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Hearing on "The Future of Electricity Delivery: Modernizing and Securing Our Nation's Electricity Grid"

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Chairman Lamb, Ranking Member Weber, members of the Subcommittee, thank you for this opportunity to discuss the critical challenge of grid modernization and cybersecurity and the steps we can take from a research perspective to create a flexible, more secure, and more resilient U.S. power system.

I am Juan Torres, and I serve as the associate laboratory director for Energy Systems Integration at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory, or NREL, in Golden, Colorado. I have been affiliated with federal research and our national laboratory system for nearly 30 years. In my current position, I direct NREL's efforts to strengthen the security, resilience, and sustainability of our nation's electric grid. In addition, I am co-chair of the DOE Grid Modernization Laboratory Consortium (GMLC) and technical lead for the GMLC's security and resilience team. The GMLC is a partnership of 14 national laboratories working to advance modernization of the U.S. power grid. Prior to joining NREL, I served for many years in various technical and managerial roles at Sandia National Laboratories, advancing cybersecurity, energy, and power grid research, most recently as deputy to the vice president for energy programs. Earlier in my career, I also served on the DOE task force that developed a plan to protect U.S. energy infrastructure in response to Presidential Decision Directive 63 on Critical Infrastructure Protection.

NREL was established in 1977 to advance renewable energy technologies as a commercially viable option. Over the years, our groundbreaking advanced energy research has contributed to transformational scientific advancements, exponential decreases in the cost of renewable energy, and more renewable installed capacity than ever before. We are continually looking ahead to understand how advanced technology options can enable a balanced national energy portfolio. From our perspective, grid modernization is one of the most crucial and urgent energy challenges our nation must address.

Why Grid Modernization

Every aspect of the economy, national security, and critical infrastructure in the United States is deeply dependent on the reliable operation of our electrical system. Yet the basic design of our country's energy infrastructure has not changed much since the earliest electric grids were developed in the late 1800s—our grid is still largely built around the concept of one-way centralized generation and control. To put that into perspective, this approach to generating and delivering electricity predates the first automobiles.

The electric grid has served our country well for a very long time. However, the energy landscape—both in the United States and around the globe—is changing quickly. Cost-competitive renewables are making up a larger share of the energy mix. The grid edge, where consumers and energy users connect to the grid, is transforming into a dynamic space where energy is not just passively consumed, but generated, stored, managed, and traded. And infrastructures that once operated in silos, such as electricity, transportation, communications, and fuels, are increasing their overlap and interdependencies with each other.

These exciting dynamics are creating many opportunities, but also present urgent challenges in assuring our grid can meet evolving consumer needs, leverage technological advances, and mitigate today's and tomorrow's threats. Managing, optimizing, securing, and adding resilience to the future power system will require new technologies and control techniques, advanced sensing and data analytics, more sophisticated models and validation techniques, as well as effective business models and other institutional support. It will also require the electric grid to operate differently than it has for more than a century, with more flexibility and resilience to withstand both cyber and physical attacks as well as disruptions from natural disasters.

The magnitude and importance of this challenge cannot be overstated. Our country's continued security and economic growth simply depend on it. There is no time to delay. These fast-moving changes, along with growing cyber threats, require immediate and sustained action.

What Does a Modern Grid Look Like?

DOE's Grid Modernization Initiative was established to work with the electricity sector to address this question and leverage our national resources to drive solutions.

The Initiative has laid out these key characteristics that a modern grid must have:

- Greater **resilience** to hazards of all types
- Improved **reliability** for everyday operations
- Enhanced **security** from an increasing and evolving number of threats
- Additional **affordability** to maintain our economic prosperity
- Superior **flexibility** to respond to the variability and uncertainty of conditions at one or more timescales, including a range of energy futures.

Getting there will require an unprecedented level of research, collaboration, and innovation. For this reason, DOE partnered with its national labs to form the Grid Modernization Laboratory Consortium. The GMLC—co-led by NREL and the Pacific Northwest National Laboratory (PNNL)—acts as the boots on the ground to execute critical research that is already delivering solutions today, with plans to continue to do so well into the future.

The Focus and Impact of GMLC Research

The GMLC has proven to be a galvanizing and impactful initiative. Since its inception in 2015, it has jumpstarted grid modernization research and collaboration in the energy sector and transitioned technologies and concepts to the power sector not otherwise possible on such an accelerated timeframe.

