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Hearing on "Opportunities to Advance Renewable Energy and Energy Efficiency Efforts in the U.S."

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Chairman Murkowski, Ranking Member Manchin, members of the Committee, thank you for this opportunity to examine future opportunities to advance renewable energy in the United States.

My name is Martin Keller, and I am the Director of the U.S. Department of Energy's National Renewable Energy Laboratory, or NREL, in Golden, Colorado. My career has included research positions in the private sector and more than a decade within the national laboratory complex. Before coming to NREL in 2015, I was the Associate Lab Director, and led DOE's BioEnergy Science Center, at Oak Ridge National Laboratory in Tennessee. I previously conducted technology development for a San Diego-based start-up company and I hold a Doctorate degree in Microbiology from the University of Regensburg in Germany. My entire career has focused on integrating foundational science into important new applications. This experience has given me a deep understanding of and profound appreciation for the role of federally supported scientific research in maintaining America's leadership in science and innovation. I also recognize, as I know you do too, how inextricably this innovation is tied to U.S. competitiveness.

Since NREL was founded in 1977, we have been pursuing foundational research in solar, wind, biofuels, and other advanced energy technologies as well as exploring innovations in energy efficiency and smart grids. This includes energy efficiencies in buildings and advanced manufacturing, sustainable transportation technologies and fuels, and using data visualizations and high-performance computing and data visualizations to evaluate energy generation, distribution, integration, and usage models.

Thanks to federal research investments, NREL has been able to advance renewable energy technologies into the mainstream on behalf of the Nation. In fact, the American renewable energy landscape is changing rapidly. Today, solar and wind electricity generation technologies are no longer alternative solutions but are becoming significant contributors to the nation's power supply. According to the Energy Information Administration's short-term energy outlook, wind and solar are expected to be the fastest growing source of electricity generation for at least the next two years.

Solar energy growth rates have averaged 59% annually over the past decade, and in the first quarter of 2018 solar accounted for 55% of all new capacity installed. Wind power is also accelerating and now accounts for 6.5% of total U.S. electricity generation, about the same as large-scale hydro power production.

These rapid advancements in the growth and impact of renewable energy technologies showcase the role that national labs play in using science to help solve our nation's biggest energy challenges. In partnership with U.S. industry, national labs accelerate innovation to market-based solutions that yield energy systems that are the engine of the U.S.' economic growth and prosperity.

Meeting Our Nation's Energy Challenges

While many advances have been made in new energy technology R&D and commercialization, much work remains to be done and opportunities for U.S. scientific and industrial leadership abound. Population and economic growth, increasing urbanization, and rapidly growing energy demand in developing nations are challenges that require innovation if new energy demands are to be met with sustainable, reliable, and affordable supplies.

As global economies continue to evolve, our energy challenges will only multiply. When cities grow, their energy needs increase. With the global expansion of the middle class, the demand for energy soars. As these urbanization trends continue, it is projected we will need twice the energy resources by 2050, presenting formidable challenges and even greater opportunities for innovation leadership.

So how do we meet these new energy challenges reliably and affordably? The answer is continuing to innovate towards the most abundant, affordable, efficient, and sustainable energy resources and technologies possible, while at the same time working to strengthen and modernize our Nation's energy grid.

Strengthening and Modernizing the Grid

The grid that we know today was designed for large, centralized power systems—and before utilities, grid operators, and customers could predict the potential for today's cyber vulnerabilities. As connected, distributed energy technology deployment increases, so does the number of access points for potential cyber threats. With legacy systems that were not designed to protect against cyber and physical vulnerabilities, our approach to securing the electric grid must change.

Researchers at NREL are looking ahead to develop intrinsic security design principles for the future grid—one that can operate autonomously, with modern grid technologies to support high penetrations of power-electronics based wind, solar, and other distributed energy resources.

