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For the U.S. House of Representatives Committee on Science, Space, & Technology
Hearing on "Lessons Learned from the Texas Blackouts: Research Needs for a Secure and Resilient Grid"

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Chairwoman Johnson, Ranking Member Lucas, members of the Committee, thank you for this opportunity to discuss the importance of grid resilience and security and the research directions that we can take to prepare for future events. In my testimony, I will present on:

- The changing state of the power grid and impacts on energy security and resilience
- Some learnings from the February 2021 Texas power grid outage and other events
- Current DOE and national laboratory activities to increase grid security and resilience
- Next Steps: strengthening and expanding capabilities to establish more resilient energy systems.

My name is 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 over 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 teams. 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 and secure national energy portfolio. From our perspective, grid resilience is one of the most crucial and urgent energy challenges our nation must address.

The Changing State of the Power Grid and Impacts on Energy Security and Resilience

There is no single owner, operator, or architect for the U.S. power system. It is an engineering marvel influenced by a collective of stakeholders over more than a century. Predicting what the grid will look like in the future is extremely difficult given uncertainties in future policies and regulations, which are implemented at the federal, state, and local level, and rarely consistent or aligned across all stakeholders. A recent study[1] by the National Academies of Sciences, Engineering, and Medicine effectively captures the driving forces (social, technical, economic) that are likely to shape the future power grid over the next several decades. Revolutionary advances in technology are also difficult to foresee, but trends can be monitored and influenced through consistent investment.

The grid is evolving from an architecture of large, centralized generation to a hybrid system incorporating more distributed, largely variable renewable resources. Significant changes are also occurring at the grid edge, near the consumer. Never before has the consumer been more proactive and engaged with the operation of the grid. Real-time pricing, transactive energy, smart appliances and lighting, smart loads, electric vehicles, and residential photovoltaics are just some of the technologies transforming the gride edge.

Also worth noting are the increasing interdependencies between the grid and other infrastructure. For example, electrification of vehicles increases the reliance of the transportation system on electricity, and advances in telecommunications technology like 5G make it attractive for utilities to communicate with the many more devices and sensors being added to their systems.

COVID-19 has changed how and where we use energy in a way not planned or predicted prior to the pandemic. A large portion of the U.S. workforce transitioned to working from home, seemingly overnight. Electricity loads from business districts shifted to residential neighborhoods. Post-pandemic, many businesses are likely to continue maintaining a remote workforce now that they have become more savvy with the virtual experience and tools. The long-term impacts and innovations resulting from the pandemic remain to be seen.

Equally significant is the dynamic threat space. The devastating consequences of extreme weather events—economically, socially, and even tragically with loss of life—remind us once again of our reliance on the power grid and its potential fragility if we don't remain vigilant to strengthening its resilience against evolving threats. Intensifying storms, wildfires, and cyberattacks, along with physical attacks, geomagnetic disturbances, electromagnetic pulse events, and aging energy infrastructure all threaten to disrupt power for millions of Americans and overwhelm an energy system that must evolve to meet 21st-century needs.

Ultimately, stakeholders, including policy makers, regulators, grid planners, and operators, could consider the following six attributes when seeking out solutions providing multiple benefits:

- **Resilient** – Recovers quickly from any situation or power outage
- **Reliable** – Improves power quality and fewer power outages
- **Secure** – Increases protection to our critical infrastructure
- **Affordable** – Maintains costs commensurate with value to consumer
- **Flexible** – Responds to the variability and uncertainty of conditions across a range of timescales, including a range of energy futures
- **Environmentally sustainable** – Reduces environmental impact of energy-related activities**.**

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[1] National Academies of Sciences, Engineering, and Medicine 2021. *The Future of Electric Power in the United States.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25968.

Some Lessons from the February 2021 Texas Power Grid Outage and Other Events

The February 2021 winter storm in Texas is another example of a devastating power grid outage caused by extreme weather events. We must view the Texas outage in the context of numerous other storms that have devasted areas such Puerto Rico, New Orleans, and other coastal regions over the past few decades. Additionally, winter storms and wildfires continue to cause seasonal power outages in other parts of the country.

