Environmental and Energy Study Institute

Issue Brief

Energy Storage

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Energy storage technology has the potential to mitigate numerous challenges currently facing the electricity industry and consumers. Large-scale storage technology could help supply daily fluctuating demand in a cost-effective manner with minimal waste, as is already being done on small scales today. Effective storage technology can keep the lights on during severe storms, supply shortages and power interruptions, and help consumers avoid high utility rates by offsetting the need to generate new electricity during peak demand. Finally, energy storage facilitates the integration of variable renewable energy sources such as solar and wind power.

Despite this potential, the implementation of many types of storage technology is limited today, primarily due to the high cost of research and development for utility-scale storage implementation.[1] Federal policy has sought to address this, most notably through Department of Energy (DOE) programs and Federal Energy Regulatory Commission (FERC) Orders. These initiatives aim to spur innovation and encourage utilities to rethink the existing transmission paradigm, and they have helped energy storage overcome hurdles in recent years. This issue brief will discuss these efforts and the opportunities they might elicit for energy storage, in addition to providing an overview of existing and developing energy storage technologies.

Energy Storage Technology

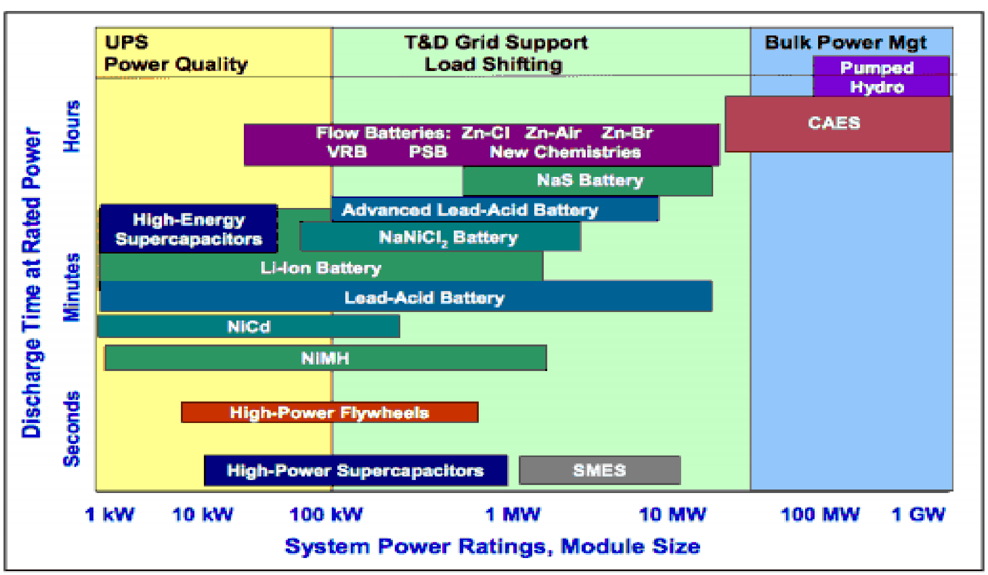

Figure 1: Comparison of existing energy storage technologies (source: Sandia National Laboratories)

The table to the left[2] is a general overview and comparison of existing energy storage technologies, sorted by their relative sizes and discharge times.

It is important to note that energy storage can be used for multiple purposes, including energy arbitrage, generation capacity deferral, ancillary services, ramping, renewable integration, electric transportation, maintaining power quality, and end-user applications.[3] Today, pumped hydro and compressed air energy storage (CAES) are capable of discharging electricity for tens of hours, with project sizes that reach 1,000 megawatts (MW). Other technologies aim to reach comparable capacities.[4] The following is an overview of energy storage technologies, with descriptions of how they work and how they are applied. The technologies are listed in the order that they are presented in the table above: starting with the highest system power ratings, module sizes and discharge times, and ending with technologies that are still being developed for utility-scale use.

