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For the House Science, Space & Technology Committee
Subcommittee on Energy
Hearing on "Advancing the Next Generation of Solar and Wind Energy Technologies"

May 15, 2019

Chairman Lamb, Ranking Member Weber, members of the Subcommittee, thank you for this opportunity to address the future research opportunities for solar and wind energy, and the many benefits these advanced technologies can deliver for our nation.

I am Peter Green, the Deputy Laboratory Director of the U.S. Department of Energy's National Renewable Energy Laboratory, or NREL, in Golden, Colorado. My career has included more than 30 years in research positions in the academic and national laboratory complex. Prior to coming to NREL in 2016, I was the Vincent T. and Gloria M. Gorguze Endowed Professor of Engineering as well as professor of materials science and engineering, chemical engineering, and applied physics at the University of Michigan. Prior to that I was the B.F. Goodrich Endowed Professor of Materials Engineering and Professor of Chemical Engineering at the University of Texas. My professional career began at Sandia National Laboratories where I was manager of the Glass and Electronic Ceramics Research Department. I am a fellow of a number of societies including the American Physical Society, American Association for the Advancement of Science, the Royal Society of Chemistry and the Materials Research society. I am a former president of the Materials Research Society. I served on advisory boards for the national academies, national laboratories, scientific journals, and universities. My B.A./M.A. degrees are in Physics, from Hunter College, and my M.S. and PhD are in Materials Science and Engineering from Cornell University.

Since my lab, NREL was founded in 1977, we have been proud to contribute to the science and innovation necessary to create vibrant new U.S. industries from what were then just niche players on the energy horizon. In 2018, wind power capacity in the U.S. added 7,588 megawatts, to a fleet that now totals 50,000 commercial-scale turbines with nearly 100,000 megawatts of capacity—about 7 percent of the nation's electricity. There are more than 100,000 Americans employed in the wind industry, which sees even greater growth in the years ahead.

Solar energy enjoys the same kinds of exciting prospects. The number of solar power installations in the United States surpassed two million this year, or about 1.6 percent of domestic power output. The Solar Foundation estimates the industry has a workforce of nearly 250,000 today, with remarkable potential for expansion into the future.

By 2030, estimates suggest that renewables could contribute a third of our nation's overall electricity generation, an amount forecast to rise to nearly 40 percent by 2040. I believe that given adequate support for a balanced research portfolio, the resulting pipeline of innovation in new materials, technologies, designs, and processes for solar and wind power can usher in a new era for U.S. energy affordability, resiliency, reliability, durability, and security. Ever cheaper supplies of wind and solar power may provide lowest-cost energy for U.S. manufacturing and the use of renewable power to produce renewable fuels. National laboratories, academics, and industry researchers are all working collaboratively on these and related challenges. Recent NREL partnerships with energy giants ExxonMobil and Shell may be a pathway to solving these research challenges.

Solar Energy Research

Foundational science, including chemistry, electrochemistry, materials science, semiconductor physics and computational applications, is enabling innovation across the solar energy spectrum. NREL's longstanding work for the DOE solar program has helped achieve massive cost reductions, increases in performance, and better integration into the existing electric infrastructure. Today, NREL also is working with the U.S. military on lightweight solar materials and applications to enable the computers and communication systems soldiers are using in forward operating environments. Drone systems are likely to use new solar technology to achieve perpetual flight.

Research conducted at NREL and other labs is evolutionary in nature. The multi-junction solar cells used on the Mars rover and many satellites were born out of NREL research several decades ago. While these technologies may be too expensive to employ in terrestrial applications today, we are working on dramatically lowering costs to bring this technology back to Earth.

By design, our research is conducted in partnership and mutual collaboration with industry, other National Labs, and universities across the nation. Our R&D goals are informed by U.S. manufacturers, energy plant developers and utilities, based on their real-world, on-the-ground needs to grow their products, services and business potential. Those partnerships even extend to the most fundamental sciences behand the technologies. In the NREL-led Center for Next Generation of Materials Design, an Energy Frontier Research Center (EFRC) we have worked with the Stanford Linear Accelerator, or SLAC, on fundamental computational materials discovery by design, to develop new materials for new solar energy concepts.