We offer the following critical lessons from past devastating storms as guidance for improving grid resilience:

- We must take actions to harden the grid and generation fleet to the broad spectrum of evolving threats through improved monitoring, planning, investments, and research and development (R&D).
- Meeting the challenges of a resilient electricity delivery system will require fully addressing the overall resilience of the energy system, from fuel to generation to delivery to load, including interdependent infrastructure (e.g., communications systems, natural gas pipelines, and transportation systems).
- We must research how a grid with more controllable devices and increasingly high penetrations of variable renewable generation integrated with a variety of legacy and emerging resources can be even more resilient than today's grid.

Addressing these topics is a multifaceted challenge. It involves new approaches to planning and operations, new investments in infrastructure, and a targeted understanding of how distinct power systems across the country can best modernize given their particular systems and circumstances. Most of all, it involves adapting to the trends currently driving change.

But this is not unknown territory for us. As I will discuss in the following sections, research is lighting the path forward. A variety of projects have delivered results that range from cutting-edge concepts to real-world demonstrations. We can use these results to inform our approach to building more resilience.

Current DOE and National Laboratory Activities to Increase Grid Security and Resilience

Communities across the nation—from remote rural locations to major metropolitan areas—are undertaking energy system transformations centered on clean energy, electrification, and integrated solutions. As such, there are significant opportunities to modernize the grid with resilience and security as inherent features to mitigate the spectrum of evolving threats. Two major initiatives spanning DOE programs and national laboratories are vanguards in leading-edge research and impact.

Grid Modernization Initiative

DOE's Grid Modernization Initiative (GMI) was established to work with the electricity sector to address the challenges of grid modernization and leverage our national resources to drive solutions. GMI brings together the efforts of the DOE Offices of Electricity (OE), Fossil Energy (FE), Nuclear Energy (NE), Cybersecurity Energy Security and Emergency Response (CESER), and Energy Efficiency and Renewable Energy (EERE). The initiative coordinates research and development across DOE to help set the nation on an affordable path to a resilient, secure, environmentally sustainable, and reliable grid in light of the rapid changes occurring throughout the system.

As part of GMI, DOE partnered with its national labs to form the Grid Modernization Laboratory Consortium, or GMLC. The GMLC—co-led by NREL and the Pacific Northwest National Laboratory—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.

DOE and its national labs, through the GMLC, have the most advanced set of grid research capabilities anywhere in the world to help guide broad grid improvements. DOE is not only applying these capabilities to carry out foundational R&D in energy security and resilience but also partnering with utilities, private industry, and local, state, and federal governments to demonstrate and deploy new technologies and concepts.

North American Energy Resilience Model

One of the most visionary efforts under GMI to look at resilience on a large scale is the North American Energy Resilience Model (NAERM). A collaboration between DOE, its national laboratories, and industry, NAERM is developing a comprehensive resilience modeling system for North American energy infrastructure, which includes the electric, natural gas, and communications sectors.

With this model in place, key actors will have real-time situational awareness and analysis capabilities for emergency events. Of equal importance, NAERM will make it possible to get ahead of emergencies before they happen. NAERM will help us transition from the current reactive state-of-practice to a new energy planning and operations paradigm in which we proactively anticipate damage to energy system equipment, predict associated outages and lack of service, and recommend optimal mitigation strategies.

In this way, NAERM serves another critical function as an infrastructure planning and investment tool. By pinpointing vulnerabilities, NAERM can also help answer questions for power grid planning and operations, such as:

- What is the next best investment that will yield contributions to national security?
- How can we improve electric and gas sector resilience to a wide range of threats?
- What are the impacts and cost-benefit trade-offs of different mitigation plans?
- Can we recommend optimal mitigation strategies to stave off large-scale system damage in real time?

NAERM has already modeled and captured different extreme events and their impacts. For example, NAERM recently modeled different polar vortices across the United States on which the team gathered historical data to understand and benchmark the impacts of cold temperatures, snow, and ice on the electric and other interdependent systems.

This allowed the team to conduct scenario analysis to ask more "what-if" questions. What if it is colder than forecasted? What if we invested in more cold weather packages? This crucial analysis and understanding of how extreme events can impact these systems and the well-being of citizens means we can work with industry stakeholders to invest, plan, and operate the grid through these types of events.

We have the research tools to guide solid decision-making at the national level. However, without regulatory, policy, and economic structures that bridge research and technical recommendations to reality, we will not be able to realize these solutions.

