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Good morning. Thank you, Senator Cantwell, and Members of the Committee. I appreciate the opportunity to appear before you today to discuss grid resilience and emergency response.

My name is Carl Imhoff, and I lead the Grid Research Program at the Pacific Northwest National Laboratory (PNNL), a Department of Energy (DOE) national laboratory located in Richland, Washington. I also serve as the Co-Chair of DOE's Grid Modernization Laboratory Consortium, a team of national labs that, along with industry and university partners, supports the Department's Grid Modernization Initiative. The consortium members include PNNL, the National Renewable Energy National Laboratory, Sandia National Laboratories, Oak Ridge National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, Idaho National Laboratory, Argonne National Laboratory, the National Energy Technology Laboratory, Savannah River National Laboratory, Lawrence Livermore National Laboratory and the National Accelerator Laboratory at Stanford.

For more than two decades, PNNL has supported power system resilience and innovation for the State of Washington, the Pacific Northwest, and the nation. Over this period, the laboratory has led DOE-industry collaborations in developing and deploying synchrophasor technology to help avoid blackouts, and developed and demonstrated transactive control concepts on the Olympic Peninsula in Washington and for the Pacific Northwest Smart Grid Demonstration project—the largest of its kind—to validate smart grid benefits and new control approaches that engage demand and distributed resources at scale. PNNL also delivered the first applications of high performance computing to deliver contingency analysis for the grid in minutes versus days, as well as the first real-time dynamic state estimation to open the door to the future world of predictive grid tools.

Based upon PNNL's extensive experience and leadership in grid research, today I offer two recommendations to enhance the resilience and reliability of our nation's power grid:

1. Improve and deliver real-time tools for situational awareness, risk assessment, and grid operations that transform our nation's capacity to assess risk and to mitigate outages caused by any hazard.

2. Advance emergency response capabilities to enhance regional and local planning and preparation for large scale disaster recovery (such as possible Cascadia seismic events).

Necessity of New Tools for Grid Resilience

The power system of the future will face substantially different challenges and risks than in the past. Today we have well-documented evidence of increased weather impacts, with both the frequency and magnitude of storms increasing. We also see increased interdependencies between grid systems and other critical infrastructures such as the natural gas pipeline system, communications systems, and emerging market models being developed to support clean distributed energy generation. In addition, increased use of digital technology is transforming the availability of new customer services and choice, while at the same time increasing the cyber security challenge.

A modernized grid that addresses these future grid challenges must enhance emergency preparedness and response in three areas:

1. Improved grid flexibility and resilience that reduces the risk and need for emergency response.

2. Real-time tools and system visibility to reduce the scope of outages, shorten the time utilities need to identify outage locations, and optimize restoration planning to get the lights back on more quickly.

3. Improved planning tools that handle the complexity of variable generation, new markets, and changing business models to improve emergency response planning at the local and regional level, particularly for extreme events such as seismic and weather emergencies.

Recommendations for delivering these modernized grid benefits follow.

Improve and deliver real-time tools for situational awareness and grid protection

Delivering real-time tools to better assess risk and operate the electric system will help operators better understand the risks they face and options to avoid outages with accuracy far beyond current practice. An example is the 2003 Northeast blackout. If the synchrophasor system of today had been in place then, operators would have had just over one-and-a-half hours advanced warning that Cleveland was separating from the Eastern Interconnect. The likely outcome would have been a much smaller blackout and faster recovery. A modernized grid reduces the likelihood for emergency response measures and supports faster recovery should an emergency strike.

Increasing efficacy and accuracy in planning and operating the grid enables utilities to better prepare for emergencies of all kinds, and be more nimble in response, with the goal of reducing the extent and duration of outages. Let me share a few efforts underway in the DOE Grid Modernization Initiative:

1. To better enable system planning and protection, DOE's Office of Electricity Deliverability and Energy Reliability (OE) commissioned the development of a new tool to assess the risk of extremely rare but large cascading outages, which are grid blackouts that start with a single failure but quickly ripple out to drop large portions of a regional system. This tool allows grid operators to better enable system planning and protection. PNNL worked with the Electric Reliability Council of Texas, Siemens and the Electric Power Research Institute (EPRI) to develop an extreme event tool that transformed such analyses, and better prepares the industry to respond to the North American Electric Reliability Corporation (NERC) standards requiring better planning for extreme cascading outages. This tool is an open source resource that is scalable for use of advanced computation, positioning it for broad industry use in the case of extremely large, complex outage scenarios. The end result will be much improved risk assessment and planning, leading presumably to fewer large outages such as the 2003 event in the Northeast.

2. Another opportunity for enhancing emergency response is improving wide-area risk assessment of the power system through contingency analysis. Today, power flow simulations are conducted to identify and rank *all* system risks to enable operators to address *key* system risks. This analysis typically requires one or more days at the interconnection level. With high performance computing platforms, PNNL has accelerated contingency analysis to reduce the computation time from days to seconds. In the case of the Western Interconnection, this method cut the computation run time from 26 hours to 7 seconds. This improvement gives operators near real-time situational awareness of risks and options to mitigate these risks. Experiments in PNNL's control room with grid operators showed a 30 percent improvement in operator diagnosis of test outage scenarios using this new approach.

