already have surpassed the U.S. in terms of public investment in nanotech, and we can be sure that those competitors will maintain significant investments in this promising field moving forward.

Congress, I believe, should commit to adequate support of cutting edge research, and I hope all my colleagues will join in working to increase National Nanotechnology Initiative funding moving forward.

We should focus on the areas of nanotech pipeline that are in the most need of additional support. There is a demonstrated lack of financing for nanotech as it moves from the development stage to the commercialization stage. I am concerned that without consistent and significant financial backing, the advancement of nano in this country could slow. We should work to ensure that promising technologies, especially those that can save and sustain human lives, have the support needed to reach and benefit the public.

Again, I am very excited about the promise nanotechnology holds for our country and the world. I look forward to hearing the perspectives of our witnesses today, especially about where we go from here.

I yield back my time.

[The prepared statement of Ms. Schakowsky follows:]

PREPARED STATEMENT OF HON. JANICE D. SCHAKOWSKY

Thank you, Chairman Terry, for holding today's important hearing on the issue of nanotechnology. I look forward to hearing from each of our accomplished witnesses about this exciting field.

I'd like to take this opportunity to introduce one of our witnesses, Dr. Milan Mrksich, a professor at my hometown Northwestern University and a leader in the field of nanotechnology. Dr. Mrksich has focused his research on biomedical advances that would not be possible without the development of nanotechnology. He has been involved in research that has made Chicago one of the premier destinations around the world for nanotechnology—from research and development on Northwestern's campus to the commercialization at the nearby Illinois Science and Technology Park and other sites. I look forward to gaining from his valuable perspective.

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Again, I am excited about the promise nanotechnology holds for our country and the world. I look forward to hearing the perspectives of our witnesses today, especially about where we go from here. I yield back.

Mr. TERRY. Does anybody wish to make an opening statement on the Republican side?

Mr. OLSON. Mr. Chairman, introduction please, sir?

Mr. TERRY. Yes, I will do that right now then. So hold on.

So our witnesses today, I want to thank all four of you for being here. We have three universities represented that are leaders in nanotech development and research, and I will just take a personal note and say we allowed one outside of the Big 10.

So I want to introduce from the University of Nebraska, Professor of Physics and Astronomy, Christian Binek. Then we also have Milan Mrksich from, a Henry Wade Rogers Professor of Biomedical Engineering, Chemistry and Cell and Molecular Biology at Northwestern University. Jim Phillips, Chairman and CEO of

NanoMech, Incorporated. And now I yield for opening statement/introduction to the gentleman from Houston, Texas.

Mr. OLSON. Thank you, Mr. Chairman.

As our guests can see by my nameplate, another Rice Owl is in the house this morning. That owl is James Tour.

Dr. Tour and I share a common idol, the late Dr. Rick Smalley, who won a Nobel Prize in 1996 for his work in nanotechnology at Rice. Dr. Smalley changed my life by showing me that I had no future, none, in nanotechnology. After my first year of chemistry with him, that was pretty apparent. But he changed Dr. Tour's life by recruiting him to Rice to a leader in the Nanoscience and Technology Institute.

Dr. Tour is a perfect witness to teach this committee about nanotechnology. He has created a thing called NanOKids, teaching kids K–12 about nanotechnology. If he can teach a fourth grader, man, he can surely teach members of Congress.

So with that observation, Mr. Chairman, I yield back. Thank you.

Mr. TERRY. We can all hope.

So have any of you testified before? A couple of you, good. For the two that haven't, this is an information hearing. It is not like a GM hearing where you have to raise your hand and get grilled. You are here to teach us. We want to hear what your work has been about, and we appreciate your testimony, which most of us have read.

So we will start from my left to right. You have 5 minutes. There should be a clock up there if you want to look up. If you are still speaking about the 5-minute mark, I will just kind of lightly tap the gavel, which is the international symbol for wrap it up.

So with that, I recognize the gentleman from the University of Nebraska, Dr. Binek.

STATEMENTS OF CHRISTIAN BINEK, PH.D., ASSOCIATE PROFESSOR, PHYSICS AND ASTRONOMY, UNIVERSITY OF NEBRASKA—LINCOLN; JAMES M. TOUR, PH.D., T.T. AND W.F. CHAO PROFESSOR OF CHEMISTRY, PROFESSOR OF COMPUTER SCIENCE, MATERIALS SCIENCE AND NANOENGINEERING, SMALLEY INSTITUTE FOR NANOSCALE SCIENCE AND TECHNOLOGY, RICE UNIVERSITY; MILAN MRKSICH, PH.D., HENRY WADE ROGERS PROFESSOR OF BIOMEDICAL ENGINEERING, CHEMISTRY AND CELL AND MOLECULAR BIOLOGY, NORTHWESTERN UNIVERSITY; AND JIM PHILLIPS, CHAIRMAN AND CEO, NANOMECH, INCORPORATED

STATEMENT OF CHRISTIAN BINEK

Mr. BINEK. Thank you, Mr. Chairman, for inviting me and having this opportunity to testify, and also, thank you, Congressmen and Congresswomen. So I am on faculty at the University of Nebraska in Lincoln and also an active nano scientist and I would like to give you a smooth start, let's say, into nanoscience and nanotechnology, so maybe we can start with the question, what is that all about?

And starting by the prefix of the word nano, which actually comes from the Greek word nanos, and it means dwarf, so we deal with something very small, as we all know by now. But what we probably lack is an intuition for what it means, one billionths of a meter, so we need actually a proper ruler, so to say, to have comparison. And if we think of something small, we may think, for example, of the red blood cell in our bloodstream. But it turns out that is actually on the order of 6 microns in diameter. So a nanometer is 10,000 times smaller than that. Or maybe it is better to look at the molecular scale, and then we would identify a nanometer as being 5 atoms next to each other. So that gives us the scale, and that sets the stage for Feynman's celebrated remark, "There's plenty of room at the bottom." And indeed, we can sort of say create and hope to create nanostructures from the bottom up, which are extremely small, much, much smaller, for example, than a cell, and have function and can, for example, travel in our bloodstream and monitor and maybe even increase health. So that was Feynman's vision of "swallowing the doctor" as he called it.

From there I would like now to switch over and give us an idea of what is the special physics that happens at the nanoscale. What are those emerging properties at the nanoscale? And again, it is Feynman who asked the question, what happens if we can arrange atoms at will? And today, we are actually in a position where we can start to do that. We can image and manipulate atoms at will, and the answer is that if we can do that, then we can basically design material properties at will, because it turns out that all material properties, literally all of them, electric, magnetic, optic, thermal, mechanic, you name it, they all depend on the underlying atomic structure. So if you can arrange atoms at will on the nanoscale, then we can design within certain limits, for example, dictated by quantum mechanical loss, we can design materials properties.

Now, that is not the end of the story. We can actually do more. An example for such a design for nanostructures would be—a simple but effective example would be nanoparticles specifically tailored in magnetic properties to be applied in magnetic hypothermia weight of potential cancer treatment.

We can do more. We can bring different materials into close proximity. We have tools now, for example, multilayer—techniques, and we bring materials A and B in proximity, which traditional chemistry doesn't allow us to do. And when that happens, new effects, new physical phenomena can emerge at the interface, and that sends the whole is indeed more as the parts A and B. Or as Herbert Kroemer said it already 40 years ago, today we can say the interface itself is the device. So from there, we can speculate and we can build a larger, more complex structures, nanostructures, and we have the tools to do that from the bottom up, like scanning macroscopy, or from top down.

And with all that, we can look a little bit into the future and can see that nanotechnology will certainly transform information technology, medical applications, energy and water supply, smart materials, and manufacturing. And specifically in the information technology, there is a nonlinear trend going on now for 5 decades known as Moore's Law, where we can see that the performance to cost ratio is actually exponentially growing, so beyond our actual intuition. To give you an example of the hard drives of IBM from

1956 had less than 5 megabyte storage capacity, was two refrigerators big and weighed 2 tons. Fifty years later, we could make hard drives with 100 gigabytes capacity of storage and just the size of a deck of cards. That is 100 million fold improvement in that kind of performance to cost ratio.

So the industry is well aware that Moore's Law is not necessarily a law of nature. It can and most likely seems right now to stop and to come to an end, and there are processes funded like spintronics, where I am involved, which allow us to tackle those problems and come to new types of electronics that we utilize the spin degree of freedom is just one example.

So I am running out of time here. I would like just to conclude with an impact nanotechnology most likely has on society and economy. We need to recognize that nanotechnology is highly interdisciplinary and that there is a positive feedback which excels the progress. We have to prepare the workforce for this interdisciplinary and have to continue funding from the industry side and from the government side.

With that, let me thank you for having me.

[The prepared statement of Mr. Binek follows:]

Nanotechnology: Understanding How Small Solutions Drive Big Innovation

Testimony Presented Before the U.S.Congress House SubCommittee on Commerce, Manufacturing, and Trade

July 29, 2014

Christian Binek, Dr. rer. nat. habil.

Associate Professor, Department of Physics and Astronomy and the Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln

Contents

1. What is nanoscience and nanotechnology?

The prefix "Nano" derives from the Greek word νᾶνος and means dwarf. In fact, nanotechnology is the manipulation, design and fabrication of the very small. More specifically, nanotechnology can be defined as control over the structure of matter at the nanoscale and nanoscience is concerned with the particular laws of nature that govern this regime. With that said, humans have no good intuition to truly grasp the smallness of the nanoscale. A nanometer as a billionth of a meter is hard to visualize because we lack meaningful comparison with objects of our daily-life experience. When we think of something small we may have length scales such as the diameter of a red blood cell or a human hair in mind. However, these objects can easily be imaged by an ordinary optical microscope. As the prefix "micro" in microscope suggests, objects that can be imaged with an optical microscope are of the order of a micron (about 6 micron diameter for a red blood cell and 50 micron of a human hair) in size or bigger. The nanometer (nm) is three orders of magnitude smaller than the micron (one thousandth of one micron) and thus about 10 000 times smaller than a red blood cell. It is therefore more appropriate to look for comparison on a molecular scale. The length of 1nm is roughly equivalent to about 5 atoms next to each other. With this in mind one can understand that a technology operating on a scale from 1 to 100 nm allows us to fabricate devices, with potentially complex function, which are just a fraction of a human blood cell in size and could be used for example as functional components traveling in our bloodstream while monitoring and actively improving our health (Feynman's dream of "swallowing the doctor").

Nanotechnology has been envisioned with remarkable accuracy by Nobel Prize laureate Richard P. Feynman in his celebrated Caltech talk from 1959 entitled "There's plenty of room at the bottom" where he sketched the technological possibilities of functional systems engineered at the molecular scale.

"There's Plenty of Room at the Bottom",

R.P. Feynman, reprint of J. Microelectromech. Sys. 1, 60 (1992).

2. Emerging material properties at the nanoscale

Feynman's vision was ahead of the technology of his time when he asked the inspiring question: "What would happen if we could arrange the atoms one by one the way we want them?". - His vision is still a guiding principle. Today we have the technological capabilities to image and manipulate structures at the nanoscale. Consequences of this achievement can hardly be overstated when considering the particular aspect that all physical properties of matter are determined by the underlying atomic structure. That means, if we can manipulate the atomic structure of matter, we are able to design all its properties at will limited only by our imagination and the constraints determined by the fundamental laws of quantum physics. A simple but effective example of the application of the structure-property correlation is seen when successively reducing the dimensions of a three dimensional bulk specimen such as a metallic block. Every physical property such as conductivity has a characteristic length scale which separates regimes such as diffusive and ballistic transport of electrons. When preparing films of a material with a thickness below the characteristic length scale, the material becomes essentially two-dimensional. Similarly one can create one-dimensional nanowires, and zero dimensional nanodots. As a rule, each dimensional transition is accompanied by qualitative changes in the electronic structure of the material with far reaching consequences on electrical, optical, mechanical, thermal, and magnetic properties. Prominent examples are the tunable and dramatically altered optical and electrical properties of gold nanoparticles with applications ranging from catalysis to therapeutic agent delivery or the use of optimized magnetic nanoparticles for cancer treatment via magnetic hyperthermia. The relation between structure on the nanoscale and material properties is the domain of nanophysics and governed by the laws of quantum mechanics although some important applications of nanoparticles arise from the simple fact that the surface to volume ration of a particle increases with decreasing diameter. However, in order to truly design material properties one has to understand and utilize the fundamental principles of quantum mechanics in a synergetic approach of theory and experiment.

A new quality is added to materials design when fabricating nanostructures from more than a single element. This is realized for example in the form of artificial multilayers which combine materials "A" and "B" through modern deposition techniques (such as molecular beam epitaxy, pulsed laser deposition and atomic layer deposition) in ways conventional chemistry does not allow. At the interface of such heterostructures new material properties can emerge which are neither present in A nor in B. Here the whole is more than the sum of its parts. Emergent interface phenomena pave the way to design materials with functions not known from traditional bulk synthesis. Because in nanostructures the number of interface atoms can be a sizable fraction of the total number of atoms, interface effects often dominate the material properties of heterolayers.

More than 40 years ago, Nobel laureate Herbert Kroemer from UC Santa Barbara coined the celebrated phrase "the interface is the device". Today, researchers such as the interdisciplinary teams at the

University of Nebraska routinely design and utilize interface properties for new functions critical for example to advance information technology.

"The interface is the device"

H. Kroemer's Nobel lecture, December 8, 2000, Quasi-electric fields and band offsets: teaching electrons new tricks

3. Complex nanostructures and nanotechnology

Today scientists and engineers are armed with unprecedented and continuously evolving characterization, fabrication, and computational tools. The former include scanning probe microscopy enabling imaging and bottom-up fabrication where atoms are actively arranged into nanostructures. The bottom-up technique is complemented by molecular self-assembly where molecules with tailored intermolecular interaction can create a self-organized nanopattern which can serve, e.g., as templates for further fabrication steps. Various lithography techniques form the backbone of the top-down approach. Here structuring of functional nanostructures such as transistors and memory cells are carved from a macroscopic block or thin film of matter. These experimental tools are accompanied by powerful computational approaches with techniques which start from quantum mechanical first principles and implement, e.g., density functional theory to simulate the properties of materials and nanostructures. We truly stand on the shoulders of giants such as Binnig and Rohrer who have been awarded with the Nobel Prize in Physics in 1986 for their design of the scanning tunneling microscope. It jumpstarted the field of scanning probe microscopy with spectacular pioneering nanoscientific achievements such as the fabrication of quantum corrals where individual atoms are actively arranged in ring-type structures. These structures reveal the interference pattern of electron waves just as predicted by quantum mechanics. Kohn and Sham (Nobel Prize in Chemistry in 1998) paved the way for computational chemistry and Watson, Crick and Wilkins (1962 Nobel Prize in Medicine) discovered the molecular structure of DNA and its significance for information transfer in living material. The work of these pioneers makes physics, chemistry and biology fundamental pillars of nanotechnology and exemplifies that nanotechnology is truly an interdisciplinary field.

The exiting race that led to the decoding of the double helix structure of DNA shows how fundamental discoveries such as Röntgen's X-rays lead to transformative breakthroughs in other fields of science. This process is continuing today for example in the field of neuroscience. The exploding increase of knowledge about the human brain became possible through modern imaging techniques most notably magnetic resonance imaging (MRI). Advances in fields such as neuroscience should no longer be considered independent from nanotechnology. It is at the interface between those scientific frontiers where future transformative breakthroughs will most likely happen. Nanotechnology is expected to play a key role in detecting and fighting brain diseases. The smallness of nanoparticles allows them to circumvent the blood-brain barrier, penetrate cell membranes, and interact with biomolecules. Nanoparticles are also used to drastically increase the contrast in tissue-specific MRI images. At the same time, advances in understanding of the human brain are expected to have major impact on information technology for example through the modern field of neuromorphic computation where spintronic nanostructures serve as artificial neurons. It is the creative application of modern tools and findings in an interdisciplinary approach which makes the realization of Feynman's dream feasible.