Current NREL-Supported Activities to Increase Grid Security and Resilience

Energy security and resilience are central to NREL's objective to develop integrated energy pathways. NREL-led work in this area primarily focuses on optimizing the safe and secure integration of renewables and energy storage, as well as controls and capabilities that support resilient operations. Much of this research happens in the Energy Systems Integration Facility, a DOE User Facility, and involves considerable participation from industry and grid operators.

Advanced Research on Integrated Energy Systems

NREL, in partnership with EERE, has developed a globally unique Advanced Research on Integrated Energy Systems (ARIES) research platform.

ARIES is designed to mirror the complexity and scale of real energy systems. Rather than evaluating new clean energy and energy efficiency technologies in silos, ARIES expands the research view to take in the full picture—from consumers to industry to utilities. This perspective uncovers opportunities and risks in the spaces where energy technologies and sectors like transportation, buildings, and the electric grid meet.

ARIES was specifically created to support the transition to a modern energy system that is clean, secure, resilient, reliable, and affordable. To get there will require new approaches to some fundamental challenges. These include coordinating many different types and sizes of energy technologies, securely controlling tens of millions of devices, and integrating diverse technologies with high amounts of renewable generation.

The ARIES platform is built to be highly flexible with the ability to plug-and-play different technologies into the core integrated system. This makes it possible to pivot and stay ahead of the rapidly evolving energy sector. It supports research of critical importance, including:

Energy storage – balance variable renewable generation and demand
Power electronics – operate and integrate rapidly increasing electronics-based technologies
Hybridization – achieve enhanced coordinated capabilities beyond isolated technologies
Infrastructure – adapt existing energy infrastructure for safety, monitoring, and controls
Cybersecurity – secure operations to prevent disruption, damage, and loss of functionality

The ARIES platform is a key tool to develop and validate energy resilience. The platform includes utility hardware—from wind turbines, solar PV and storage, to transmission lines and substations—augmented by high-performance computing and high-speed links to other DOE lab assets. All together, ARIES is a large sandbox to experiment with at-scale energy concepts such as microgrids, distribution system controls, integrated mobility, and resilience scenarios.

ARIES is also a unique capability to make progress in step with industry. As GMI mobilizes close collaboration between industry and the national labs, ARIES is the most high-power, high-impact research platform to support this work. ARIES connects industry with the equipment, modeling, and expertise needed to collaboratively design future energy systems that power the entire nation safely and sustainably.

Synchronous Interconnections

Through a series of multiyear studies, NREL has joined with national lab, university, and industry partners to evaluate the benefits and costs of options for continental transmission across the U.S. electric grid. These interconnections would create a more integrated power system that could drive economic growth and increase efficient development and use of the nation's abundant energy resources, including solar, wind, and natural gas.[2]

Currently, the three major components of the U.S. power system—the Western Interconnection, the Eastern Interconnection, and the Electric Reliability Council of Texas—operate almost independently of one another. Very little electricity is transferred between the interconnections due to limited transfer capacity. Our studies quantify the costs and benefits of strengthening the connections between these three interconnections to encourage efficient development and use of U.S. energy resources.

In one study looking at integrating the Western and Eastern Interconnections, the results show benefit-to-cost ratios reaching as high as 2.9. This indicates significant value to increasing the transmission capacity between the interconnections under the cases considered, realized through sharing generation resources and flexibility across regions. Further benefits can be realized through job creation and economic growth resulting from the required infrastructure build-out.

Work on related studies is continuing (including the North American Renewable Integration Study and Extreme Weather Event Analysis), focusing on a wider variety of scenarios and prioritizing resilience considerations.

New Operations for Diverse and Distributed Energy

One of the greatest challenges in grid modernization is the immense number of distributed energy resources that are interconnecting—and the degree of connectivity that will follow. Between electric vehicles, digital and interactive buildings, rooftop solar PV, and other resources, new energy devices could reach into the tens of millions in the near future. From a control perspective, we have never seen anything like this. From a resilience perspective, we want to know how these devices can contribute to a secure and stable power grid.

