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"Fostering Innovation: Contributions of the Department of Energy's National Laboratories."

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Chairman Gardner, Ranking Member Manchin, members of the Subcommittee, thank you for this opportunity to discuss the importance of the Department of Energy's National Laboratories, and the value they provide to our country's security, economic prosperity, and science leadership.

My name is Bill Tumas, and I am the Associate Laboratory Director for Materials and Chemical Science and Technology at the National Renewable Energy Laboratory (NREL), in Golden, Colorado. Most of my career has been devoted to understanding and controlling chemical reactions and the properties of materials for sustainable products, energy conversion, and energy storage, as well as the safe disposal of chemical weapons. I have been associated with the federal research and national laboratory system for 24 years.

At the Los Alamos National Laboratory (LANL), I directed the Applied Energy Programs and held leadership positions in basic and applied chemistry and materials, as well as energy storage. Currently, at NREL, I lead programs on solar energy conversion; materials discovery, synthesis and development; hydrogen production and storage; and fuel cells. At both LANL and NREL, I have led multi-lab consortia that included other national laboratories, university researchers, and industry. Today I also direct the Energy Department's Energy Frontier Research Center focused on Next Generation of Materials by Design.

My career began in the private sector at DuPont Central Research as a research scientist and project leader working on catalysis and environmental chemistry. My research activities have resulted in multiple patents and publications. This combination of industrial and national laboratory experience has helped me gain perspective on the challenges and impacts associated with scientific discoveries and how they may be transitioned into marketable products of value to society.

Labs Use Science To Benefit the Nation
A strong national laboratory system is a vital component of our country's future. Every day our national laboratories work collaboratively with industry and our country's top academics to find solutions to advance basic science and applied technology, addressing many of our nation's most critical challenges in the areas of national security, economic competitiveness, and advanced energy. Wherever we may look, the fruits of decades of innovation from our national labs abound.

In science, the labs have led the world in physics, chemical, biological and computer sciences, and increasing our understanding of the fundamental interactions of the physical environment. National labs have revolutionized materials with widespread applications in energy, transportation, and manufacturing. For national security, our national labs have ensured that the U.S. nuclear deterrent is maintained and remains safe, while undertaking global initiatives to curb the proliferation of weapons of mass destruction. Technologies for security at airports can be traced back to research at our national labs. In transportation, national laboratories created computer modeling and materials that has made cars and planes safer, stronger, and more efficient. Other computational models now reliability predict natural disasters and infrastructure recovery.

So that our nation continues to benefit from our wealth of domestic energy resources, national laboratories are researching advancements in virtually all energy technologies. Examples include carbon capture and storage work performed by a team under the leadership of the National Energy Technology Laboratory, the advanced battery technologies from Argonne National Laboratory and others, and the solar photovoltaic technologies produced by my laboratory, NREL. Our discoveries have and will continue to pave the way for growing industries in the United States.

We are able to accomplish goals such as these because the nation has invested in our national labs to build and maintain a collaborative constellation of scientific and engineering facilities that are unmatched by any other nation. Our deep scientific strengths come with having teams composed of many of the world's very best researchers, across all relevant disciplines, coupled with a built-in expectation of inter-lab cooperation. My personal experience building scientific teams has resulted in collaborative research projects with 10 different national laboratories. Collaborations tap the scientific strengths of each participating laboratory while bringing efficiency to the national lab system.

Labs' Unparalleled Capabilities Drive U.S. Innovation
The combination of capabilities and expertise at national labs has served our Nation well. They provide a huge engine for developing and maintaining the nation's science and technology capability. This is a major reason the United States has long led the world in technological innovation, which we've learned is a driving force in our nation's vital economic competitiveness. Highly specialized scientific and engineering facilities form the backbone of the national lab system. These facilities,

coupled with a pool of exceptionally talented individuals, give the labs capabilities found nowhere else.

These facilities are of course essential to the research and development (R&D) conducted by the labs themselves, and those designated as "user facilities" also serve as singularly capable tools to conduct the science undertaken independently by universities and the private sector. They also provide a training ground for the next generation of scientists and engineers, providing access to cutting-edge research capabilities for tens of thousands of industry and university scientists.