Pumped Hydroelectric Storage is already in use on commercial- and utility-scales worldwide. Typical systems employ off-peak electricity to pump water from a lower-elevation reservoir to a higher-elevation reservoir, and then release water from the upper reservoir when electricity is needed. As this happens, the water flows through a turbine that generates electricity. Pumped hydro projects can currently be sized up to 4,000 MW at up to 85 percent efficiency, with a lifespan of up to 60 years. The first projects were installed in the United States in the late 1920s, and today the country has more than 22 gigawatts (GW) installed.[5] Over 15 GW of new pumped hydro storage facilities are expected to be installed in Europe by 2020.[6]

Compressed Air Energy Storage (CAES) uses electricity when prices are low to compress air and store it either in underground geologic features or in pipes. When demand for electricity rises, the compressed air is mixed with natural gas, heated, expanded and directed through a turbine to generate electricity. Other than pumped hydro, this is the only commercial, bulk-energy storage plant deployed today. There are two operating first-generation systems, in Alabama and Germany. Designs for second-generation systems are currently underway, with plans for lower costs, higher efficiencies and faster construction times.[7] One such project, known as the Bethel Energy Center, is being developed in Tennessee Colony, Texas, and is expected to reach 317 MW.[8] Discharge time for new CAES projects is expected to be up to six hours.[9]

Flow Batteries pump liquid chemicals through a membrane to convert chemical energy into electricity. The technology has seen major technological breakthroughs in the past year at the DOE's Joint Center for Energy Storage Research (JCESR). For example, previous flow batteries used two expensive and high maintenance streams of rare vanadium, but newly designed flow batteries at JCESR use one liquid made of inexpensive lithium and sulfur. This reduces the cost and maintenance required for battery operation, and could be a cost-effective way to integrate solar and wind power for grid support.[10]

Molten Salt or High-Temperature Batteries form ions by dissolving chemical compounds, such as Sodium-Sulfur (NaS) and Sodium-Nickel-Chloride (NaNiCl2), at high temperatures. NaS batteries have potential for utility-scale wind and solar integration due to their discharge period of six hours or more. The 280 MW Solana power plant in Arizona, which will begin operations in 2013, includes six hours of molten salt thermal energy storage, to dispatch electricity when the sun is not shining.[11] In Japan, the 34 MW Rokkasho wind-stabilization project is currently the largest NaS battery in the world.[12] NaNiCl2 is used for smaller-scale load leveling, but is also considered to have potential for use in electric vehicles.[13]

Lithium-ion Batteries, which are ubiquitous in the mobile electronics market, have quickly emerged in applications such as electric vehicles and plug-in hybrids, and in these applications can be used to discharge to the grid through Vehicle-to-Grid (V2G) technology.[14] They also are used for grid services and larger storage projects such as the Laurel Mountain Wind Farm in West Virginia, discussed below.[15]

Lead-Acid Batteries, invented in the mid 1800s, are the oldest form of rechargeable battery. While they are used in a wide variety of applications, from automobiles to telephones, they are rarely used for electricity storage on a commercial scale, due to their relatively heavy weight, bulk, lifecycle limitations and maintenance requirements. However, a 1 MW lead-acid battery in Metlakatla, Alaska, has been operating for over 12 years, and lead-acid batteries remain popular for the off-grid use of renewables.[16]

Flywheels use spinning rotors to store kinetic energy, and then transfer that energy into AC power through the use of controls and power conversion systems. Energy flywheels typically have rotors enclosed in vacuum containment systems with magnetic bearings. While they have fast response times and may be used for durations of up to four hours, flywheels are currently limited in terms of the energy they can store – typically no more than 1.65 MW. Despite this, they could be a key part of the energy storage picture because of their reliability, lifecycle and environmental safety. Flywheels have been deployed in several test projects for voltage regulation and the stabilization of wind generation, including a frequency regulation plant for a 20 MW storage system in New York (see the section below on energy storage projects in the United States). Stanford University, University of Texas and Boeing are among the institutions and corporations that are currently researching higher-capacity flywheels.[17]

Emerging Storage Technology is largely comprised of advanced versions of current technologies. For example, there are efforts to develop underground pumped hydro and non-fuel CAES.[18] Advanced flywheels with higher energy density are expected to be developed by 2015, and advanced lead-acid batteries are undergoing early field trials today.[19] Other technologies are being tested as well, including liquid air energy storage systems over 1 MW, vanadium air batteries, supercapacitors, and advanced batteries such as nickel-cadmium (NiCd) and nickel metal hydride (NiMH). [20] The following sections will discuss some of these newest developments.