A major undertaking of GMI relates to modern controls that can leverage distributed energy resources, not only for behind-the-meter assets, but utility power plants that could include solar, wind, and storage. Compared to conventional operation, these new controls introduce resilience through adaptivity and distributed management, rather than centralized control—the advantage being that resources are aggregated, deployed, or more locally managed in real time for flexible and efficient power distribution. A couple examples of NREL-led work in this space are below:

- One GMI project, FAST-DERMS, is developing distributed controls that integrate with utilities' current management systems. These controls use real-time data from sensors and monitoring to support scalable management of energy storage and renewables, so they can provide bulk grid

[2] https://www.nrel.gov/docs/fy21osti/76850.pdf

services at least as well as conventional power plants. From the perspective of transmission system operators, these controls add flexibility without changing market operations.

- In another GMI project, FlexPower, NREL is leading a coalition of multiple laboratories and industry partners to validate hybrid power plants that combine solar, wind, and other resources with energy storage. Results from this project demonstrate how combined renewable assets can provide dispatchability[3] similar to conventional generation, improving grid reliability. In the case of this project, energy market regulation will need to advance to benefit from these findings.

Resilience Through Autonomous Systems

Within NREL, we have also been pioneering an all-new approach to power grid operations. The Autonomous Energy Systems research effort establishes a new foundation for grid organization based around dynamic microgrids. The idea is that dynamic reconfiguration can allow “cells” of the grid to island and secure their own power, or automatically reconnect to exchange power with other cells. Critically, this concept also addresses the challenge of controlling and optimizing millions of grid-connected devices. It overcomes complexity by breaking down the problem into manageable parts, built on an inherently resilient structure.

As part of the Autonomous Energy Systems effort, NREL researchers developed OptGrid, a product licensed by NREL that has industry-shifting potential to help manage today’s increasingly distributed energy infrastructure. OptGrid has been trialed in rigorous lab experiments and on real power systems, and it has emerged as a commercial solution for real-time coordination of distributed energy resources. OptGrid manages energy from the bottom up, using a distributed rather than centralized approach to control devices. This shift brings real-time management to the grid edge, where devices can be leveraged for flexibility, recovery, and energy savings.

OptGrid was developed under funding from Advanced Research Projects Agency-Energy, or ARPA-E, within the Network Optimized Distributed Energy Systems (NODES) program. NREL first deployed and field-tested the NODES algorithms at a net-zero-energy affordable housing development in Basalt Vista, Colorado, in partnership with Holy Cross Energy in 2019. This technology has led to an average 85% drop in residents’ utility bills. In March 2020, Utilidata announced that it had secured the rights to OptGrid, the software NREL developed from the NODES algorithms, and will commercialize it.

We continue to build out and evaluate these controls with partner utilities, which could localize the future of energy resilience in community-scale microgrids and their resources.

Microgrids as a Modern Foundation for Resilience

At a more applied level, NREL has supported the development of microgrids that are now proving to be reservoirs of power resilience.

- For example, in August 2020 during the California wildfires, several microgrids were able to independently provide power, or otherwise reduce bulk system load.[4] One of these microgrids,

[3] https://www.nrel.gov/news/features/2020/renewables-rescue-stability-as-the-grid-loses-spin.html
[4] https://microgridknowledge.com/california-blackouts-microgrids-flexible-load/

located in the remote and weather-battered town of Borrego Springs, California, remained islanded from the local utility and operated throughout the disaster using controls derived from NREL's Autonomous Energy Systems research. This demonstrates, even under the most trying conditions, how advanced microgrid controls and local assets can provide resilient power. The Borrego Springs microgrid project also demonstrates that high-renewable microgrids can be resilient, which helps to validate operations with a broader mix of assets that includes energy storage, electric vehicles, and customer devices.

- The U.S. Department of Defense (DOD) has led early adoption of microgrids, and through our partnership with DOD, we have refined the controls and operations for live microgrid systems. A microgrid at Marine Corps Air Station Miramar that was developed in partnership with NREL is another example of a live microgrid that provided resilience throughout the August wildfires by reducing power draw from the local utility and maintaining power for its community.[5]

- We recently faced our own microgrid scenario at NREL—after an onsite device failure, we successfully repowered our Flatirons campus using renewable energy assets, storage, and in-house controls.[6] This event points to the importance of microgrid capabilities and suggests our technical validations to date have provided a sophisticated understanding of microgrid operations.