Synergy between experimentation and computation allows for systematic progress faster than ever before. An important role play advances in computational quantum physics and quantum chemistry and the ability to model on multiple length and time scales (multiscale modeling) ranging from the nanoscale all the way up to the device and circuit scale. The role of computational tools to systematically guide experimentation has been identified and its use is substantially fostered through President Obama's Materials Genome Initiative.

4. Grand challenges, vision of the future and current research

Virtually all of the national and global challenges can at least in part be addressed by advances in nanotechnology. Although the boundary between science and fiction is blurry, it appears reasonable to predict that the transformative power of nanotechnology can rival the industrial revolution. Nanotechnology is expected to make major contributions in fields such as

- Information Technology
- Medical applications
- Energy
- Water supply with strong correlation to the energy problem
- Smart materials
- Manufacturing

It is perhaps one of the major transformative powers of nanotechnology that many of these traditionally separated fields will merge. For example, the use of nanotechnology in medical applications doesn't have to be and most likely will not be limited to monitor and maintain health. Merging of molecular biology and information technology in nanotechnological applications has the potential to expand human's physical and cognitive potential as well as life expectancy far beyond today's limits. Nanotechnology will without question continue to strive in the near future through obvious applications such as better computers and more powerful cellphones, but it will not be limited by these rather conventional advances. If we chose to do so, nanotechnology may very well become an integral part of human existence and an integral part of many of the objects surrounding us which in turn might allow us to interact with our environment in radically new ways. One of the goals that appear within reach is the possibility to give non-biological materials properties known from biological entities such as self-repair and replication.

In all areas affected by nanotechnology, changes will most likely not be incremental but have the potential to radically transform our lives in ways that are hard to imagine. The lack to appropriately extrapolate the technological progress originates from the fact that human intuition is ill-prepared to understand the potential of exponential growth. Typically, we extrapolate linearly. Information technology, today one of the forefronts of nanotechnology, is perhaps the prime example where linear extrapolation fails and we can witness the effects of exponential growth in accordance with Moore's law

(Gordon Moore co-founder of Intel Corp.). It states that the performance-to-cost ratio of major components in information technology doubles about every 18 months. Moore's law holds now for more than half a century and can be extended up to a century if vacuum tube technology and mechanical calculators are included. Moore's law applies remarkably well for microelectronic components and data storage technology such as magnetic hard disc drives (HDD).

IBM's HDD from 1956 had a capacity of less than 5MB, was as big as two refrigerators, and weighed about two tons. In 2006 the HDD of a typical laptop computer could store 20-100 GB and shrunk to the size of a deck of cards. This is a 100 million time increase in the information stored per area of magnetic material and an even bigger increase in the performance-to-cost ratio.

The improvement of magnetic storage media depends on numerous breakthroughs in nanotechnology. Examples are the reduction in the size of magnetic grains which constitute a bit, and the discovery of the giant magneto resistance (GMR) effect in nanostructured magnetic thin film multilayers (awarded with the Nobel Prize in Physics in 2007 by Albert Fert and Peter Grünberg). Today grain sizes of HDD media are only a few nm in diameter making the material science of magnetic recording a true nanoscience. The discovery of the scalable GMR effect allowed for a qualitatively new way to read the magnetic stray-fields of ever smaller magnetic bits replacing the magnetic induction of small pick-up coils which show a rapid decrease in the signal-to-noise ratio when scaled down. It is often stated that the computing power of a modern cellphone is higher than all of NASA's computers in 1969 combined. This is another manifestation of Moore's law in the field of integrated electronic circuits. Both examples show that the transformative power of information technology, in case Moore's law holds for a few additional decade, is hard to comprehend.

The continuation of Moore's exponential growth in performance-to cost is not self-evident. After all, Moore's "law" is not a law of nature. There are various energy related challenges which collide with the demands for miniaturization and ever faster processing of information. Those challenges require a common solution through nanotechnology. Exponential progress has been achieved over the decades by making transistors ever smaller without changing the basic principle of CMOS technology. Today, fundamental limits dictated by phenomena such as quantum tunneling demand for radically different solutions. There are at least two energy aspects that challenge progress in information technology. The ongoing miniaturization of transistors and the increasing clock-speed of computers give rise to power dissipation. Insulating barriers are no longer effective on the nanoscale. With decreasing thickness of the gate insulator of a field-effect transistor, electrons can tunnel through the barrier and electric leakage currents rise dramatically. As a result heat production increases. Heat is not only wasteful but also detrimental to the electronic components. Latest by 2005 it became clear that business as usual meaning continuation of scaling down CMOS electronics to ever higher transistor densities without conceptual innovations will lead to power densities inside a computer's CPU comparable to the surface of the sun. In addition, the energy demand for technologies such as modern cloud computing is growing at a staggering rate. Extrapolating this rate 10 years into the future reveals that a multiple of today's entire electricity production will be necessary just to satisfy the energy demand of cloud computing.

"If scaling continues at present pace, by 2005, high speed processors would have power density of nuclear reactor, by 2010, a rocket nozzle, and by 2015, surface of sun."

Patrick Gelsinger Intel Corporation Microprocessors of the New Millennium: Challenges, Opportunities, and New Frontiers ISSCC 2001

Advances in nanotechnology are mandatory to continue growth according to Moore's law or progress even faster with new device concepts combining, e.g., memory and logical function to achieve what is known as "More than Moore". Latest by 2020 today's approach to scale down CMOS circuits comes to a hold while clock-speed is already stagnating for years. The US industry is very well aware of challenges and opportunities for information technology and sponsors national research programs for example in the field of spintronics. My group and I are privileged to be involved in two such programs. The Center for NanoFerroic Devices (CNFD) is sponsored by the Nanoelectronics Research Initiative (NRI) and the National Institute of Standards and Technology (NIST). CNFD is a partnership of investigators from six academic institutions: University of Nebraska-Lincoln (UNL), University of California at Irvine (UCI), University of Wisconsin-Madison (UWM), University at Buffalo, SUNY (UB), University of Delaware (UD), and Oakland University (OU). UNL serves as lead institution. The second program is the Center for Spintronic Materials, Interfaces, and Novel Architectures- C-SPIN. Here 32 experts from 18 universities collaborate and are sponsored (overall funding $31M) through one of several STARnet programs funded through the Semiconductor Research Corporation with member organizations such as IBM, Intel, Micron, Applied Materials, GLOBALFOUNDRIES, Raytheon Company, Texas Instruments Incorporated, United Technologies Corporation and government participation through the Defense Advanced Research Projects Agency (DARPA).

Research in the field of spintronics specifically targets at nanotechnological solutions for energy related limitations of information technology inherent to today's CMOS based electronics. Spintronics is an approach to process and store information by utilizing the spin degree of freedom of electrons rather than their charge alone. Today's electronic devices rely on the control of electric currents through electric fields and their coupling to the electron's charge. Spintronics allows us to utilize the quantum mechanical electron spin in addition to charge with multiple advantages. The collective order of interacting spins in nanomagnets is inherently non-volatile. That means non-volatile memory function is relatively easily implemented in spintronic devices allowing for innovations such as instant-on technology which eliminates the booting procedure of a computer. Moreover, there are multiple strategies to switch magnetic state variables virtually in the absence of electric currents solely by voltage or at least strongly supported by voltage. This means spintronic devices have the potential to solve the problem of energy consumption and overheating of processor cores due to the absence or strong reduction of electric currents and their accompanying heat production through Ohmic losses.

Nanotechnological solutions can be found in diverse and rather unexpected applications allowing for advanced energy efficiency, electric power generation and more. For example, nanotechnology is used to optimize permanent magnetic materials with a large range of transformative applications such as lightweight headphones, powerful and lightweight electrical motors used in unmanned aerial vehicles, generators in wind turbines and many more. All of them rely on modern permanent magnets with their unprecedented high energy product. At the University of Nebraska for instance there is a substantial effort to find alternatives to rare earth permanent magnets such as NdFeB or SmCo with the help of nanotechnology. The need to reduce the use of rare earth materials becomes obvious when considering for instance that a 2MW wind turbine contains about 800 pounds of rare earth minerals. Rare earth minerals are primarily mined in China creating unwanted dependencies, high costs, and significant pollution.

For similar reasons we use nanotechnology to create prototype materials with applications in near room temperature magnetic refrigeration. 36% of the electrical energy consumed by US households is used for heating, ventilation and cooling (DOE Energy Information Administration). Therefore, a sizable increase in the efficiency of cooling technology is a potentially big part of the solution to the energy crisis. The magnetocaloric effect forms the basis of such an energy efficient and environmentally friendly cooling technology. Magnetic refrigeration is based on the phenomenon that a magnetic material increases its temperature when exposed to a magnetic field and lowers its temperature when the magnetic field is removed. This phenomenon can be utilized in a refrigeration cycle in close analogy to gas compression refrigeration. We use nanotechnology as an effective tool in materials design. On the macroscopic level one has to tailor the response of the magnetization of a material on temperature and fields. The structure-property relation underlying the success of nanotechnology allows us to tune microscopic parameters such as the quantum mechanical exchange to systematically realize the desired macroscopic properties. Optimizations, which are necessary for a breakthrough of this technology, include again the elimination or rare earth materials. Moreover, nanotechnology opens the possibility to eliminate the need for magnetic fields replacing them by electric fields in artificial multiferroics materials. This approach gave rise to my pending patent on refrigeration through voltage-controlled entropy change and has promising applications in miniaturized cooling devices useful for instance in night-vision goggles.

5. Impact on society and economy

The outlined examples provide a glimpse into the transformative power of nanotechnology. It is important to realize that advances in one field, such as information technology, will in turn advance fundamental aspect of nanoscience for instance in the important field of friction and lubrication on the atomic scale (the domain of nanotribology). Those insights enable ever more sophisticated nanotechnological machines and tools for imaging and fabrication which in turn accelerates our understanding and ability to master engineering on the nanoscale. This upward spiral makes extrapolation difficult and most likely leads to an underestimation of progress and its impact on society and economy.

Nanotechnology will gradually but at a fast rate become ever more important for the fabrication of consumer products. As outlined, a hallmark of nanotechnology will be its potential to include all sciences. Interdisciplinarity will become a key quality for innovation. This has important implications for the education of the workforce. A basic understanding of nanotechnology and the sciences it is based on will be of increasing importance and decide about competitiveness of the industry. Already today research consortia such as the Semiconductor Research Corporation (SRC) are extremely interested to be in close contact with the nation's graduate students for instance via meetings such as Techcon 2014. Here students working in SRC sponsored programs interact face-to-face with industry leaders, e.g., during poster presentations. SRC certainly understands the importance to compete for the best of the next generation of engineers and scientists.

Nanotechnology will very likely come with a large number of opportunities enriching our lives but it will also create new challenges for example those that accompany an unprecedented increase in life expectancy of the population. For the US economy it remains important to stay ahead of the technological development because one can expect a separation into mass products and nanotechnological products which require a high level of research and development. Successful competition with other nations, which certainly understand the importance of nanotechnology as well, requires a constant financial effort through industry and government participation especially in high risk and fundamentally oriented long-term research. It requires the constant attention and support of policy makers, and constant improvement in the education of the workforce and the general public.

Mr. TERRY. Thank you, Dr. Binek.

Dr. Tour, you are now recognized for 5 minutes.

STATEMENT OF JAMES M. TOUR

Mr. TOUR. My name is James Tour, and I am the T.T. and W.F. Chao Professor of Chemistry, Professor of Material Science and Nanoengineering, and Professor of Computer Science at the Richard Smalley Institute for Nanoscale Science and Technology at Rice University in Houston, Texas.

Rice's home is the home of nanotechnology where carbon 60 was discovered. I have over 500 research publications and 70 patents in nanotechnology in the fields of nanomedicine for treatment of traumatic brain injuries, stroke, and autoimmune diseases, nanomaterials including graphene and carbon nanotubes for electronics, optics, and composites, and high surface area nanomaterials for environmental capture of carbon dioxide and for water purification. All of these technologies are licensed to companies from my laboratory at Rice University, and all are transitioning from basic research to deployment in the U.S. and abroad.

It is possible for Congress to directly improve the research enterprise in U.S. universities and to mitigate the current brain drain of our best and brightest scientists and engineers. This can be done without commitment of any new spending.

Among the most ingenious pieces of legislation in my view was the Bayh-Dole Act dealing with intellectual property arising from Federal Government funded research. Prior to the enactment of the Bayh-Dole Act, the U.S. Government had accumulated 28,000 patents, but fewer than 5 percent of those patents were commercially licensed. The key change made by Bayh-Dole was ownership of the inventions that were made by federal funding. Bayh-Dole permits a university, small business, or nonprofit institution to elect to pursue ownership of an invention in preference to the government. Government got out of the way, and this spawned enormous entrepreneurial endeavors and led to startup companies and jobs being birthed throughout the country. And most interestingly, the legislation required no new allocation of funds.

Unfortunately, there has been a dramatic loss of research funding to U.S. universities on a per-investigator basis over the past 5 years. The situation has become untenable. Not only are our best and brightest international students returning to their home countries upon graduation, taking our advanced technology expertise with them, but our top professors are moving abroad in order to keep their programs funded. The trolling by foreign universities upon top U.S. faculty has become rampant due to the declination of U.S. funding levels on a per faculty member basis. The brain drain is not something that we can recover. The impact of what has already been lost will last decades.

I am not here to present to you an apocalyptic scene and then cry for money to slow the problem. I realize the cupboards in Washington are bare, and I offer you a no new spending solution. I have a large research laboratory, 30 graduate students and postdocs working busily to make new nanotechnology discoveries and translate those into exploitable applications. In 2008, my program was 90 percent federally supported and 10 percent industrially supported. Then for the first time in my 26-year career as a faculty researcher, I could no longer survive. One federal grant after another was unfunded. So I started to appeal to industries, showing them how our nanotechnology research could solve technical problems in their industries. Presently for company funds research at an academic institution through a sponsored research agreement, thereby guaranteeing the company access to research reports and their setting of milestones, then the company loses the benefits of a significant tax deduction of their allocation of funds. In other words, their allocation to sponsored research no longer has the same tax deductible benefits as a non-researched based gift would have afforded them.

I am asking Congress to consider legislation that would incentivize industry to fund academic research universities and nonprofits by granting the companies with a total or significant tax deduction for such university research investments. This permits companies to take up the slack where the Federal Government has been unable to maintain the research enterprise. Help me and my colleagues to raise our own research funds through partnerships with corporations. If I can explain to industries that there will be a complete or significant tax deduction for the sponsored research agreement, then I can sell my research to them with the utmost attractiveness.

Let me close with this. King Solomon wrote in Proverbs 25:11, “Like apples of gold, in settings of silver, is a ruling rightly given.” I pray your kind consideration for new Bayh-Dole-like ingenious legislation to be enacted, nullifying the dire conditions facing the U.S. research enterprise and loss of our U.S. trained scientists and engineers. This legislation would require no new federal allocations, and it can become part of the holistic approach to funding of academic science.

Thank you.

[The prepared statement of Mr. Tour follows:]

Summary of the testimony of

James M. Tour, Ph.D.

Before the

House Energy and Commerce Subcommittee on Commerce, Manufacturing and Trade

"Nanotechnology: Understanding How Small Solutions Drive Big Innovation"

July 29, 2014

There are three topics relevant to my testimony today:

1. The research enterprise in universities;
2. Industries and their need to recruit top personnel in science and technology; and,
3. Stemming the tide of the brain drain, wherein we are losing our best and brightest to overseas institutions.

