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Good morning. Thank you Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee. I appreciate the opportunity to appear before you today to discuss U.S. energy infrastructure challenges and opportunities.

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 Chair of DOE's Grid Modernization Laboratory Consortium, a team of national labs that, along with industry, industry groups such as the Gridwise Alliance and Electric Power Research Institute (EPRI), 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 reliability and innovation for the State of Washington, the Pacific Northwest, and the nation. Over this period, the laboratory has:

1. Led DOE-industry collaborations in developing and deploying synchrophasor technology to help avoid blackouts. Phasor measurement unit networks are designed to enhance situational awareness of wide area systems. This new grid tool has demonstrated value by detecting impending system control and equipment faults for system operators thus avoiding major outages. In California, avoided outages resulted in an estimated $360 million annual savings to customers, and $90 million annual savings were the result of improved utilization of existing generation and delivery systems. In east Texas, phasor measurement units enabled Entergy to respond to major storm outages by synchronizing a temporary electrical island to reduce outages during the recovery. The Bonneville Power Administration has demonstrated savings of $400,000 on average for testing generator controls settings on the Columbia Generating Station, an 1100 megawatt nuclear reactor in Washington State, without requiring a plant shutdown.

2. Led a public-private collaboration with utilities and vendors to develop and demonstrate 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. Example outcomes include Avista Corporation implementing distribution automation and smart metering pilots that delivered a 10 percent reduction in customer outages, reduced consumer outage durations by 21 percent and resulted in 1.5 million avoided outage minutes between April 2015 and April 2016. Avista also saved 42,000 megawatt hours in 12 months. Idaho Falls Power implemented transactive control of end uses and utilized the concept to minimize customers' outages during an extreme winter storm when western system operators were calling for emergency load reductions.

3. Delivered the first applications of high performance computing to grid tools such as interconnection-scale contingency analysis, reducing run times from days to under two minutes. PNNL also applied high performance computing and phasor measurement unit data to deliver the first real-time dynamic state estimation to open the door to the future world of predictive grid tools. This parallelized state estimator tool enabled PNNL to meet an ARPA-E challenge to reduce dynamic line rating calculations from 24 hours to 10 minutes, creating the potential to operate the system with much higher asset utilization.

These examples illustrate the high return on investment encountered by utilities and national labs across the country when combining new electric infrastructure innovation with public-private validation and deployment.

The DOE Grid Modernization Initiative is an important source of innovation for the national efforts to modernize energy infrastructure. The Initiative is a DOE-wide effort across multiple program offices to accelerate the development of technology, modeling analysis, tools, and frameworks to enable grid modernization adoption. As a key component of this initiative, the Grid Modernization Laboratory Consortium is working closely with partners in industry, academia, and cities and states to deliver on the objectives outlined in DOE's Grid Modernization Multiyear Program Plan. These integrated efforts will deliver new concepts, tools, platforms, and technologies to better measure, analyze, predict, and control the grid of the future. The federal role is to invest in high risk research and then collaborate with vendors, utilities and state/regional regulatory entities to provide the tools and data and demonstration support. This accelerates the development of lessons learned and data that support states and utilities to develop business cases for their grid modernization efforts. The inaugural peer review for this effort is scheduled for April 18-20 in Arlington, VA and is open to the public. I respectfully request that the appended fact sheet on the Grid Modernization Laboratory Consortium be entered into the record along with my written testimony.

Today I will address three main points:

1. The electric sector is fundamental to a secure, robust and vibrant energy infrastructure, and it is comprised of assets beyond concrete and steel.

2. Electric infrastructure is changing dramatically due to technology and economic drivers. Plans for energy infrastructure modernization must account for a significantly different electric infrastructure over the next decade.

3. Opportunities exist to leverage technology innovation and public-private partnership to enhance the energy infrastructure modernization efforts.

