Environmental and Energy Study Institute

Fact Sheet

Energy Storage

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Due to growing concerns about the environmental impacts of fossil fuels and the capacity and resilience of energy grids around the world, engineers and policymakers are increasingly turning their attention to energy storage solutions. Indeed, energy storage can help address the intermittency of solar and wind power; it can also, in many cases, respond rapidly to large fluctuations in demand, making the grid more responsive and reducing the need to build backup power plants. The effectiveness of an energy storage facility is determined by how quickly it can react to changes in demand, the rate of energy lost in the storage process, its overall energy storage capacity, and how quickly it can be recharged.

Energy storage is not new. Batteries have been used since the early 1800s, and pumped-storage hydropower has been operating in the United States since the 1920s. But the demand for a more dynamic and cleaner grid has led to a significant increase in the construction of new energy storage projects, and to the development of new or better energy storage solutions.

Fossil fuels are the most used form of energy, partly due to their transportability and the practicality of their stored form, which allows generators considerable control over the rate of energy supplied. In contrast, the energy generated by solar and wind is intermittent and reliant on the weather and season. As renewables have become increasingly prominent on the electrical grid, there has been a growing interest in systems that store clean energy

Energy storage can also contribute to meeting electricity demand during peak times, such as on hot summer days when air conditioners are blasting or at nightfall when households turn on their lights and electronics. Electricity becomes more expensive during peak times as power plants have to ramp up production in order to accommodate the increased energy usage. Energy storage allows greater grid flexibility as distributors can buy electricity during off-peak times when energy is cheap and sell it to the grid when it is in greater demand.[1]

As extreme weather exacerbated by climate change continues to devastate U.S. infrastructure, government officials have become increasingly mindful of the importance of grid resilience. Energy storage helps provide resilience since it can serve as a backup energy supply when power plant generation is interrupted. In the case of Puerto Rico, where there is minimal energy storage and grid flexibility, it took approximately a year for electricity to be restored to all residents.[2]

The International Energy Association (IEA) estimates that, in order to keep global warming below 2 degrees Celsius, the world needs 266 GW of energy storage by 2030, up from 176.5 GW in 2017.[3] Under current trends, Bloomberg New Energy Finance predicts that the global energy storage market will hit that target, and grow quickly to a cumulative 942 GW by 2040 (representing $620 billion in investment over the next two decades).[4]

ENERGY STORAGE TODAY

In 2017, the United States generated 4 billion megawatt-hours (MWh) of electricity,[5] but only had 431 MWh of electricity storage available.[6] Pumped-storage hydropower (PSH) is by far the most popular form of energy storage in the United States, where it accounts for 95 percent of utility-scale energy storage. According to the U.S. Department of Energy (DOE), pumped-storage hydropower has increased by 2 gigawatts (GW) in the past 10 years.[7] In 2015, the United States had 22 GW of PSH storage incorporated into the grid.[8] Yet, despite the widespread use of PSH, in the past decade the focus of technological advancement has been on battery storage.

By December 2017, there was approximately 708 MW of large-scale battery storage operational in the U.S. energy grid.[9] Most of this storage is operated by organizations charged with balancing the power grid, such as Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs). ISOs and RTOs are "independent, federally-regulated non-profit organizations"[9] that control regional electricity pricing and distribution.

PJM, a regional transmission organization located in 13 eastern states (including Pennsylvania, West Virginia, Ohio and Illinois), has the largest amount of large-scale battery installations, with a storage capacity of 278 MW at the end of 2017. The second biggest owner of large-scale battery capacity is California's ISO (CAISO). By the end of 2017, CAISO operated batteries with a total storage capacity of 130MW.[9]

Most of the battery storage projects that ISOs/RTOs develop are for short-term energy storage and are not built to replace the traditional grid. Most of these facilities use lithium-ion batteries, which provide enough energy to shore up the local grid for approximately four hours or less. These facilities are used for grid reliability, to integrate renewables into the grid, and to provide relief to the energy grid during peak hours.[9]

There is also a limited market for small-scale energy storage. While a minor portion of the small-scale storage capacity in the United States is for residential use, most of it is for use in the commercial sector—and most of these commercial projects are located in California.[9]