With growing interest around this topic, we have also defined potential regulatory pathways forward for microgrids.[7]

These promising examples would suggest that a more widespread application of networked microgrids that combine storage and other renewable assets could reduce community exposure to damage or generation loss and hasten recovery following a disaster by providing reliable backup power. GMI and industry partnerships continue to be valuable resources for insight around integrating microgrids, as well as the Autonomous Energy Systems program and new efforts to deploy adaptive controls.

Cybersecure Systems

With the rise in new energy technologies that are driving system configurations, operating strategies, market structures, overseas supply chains, and business models, new cybersecurity vulnerabilities are emerging.

These trends will continue to underline three grand challenges, all of which have implications for system resilience:

- The exponential increase in control system devices that are being connected to the grid
- The rise in private or third-party owners of such assets who may not have a vested interest in cybersecurity
- The loss in control and knowledge of the technology supply chain.

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[5] https://www.nbcsandiego.com/news/local/mcas-miramar-helps-san-diego-combat-rolling-blackouts/2388878/
[6] https://www.nrel.gov/news/features/2020/an-unexpected-debut-aries-microgrid-infrastructure-powers-nrel-campus-through-outage.html
[7] https://www.tdworld.com/distributed-energy-resources/article/21131999/the-regulatory-path-forward-for-networked-microgrids

NREL considers these challenges opportunities for action, and continued investments in energy security and resilience will allow for innovation that hardens our grid against cyberattacks as well as disruptive weather.

Our researchers bring the unique expertise of renewable and increasingly distributed systems that are complex, autonomous, and built with greater resilience in mind. With our partners, we are looking at security solutions for future energy systems to expand situational awareness for highly distributed energy systems, dynamic power-communication systems emulation, cybersecurity standards and evaluation for distributed energy systems, and encryption technologies protecting the integrity of communication to and from new grid devices.

We're leading the development of the ARIES Cyber Range, which is powered by NREL's unique Cyber-Energy Emulation Platform (CEEP). With the ability to create entire energy systems in a virtual world, CEEP offers the safe exploration of cyber vulnerabilities and mitigation strategies—and it can support workforce development and training for growth in grid resilience and cyber defense jobs. CEEP is integrated with physical grid and cyber assets in the vast ARIES experimental platform to provide validation and ground truth in cyberattack scenarios.

But there is a lot more work to do. More investments will be needed for innovation, public-private cyber defense coordination, and workforce development focused on the security of future renewable and distributed energy systems.

We recognize a need to expand vulnerability assessments of future grid systems that can prioritize strategic innovation development. Within this space, NREL is leading a public-private partnership with the wind industry to coordinate and improve cyber defense for bulk power wind, but our vision is to bring this effort to every renewable energy sector. Current cybersecurity strategies applied to the bulk power systems will need to be improved or augmented if we're going to be successful in addressing the unique challenges we anticipate as the grid transforms to adopt more modern critical infrastructure.

The following offers a sample of additional projects and collaboration that highlight our efforts to enhance national energy security.

- ***Device-Level Security with Firmware Command and Control:*** As part of GMLC, NREL is collaborating with Argonne National Laboratory, Idaho National Laboratory, and Sandia National Laboratories to investigate the security of internal software in devices interacting with the grid. This project contributes to the state of the art in firmware research by gaining insight into embedded systems operations, evaluating operations through detection and remediation, response and detection based on machine-learning-firmware code behaviours, and connectivity to upstream data analytics.

- ***Blockchain for Optimized Security and Energy Management (BLOSEM):*** BLOSEM is a GMLC collaboration that aims to de-risk blockchain-based concepts through standardized metrics and cross-sector guidance. The team is exploring how blockchain can enable authentication of operating parameters for generation assets, secure communications for accessing and balancing demand response, secure market operations at the distribution level, and secure registration and authentication of distributed energy resources.

Situational Awareness of Grid Anomalies: With support from CESER, NREL is working with industry partner CableLabs on advanced electric grid data analytics and visualization for situational awareness of grid activity. The project is developing a method for cyber-physical anomaly detection so that early warning is possible for weather- or cyber-induced outages, safety violations, and economic disruption.

Resilience Planning and Recovery – Costs and Benefits, Technoeconomic Analysis

Rooted in disaster recovery, NREL researchers have learned first-hand what systems do and do not work during and after different disruptive events. We've developed replicable methodologies for assessing resilience postures and are developing quantifiable frameworks to model resilience metrics.

