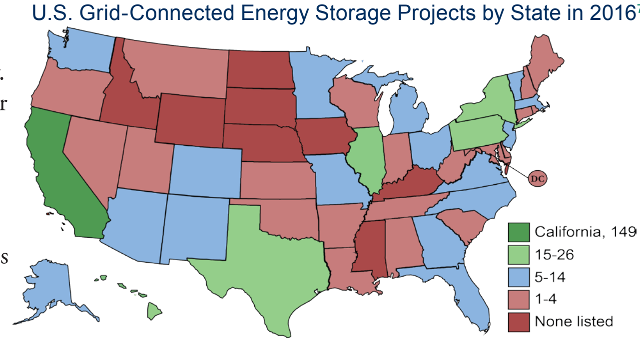
U.S. Grid Energy Storage

Electrical Energy Storage (EES) refers to the process of converting electrical energy into a stored form that can later be converted back into electrical energy when needed.[1] Batteries are the principal devices used for EES. The first battery—called Volta's cell—was developed in 1800 and the first U.S. large-scale energy storage facility was the Rocky River Pumped Storage plant in 1929, on the Housatonic River in Connecticut.[2,3] Research in energy storage has increased dramatically, especially after the first U.S. oil crisis in the 1970s, and with advancements in the cost and performance of rechargeable batteries.[2,4] The impact energy storage can have on the current and future energy grid are substantial.[5]

- EES systems are often expressed by rated power in megawatts (MW) and energy storage capacity in megawatt-hours (MWh): the maximum charge/discharge power and the amount of energy capable of being stored, respectively.[6]
- As of June 2016, the U.S. had over 21.6 GW of rated power in energy storage compared to 1,068 GW of total in service installed generation capacity.[7,8] Globally, installed energy storage totaled 149.91 GW.[7]
- 2.5% of delivered electric power in the U.S. is cycled through a storage facility. For comparison, 10% of delivered power in Europe and 15% of delivered power in Japan are cycled through energy storage facilities.[9]
- Globally, 1,060 energy storage projects were operational in 2016, with 196 projects under construction. 39% of operational projects and 33% of projects under construction are located in the U.S.[7]
- California is leading the nation in energy storage with 149 operational projects (4.03 GW), followed by Virginia with 3.25GW and Texas with 24 projects.[7]
- U.S. energy storage projects increased by 105% from 2013 to 2016.[7,10]

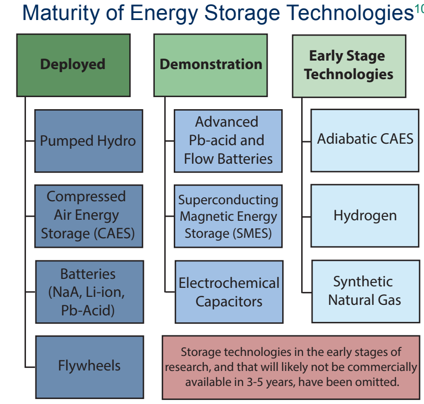
U.S. Grid-Connected Energy Storage Projects by State in 2016[7]



Deployed Technologies

Several EES technologies are in research phases, but four storage technology types are considered deployed: Pumped Hydroelectric Storage (PHS), Compressed Air Energy Storage (CAES), Advanced Battery Energy Storage (ABES), and Flywheel Energy Storage (FES).[10] Thermal Energy Storage (TES) is also considered deployed. PHS and CAES are large-scale technologies capable of discharge times of tens of hours but are geographically limited.[10] ABES and FES have lower power and shorter discharge times (from seconds to 6 hours) but are often not limited by geography. FES also suffers from short durations of storing energy (without significant self-discharge).[10]

Maturity of Energy Storage Technologies[10]



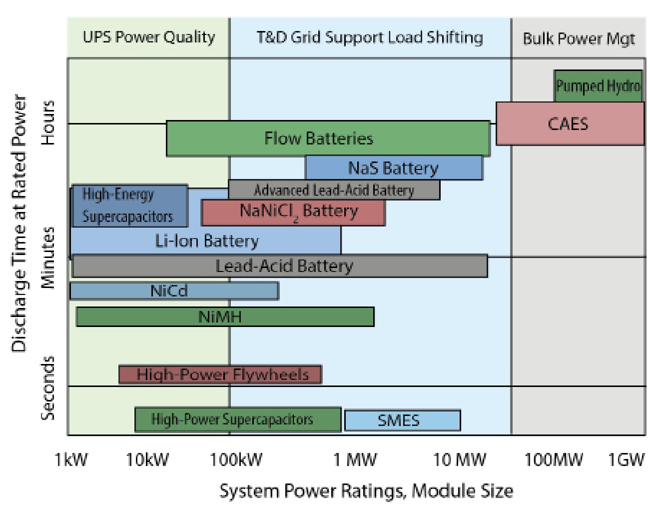
Pumped Hydroelectric Storage (PHS)

- PHS systems generate electricity by pumping water from a low to a high reservoir, releasing the water from the higher reservoir through a hydroelectric turbine when electricity is needed.[10]
- 95% of U.S. energy storage is from PHS, equating to 20.4 GW as of June 2016.[7,10]
- PHS plants have long lifetimes (50-60 years) and operate at 76-85% efficiency.[10]

Compressed Air Energy Storage (CAES)