In the past decade, the cost of energy storage, solar and wind energy have all dramatically decreased, making solutions that pair storage with renewable energy more competitive. In a bidding war for a project by Xcel Energy in Colorado, the median price for energy storage and wind was $21/MWh, and it was $36/MWh for solar and storage (versus $45/MWh for a similar solar and storage project in 2017).[10] This compares to $18.10/MWh and $29.50/MWh, respectively, for wind and solar solutions without storage, but is still a long way from the $4.80/MWh median price for natural gas.[11] Much of the price decrease is due to the falling costs of lithium-ion batteries; from 2010 to 2016 battery costs for electric vehicles (similar to the technology used for storage) fell 73 percent.[12] A recent GTM Research report estimates that the price of energy storage systems will fall 8 percent annually through 2022.[13]

SELECTED ENERGY STORAGE TECHNOLOGIES

There are many different ways of storing energy, each with their strengths and weaknesses. The list below focuses on technologies that can currently provide large storage capacities (of at least 20 MW). It therefore excludes superconducting magnetic energy storage and supercapacitors (with power ratings of less than 1 MW).

	Max Power Rating (MW)	Typical Discharge time	*Max cycles* or lifetime	Energy density (watt-hour per liter)	Efficiency
Pumped hydro	3,000	4h – 16h	30 – 60 years	0.2 – 2	70 – 85%
Compressed air	1,000	2h – 30h	20 – 40 years	2 – 6	40 – 70%
Molten salt (thermal)	150	hours	30 years	70 – 210	80 – 90%
Li-ion battery	100	1 min – 8h	*1,000 – 10,000*	200 – 400	85 – 95%
Lead-acid battery	100	1 min – 8h	6 – 40 years	50 – 80	80 – 90%
Flow battery	100	hours	*12,000 – 14,000*	20 – 70	60 – 85%
Hydrogen	100	mins – week	5 – 30 years	600 (at 200bar)	25 – 45%
Flywheel	20	secs - mins	*20,000 – 100,000*	20 – 80	70 – 95%

Characteristics of selected energy storage systems (source: The World Energy Council)[21]

Pumped-Storage Hydropower

Pumped-storage hydro (PSH) facilities are large-scale energy storage plants that use gravitational force to generate electricity. Water is pumped to a higher elevation for storage during low-cost energy periods and high renewable energy generation periods. When electricity is needed, water is released back to the lower pool, generating power through turbines.[14] Recent innovations have allowed PSH facilities to have adjustable speeds,[15] in order to be more responsive to the needs of the energy grid, and also to operate in closed-loop systems. A closed loop PSH operates without being connected to a continuously flowing water source, unlike traditional pumped-storage hydropower, making pumped-storage hydropower an option for more locations.[15]

In comparison to other forms of energy storage, pumped-storage hydropower can be cheaper, especially for very large capacity storage (which other technologies struggle to match). According to the Electric Power Research Institute, the installed cost for pumped-storage hydropower varies between $1,700 and $5,100/kW, compared to $2,500/kW to 3,900/kW for lithium-ion batteries.[16] Pumped-storage hydropower is more than 80 percent energy efficient through a full cycle,[15] and PSH facilities can typically provide 10 hours of electricity, compared to about 6 hours for lithium-ion batteries. Despite these advantages, the challenge of PSH projects is that they are long-term investments: permitting and construction can take 3-5 years each. This can scare off investors who would prefer shorter-term investments, especially in a fast-changing market.

In Bath County, Virginia, the largest pumped-hydro storage facility in the world supplies energy to about 750,000 homes. It was built in 1985 and has an output of approximately 3 GW of energy.[17]

Compressed Air Energy Storage (CAES)

With compressed air storage, air is pumped into an underground hole, most likely a salt cavern, during off-peak hours when electricity is cheaper. When energy is needed, the air from the underground cave is released back up into the facility, where it is heated and the resulting expansion turns an electricity generator. This heating process usually uses natural gas, which releases carbon; however, CAES triples the energy output of facilities using natural gas alone. CAES can achieve up to 70 percent energy efficiency when the heat from the air pressure is retained, otherwise efficiency is between 42 and 55 percent. Currently, there are only two operating CAES facilities: one in McIntosh, Alabama and one in Huntorf, Germany.[18] The McIntosh plant, which was built in 1991, has 110 MW of energy storage.[19] A 317 MW CAES plant is under construction in Anderson County, Texas.[20]

Thermal (including Molten Salt)