With a focus on understanding both human and natural threats to the grid, NREL's power systems engineers and cybersecurity researchers are working with researchers around the country to mitigate threats to today's energy infrastructure and provide a pathway to a more secure and resilient future grid.

Coordinating Large Generation Plants with Autonomous Grids

Households, businesses and utilities are installing new devices such as electric vehicle chargers, rooftop solar, energy storage, and smart appliances onto the grid at a rapidly increasing rate. As the number of grid-connected devices grows, new solutions and capabilities are needed to optimize distribution power management.

The ability to handle large volumes of communications and data will also become a challenge in managing power. In an optimal system, there would be good communications and visibility between the bulk power and distribution systems to keep the overall grid in equilibrium and to optimize asset use. This would create more real-time options for operating decisions that could benefit customer preferences, energy economics, and grid stability.

One solution to this challenge that NREL researchers and other research institutions are exploring is Autonomous Energy Grids—or AEGs. Unlike current systems that rely on centralized grid control, AEG systems could self-organize and control themselves across all parts of the grid using advanced machine learning and simulation. Sections—or "cells"—of AEGs use pervasive communication to continually pursue optimal operating conditions, which continually adjust to changing customer demand, available generation, and pricing.

There's already progress toward commercialization of AEG algorithms. The NREL created mathematical approach to power and optimize AEG has been selected by DOE's I-Corps program for advancement to market and IP Group has picked up AEG as a candidate for their tech-acceleration portfolio. In addition, Siemens and NREL are collaborating on distributed control techniques with support from the DOE Solar Energy Technologies Office.

Deploying Microgrids for Resilience

Beyond capturing and optimizing the use of energy, it is equally imperative to look at ways to make our energy system more responsive, flexible, and resilient. Microgrids are important elements to look at as they have the potential to increase overall grid resiliency by isolating both the impact of threats and the magnitude of recovery efforts. This capability will be critical to the protection of critical infrastructure such as defense facilities, hospitals, and emergency response centers. Continued research and experimentation are needed to develop better microgrid controllers and strategies for managing new energy systems configurations.

The Future of Solar Energy Research

Decades of investment by DOE in solar energy research and development has driven unprecedented advances in performance, massive cost reductions, and ultimately greater commercial adoption of solar technologies. While innovation is happening at a record pace across the entire solar energy ecosystem, further research is needed for solar to reach its full potential. Continuing foundational science—including chemistry, electrochemistry, materials science, semiconductor physics, and computational science—is crucial to driving the next generation of breakthroughs that will make solar an essential part of the energy systems at all scales.

Foundational science underpins the innovation we are achieving in photovoltaics, what we refer to as PV. Not only for the materials needed for the cells, but also for the research behind power electronics, energy storage, and grid integration. This science ranges from enabling new and low-cost solar absorber materials and manufacturing techniques to complex energy systems modeling and new field applications. For example, lightweight PV materials are becoming increasingly important to the U.S. military, which is seeking highly mobile and agile methods of powering computer and communication systems for soldiers on the ground. New uses of solar technology could give drones the ability to operate continuously or enable extended forward military operations with PV-powered microgrids.

Transforming Solar with Perovskites, Concentrating Solar Power

New materials offer the opportunity to accelerate solar innovation and adoption. Perovskites, for example, could become one of our greatest advances in PV materials. In recent years, perovskites have shown promise as a viable PV material with the potential to increase efficiencies and lower manufacturing capital and operating costs when compared to traditional silicon materials, which currently dominate the market.

We have shown that perovskite-based solar cells could be produced quickly and inexpensively using techniques such as roll-to-roll manufacturing. Imagine solar cells rolling off the production line as quickly as a newspaper is spun across a printing press. We are convinced that PV based on these materials would forever transform the U.S. solar industry.

NREL is a world leader in this technology and we are working with major academic groups and startup companies to make power from perovskites commercially viable. The time is right to accelerate perovskite research. We can bring industry, universities, and national labs together to solidify U.S. leadership in this potentially huge new field.