The decrease in federal support for university-based basic research in recent years is resulting in a serious brain drain that imperils the future of the U.S. economy as we know it. International graduate students are returning to their home countries in Europe and Asia to do research. The serious lack of research funding has lead to a lack of new academic positions for young researchers and has made top faculty susceptible to be lured overseas.

This situation can slowed and perhaps even halted without commitment of <u>any new monies</u>. Congress must properly incentivize industry to invest in university research. Expanding tax deductions to companies who enter into sponsored research agreements with universities will spur investment and encourage faculty to be more entrepreneurial while underwriting the basic research needed to help America retain her competitive edge.

NANOTECHNOLOGY: UNDERSTANDING HOW SMALL SOLUTIONS DRIVE BIG INNOVATION

Testimony before the Subcommittee on Commerce, Manufacturing and Trade

Committee on Energy and Commerce, United States House of Representatives

July 29, 2014

James M. Tour, Ph.D.

Richard E. Smalley Institute for Nanoscale Science and Technology

Rice University

Chairman Terry, Vice Chairman Lance, Ranking Member Schakowsky and other committee members, I appreciate the opportunity to testify before the subcommittee. I am the T.T and W.F. Chao Professor of Chemistry, Professor of Computer Science and Professor of Materials Science and NanoEngineering in the Richard E. Smalley Institute for Nanoscale Science and Technology at Rice University in Houston, Texas.

Rice University is considered the birthplace of nanotechnology and is a leader in the field of finding pathways to commercialization of this promising technology. Rice is the location where C60, known as Buckminsterfullerene or the "buckyball", was discovered in 1985 by Richard Smalley, Robert Curl, Harold Kroto, and their team of students. That discovery, more than any other single discovery, is credited with the genesis of nanotechnology, and that single discovery led to three Nobel Prizes in Chemistry. Rice is now one of the premier research facilities in the world that supports and promotes researchers who use nanotechnology to tackle civilization's grand challenges – energy, water, environment, disease, education – by providing experienced and knowledgeable leadership, a solid administrative framework, world-class scientific infrastructure, and productive community, industry, and government relations. To demonstrate the tremendous depth of nanotechnology research at Rice, I have provided an extensive list of the major nanotechnology breakthroughs that occurred on our campus in Appendix 1.

I personally have over 500 research publications and 70 patents in nanotechnology including:

(1) nanomedicine for treatment of traumatic brain injury (the number one disabler of young adults), stroke (the number one disabler of older adults), and autoimmune diseases;
(2) nanomaterials including graphene and carbon nanotubes for electronics, optics and composites;
(3) nanoelectronic memories set to rival flash memory; and,

(4) high-surface-area nanomaterials for environmental capture of carbon dioxide from natural gas wells and radioactive element removal from water for clean-up of mining waters, oil extraction waters, and nuclear legacy site waters.

All of these are licensed technologies to companies from my Rice laboratory and all have transitioned from the basic research phase to deployment in the US and abroad.

There are three topics relevant to my testimony today:

1. The research enterprise in universities;
2. Industries and their need to recruit top personnel in science and technology; and,
3. Stemming the tide of the brain drain, wherein we are losing our best and brightest to overseas institutions.

Congress can directly impact these three situations, and this can be done without commitment of <u>any new monies</u>.

Among the most ingenious pieces of legislation, in my view, impacting university-based research was the Bayh--Dole Act dealing with intellectual property arising from federal government-funded research. Before Bayh-Dole was enacted, the U.S. government had licensed fewer than 5 percent of the 28,000 patents it has accumulated.[i] Bayh-Dole changed the ownership of inventions, which had been assigned to the federal government, resulting from federal grants.[ii] Under Bayh-Dole, universities, small businesses, and non-profits have preference in pursuing ownership of an invention.[iii] Government got out of the way, and this spawned enormous entrepreneurial endeavors that led to start-up companies and jobs being birthed throughout the country, like those in Silicon Valley. And most interestingly, the legislation required no new allocation of funds.

Unfortunately, there has been a dramatic loss of research funding to U.S. universities, on a per investigator basis, since the outpouring of the stimulus funds in 2009. The situation has become untenable. Not only are our best and brightest international students returning to their home countries upon graduation, taking our advanced technology expertise with them, but our top professors also are moving abroad in order to keep their programs funded. For the past century or more, the U.S. has been the recipient of the world's most talented students, profiting from the brain drain of other nations.

In 2011, I testified before the House Science, Space and Technology Subcommittee on Research and Science Education that if the funding of U.S. research did not increase, the United States would experience a brain drain like we have never known. Unfortunately, my projections have come true: we are presently in the throes a brain drain that should be frightening to everyone. My best students are returning to Asia and Europe to embark on research careers solely because there are so few academic positions available for them in the United States due the lack of federal research support. Equally alarming is the loss of key US-based nanotechnology faculty to the U.K., South Korea, China, Singapore and Australia. This is not from any specific government report; this is based upon my own knowledge of the field. I formerly testified that university researchers are industrious folks, and the most astute among them would rather move abroad than to see their prized research programs close. This is now happening. And the trolling by foreign universities upon top U.S. faculty has become rampant due to the decline of federal funding levels on a per faculty-member basis. This brain drain is not something that we can recover-- the impact of what has already been lost will last decades. .

As university research programs shrink substantially or close down, there will be a diminishing supply of US-trained and US-national scientists and engineers. Certainly the United States can hire from abroad, but that is not so easy for some industries, such as in the aerospace sector. Moreover, the cutting-edge of our nation's leading enterprises will be dulled into disrepair. The lack of highly trained scientists and engineers is already felt, but it will grow far worse. I am not here to present you with an apocalyptic scene and then cry for money to slow the problem. I realize that the cupboards in Washington are bare. Instead, I offer you a no-new-monies solution. I shall share with you the secret and then show you what your committee can do to make this an easier transition for many research groups around the country.

I have a large research laboratory: 30 graduate students and post-docs working busily to make new nanotechnology discoveries and translate those into exploitable applications. My research funding situation is as good as it has ever been. In 2008, my program was 90% federally supported and 10% industry supported. That was the norm for many research groups. Then, for the first time in my 26-year career as a faculty researcher, I could no longer survive. One federal grant after another was unfunded. Federal programs would attract 300 initial applicants, 150 full proposals, and then only have enough to fund 5 research groups. Federal organizations would post programs for proposal submissions. I would submit a proposal, only to learn that they would shut down the program without even reviewing a single proposal. There was no recognition of the time I already spent in writing proposals – it felt humiliating and disrespectful.

I started to appeal to industry, showing them how our nanotechnology research could address the technical needs in their industries. I have the good fortune of being in Houston where oil companies are headquartered, and the energy industry is doing well. But this has now expanded to companies far beyond Houston. We do basic research in nanoscience, and then parlay that into applied nanotechnology research that can benefit companies. More than 15 companies have stepped up to fund my research.

If a company gives a monetary gift to a university, the company can get a healthy tax deduction. However, industry cannot request a report on the outcome of gift-supported research, meaning companies are less likely to give gifts. There is little accountability in providing gifts, so few companies choose this route. If the company grants money though a sponsored research agreement, they can require reports of the work and even request milestones. These sponsored research agreements are indirect-cost bearing, so they maintain the academic laboratory infrastructure. According to Bayh-Dole, the intellectual property still resides with the university, but the university can license, even exclusively, to the company sponsoring the work. While the intellectual property cannot be "pipelined," meaning that it cannot be assigned to the company prior to its being generated, a letter of intent to license to the company is sufficient to give the company assurance that it could be the recipient of the funded work. And per Bayh-Dole, the government receives a "nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world."[iv] Such restrictions have never bothered a U.S. company with which I have dealt.

Here is where Congress can help. If the company funds research at an academic institution through a sponsored research agreement, thereby guaranteeing the company access to research reports and their setting of milestones, then the company loses the benefits of a significant tax deduction through their allocation of funds. I ask Congress to consider legislation that would incentivize industry to fund academic research universities and non-profits by granting companies with a total or significant taxable deduction university research investment. This permits companies to take up the slack where the federal government has been failing to maintain the research enterprise. Such a program will slow the brain drain, possibly even mitigate it, and provide for the high tech training of students that will be needed to fill jobs in those industrial sectors. It will further encourage faculty to be more entrepreneurial in their raising of funds for research.

The complexity associated with industry grants to universities needs to be streamlined and incentivized. There is no simple answer as to how much a company can presently deduct, if anything, on a sponsored research agreement. Even when I consulted with industry tax experts they provided no easy answers. This is an issue for Congress to explore further, working with industry, tax experts, and universities to design an effective incentive structure that will increase industry support for research and development – especially as it relates to nanotechnology. This is a win-win for all parties: more university research getting funded, slowing the brain drain, and providing a substitute for federal research support.

Such a strategy can help me and my colleagues to raise our own research funds through partnerships with corporations. If I can explain to industries that there will be a complete or significant tax deduction for the sponsored research agreement, then I can sell my research to them with the utmost attractiveness.

Some researchers might argue that basic research will suffer at the expense of applied research. Not so. I always tell industries that their investment will be used, in part, to expand upon the basic research scope while still delivering upon the applications. We file patents regularly to secure the intellectual property, and then we publish as usual in the academic literature. The protocol works.

In closing, I ask your kind consideration for new, Bayh-Dole-like legislation to be enacted to mollify the dire conditions facing the U.S. research enterprise: legislation that would require no new monies while incentivizing industry to fund research where the federal government has been deficient.

Appendix 1: Nano Breakthroughs at Rice

Bio/Health Science

Finding and Killing Cancer:

- **Nanoscale composites improve MRI: Rice, Methodist researchers merge magnetic particles to detect, fight disease.** ***(Wilson, Gizzatov, 6/13/14)***
- **Short nanotubes target pancreatic cancer: Rice, MD Anderson scientists refine technique for attacking hard-to-reach tumors.** ***(Barron, 6/5/14)***
- **'Quadrapeutics' works in preclinical study of hard-to-treat tumors: Animal tests show Rice-developed technology effective against aggressive cancer.** ***(Lapotko, Lukianova-Hleb, 6/1/14)***
- **Bismuth-carrying nanotubes show promise for CT scans: Rice-led collaboration finds element shines as contrast agent for tracking stem cells.** ***(Wilson, 9/4/13)***
- **3-D scaffolds a new tool to fight cancer: Rice University and MD Anderson researchers see more realistic tumor growth and response to anti-cancer drugs using polymer scaffolds .** ***(Mikos, 4/1/13)***

Healing Babies, Soldiers and Accident Victims:

- **A hydrogel that knows when to go: Rice University bioscaffold material degrades as bone grows to replace it.** ***(Mikos, Watson, 5/7/14)***
- **Synthetic collagen promotes natural clotting: Hydrogel invented at Rice University may help 'nuanced' healing of surgical wounds.** ***(Hartgerink, 4/9/14)***

- **Tiffany Vo wins Ruth L. Kirschstein National Research Service Award: Research uses dual-gelling, temperature-sensitive scaffolds to engineer bone.** *(Vo, 11/27/13)*

- **Grant to Rice, UTHealth will push regenerative medicine: Department of Defense backs tissue-engineering research for soldiers, civilians.** *(Mikos, 9/27/13)*

- **Jacot's TEDx talk posted online: assistant professor of bioengineering discusses the use of stem cell-derived tissue, plus synthetic materials, to repair infant hearts.** *(Jacot, 7/29/13)*

Keeping People Safe from Bad Food and Other Diseases

- **New test targets salmonella: Rice University-based research develops fast biosensor for pathogens in food.** *(Biswal, et al., 1/21/14)*

- **Vapor nanobubbles rapidly detect malaria through the skin: Transdermal malaria technology successfully completes first preclinical tests at Rice.** *(Lapotko, Hleb, 1/1/14)*

- **New clues illuminate Alzheimer's roots: Rice, Miami researchers find binding sites in amyloid fibrils that may lead to therapies.** *(Marti, 7/19/13)*

- **Rice's Laura Segatori wins NSF CAREER award: Engineering researcher creating new nanoscale tools to study Parkinson's disease.** *(Segatori, 3/28/13)*

- **Heart cells beat in bioscaffold for babies: Rice, Texas Children's team creates biocompatible patch to heal infants with birth defects.** *(Jacot/Park, 12/12/12)*

- **Smart scaffolding aims to rebuild tissue from the inside: what's new is injecting scaffolds infused with living cells, to facilitate repairs inside the tissue's natural environment.** *(Hartgerink, 11/12/12)*

Energy and Environment

- **Water-cleanup catalysts tackle biomass upgrading: Rice University researchers using catalysts to convert waste from biodiesel production into valuable chemicals.** *(Wong, 6/26/14)*
- **Rice's Thomann wins CAREER grant to study photocatalysis: Rice lab's unique spectrometer will shed light on solar-powered CO2 reduction.** *(Thomann, 6/19/14)*
- **Rice produces carbon-capture breakthrough: Porous material makes it feasible to do CO2 capture at natural gas wellheads.** *(Tour, Hwang, 6/3/14)*
- **Nanoreporters tell 'sour' oil from 'sweet': Rice University's hydrogen sulfide nanoreporters gather intel on oil before pumping.** *(Tour, Wong, Tomson, Marti, 4/18/14)*
- **Nanoparticles show fluid flow in wells: can test safety of frack fluids, frack jobs and other Oil & Gas production.** *(Barron, Boyle, 2/24/24)*
- **Rice startup Rebellion Photonics wins Wall Street Journal Startup of the Year competition, 2013.** *(Allumni Kester and Sawyer; faculty Tomasz Tkaczyk, 11/6/13.)*
- **Using foam to get more oil & gas out of the ground: may prove big advantage over tradictional water or CO2 flooding for enhanced oil recovery.** *(Biswal, 10/7/13)*
- **Off-grid sterilization with Rice U.'s 'solar steam': solar-powered sterilization technology supported by Gates Foundation.** *(Halas, Neumann, 7/22/13)*

- **Chloroform cleanup: Just the beginning for palladium-gold catalysts: Federally funded research pays off with new process for environmental remediation.** *(Wong, 4/15/13)*

Batteries and Solar Energy

- **One step to solar-cell efficiency: Rice University researchers' chemical process may improve solar cell efficiency and manufacturing via etched nanospikes.** *(Barron, 6/19/14)*
- **Flexible battery, no lithium required: Rice University lab creates thin-film battery for portable, wearable electronics.** *(Tour, Yang, 4/25/14)*
- **Clay key to high-temperature supercapacitors: Rice University lab creates energy storage that may find use in oil discovery, space, military applications.** *(Ajayan, Reddy, 9/3/13)*
- **Rice cultivates green batteries from plant: extract of madder plant works as environmentally friendly lithium-ion cathode.** *(Ajayan/Reddy, 12/11/12)*
- **James' bond: A graphene/nanotube hybrid: Rice University's James Tour Group creates single-surface material for energy storage, electronics.** *(Tour, 11/27/12)*
- **Rice unveils super-efficient solar-energy technology: 'Solar steam' so effective it can make steam from icy cold water.** *(Halas, 11/19/12)*
- **Toughened silicon sponges may make tenacious batteries: Rice, Lockheed Martin researchers extract multiple anodes from a single wafer for lithium-ion batteries.** *(Biswal, 7/16/12)*

- Paintable battery: uses carbon nanotechnology to enable layers to be cathode, anode, etc. *(Ajayan, 6/28/12)*

