Written Statement of

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Expanded Deployment of Grid-Scale Energy Storage

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Chairman Murkowski, Ranking Member Manchin, and distinguished members of the Committee, I am honored to testify before you at this hearing. This is a time of great transition in the electricity grid. Efforts are under way to strengthen its resilience and reliability against extreme weather events and possible cyber attacks, decarbonize it, and incorporate renewable energy into it as the cost of wind and solar electricity falls to compete with fossil fuels. In addition, rooftop solar panels require conversion from one-way to two-way electricity flow to allow local solar energy distribution on the grid. Moreover, as electric vehicles penetrate the marketplace more deeply, the grid will see great new opportunities for electricity supply and domestic job growth. Energy storage is critical to advancing all of these historic transitions.

Ever since the grid was born in the 19th century, it has operated under a constraining principle – we must generate electricity at the same rate that we use it, requiring minute-by-minute matching of generation to demand. This elaborate balancing act has serious downsides. One is that we must build the grid to meet the peak demand, about 40% greater than the average demand. This means we are building 40% more infrastructure than we need, and often operating the grid at peak demand with the least expensive, outmoded means of energy generation because this equipment runs only a few hours a week, and there is no economic justification to upgrade or replace it. If storage were cheap enough, we can imagine a fully modern energy generation system running continuously at its most efficient level to meet the average demand, storing excess generated electricity when demand is low, and releasing it when demand is high. Energy storage enables replacing the present just-in-time-delivery grid with an inventory-based grid that dramatically lowers capital and operating costs while raising resilience, reliability, and flexibility.

I would like to share a few fundamental messages with the Committee:

- Energy storage plays many pivotal but distinct roles in all sectors of the grid – electricity generation, transmission, and distribution.

- Although energy storage technology is advancing rapidly, we urgently need significant basic and applied research advances to innovate and develop the storage technologies that will enable the full transition to a modern electricity grid.
- We are just now discovering, through early stage deployments, the best practices for deploying storage in the highest impact and most cost-effective manner. We need to encourage many more early stage deployments to learn what works and what does not work, and to set a deliberate strategic path for the full deployment of energy storage on the grid.
- Storage plays a central role not only in transforming the electricity grid, but also in transforming other critical areas of the economy, including ground-based transportation through electric cars and trucks, and aviation through air taxis, package delivery, and hybrid-electric regional passenger flight. The military has all of the storage needs of the civilian economy, as well as special storage needs for surveillance, weaponry and the resilience for its foreign and domestic bases to operate independently of the local grid for up to several months. Advances in storage for the grid will spill over to advance the frontiers of these other critical areas of the economy.

Let me briefly elaborate on those points, as well as my organization's contributions to advancing the state-of-the-art of energy storage.

Diverse Roles for Storage in the Electricity Grid
Electricity storage plays a pivotal role in the generation sector of the grid. It reduces or eliminates generation peaks and valleys, and allows generation to run steadily at its most efficient level. Storage is critical to integrating variable wind and solar electricity in the grid, smoothing variations on time scales of seconds to minutes, and time-shifting excess afternoon solar-generated electricity by several hours to meet evening peak demand. In the transmission sector, batteries at both ends of a transmission line allow the line to operate continuously at its highest efficiency, deferring or avoiding the high cost of new or upgraded transmission lines. In the distribution sector, storage is needed for managing the two-way flow of electricity from rooftop solar panels back to substations for distribution to other users, for managing demand and reducing demand charges, and for providing resilience, reliability, flexibility, and high-quality digital power. These "non-wires" solutions to grid challenges are becoming more common as we deploy more storage to the electricity grid.

For these reasons, there appears to be wide, bipartisan and bicameral support for the deployment of grid-scale energy storage. In particular, the Better Energy Storage Technology (BEST) Act would authorize $300 million over five years to reduce the cost of promising grid-scale energy storage systems. This bill would further promote research and development efforts that hold the potential of considerably improving the efficiency of the nation's electrical grid.

Significant Storage Advances Needed
Achieving the vision of a reliable, resilient and flexible grid taking full advantage of renewable electricity requires significant advances in energy storage. First, storage must become much

less expensive. Although the cost of storage has fallen faster than the cost of solar panels, it must fall significantly further. The present cost of lithium-ion battery packs, about $200/kWh, must fall by a factor of two or more to make storage economically appealing across all its uses in the grid. In addition, we must be able to purpose-design batteries for a diversity of applications in the grid spanning generation, transmission, and distribution. An example is long-duration storage, needed to fill in for renewable generation when the wind does not blow or the sun is blocked by clouds for as many as seven days in a row. These long, cloudy, or calm periods are common in weather patterns in the Northeast and Midwest. The present generation of lithium-ion batteries can optimally discharge for about four hours, much too short to span many weather-related generation gaps. New battery materials, concepts, and technology are needed to meet the challenges of long-duration-discharge energy storage.

