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Chairman Weber, Ranking Member Veasey, members of the Subcommittee, thank you for this opportunity to address future research opportunities for the United States' electric grid and to describe the many benefits and reduced risks that would result from a more integrated, resilient, and modernized grid infrastructure.

My name is John Sarrao, and I am the Principal Associate Director for Science, Technology & Engineering at Los Alamos National Laboratory in Los Alamos, New Mexico. I have spent my entire professional career at Los Alamos. Prior to being appointed to my current role in April, 2018, I was Los Alamos' Associate Laboratory Director for Theory, Simulation, and Computation for the prior five years. I hold a Doctorate in Physics from the University of California, Los Angeles. My personal research and technical leadership career has emphasized national security science from plutonium physics research to advanced materials design and discovery to stewarding Los Alamos' high performance computing resources and simulation capabilities. Energy security is a national security priority, and Los Alamos National Laboratory has contributed meaningfully to energy security in general and grid resilience research in specific for many years.

Why Grid Research at Los Alamos National Laboratory

Los Alamos has a 75-year tradition of solving complex national security challenges using an interdisciplinary, team-based approach, providing solutions to decision makers. Our work in infrastructure analysis and grid research exemplifies this approach and includes our role in the National Infrastructure Simulation and Analysis Center supported by the Department of Homeland Security. Further, exercising and expanding our capabilities in these areas directly contributes to the successful performance of our core mission in stewarding the United States' nuclear deterrent.

The challenges that today's domestic electricity grid faces include the need for i) enhanced resilience, against both natural events and external actors, ii) robust optimization and control capability for integrating renewables, and iii) expanded tools for grid operators to detect anomalies, including the effective utilization of machine learning methods.

In responding to these challenges Los Alamos brings expertise in physics and engineering, applied math and statistics, and simulation and computation. We further have a proven track record of providing mission-centric reach-back expertise in weapons physics and design, including weapons effects; high-fidelity and multi-scale earth systems modeling; and space science and space weather capabilities.

Finally, Los Alamos is deeply committed to workforce development and idea dissemination, hosting a regular "Grid Science Winter School and Conference" to help educate and expand the grid research community.

To support these efforts, Los Alamos has launched the Advanced Network Science Initiative (ANSI). ANSI is designed to facilitate cross-project basic and applied research that is focused on modeling and understanding the nation's critical infrastructures, such as electric power, water, petroleum and natural gas. The initiative's expertise includes statistics, stochastic methods, machine learning, control theory, dynamical systems, discrete and continuous optimization, statistical physics, and graphical modeling. The interdisciplinary nature of ANSI ensures the scientific and technological validity of our approaches by working closely with physicists, engineers, mathematicians, statisticians, computer scientists, and economists through connections with industry, academia, and other national laboratories.

A few recent examples of Los Alamos' contributions to national energy security challenges include:

- Solar Geomagnetic Disturbances (GMD) and the science of transmission standards
    - Critical input from LANL into FERC Order 830 on GMD standards.
    - LANL's contribution called out individually by Commissioner La Fleur in Order 830
    - Working directly with industry groups (EPRI) to improve updates planning standards

- Nuclear electromagnetic pulse (EMP) effects; clarifying the threat to US power systems
    - Leading joint Department of Energy and Department of Homeland Security study to characterize nuclear EMP impacts
    - Leading interagency study to determine foreign nuclear EMP threats and impacts
    - Working directly with industry groups (EPRI) to improve modeling and simulation

- Natural Gas-Electric Power Joint Reliability—Complex reliability assessments of Southern California's coupled energy system during Aliso Canyon outage
    - Jointly worked with CaISO, SoCal Gas, and California Public Utility Commission (CPUC) to resolve complex analysis issues
    - Provided official testimony to CPUC proceedings on Aliso Canyon

Successes of the Grid Modernization Laboratory Consortium

Given our demonstrated history in infrastructure analysis and grid research, Los Alamos was excited to participate in the Grid Modernization Laboratory Consortium (GMLC), beginning in fiscal year 2016. While there were naturally some growing pains in the initial definition of GMLC, the initiative has allowed a number of National Laboratories to work together, bringing their complementary capabilities to bear on key challenges and delivering positive impacts for our electricity grid.

While the respective National Laboratories have complementary capabilities – and this diversity is a strength of GMLC, they also previously competed with each other in some areas of grid research. As such, an early aspect of GMLC formulation was educating each other on our respective approaches to technical challenges. Initially, this can slow progress and lead to a lowest-common-denominator research approach. Fortunately, GMLC's use of peer review has ensured the best ideas are brought forward and implemented quickly.

As a measure of the success of GMLC, not only are new multi-Laboratory teams working together to address grid research challenges, but also these newly formed and GMLC-inspired teams are collaborating in broader areas of research beyond the initial scope of GMLC.

Future Challenges and Opportunities for Grid Research

As we look to the future of grid research, both under the auspices of GMLC and more broadly, Los Alamos sees several important challenges that need to be addressed.

