

**U.S. House of Representatives Committee on Science, Space and Technology
Subcommittee on Research and Technology**

Examining Federal Advanced Manufacturing Programs

Summary of Major Points of Expert Testimony by

Thomas M. Baer, Ph.D.

- The Federal government can best assist the needs of US industry by leveraging the exceptional capabilities found in US universities and government labs.
- The US has the world's best university educational system, the best system of national laboratories, and the highest level of private sector entrepreneurial activity and technological innovation.
- However, other nations appear to do more to encourage interaction between these three sectors, and provide effective programs that directly incentivize collaborations focusing on advanced manufacturing technology.
- Within the US government NIST is uniquely positioned to provide a wide range of support for advanced manufacturing within US industry.
- Although almost all industrial sectors in the US could benefit from these government programs, industries that would benefit the most are those in early rapid growth phases, where financial resources are typically not as readily available to explore new manufacturing methods.
- Special attention should be paid to deploying adequate resources specifically in high growth areas such as renewable energy generation and storage, batter technology for electric vehicles, expanding our long and short haul information technology bandwidth capabilities, and new transformative areas of manufacturing incorporating protein engineering and synthetic biology.
- Federal funding of advanced manufacturing in the US, programs such as the NNMI and AMTech, are well conceived, providing much needed funding to enhance US leadership in manufacturing. I encourage you to give these programs highest priority.

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Expert Testimony by

Thomas M. Baer, Ph.D.

Tuesday, September 10th, 2013

Good morning, Chairman Bucshon, Ranking Member Lipinski, and members of the Committee. Thank you for inviting me to speak with you today about federal advanced manufacturing programs specifically those at the National Institute of Standards and Technology (NIST). As an introduction, I am currently the Executive Director of the Stanford Photonics Research Center and a Consulting Professor in the Department of Applied Physics at Stanford University. Prior to my tenure at Stanford University I was CEO and founder of Arcturus Bioscience, a company that developed biomedical instrumentation for cancer diagnosis and life science research. Throughout my career I have been involved with a number of high technology companies in Silicon Valley where advanced manufacturing technology was a critical corporate focus.

I have had a long, productive association with NIST, serving six years during the 1990s on the NRC review panels for both the Physics and the Chemical Science and Technology Laboratories. I have also served for the past six years on the Visiting Committee for

Advanced Technology (VCAT). I want to state clearly that in my testimony today I am presenting my own perspective on the topic being discussed, and I am not speaking on behalf of the VCAT committee or Stanford University.

My colleague, Professor Alan Taub, has described in his testimony the important role NIST and the US government can play in supporting federal programs in advanced manufacturing. I agree with and strongly endorse his position that the Federal government can best assist the needs of US industry by leveraging the exceptional capabilities found in US universities and government labs. In my view, the US has the world's best university educational system, the best system of national laboratories, and the highest level of private sector entrepreneurial activity and technological innovation. However, other nations appear to do more to encourage interaction between these three sectors, and provide effective programs that directly incentivize collaborations focusing on advanced manufacturing technology. I believe the programs we are discussing at this hearing would enhance US industrial competitiveness and in short order increase the number of high quality jobs available within the US.

Within the US government NIST is uniquely positioned to provide a wide range of support for advanced manufacturing within US industry. NIST capabilities include its expert staff and standards programs in the Material Measurement Labs (MML), its world-class facilities in the National Measurement Laboratories (NML), and the specialized instrumentation that is part of the user facilities in both the Center for Nanoscale Science and Technology (CSNT) and the Center for Neutron Research (CNR). These assets plus its broad charter to support US industrial competitiveness position NIST to be the optimal choice as the focal point for federal programs in advanced manufacturing.