Although it is not possible to highlight all the impressive achievements of GMLC projects here, it is worth noting a few real-world benefits that have already been realized:

- Developed an advanced microgrid design tool kit to increase the resilience of critical loads to major grid disruptions
- Developed concepts to improve the black start capability for recovery after a major power outage
- Developed the Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS) framework to couple grid transmission, distribution, and communications models to understand cross-domain effects
- Advanced 13 different sensing technologies across the end-use sector, transmission and distribution, and asset monitoring
- Developed a valuation framework that will allow stakeholders to conduct and interpret valuation studies of grid technologies with high levels of transparency, consistency, and extensibility
- Developed analytic tools to differentiate between cyber- and noncyber-initiated events
- Provided microgrid design support to Puerto Rico and the U.S. Virgin Islands after the devastation of Hurricane Maria
- Leveraged grid modeling tools and expertise toward development of the North American Energy Resilience Model (NAERM).

We have come a long way in a few short years, but there remains much work to do. Research within the GMLC has the opportunity to strengthen the trajectory of our grid's development at this timely juncture when investment decisions that our nation makes today will likely remain with us for decades to come. Steps taken now can help establish the modern grid of the future by positioning our grid with inherent resilience and flexibility to accommodate new trends and challenges, such as:

- A changing mix of generation types
- Extreme weather events
- Increasing cyber and physical threats
- Opportunities for customers to participate in electricity markets
- Growing use of digital and communication technologies.

I will touch on a few of the most important areas of future research in the following sections.

I commend the Subcommittee for the commitment and insight you have shown in addressing the critical challenges of developing the electric grid we need to meet the burgeoning demands of the future. Reflecting the importance of these very issues to DOE, to the national laboratories, and, of course, to Congress, I'd like to invite you to attend the National Lab Day on Capitol Hill next week, July 24, in the Rayburn House Office Building. The event will be focused exclusively on grid modernization, and many grid researchers, other experts from the labs, as well as myself will be on hand for discussion at a series of exhibits that will highlight much of the work I am discussing today.

Keeping Pace with Cybersecurity

The grid that we know today was designed before we could foresee today's cyber vulnerabilities, and the grid that we evolve to must be resilient to tomorrow's threats. The increasing use of digital technology in our power grid is driving new system configurations, operating strategies, market structures, and business models, but at the same time, increasing our cybersecurity attack surface.

It is paramount that we keep pace with advanced cyber solutions to protect evolving energy systems.

Cybersecurity is not only a top priority for NREL; it is critical to the success of DOE's missions, from maintaining the nation's nuclear deterrent, reducing the threat of nuclear proliferation, overseeing the nation's energy supply, and managing the science and technology powerhouse of the 17 national laboratories.[1]

Secretary Perry has identified protection of the energy infrastructure from cyber threats as one of DOE's highest priorities. Across the national laboratory complex, we acknowledge the challenges, opportunities, and responsibility we have to advance the science and technology of cybersecurity to detect, protect, and mitigate against threats to our energy systems.

Sandia National Laboratories has developed SCEPTRE, a cyber-physical environment to analyze how cyber-initiated events affect the physical world. At Argonne National Laboratory, the Dynamic Application Rotational Environment (DARE) rotates web applications across multiple attack servers, allowing analysts to further understand the complexities and intricacies of national security in the cyber realm. Los Alamos National Laboratory is developing technologies designed to defeat today's intrusions into both government and critical infrastructure systems, expanding unique capabilities such as steganography and quantum-enabled security. With Pacific Northwest National Laboratory's cybersecurity test bed, analysts can provide hands-on workshops to teach cybersecurity best practices so that defenders can practice their skills against a safe adversary in a controlled environment. The Idaho National Lab's cybersecurity test bed includes a full-scale transmission loop to assess vulnerabilities and assess impacts on the power grid.

[1] "U.S. Department of Energy Cybersecurity Strategy," 2018–2020. https://www.energy.gov/sites/prod/files/2018/07/f53/EXEC-2018-003700%20DOE%20Cybersecurity%20Strategy%202018-2020-Final-FINAL-c2.pdf

At NREL, we are developing a virtual environment that will allow us to emulate millions of digital, cloned devices working with physical grid devices, including solar inverters, batteries, and other components throughout our Energy Systems Integration Facility (ESIF) and our Flatirons Campus. In this virtual world, researchers will be able to evaluate the performance of these devices operating simultaneously, while safely launching cyberattacks in a controlled grid environment. Learning to think like an adversary in future grid scenarios will be critical, and it will require the right environment for simulated cyberattacks to highly complex systems.

Protecting Critical Infrastructure

As we have recently witnessed from a multitude of threats across different sectors, malicious actors have demonstrated willingness to employ large-scale cyberattacks, which can be crippling and costly. Reliable power generation keeps our hospitals operating, transportation systems moving, and emergency systems responding, and it provides our homes with power and water.