Thermal energy storage facilities use temperature to store energy. When energy needs to be stored, rocks, salts, water, or other materials are heated and kept in insulated environments. When energy needs to be generated, the thermal energy is released by pumping cold water onto the hot rocks, salts, or hot water in order to produce steam, which spins turbines. Thermal energy storage can also be used to heat and cool buildings instead of generating electricity.[21] For example, thermal storage can be used to make ice overnight to cool a building during the day. Thermal efficiency can range from 50 percent to 90 percent depending on the type of thermal energy used.[22]

Lithium-ion Batteries

First commercially produced by Sony in the early 1990s, lithium-ion batteries were originally used primarily for small-scale consumer items such as cellphones. Recently, they have been used for larger-scale battery storage and electric vehicles.[23] At the end of 2017, the cost of a lithium-ion battery pack for electric vehicles fell to $209/kWh, assuming a cycle life of 10-15 years. Bloomberg New Energy Finance predicts that lithium-ion batteries will cost less than $100 kWh by 2025.[24]

Lithium-ion batteries are by far the most popular battery storage option today and control more than 90 percent of the global grid battery storage market.[25] Compared to other battery options, lithium-ion batteries have high energy density and are lightweight.[26] New innovations, such as replacing graphite with silicon to increase the battery's power capacity, are seeking to make lithium-ion batteries even more competitive for longer-term storage.[27]

Additionally, lithium-ion batteries are now frequently used in developing countries for rural electrification.[28] In rural communities, lithium-ion batteries are paired with solar panels to allow households and businesses to use limited amounts of electricity to charge cell phones, run appliances, and light buildings. Previously, such communities had to rely on dirty and expensive diesel generators, or did not have access to electricity.

When the Aliso Canyon natural gas facility leaked in 2015, California rushed to use lithium-ion technology to offset the loss of energy from the facility during peak hours. The battery storage facilities, built by Tesla, AES Energy Storage and Greensmith Energy, provide 70 MW of power, enough to power 20,000 houses for four hours.[29]

Hornsdale Power Reserve in Southern Australia is the world's largest lithium-ion battery and is used to stabilize the electrical grid with energy it receives from a nearby wind farm. This 100 MW battery was built by Tesla and provides electricity to more than 30,000 households.[30]

General Electric has designed 1 MW lithium-ion battery containers that will be available for purchase in 2019. They will be easily transportable and will allow renewable energy facilities to have smaller, more flexible energy storage options.[31]

Lead-acid Batteries

Lead-acid batteries were among the first battery technologies used in energy storage. However, they are not popular for grid storage because of their low-energy density and short cycle and calendar life.[32] They were commonly used for electric cars, but have recently been largely replaced with longer-lasting lithium-ion batteries.[33]

Flow Batteries

Flow batteries are an alternative to lithium-ion batteries. While less popular than lithium-ion batteries—flow batteries make up less than 5 percent of the battery market—flow batteries have been used in multiple energy storage projects that require longer energy storage durations.[34] Flow batteries have relatively low energy densities and have long life cycles, which makes them well-suited for supplying continuous power. The Avista Utilities plant in Washington state, for instance, uses flow battery storage.[35]

A 200 MW (800 MWh) flow battery is currently being constructed in Dalian, China. This system will not only overtake the Hornsdale Power Reserve as the world's biggest battery, but it will also be the only large-scale battery (>100 MW) that is made up of flow batteries instead of lithium ion batteries.[36]

Solid State Batteries

Solid state batteries have multiple advantages over lithium-ion batteries in large-scale grid storage. Solid-state batteries contain solid electrolytes which have higher energy densities and are much less prone to fires than liquid electrolytes, such as those found in lithium-ion batteries. Their smaller volumes and higher safety make solid-state batteries well suited for large-scale grid applications.[37]

However, solid state battery technology is currently more expensive than lithium-ion battery technology because it is less developed. Fast-growing lithium-ion production has led to economies of scale, which solid-state batteries will find hard to match in the coming years.[38]

Hydrogen

Hydrogen fuel cells, which generate electricity by combining hydrogen and oxygen, have appealing characteristics: they are reliable and quiet (with no moving parts), have a small footprint and high energy density, and release no emissions (when running on pure hydrogen, their only byproduct is water). The process can also be reversed, making it useful for energy storage: electrolysis of water produces oxygen and hydrogen. Fuel cell facilities can, therefore, produce hydrogen when electricity is cheap, and later use that hydrogen to generate electricity when it is needed (in most cases, the hydrogen is produced in one location, and used in another). Hydrogen can also be produced by reforming biogas, ethanol, or hydrocarbons, a cheaper method that emits carbon pollution. Though hydrogen fuel cells remain expensive (primarily because of their need for platinum, an expensive metal), they are being used as primary and backup power for many critical facilities (telecom relays, data centers, credit card processing…).