I have been asked to assess Federal advanced manufacturing research and development programs, including research and development programs at NIST. Several programs are currently being planned and implemented including the NNMI, AMTech, and MEP programs already well described by Professor Taub in his testimony. HR 1421, "Advancing Innovative Manufacturing Act of 2013" is an additional program directing funding to this important area. Even after reading through the descriptions of these various programs, the similarities and differences between these separate initiatives are not terribly clear to me. Given the current status of the federal budget and the need for careful allocation of precious federal resources it will be very important to coordinate and possibly combine these programs in order to eliminate duplication and optimize implementation efficiency. It also quite important that the specific activities funded by these initiatives be optimized

by getting input from US industry. The current leadership at NIST, specifically Director Dr. Patrick Gallagher and Associate Director of Laboratory programs Dr. Willie May, are very experienced, successful managers of government programs with proven track records of working constructively with US companies. I urge the oversight committees to allow these individuals the freedom and flexibility to decide how to best implement these programs and thus optimize the return on investment of the federal funds allocated to these programs.

Although almost all industrial sectors in the US could benefit from these government programs, industries that would benefit the most are those in early rapid growth phases, where financial resources are typically not as readily available to explore new manufacturing methods. It is in these areas that government programs can provide great benefit and a large return on investment. In my testimony today I would like to focus on several examples where government programs such as the NNMI, AmTech, and the initiative described in HR Bill 1421, "Advancing Innovative Manufacturing Act of 2013", could be pivotal to future US competitiveness in industries at early stages in their development, which will become strategic growth sectors of US industry.

Energy Generation

Advances in manufacturing technology will be critical for expanding the production of electrical power using renewable resources. A recent publication based on the National Academy report states: "While today's solar-generated electrical power represents a small fraction of the world's production capacity — less than 0.5 percent— solar power is the fastest energy generation source in the United States. In 2012, the US market size for solar energy was \$11.5 billion, a 34 percent increase over 2011." (From the National Photonics Initiative, www.lightourfuture.org "Lighting the Path to a Competitive, Secure Future", accessed September 8, 2013.) By 2020 the market size for solar energy is expected to exceed \$50B US. (<http://about.bnef.com/files/2013/04/Global-Renewable-Energy-Market-Outlook-2013.pdf>, accessed September 8, 2013) This growth will be accelerated by reducing manufacturing costs of existing photovoltaic panels and through the development and introduction of new, lower-cost semiconductor materials, manufacturing processes, and panel designs. Solar energy can provide a sustainable energy source to meet a significant portion of the nation's total projected energy needs, but component and production costs must be reduced in order to be competitive with other existing fossil fuel based energy sources.

For example, new photovoltaic materials provide the potential to employ high-volume, reel-to-reel manufacturing techniques to dramatically reduce the cost of manufacturing. These new materials can be applied in thin films to flexible substrates decreasing the overall panel weight, cost, and time of manufacture. Although laboratory demonstrations of highly efficient operation of small scale devices have been published, challenges remain to fully exploit the commercial potential of these new approaches. These challenges include: improving the crystalline quality of the deposited material, optimizing the deposition process, and developing high-speed, post deposition cutting and scribing necessary for electrical isolation of individual solar cells. Expanding federal funding in support of collaboration among government laboratories (e.g., NIST and NREL), US companies, and university research groups focusing on developing manufacturing technology in this area would greatly facilitate progress towards achieving cost-parity of solar energy with conventional fossil fuel based energy sources and reduce the overall production of green-house gases produced in the US.

