Testimony of

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"Material Science: Building the Future"

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Introduction

Chairwoman Comstock, Chairman Weber, Vice Chairmen Abraham and Knight, Ranking Members Lipinski and Veasy, and Members of the Committees, I am Dr. Laurie Locascio, Director of the Material Measurement Laboratory (MML) and Acting Director of Laboratory Programs at the Department of Commerce's National Institute of Standards and Technology (NIST). Thank you for the opportunity to appear before you today to discuss NIST's role in and programs focused on enabling fundamental advances in materials that strengthen U.S. innovation and industrial competitiveness. The NIST laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded in sound scientific and technical principles. Today, the NIST laboratories address increasingly complex measurement challenges, ranging from the very small (nanoscale devices) to the very large (vehicles and buildings), and from the physical (renewable energy sources) to the virtual (cybersecurity and cloud computing). As new technologies are developed and evolve, NIST's measurement research, standards, and services remain central to innovation, productivity, trade, and public safety.

NIST and Materials Science

Many examples of NIST's work I just mentioned are manufactured from materials like steel, cement, plastics, carbon, and silicon. NIST has a role in ensuring accurate measurements of these materials and many more. Why do measurements matter? Measurements give us a common language for the performance of materials and help us have confidence in them, which is particularly important for buildings, bridges, jet engines, and medical devices, and for acceptance of new technologies like wearable electronics and tissue engineering. Since it was founded as the National Bureau of Standards in 1901, NIST has been finding new ways of measuring materials with ever increasing precision and accuracy, and developing ways of characterizing novel materials for the first time. We have world-leading measurement capabilities, in both expertise and equipment, that no individual company or even industry group could amass, and the authorities granted NIST by Congress enable us to respond to the needs of American companies across the manufacturing landscape, working on intractable problems to the benefit of entire sectors. We collaborate closely with other government agencies, including the Department of Energy, and I will highlight some of that work today.

Let me share some examples of NIST responding to the needs of entire sectors. The U.S. semiconductor industry generated global sales of $166 billion in 2015 and held 50 percent of the worldwide market share,[1] but faces increasing competition from overseas. The industry often asks NIST to help them overcome measurement and material limits to making the advanced chips found in the electronic devices used by consumers, scientists and the military. As the semiconductor components in chips become smaller, new materials and processes are required to fabricate these tiny structures, from the substances used to etch the circuits to methods used to automate the assembly of nanoscale components. The semiconductor industry needed new ways to measure novel nanometer-sized structures with sub-nanometer resolution. In response, NIST scientists developed a new, nondestructive way to measure the shapes of semiconductor patterns in three dimensions with X-rays. This method is now used to "see" how polymers can actually assemble themselves into the nanoscale structures needed for semiconductor manufacturing. This method requires minimal retooling, working with the

[1] https://www.selectusa.gov/semiconductors-industry-united-states

equipment that chip manufacturers already have in place. To accelerate the transfer of this technology, NIST holds courses to train semiconductor industry chip makers and equipment manufacturers on how to use the method.

Another bedrock of the U.S. economy, the auto industry, has asked for our help in adopting new aluminum alloys, high-strength steels, polymer composites, carbon fibers, and other materials while avoiding traditional—and costly—trial-and-error build cycles. At the NIST Center for Automotive Lightweighting, we measure the micro-scale changes in metals that result from manufacturing processes to illuminate the ideal methods for shaping lightweight alloys while maintaining their resistance to impacts. The NIST Center for Automotive Lightweighting has more than 20 industry partners, including Chrysler, Ford, Novelis, GM, Auto/Steel Partnership, and Alcoa. One major manufacturer used NIST's data to save nearly four months of development time in making a new vehicle that is 700 lbs. lighter and 50 percent more efficient. The sector's scientists have speculated that reducing the number of trail-and-error cycles by half could have significant savings for U.S.-based automakers,[2] and NIST is leading that effort through development of precise measurements. This NIST center collaborates closely with Lightweight Innovations for Tomorrow (LIFT), a Department of Defense-funded institute in the Manufacturing USA network and a recipient of a grant from the Department of Energy.

