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Chairman Weber, Ranking Member Grayson, and members of the Committee, thank you for your invitation to testify at today's hearing on "Innovations in Battery Storage for Renewable Energy." I appreciate the opportunity to share with you the important progress the Department of Energy's Office of Electricity Delivery and Energy Reliability (OE) Energy Storage Program is making to address the challenges facing the widespread deployment of grid energy storage.

Electricity is central to the well-being of the Nation. The United States has one of the world's most reliable, affordable, and increasingly clean electric systems, but it is currently at a strategic inflection point—a time of significant change for a system that has had relatively stable rules of the road for nearly a century. Last week, the Administration released the first-ever Quadrennial Energy Review (QER). This first installment of the QER looks at the infrastructure used for the transmission, storage, and distribution of energy. Included is a major look at the electricity part of that infrastructure, in terms of modernizing the electric grid. Several of the QER's findings and recommendations note and address the opportunities that grid energy storage can provide as part of its role in modernizing the electric grid.

As the QER points out, changes in technologies, markets, and public policies are transforming electricity delivery. Some key trends driving the evolution of the grid include a changing mix of electricity generation sources and characteristics, growing expectations for a resilient and responsive power grid, and growing customer participation in retail electricity markets. Much innovation is occurring in electricity technologies, including innovation in grid energy storage as this panel will hear today. Today, I will discuss the Department of Energy's role in grid storage innovation.

Grid Energy Storage Defined

Grid energy storage helps address, among other existing and emerging methods, the continuous 24/7 need to balance the generation of electricity and demand for electricity from the grid's customers. That balance must be maintained on a narrow and precise basis and must address a set of legally-enforceable reliability standards set by Congress in its Energy Policy Act of 2005.

Storage provides a buffer between generation and customer demand, freeing the grid from the need for instantaneous response. Energy storage increases reliability and resiliency of the electric grid and can provide greater asset utilization of generation. Energy storage provides power when it is needed, just as transmission and distribution provide power where it is needed.

The OE Program

The Department of Energy's Office of Electricity Delivery and Energy Reliability's mission is to drive electric grid modernization and resiliency in energy infrastructure. OE accomplishes this mission through research, partnerships, facilitation, modeling and analytics, and emergency preparedness. OE's Energy Storage Program is an important component of the Department's strategy to support a more economically competitive, environmentally responsible, secure and resilient U.S. energy infrastructure by accelerating the development of emerging storage technologies.

The program's R&D activities focus on lowering cost while improving value, and advancing the performance, safety, and reliability of stationary energy storage technologies for utility-scale applications. Additionally, the program is designed to work with states, communities, industry, and other stakeholders to develop and demonstrate energy storage technologies, devices, and systems that can reduce power disturbances, improve system flexibility to better incorporate growing use of variable renewable resources, reduce peak demand, and provide resiliency to advance the modernization of the electrical utility grid.

The OE Energy Storage Program is an integrated program: it takes technologies from applied electrochemistry through device and system development, to field tests and applications. The focus is firmly on commercialization and transfer to the private sector. The program involves National Laboratories working closely together as well as projects at universities, private industry, and initiatives through the Small Business Innovation Research (SBIR) program. The program has an annual public peer review and reports its result in numerous public forums. In collaboration with the Advanced Research Projects Agency-Energy (ARPA-E), the Office of Science, and the Office of Energy Efficiency and Renewable Energy (EERE), OE has developed a

Grid Energy Storage report[a] that forms the framework of the storage program and identifies the following priorities:

- Cost competitive energy storage technologies: targeted scientific investigations of key materials and systems
- Validated reliability & safety: independent testing of prototypic devices and understanding of degradation.
- Equitable regulatory environment: enabling industry, utility, and developer collaborations to quantify benefits and provide input to regulators.
- Industry acceptance: highly leveraged field demonstrations and development of storage system design tools.

Collaboration within the Department

To further leverage work done by various DOE offices on this issue, DOE has developed a crosscutting effort involving the OE, the Office of Energy Efficiency and Renewable Energy, and the Office of Energy Policy and Systems Analysis called the Grid Modernization Initiative.