Federal Energy Storage Policy

Federal Energy Regulatory Commission

The Federal Energy Regulatory Commission (FERC) is an independent agency that regulates the interstate wholesale markets for transmission of electricity, and distribution of natural gas and oil. Several of its rulings have been instrumental in the implementation of energy storage technology, most notably Order No. 1000 and Order No. 755. Other FERC rulings affecting energy storage are Order No. 890, which prevents undue discrimination in transmission services; Order No. 719, which sets standards for system operators to call on "non-generator resources" for ancillary services; and Order No. 784, which addresses accounting and financial reporting for new electric storage technologies and which was revised in August 2013 to foster competition in the ancillary services market.[21,22,23,24] These orders help ensure fair market access and pricing for electricity storage technologies.

FERC Order No. 1000, issued in 2011, reforms the Commission's electric transmission planning and cost allocation requirements for public utility transmission providers.[25] This is pertinent to energy storage because of its guidelines for planning, building and funding more efficient transmission lines, thereby setting the stage for utilities to provide transmission alternatives such as new storage technology and large-scale integration of renewable energy.

The rule requires grid operators to collaborate on regional planning and allow independent developers to compete with utilities in building new power lines. Utility transmission providers must establish procedures to identify transmission needs, evaluate proposed solutions and allocate funds for new transmission facilities. Energy storage would have a clear pathway to integration under Order 1000, since it can make transmission more cost-efficient.[26]

FERC Order No. 755, issued in 2011, mandates that technologies providing frequency regulation and other grid stabilization services are compensated commensurate to performance. Since energy storage technologies provide real-time load matching services with rapid ramp rates, Order 755 is considered to be a major step for energy storage, as it allows payment for ancillary services provided by energy storage in wholesale electric markets. It also creates reporting mechanisms to track installations, operations and maintenance costs for energy storage systems, increasing projects' transparency.[27]

Department of Energy

The Department of Energy (DOE) plays a crucial role facilitating the research, development and deployment of energy storage technologies. As part of the *American Recovery and Reinvestment Act of 2009* (ARRA, P.L. 111-5), the DOE invested in numerous energy storage projects through the Office of Electricity Distribution and Electric Reliability (OE) from 2009-2012. The twelve projects included storage implementation in seven states – California, Texas, New York, New Mexico, West Virginia, Pennsylvania and Michigan – and research for new batteries by Aquion Energy and SustainX.[28] These grants amounted to $185 million in total, each covering half the costs of the accepted project.[29] Three of these projects – the Notrees Wind Farm in Texas, the AES Laurel Mountain Wind Farm in West Virginia, and the Beacon Power flywheel plant in New York – are discussed in the subsequent section.

The Joint Center for Energy Storage Research (JCESR)'s Battery and Energy Storage Hub in the suburbs of Chicago, Illinois, was founded in 2012 through a DOE appropriation of $120 million over five years for a team of five DOE national laboratories, five universities and four private companies to improve battery storage capacity for community infrastructure and vehicles. JCESR is coordinating its efforts with the DOE Energy Frontier Research Centers and other programs in the DOE technology offices and in ARPA-E.[30] The program's goal is to surpass today's lithium ion storage technology by providing five times the energy storage at one-fifth the cost by 2017.[31]

JCESR is following four approaches to accomplish its goals: [32]

1. Develop new electrochemical storage concepts to store more energy
2. Employ research from the last decade to characterize the performance of new materials at the atomic level
3. Design virtual batteries on the computer and estimate their performance
4. Design and prototype cells, to deliver pre-commercial models for grid and transportation applications

JCESR's research is motivated by two goals of President Barack Obama's economic plan: to put one million all-electric plug-in hybrid (PHEV) vehicles on the road by 2015, and to generate 25 percent of U.S. electricity from renewable energy technologies by 2025.[33] In trying to meet these goals, JCESR will work to bring the watt-hour per kilogram (W-h/kg) capacity of batteries close to that of gasoline, as illustrated in the table below.[34]