Energy conservation

Advances in manufacturing technology are also essential for improving energy conservation in the US. Roughly 20% of the electrical power generated in the US is used for lighting. Light emitting diodes (LED) or solid-state (SS) lighting are 5 times more efficient than incandescent lamps currently in use. Moreover, LEDs last up to 20 times longer than incandescent bulbs. The overall market size for these new light sources is expected to grow rapidly with improvements in manufacturing. "The global solid-state high-brightness LED market was \$13.7 billion in 2012. With continued improvements in performance and reductions in manufacturing cost, LEDs should begin to dominate general lighting, with an estimated market of \$84 billion by 2020. By 2030, the forecasted energy savings from the use of LED lighting in the United States is about 45 percent — a savings of \$30 billion at today's energy costs." (From the National Photonics Initiative, www.lightourfuture.org "Lighting the Path to a Competitive, Secure Future p. 21). In addition, a National Academy report concludes: "Cost is the main issue preventing widespread adoptions of SS lighting, but substantial progress is being made in lowering the cost of light-emitting diodes (LEDs).... The cost of white LEDs is still very high due to the lack of scalability in the manufacturing processes." ("Optics and Photonics: Essential technologies for our Nation", p. 130,155, National Academy Press, http://www.nap.edu/catalog.php?record_id=13491, accessed September 8, 2013.)

Current prices for LED lamps are roughly 10 times higher than comparable incandescent bulbs, a significant barrier to their wide-spread adoption. Advances in manufacturing methods could substantially improve semiconductor yields and lower the cost of power conversion electronics, and other necessary components for cost-competitive LED lighting.

Personal Transportation

Electric automobiles are one of the fastest growing segments of the automotive industry; sales have doubled this past year and are expected to continue to grow rapidly over the next decade. (<http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952>) The US is currently the world's largest producer of electric cars and the leader in electric car technology. US manufacturers were the first to win the prestigious Car of the Year award given by Motor Trend: the GM Volt in 2011 and the Tesla Model S in 2013. Plug-in hybrid and fully electric cars are the future of personal transportation technology. They are 3 times more efficient than gasoline powered automobiles in delivering power from the energy source to the wheels, and they have the potential for much lower maintenance due to the very large reduction in the number of engine components and engine complexity.

A major impediment to wide-spread commercial adoption of electric vehicles is the cost of manufacture of the batteries, which are primarily responsible for the increased price of an electric car compared to its gasoline powered equivalent. Batteries are the most expensive component in an electric car, adding about 20% to the cost of the electric automobile. Reducing the cost of battery manufacture by three fold would make the cost of ownership of an electric vehicle comparable or less than its gas powered equivalent. " In the United States, with gasoline prices at or above \$3.50 a gallon, automakers that acquire batteries at prices below \$250 per kWh could offer electrified vehicles competitively, on a total-cost-of-ownership basis, with vehicles powered by advanced internal-combustion engines . " http://www.mckinsey.com/insights/energy_resources_materials/battery_technology_charges_ahead

Future battery technology will use components made from nanostructured materials providing lighter weight, more efficient ion and electrolyte flow, as well as improvements in overall efficiency and life time. (Jun Chen and Fangyi Cheng, Combination of Lightweight Elements and Nanostructured Materials for Batteries, Accounts of Chemical Research 713-723 June 2009 Vol. 42, No. 6.) These new materials will require advanced manufacturing methods to be developed and new methods for measuring quality and performance of these nanostructured materials. NIST has exceptional, world-class facilities for assisting in

the development of these capabilities within the National Measurements Laboratory and the Center for Nanoscale Science and Technology.

Overall performance of electric vehicles will also be greatly improved by reducing the weight of the vehicle. As mentioned by Professor Alan Taub in his testimony, the Oak Ridge National Laboratory Carbon Fiber Technology Facility (CFTF) is well positioned to assist US car manufacturers in developing the manufacturing process by incorporating these light-weight materials in their designs. "The next generation of carbon-fiber composites could reduce passenger car weight by 50 percent and improve fuel efficiency by about 35 percent without compromising performance or safety -- an advancement that would save more than \$5,000 in fuel over the life of the car at today's gasoline prices."