EERE is working on energy storage across several offices including solar, vehicles, fuel cells, and wind and water power. Much of the work is focused on vehicles and behind-the-meter storage. EERE is also involved in pumped storage hydro and thermal energy storage combined with concentrating solar power.

In addition, OE activities are complemented by efforts from ARPA-E and the Office of Science. For example, ARPA-E has efforts in grid storage, such as the “Grid-Scale Rampable Intermittent Dispatchable Storage” (GRIDS) and “Agile Delivery of Electrical Power Technology” (ADEPT) programs. DOE’s Office of Science, through its Basic Energy Sciences program, supports a portfolio of fundamental research to provide scientific understanding of the physical and chemical phenomena underpinning the properties of batteries, fuel cells, and supercapacitors, including the Joint Center for Energy Storage Research. The Grid Energy Storage report further describes the roles each office plays in the energy storage field.

[a]http://energy.gov/oe/downloads/grid-energy-storage-december-2013

Developing Technology for Commercialization

Although the notion of practical widespread energy storage appears evident, it was almost an unknown concept in the utility world some 12 years ago. The exception is pumped hydro, of which 22 GW of installed capacity currently exists in the United States.

Since 2003, DOE OE has been in the forefront of developing energy storage into a technology ready for commercialization by industry. This has meant taking the field from research to development, to demonstrations in niche markets, until it is finally ready to enter the mass market. The program has informed regulatory changes, policy adoption, and sizable investments. Progress is remarkable, but there is more work to be done to develop technologies that could allow widespread deployment of energy storage technologies by industry.

Recent Successful Projects

The American Recovery and Reinvestment Act of 2009 (ARRA) provided a very considerable boost to the development of the program. OE received $185 million of funding for storage demonstration projects, but was able to boost this with $585 million of cost share from industry. This showed evidence of strong buy-in from industry and utilities.

Selected through a competitive solicitation, 16 projects were chosen for funding. The scope comprised a spectrum from large utilities, to small companies, and recent start-ups. The technologies involved were diverse, including advanced batteries, flow batteries, flywheels, and compressed air.

The goal of the projects was fourfold: to show technical feasibility, gather cost data, inform regulatory changes, and generate follow-on projects. Most of the projects were first of a kind and established technological know-how and business cases that provided the basis for later development. I highlight examples of successful projects throughout the testimony.

Power Systems and Energy Systems

Energy storage systems provide for multiple applications in the electric system: energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization. However, not all storage systems are equal because not every type of storage is suitable for every type of application, motivating the need for a portfolio strategy for energy storage technology. Therefore, the OE program develops a broad portfolio of technologies for a wide spectrum of applications. Storage applications can involve power systems or energy systems.

Power systems for storage respond rapidly, but their energy content is limited. They are appropriate for smoothing out the short term variability of wind and solar renewable generation, as one of several methods that can be used to address that variability. They can also provide “frequency regulation” that is used by grid operators to maintain grid stability and thus reliability. A 20MW flywheel project developed with OE funding demonstrated that frequency regulation provided by storage can be twice as technically effective as doing the same thing by generation that currently provides such frequency regulation. In Texas, OE also supplied funding for an advanced lead-acid battery facility. Built by Duke Energy in Notrees, West Texas, the impressive 36MW battery provides wind smoothing and frequency regulation services to the grid. This project helped inform the Texas Public Utility Commission’s new regulations regarding storage. Since the completion of these two projects, the Federal Energy Regulatory Commission issued in 2013 its FERC Order No. 784, “Third-Party Provision of Ancillary Services; Accounting and Financial Reporting for New Electric Storage Technologies”. FERC Order No. 784 mandated reforms in grid “ancillary service” markets that are provided by FERC-regulated transmission providers, thus creating new business opportunities for energy storage technologies that can supply regulation and frequency response service forms of grid ancillary services.