Electrical, Electronics

- Rice's silicon oxide memories catch manufacturers' eye: Use of porous silicon oxide reduces forming voltage, improves manufacturability. *(Tour, 7/10/14)*
- Silicon oxide memories transcend a hurdle: Embedded diodes boost Rice University invention's potential as robust, roomy memory. *(Tour, 7/9/13)*
- 2-D electronics take a step forward: Rice, Oak Ridge labs make semiconducting films for atom-thick circuits. *(Ajayan, Lou, Liu, Yakobson, 6/10/13)*
- Totally tubular films show promise for touchscreens: Rice University lab creates simple method for flexible, conductive carbon nanotube sheets. *(Pasquali, 10/29/12)*
- Thanks for the transparent memories: Rice team progresses in quest for reliable, flexible computer memory. *(Tour, 10/2/12)*

Materials: Structure, Multifunction

- 3-D nanostructure could benefit nanoelectronics, gas storage: Rice researchers predict functional advantages of 3-D boron nitride. *(Shahsavari, 7/15/14)*
- Rebar strengthens case for grapheneRice University lab makes hybrid nanotube-graphene material that promises to simplify manufacturing. *(Tour, 4/4/14)*
- Diamonds are an oil's best friend: Rice University leads research to find the best nanofluid for heat transfer. *(Ajayan, 3/27/14)*

- <u>**Graphene nanoribbons an ice-melting coat for radar: Rice University discovery is cheaper, lighter and more effective than current deicers.** *(Tour, Volman, Zhu, 12/13/13)*</u>
- <u>**Carbon's new champion: Rice U. theorists calculate atom-thick carbyne chains may be strongest material ever.** *(Yakobson, 10/9/13)*</u>
- <u>**'White graphene' halts rust in high temps: Rice U. researchers find nano-thin films of hexagonal boron nitride protect materials from oxidizing.** *(Ajayan, Lou, 10/4/13)*</u>
- **<u>New nanotech fiber: Robust handling, shocking performance. Nanotube fibers have unmatched combination of strength, conductivity, flexibility</u>.** ***(Pasquali, 1/10/13)***
- **<u>Microbullets reveal material strengths: Rice, MIT research could help maximize strength of body armor for soldiers, aerospace materials</u>.** ***(Thomas, 10/30/12)***
- **<u>Strain Paint: uses carbon nanotubes to detect strain in real time</u>.** ***(Nagarajaiah, Weisman, 6/21/12)***

<u>Photonics, Opto-Electronics</u>

- <u>**Rice nanophotonics experts create powerful molecular sensor: Sensor amplifies optical signature of single molecules about 100 billion times.** *(Halas, LANP, 7/14/14)*</u>
- <u>**San Marcos tech company bets big on tiny quantum dots [Austin American-Statesman]: Quantum Materials licenses Prof. Mike Wong's tetrapod technologies from Rice; attracts interest from Sony and others.** *(Wong, 11/16/13)*</u>

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[i] http://www.gao.gov/archive/1998/rc98126.pdf
[ii] http://www.bu.edu/otd/files/2011/02/The-Enactment-of-Bayh-Dole.pdf

[iii] http://www.natlawreview.com/article/emerging-energy-and-intellectual-property-often-unappreciated-risks-and-hurdles-gove

[iv] 35 USC Sec 202 (c) (4) of the Bayh-Dole Act

Mr. TERRY. Thank you. Dr. Mrksich, you are now recognized for your 5 minutes.

STATEMENT OF MILAN MRKSICH

Mr. MRKSICH. There it is. The last name is not easy. My mother-in-law struggled with it for many years.

But I am currently the Henry Wade Rogers professor at Northwestern University with appointments in chemistry, biomedical engineering, and cell biology. I direct a research lab that develops nanomaterials for applications in drug discovery and diagnostics, and medical devices. I have also been involved in the translation of university-based science into companies, having co-founded SAMDI Tech, 480 Biomedical, a stent company, and Arsenal Medical. I am glad to be here to share some of my perspectives.

As you have heard, the nanotechnology field has been enabled by the development of methods that can create materials with dimensions that are tiny, thousands of times smaller than the width of a hair. And we now know that the properties of a material that can vary strongly on their dimensions, and we have the ability to tailor-make materials with novel and important properties. This is a broad-based field. Unlike traditional disciplines, it cuts across the entire science and engineering enterprise, and has really led to paradigm shifting technology across the board.

The National Nanotechnology Initiative recognizes transformative potential and required federal agencies across the board to invest in nano. And that really was important to creating a national strength and infrastructure in this new and exciting area.

At Northwestern, we started the International Institute for Nanotechnology, now one of the largest such centers. This partners with departments across campus and to date, has raised over $600 million in research funding to develop this next generation of technology. It has also trained hundreds of students, many of which are now faculty members across the globe in this area.

This investment has already led to a nascent but growing and important industry. Again, at Northwestern, our institute has seen about 25 companies get started, and those have raised greater than $700 million in research support to commercialize their products. And these success stories aren't unique, of course, to Illinois. They are found across our Nation.

At the same time, there is a wide recognition that a lack of predefined regulatory processes can still present challenges to the commercialization of nanotechnologies. While regulations for safety and environmental impact are important, they should be effective at providing for the public's concerns and safety, but they need to be tailored to different classes of materials used in different sectors, and they need to be defined to remove the risk of uncertainty that product developers face when taking on these initiatives.

Similarly, the manufacturing methods and standards that will be important to all companies in this space are still not well-developed. We don't have the standard tools we can rely on to produce in volume products based on nanomaterials, and this is an area where a public/private partnership based perhaps on the National Network for Manufacturing Innovation Centers could be quite effective at providing the entire industry with engineering practices that will enable the growth of this area.

I would like to add comments to the theme of globalization that we have heard. The scientific and economic promise of nanotechnology has certainly been recognized by our foreign partners and competitors, and recent trends in those regions point to challenges that the United States has not faced before. First, governments in Europe and Asia continue to make targeted investments in nanotechnology, with annual growth rates that are in the double digits, and approaching 50 percent in China. Second, the culture and infrastructure has changed in Europe and Asia, and unlike 10 and 15 years ago, researchers there are quite effective at starting new companies. And finally, as you have heard, we are seeing the recruitment of our best scientists to full-time and part-time positions in other countries. And the globalization has certainly had and will have many benefits, but it will also level the global playing field for translating basic research into commercial entities, and it will dilute the positive impact of nanotechnology on our own economy.

We must act now to ensure that our early investment and the very substantial impact it is positioned to deliver can be realized. We must renew our support for fundamental research in the nanosciences, as this will retain and continue to attract the best researchers to the United States, and keep our development pipeline full. We must remove barriers that make it challenging to start new companies that are in the early stages of product development. We must develop effective regulatory standards, but also clearer standards that remove the risk of uncertainty that many companies face in product development. And we must make the patent system more efficient, and remove the five or more year delay it can take to realize patent protection and keep out would-be competitors. We must engage our partners in industry, academia, and the government to create a manufacturing toolbox and kit that is universal, and again, serves the entire field.

I thank you for your time, your attention, your service to our country, and I am happy to answer any questions that you may have.

[The prepared statement of Mr. Mrksich follows:]

TESTIMONY

of

Professor Milan Mrksich

Northwestern University

Evanston, Illinois

to the

Committee on Energy and Commerce

Subcommittee on Commerce, Manufacturing, and Trade

U.S. House of Representatives

29 July 2014

Introduction

On behalf of Northwestern University, I would like to thank Chairman Terry, Ranking Member Schakowsky, and the entire Subcommittee on Commerce, Manufacturing, and Trade for the opportunity to participate in today's hearing entitled "Nanotechnology: Understanding How Small Solutions Drive Big Innovation." I am the Henry Wade Rogers Professor at Northwestern University, with appointments in the Departments of Biomedical Engineering, Chemistry, and Cell & Molecular Biology. I direct a research group that develops nanomaterials for a broad range of biological and medical applications, including screening technologies used in drug discovery, materials coatings used in medical devices, and devices used to diagnose disease. I have also been involved in the translation of University-based research to technology companies, having Co-Founded SAMDI Tech, 480 Biomedical and Arsenal Medical and having served as a member of several Scientific Advisory Boards of nanotechnology companies. I appreciate the opportunity to share my experiences and perspectives on several topics related to the commercialization of research and engineering advances in nanotechnology.

Fundamental Research

The nanotechnology field has been enabled by the development of methods that can prepare materials having tiny dimensions—in the range of 1-100 nanometers—and by the development of advanced tools that can characterize the structures and properties of these materials. We now know that the properties of a material can vary widely as its dimensions change, and we understand how to engineer nanomaterials with tailored properties, and in many cases with properties that do not exist with traditional materials. The availability of materials having novel properties is having a major impact in all technological areas. In medicine, nanotechnologies will allow more predictive diagnosis and treatment of diseases, including Alzheimer's, cardiovascular disease and cancer. In electronics, nanotechnologies have already radically increased the computational power of devices all around us, and in energy nanotechnologies are important to realizing practical power for electric vehicles. Indeed, nanotechnology is a broad-based field that, unlike traditional disciplines, engages the entire scientific and engineering enterprise and that promises new technologies across these fields.

The National Nanotechnology Initiative recognized this transformative potential of nanoscience and the importance of having each of the funding organizations participate in the development and commercialization of nanoscience. By requiring each of the federal agencies to commit a fraction of their budgets to developing the nanosciences, the NNI has brought about the creation of a national infrastructure for nanoscale science and engineering. At my Institution, for example, Northwestern University created the International Institute for Nanotechnology. This Institute operates across many academic Departments and has built a leading community for nanotechnology, having attracted leading faculty to our campus and having trained many students who are now leading faculty members across the globe. Indeed, a good fraction of our Nation's universities have created units devoted to nanoscience and these have collectively given the United States a strong infrastructure and a leadership position.

Commercialization

The Federal investment in nanotechnology that the NNI started 15 years ago has rapidly led to a nanotechnology industry. At Northwestern's IIN, for example, we have seen more than 25 companies started by our faculty and these have raised greater than 700 M in private funding. These companies include Nanosphere, which is a public company that sells a system for clinical diagnostics, AuraSense Therapeutics, which is a private company that is developing nanoparticles for gene therapy, and SAMDI Tech, which I Founded in 2011 and which is now a profitable company that provides assay services to the pharmaceutical industry. These are just a few of many examples across the United States.

At the same time, there is wide recognition that a lack of pre-defined regulatory processes still presents challenges to the commercialization of nanotechnologies. Regulations for safety and environmental impact should recognize that one set of standards will not optimally apply to products in each industry and therefore the existing regulatory agencies should be given responsibility to develop best practices in their sectors. Those in the semiconductor industry, for example, are more defined than those in the therapeutics area. Here, a public-private consortium may be important to defining efficient and effective standards that benefit the industry. Similarly, the manufacturing methods and standards that will be important to producing products in several areas are still not well-developed and therefore introduce substantial risk in advancing a prototype device to a manufacturing process. Here again, a public-private partnership—based on the National Network for Manufacturing Innovation Centers—can be effective at advancing the industry as a whole.

While there are substantial resources directed towards fundamental discovery and also substantial private capital available for companies that are close to having products on the market, there is comparatively less investment available for bridging these two activities and in creating small companies that aim to validate a prototype or a manufacturing process. Policies that promote this transition—which is particularly challenging for first-time entrepreneurs—could be important, including streamlined access to a SBIR contract for those nanotechnology grantees that have filed a patent application. Finally, the time that separates fundamental discoveries and translation into a company is shorter in nanotechnology than in other fields, and this change has highlighted a challenge with our patent system. It typically requires five years to obtain a patent, which means that new companies do not have patent protection as they move towards introduction of a product, which encourages competition from competitors outside the United States.

GLOBALIZATION

The scientific and economic promise of nanotechnology has been recognized by our foreign partners and competitors. Recent trends in those regions point to challenges that the United States has not faced before. First, Governments in Europe and Asia continue to make targeted investments in nanotechnology, with annual growth rates that are in the double digits and that have approached 50% in China. Second, the culture and infrastructure for rapidly translating academic research into companies has changed dramatically over the past decade in Europe and Asia and researchers in those regions are now quite effective at starting technology companies. Finally, we are now seeing the recruitment of our best scientists to full-time and part-time research positions in other countries. The globalization of science has many benefits, but it is clear that it will also level the global playing field for translating basic research into commercial entities and will dilute the positive impact of nanotechnology on our economy.

CONCLUSIONS

In conclusion, the creation of the National Nanotechnology Initiative in 2000 has been successful in advancing fundamental discoveries across the science and engineering disciplines, in training a new generation of skilled scientists in these areas, in translating discoveries to commercial entities and in realizing the first nanotechnology-enabled products. Current challenges to realizing the broader economic promise of the nanotechnology industry include the development of strategies to ensure the continued investment in fundamental research, to increase the fraction of these discoveries that are translated to technology companies, to have effective regulations on nanomaterials, to efficiently process and protect intellectual property and to ensure that within the global landscape, the United States remains the leader in realizing the economic benefits of the nanotechnology industry. I thank you for your time, attention and service to the country, and am happy to answer any questions that you may have.

Mr. TERRY. Thank you.

Mr. Phillips, you are now recognized for your 5 minutes.

STATEMENT OF JIM PHILLIPS

Mr. PHILLIPS. As a manufacturer of nanotechnology it is a great time to be alive. With the inventions of the chip and the software storage and the internet, more will be invented in the next 10 years than in the history of mankind, and no more place than nanotechnology will achieve these great new inventions and competitiveness that America is going to depend on, especially in manufacturing, where we see manufacturing drop as part of our GDP from about 79 percent to 17, 18 percent, giving us a distinctive competitive disadvantage on a global basis.

I am proud to be chairman and CEO of NanoMech. We are based in northwest Arkansas, down the street from the likes of Walmart, Tyson headquarters, and we have, over the last year, won a portfolio of award-winning inventions and commercial products, including innovations in machining and advanced manufacturing, lubrication and energy, biomedical implant coatings, and very strategic military applications. We feel we are poised for dramatic expansion of our manufacturing operations. I am proud to say we are in the process right now of adding an additional 25,000 square feet to our existing factory. We have bought up the entire technology park that we live in with the belief that we will be needing that kind of manufacturing capacity to keep up with our demand.

Today, the United States is locked in a moon race, in an absolute moon race with other major countries trying to take the lead in materials science and bio nanoscale engineering research, development, commercialization in what is sure to be the next industrial revolution of progress. While these competitive countries lost out to an extent to the U.S. in the information technology revolution, they are determined to put enormous amounts of public and private capital to work to win this more important race. Given the monopolistic efforts of China alone to control all of the world's dwindling resources. Today they control about 85 percent, the U.S. is now at great risk of not having the materials and the rare earth metals that are core to the most important manufactured goods that are essential to our daily lives. Nanoscale engineering is our greatest hope in providing a way to do more with less and amazing and sustainable ways to keep America secure, and the world leader in commerce, technology, and especially defense. Speaking of defense, it is clear by now that the country with the best UAVs wins. And no weaponization area more than UAVs will benefit from the tremendous advantages of nanoengineering and manufacturing. This, of course, is not to mention the huge gains already realized in defense and national security and weapons systems deploying quantum leaps in super-advanced nanoengineered coatings, lubricants, fuels, energetics, faster processors, and battlefield gear, all due to nanotechnology.

Over the past 2 years, I have had the opportunity to participate in the Council on Competitiveness executive committee, as well as its U.S. Manufacturing Competitiveness Initiative, and the Office of the Comptroller General's Study on Nanotechnology. I take this opportunity to offer my perspective as an entrepreneur and a nanomanufacturer.