Flywheels

Flywheels are not suitable for long-term energy storage, but are very effective for load-leveling and load-shifting applications. Flywheels are known for their long-life cycle, high-energy density, low maintenance costs, and quick response speeds. Motors store energy into flywheels by accelerating their spins to very high rates (up to 50,000 rpm). The motor can later use that stored kinetic energy to generate electricity by going into reverse. Flywheels are commonly left in a vacuum so as to minimize air friction, which would slow the wheel.[39] The Stephentown Spindle in Stephentown, New York, unveiled in 2011 with an energy capacity of 20 MW,[40] was the first commercial use of flywheel technology to regulate the grid in the United States. Several other flywheel facilities have since come on line.

Storage and Electric Vehicles

Energy storage is especially important for electric vehicles (EVs). As electric vehicles become more widespread, they will increase electricity demand at peak times, as professionals come home from work and plug in their cars for a nightly recharge. To prevent the need for new power plants to meet this extra demand, electricity will need to be stored during off-peak times. Storage is also important for households that generate their own renewable electricity: a car cannot be charged overnight by solar energy without a storage system.

Interestingly, electric vehicles can be used as back-up storage during periods of grid failure or spikes in demand. Although most EVs today are not designed to supply energy back into the grid, vehicle-to-grid (V2G) cars can store electricity in car batteries and then transfer that energy back into the grid later. EV batteries can still be used in grid storage even after they are taken off the road: utilities are using the batteries from retired EVs as second-hand energy storage. Such batteries can be used to store electricity for up to a decade for grid applications.[41] An example of this can be found in Elverlingsen, Germany, where almost 2,000 batteries from Mercedes Benz EVs were collected to create a stationary grid-sized battery that can hold almost 9 MW of energy.[42]

Federal and State Energy Storage Policies

In February 2018, the Federal Energy Regulatory Commission (FERC) unanimously approved Order No. 841, which required Independent System Operators and Regional Transmission Organizations to remove barriers to entry for energy storage technologies, by having these groups reevaluate their tariffs. The FERC believes this will lead to greater market competition in the energy grid sector.[43]

In May 2018, the Department of Energy's Advanced Research Projects Agency (ARPA-E) committed up to $30 million in funding for long-term energy storage innovation. The funding went to the Duration Addition to electricitY Storage (DAYS) program, which focuses on developing new technologies that can make it possible for energy storage facilities in all U.S. regions to power an electrical grid for up to 100 hours.[44]

Several U.S. states have taken a keen interest in energy storage, and their policies can serve as inspiration for others.

- **Hawaii**, where importing fossil fuels is very costly, has been at the forefront of the transition to renewables and energy storage. Two recent Hawaiian Electric Industries projects come in at 8 cents per kilowatt-hour, half as much as the price for fossil fuel generation in the state.[45]
- **Massachusetts** passed H.4857 in July of 2018, setting a goal of 1,000 MWh of energy storage by the end of 2025.[46]
- **New York** Governor Andrew Cuomo announced in January 2018 that New York had set a goal of reaching 1,500 MW's worth of energy storage by 2025. Under this directive, New York Green Bank has agreed to invest $200 million towards energy storage technologies.[47]
- **California's** three largest electric cooperatives have been mandated to develop a combined energy storage capacity of 1,325 MW by the end of 2024. An extra 500 MW was added to the mandate in 2016.[48]
- In **Oregon,** law HB 2193 mandates that 5 MWh of energy storage must be working in the grid by 2020.[49]
- **New Jersey** passed A3723 in 2018 that sets New Jersey’s energy storage target at 2,000 MW by 2030.[50]
- **Arizona** State Commissioner Andy Tobin has proposed a target of 3,000 MW in energy storage by 2030.[51]

This fact sheet is available electronically (with hyperlinks and endnotes) at *www.eesi.org/papers*.

Author: Alexandra Zablocki
Editors: Carol Werner, Amaury Laporte

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