(<http://www.fueleconomy.gov/feg/evtech.shtml>, accessed September 8, 2013)

Information Technology and the Internet

The Information and Communication Technology (ICT) sector has evolved to become an essential infrastructure for a major fraction of the US economy. The global ICT system includes smartphones, laptops, the internet long-haul backbone, and computer-server farms that drive search engines (Google and Yahoo, for example) and internet services such as YouTube, Facebook, and Amazon. Demand for ICT data bandwidth is growing at 60%/year implying a 100 fold increase in 10 years. Sustaining this growth is a major challenge since ICT already consumes approximately 5% of the total electrical power generated world-wide. (D8.1: Overview of ICT energy consumption, http://www.internet-science.eu/sites/internet-science.eu/files/biblio/EINS_D8%201_final.pdf, accessed September 8, 2013) It is generally recognized that semiconductor technology used in present day data centers requires too much power to sustain the predicted growth rates in data demand. (*Device Requirements for Optical Interconnects to Silicon Chips* – D. A. B. Miller, Proceedings of the IEEE (Volume:97 , Issue: 7) (1165-1185))

A typical computer processor used in data centers requires roughly 200 W of power and most of this ends up as generated heat. (As a point of comparison, the heat generated per square centimeter in a typical computer processor exceeds that of a clothes iron.) A data center can contain 100,000 such processors, requiring many megawatts to operate; enough power to sustain a small city.

Much of the power consumed in today's processors and data centers is due to the amount of energy required to transfer data from one point to another within the data center. Currently data is transferred primarily by moving electrons over copper wires. Replacing these copper wire electrical interconnects with optical interconnects using photons and guided wave structures has the potential to greatly increase power efficiency. The NRC HLII report states: "As data communications increase at an exponential rate, the power consumption by the communication infrastructure is growing rapidly. Moreover, it has been well known that although electronic power consumption scales with increased data rate, the power consumption of photonics does not." ("Optics and Photonics: Essential technologies for our Nation", p. 83 National Academy Press, http://www.nap.edu/catalog.php?record_id=13491, accessed September 8, 2013)

Laboratory demonstrations of integrated optics devices indicate that major energy efficiencies can be achieved using optical interconnects within the microprocessors, between chips on a circuit board, and separate computer servers within a data center. Current road maps for integrated circuit development state: "Despite these problems of wiring and the arguments in favor of optics for interconnects to or even on the silicon chip, there is essentially no such use today. There are many possible reasons for this absence of short-distance optical interconnects, but certainly cost targets for introduction of optics at short distances are extreme because wires on chips and boards are very inexpensive. Being able to make the necessary optical and optoelectronic components in a low cost process compatible with silicon electronics may well be essential for any commercial introduction of optical interconnects." (*Device Requirements for Optical Interconnects to Silicon Chips* - D. A. B. Miller. Proceedings of the IEEE (Volume:97 , Issue: 7) (1165-1185))

Moreover, cost effective, volume manufacturing of these optoelectronic components has not been demonstrated. Recent estimates are that "...Developing silicon photonics process is at least a multi-million dollar endeavor..." However, "A number of organizations around the world including A*STAR Institute of Microelectronics (IME), CEA-Leti, IMEC and others, have now developed processes with various levels of capabilities..." (It should be noted that these organizations are located in Singapore, France, and Belgium. respectively.) (Optics and Photonics News, September, 2013, p.34, Optical Society of America.) Development of US manufacturing capability of photonic integrated circuits compatible with industry standard, silicon CMOS processes will be critical to maintaining US leadership in the semiconductor industry. Moreover, domestic supplies of these devices, soon to be critical components in data centers, may very well be essential to ensuring the security of data traveling through and residing in US data centers.