Electric Power System is Vital to U.S. Energy Infrastructure

The electric grid infrastructure spans the nation providing essential services to the U.S. economy. It entails 640,000 miles of transmission lines and 6.3 million miles of distribution lines serving over 19,000 electric generators and is over one megawatt in size, ultimately engaging virtually all Americans via over 3,500 utilities. It also includes small, remote communities that must provide their own electric services, predominantly through local diesel generation and microgrids. The digital revolution is increasing the role that electricity plays in our gross domestic product, and the emergence of smart grid concepts and new advanced generation concepts is unleashing new opportunities for consumer services and choice.

But there is more to the electric infrastructure than cables, towers and generators. Utilities rely increasingly on major control centers to coordinate and operate the power system, requiring substantial investment in software systems, communications and controls. Sensor networks that provide real-time sensing both locally and across entire interconnections are emerging to dramatically improve reliability and asset management. Locally, over 64 million smart meters deliver advanced services to consumers and utilities. At the interconnection level, a fleet of high resolution phasor measurement units has recently been installed that provide unparalleled insights on real-time grid health protect against blackouts. Over 2000 of these devices are now networked across the North American grid, providing unparalleled system observability and a key new tool for delivering increased reliability of the high voltage system. High voltage transmission systems include complex control systems necessary to protect the system from damage during outages. Finally, utilities, vendors, universities and laboratories maintain a network of research and testing infrastructure necessary to support the health and revitalization of the electric infrastructure.

Major Forces of Change Facing the Electric Infrastructure

Recent industry trends are increasing the interdependence of traditional power system infrastructure with other critical infrastructures.

- Abundant, low cost natural gas generation has dominated new centralized generation additions, creating a growing dependence on the reliability of natural gas supply to electricity generators. System operators are modifying risk management and planning practices to reflect the important role that natural gas infrastructure plays in grid reliability.

- The advent of smart grid concepts and advanced system controls has dramatically increased the role of communications networks in power systems.

- Recent trends in extreme weather events including heat waves and droughts point to increased importance in the interaction of electric generation infrastructure and water infrastructure planning and operations.

This growing interdependence of the grid with other critical infrastructures dictates that modernization policy should address these infrastructures collectively.

In addition to growing interdependency across multiple critical infrastructures, changes in electric generation technology, grid controls, customer energy management systems and information technology are collectively reshaping utility business models and enabling new innovations and market participants. It is essential that plans for electric infrastructure modernization target the future power system as opposed to current system design and concepts.

Let me highlight a few of the main changes underway:

- The revolution in intelligent devices is creating an explosion of connected devices at the grid edge that will strongly influence the electric infrastructure; utilities expect over 20 billion intelligent devices to be connected at the grid edge by 2025, many of which will be on the customer side of the meter.

- The emergence of distributed energy resources is accelerating, including distributed generation (e.g. photovoltaics), smart loads and demand response, electric vehicles and energy storage.

- Renewable generation has increased significantly, providing more variable generation on the system and driving changes in the approaches for planning system expansion and operations.

- Potential new business models for the distribution system are being considered in states and regions as a potential response to the opportunities for distributed energy resources and pressures on the current utility business model. Commissions in New York, California, Hawaii, Minnesota, and Washington, D.C. are engaged with DOE and national labs now; new discussions are just starting with Ohio and North Carolina. This collective effort is exploring new models for distribution system platforms, with a focus on the objectives, functions, and components for distribution system planning, grid operations, and distributed energy resource markets.

- The proliferation of internet and digital devices throughout our economy has increased the challenges of cyber-attack on the electric infrastructure. The electric grid is under regular reconnaissance and cyber-attack activities from both foreign state and non-state actors. The electric industry, in partnership with government, has responded strongly to address these challenges, including by improving best practices through self-assessment and launching the Electric Sector Coordinating Council to coordinate and prioritize national cyber resilience of the electric sector

In addition, PNNL developed the Cyber Risk Information Sharing Program (CRISP) with DOE and is now supporting the North American Electric Reliability Corporation (NERC) in the deployment of the program to utilities nationwide. The CRISP program is a collaboration with utilities to provide cyber threat intelligence to identify tactics, techniques, and procedures used by advanced threat actors from nation states as well as aspirational or professional hackers. This analytic capability is made possible by the unique partnership between the U.S. government and private sector partners. Currently CRISP participants represent over 60 percent of the total bulk energy transmission infrastructure in the nation. The program is actively engaging new participants with the goal of expanding this coverage to 70 percent of the bulk energy transmission by the end of 2017.