For example, a research group may schedule time to use the SLAC Linear Accelerator Laboratory's Linac Coherent Light Source, which operates as the most powerful x-ray laser in the world. In our Energy Frontier Research Center, we collaborate with SLAC to study the "dance" between electrons and vibrations in a series of experiments to better understand, improve, and synthesize new semiconductor materials.

National labs also provide high-performance computing systems including the National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Laboratory and the Leadership Computing Facilities supercomputers at Argonne and Oak Ridge, which have enabled a variety of advances for both leading scientific and industry users. The Argonne, Lawrence Berkeley, Lawrence Livermore, Los Alamos, Oak Ridge, and Sandia national laboratories are also leading the Exascale Computing Project, which aims to develop supercomputers that run 50 times faster than today's leading supercomputers within the next six years.

NREL Research for Advanced Energy Solutions

At my own Lab, NREL, we designed and built the Energy Systems Integration Facility (ESIF)—a DOE user facility uniquely dedicated to developing and testing the new technologies and systems we need to modernize our entire electricity grid. The challenges of incorporating our all-of-the-above energy strategy into the grid, while maximizing affordability and resiliency, are great. America's electric utilities need to reduce the risk of incorporating high levels of variable generation sources, and research underway at ESIF is doing just that.

Employing time-series modeling, big data, and visualization tools that are only feasible through use of a high-performance computer, ESIF's researchers this year completed the Eastern Renewable Generation Integration Study, or "ERGIS," which is providing grid operators with the kind of real-time supply and demand modeling capabilities heretofore unavailable anywhere. Duke Energy is also using ESIF's capabilities to test new equipment and how it pairs with software used for grid operations.

ESIF is also home to the Consolidated Utility Base Energy project, or "CUBE," which was developed for the U.S. Army's forward operating bases. The CUBE helps to integrate solar and battery power systems with these bases' diesel generators, providing reliable energy to remote outposts while using up to 30 percent less fuel. CUBE will save money and reduce the troop fatalities that have been associated with fuel transportation.

ESIF teams are similarly at work solving the challenges we face from an increasingly autonomous complex grid that , and the complexities of incorporating rooftop solar power systems, smart meters, and internet-connected appliances into the existing infrastructure. New control systems are needed for home power systems, the distribution grids they feed into, and the larger transmission grid, possibly leading to a "self-healing" or autonomous grid that responds to changing loads and generation sources without the need for grid operators to step in. As an example of multi-lab collaboration, NREL co-leads the Grid Modernization Laboratory Consortium, a collaboration of 14 national laboratories, developing the systems needed to provide resilient, reliable, secure and affordable electricity for decades to come.

NREL efforts encompass fundamental science, applied science and engineering, technical analysis and assessment, and systems integration. NREL's efforts, and those of the national lab system, have helped changed the energy landscape significantly:

- Over the last two decades we have seen significant increase in the performance of solar cells and a reduction in the cost. The costs now rival traditional electricity generation, with deployment of more than 60 gigawatts of solar globally last year alone (the equivalent of roughly 60 nuclear reactors). Solar now constitutes an $84 billion U.S. industry.
- Wind energy has moved from an engineering curiosity to a common sight across many states with an average contracted sales price of approximately 2 cents per kilowatt-hour, for projects that signed agreements in 2016 and the first half of 2017.
- Wind energy provides a steady source of income for farmers and ranchers across the nation, primarily in America's heartland, and also provides the fastest-growing job in the United States: wind turbine technician.
- America's heartland is one of the world's largest biomass resources for domestically sourced biofuels, bio-based products, and jobs.
- The all-of-the-above energy strategy includes renewable resources that have provided more than half of all new power generation capacity since 2008. Cumulative U.S. renewable capacity now totals 232 gigawatts, or more than 20 percent of the nation's generating capacity.

In addition to making energy more affordable and domestically available, these and other advances will continue to make U.S. industry more competitive. From a resiliency standpoint, our understanding of the electric grid has improved markedly so that we are better able to endure transient conditions—like extreme demand or production shortfalls—with reduced disruption.