Many U.S. States and localities do too little to attract manufacturing facilities, imposing complicated time-consuming procedures on top of federal rules to site and build production facilities. The permitting process for a manufacturing facility in the United States might take months, if not years, where in some countries the time required is merely a few weeks or less. We are certainly offered by China and Russia it seems like on a quarterly basis to move our entire operation there. Never will do it. Former ex-pilot in the Air Force and definitely a patriot, and we just won't do those kinds of things. We don't even take their money, even though they offer it to us all the time. Consider, for example, NanoMech, though, as our very safe product platforms. I don't know of any nanotechnology lawsuits for liability in the 30-year history of nanotechnology to date. We utilize convergent assembly so that we can nanoengineer tremendous improvements in many products and through this process, what we ship, even though nanoengineered and nanomanufactured, is no longer at nanoscale, but vastly superior to conventionally manufactured products. We are developing cutting edge technology that enables dramatically more efficient industrial processes, and therefore can save billions of dollars across several industries, while dramatically increasing performance.

At the nanoscale, we and other manufacturers can reduce or eliminate harsh chemicals and materials and replace them with more environmentally sound and sustainable components. We do that every day. One of our products is called nGlide. This is a new super additive for the energy space. For that reason, we have opened up in Texas and are working with some of the largest companies in the energy manufacturing space. We add just a small amount of lubricant, and we reduce the coefficient of friction down to literally zero. Hardly any wear for that product going forward. We work with the largest companies around the United States in this. We also work with racing teams where this has all been demonstrated. Think of it, no wear, yet higher performance. The ability to increase miles per gallon, miles per hour, reduce heat, reduce wear.

One of the other products we have is called TuffTek. This is where we spray a nano spray in a very safe facility with cubic boron nitride, the hardest substance known to man. When we do that, it creates a very hard coating surface on cutting tools. When we do that, cutting tools can last as much as 10 times longer. Of course, cutting tools are at the core of everything that is manufactured. This year, we were awarded the R&D100, the Edison, and the Tibbetts Award for that, the Tibbetts Award coming through the EPA.

Talent is perhaps the most important driver for manufacturing competitiveness, especially nanotechnology. The United States needs highly skilled workers to realize the productivity gains essential to remain globally competitive in the digital and nano age. Yet current and anticipated human capital deficiencies exist across the board. Not only are current openings for highly skilled workers challenging, manufacturing workers are retiring at a much higher rate than they are being replaced. For that reason, we ask this committee to consider taking a real hard look at the area of visas. Visas have turned out to be a huge problem for us as we try to man and staff our company with the very best and brightest.

At this point in time, it looks like time is up so I will defer to questions.

[The prepared statement of Mr. Phillips follows:]

James Phillips

Chairman & CEO

NanoMech, Inc.

U.S. House Subcommittee on Commerce, Manufacturing and Trade

Nanotechnology: Understanding How Small Solutions Drive Big Innovation

July 29, 2014

Thank you for inviting me to appear here today. It is a rare privilege to have the opportunity to comment to you on the importance of advanced nano-manufacturing and restoring U.S. competitiveness quickly to revitalize our most important economic engine of innovation.

I have had the opportunity to be involved in some of the most exciting developments of the digital revolution that have transformed our everyday lives. By way of background, I helped lead the teams that created and launched instant messaging, the cable modem, broadband, immersive imaging, the eBay drag and drop imaging system, and many other now-ubiquitous products. I now serve as Chairman and CEO of NanoMech, a leading nano-engineering and manufacturing company.

NanoMech is a highly innovative nano-manufacturing firm, based in Northwest Arkansas, down the street from the likes of Walmart and Tyson headquarters, with a portfolio of international award winning inventions and commercial products, including innovations in machining and advanced manufacturing, lubrication and energy, biomedical implant coatings, and strategic military applications. We feel we are poised for dramatic expansion of our manufacturing operations.

The former Chairman of the House Committee on Science and Technology, U.S.Rep. Bart Gordon, (TN), said "We stand at the threshold of an age in which materials and devices can be fashioned atom-by-atom to satisfy specified design requirements. Nanotechnology-based applications are arising that were not even imagined a decade ago. The range and potential application is broad and will have enormous consequences for electronics, energy transformation and storage, materials, and medicine and health, to name a few examples. Indeed, the scope of this technology is so broad as to leave virtually no product untouched."

This is even more true today. The United States is locked in a moon race with other major countries trying to take the lead in material science and bio nanoscale engineering research, development and commercialization in what is sure to be the next industrial revolution of progress. While these competitive countries lost out, to an extent, to the U.S. in the Information Technology revolution, they are determined to put enormous amounts of public and private capital to work to win this even more important race. Given the monopolistic efforts of China alone to control all of the world's dwindling resources, the U.S. is now at a great risk in not having material and rare earth metals that are core to our most important manufactured goods that are essential to our daily lives. Nanoscale engineering is our greatest hope in providing a way to do more with less in amazing and sustainable ways to keep America secure and the world leader in commerce, technology and defense. Speaking of defense, it is clear to most by now, that the country with the best UAV's wins, and no weaponization area more than UAV's will benefit from the tremendous advantages of nano-engineering and manufacturing. This of course is not to mention the huge gains realized in defense and national security in weapon systems deploying quantum leaps in super-advanced nano-engineered coatings, lubricants, fuels, energetics, faster processors, and battlefield gear.

Manufacturing Today

Over the past two years, I have had the opportunity to participate in the Council on Competitiveness U.S. Manufacturing Competitiveness Initiative, and The Office of the Comptroller General's Study on Nanotechnology. I take this opportunity to offer my perspective as an entrepreneur, innovator and nano-manufacturer. Much of manufacturing in the United States centers on higher value-added activities that require highly-skilled workers, unique knowledge from innovators or sophisticated infrastructure. Other U.S. manufacturers are in sectors that require proximity to end consumers due to transportation or other factors. Still other producers have unique quality-assurance relationships with larger firms or support America's defense base. A recent study by Deloitte and the Manufacturing Institute found that 5 percent of manufacturing jobs remain unfilled simply because people with the right skills are not available. That translates to 600,000 available U.S. jobs.

Not only are manufacturing and services interdependent, they are distributed globally. For most of the 20th century, "Made in America" meant just that: design, development, fabrication and associated transactions were performed in U.S. factories and offices by U.S. workers. Today, many goods are no longer designed, produced and sold within a single country. Instead, the activities needed to bring a product from concept to consumption are routinely performed in different countries. Many manufacturers believe that global competition has made them stronger, more productive and more competitive. Gains in productivity and output, however, are not translating into broader economic gains.

Furthermore, many U.S. states and localities do too little to attract manufacturing facilities, imposing complicated and time-consuming procedures on top of federal rules to site and build production facilities. The permitting process for a manufacturing facility in the United States might take months, if not years, whereas in some countries, the time required is merely a few weeks or less. Manufacturing also suffers from its public image. Many American's still think about manufacturing in terms of product fabrication—humming factories for the transformation of materials into new products, basically, "bending metal" in operations that are easily sent elsewhere. However, manufacturing today is part of a much more complex, high value-added and tightly integrated global web.

Consider, for example, NanoMech's very safe product platforms. We utilize convergent assembly so that we can nanoengineer tremendous improvements in many products, and through this process, what we ship is no longer at nanoscale, but vastly superior to conventionally manufactured products. We are developing cutting edge technology that enable dramatically more efficient industrial processes, and therefore, can save billions of dollars across several industries while dramatically increasing performance. At the nanoscale, we and other manufacturers, can reduce or eliminate harsh chemicals and materials and replace them with more environmentally sound and sustainable components. These include:

- **Lubricant Additives**: We have developed advanced nano-lubricant additives that dramatically reduce friction and thus wear to near zero in machines, and are able to deliver extraordinary energy savings as well as quantum leaps in performance. This work supports multiple industrial sectors including heavy machinery, agriculture, all forms of transportation, aerospace, advanced machining, the flow of gas and oil, wind turbines, the military, and others.

· **Machining and Coatings**: NanoMech has developed the world's first cubic boron nitride coating for manufacturing cutting tools allowing them to cut up to 1000% longer and in ways that allow the creation of better or new types of machines. It is not only an alternative for machining hardened steels but it enhances productivity by orders of magnitude. Through this innovation, the company has also developed strategic know how in ultra fast coating of nanoparticles for various applications such as machining, wear resistant surfaces, and anti-corrosion. We were awarded the R&D100, The Edison, and the SBIR Tibbetts Awards for this manufacturing advancement over the last year. At these awards ceremonies I couldn't help but notice that the majority of the award winners came out of the nanotechnology field.

· **Additives for Sustainable and Security Products**: NanoMech has developed additives for fabric, polymers, and wood-polymer composites for delivering sustainability and security. For example, NanoMech is currently providing an anti-microbial, fire-proof, anti-odor, anti-fungal and water-proof coating for armor vests and uniforms for public safety officers and the military that is much safer and causes no comfort change in the soft feel of the original material or cloth.

· **Metal Nanopowders**: Metals are a strategic commodity for the United States. Nanoparticles of metals allow us to deliver "more value for less usage." We have the ability to produce large quantities of metal nanopowders including copper, nickel, and rare earths such as lithium, silver-indium alloy, aluminum, selenium and others. These materials are strategic and critical for multiple U.S. industries including energy, aerospace propulsion, electronics, and agriculture.

A broad array of government polices both foreign and domestic have important impacts on the innovation and production process, from research funding to taxes to market access. Presently, U.S. policies are not aligned with the full life-cycle perspective of innovation that includes production at scale. The policies, programs, strategies and business models that worked in the past are inadequate to secure America's future in the digital and nano age. Government, business, labor and academic leaders must rethink and retool the nation's business environment to seize arising opportunities and address several shortcomings. The leveling effects of globalization are diminishing the lost cost advantages offered in emerging economies and potentially opening the door to increased manufacturing in the United States.

Structural Changes in the Global Economy Create Opportunities and Challenges

The global migration toward free enterprise and open markets is driving growth in emerging economies. Several nations have rapidly developed into formidable manufacturing competitors. China's manufacturing output, for example, is now approaching that of the United States. As development spreads, a new consumer class is burgeoning around the world. About 1.8 billion people occupy the consumer class today. By 2030, this number could reach 5 billion, with 95 percent of the growth occurring in emerging and developing economies—creating large new demands for manufactured goods.

Global companies see significant sales and investment opportunities in emerging countries. U.S.-based operations must also compete with aggressive mercantilist policies from foreign governments. Many countries have put in place policies and financial incentives to attract investment, manufacturing facilities, foreign intellectual property and talent while protecting domestic business interests.

The digital and nanotechnology revolutions and the pace of technological change also profoundly impact the way that business and production are organized. Digital technologies have made many facets of the global economy nearly borderless. In an earlier era, the location of natural resources often determined where manufacturing would take place. In today's economy, knowledge, know-how, technology, creativity and capital are the most important resources for production, and they are highly mobile.

Put together, these trends—emerging manufacturing nations, growing consumer class, neo-mercantilist policies and revolutions in digital and nanotechnology—create a hyper-competitive manufacturing environment. Not surprisingly, firms are growing more sophisticated in their ability to react to these changes and, where possible, leverage them to their advantage in the marketplace.

Global firms are becoming more sophisticated and recalculating the total cost of production. Successful global firms rely on their ability to react rapidly to changes across the global marketplace. In the early stages of offshoring, inefficient manufacturing operations were often relocated from higher-cost economies to low-cost labor economies to maximize returns and ensure that products were price-competitive.

Talent is perhaps the most important driver for manufacturing competitiveness, especially in nanotechnology.

The United States needs highly-skilled workers to realize the productivity gains essential to remain globally competitive in the digital and nano age. Yet current and anticipated human capital deficiencies exist across the board. Not only are current openings for highly skilled workers challenging, manufacturing workers are retiring at a much faster rate than they are being replaced. The growing shortfalls represent a critical need for a wide range of skills across many occupational cuts, from the most rudimentary to the most sophisticated PhD level.

Another major focus continues to be graduating more students with advanced degrees in Science, Technology, Engineering and Mathematics (STEM) disciplines, as well as improving STEM literacy in general. Unfortunately, this re-engineering of our home grown workforce will take another 10 to 20 years. Current visa policies are reversing decades of openness to foreign scientific excellence. This is a major problem we face at NanoMech in hiring and retaining the best nanoscale trained engineers. Foreign nationals with advanced degrees from American institutions are returning to their countries of origin and pursuing employment opportunities unavailable to them in the U.S. With them, they take the skills and knowledge necessary to create next-generation goods and services, and reduce America's competitive advantage while increasing that of the country to which they return. It almost seems as if after subsidizing the education of these bright and gifted individuals in the best University system in the world, we are, in effect, pushing the Einstein's and Wernher von Braun's to leave our Country. No one disputes the need for safe-guards and assessment of foreign entrants. However, a system that is transparent and efficient and also offers fresh incentives for the best and brightest can offset current obstacles.

America Must Leverage its Edge in Innovation, Technology and Computing

America's technology and innovation capacity remains among the greatest in the world. In crucial fields like biotechnology, biomimicry, nanotechnology, materials science and computing, U.S. researchers and entrepreneurs define the leading edge. American universities and research laboratories are unparalleled, pushing the boundaries of knowledge in life, physical and social sciences. Despite the nation's budget woes, Congress has thus far been reluctant to impose drastic cuts to scientific research funding that is viewed correctly as an engine of economic growth. America remains the world's largest investor in R&D and is among the upper ranks in R&D investment as a share of GDP. At the same time, other nations are making rapid progress relative to the United States in the talent, investment and infrastructure needed to foster innovation. Furthermore, a number of policies and practices limit American innovation today. Licensing practices, export controls and immigration policy, for example, were designed for a different era. Removing those impediments could generate greater levels of innovation and commercialization from today's assets and investments. In addition, the United States had the most generous R&D credit of any nation in the 1980s, but today, 16 other nations have a more generous tax break for R&D, which means many U.S. firms are sending R&D overseas.

In 1960, the United States accounted for more than two-thirds of global R&D. Today, two-thirds of global R&D is performed somewhere other than the United States. Although a more prosperous and innovative world is a welcome trend, the shift has significant implications for U.S. manufacturing and security interests. America has long been the global leader in creating new, high value-added goods and services. That lead will undoubtedly narrow and the greater issue will become whether Americans continue to develop and produce sufficient numbers of high-margin products to sustain and improve living standards.

America Also Must Better Leverage Its Entrepreneurial Enterprise

By combining innovation, entrepreneurism and risk capital, America has spawned more globally-recognized brands in more sectors than any other economy over the past several decades. The U.S. entrepreneurial enterprise is a critical advantage, since as much as one-third of the difference in economic performance among countries is attributed to the difference in their levels of entrepreneurial activity. Highly skilled entrepreneurs and business start-ups also create middle-skill jobs though the number of new businesses has declined significantly.

Consistent with other facets of the hyper-competitive manufacturing environment, many nations around the world—plus states and localities—are working to narrow the U.S. entrepreneurship advantage. They are creating tax incentives, sovereign wealth funds, skilled immigration incentives, regional innovation clusters and global collaboration forums with varying levels of success.

America must do more to enable entrepreneurs to take risks and to translate ideas into innovation. America is still leaving ideas on the table. On average, only one in ten U.S. patents is ever commercialized. Thousands of inventions lie dormant in the hands of universities, research centers and private companies. For those ideas that are pursued commercially, only seven out of every 1,000 business plans receive funding. And even fewer are scaled to full production in the United States.