Suggested Technical Recommendations to Support Energy Infrastructure Modernization

As the Committee considers the needs of grid infrastructure, I offer the following technical suggestions.

1. **Account for interdependencies across multiple critical infrastructures** (e.g. electric, natural gas, communications, water, emergency response etc.) when defining an energy infrastructure modernization strategy. This could include:
    a. Leveraging the emerging Grid Modernization Laboratory Consortium Consensus Grid Architecture work to identify and prioritize interdependencies to support planning at the federal, regional and state levels.
    b. Utilizing emerging high performance planning tools, valuation tools and grid modernization metrics from Consortium to aid in infrastructure planning at state, regional, interconnection and national level.

2. **Include "grid flexibility" as an important attribute in energy infrastructure investments to accommodate the dramatic changes in the electric system.** Given the multi-decade lifetime of most energy infrastructure projects, planning efforts must include "grid flexibility" in the planning process for infrastructure improvements. Grid flexibility means the capacity of grid resources such as generators and responsive demand, to provide fast response—both up and down in supply or load—to help the system adapt to variable generation, requirements for frequency or voltage support etc. The benefits to the nation would include increased capacity to manage increasing distributed energy resources such as renewable generation and demand response, improved resilience to grid outages—caused by all hazards— and improved emergency response and recovery.

3. **Leverage recent successful results in recent public-private demonstrations of distribution system modernization to jumpstart electric infrastructure modernization** that will directly improve consumer service and add quality jobs to the economy. These include distribution automation, advanced metering, conservation voltage reduction, and use of Distribution Management System software control systems. Today the majority of utilities still depend on customer phone calls to alert an outage. Rapid modernization of distributions systems can make a significant difference as already demonstrated in successful public-private demonstrations in all regions of the country. These completed projects, in concert with new planning tools from the GMLC and grid data repositories being developed by ARPA-E, offer lessons learned and tools that can help the utilities balance their plan and implement upgrades that make sense for their customers.

4. **Use emerging high performance planning and risk assessment tools to augment current practice to mitigate risks from system threats.** This could include:
    a. Accelerating industry utilization of DOE's new dynamic contingency analysis toolset to improve planning for mitigation of large dynamic cascading outages.
    b. Extending recent DOE/NERC efforts in use of "design basis threat" tools to better plan physical security of energy infrastructure.
    c. Supporting extension of self-assessment tools, training and information to mid-sized and small utilities to broaden the cyber resilience of the entire utility industry.

5. **Consider the use of public/private partnerships to conduct infrastructure pilots at the regional level**. These pilots can rapidly validate the emerging new modernization concepts and tools emerging from industry, the DOE research portfolio and elsewhere.

Traditionally, energy infrastructure is thought of as the energy generation and delivery system, such as the electric grid and the various means associated with transporting energy. However, it is important to note that creating the means to move energy requires smart scientists and engineers—which we have, including at our national laboratories—and modern laboratory space and equipment, which faces a significant backlog in infrastructure investment. The DOE Office of Science's Science Laboratories Infrastructure program supports science and technological innovation at national laboratories by funding and sustaining mission-ready infrastructure. It is this mission-ready infrastructure that enables the national laboratories to collaborate with academia and industry to solve our nation's most pressing challenges, including regarding the electric grid.

In conclusion, the electric grid is a critical component of our nation's infrastructure and economy. Infrastructure investments are required to integrate the connected nature of our economy and energy resources and to transition to the grid of the future. Should Congress make such investments, it is important to look forward in grid infrastructure planning to ensure grid flexibility and other traits that will continue to advance our economy as the grid is modernized.

Physical and cyber security of the grid will remain a critical issue into the foreseeable future, and any infrastructure investments must consider these challenges to ensure the resiliency of the grid.

The work of DOE’s Grid Modernization Initiative and Grid Modernization Laboratory Consortium is designed to address these and other challenges associated with grid modernization. I appreciate the opportunity to discuss this important issue with you today, and I am happy to answer your questions. Thank you.