The resulting transformation of our nation's energy system is creating opportunities for hundreds of thousands of new domestic jobs. An estimated 6.4 million U.S. workers are employed in the design, installation, and manufacture of energy products and services. Advanced energy technological breakthroughs are fueling this growth and bolstering American competitiveness. The pathway from laboratory to commercial product viability is rarely smooth, nor as short as investors might like, but it is useful to note how far we have come in terms of U.S. jobs:

- Jobs in the solar industry last year grew at a rate 12 times faster than overall job growth in the United States, with more than 373,000 domestic jobs. In 2016, one of every 50 new jobs in the United States was in the solar power industry.
- Today the U.S. wind industry supports more than 101,000 domestic jobs spread across all states, and nearly 250,000 jobs are expected to be needed to support the U.S. wind industry by 2020.
- In 2016, more than 112,500 Americans were employed in the biomass electricity generation and in the biofuels and bioproducts industries.

NREL has helped spur these advances through a number research impacts stemming from integrating fundamental and applied science:

- NREL researchers have worked with US industry to develop solar cells where the thin-film active layers are less than one-tenth the diameter of a human hair. Thin-film solar cells now produce tens of gigawatts of reliable, clean power at extremely low costs.
- NREL scientists developed multi-junction solar cells that power satellites and are being increasingly used for U.S. military applications.
- The National Wind Technology Center led innovations including airfoil designs, pitch control, and variable speed strategies, resulting in broad wind industry adoption.
- NREL's work on microbes and enzymes helped reduce costs and improved process technologies for cellulosic ethanol plants.
- NREL and scientists from the Joint Center for Artificial Photosynthesis (Caltech, Lawrence Berkeley National Lab) engineered and synthesized multi-layer semiconductor devices that directly convert sunlight to hydrogen by splitting water at efficiencies greater than 15%.
- NREL energy systems integration expertise successfully advanced a microgrid system for the Marine Corps Air Station Miramar that draws on batteries and solar photovoltaic energy for its power.

Lab R&D Necessary To Meet Future Challenges

Innovation is the hallmark of the national laboratory complex. Reducing costs, increasing efficiencies, and improving performance for solar, wind, bioenergy, energy storage, grid modernization, and other energy technologies will require pushing the fundamental limits of current materials and technologies as well as creating the new materials, processes, and concepts for next-generation technologies.

For solar, NREL and other labs are working to increase efficiencies and bring costs down to or less than current wholesale electricity costs. NREL and others are exploring new materials such as perovskites that already exhibit high efficiencies and can compete with current technologies on price, can provide coatings that could greatly enhance the efficiency of current technologies, and could lead to printing of high-efficiency, low-cost solar cells, much the way we print newspapers today. For much broader deployment, we will also need to expand solar R&D to include more work on innovative energy storage and power electronics, while ensuring the resiliency, security, and reliability of the grid.

Nanoscale materials such as the quantum dots that now light up high-definition televisions can impact new batteries for energy storage as well as solar windows.

For wind energy, we need to develop higher elevation turbines to access wind across more of the country. We need to model large-scale wind farms for design, performance, and predictability, as well as developing innovative control systems. Lastly, as we go to larger turbines we need to develop on-site manufacturing using new composite materials, such as those being examined in the University of Tennessee-led Institute for Advanced Composites Manufacturing Institute, a public-private partnership.

We also need to harness innovative bioprocesses for new materials, products, and feedstocks. NREL leads the Renewable Carbon Fiber Consortium, comprised of national lab, academic, and industrial partners to demonstrate the cost-effective production of domestic supplies of renewable carbon fiber from cellulosic biomass-derived acrylonitrile for vehicles, wind blades, and products.

The national labs have helped us understand photosynthesis and we are moving forward with universities to advance artificial photosynthesis concepts to convert sunlight directly into fuels. We can also combine advances in carbon with cheap electricity and advances in electrochemistry, materials, catalysis, and synthetic biology to convert carbon dioxide into valuable products and feedstocks.

Harnessing the labs' powerful supercomputers and their interplay with advanced experimental tools will allow us to not only discover new materials more rapidly, but will also help us design and control new processing concepts for advanced manufacturing.