Early-Stage Storage Deployment

Recently, two major storage deployments have demonstrated the value of large-scale energy storage on the grid. A massive natural gas leak in the Aliso Canyon reservoir discovered in 2015 prompted the utility to solicit 70 MW of storage to replace gas peaker plants needed to maintain reliability during summer peak demand. The storage went on-line in January 2017 and has operated as expected for over two years, demonstrating the value of energy storage at scale for grid resilience and reliability. In December 2017, a second larger storage system, 100 MW, was deployed in South Australia to stabilize that grid, with equally satisfactory results. A third even larger storage system, 300 MW, has been approved for deployment at Moss Landing, California.

These early stage deployments of storage at scale demonstrate that large-scale batteries can solve grid challenges without incurring unexpected downsides. Despite their success, they represent only a small fraction of the many critical needs for energy storage related to the generation, transmission, and distribution sectors of the grid. Many more early stage deployments are needed to learn what works and what does not, so that we may set in place robust policy and regulatory structures to manage the complete transition of the entire grid to a fully modern state.

The Wide Reach of Electricity Storage

Storage plays a central role not only in transforming the electricity grid, but also other important areas of the economy. Electric vehicles are a step in the emerging transformation of transportation from exclusive reliance on personal car ownership to alternative modes of transportation, such as shared rides and mobility as a service. Batteries for electric vehicles share many challenges with batteries for the grid: higher capacity, faster charging, lower cost, greater safety, and longer life. While the external form of an electric vehicle battery and a grid battery may be different, the advances needed in the underlying materials and atomic-level electrochemical phenomena that power the two kinds of batteries are remarkably similar.

Electric vehicles unite, for the first time, the electricity grid and transportation, the two largest energy users in the economy. Powering vehicles with electricity dramatically expands their flexibility, allowing them to run not only on gasoline but also on wind, sunlight, hydropower, nuclear power, or natural gas. All these domestic electricity sources decrease our dependence on imported oil. Moreover, electric vehicles are fast becoming a major new market for electricity, and may require up to 30% more electricity generation to satisfy the driving demands of the country. This significant growth in electricity demand will drive building considerable new domestic infrastructure spanning the generation, transmission and distribution sectors of the grid, as well as rolling out a national network of charging stations for electric vehicles. This extensive infrastructure expansion will create numerous domestic jobs and introduce a new horizon of opportunity for the electricity grid.

Beyond propulsion power sources for cars, buses, and trucks, batteries are beginning to penetrate flight. We already have drones capable of remotely inspecting the moisture levels of farmers' fields, surveying the condition of roads and bridges, and delivering mail-order packages. Boeing and Airbus are working on vertical-takeoff air taxis to take commuters to work and hybrid electric aircraft for regional passenger service, both set to debut by 2025. Batteries needed for electric flight must perform a step above those needed for the grid or ground transportation, but they are built on the foundational knowledge of materials and electrochemistry created in developing grid and transportation batteries.

The Urgency of Battery Research and Development

These examples illustrate the urgent need to advance the state-of-the-art of battery research and development. Batteries and energy storage are central to the emerging transformations of the electricity grid, of ground-based electric transportation, and of electric flight. Congress and the federal government have taken this challenge seriously, with the creation in 2012 of the Joint Center for Energy Storage Research (JCESR), an entirely new kind of Energy Innovation Hub designed to meet the battery needs of the future.

JCESR is led by Argonne National Laboratory, whose mission is to accelerate science and technology that drive U.S. prosperity and security. At its foundation, JCESR comprised 20 leading battery research and development institutions, including national labs, universities, and industry. These institutions have been working collaboratively to create the battery science and technology needed to support the emerging transformations of the electricity grid, ground transportation, and flight. JCESR's talent is drawn from across the United States, including MIT in the East, Lawrence Berkeley National Laboratory in the West, and everything in between. Such a collection of talent – a real dream team – cannot be found in any single institution. The battery challenge requires a major effort, combining the frontiers of electrochemistry, high-performance computing, atomic-level materials characterization, and advanced synthesis and discovery of new materials. Each of these frontiers has its own group of special techniques and leading researchers. Bringing them all together in a single collaborative unit is the only way to make the needed progress in battery technology.

In its first five years, JCESR introduced new tools for simulating and characterizing battery materials at atomic and molecular levels and for techno-economic modeling of new battery systems. Techno-economic modeling is central to JCESR's strategy, guiding its choice of particular battery systems to pursue based on their expected performance, cost, and materials challenges. JCESR took to a new level computer simulation of battery materials before making them in the laboratory. Its computer simulations have permitted comprehensive atomic- and molecular-level prediction of capacity, voltage, and mobility of ions in solid electrodes and liquid organic electrolytes. For example, JCESR simulated 1800 combinations of working ions and cathodes in the search for a cathode for a magnesium battery, finding five that looked promising. We then synthesized two of the five and discovered that they worked. Exploring this many combinations of materials could never have been done in the laboratory, even with an army of graduate students devoting their full attention to the task. JCESR's high-throughput computer simulation dramatically accelerates the pace of materials discovery.

JCESR's many other significant advances include

- invention of inexpensive nanoscale polymer membranes that selectively transmit or block organic molecules on the basis of size,
- introduction of the Electrolyte Genome, a comprehensive database of predicted properties of liquid organic molecules for next-generation batteries,
- development of the concept of redox active polymers or "redoxmers" for a new kind of high-performance, low-cost flow battery,
- discovery of high mobility pathways for doubly charged ions, such as magnesium in crystalline electrodes and electrolytes, and
- pursuit of a promising new direction for lithium-air batteries with high energy density and low cost.