Another area of promise is concentrating solar power, or CSP. By concentrating, storing, and releasing the heat generated by the sun, CSP systems could achieve competitive generation costs with 8-to-15 hours of energy storage. However, the challenge of CSP research is developing a viable thermodynamic power cycle, which requires advanced, high-temperature working fluids and long-term thermal energy storage. In addition, the capital expenditures needed to deploy the solar mirror fields of CSP systems are very high. Cost-effective, next-generation CSP field designs are needed to drive adoption and we are working closely with industry to reduce these costs by using advanced manufacturing concepts and new materials currently being researched.

The Future of Wind Power Research

Federal investments into wind power research and development are responsible for major advances in wind technology and commercial adoption. We are collaborating with universities, national laboratories, and industry with the goal of using foundational research and applied science to drive innovations that produce energy at half the cost of current wind generation in the United States.

We believe there are opportunities to design and engineer wind turbines that are larger and more flexible than current turbines, which will allow access to the additional wind power available at taller turbine heights. Researchers and industry alike project an increase in land-based turbine size into the 200-meter-plus diameter range deployed on towers extending to more than 150 meters high (a total height of greater than 800 feet). These heights are necessary in order to achieve the economies of scale needed for a significant reduction in the cost of wind energy. Putting this scientific and engineering challenge into perspective, it will make next-generation wind turbines the largest rotating machines ever built.

The complexities presented by offshore wind turbines that also continue to grow in size is an area where significant research is needed—including the aerodynamics of wind flow through rotors, hydrodynamic forces of waves and currents on the support structures, advanced materials, and controls. In addition, these machines must be designed to survive extreme weather such as hurricanes and icing that are prevalent along the East Coast and in the Great Lakes where some of the best wind resources exist.

Large, floating offshore systems located in the Atlantic and Pacific Oceans at water depths of 50 meters or more, present additional challenges. Research is needed to address the motion of the buoyant turbine platforms anchored to the sea floor by mooring cables. With larger turbines and platforms, there is greater need to moderate buoyant motions with advanced control methods, lightweight material designs, and new hydrodynamic platform configurations to ensure reliable operation.

Reducing Costs with On-Site Blade Manufacturing

Turbine blade materials and manufacturing techniques have not advanced significantly since the 1990s and are still based on low-cost composite fibers and durable epoxy resins. Research into advanced materials and adhesives are needed, as is R&D into new manufacturing methods such as 3D printing and onsite manufacturing. For example, one opportunity for blade improvements through materials is the transition to thermoplastic resins. These resins would allow the "welding" of the composite structural elements while enhancing blade recyclability at the end of commercial life.

As turbine blades increase in size—extending up to two football fields long—the greater the costs are of transporting blades from manufacturing sites to wind farms. Much of this cost, and the associated logistics and transportation challenges, can be reduced by using on-site manufacturing methods. Research into creating mobile, on-site manufacturing facilities and techniques is needed to produce strong, lightweight blades in ways that reduce costs and speed field deployments. Success in this area will require advanced materials and processing science.

The Future of Bioenergy Research

Another area in which NREL is pursuing foundational science is the broad spectrum of bioenergy technologies. Our research is advancing biofuels, biochemicals, and biomaterials sourced from lignocellulosic biomass—plant matter abundant across the United States that is typically available as agricultural waste and other residue. Estimates show that by 2030, the United States will have the capacity to produce a billion dry tons of biomass resources annually for energy use, without impacting other vital U.S. farm and forest products. This domestic resource represents a significant opportunity for sustainable, low-carbon energy and fuels.

What does this mean for the average American citizen? A billion dry tons of sustainable biomass has the potential to produce: electricity to power 7 million households; 50 billion gallons of biofuels displacing almost 25% of all transportation fuels; 50 billion pounds of bio-based chemicals and bio-products, supplying a significant portion of the chemical market; and 450 million tons of carbon dioxide equivalent reductions every year.