As I have noted, NanoMech develops "platform technologies" which can be customized for multiple industrial sectors. The world runs on machines, and machines run on lubricants. In the area of lubricant additives, that means we are developing specific formulations for transportation wind turbine gear boxes, aviation, marine, agriculture – if it has an engine, or any moving parts, it can benefit from our product. Collaborating with industrial end users too early in a product's development often results in that product embodying a lower-risk, single, narrow application of the technology that ties up the underlying IP. This outcome precludes us from realizing the technology's benefits for other key applications necessary to advance nanomanufacturing. The development timeline would also likely be much longer. In other words, if we engage with an industrial end-user too early, we will not be able to develop the technology for the many other sectors – which often include defense—that will reap substantial economic and energy benefits. Public funding for early development and testing at commercial production scale preserves our ability to market to multiple industrial sectors, which maximizes the impact of the technology.

Remember, the science underlying NanoMech's products represents the best of the American R&D enterprise. When the resulting innovative products proliferate through the industrial base, the economic benefits are a return on the taxpayer's investment. Furthermore, because NanoMech's products are enabling technologies that will improve the energy efficiency of industrial processes, we can actually help to restore competitive advantage to industries that have lost out to global competitors in the last few decades.

America Falls Short of Its Potential as a Market for Manufacturing Investment

The American nanotechnology marketplace also is competing against aggressive, coordinated and well-funded foreign efforts to attract manufacturing facilities. China is spending billions in building the Nanopolis in Suzhou to attract nano research and commercialization from around the globe into China, while RusNano is a $10 Billion dollar investment fund investing in major nanotechnology companies and venture capital companies in the United State's and other countries. America needs pro-growth fiscal and monetary policies that spur private sector nanotechnology investment, expanding R&D capacity, growing capital expenditures for nano-manufacturing at scale. These policies should be informed by these competing policies and cost structures overseas.

There are four primary stages of innovation and production where investment is needed:

• the technology creation stage, where the federal government plays a major role.

• technology transfer, where there is typically limited funding.

• the early commercialization stage, where angel investors and venture firms like to engage. •

the scale-up to full production stage.

Getting a new innovation to market often stumbles due to technology transfer functions with limited resources that struggle to connect researchers with limited business backgrounds to outside technologists, entrepreneurs and investors. The availability of government funds decreases abruptly after the technology or knowledge is created because the government views subsequent investment as the domain of the private sector. This drop-off of investment occurs at the same time that the investment needs of a company or entrepreneur are growing to test, develop and begin commercializing the technology. This is the traditional valley of death referred to in the innovation process.

Often overlooked, however, is a second valley of death. A few of my colleagues from the Council on Competitiveness have suggested that this second valley emerges at roughly the point of scaling up production beyond $10 million to $100 million in revenue. Many firms are finding it more difficult to obtain scale-up capital in the United States than overseas. To capture the full fruits of the U.S. innovation ecosystem, the U.S. must bridge both valleys through deploying more into Public-Private Partnerships.

Conclusion

It is time for America to lead. Many question whether America has the resolve and resources to right its own ship, let alone lead a global recovery. I harbor no illusions about America's daunting economic challenges, but believe steadfastly that the challenges are solvable and that Americans and their leaders will summon the will to act decisively.

I do not want to manage a "State-run" company, but I do have to compete against them. America must coalesce around a new vision focused on innovation and leadership in high value-added, next-generation manufacturing. Public-Private Partnership business models have not been more important to U.S. GDP and knowledge job growth since World War II. For more than 200 years, the United States has prospered because it is the home for people from every nation who are drawn to freedom, confident in their abilities to carve out a better life. That "can do" optimism for which America is known is more than a cliché; it is a deep-seated cultural belief reinforced by experience on battlefields and in boardrooms, in classrooms and laboratories...and on the factory floor. It remains within America's ability to make its future.

We must capitalize immediately on our great University system, our National Labs, and tremendous agencies like the National Science Foundation, to be sure this unique and best in class innovation ecosystem, is organized in a way that promotes nanotechnology, tech transfer and commercialization in dramatic and laser focused ways so that we capture the best ideas into patents quickly, that are easily transferred into our capitalistic economy so that our Nation's best ideas and inventions are never left stranded, but instead accelerated to market at the speed of innovation so that we build good jobs and improve the quality of life and security for our citizens faster and better than any other country on our planet. The America Way.

Thank You.

Mr. TERRY. Thank you.

Mr. PHILLIPS. Thank you.

Mr. TERRY. So all witnesses have testified. This is our opportunity to begin our questions for you, and so as chairman, I get to start, and I will start with Dr. Binek.

Now in your testimony, Doctor, you mentioned the interdisciplinary field. Could you expand on how you and the University of Nebraska are engaged in interdisciplinary practice, and who is part of that and how it enhances the ability to advance nanotechnologies?

Mr. BINEK. Yes, thank you, chairman, for that question.

Let me first start locally, at the University of Nebraska, we have Nebraska Center for Materials and Nanoscience, which is an interdisciplinary center where we work together as physicists, chemists, and engineers on nanotechnological problems that includes building where all the tools and for electro-microscopy to x-ray machines to lithography, all housed in our actually quite new Walt A. Keaton building. And in addition, we are fortunate to have an NSF-funded MRSEC, Materials Research Science and Engineering Center, and in the same spirit interdisciplinary, we have physicists, we have chemists, and engineers all coming together and working on nanotechnological problems.

I am also involved in two centers. One center is located also at the University of Nebraska, led by us. It is the Center for Nanophotonic Devices. It is an interdisciplinary research between six universities. And another center I am involved in is the C–Spin Center, where 18 universities nationwide——

Mr. TERRY. That is C–Spin, and what is that?

Mr. BINEK. It is a lengthy acronym for a center where we, again, look for spintronic solutions, mainly to sort of say the barrier which is anticipated by extrapolations of scaling. It is known in the semiconductor industry it is known that if you continue the scaling, making things just smaller and smaller, we will hit a barrier latest by 2020, which is determined by many reasons and also fundamental reasons, like quantum tunneling. We are asked to look for solutions to solve those heat problems you mentioned in your introduction, and spintronics is one of those potential solutions where you use the spin degree of freedom and we can have new functions in our devices, not only processing, but also processing and memory in one device. The spin or the collective phenomenon of magnetism is ideal for non-volatile memory, and we can switch those state variables also by electric means, avoiding electric currents, and that seems to be one way in the future to solve that problem.

Mr. TERRY. And as I understand, there are industries that are also involved, and so how do they participate? Talent, money, whatever.

Mr. BINEK. They participate on various levels, mainly money, and that is a good thing. So for example, the C–Spin center, if I am not mistaken, we talk about a volume of $31 million of funding for a 6-year period. It is mainly by the Semiconductor Research Corporation, which is a consortium of who is who in the semiconductor industry from IBM, Intel, Global Foundries, Micron, you name it. And in addition, with the contribution.

Mr. TERRY. Thank you.

Mr. Phillips?

Mr. PHILLIPS. Yes, sir.

Mr. TERRY. You take that nanotechnology and then apply it in manufacturing. I am interested about how you make that shift and the capital that is necessary to get that done. How do you do it?

Mr. PHILLIPS. Well, it is pretty conventional, the way American businesses always run. You have got to raise capital to build anything, whether it is a space shuttle or a Dairy Queen. You have to be able to capitalize it, and sometimes it comes from purely private capital, in my case, my capital as well. And then sometimes you are also able to get grants, both on a state and federal level, and those are very important. So we have received over time grants from National Science Foundation, the Office of Naval Research, Department of Energy, and so forth. Although very minimal compared to the totality of capital we have raised.

When you build a company like this, the first thing you have to do is have the incredible ideation and invention, the concept and everything, and then you have to turn that into something that is manufacturable. You have to be able to create assembly lines that have quality control with repeatability, scalability, so that it prices out whatever it is you are manufacturing, that it becomes a must-have that people can afford. So it is basic business practices. In this technology which is very, very new, there are more regulatory probably than conventional. We know in the U.S., we appreciate the regulatory. We believe in safety and the controls that are in place, albeit we have to compete against countries that perhaps—have 5 percent total regulatory costs against our 30 to 35 percent regulatory cost. So we have to build in an effort to accommodate that.

Mr. TERRY. Thank you, and my time is expired.

I recognize the ranking member, Jan Schakowsky, for your 5 minutes.

Ms. SCHAKOWSKY. Instructor Tour, I appreciate all of the commercialization, especially that and the problems that you face because companies seem, you are saying would want these tax breaks. But I want to just make the very clear point that you say without any new federal dollars. Not true. It is a decision on whether there is direct federal subsidies and grants, or we give tax breaks. There is a reason that we talk about tax breaks as tax expenditures, because clearly, that is a cost to the Federal Government as well, any tax dollars that would be lost because we would, and so there is a lot of other considerations. Is it better for the Federal Government to make some of the decisions about where the money goes? Do we just leave it to the private sector? And I know others have mentioned public/private partnerships as another way to go.

So I just wanted to make the point that this is not a freebie for the Federal Government when we say that we do it through tax breaks that we would give to corporations. Not ruling that out, but it is a tradeoff that we have to discuss.

I wanted to ask Dr.——

Mr. TOUR. May I comment on that?

Ms. SCHAKOWSKY. Yes, of course.

Mr. TOUR. I think that I said no new spending and no new allocations, because I well appreciate what you are saying, Congresswoman. It is a reality that when you don't have taxes, you don't have money coming in. So that is why I used the words that no new spending, no new allocations.

But the other thing that I hope that I underscored is that it is really a dire situation in the federal dollars that are able to come in and by doing this, somehow we are spreading the load out a little bit to incentivize industry coming in.

Ms. SCHAKOWSKY. I am all for that and it is not a criticism. I just wanted to make sure that we are clear that one way or another, it is money from the Federal Government.

I just have a suggestion, Dr. Mrksich. If you added another vowel between the M and the R, if you added an E, everyone could pronounce your name.

Mr. MRKSICH. You should see my mailbox. I have about 10 good versions of improvements on my name.

Ms. SCHAKOWSKY. Just an idea. Four vowels, four consonants in a row makes it hard. OK. I don't want to take up too much of my time.

I know that you primarily focus on nanomaterials for biological and medical applications, and I am wondering if you could provide a little more detail on the research that you are doing. What kind of advances might happen over the next 5 to 10 years due to your research?

Mr. MRKSICH. I would be happy to. In the area of therapeutics, one kind of a very special properties that nanomaterials give us is the ability to target tissues more selectively. So a lot of drugs that are intended to act in the brain, whether it is for Alzheimer's Disease, those drugs are being developed, Parkinson's and others, those drugs have a difficult time crossing the blood brain barrier. So they can be taken, they are in the system, but they don't get to the site where they can act and improve health.

We have now found that nanoparticles, because of their small sizes, but larger than molecules so they avoid some of the systems that molecules get tied up in, are much more effective at crossing that barrier. So this could be a platform to deliver medicines to the site where they can act so that when we have a medication, a pharmaceutical that is not useful because it doesn't get to the site, one can literally have to drill through the skull and put a device in the brain, or one might be able to use nanoparticle carriers to get them there. We still haven't worked through all of the safety issues and what the dosing should be, what the properties of those particles—but that is one example where nano would take existing trends and just put them at a different—on a different plane.

Ms. SCHAKOWSKY. I was going to ask you about the support gap, but I think we have really heard from everybody that one way or another, the United States needs to figure out how we support this industry, and I just want to make sure that that has absolutely been heard.

In your testimony, Dr. Mrksich, you mentioned the multi-agency structure of the National Nanotechnology Institute, but I don't know if you know that Congress has not reauthorized that or provided an updated vision for it since 2003. I am wondering if there are any particular changes you think need to be made in order for it to get new life.

Mr. MRKSICH. Absolutely. The NNI, started in 2000, has absolutely been a success in terms of creating an infrastructure in the U.S., making the U.S. the global leader in innovating, and having the opportunities to translate into commercial entities. The NNI never had its own money. It required the agencies to redirect a fraction of their budgets to nano-related research. I think we are at the point where we have got this incredible infrastructure and we are now beginning, just in the last 3, 4, 5 years seeing a reverse brain drain. Our best people leaving and other folks who would have come to the United States staying. And this is a direct reflection of the imbalance of research money and infrastructure that is available.

So there is no question in my mind that in renewing, it is really reinventing the NNI to put real money behind it and to ensure that our best people have the tools, have the funding to continue on this incredible first 15-year history we have created.

Ms. SCHAKOWSKY. So for me, lesson learned. Private and public money is really needed to keep us in the forefront. Thank you.

Mr. TERRY. Recognize, I will not recognize the gentleman from Kentucky. Mr. Olson, you are recognized.

Mr. OLSON. I thank the chair, and my questions, first off, will be for Dr. Tour.

Doctor, you mentioned in your testimony you have 30 grad students and undergrads, doctors, and post grads working for you at Rice. You mentioned concern about the brain drain, because many of these people come from overseas. How many people of that 30 are not from here in America? Half, two-thirds?

Mr. TOUR. Of that 30, probably 25 are not Americans.

Mr. OLSON. How many people find a way to stay here after they graduate? You give them that great diploma, that sheepskin?

Mr. TOUR. I would say that half of them will stay. More would stay if they could. The very best of the international students are returning to their home countries where they can get faculty positions. There are no opportunities for them here. There are very few faculty positions opening up in the United States because of the funding situation, and that funding situation being a lack of money that is coming in in federal grants, and mechanisms for that. So they are getting very attractive offers from their home countries, or from countries like Singapore, and also, interestingly enough, the U.K. and Europe because of the large amounts of money in the area, specifically in carbon nanotechnology graphene. So many of them are leaving that would have liked to have stayed.

Mr. OLSON. And Doctor, you said in your testimony that corporations get a deduction if they fund research through your institute. Any example of a corporation that has lost their deduction, that has not invested in your institute because they lost a tax credit, tax, whatever you want to say about the tax preference. Any example of somebody who said listen, Doctor, I want to help you out but I just can't do it. I have to have that——

Mr. TOUR. Oh, there are companies that have said that they just can't swing this, but they are the companies that have come forward are doing it anyway, but it is very hard to get companies to step forward, and if I can use this as a leveraging point, it actually works out quite well for both of us. And as to the amount of deduction that they presently get, it is very hard even to figure that out. I am not a tax person and I tried to get that data even to bring it in here to speak to these companies how much they say definitely that it would help if we had had that tax deduction. But they didn't know how much they are really allowed to deduct. And different companies had different views on this in trying to understand the tax law even.

Mr. OLSON. It sounds like it does hurt for sure. I mean, these guys sort of sit back and say hum, Dr. Tour, you are doing great work, but I have got shareholders I got to take care of, a legal obligation to do that, so I may not invest in your great research because of our tax policies.

Mr. TOUR. Absolutely, and there are companies that may even be in your district that have said that. I am not exactly sure where the border of your district is.

Mr. OLSON. It changes dramatically. But sir, you and I live in the energy capital of the world, and so I am thrilled about what is happening in the energy sector with nanotechnologies.

On your Web site, it mentions oil and gas, enhanced recovery operations, those type of things. Elaborate on what is going on, how you are getting help from industries around there, and what we should be excited about.

Mr. TOUR. So we have a project that is funded in total by Apache Corporation where we have been able to capture CO_2 coming out of a natural gas well, so natural gas is a very clean sort of carbon fuel, 30 percent lower CO_2 emissions than running a car on gasoline. But coming out with natural gas is CO_2. That CO_2 is generally just vented to the air. We have figured out how to trap it and how to send it back down whole. Apache is working on the conversion of that to industrial scale for the deployment. We are working on nano reporters, which these are funded by seven different oil companies in a consortium called the Advanced Energy Consortium, where we developed sensors that can go down hole and they can travel through the sub-three nanometer ports, the sub-three nanometers ports down hole, and then bring up information as to how much oil is down there. And also nanoparticles for enhanced oil recovery, when they see that oil to grab that oil and bring it back up, and then self separate. So those are a few examples from the oil industry.