The Evolving Bioeconomy

A recent report on The National Bioeconomy states: “Decades of life-sciences research and the development of increasingly powerful tools for obtaining and using biological data have brought us closer to the threshold of a previously unimaginable future: “ready to burn” liquid fuels produced directly from CO₂, biodegradable plastics made not from oil but from renewable biomass, tailored food products to meet specialized dietary requirements, personalized medical treatments based on a patient’s own genomic information, and novel biosensors for real-time monitoring of the environment.” The report goes on to state that: “According to the USDA, US revenues in 2010 from genetically modified crops were approximately \$76 billion. ² Beyond agriculture, based on the best available estimate, 2010 US revenues from industrial biotechnology—fuels, materials, chemicals, and industrial enzymes derived from genetically modified systems—were approximately \$100 billion. ³ The growth of today’s U.S. bioeconomy is due in large part to the development of three foundational technologies: genetic engineering, DNA sequencing, and automated high-throughput manipulations of biomolecules.”

(http://www.whitehouse.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf)

The US has been the leader in developing much of the technology that has enabled this biotechnology revolution. To continue our world leadership position the US will need to establish itself as a leader in developing high volume manufacturing methods for safe and efficient production of the organisms necessary to produce these extraordinary new products.

Recognizing the needs of this fledgling industry NIST has initiated several programs to develop the necessary standards, reference materials and safety protocols. A recent report published by NIST summarized their vision: “Despite major breakthroughs and discoveries in recent years, our understanding of biological systems still faces many challenges. Biology is an informational science that depends on accurate measurements and standards. Whether quantifying the amount of protein in a cancer cell or the rate at which an organism converts sugar to alcohol, measurements are the foundation for improving our understanding of biological systems.” (**Conference Report Accelerating Innovation in 21st Century Biosciences: Identifying the Measurement, Standards, and Technological Challenges**, NIST, http://www.nist.gov/manuscript-publication-search.cfm?pub_id=903034)

For example, NIST has been working with the NIH and FDA on programs to develop measurement standards for new diagnostic methods and therapies based on advances in our understanding of molecular biology. A major program, the "Genome in a Bottle Initiative" is coordinating the efforts of government agencies and dozens of companies to develop standard reference materials for whole genome sequencing using the latest generation of high throughput DNA sequencing instruments.

([http://www.nist.gov/mml/bbd/biomolecular/genome in a bottle consortium.cfm](http://www.nist.gov/mml/bbd/biomolecular/genome%20in%20a%20bottle%20consortium.cfm), accessed September 8, 2013)

Along with colleagues at Stanford University, I have been working with NIST management to establish collaborations with several major US biotechnology companies through a program entitled Advances in Biomedical Measurement Science (ABMS).

(<http://abms.stanford.edu>, accessed September 8, 2013) This program was initiated to enable significant improvements in the accuracy and comparability of vital data used to make important research, regulatory, clinical, and manufacturing quality control decisions. The program is co-led by Stanford University (SU) and the National Institute for Standards and Technology (NIST), and involves life science and biotechnology companies, federal and state regulatory agencies, and other interested universities as essential participants. The ABMS program is a good example of a public/private partnership, funded by NIST, Stanford University, and US industry. NIST personnel have been detailed to Stanford University to work with biotechnology companies located in Silicon Valley and with the Stanford University scientific and hospital faculty on problems in medicine where advances in measurement science could substantially accelerate progress. Through the ABMS program NIST can take advantage of access to a leading university research hospital, animal testing facilities, and other capabilities not available at NIST laboratories, as well as proximity to one of the largest concentrations of biotechnology companies in the US located in Silicon Valley.

Conclusion

Federal funding of advanced manufacturing in the US, programs such as the NNMI and AMTech, MEP and HR1421 will provide valuable federal funding to enhance US industrial leadership in manufacturing. I encourage you to give highest priority to allocation of funds to these programs. Coordinating and perhaps combining these programs to avoid duplication and optimize efficiency will be important. Federal programs should be designed to support industry, government lab and university collaboration; taking advantage of our world leading government laboratories, universities, and private sector

research and development. Special attention should be paid to deploying adequate resources specifically in high growth areas such as renewable energy generation and storage, expanding our long and short haul information technology bandwidth capabilities, and new transformative areas of manufacturing incorporating protein engineering and synthetic biology.