It is essential to pursue breakthrough science focused on improving efficiency, reducing costs, improving durability and reliability and streamlining manufacturing processes, if we are to make the U.S. solar energy industry competitive and profitable. Research on advanced photovoltaic cells and devices should include a range of materials and technologies. For perovskites, we need to continue working toward creating stable and efficient modules, as well as innovative processing concepts to create low-capital-cost manufacturing platforms. For organic solar cells we need to improve efficiency and performance. For silicon, we must reduce costs through research into materials, module designs, and manufacturing systems that are more sustainably based. For thin films, increasing energy efficiency and driving down the cost of manufacturing remain crucial. For so-called III-V (three-five) cells, here again the overarching goal is to pursue lower costs, and still higher efficiencies. For tandem devices, we are closing in on a commercially viable design that meets cost targets at the system level, while demonstrating adequate performance and reliability.

Research should also encompass advanced module and installation designs to improve production output, as well as reduce hardware and installation costs. In the case of the electronics needed at the module level, we need to reduce operational and maintenance costs, while increasing system longevity.

Research in Solar-to-X

As solar power becomes abundant, we look forward to a time when new opportunities to use surplus solar power can increase our nation's economic competitiveness. Looking at the potential of solar beyond the electric grid, we are exploring Solar-to-X technologies, from solar fuels directly from sunlight, to advanced electrolysis and thermal processes. In this realm, research into technologies for solar to create additional products could be revolutionary. Converting solar electricity to something else of value, such as solar-to-fuels, solar-to-hydrogen, or solar-to-chemicals, such as ammonia, has great potential.

To be sure, these technologies today are still in the research stage, but comprise untold opportunities for the future. The technological potential across solar thermochemical, photo-electrochemical, high-temperature electrolysis and photo-thermal platforms, is waiting to be exploited. Thermal solar systems may be an entry into large-scale solar-fuel production, which could cut energy costs for large-scale hydrogen production from water-splitting. These Solar-to-X possibilities could support growth of U.S. manufacturing and other industries, with associated economic and workforce expansion. Sustained research into each of these scientific lanes will be required.

Another research area is "power anywhere," which seeks to take advantage of some of the unique properties of photovoltaic solar, whether it's lightweight, flexible, or portable. That means not just stationary power sources, but solar installed on a myriad of surfaces, able cover whatever application is available. Finally, solar technology advances also demand more detailed analysis of economics, life cycles, materials availability, and other, indirect but essential factors.

Concentrating Solar Power

Concentrating solar power, or CSP, technology has heading toward systems that can achieve costs of 4-to-5 cents per kilowatt-hour, including 8-to-15 hours of energy storage. The fundamental challenge for CSP research is a thermodynamic power cycle, which requires development of advanced, high-temperature working fluids, alongside thermal energy storage. Moreover, because the solar mirror field essential to CSP systems represents a major cost, coming up with next-generation CSP field designs is crucial as well. We are working closely with industry to reduce solar field costs by using advanced manufacturing concepts and new materials.

Solar energy will be an enormous economic opportunity in the years ahead. To lower initial costs and maximize return on investment in this multi-billion-dollar industry, solar technologies need to perform optimally and reliably across their intended lifespans. Beyond the value proposition that solar installation revolves around, longer-term consideration of lifecycle costs, and ultimately, opportunities for economically viable material recycling and reuse, are of the highest order. In today's developing circular economies for industries and materials, we want to minimize use of hazardous inputs and extract value from materials recovered and recycled at end of life.