Mr. OLSON. Finally, healthcare, medical. As you know, right across from Rice University is the Texas Medical Center, the largest research institution in America for healthcare research. You mentioned—I am sorry, your Web site mentioned carbon nanovectors involved in this. What is so exciting about carbon nanovectors?

Mr. TOUR. OK, so we can take these carbon particles now, and all of this has been licensed to a company. They bought the whole suite of patents, licensed the whole suite of patents. This is in collaboration with Baylor College of Medicine across the street, UT Health Science Center, M.D. Anderson Cancer Center, and Methodist Hospital and joint patents between us all. These carbon particles, they can trap something called super oxide. Super oxide, if someone gets a traumatic brain injury, traumatic brain injury is the number one disabler of young adults and super oxide causes great degradation to the brain in the first several hours after. It is exactly the same as the biggest disabler in older adults, which is stroke. It is a lack of oxygen. There has been a blockage. There is a lack of oxygen. When that blockage is removed and oxygen comes in, super oxide forms which degrades the brain. We inject the nanoparticles just before we clear the blockage, and then what happens is this sequesters the super oxide and makes it unreactive towards the brain, and so you get far less brain degradation.

Mr. OLSON. I am out of time. Thank you.

Mr. TERRY. I recognize Mr. Johnson. Bill, you are recognized.

Mr. JOHNSON. Mr. Chairman, I pass. Thank you.

Mr. TERRY. OK, then the gentleman from Missouri, Mr. Long, you are recognized for your 5 minutes.

Mr. LONG. Thank you, Mr. Chairman, and Mr. Phillips, as someone who started a firm from the bottom, can you give more insight into the hurdles that startups deal with with nanotechnology?

Mr. PHILLIPS. Thank you, sir, I would be glad to. We, too, as a company and as a scientific nanotechnology company, the majority of our scientists are on visas or trying to get visas, to the tune of about 80 percent of those, and trying to maintain them in the United States is one of our most difficult problems. I mean, basically the visa program in the United States is so out of date, and so difficult that it is like we are telling our Einsteins and our Wernher von Brauns to get the heck out of the United States, go home. It is exactly like that. We face that issue very day. A number of our scientists have become American citizens while working at NanoMech. I am proud to say they have gone down to Judge Parker's courtroom down in Ft. Smith, Arkansas, raised their hand, and some of the greatest scientists ever come out of the Ukraine, India, China, have become American citizens through working at NanoMech on our nanotechnology. One of the scientists that came out of China ran the entire water management program for China when he was 29. He is now a proud American citizen. But every day it is harder and harder with this visa program. We have one our top researchers right now that is working on the most advanced systems for the Department of Defense in the way of creating the best body armor that ever has existed, totally fireproof, totally waterproof, totally antimicrobial, antibacterial. We basically finished and we have been trying for 2 years to get his wife a visa to join him here in the United States, although he was educated here in the United States, received his Ph.D. here in the United States. That is kind of an everyday problem for us in terms of visa programs.

Other things in nanotechnology that are difficult, I am not a state-run company. I don't want to be a state-run company, but I have to compete against state-run companies. In China today they have the Nanopolis. The Nanopolis is a multi-, multi-, multi-billion dollar project to create commercialized nanotechnology. They invite us over there every day. I have been invited to be their keynote speaker in China this year for the third year in a row, and for the third year in a row, I will turn it down. But they are really outspending us at this point in time in a big way, along with Russia. Russia has a $10 billion fund that they are operating in the United

States called RusNano. Dmitri, who is based out in Silicon Valley, is a Russian who has been trying to either invest in us or in other companies, and have successfully invested in many nanotechnology companies in the United States, as well as venture capital companies in an effort to gain access, or if not even control, of our nanotechnology that has been produced through billions of dollars worth of research through National Science Foundation, NIH, down through our incredible university system. So we have to capitalize this company in order to build very fast. I think we are the fastest growing nanomanufacturing company in the United States to do things like we do to create new types of greases and lubes. That may not sound like a very important thing, it may sound kind of boring, but the world runs on machines. Machines run on lubricants. Without it, they don't run as well. So we are able to create lubricants that make machines basically last a lot longer. For instance, we believe if we were lubricating the Navy ships, I have had conversations with the Secretary of the Navy on this; we could extend the life of our Navy fleet immediately 10 to 20 years without any other expenditures, and many things like that. So getting access to government-type contracts is very tough for smaller companies. Getting access to competitive capital on a national and global scale through public/private partnerships is becoming harder and harder. Overcoming this thing called the valley of death where you go to full-scale scaling companies like ours and we operate on patents that we have licensed from leading American universities. So just in the area of competitiveness, we have the willpower at NanoMech to grow this company, to provide incredible new technologies like very lightweight body armor that is much, much safer than what is out there today, new types of weapons that have never even been dreamed of that can be reached through nanotechnology——

Mr. LONG. Let me interrupt you there. I know nanotechnology is extremely exciting and there are a lot of tremendous benefits from it. I know that in my home State of Missouri that Brewer Science has partnered with Missouri State University in my hometown and have a very, very good partnership with the development of nanotechnologies, so I think that some of these public/private partnerships are starting to take root, and I hope to see them expand, so good luck to you on your ventures.

Mr. Binek, can you tell me is Nebraska in the SEC?

Mr. TERRY. That is a cheap shot.

Mr. LONG. Well, I know they are not but I just love hearing it. I yield back.

Mr. TERRY. We are united in being former members of the Big 12 with you.

Recognize the gentleman from the SEC, Mr. Bilirakis.

Mr. BILIRAKIS. Absolutely, best team in the SEC, University of Florida Gators. Go Gators.

Thank you, Mr. Chairman, for holding this hearing on a growing sector of America's innovation economy.

Nanotechnology is a sector that holds exciting prospects for the United States with its continued position at the forefront of technological advancement and economic growth. Nanotechnology is the perfect demonstration of how the private marketplace continues to innovate to solve economic and societal problems.

For example, in my district, Dais Analytic, which was named to the Forbes magazine's top energy projects to watch in 2012, has developed technologies and programs to clean dirty air and dirty water. Because nanotechnology is still a relatively new phenomenon, it is important that the Federal Government not stifle innovation and growth with burdensome and unnecessary regulations and red tape.

Here is my question. I currently serve as the co-chair of the Congressional Technology Transfer Caucus, and I am interested in how we economically capitalize upon the investments made in technology research. I understand that it may be difficult to transition from research to licensing to commercial development. Can you walk us through, and this is for the panel, can you walk us through the challenges that are faced in the stages of development, from patenting new research and technology to licensing it to companies to commercializing it, please? Whoever would like to start.

Mr. MRKSICH. I can begin. I have done this a number of times, and having advances in my university lab lead to something interesting. Within the universities, we disclose that, apply for patents, and at the same time start to form a small company. That is sometimes done by raising seed or angle money. Sometimes it is done by going straight to venture capitalists, if that is the scale of the investment required. Then from there it gets a start, and runs on the treadmill and hits milestones and raise more capital.

One comment I want to make about nano, though, this is a new area. If you look at biotechnology, there are many repeat entrepreneurs that really are quite effective at getting new technologies out. There are venture capital firms and angels who specialize in that space, and so they are very sophisticated in recognizing opportunities and aggressively pursuing them.

Ten years ago, there were just a handful of nanotechnology companies that got started. We didn't have the capital infrastructure, the sophisticated investors that made it and the repeat entrepreneurs that made it more straightforward to get started. So as I look back, I think, and in my case, this is true as well, the SBIR program has oftentimes been the stepping stone to get IEP out of the university into a company where you can start working on a prototype and de-risk the technology. And I think in this young field still, where many of the founders of new companies are first-time founders, they are not familiar with the process and there are many barriers to getting going. Making it more straightforward to direct SBIR funds towards those folks, I would even think about a policy that said if you have a research grant from the NSF or the NIH or the DOE and a nanospace, and you apply for a patent, that you have a streamlined access to an SBIR to get that out of the university and put it into the commercial sector where it can get going. Because I think there are a lot of things that are left on the floor because, again, this young area with first-time entrepreneurs don't have a straightforward time getting something started.

I will let the others add other perspectives.

Mr. BILIRAKIS. Yes, please. Anyone else, please?

Mr. TOUR. I have gone through this many times. I agree with Milan and I have known Milan for a long time, is that what I am finding now is that it is international companies and entities and investors that are coming and wanting to buy up the technology.

Just recently, one of our patents was licensed to a Chinese company for the development of super capacitors, and they are going to take this on and make batteries for electric vehicles this way. Three of our technologies are currently being licensed by the Israelis to start companies in three different areas, based on the technology that was developed in our laboratory. There was a company that was going to start and the tax advisor said don't start it in the United States, start it in Singapore. And that was purely from a tax consideration standpoint.

So at no other time in my career in the last year or two I am seeing this coming of foreign entities and buying up U.S. technologies, and so the question then becomes why aren't the U.S. entrepreneurs stepping forward as aggressively as the international entities, and I am not sure that I have answer to that for you, and that is something that there is probably, you in this room have thought about this more than I have. But this is a trend that I am noticing that the biggest and most aggressive buyers of the technology now, in my experience in the last several years, are not U.S. entities anymore.

Mr. TERRY. Thank you.

Recognize the gentleman from Ohio, Mr. Johnson.

Mr. JOHNSON. Thank you, Mr. Chairman. I did want to come back and kind of take off on what, Dr. Tour, you were just talking about. What do you think we need to do to regain U.S. competitiveness for human talent and corporate investment as compared to what some of those other countries that are doing that are state-sponsored, subsidized countries like China and others?

Mr. TOUR. Right. So even before coming here, I talked to this Israeli group that is licensing three of our technologies to certain companies. And I said show me the tax structure of what it would cost me to start up a company in Israel. And they sent me the links to all of that data, and the tax structure is a lot more friendly towards small companies, especially if you are going to build your manufacturing entity outside of Tel Aviv, moving it. So I am talking about tax rates that are on the order of about 7 percent.

So you look at numbers like this, and I am cognizant of the fact that the U.S. government runs on taxes, but I have started several small companies myself and I will never start another one again. It is a very difficult and arduous task, and so now I just go into the licensing and license it out to others. But the tax structure is quite aggressive here, and again, I am deferring to what the Congresswoman said, and I acknowledge that. I am just saying that when you look at the tax structure, it is very different.

My testimony here is saying that without a proper mechanism for funding, many of these very smart people that we have are now leaving. The U.K. has come with a graphene and carbon program that is enormous. The European Union, that is enormous and funding at a very large scale. And they are trolling U.S. faculty. I had two offers, two offers in the last year from the U.K. to move my program there. My program that was 90 percent federally funded, 10 percent industrially supported in 2008 is now 80 percent industrially supported and 20 percent federally supported. Same amount of money. I have been able to make that transition, so my testimony is help me to make that transition. If the Federal Government can't step up, what can you do in the meantime to allow me to bring more money into my laboratory and my colleagues into their laboratories to maintain their programs here, rather than just having us move abroad. Because these folks are industrious folks and they are going to find out how to get their program continued. And if that means moving overseas, they will do it.

Mr. JOHNSON. So is it safe to say, then, that tax reform is critically important to retaining nanotechnology expertise in America and making us competitive?

Mr. TOUR. I absolutely think so, sir, and I know that is not the direct privy of this committee, but I know that you have influence in that.

Mr. JOHNSON. Dr. Binek, how can research consortia such as the Semiconductor Research Corporation be encouraged in the U.S.? Have you worked with other similar organizations or know of similar organizations working with universities to support nanotechnology research?

Mr. BINEK. In the case of the Semiconductor Research Corporation, their motivation is basically driven by,I mean, they look at the scaling issue and they know if we don't do something drastically soon, there will be a major problem because who wants a next generation cell phone which just changes color, right, but there is no progress anymore. So this kind of driving force can, I think, be very strong, but it can probably also be very strong, although I have less experience outside the semiconductor industry. For other industries, however, my concern here is that it is mainly short-driven to some extent they have to see the abyss in front by doing their own extrapolations, seeing that scaling 2020 will, and then they say OK, we better do something, and now it is already a little late. And I think we should find ways to do something in advance.

Mr. JOHNSON. OK. In your testimony, you discuss U.S. dependence on rare earth permanent magnets, which are predominantly mined in China. So why are these magnets important to the U.S. economy and what are the benefits of finding alternatives?

Mr. BINEK. So you find them everywhere, from your cell phone in the modern lithium ion batteries and I was specifically referring to the important use of them in permanent magnets. There are high energy permanent magnets which enable this extremely lightweight electrical engines, which allow for this unmanned aerial vehicles, for example, or headphones even. All kinds of applications, wind turbines. For example, a 2 megawatt wind turbine has 800 pounds of rare earth minerals in it, so they are very important and the thing about rare earth, as the name may suggest, they are not that rare. You cannot just mine them as other metals like gold or copper. They are not really concentrating that much, so you have to operate with large volumes and then extract small amounts of them. And that is a very costly enterprise, and also it comes with a huge burden on the environment. I mean, there are stories about these toxic lakes in China which are a big problem.

So finding alternatives to rare earth is certainly an important thing, and nanotechnology, again, can help here. For example, in the field of permanent magnets we do that also at the University of Nebraska. We use nanostructuring of materials, bringing hard and soft materials into proximity and then get those properties without rare earth, just really metals, for example.

Mr. TERRY. Thank you.

Mr. JOHNSON. Thank you, Mr. Chairman.

Mr. TERRY. I recognize the gentleman from Mississippi.

Mr. HARPER. Thank you, Mr. Chairman, and thank each of you for being here and for your insight. It is certainly amazing some of the progress that is being made and the excitement for the future of what we can do if we do this properly.

Dr. Binek, if I may ask a follow-up on Mr. Johnson's question, specifically about the rare earth materials. How far away are we from developing alternatives at a commercially viable high volume manufacturing process?

Mr. BINEK. I think we are still quite a step away to replace them. Certainly we will not replace them with a switch everywhere. There are different field and different needs applications where we can hope to find replacements soon, but I am very certain as far as I can predict that they will still play an important role in the foreseeable future in many, many applications.

Mr. HARPER. Thank you very much.

Mr. BINEK. I may want to mention that there are—as a mining operation also again reopened in the United States, but it comes with its own problems.

Mr. HARPER. OK, and where is that?

Mr. BINEK. To be honest, I need to pass on that.

Mr. HARPER. OK, that is fine. Thank you very much.

Mr. Phillips, if I could ask you a few follow-up questions. In your testimony, you discuss the U.S. permitting process for manufacturing facilities. Why is the time table for approval longer in the United States than other countries?

Mr. PHILLIPS. Well, you could basically say the United States perhaps is more advanced in that area in terms of guarding safety and regulations and things like that, and to a great extent, a lot of those regulations are necessary for a good, safe country. But——

Mr. HARPER. OK, and how have other countries——

Mr. PHILLIPS. I am up against countries that don't even know what OSHA is. They have no OSHA. They have no requirements for insurance. They have no permits, typically, and so all I do is try to make a comparison as to trying to compete against those companies and countries like that that are state-run companies. It makes it more difficult for a company like us. Albeit, we work very closely with our municipalities, our state governments, and so forth to expedite those situations to reduce the amount of paperwork, typically, that comes with it. A lot of it is incredibly redundant paperwork, committees upon committees upon committees that you have to deal with that I would say could be incredibly streamlined. Having founded a company in Mississippi, co-founded a company called Skytel in Jackson, Mississippi that became instant messaging and ushered that in on a worldwide basis. I can remember back to the days in the '90s on how easy it was to do things like that. Of course, that was in the digital space, as we moved from analog to digital and totally transformed the way business is done. I believe that the transformation that is taking place in moving from micron technology in a manufacturing scale to now nanoscale will dwarf all the benefits we saw in the digital world, moving from analog to digital. Unfortunately, as the testimony shows today, in Europe and Asia and so forth, they are taking nanotechnology tremendously more serious than the U.S. government is in terms of advancing it with incredible speed, with developing either public/private partnerships or outright gifts to corporations to make them competitive. We have seen a couple of those in the U.S. A lot of criticism about Solyndra. Solyndra received $500 million in funding and then went bankrupt, but in China, there were four competitors to Solyndra that received $5 billion each to compete and dropped the price on a worldwide basis and took the worldwide lead in solar. And now the remains of Solyndra are owned by China, as is A123, our leading battery company, that received $500 million in funding in the U.S., but compared to China it was dwarfed.