Stories about cyber breaches to major global companies, government agencies, and electricity systems are becoming all too familiar—such as the 2015 attack on Ukraine's power grid and the $10 billion price tag of the malware attack NotPetya.[2]

Just a few months ago, a western utility in the United States experienced a denial-of-service attack, which caused disruption to grid operations in their region. Although no harm to power generation was reported, the instance led to a temporary loss in visibility to parts of the utility's SCADA (supervisory control and data acquisition) system.[3] Gaining access to a utility's SCADA system, which is used to manage energy infrastructure, could open the door to multiple substations and other distribution assets.

Directed research is needed in scalable cyber data analysis, advanced encryption, adversary isolation, in-depth assessments, and security for future autonomous systems. In NREL's expertise of distributed energy systems, the attack surface is increasing around the communications and control of devices, such as rooftop solar, grid-connected vehicles, grid-interactive buildings, and microgrid systems. In the coming years, it will be critical to invest in research capabilities that keep our power systems inherently secure and ahead of cyber adversaries.

The Need for Energy Resilience

With every first line of defense, there must be a second. Alongside the concern for cyber threats, there are other significant sources of disruption to the electric grid—both natural and human—that are just as relevant. These include intensifying weather events, geomagnetic storms from solar flares, and deliberate physical interruption.

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[2] Andy Greenberg, "The Untold Story of NotPetya, the Most Devastating Cyberattack in History," *Wired*, August 22, 2018.
[3] Bob Sobczak, "Experts assess damage after first cyberattack on U.S. grid," *E&E News*, May 6, 2019.

When a disruption occurs and energy services are interrupted, we must be prepared to recover quickly. Resilience can be defined as the ability to "prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions."[4] Energy resilience contributes to the strategic goal of energy security: ensuring sustained energy services with minimal interruptions.

As we have seen from recent storms in Puerto Rico, the Virgin Islands, and other coastal regions throughout the United States, weather alone can interrupt energy systems from multiple entry points and lead to cascading impacts on power systems, water systems, transportation systems, and businesses. We must also be aware of physical interruptions to energy delivery services and the looming potential of an electromagnetic pulse or geomagnetic disturbance event, which could cause a large-scale grid disruption within minutes.

These evolutions give urgency to a better understanding of underlying science and engineering principles that are foundational to designing more inherently resilient energy systems. We need advancements in resilience science—a study of the possibilities for protective and resilient design, and, in the event of a disruption, an effective path to restoring energy services with minimal economic costs and societal impacts. For an in-depth look at the challenges and opportunities around grid modernization, I would call your attention to a study DOE-supported study by the National Academies of Sciences: "Enhancing the Resilience of the Nation's Electricity System."[5]

Resilience Through Autonomous Systems

One of the ways NREL is working to strengthen reliability and resilience on the future electric grid is through its research and development into autonomous energy systems—fast-reacting energy systems that are managed through artificial intelligence. These systems could have greater precision and speed than a human-controlled system could ever achieve. For the hundreds of millions of grid devices that are on pace to come online in the coming years, autonomous distributed control appears to offer the most resilient framework.

With highly advanced monitoring and control technologies, autonomous energy systems are being researched for strength against a broad spectrum of threats, even offering resilience against potential threats that we may not yet understand.

The autonomous energy systems platform is built on basic research in optimization theory, control theory, big data analytics, and complex system theory. Unlike current systems that rely on centralized computing platforms for grid control, autonomous energy systems could self-organize and manage themselves.

For an autonomous energy system to perform optimally, it would rely on scalable cellular blocks—essentially variably sized microgrids—that self-optimize when islanded and participate in optimal operation when interconnected to a larger grid. NREL has developed and tested several algorithms that

[4] "Presidential Policy Directive (PPD)-21—Critical Infrastructure Security and Resilience," 2013.
[5] https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricity-system

have advanced the optimization and control of networked systems and significantly reduced the time of the optimization. Scaling these algorithms to a realistic power system is the next line of research.

By furthering our investments to advance innovative solutions like this, we will be better equipped to adapt, withstand, and recover from current and anticipated sources of power disruption.

Adapting to Sustainable Sources With Flexibility

Grid modernization includes building on our existing generation mix, such as natural gas and nuclear, with emerging generation resources. For example, DOE programs are promoting research into more novel resources such as tidal energy[6] and hydrogen fuel cells. By powering our nation with a mix of energy sources, we can strengthen our energy security and achieve energy independence. But to get there means adapting our infrastructure and markets around energy that includes both centralized power plants and distributed and variable generation.