Wind Power Research

Federal R&D investments into collaborative R&D between national laboratories, universities, and industry have largely been responsible for the major advances in wind energy and its current impact. Today, research proceeds in a wide range of wind-related topics. Just the advancing technologies in wind machine control systems could, for instance, optimize the overall efficiency of entire multi-turbine wind farms, realizing hundreds of millions of dollars in savings to the industry, and consumers. Our eventual goal is to use a combination of foundational scientific understanding to drive innovations to produce wind power at half the cost of current wind generation, operating anywhere in the United States.

NREL contributed extensively to a just-released International Energy Agency study that brought together more than 70 wind energy experts, and which lays out "A Grand Vision for Wind Energy Technology." The report concludes that "realizing the full potential of wind technology will require a paradigm shift in how wind turbines and power plants are designed, controlled, and operated. Notwithstanding the accomplishments … to date in driving down costs and increasing performance, there is still an immense opportunity for innovation to enable continued expansion of wind power."

Underscoring the complexity of the R&D challenges, the report divided the most promising research requirements into these categories: turbine design and technology, manufacturing, atmospheric science and forecasting, plant controls and operations, grid integration and, finally, R&D that is specific to off-shore technologies. Each of these areas holds promise in significantly increasing deployment potential and reducing costs of wind energy generation.

Turbine Design and Technology

There is continuing opportunity to make future wind turbines even bigger and more flexible than previous technological generations to access greater power at higher elevations, 200250 meters, and to achieve the additional economies of scale that can be achieved from these gigantic machines. Researchers and industry alike project that turbines need to increase their size into the 200-meter-plus diameter range, set atop towers that need to extend over 150 meters high (total height of greater than 800 feet) to achieve the economies of scale for significant cost of energy reduction.

Putting the R&D challenge into perspective, it will also make wind machines the largest rotating machines ever built. We have yet to establish the boundaries of safe operation for such turbines. Recent research results indicate that at this scale, some of the basic aerodynamic assumptions upon which the current generations of efficient commercial turbines have been based, may no longer be valid.

As offshore wind turbines continue to increase in size—with rotor diameters larger than two football fields—they present unique research challenges that require the combined understanding of wind flow aerodynamics through the rotor, hydrodynamic forces from waves and currents acting on the structure, advanced materials, and controls. Moreover, these machines must be flexible to survive extreme weather events, like hurricanes or icing events, that are prevalent along the East Coast and in the Great Lakes, where offshore wind energy deployments are planned. Floating offshore systems, which promise to enable wind energy in large areas of the ocean off the East and Pacific Coasts in water depths of 50 meters or more, present additional research challenge because they have additional sources of motion in the turbine platform anchored to the sea floor by mooring cables. Because floating systems are tethered by cable moorings to buoyant platforms, the greater turbine motions which need to be moderated with advanced control methods, lightweight material designs, and new hydrodynamic platform configurations.

Turbine Manufacturing R&D

It may come as surprise that modern wind turbine blades still use materials and processes similar to those used for machines of the 1990s, based as they are on low-cost composite fibers and durable epoxy resins. Research into tailored matrix, fiber reinforcement, and core materials, as well as adhesives and innovative ways of manufacturing, such as 3D printing, is needed to improve the strength and stiffness, and reduce the weight—all at very low cost. Current blade costs are more than an order of magnitude less, pound for pound, than aerospace materials used for similar functions. Research is needed for these costs to continue to come down.

An opportunity to improve blade manufacturing is the transition to thermoplastic resins, if they could be proven for blade applications. This would allow the "welding" of the composite structural elements, and this is critical, the recyclability of blades at the end of their commercial life. Beyond blades, other components will also require distinct solutions in materials, including the tower; load-bearing supports; sensors for the machine and the environment; mechanical drive components, such as bearings and lubricants; and electrical drivetrain components, such as generators.

The on-site manufacturing of larger blades, thereby avoiding transportation barriers of blades from manufacturing sites to wind farms, is important. Development of reliable processes to improve blade manufacturing, involving thermoplastic resins, has important benefits. This would enable "welding" of the composite structural elements, and moreover, the recyclability of blades at the end of their commercial life.