Key to this area of research is the development of infrastructure-compatible fuel technologies from biomass that enable affordable, low-carbon gasoline, diesel, and jet-fuel alternatives. Through research on bio-based hydrocarbon fuel technology development—in collaboration with Ensyn, Petrobras, and Chevron—NREL has demonstrated proof of concept for co-utilization of pyrolysis oil in existing refinery operations. The resulting renewable gasoline and diesel has garnered EPA approval as an advanced biofuel.

Using Our Bioenergy Expertise to Solve Other Challenges

The added benefit of conducting foundational science is serendipitously finding ways to solve other crucial challenges. In a logical evolution of our current research in converting biomass into biofuels and bioenergy, we have discovered industrially relevant solutions to help solve challenges associated with the world's plastics pollution problem. For example, NREL scientists have discovered how to transform discarded plastic products into new, high-value materials of better quality and environmental value—referred to as "plastics upcycling"—that could economically incentivize the recycling of waste plastics. The NREL team chemically combined reclaimed polyethylene terephthalate plastic, or PET, with bio-based compounds to produce valuable, fiber-reinforced plastics that can be used in products from snowboards to wind turbines. Not only are the resulting composites worth more than the original PET, the materials are twice as strong and use a more energy efficient and less hazardous process compared to the standard petroleum-based manufacturing processes.

In addition, NREL and an international team recently engineered a natural enzyme to more efficiently break down PET, and we are working now with a large group of collaborators to find even better enzymes that can operate at much higher temperatures in an industrial setting. NREL also leads a consortium of industrial, national lab, and academic partners focused on the development of bio-based acrylonitrile for renewable carbon fiber applications—such as aircraft and vehicles—which have the added transportation-related benefit of light-weighting these vehicles to improve fuel efficiency. We are now engaged with industry to take this exciting technology to a more commercially relevant scale.

Collaborating to Benefit All

NREL's collaborative approach with industry, other national labs, and universities to support commercialization of our research has been demonstrated to be highly impactful, reducing private sector risk in early-stage technologies enabling continued private-sector investments and U.S. competitiveness. That's why the R&D projects I've mentioned are crucial to finding meaningful solutions to today's energy and environmental challenges. We give U.S. companies a competitive edge in the global energy race by bridging the gap from concept to market and linking R&D with real-world applications.

Underscoring this approach is the $100 million, 10-year agreement we recently signed with the National Energy Technology Laboratory and ExxonMobil. This partnership will support research into ways to bring biofuels and carbon capture and storage to commercial scale across the transportation, power generation, and industrial sectors. It will also foster research collaboration on projects to advance potential scalable technologies that improve energy efficiency, minimize greenhouse gas emissions, and reduce emissions from the production of fossil fuels and petrochemicals. Our combined efforts could expand the U.S. energy portfolio and strategy. Working together with other national labs, we are proving that we can grow our economy while being environmentally responsible and reducing emissions.

In Conclusion

The United States has a unique system for R&D and scientific leadership through the DOE national laboratory system, which many refer to as the "crown jewels" of American scientific discovery. But what does that mean? It means that national labs, like NREL, and their partners are the engines for America's innovation. The scientists and engineers who choose to work at NREL and other national laboratories are among the very best, and they have an abiding determination to shape our energy future into one that is clean, reliable, affordable, and secure. These are the same experts that have enabled NREL to find new pathways to transform and enhance our energy system—everything from keeping our grid secure and the exciting new possibilities of perovskites, to modeling the aerodynamics of wind turbines and creating ways of upcycling plastics.

It's these innovations that keep us in the leadership role on the world's scientific stage. But we should not overestimate the security of our role. Other nations continue to ramp up research in all of the areas I've talked about today. They are looking at our labs systems and thinking they can do something similar or even better. This makes it crucial, for our economic and national security, that we maintain our leadership in this area by supporting and advancing our national lab system. If we do not, it is certain that others will be waiting to step in and take our place.