Nascent industries also come to NIST for help. Additive manufacturing, also called 3D printing, is relatively new, and there is little knowledge and data to ensure that reliable parts can be made on a large scale. An economic analysis estimates that we can lower the costs of additively manufactured parts by 18 percent and save the sector more than $4 billion each year by meeting key technical needs.[3] NIST has led and participated in several industry-driven roadmaps to help identify those key technical needs, and is applying measurement science to every step of the additive manufacturing process so that manufacturers can choose the right starting materials, equipment, and printing and finishing processes to reliably and reproducibly get the properties they want. In addition, we recently launched the NIST Additive Manufacturing Benchmark Test Series (AM-Bench), with help from the Department of Energy and other Federal agencies. AM-Bench engages multiple companies to build the same part using the same starting materials, while multiple computer modelers try to predict the finished parts' shape and physical properties, which NIST material science experts will measure. The results will be available to any company to compare how their own modelling efforts perform against NIST's data, providing them with a way to validate their additive manufacturing simulations and processes. More than forty companies, national laboratories, and universities participate in AM-Bench. New builds, predictions, and tests will recur every two years. The robust simulation tools that result from AM-Bench will replace much of the current trial-and-error approach to making parts that perform as needed.

NIST has a long history of using test series and challenges to bring a community together to solve ambitious problems in support of the NIST mission "to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life." In 2015 NIST announced its first prize

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[2] Personal communication with Timothy Foecke, Director, NIST Center for Automotive Lightweighting, at automotive industry project meeting, 2013.

[3] NIST Economic Analysis Brief, "The Economic Impact of Technology Infrastructure for Advanced Manufacturing: An Overview," Gary Anderson, October 2016. http://nvlpubs.nist.gov/nistpubs/eab/NIST.EAB.1.pdf

competition[4]— the Head Health Challenge III in partnership with the NFL, GE, and Under Armour, in which our test results helped to determine a winning material that will garner a $500,000 grand prize. The goal of the challenge was to spur the creation of innovative impact absorbing materials that will result in increased protection for rec-league and professional athletes, warfighters, and first responders. We set up a national prize competition to attract attention from a hugely diverse set of communities, from aerospace to automotive to sports medicine, inviting them to submit their materials to NIST for extensive testing in a broad range of conditions, including temperature extremes from freezing to a hot summer day, and a year's worth of repeated impacts. Participants in two rounds of competition received NIST's test data to further their products; expert judges chose a winner—to be announced in a few weeks—from five finalists. Among the final entries, we saw dramatic technical advances in how well a material can absorb impact. Some of the materials we tested reduced the force of an impact by up to 80 percent, compared to conventional materials. These types of innovative materials can catalyze the development of protective equipment that will mitigate impact and injury in high school athletes or soldiers. In addition to the prospect of a monetary prize, finalists reported that they are using NIST's data to adjust their materials to expand into new product lines or markets, and attract commercial partners for further development and testing.

NIST also provides industry, academia, and other government agencies with access to unique, world-class user facilities that support innovation in materials development. The NIST Center for Neutron Research (NCNR) provides neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology supports the U.S. nanotechnology enterprise from discovery to production by providing access to measurement and fabrication methods and technology. A prime example of the impact that these facilities can have on materials innovation is the work taking place at the NCNR as part of the nSoft Consortium. The nSoft Consortium brings together manufacturers of soft materials (like polymers and biomaterials) and provides a new model to increase their access to the unique instrumentation available at the NCNR. With training and support from NIST technical staff, scientists from companies like Amgen, Dow, and Procter and Gamble use the NCNR facility to measure and characterize new materials in development. This collaboration provides a direct benefit to the industry partners, and helps NIST learn about critical problems in multiple industry sectors so we can develop new capabilities in response. For example, nSoft and its partners developed new sample environments to simulate the extreme pressures, temperatures, and flow rates needed by the pharmaceutical and shale gas industries to measure the structure of fluids in very small geometries. To date, nSoft has helped companies develop therapeutics with a longer shelf-life and higher strength materials, and provided key insight into how plants can stay hydrated in arid and harsh environments.

NIST also partners with a Department of Energy user facility, the National Synchrotron Light Source II at Brookhaven National Laboratory, which produces X-rays that are 10,000 times brighter than the facility it replaces, allowing researchers to see individual atoms in materials. The National Synchrotron Light Source II contributes to the development of new semiconductors for computers and other applications, batteries and solar and fuel cells, superconducting materials, catalysts for chemical production, and materials that can assemble into complex structures by themselves, mimicking how cells, bones, and tissues grow.