Understanding the nuances of power system vulnerabilities and how to finance resilience solutions has historically been a barrier for implementing resilient systems. Our research is working to overcome those barriers through robust energy modeling to further knowledge in this space. We build on our capabilities of visualizing, modeling, and developing tools to create a suite of resources for stakeholders to understand the greatest risks to their systems and operations and create a portfolio of mitigation and resilience solutions that apply to their specific context. These resources include the following:

- ***Proven Resilience Assessment Methodology:*** NREL researchers applied decades of lessons learned from disaster recovery technical assistance to develop a qualitative and quantitative approach to resilience assessments and planning. Historically, resilience assessment efforts external to NREL provide insight into where vulnerabilities exist but do not offer solutions. The methodology NREL developed establishes a baseline; identifies potential hazards, threats and vulnerabilities; and assigns scores to assess the highest risks. The methodology has been developed into a series of tools which also offer options to reduce the exposure or consequence of each potential vulnerability. Applying this methodology to grid systems can further enable resilience planning efforts.

  Resilience Planning – Costs and Benefits: An NREL-developed framework provides a methodology to determine the value of multiple resilience metrics (e.g., number of hours without power, potential business lost during an outage) over time and assign costs and values to those metrics. NREL has used this framework to provide site resilience assessments to partners and has incorporated it into the techno-economic analysis tool REopt, which is used for decision support in renewable energy projects. As we build the power system of the future and seek strategies for improving resilience, integrating the value of resilience into investment and operational decisions is critical. Though no one metric will cover all resilience planning needs, measuring the benefits of resilience investments, along with establishing valuation methodologies for such measures, will help enhance our ability to monetize investments associated with a more resilient electricity supply.[8]

- ***REopt:*** DOE's Federal Energy Management Program (FEMP) supported the development of REopt, a suite of tools that helps federal and private-sector decision makers make informed decisions about energy system investments. Developed to assess the technical, economic, and resilience benefits of energy investments, the REopt suite of tools is available as a free, online

[8] https://www.nrel.gov/docs/fy19osti/74673.pdf

tool, REopt Lite, and as open-source software for academia and the private-sector to improve upon.

- ***Technical Resilience Navigator:*** Another resource for energy system resilience planning is the Technical Resilience Navigator, developed for FEMP to identify risks and resilience opportunities for federal sites and their critical loads. The Technical Resilience Navigator leads users through resilience assessments that depend on site-specific load, risks, or other hazards, and proposes strategies to improve resilience.

Next Steps: Strengthening and Expanding Capabilities To Establish More Resilient Energy Systems

Our greatest capabilities to establish energy system resilience already exist: They are the combined national lab network, NREL's state-of-the-art ARIES research platform for integrated large-scale studies, and an engaged group of industry collaborators who are pushing the frontier of energy innovations.

Still, we've only just opened the door to many new research directions. Our capabilities are poised to reach even higher limits in designing and evaluating resilient systems. Unlike anything before, we are now able to study full-scale power systems in a controlled environment and look beyond to future energy scenarios.

Large-Scale Energy Transitions

Complementing the experimental scope of ARIES, we have the capacity to analyze energy systems and future scenarios in unprecedented detail, powered by high-performance computing and the combined simulation resources of multiple national labs. Through studies like the following, we can uncover the specific impacts of future market possibilities, or technological changes, and their effects on an energy system's resilience:

- ***The Los Angeles 100% Renewable Energy Study,*** or LA100, provides rigorous engineering-economic analysis of the Los Angeles energy system to support the city in its long-term planning.[9] Following the lead of LA100, large urban areas can answer essential questions about their integration options. As resilience is always the result of multiple factors, this level of detail and computational ability can express the principal components behind a community's resilience.

- ***Dallas-Fort Worth Airport:*** ARIES is also being used for a project in Texas to optimize the Dallas Fort-Worth airport's transportation and energy systems.[10] Along with more than a dozen collaborators, NREL is using ARIES to build a digital twin of the airport's energy system, including its complex transportation dynamics. Transportation hubs like DFW—one of the largest in the world—will continue to undergo energy transitions and understanding their investment options will be essential to maximize efficiency and resilience. NREL and national lab capabilities are now equipped to perform such integrated studies.