Atmospheric Science and Forecasting

The evolving scale of wind machines is reaching farther than many, if not all, other large-scale dynamic systems ever built and operated. The natural dynamics of the atmospheric flows that power machines at this scale needs to be better understood. Clearly, the methods we have used historically to understand and predict the larger scale physics of the weather is no longer sufficient, as we will be operating in zones of the atmosphere where less is known about the dynamics of the wind, which creates new needs for research into the wind resource.

Since the energy comes from the weather, and designing turbines depends on the how that weather translates into small scale turbulence, these scales must be linked based on a more comprehensive understanding of the nature of the transition. In addition to accurately capturing the deep dynamics between weather and wind plants, there is a need to understand the physics of the wakes, the downwind zones of low-speed air created when energy is extracted from the wind. The new science of data analytics is opening the door to innovative ways to use both turbine and weather data to not only predict future power generation, but to develop control systems that manage the wakes and increase intra-plant power productivity.

Energy Storage and Grid Integration

With penetration of wind and solar generation growing, it is vitally important that we continue to develop energy storage technologies. Energy storage today is revealing real-world potential for resolving many of the challenges associated with variable wind and solar resources.

Different storage technologies require diverse technology solutions, because storage needs change depending on how much and how long storage is needed. For example, stationary storage, which increasingly accompanies solar energy systems on the grid, is a field ripe for innovation. Energy storage research pivots around the three key research goals: higher energy density, longer life, and enabling greater adoption of energy storage. Scientists and engineers are especially focused on technologies at the intersection of these three goals, such as low cobalt cathodes, solid state electrolytes to enable lithium metal anodes, and engineering analysis and high-performance computing modeling.

As solar and wind generation expands, and localized, distributed energy systems proliferate, our electric grid must be modernized to ensure safe, reliable, and affordable electric power to all Americans. To meet this challenge, NREL and other research institutions are engaged in foundational science research in autonomous energy systems, or AES, that will allow for the real-time, monitoring, optimization, and control of integrated energy systems. Groundbreaking AES technology studies are underway at NREL's Energy Systems Integration Center, and at our new Flatirons Campus, a one-of-a-kind facility that provides utility-scale grid integration and energy systems research and testing. Plans have been approved to employ AES control concepts at 1–2MW scale with a range of devices in the Energy Systems Integration Center and to build out 10–20MW of integrated system assets at the Flatirons Campus. In the long-term, this research will provide the opportunity to evaluate autonomous control of multiple generation, storage, and load technologies at utility-scale to enable future energy systems.

Improving the technologies behind the power electronics across our energy systems holds great promise. Solar and photovoltaic systems and wind turbines all depend on a diverse set of power electronics to connect to the grid. Operational control systems likewise depend on power electronics. Improving the cost, efficiency, and reliability of these electronic control systems can benefit individual installations, and the entire national grid.

Energy system resilience and cybersecurity are also critically important research areas. Identifying, isolating, responding to and protecting against natural and man-made threats to our energy systems is paramount.

In Conclusion

If solar and wind power are to fulfill their potential as critical drivers to achieve our nation's future energy goals, a balanced portfolio of research is required. The goal of the research community and of industry is to enable multiple terrawatts of wind and solar power by 2030. This is projected to be at the lowest cost of electricity ever produced, without subsidy, and with minimal environment impact. This will not be possible without a robust federal commitment to solar and wind R&D. Along with new technologies, we are already seeing that new industries, and new business models for established industries, will transform energy production and use in the decades ahead. The scientists and engineers in laboratories and across energy industry facilities nationwide provide the United States with unique and unparalleled capabilities to be the global leaders in this rapidly changing energy sector—one which powers virtually all other areas of economic activity, not to mention our daily lives. These research endeavors are even more compelling when we consider the fact that when it comes to solar and wind, the United States is fortunate to be home to the world's most abundant resources for each.