[4] NIST has a long history of using challenges to engage the public in its many research efforts. Head Health Challenge III was NIST's first cash prize competition announced under the authority of 15 USC § 3719.

These examples show how NIST helps American industries gain competitive advantages by enabling them to more rapidly develop and use new materials with amazing properties: These materials are lighter, stronger, have more function, and require less energy to make or generate less waste in processing. Consumers benefit, in turn, from access to improved products with more features. In fact, historical leaps in our quality of life are linked to revolutionary leaps that improved the performance of materials. Advancing from iron to steel transformed transportation and our built environment. Medical implants—once limited to ceramic, steel, or harvested bone—are now often made from titanium alloys or polymers. They are stronger, lighter, less likely to cause immune reactions, and can be custom made for an exact fit. Your 6-ounce cellphone contains more processing power than a desk-sized 1980's era supercomputer, thanks to innovations in the materials in its integrated circuits, and its usability is greatly enhanced by developments in materials to improve the screen, and the metal case. Many of these advances could not even have been possible without NIST innovations in materials measurements.

As exciting as these advances have been, however, the slow pace at which new and useful materials emerge by trial and error has not changed much since the 19th century. That 19th century approach is inadequate for the 21st century substances that we desperately need to make better prosthetics for injured soldiers; water sensors that detect biological threats and filters that eliminate them; and more efficient solar cells. Typically, it can take 20 years or longer and tens of millions of dollars to find, fine-tune and deploy new a material through a series of trial-and-error experiments. Our Nation's problems are too big to wait that long, and we risk losing America's manufacturing prowess to competition from abroad.

A Materials Innovation Infrastructure

Fortunately, there's a new paradigm for advancing the materials sciences. NIST is a leader in establishing a nation-wide infrastructure so that members of industry, academia, and other government agencies can develop materials *by starting with the properties they need from those materials*, rather than seek to discover materials that might or might not work. This new approach is known as "materials by design." Researchers develop new materials more quickly by working smarter and faster: They use data on the known properties of materials, along with computer modelling, to make informed choices about how to combine or process substances to get the performance they need. GE used this method to make new alloys for jet engines in nine years instead of the usual 15 years. The metals used in Apple watches were developed and deployed to market in just about two years thanks to this approach. Making materials by design is such a game-changer that adoption of the method became a national priority with the Materials Genome Initiative, or MGI, launched in 2011. The MGI launched a partnership among 18 Federal agencies, including the Department of Energy, the Department of Defense, and NIST, that is still very much active today.

Over the years, NIST has conducted millions of measurements to determine the properties of materials, so you can imagine that we have become experts at handling the large amounts of data those measurements generate. That is why NIST supports the MGI with an infrastructure for materials property data. There's no lack of data on metals, polymers, and ceramics: Many research and design programs in the military and government agencies, and in universities and industry, are generating and storing data as well. Making that wealth of knowledge widely accessible as a national resource, however, requires new protocols to ensure that data can be found and is in a recognizable form, and that there are methods for assessing whether the data is of sufficient quality to be useful.

An effort like the MGI requires a variety of industries and industry players, normally fierce competitors, to come together and collaborate effectively—a tall order. NIST has a track record of success in bringing together industry, academia, and government to achieve foundational technological advances, on the strength of its credibility as a trusted, objective third party, concerned with accelerating innovation across entire industry sectors. By developing tools to make better use of the country's wealth of data, NIST combines its own world-class technical expertise with its role as a convener to accelerate innovation across an even larger swath: *all* of the enterprises based in *all* of the materials sciences. We are fostering the availability of information across organizations, locations, and disciplines.

The Materials Development Ecosystem

NIST's position as a well-respected, non-regulatory scientific agency known for objectivity gives us the capability to work with industry and academia to build an infrastructure that enables data sharing. Establishing this data sharing infrastructure amongst competitors requires significant engagement in partnerships that clearly demonstrate how these new approaches will help accelerate innovation.