Energy systems for storage contain large amounts of energy and typically provide power for three or four hours. This makes them suitable for peak shaving, load shifting, and ramping, which are helpful in mitigating the impact of intermittent energy sources like wind and solar on the grid. For example, wind blows predominantly at night. In fact, on the average, little of the nominal wind capacity is available during peak load periods. Summer heat can present the grid with midday demands it cannot satisfy without brownouts or denial of service. During morning and evening hours when photovoltaic (PV) generation is rapidly increasing or decreasing large ramps may occur which utilities can only follow with difficulty. This was the reason for California’s recent 1.3GW mandate for storage. In all these situations energy storage with multiple hours of storage capacity can provide stability to the grid. Lithium-ion batteries and advanced lead-acid batteries can provide this service. But, perhaps, the most suitable technology is represented by the family of flow batteries. Zinc-bromine, iron-chromium, and vanadium-vanadium are among the available options being explored.

The ARRA program featured several projects providing multi-hour storage connected with wind and solar. One of the biggest lithium-ion facilities is an 8MW/4 hour project with Southern California Edison in Tehachapi, CA. It is situated next to one of the world’s biggest wind fields. Currently this facility is exploring the whole suite of business cases for energy storage. OE also funded a number of promising start-ups in this area. Notable among these is Aquion, a small company developing a novel aqueous hybrid ion battery which is now in commercial production. This technology has not only attracted very substantial venture capital, but also led to the employment of over one hundred technical personnel.

Material Science

The OE energy storage program develops technology from material science, to the design of devices and system. Activities are all firmly focused on commercialization and eventual transfer to the market place. The program has generated over 90 peer reviewed publications in the last four years, as well as some 45 patents. A wide variety of chemistries are being investigated at Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories, and Oak Ridge National Laboratory (ORNL). Universities participate through special sub-contracts with recognized experts in the field. As an example, University of Illinois is working on 2-electron transfer redox reactions in hybrid sodium-based flow batteries, potentially a breakthrough technology leading to a substantial increase of efficiency and cost reduction. SBIR projects are also firmly integrated into the programmatic structure, taking part in peer reviews, interacting with storage systems developers, and winning international recognition through R&D 100 awards, a recognition of the 100 top technology products of the year worldwide.

A particularly promising line of research concerns vanadium flow batteries. PNNL discovered that a mixed electrolyte consisting of sulfuric and hydrochloric acid makes the resultant system much more stable. This doubles the energy density and allows an appreciably bigger temperature window. PNNL has been developing this system for the past five years driving down the system cost from $650/kWh to $325/kWh thus reaching commercial viability. The cutting edge technology has been licensed to 5 companies for commercial production and transfer to the private sector.

Using a flow battery analysis model reveals that further cost reductions will need to come from the cost of the material. A promising candidate is zinc-iodide, potentially yielding five times the energy density of zinc-bromide. Other systems being investigated for technical feasibility and cost effectiveness are organics and organo-metallic structures. Another candidate for cost reduction is the membrane that is crucial in the rechargeable electrochemical cell. Research at Sandia has found a durable polymer film that may be two orders of magnitude more cost effective than Nafion, the currently used material. Tests with a vanadium system show that the material also lasts substantially longer than Nafion.

Because power electronics may be responsible for as much as 25 percent of the cost of a storage system, OE's energy storage program actively pursues research on advanced power electronics. Beyond the common silicon devices, so called "wide band gap" materials such as silicon-carbide and gallium- nitride offer a vastly improved footprint and much higher operating temperature, potentially resulting in substantial cost reductions. OE has an ongoing research program with small companies that have established many firsts in the field and brought technology to market. This work, at the cutting edge of technology, has been recognized through numerous R&D 100 awards.

Resiliency and State Projects

Natural disasters like hurricanes Sandy and Katrina have brought into focus the importance of emergency preparedness of the local electrical system. Experience has shown that diesel generators cannot always be relied on during emergencies. A more reliable solution is the formation of micro-grids which include both storage and renewable generation. Such a system can be islanded and provide critical services for extended time periods. But during normal times the storage facility can also provide demand management for the user and compensated services to the grid.