Most important, JCESR promised to deliver two prototype battery systems, one for the grid and one for transportation. At the end of five years, JCESR delivered four prototypes, two for the grid and two for transportation. Our prototype development effort led to several important breakthroughs. For portable applications such as vehicles, we demonstrated innovative batteries based on magnesium, zinc, and calcium, each of which carries two charges instead of the single charge on lithium, doubling the energy stored or released by these ions on each charge or discharge cycle. We developed the concept of sparingly solvating lithium-sulfur batteries to raise their energy density while prolonging their cycle life. For stationary applications such as the grid, JCESR's new concept of redox-active polymers or "redoxmers" promises flow batteries with low cost, high capacity, and self-healing properties to extend their life. Finally, JCESR's invention of inexpensive aqueous air-breathing sulfur batteries for long duration storage fills a long-standing and challenging gap in grid storage technologies.

JCESR spun out three startups in its first five years. Blue Current is pursuing solid state electrolytes. Sepion is commercializing inexpensive size-selective polymer membranes. Form Energy is commercializing JCESR's long-duration inexpensive flow battery based on sulfur, water, and oxygen. With Form Energy, JCESR took the new idea of this aqueous, air-breathing sulfur battery for long duration storage from initial concept to commercialization in less than five years.

At the end of its first five years, JCESR won the Secretary of Energy Achievement Award for its development of new strategic and operational concepts for large collaborative projects, such as

Energy Innovation Hubs. This confirmation of our success allows us to push our research boundaries even more aggressively going forward.

In September 2018, the Department of Energy (DOE) renewed JCESR for a second five-year period. In the renewal, JCESR shifted its focus from particular battery systems to transformational battery materials. We realized toward the end of our first term that even if all four of our prototypes were commercialized, this would not come close to satisfying the urgent need for a diversity of new batteries for a diversity of emerging applications in the electricity grid, ground-based transportation, and electric flight. Moreover, the roadblock in creating new battery technologies is typically lack of high performance materials. To address these challenges, JCESR shifted its focus in its renewal to transformational battery materials including anodes, cathodes, electrolytes, and interfaces that will enable a diversity of purpose-designed batteries for a diversity of uses. JCESR will work with end users, such as its start-up Form Energy, to create specific batteries needed for specific purposes.

JCESR's renewal introduces a new approach to transformational battery materials: building them "from the bottom up," atom by atom and molecule by molecule, where each atom or molecule plays a prescribed role in achieving targeted overall materials behavior. This kind of atomic- and molecular-level materials design would not have been possible ten years ago because our knowledge of the atomic and molecular origins of electrochemical behavior was incomplete. The advanced atomic-level computer simulation and experimental characterization of battery materials in JCESR's first five years are part of the foundation for our new bottom-up materials design approach. Introducing such innovative approaches helps to secure America's energy future and deliver economic—and scientific—competitiveness and growth.

JCESR's renewal provides a natural platform for strengthening broader research alignment among its partner institutions. JCESR's partners are working to ensure that their broader lab strategies and capabilities beyond the JCESR program are complementary and closely aligned with long-term DOE goals, such as research challenges for future U.S. battery manufacturing needs. This fostering of research alignment raises the effectiveness of the labs as a whole, collectively champions engagement with U.S. industry, and serves as a role model for cooperation across the national lab and university systems.

JCESR is sponsored by the DOE Office of Basic Energy Science in the Office of Science to pursue fundamental research on the materials and phenomena of next-generation batteries. In this role, JCESR frequently interacts with the applied energy offices of the DOE, including the Office of Energy Efficiency and Renewable Energy and the Office of Electricity. On its renewal, JCESR added a new position, liaison with the Office of Electricity, to better understand its materials and performance needs and promote sharing of strategy, information, and results. In addition, JCESR interacts strongly with other DOE programs, including Vehicle Technologies and Advanced Manufacturing in Energy Efficiency and Renewable Energy.

Conclusion

Energy storage will play a vital role in the transformation of the electricity grid spanning generation, transmission, and distribution. We are taking the initial steps of this transformation, but we have not yet walked through the door. Achieving this transformation requires enduring support of basic and applied research for energy storage. Disruptive fundamental research is essential to produce the transformative materials that will enable next-generation purpose-designed batteries for the diversity of storage needs on the grid. Equally important is the applied research needed to realize these batteries, and the innovative policy, regulatory, and business plans required to successfully deploy the batteries on the grid.

The societal pay-offs of next-generation energy storage for the grid will be enormous. Yet, the ultimate path to its development is uncertain, and the risk of failure is significant. This task is best assumed by research organizations that can tolerate that risk, such as universities, national laboratories, and multi-organizational Energy Innovation Hubs like JCESR. As the winning technologies become evident, the private sector will adopt and deliver them to the public. This combination of high-risk, high-reward public sector research enabling innovative private sector development and deployment is essential to the transformation of the electricity grid to its fully modern form.