So although I'm not, again, wanting to be a state-run company or anything like that. We have to look at the entire business model on a global basis, not on a U.S. basis, in order to compete going forward. It is something we have to get a handle on, because if we don't make things, we really cease to be a country.

Mr. HARPER. So what you are saying is if there is a way to fast track some of this process, that is a great benefit to you. And you mentioned countries that maybe are not doing it right. Are there some countries that are, indeed, doing it well on nanotechnology R&D?

Mr. PHILLIPS. Well, you look to Germany and Japan and so forth and the amount of public/private partnerships that you see there are fantastic in terms of the speed, Sweden and others. And this is not to over-criticize my country which I love dearly and represent it, as in the military days. I think we are definitely trying a lot of things, but we are stymied to a certain extent in patents right now. The cost of a U.S. patent compared to overseas many times is prohibitive and in the area of nanotechnology, in order to protect gigantic investments it takes to enter into a manufacturing, as opposed to digital space, that cost is very high. I just hope 100 years from now when America looks back, we don't basically say well, we are the country that did Facebook, compared to the country that came up with new ways to manufacture that totally created new cures, whether it was for cancer or what have you, and nanotechnology and maintained a very competitive weaponization system, as weapons became smaller and easier to perhaps control those weapons in strategic and tactical applications.

Mr. HARPER. Thank you very much, Mr. Phillips. I yield back.

Mr. TERRY. Thank you, and the gentleman from New Jersey is recognized for 5 minutes.

Mr. LANCE. Thank you, Mr. Chairman.

Mr. Phillips, in your testimony you referred to various policies that may be hampering business investment in nanotechnology, including the R&D tax credit. In 16 countries with a higher R&D credit than the U.S.—and I am sorry that that is the case—I believe that their corporate tax rate is different from the United

States, and our corporate tax rate is among the highest, perhaps the highest in the industrialized world. Could you comment on that in a little greater detail, and any advice you might be willing to give us in that regard?

Mr. PHILLIPS. Well, when we have a breakthrough technology that hits like digital or like in the case of nanotechnology, maybe the Federal Government needs to look at investment tax credits on spending by companies in nanotechnology of a variety of types so that they can capitalize their manufacturing facilities faster, perhaps do more research and development faster, and through investment tax credits produce new goods that return in the purchase of those goods through sales taxes and other type taxes, including income taxes on a federal basis, actually multiply the receipts on the tax base, even though in the early stages of those companies those changes could, without question, accelerate the development, and also lead to more investments in those companies from the private sector if it favored a technology as robust and with as much potential as nanotechnology.

Mr. LANCE. Thank you. I certainly agree with that.

Dr. Tour, the regulatory landscape for nanotechnology drives industries as how they look today. If you would, sir, could you expand on the regulatory process for startups and how Congress might be involved in improving the situation.

Mr. TOUR. All right. So we don't have good standards now to make comparisons and upon which to really target ways to mitigate the problem so that the improvement of standards against which we could direct these would certainly be a help for us to be able to move these along so we generate new materials. And then sometimes our—I served for 3 years on E–Track, which is a Department of Commerce committee to rewrite some of the export control laws, and because we have a very large book of things that we can export—and it was interesting that we couldn't export many of the things that are made overseas in much larger volumes than we are even making them. So we were hampered in that way and many ways, and that even hampered the basic research of collaborating with people.

So things become archaic, and after 3 years on that committee, I stepped down because everything that was proposed I wasn't even sure if it was even read. And so I am not sure that anything ultimately changed as a result of that.

So I realize that this is a big country and lots of things have to be done, but some of these barriers that really there was no good scientific rationale for the inhibitions that were there.

Mr. LANCE. And from your expertise, could those matters be changed by administrative rule and regulation, or would it require a statutory change, change from us here in Congress?

Mr. TOUR. I am sorry, I don't know that.

Mr. LANCE. Certainly it might be easier if it were only to require some sort of change from the Department of Commerce or another agency of the Executive Branch, but obviously, we and our co-equal responsibilities are looking for statutory change as well to improve the situation.

Mr. TOUR. Right.

Mr. LANCE. Certainly I thank you for your service, and it may seem frustrating but I certainly think it is important that talented professionals, including academics, are involved in what you do, sir.

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

Mr. TERRY. Thank you, Mr. Vice Chairman. And that concludes our question and answer period. I want to thank all of you for being here. I think you have enlightened us, especially on policy aspects, which is hopefully one of your goals here today. I think you have given us several things to think about how we can help improve the research and development of nanotechnologies in the United States, so I appreciate that.

So with that, did you want to say something?

Ms. SCHAKOWSKY. Well, let me just thank the witnesses. I think this is a real growth area for our country if we do the right thing. We have the brains. We have an infrastructure to do this, and it would just be such a pity if we lost this in the global marketplace.

So thank you very much for underscoring that, and for sharing your expertise.

Mr. TERRY. So we have up to 2 weeks to submit written questions to you. Don't know if there will be any, but we have that and if we do send you written questions, we would appreciate about a couple of weeks timeframe to get your written answers back to us.

With that, thank you again. You have been a great service to us, and we are adjourned.

[Whereupon, at 11:45 a.m., the subcommittee was adjourned.]

[Material submitted for inclusion in the record follows:]

PREPARED STATEMENT OF HON. HENRY A. WAXMAN

Today's hearing is a valuable one. We will learn how scientists and engineers are making significant advances by working with nanoparticles.

Nanoparticles are extremely small. One nanometer is one billionth of a meter. A single hair is roughly 75 to 100 thousand nanometers wide.

Nanotechnology can be used to reduce the effect of oil spills on the environment, improve solar panel output, and help detect early-stage Alzheimer's disease. Researchers are working on even more applications, including groundbreaking uses in cancer treatment and the fight against climate change.

At the federal level, the National Nanotechnology Initiative, or NNI, provides participating agencies with a coordinated framework for supporting nanotechnology research, development, and manufacturing. I applaud President Obama and the Presidential Council of Advisors on Science and Technology, or PCAST, for their ongoing support of NNI and their broader efforts to bolster this field.

Thanks in part to their efforts, the United States leads the world in nanotechnology investment and research. Important research occurs throughout the country, including at the California NanoSystems Institute, which I am proud to say has one of its two locations within the district I represent, at UCLA.

But our lead in this technology is being challenged. Nanotechnology is flourishing not just here, but around the globe. Nations have devoted significant effort—and public funds—in order to become the most attractive place to research, develop, commercialize, and manufacture nanotechnology products.

One problem is that in the United States, the NNI has not been reauthorized since 2003, when Congress first gave the initiative a statutory foundation and appropriated funds for its work. In addition, public funding for nanotechnology research has been significantly cut over the last few years, with total federal R&D funding for the field dropping nearly 20 percent from 2010 to 2014. This is a mistake.

We in Congress should demonstrate our support for nanotechnology by increasing scientific research funding in next year's budget. We should enhance the educational opportunities available to students and workers to ensure they have the science, technology, engineering, and mathematics knowledge necessary for jobs in nanotechnology. And we should play a more active role in the NNI. The program should be reauthorized, and in doing so, we should provide an updated, cohesive vision for how the U.S. can stay competitive on a global scale.

I am pleased that the Subcommittee will have the opportunity today to learn more about nanotechnology from those who know it best. While the main topic of this hearing is innovation, I encourage members and panelists to remember, in addition, that advances through nanotechnology are made possible by altering particles at a very basic level. As nanotechnology becomes more prolific, scientists like those on this panel must come to understand exactly what the environmental, health, and safety implications are. And members of this Committee must work with agencies, including the Environmental Protection Agency, the Food and Drug Administration, and the Consumer Product Safety Commission, to ensure that human health and safety and the environment are protected.

Thank you.

FRED UPTON, MICHIGAN
CHAIRMAN

HENRY A. WAXMAN, CALIFORNIA
RANKING MEMBER

ONE HUNDRED THIRTEENTH CONGRESS

Congress of the United States

House of Representatives

COMMITTEE ON ENERGY AND COMMERCE
2125 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515–6115
Majority (202) 225–2927
Minority (202) 225–3641

December 19, 2014

Mr. Christian Binek, Ph.D.
Associate Professor
Physics and Astronomy
University of Nebraska – Lincoln
310 G Theodore Jorgensen Hall
Lincoln, NE 68588

Dear Dr. Binek,

Thank you for appearing before the Subcommittee on Commerce, Manufacturing, and Trade on Tuesday, July 29, 2014 to testify at the hearing entitled "Nanotechnology: Understanding How Small Solutions Drive Big Innovation."

Pursuant to the Rules of the Committee on Energy and Commerce, the hearing record remains open for ten business days to permit Members to submit additional questions for the record, which are attached. The format of your responses to these questions should be as follows: (1) the name of the Member whose question you are addressing, (2) the complete text of the question you are addressing in bold, and (3) your answer to that question in plain text.

To facilitate the printing of the hearing record, please respond to these questions by the close of business on Monday, January 5, 2015. Your responses should be e-mailed to the Legislative Clerk in Word format at **Kirby.Howard@mail.house.gov** and mailed to Kirby Howard, Legislative Clerk, Committee on Energy and Commerce, 2125 Rayburn House Office Building, Washington, D.C. 20515.

Thank you again for your time and effort preparing and delivering testimony before the Subcommittee.

Sincerely,

Lee Terry
Chairman
Subcommittee on Commerce,
Manufacturing, and Trade

cc: Jan Schakowsky, Ranking Member, Subcommittee on Commerce, Manufacturing, and Trade
Attachment

UNIVERSITY OF Nebraska Lincoln

Dr. habil. Christian Binek
Associate Professor of Physics

COLLEGE OF ARTS AND SCIENCES
Department of Physics and Astronomy
310G Jorgensen Hall
Lincoln, Nebraska 68588-0299
phone: 402-472-5231; FAX 402-472-2879
e mail: cbinek2@unl.edu
http://www.physics.unl.edu/~cbinek/index.htm
http://www.unl.edu/cmra/faculty/binek.htm

January 07, 2015

Kirby Howard
Legislative Clerk
Committee on Energy and Commerce,
2125 Rayburn House Office Building, Washington, D.C. 20515

Respected Chairman Terry,

It was my greatest honor to testify before the Subcommittee on Commerce, Manufacturing, and Trade, Tuesday, July 29, 2014 on the subject of nanotechnology. I hope that my testimony helped to facilitate a better understanding on "how small solutions drive big innovation".
It is likewise with great honor and pleasure that I reply to the additional questions which my testimony stimulated.
Next I address each question in the order raised by **The Honorable Lee Terry**

1. **The high risk nature of nanotechnology research and development is generally described as a barrier for investment. Have you seen any increase in industry investment as more nano-driven technologies are developed for the commercial market?**

Reply 1: As a scientist my primary concern is pushing the boundaries of knowledge. With that said, I am fully entangled in the need for commercial success of nanotechnology both as scientist and consumer. I can particularly comment on those aspects of nanotechnology, which connect the work of my group at the University of Nebraska-Lincoln with partners from industry. From this perspective I confirm that in the emerging field of nanoelectronics a significant increase in industry investment takes currently place. In fact, by far the largest fraction of funding benefitting my group originates currently and in the foreseeable future from industry sponsored sources such as the Nanoelectronics Research Initiative but also the Intel Corporation as an important

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individual sponsor. As mentioned in my testimony, this increase in funding of basic research is triggered by the realization that the continuation of Moore's exponential growth of performance-to-cost ratio of integrated electronic circuits is jeopardized in the absence of major fundamental breakthroughs. In the field of nanoelectronics, industry bundles the efforts in a very efficient and intelligent manner through research consortia such as the Semiconductor Research Corporation. Guided by the industry needs but with sufficient room for curiosity and creativity, cooperative research among top US universities is successfully fostered with special attention to the next generation of leaders in nanoelectronic research.

2. In your testimony, you discuss your pending patent on refrigeration through voltage-controlled entropy change. Please describe in more detail the potential commercial applications for this technology.

Reply 2: I briefly mentioned in my testimony that heating, ventilation and cooling account for a large fraction of electrical energy consumed in US. Alternative refrigeration technologies can be a part of the solution of the energy crisis. It might be worth to mention that I am convinced that the current drop in oil prices does not improve the situation in the long run and certainly does not solve the problems accompanying the excessive consumption of fossil fuels.

Magnetic refrigeration has been proposed as an alternative superior to today's conventional gas compression refrigeration. However, a major problem of magnetocaloric refrigeration technology is the need for strong magnetic fields. Until recently, the only viable option providing the required magnetic fields have been permanent magnets based on rare earth materials. This makes magnetic refrigeration expensive and limits its potential for miniaturization.

My disclosed technology eliminates the need for applied magnetic fields and replaces them by electric fields. One can envision various magnetoelectric coupling schemes to realize a magnetocaloric response in the absence of an applied magnetic field. A straight forward solution suggested in my disclosure together with others concepts is the utilization of the piezoelectric effect. It allows to create periodic stress through applied voltage. The stress is mediated into an adjacent magnetic material which gets periodically strained. The strain changes the magnetization via magnetoelastic response which in turn gives rise to the desired temperature change via the magnetocaloric effect. Nanotechnology and materials science can help optimizing each step in the cascade of entangled phenomena.

The absence of permanent magnets allows for compact and miniaturized cooling devices with a coefficient of performance that potentially outperforms alternatives based for instance on the Peltier effect. Size and weight limited cooling applications have numerous applications such as cooling of laser diodes for improved output stability, performance enhancement of microelectronic processors through cooling of local hot

Jorgensen Hall / 855 N 16th Street / P.O. Box 880299 / Lincoln, NE 68588-0299
(402) 472-2770 / FAX (402) 472-6148 / physics.unl.edu

University of Nebraska Lincoln

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Department of Physics and Astronomy

spots, and enhancement of the signal-to-noise ratio in infra-red detectors such as night-vision goggles.

3. Have you experienced challenges in licensing your patents for commercial development? If so, how have you overcome these obstacles?

Reply 3:Yes, I have experienced challenges in licensing patents for commercial development. Like many early-stage, university-developed technologies it can take four years or more to secure a license, which is typical. Over the past 10 years, I have disclosed five technologies to NUtech Ventures, the entity which evaluates, protects, markets, and licenses innovations and discoveries at the University of Nebraska-Lincoln. As a faculty member I work with NUtech Ventures to overcome the obstacles in commercial development and licensing so that I can focus on research and education. I have been informed that two of the technologies are licensed to an industry consortium, and two, including the refrigeration through voltage-controlled entropy change technology have not been licensed, to date. These technologies will continue to be marketed via the internet and through other marketing efforts to prospective licensees.

Sincerely

Christian Binek

Jorgensen Hall / 855 N 16th Street / P.O. Box 880299 / Lincoln, NE 68588-0299
(402) 472-2770 / FAX (402) 472-6148 / physics.unl.edu