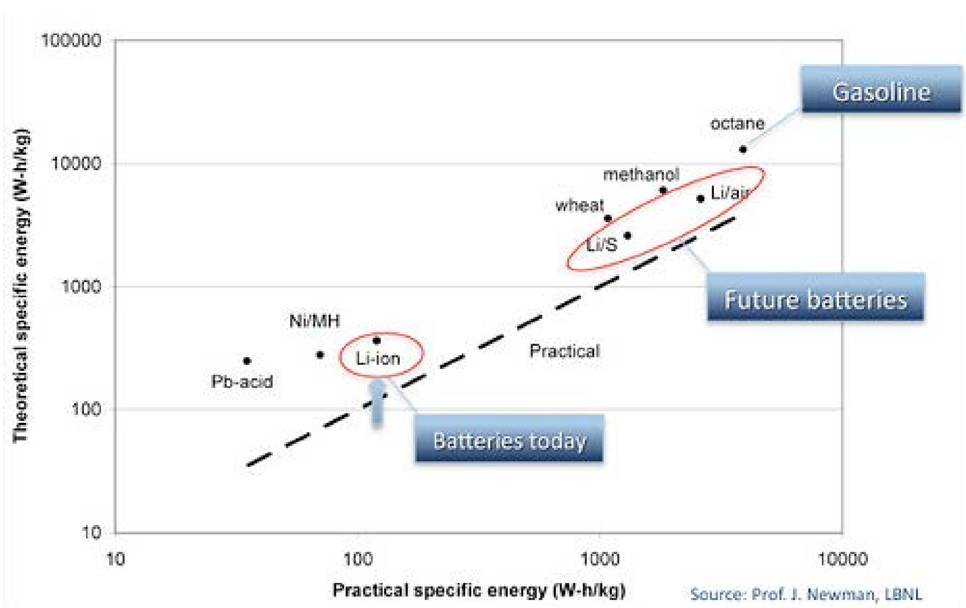

Figure 2: Watt-hour per kilogram (W-h/kg) capacity of various energy sources

Proposed Energy Storage Legislation

In addition to these FERC and DOE initiatives, there have been efforts by lawmakers in Washington to pass bipartisan legislation to advance energy storage technology during the 113th Congress.

S. 1030, *The Storage Technology for Renewable and Green Energy Act of 2013* (STORAGE Act), was introduced in May 2013 by Senators Ron Wyden (D-OR), Susan Collins (R-ME), Jeff Merkley (D-OR) and Angus King (I-ME) to lower consumer energy costs through storage technology and encourage the deployment of renewable energy.[35] The bill offers a 30 percent investment tax credit (ITC) to businesses that use storage technology to distribute electricity during peak demand times, and to homeowners who install energy storage systems on their property. It also would provide a 20 percent ITC, up to $40 million per project, for grid-scale storage systems. The legislation would have a $1.5 billion budget and includes language allowing the market to decide which storage technologies are best suited for installation. The companion House bill (H.R. 1465), was introduced in April 2013 by Rep. Christopher Gibson (R-NY) and Rep. Mike Thompson (D-CA).[36]

S. 795, *The Master Limited Partnerships Parity Act*, was introduced in the Senate in April 2013 by Senators Christopher Coons (D-DE), Jerry Moran (R-KS), Lisa Murkowski (R-AK), and Debbie Stabenow (D-MI) to expand the availability of the MLP corporate structure – a publicly-traded partnership currently available to and widely used by the fossil fuel industry – to include companies that use renewable energy technologies, including electricity storage.[37] The MLP structure has the potential to increase access to, and decrease the cost of, capital for electricity storage technologies. Companion legislation (H.R. 1696) was introduced in the House in April 2013 by Reps. Ted Poe (R-TX), Earl Blumenauer (D-OR), Cory Gardner (R-CO), Christopher Gibson (R-NY), Mike Thompson (D-CA), and Peter Welch (D-VT).[38]

Examples of Energy Storage Projects in the United States

The following examples are just a handful of the energy storage projects that exist throughout the United States. They were chosen for this issue brief because they illustrate a range of prominent and promising storage technologies that currently supply large amounts of electricity. Some also were chosen because they demonstrate the ability of energy storage to integrate variable renewable energy sources into the grid.