A system of this kind is currently nearing completion in Rutland, Vermont. Initiated through a joint solicitation by the Vermont Public Service Department and OE, the project will feature 4MW of storage integrated with 2MW of PV installed by Green Mountain Power. During disaster events the system will serve a high school/emergency center. At other times it will provide services to the grid. Rutland was subject to extensive flooding and long lasting electrical outages during tropical storm Irene in 2011. Although resilience is difficult to monetize, it is a strong motivating factor for this Vermont community.

Another OE state initiative is with Washington State. A solicitation by the Washington State Clean Energy Fund provided $15 million for three selected energy storage projects. All three projects involve technology developed with OE funding. Two of the projects, 1MW and 2MW respectively, use vanadium-vanadium flow battery technology as developed by PNNL and licensed to UniEnergy, a Washington based start-up company. The other project uses a zinc bromine battery developed with ARRA funding. Under a memorandum of understanding (MOU) between OE and Washington State, PNNL will develop a detailed cost benefit analysis of all three projects and suggest optimal economic use of the facilities. The next state planning a joint solicitation with OE is Oregon. Work with other states is under negotiation. One potential site is Florida, where OE is providing technical advice to the Kennedy Space Center for a possible micro-grid with storage and solar energy.

Industry Tools

With growing demand, new storage systems are entering the market and many of these are relatively unproven with respect to performance. OE has developed performance-based criteria and testing protocols with the consensus of the industry. OE is also providing a testing platform at Sandia where new storage systems up to 1MW can undergo comprehensive testing following standard load patterns based on various applications. The test center has provided help in establishing other test centers by private entities.

To keep track of the growing number of energy storage projects, OE has funded the establishment of the DOE Global Energy Storage Database. The database gives concise information on location, ownership, type of application, technology, and storage parameters. Owners of storage facilities enter their own data, but the input is vetted by experts. The database is internet based and free to storage providers and users, regulators, and the general public. There are now over 1,200 entries reporting projects from 58 countries. The searchable database is proving a valuable tool for regulators who are faced with accommodating the changing generation mix and the application of unfamiliar storage technologies.

As more and more projects are being deployed and an increasing number of vendors are entering the market it is becoming of paramount importance to develop proper safety codes. While the technology is generally safe, accidents have happened. Yet, there are at present no codes and standards specifically dedicated to grid-scale energy storage safety. For this reason OE convened a workshop last year, attended by scientists, the utilities, storage vendors, firefighters, and the insurance industry, to define the issue and make safety recommendations. Based on this input, OE has produced an Energy Storage Safety Strategic Plan to outline needed work in this field. A working group of leading experts from the various relevant professional institutions has been established under OE leadership. The group will determine priorities for needed research and form a core of future committees with wider public participation. Eventually this effort will lead to an accepted and coherent set of codes and standards to guide the industry.

Conclusion

DOE has provided leadership in establishing energy storage as an effective tool for promoting grid reliability, resiliency, and better grid asset utilization of renewable energy. The program has developed new cost effective storage technologies that industry has commercialized. Through field test and highly leveraged deployment, OE has opened new benefit streams and developed optimization tools for storage projects. The program has contributed to the establishment of new regulatory structures and is developing codes and standards for safety. OE is providing input into major solicitations driven by state mandates, such as those of California and Hawaii, and is partnering with other states in pioneering storage projects. DOE's leadership in creating a storage industry is widely recognized in the U.S. as well as abroad.

Although grid energy storage has made a creditable beginning, much remains to be done. More cost effective technologies need to be developed and available benefit streams need to be fully monetized. Institutional barriers to storage deployment need consideration. Greater storage system safety must be assured through development of a body of storage specific codes and standards. Public-private partnerships and joint solicitations with the states need to bring technical expertise at the National Laboratories within reach of private industry to establish storage projects in diverse geographic areas and for diverse applications.

DOE looks forward to continuing this important work. As our electric grid evolves, we expect that energy storage will be an integral component in assuring that electricity delivery for communities will be more flexible, secure, reliable, and environmentally responsive.

Mr. Chairman, and members of the Committee, this completes my prepared statement. I would be happy to answer any questions you may have at this time.