In addition, grid flexibility is an important new development in managing the grid in real time. This flexibility enables the system to better protect against threats and recover more quickly. One example of providing greater grid flexibility to improve grid reliability, resiliency and renewable integration is the development and full-scale deployment of grid scale energy storage. Key to enabling wide spread deployment of energy storage, for multiple grid applications, is to realize a significant reduction in the lifecycle cost of the energy storage systems and validation of the value proposition for multiple grid applications. To reduce energy storage costs, while improving lifecycle performance, PNNL is actively engaged in research in both the discovery and development of next generation energy storage materials. Early PNNL R&D advances have been licensed to several companies, including UniEnergy Technologies, which is located Washington State and is deploying stationary flow batteries for grid scale applications globally. Through DOE and Washington State Clean Energy Funding, PNNL is partnered with Avista Utilities, Snohomish Public Utility District and Puget Sound Energy to validate performance and use-cases for field deployed energy storage technologies. At the national level, PNNL is partnered with Sandia National Laboratories, Argonne National Laboratory, Lawrence Berkeley National Laboratory, Idaho National Laboratory, Brookhaven

National Laboratory and several universities to advance energy storage technologies.

A second example of enhancing grid flexibility is advanced distributed control theory and concepts that enable distributed energy resource (DER) technologies to be integrated at scale across the grid in a way that assures continued reliability, improved resilience, and lower carbon emissions. Transactive control concepts, a blending of traditional and economic incentives to engage distributed resources, have been demonstrated in the Pacific Northwest Smart Grid Demonstration project, which was co-funded by DOE. These concepts are being extended in the Clean Energy and Transactive Campus project, a partnership with DOE and the Washington State Department of Commerce. Taking place at PNNL, the University of Washington and Washington State University, this project will help demonstrate the benefit of demand-side controls across multiple buildings that can provide load flexibility to reduce peak demand and support ramping of renewable energy resources. Finally, the Grid Modernization Laboratory Consortium portfolio includes research on grid architecture and distributed control to further advance the theory and practice of distributed control for a modern grid. This will support improved flexibility by enabling local resources to provide grid services during times of grid stress, such as coordination of multiple micro grids.

Advance emergency response capabilities

PNNL supports DOE's Office of Infrastructure Security and Energy Restoration (ISER) and other federal agencies in their respective energy emergency response functions through the development of technologies and processes to aid the response and recovery to grid interruptions. PNNL is launching an effort to support ISER with its situational awareness capabilities during national emergencies through the automated analysis of digital satellite imagery to quickly assess infrastructure damage, and is also providing improved platforms for the communication of damage assessments and restoration challenges, through its Electricity Infrastructure Operations Center.

PNNL is assisting the electric industry, through NERC, with the deployment of tools and processes to assess the vulnerabilities in their systems and correct them. In the past year, PNNL helped NERC develop the first-ever Design Basis Threat for the electric industry, which is now being rolled out to industry to guide them in prioritizing threats and improving the protection of critical assets.

Additionally, PNNL has been working with another federal sponsor on a grid restoration framework, based upon the Cascadia Subduction Zone scenario, which details the roles, responsibilities, and requirements of the multitude of government agencies and electrical industry service providers in the Northwest.

And finally, PNNL is working with ISER to provide real-time assessment support and expertise during national emergencies through visualization and communication platforms Through established partnership with the HAMMER Federal Training Center in Richland, Washington, PNNL technologies are being transitioned to real-life applications through HAMMER's emergency response training of ISER responders.

Grid Cyber Resilience

Cyber security is a critical element of all grid-related efforts. PNNL developed the Cyber Risk Information Sharing Program (CRISP) with DOE and is now supporting NERC in the deployment of the program to utilities nationwide. The CRISP program coordinates information sharing between industry and with federal agencies to ensure rapid dissemination of cyber threats and possible remedies. By the end of September 2016, CRISP is expected to cover the utilities that generate 75 percent of the country's power. PNNL is also directly involved in designing and delivering national cyber response exercises, such as GridEX, to better train stakeholders in handling potential cyber events on the grid.

Conclusion

In conclusion, a modernized grid will substantially enhance our ability to see and operate the nation's power system in real time, enabling grid operators to better avoid outages and reduce the extent and duration of those outages that do occur. Advanced planning tools that handle the complexities of the future grid will also improve the assessment of risk for extreme events, improving emergency response planning and implementation.

With these advanced tools developed and deployed, it is important to directly support emergency response agencies with data, situational awareness and analytic tools to help them better assess risk, plan for response, assessment of damage, and on the ground response efforts.

Thank you for the opportunity to provide the Committee with information on the work PNNL and the Grid Modernization Laboratory Consortium are doing in this important area. I would be happy to answer any questions you may have.