In Hawaii and California, two states where rooftop solar is extensive, we are experiencing firsthand how consumer and industry-driven growth in new energy resources needs parallel efforts in grid modernization. NREL has supported this energy transition in both states, prominently through our leadership in publishing solar energy's most important standard for interconnection, *IEEE 1547*. Revising this standard, which was part of our GMLC portfolio, has brought consensus across sustainable energy's many stakeholders, ultimately helping the market keep its momentum.

What we have learned from our partnerships with utilities, planning authorities, and product vendors is that there are many angles to adopting a broader energy mix. But above all, we need institutional collaboration and proper planning tools so that strides in sustainable energy technologies are met by a prepared grid and a prepared workforce.

Finding Solutions for Energy Storage

Developing reliable, cost-effective technology to store electrical energy so it can be available to meet demand whenever needed would be a major breakthrough in the existing power grid. The addition of variable sustainable energy sources presents a new challenge requiring continued research.

At solar energy's most productive hours, utilities in California curtail significant energy generated—at times, more than enough energy to power the same distribution system. Likewise, wind gusts do not always correspond to customer electricity demand. How to reserve this energy for later use, whether for emergency backup or efficient day-to-day use, is a priority across both industry and DOE's grid modernization efforts.

As with much of our grid's transition, energy storage is largely driven by private industry. Storage technologies from diverse vendors are entering the grid at both customer and utility scales, with varying

[6] https://www.energy.gov/articles/us-department-energy-awards-25-million-next-generation-marine-energy-research-projects

performance and configuration, leaving a gap in understanding of how storage can best serve our power systems, economically and reliably.

Furthermore, energy storage comes in more than one flavor. Hydrogen and lithium-ion are relevant modes of storage for vehicles, while renewably produced natural gas may function for community-scale storage. A pumped-storage hydropower plant in Virginia has a generation capacity of nearly 3 gigawatts,[7] while the much drier and sunnier climate of Nevada is better suited for storing solar energy thermally. The federal government can help power system planners across the nation understand how energy storage could fit into their systems.

Growth in energy storage could mean dramatic cost savings and critical importance to grid resiliency—but only if power system operators are well equipped to use storage assets. Hawaii's island of Kauai, for example, has just launched a record-setting "storage plus solar" plant.[8] But prior to launch, the plant's developer, AES Corporation, needed to arrange the storage for Kauai's grid. Only with NREL's advanced hardware and computing infrastructure was AES able to validate the new plant for Kauai. Similar configuration will be necessary for the many megawatts of energy storage that will soon be coming online.

For an NREL overview of energy storage in grid modernization, see "The Role of Storage and Demand Response."[9] For a high-level examination of emerging energy storage trends, please see the article "Maintaining Balance: The Increasing Role of Energy Storage for Renewable Integration,"[10] co-written by NREL energy storage analyst Paul Denholm.

Summarizing the Grid's Future Needs

Since the first power lines were installed, our nation's grid has never experienced a transition like the present. Through decades of industry-spanning partnerships at NREL, we have been granted perhaps the best perspective of how our nation's energy system is changing and how we can adapt.

Though many of the technological changes to our grid are being carried by private industry, we identify an important role for government to guide and facilitate the transition, and to do so with respect to our national interests of energy independence and security.

At its core, our future grid must be resilient against threats, both known and unknown. We have the opportunity to shape our power systems to be inherently secure and efficient. We need systems that minimize damage done when events do occur, and systems that use breakthroughs in artificial intelligence and data science to react flexibly and precisely to grid changes. At their foundations, these

[7] https://www.dominionenergy.com/company/making-energy/renewable-generation/water/bath-county-pumped-storage-station
[8] https://www.greentechmedia.com/articles/read/aes-completes-its-record-breaking-solar-and-battery-plant-on-kauai#gs.of9dp4
[9] https://www.nrel.gov/docs/fy15osti/63041.pdf
[10] https://ieeexplore.ieee.org/document/8070540

power systems will be adaptable to the complex mix of technologies and energy types that are emerging.

To arrive at such a grid, the nation's future utility workforce will need new tools and training. The growing complexity of the grid will create demand for a dynamic workforce that is up to the task of building, operating, and maintaining future power systems. This pipeline of education and mentorship will need to be complemented by tools for decision support and situational awareness, as well as autonomous systems that can overcome contingency events.

Research into grid modernization needs to be ongoing and based on evolving needs. It needs to match the rapid technical advancements spurred by industry, and the intensity and spectrum of threats that are mounting against power systems. Our nation's next steps in grid modernization could be the most important yet.

I am appreciative of this opportunity to appear before the Subcommittee on a topic of vital national importance, and I look forward to answering any questions you may have.