As mentioned, our resources for addressing "what-if" questions will be key for making informed progress. NAERM is our single most comprehensive capability to address national resilience, and there is

[9] https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study.html
[10] https://www.athena-mobility.org/

room to build this tool out further to capture deeper dynamics while becoming more functional for grid operators and planners. Our “what-if” resources can look ahead and deliver projections around electrification[11]or integrated mobility to reveal nationwide opportunities for energy security and resilience.

Summary of Key Takeaways and Research Needs for a Resilient Power System

- The February 2021 blackouts in Texas are another opportunity to explore how we can increase resilience of the U.S. electric infrastructure.
- A better understanding of extreme events and their impact on the complete power system, including interdependencies with other infrastructures, is necessary.
- DOE and the national lab complex have the capabilities and facilities to help the nation address its grid resilience challenges.
- DOE and the national laboratory system have significant simulation and analysis capabilities, such as the North American Energy Resilience Model, that can help understand the impacts of extreme events.

A variety of research needs should be investigated to help us prepare for transitioning to a future clean energy grid. These include:

- New methods to improve community preparation for, and response to, large-area, long-duration electricity interruptions, including through the use of energy efficiency, storage, and distributed generation technologies
- Technologies and capabilities to withstand and address the current and projected impact of the changing climate on energy sector infrastructure, including extreme weather events and other natural disasters
- Innovations to use distributed energy resources, such as solar photovoltaics, energy storage systems, electric vehicles, and microgrids, to improve grid and critical end-user resilience
- Advanced monitoring, analytics, operation, and controls of electric grid systems to improve electric grid resilience
- Analysis of technologies, methods, and concepts that can improve community resilience and survivability of frequent or long-duration power outages
- Advanced power flow control systems and components to improve electric grid resilience
- Methodologies to maintain cybersecurity at all times and especially during restoration of energy sector infrastructure and operation
- Consensus-based best practices to improve cybersecurity for distributed energy resources, including generation, storage, electric vehicles, and electric vehicle chargers
- A deeper exploration of resilience science to track resilience parameters of a system and provide the foundational principles to engineer more inherently resilient systems at a reasonable cost
- An integrated framework for cyber-resilience in the design and operation of autonomous energy grids, to include self-healing and self-optimizing communication networks; autonomous decision-making under adverse cyber events; and zero-trust architectures with new algorithms, methods, and tools.

[11] https://www.nrel.gov/analysis/electrification-futures.html

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.

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Mr. Juan Torres is the Associate Laboratory Director for Energy Systems Integration at the National Renewable Energy Laboratory. In this role, he oversees NREL's research to modernize and strengthen the security, resilience and sustainability of the nation's electrical grid. Mr. Torres is Co-Chair for the Department of Energy's Grid Modernization Laboratory Consortium (GMLC), a partnership of 14 national laboratories to advance modernization of the U.S. power grid. In July 2019, Mr. Torres provided testimony to the Energy Subcommittee of the U.S. House of Representatives Committee on Science, Space, & Technology on modernizing and securing our nation's electricity grid. In 2018, Mr. Torres provided testimony to the U.S. Senate Energy and Natural Resources Committee on the topic of blackstart, the process of returning energy to the power grid after a system-wide blackout.

Prior to joining NREL in June 2017, Torres served in a variety of technical and management positions throughout his 27-year career at Sandia National Laboratories, most recently as deputy to Sandia's vice president for Energy and Climate programs. At Sandia, Mr. Torres led research efforts and vulnerability assessments in cybersecurity, guided research in advanced microgrid and renewable energy, and led the security and resilience team under the DOE's GMLC efforts. In 2004, Mr. Torres co-led the establishment of the DOE National SCADA Test Bed to secure power grid control systems from cyber attack. In 1998, Mr. Torres served as a member of the DOE task force that developed a national plan to secure the U.S. energy infrastructure in response to PDD-63 Critical Infrastructure Protection. From 1993-1995, Mr. Torres served as Sandia's engineering liaison to the Air Force Materiel Command at Peterson Air Force Base, CO, for development and deployment of mobile command and control systems in support of US Space Command and NORAD missions.

Mr. Torres holds a bachelor's degree in electronics engineering technology from the University of Southern Colorado, a master's degree in electrical engineering from the University of New Mexico, and has completed additional graduate work in Management Science and Engineering at Stanford University.