Bath County Pumped Storage Station, Bath County, Virginia: Operating since 1985, this is the world's largest pumped hydro site, and helps to power millions of homes and businesses across six states. The lower reservoir lies 1,262 feet below the higher one, and water flows at a rate of up to 13.5 million gallons per minute, turning six turbine generators. The station has a rated capacity of 3,003 MW and a storage cycle efficiency of 78 percent.[39]

McIntosh Compressed Air Energy Storage (CAES) Facility, McIntosh, Alabama: Commissioned in 1991, this is the first and only utility-scale CAES system in the United States. The unit captures off-peak energy at night when electricity demand is low, forces air into an underground storage reservoir, and then uses the stored energy during peak demand periods to generate electricity. Although it uses natural gas, it burns roughly one-third of the gas per kilowatt-hour of electricity compared to a conventional combustion turbine. At full capacity, it can power approximately 110,000 homes.[40]

Golden Valley Electric Association (GVEA), Fairbanks, Alaska: Commissioned in 2003, this 27 MW, 14.6 MW-hour (MWh) project was, for several years, the largest battery in the United States. It is the only energy storage system in the United States that uses nickel cadmium (NiCd) batteries. The system supports the grid in several ways, including providing voltage support, spinning reserve and emergency power for Fairbanks in case of an outage on the transmission line that connects Fairbanks to Anchorage.[41]

Notrees Wind Farm and Battery Facility, Ector and Winkler Counties, Texas: Online since December 2012, this is the world's largest battery storage system for wind energy: a 153 MW wind project that includes lead-acid batteries with 36 MW of capacity for non-windy periods. The facility is part of the Electric Reliability Council of Texas (ERCOT) and is owned by Duke Energy, which was able to add the batteries with the help of a $22 million grant from the DOE that covered half of the project's costs.[42]

AES Laurel Mountain Wind Farm, Laurel Mountain, West Virginia: Operating since October 2011, this 98 MW wind project includes a 32 MW lithium-ion storage facility that can deliver a nearly instantaneous response to power requests from grid operators. Due to its on-site integration with the wind farm, the storage facility qualified for the 30 percent federal wind Investment Tax Credit (ITC).[43]

Beacon Power Stephentown Advanced Energy Storage, Stephentown, New York: Commissioned in 2011, this 20 MW storage complex is the first live connection of a grid-scale flywheel storage system for a frequency regulation plant. It uses 200 high-speed flywheels to provide fast-response frequency regulation services with no emissions or fuel consumption. It provides 10 percent of New York's frequency regulation needs.[44]

Rice Solar Energy Project, Riverside, California & Solana Power Plant, Gila Bend, Arizona: In January 2013, the California Public Utilities Commission approved a 25-year power purchase agreement between the utility Pacific Gas and Electric Corp. (PG&E) and the 150 MW Rice Solar Energy Project, which will be the largest American solar project with energy storage capacity.[45] The project will begin construction in 2014 and is planned to go online in 2016. It will use concentrating solar power (CSP) technology to convert sunlight into electricity, or store the heat in a molten salt thermal energy storage system, with the capacity to provide up to eight hours of electricity at full capacity when the sun is not shining.[46] Another notable CSP site is the Solana Solar Energy Generating System, set to begin operation in 2013. The 280 MW project uses molten salt thermal storage to provide up to six hours of electricity at maximum power.[47]

Conclusion

Over the past several years, federal initiatives in conjunction with technological advances have helped overcome major barriers to energy storage implementation in the United States, including regulatory treatment, technological development risks, incomplete valuation of benefits and economic uncertainty.[48] As more large-scale storage projects are deployed across the country, the business, scientific and legislative communities will collectively attain a better quantitative understanding of storage technology's value to the economy and its wide range of applications to the grid. Furthermore, advanced storage technology is essential for integrating renewable energy, as variable solar and wind power gain ground in the national and global energy portfolio. The advancements in energy storage that have directly followed federal initiatives like the opening of JCESR and the issuance of FERC Orders No. 755 and 1000, demonstrate the importance of the government and private sector working together to develop energy storage for a more reliable U.S. electricity grid.

This issue brief is available electronically (with hyperlinks and endnotes) at www.eesi.org/papers.

Author: Ben Wolkon
Editor: Blaise Sheridan

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