U.S. Innovation Requires Public Sector-Private Sector Partnerships
Innovation is a continuing spectrum and one cannot expect success if any portion of the basic-research-to-product pipeline is ignored. We need to accept that funding R&D is a risk, and while I am not arguing for any relaxation in selection criteria, we need to be realistic—if we are not funding cutting-edge science, with all of its risk,

we are not investing in our collective future.

While the role of private industry is indisputably paramount—national labs after all do not produce finished products—it is simply unrealistic to believe that the private sector can or would fill the R&D void that would be created if federally sponsored research were curtailed. Everyone may talk, and rightfully so, about the discoveries that emerged from Bell Labs—the transistor, lasers, cell phone communication and, my favorite, solar cells. But they don't often add that Bell Labs, as it was then conceived, no longer exists. The truth is that Lockheed's Skunk Works, the notable Westinghouse labs, and my former employer, DuPont's Central Research and Development—corporate research centers responsible for the science that underpins myriad products today—are a thing of the past. The truth is: *These R&D centers are not operating today, or are skeletons of what they once were.*

Despite significant reductions in long-term industrial research, the United States still has a vital innovation ecosystem that stems from partnerships between national labs universities and industry at all phases of the science-to-product ecosystem and are critical for successfully moving scientific discoveries into beneficial use. National labs continue to play a critical role in accelerating innovation. Our industry partners look to the national laboratories for larger-scale and higher-risk fundamental and applied research would not be accomplished in the private sector.

For example, the remarkable success in solar power and energy storage—areas where national labs continue to work closely with industry and with universities—stems from national labs not only discovering new materials but also from foundational research on devices, components, and prototypes, as well as testing, understanding, and controlling reliability and durability. Fundamental to this ecosystem is the critical role-played by private entrepreneurs and small businesses across the nation. There are now a number of innovative mechanisms that give start-up companies access to the national lab capabilities and scientific infrastructure. At NREL, we work to be as innovative in how we connect with the marketplace, and partner with companies, as we are in developing new technology.

NREL's Industry Growth Forum connects newly established technology companies with private sector capital. More than $5 billion has been raised by startup companies presenting at the Forum over the last ten years. Working with the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, NREL pioneered the Small Business Voucher program, which funds lab work with innovative clean energy businesses. A recent program that helps clean energy start-ups mature and demonstrate their technology in a commercial setting is a partnership between NREL and the Wells Fargo Foundation. Twenty companies are in this program and another 30 will be selected in the near future.

Global Competition for Scientific Supremacy

We are not the only country with excellent scientific and engineering capabilities and an interest in innovation. Over the past 30 years, I have been fortunate enough to visit, lecture, or conduct research in foreign universities and labs in the Netherlands, the United Kingdom, France, Brazil, Japan, Germany, Italy, and India. I have found smart, capable, and motivated scientists and engineers everywhere I have been. The United States holds a position of leadership in many, but not all, areas of science, but I assure you from my personal experience that other countries are investing and growing their scientific capabilities. This is in many respects a race and if we falter, the competition is not far behind.

It is no secret that one of the biggest challenges confronting us is how we as a nation can maintain our competitive edge. Our continued leadership in science and innovation is in no way guaranteed—the rest of world is fervently working to capture the innovation flag. The headlines are full of examples of how nations including China, South Korea, and India are investing significant sums to wrest our competitive advantage for themselves.

Dividends From A Renewed U.S. Commitment To Science

If we fail to both take advantage of our current science assets and capitalize on our prior investments, we run a growing risk that we will become dependent on others for knowledge, for ideas, and ultimately for products. Think for a moment about the tax revenue, the jobs, indeed, entire industries that have grown up around the science discoveries mentioned here. All arose from our historic commitment to early-stage research. For these reasons, America will significantly benefit from continued investment in university and national lab scientific advancements. These investments will continue to pay dividends in increased employment, exports, and progress.

The National Renewable Energy Laboratory, along with our partner laboratories across the Department of Energy complex, will continue to help our country succeed in an increasingly competitive global economy—*if and only if* our lifeblood of federal support continues. Our country, indeed our planet, needs the progress science can deliver.

Thank you again for the opportunity to testify today, and thank you as well for the leadership this Subcommittee has shown in supporting the federal research portfolio. I will be happy to answer any questions you may have.