Complex Threats to US Power Systems—US power systems are potentially vulnerable to large-scale impacts from complex threats including geomagnetic disturbances and EMP from high-altitude nuclear detonation. Our understanding of the science underlying the components of these threats and their impacts on power systems has improved significantly over the last decade. Additional work is required to both provide high fidelity quantitative impact analysis to determine the scope of the concern and, where necessary, to provide improved situational awareness tools to provide input into operational responses taken by the infrastructure owners.

Cyberphysical Threats

Cyber or combined cyber and physical attacks on infrastructure can have widespread and lasting impacts on critical infrastructure. Developing a cyber-physical impact and consequences modeling and simulation capability will enable stakeholders to assess the possible consequences of different types of cyberattacks on critical infrastructure and prioritize additional investments in both impact studies and research and development into cyber-physical systems modeling and simulation.

There are also opportunities to develop new methods to jointly design cyber and physical systems to be resilient to natural and man-made threats. The objective of such an effort is to provide rigorous, optimization-based design methods to evaluate the optimal allocation of future, secure communications components (including quantum secured communications lines and associated trustworthy node relays). The goal is to utilize these methods to characterize the value of the future, advanced communications components to the resilience of electrical power systems. The results generated by this effort are threefold—rigorous mathematical models of cyberphysical components, prototype software that embodies optimal network design formulations for cyberphysical systems, and design results that characterize the resilience of different cyberphysical architectures.

Grid resilience, optimization, and disaster recovery all depend critically on having communication links that are authenticated, secure, and reliable. We at Los Alamos have a twenty-year history of developing secured communication systems by leveraging quantum science and technology. DoE Office of Electricity Delivery and Energy Reliability currently funds several LANL projects to develop and deploy quantum-secured communication hardware specifically tailored to the power industry.

Gas-Grid Coupled Systems

Natural gas pipelines are a key energy infrastructure for the US, and they are only becoming more so with the addition of supply from unconventional natural gas resources; the expansion of central-plant, natural gas-fired electric generation in the electric transmission system; and the expected expansion of gas-fired distributed generation in the electric distribution system. The economic and environmental

drivers behind this evolution will continue as the country leverages advances in the science and engineering of resource extraction. A side effect of this evolution of the US energy systems is the complex coupling between the electric power system and the "just in time" delivery of natural gas to electric generation. This coupling is necessary to leverage these new resources; however, it is also resulting in emerging technical and regulatory challenges that require foundational and applied research and development.

Gas-Grid Coupling at the Transmission Level:

1. LANL is working with our industry and commercial partners to develop intra-day, dynamical optimization and control of pipeline flow and compressor operation with the objective of developing a mathematically sound basis for advanced gas pipeline operation and potential natural gas balancing markets.
2. LANL is also working across the Department of Energy (DOE) to develop integrated models of gas-grid systems that reveal vulnerabilities in this complex, joint systems. We are working to integrate these models of vulnerability into rigorous design approaches with the objective of providing methods to industry to eliminate vulnerabilities.
3. LANL continues to work the coupled gas-grid reliability issue in Southern California. We are currently working with the California Public Utility Commission to develop methods to assess the needs for future underground gas storage to ensure the reliability of the gas pipeline systems and to provide gas supply to the regional electrical transmission and generation system.
4. LANL is leveraging DOE-funded work on gas and gas-grid systems to provide strategic analysis tools to the Defense Threat Reduction Agency, and ultimately to USSTRATCOM, to assess impacts to natural gas pipeline networks.

Gas-Grid Coupling at the Distribution Level:

1. DOE Office of Energy Efficiency and Renewal Energy projections show substantial increases in distributed generation in the form of smaller scale combined heat and power (CHP). If this trend materializes, there are potential technical challenges that may arise in natural gas distribution that mirror the challenges already evident in transmission, i.e., the ability of the gas distribution pipelines to supply the increased and more variable demand from CHP. DOE should work together with the national labs to get ahead of the design, optimization and control issues to avoid the integration issues that arose with other distributed generation technologies, such as solar photovoltaics.

Grid-Water Network Coupling and Control:

1. Potable and waste water systems are major electrical loads that can be controlled to the benefit of both the water and electrical systems. With storage naturally built in, potable water networks are an infrastructure that could play a key role in advanced control and optimization of the electrical system. However, as a critical infrastructure, these water networks must also maintain their own reliability and resilience. Balancing the needs of these complex networks in optimization and control is a key gap in enabling advanced functionality. DOE should take a more active role is developing the foundational research needed to more closely integrate these systems.

In Conclusion

I appreciate the opportunity in these brief remarks to describe some of the future challenges and research opportunities for the United States' electric grid that we see at Los Alamos. Success in these endeavors would result in a more integrated, resilient, and modernized grid infrastructure. The Grid Modernization Laboratory Consortium has been a positive step forward in addressing these issues, and Los Alamos has been proud to play a key role in GMLC with our peer National Laboratories. As we look to the future, we see additional challenges in responding to complex threats, including cyber-physical challenges, to our grid infrastructure and in considering the integrated system of systems represented by our coupled gas and electrical infrastructure at both the transmission and distribution scale.

In closing, I would like to thank you again for the opportunity to appear before the Subcommittee. I look forward to answering any questions that you might have.