To help establish this infrastructure and provide a powerful proof of concept, NIST established the Center for Hierarchical Materials Design, a consortium led by Northwestern University, the University of Chicago, and Argonne National Laboratory. ChiMaD, as it is known, is developing the next generation of computational tools, databases, and experimental techniques—an entire ecosystem—to enable the accelerated design of novel materials and their integration to industry. CHiMaD works in emerging areas such as two dimensional electronic materials for advanced computing, additive manufacturing, super-alloys for aerospace engines, and flexible, organic solar cells—programs informed by the many industry members who serve as partners, collaborators, and advisors. ChiMaD also educates undergraduate and graduate students in the materials-by-design approach. Partnerships with Fayetteville State University, a minority-serving institution, and ASM International, a professional society, help share the program with even more communities, preparing a new generation of materials scientists and engineers to meet the workforce needs required by wider adoption of the materials-by-design approach.

ChiMaD hosts the NIST-funded Materials Data Facility, a cloud-based repository where materials scientists can publish, preserve, share, and collaboratively analyze research data. Additional NIST resources in the materials-by-design ecosystem include:

- The NIST Materials Data Repository, a public-access databank hosting about 133 gigabytes of data from 123 groups
- The Materials Resource Registry, which is like a yellow-pages for the materials-by-design approach that enables in-depth, world-wide searches of available resources such as organizations, data collections, data and computational services, and analysis and modeling software
- The High-Throughput Experimental Materials Science Virtual Laboratory, a collaboration with the National Renewable Energy Laboratory to develop a network of computational tools and data resources for comprehensive materials discovery efforts
- The Materials Data Curation System, which helps materials researchers annotate, organize, save, later retrieve, analyze, and share data

Conclusion

NIST has a long history of addressing industry needs with measurement science. Established and emerging industries alike seek our measurements and methods to help them innovate and remain competitive globally, contributing to our economy. While traditional materials science research has been trial and error, the demand for accelerated innovation requires a new approach. NIST is establishing the necessary data and computational infrastructure that allows designers to intentionally develop new materials for the properties their new products require. In these efforts, NIST is proud to be regarded, as it has for more than a century, as a trusted, neutral third party that facilitates collaboration among industry, academia, and government agencies to meet critical national needs.

We greatly appreciate the efforts of the members of these committees and other members of Congress to support Federal agency acceleration of the innovations in the materials sciences that keep the Nation globally competitive and secure, and that contribute to our quality of life.

I will be pleased to answer any questions you may have.

Laurie E. Locascio

Dr. Laurie E. Locascio is the Acting Associate Director for Laboratory Programs (ADLP) at the National Institute of Standards and Technology (NIST). As Acting ADLP, she provides direction and operational guidance for NIST's scientific and technical mission-focused laboratory programs and serves as principal deputy to the Under Secretary of Commerce for Standards and Technology and NIST director, among other duties.

Dr. Locascio's current permanent position is director of the Material Measurement Laboratory (MML) at NIST. MML, one of seven research laboratories within NIST, has an annual budget of $175 million and nearly 1,000 federal employees and guest researchers from industry, universities, and foreign laboratories. MML provides a measurement science and standards infrastructure for the Nation's industries based in the biological, chemical and materials sciences, promoting U.S. innovation and industrial competitiveness in ways that enhance economic security and improve our quality of life. MML is a source of unbiased measurement standards, data, and cutting-edge methods and technologies that promote innovation, market readiness, and quality control in vital economic sectors.

MML develops measurement standards in the form of documented measurement methods and instrument calibrations, and coordinates the NIST-wide Standard Reference Material® and Standard Reference Data programs. MML provides more than 1,200 Standard Reference Materials that ensure the accuracy of millions of measurements vital for efficient manufacturing, acceptance of American-made goods in international markets, regulatory approval of new technologies and medical treatments, and consumer confidence.

Dr. Locascio previously served as chief of the Biochemical Sciences Division in the Material Measurement Laboratory. She has published more than 100 scientific papers and holds 11 patents in the fields of microfluidics, biosensors and sensor/flow systems. She is a Fellow of the American Chemical Society (ACS) and the American Institute for Medical and Biological Engineering (AIMBE). She received her doctorate in toxicology from the University of Maryland at Baltimore.

Education

Ph.D. in toxicology from the University of Maryland at Baltimore

M.Sc. in bioengineering from the University of Utah

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