- CAES captures and stores compressed air in an underground cavern. To create electricity, the pressurized air is heated and expanded in an expansion turbine, driving a generator.[12,13]
- As of June 2016, there are 3 operating CAES systems in the U.S. with a combined rated power of 0.114 GW.[7]
- Existing CAES plants are based on the diabatic method, where the compression of the combustion air is separate from the gas turbine. The diabatic method can generate 3 times the output for every natural gas input, reduce CO_2 emissions by 40-60%, and enable plant efficiencies of 42-55%.[13]

Characteristics of Energy Storage Technologies[11]



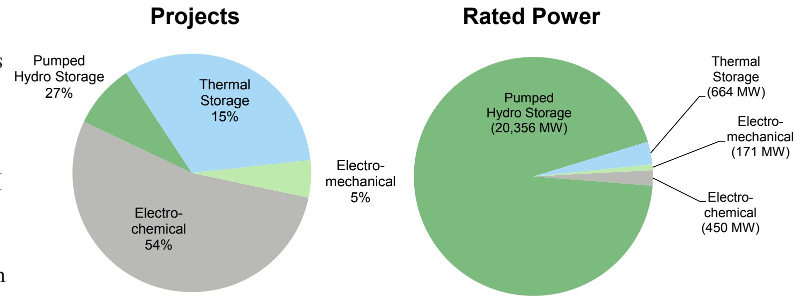
Advanced Battery Energy Storage (ABES)

- ABES stores electrical energy in the form of chemical energy, which is then converted back into electricity when needed.[14]
- Batteries contain two electrodes (anode and cathode), two terminals composed of different chemicals, and the electrolyte that separates the terminals.[2,14] The electrolyte enables the flow of ions between the two electrodes and external wires to allow for electrical charge to flow.[14]
- The U.S. has several operational battery-related energy storage projects based on lead-acid, lithium-ion, nickel-based, sodium-based, and flow batteries.[7] These batteries account for 0.380 GW of rated power in 2016 and have efficiencies between 60-95%.[7,15]

Flywheel Energy Storage (FES)

- FES is mainly used for power management rather than longer-term energy storage. FES systems store electric energy via kinetic energy by spinning a rotor in a frictionless enclosure.[16] The rotor is sped up or down to shift energy to or from the grid, which steadies the power supply.[10]
- There are two categories of FES: low-speed and high-speed. These systems rotate at rates up to 10,000 and 100,000 RPM (rotations per minute), respectively, and are best used for high power/low energy applications.[16]
- In 2016, flywheels accounted for 0.058 GW of rated power in the U.S. and have efficiencies between 85-87%.[7,15]

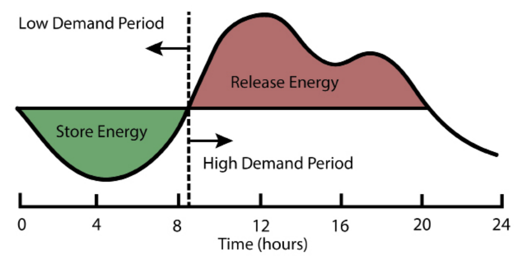
U.S. Energy Storage Projects by Technology Type in 2016[7]
(Including Announced Projects)



Applications

- EES has many applications, including energy arbitrage, generation capacity deferral, ancillary services, ramping, transmission and distribution capacity deferral, and end-user applications (e.g., managing energy costs, power quality and service reliability, and renewable curtailment).[18]
- EES can operate at partial output levels with fewer losses and can respond quickly to adjustments in electricity demand.[19] Much of the current energy infrastructure is approaching—or beyond—its intended lifetime.[20] Storing energy during low demand (off-peak periods) and using that energy during high demand (on-peak periods) saves money and prolongs the lifetime of energy infrastructure.[17]
- Many renewable energy options, such as wind and solar, have intermittent power. Energy storage systems can enable these technologies to store excess energy for times when the sun is not shining and the wind is not blowing, making them more competitive with fossil fuel-based energy sources.[21]

Daily Energy Storage and Load Leveling[17]



Five Categories of Energy Storage Applications[19]

1) Electric Supply	g) Voltage Support	m) Demand Charge Management
a) Electric Energy Time-shift	**3) Grid System**	n) Electric Service Reliability
b) Electric Supply Capacity	h) Transmission Support	o) Electric Service Power Quality
2) Ancillary Services	i) Transmission Congestion Relief	**5) Renewables Integration**
c) Load Following	j) Transmission & Distribution Upgrade Deferral	p) Renewable Energy Time-shift
d) Area Regulation	k) Substation On-site Power	q) Renewables Capacity Firming
e) Electric Supply Reserve Capacity	**4) End User/Utility Customer**	r) Wind Generation Grid Integration
f) Voltage Support	l) Time-of-use Energy Cost Management	

Solutions

Research & Development

- The U.S. Department of Energy (DOE) administered $185 million of the American Recovery and Reinvestment Act (ARRA) stimulus funding to support 16 large-scale energy storage projects with a combined capacity of over 0.53 GW.[22]
- Storage technologies are becoming more efficient and economically viable. One study found that the economic value of energy storage at maximum market potential in the U.S. is $228.4 billion over a 10 year period.[19]
- Lithium-ion batteries are one of the fastest-growing energy storage markets due to their high energy densities, high power, near 100% efficiency, and low self-discharge.[23,24] The U.S. has 38,000 tonnes of lithium in reserves alone, capable of powering 13-27 million electric vehicles (EVs) or 5-10% of U.S. vehicles (automobiles, buses, trucks, and motorcycle).[25,26] Globally, there are 14 million tonnes of Li reserves.[25]

Policy & Standardization

- The Energy Independence and Security Act of 2007 enabled an Energy Storage Technologies Subcommittee to form through the Electricity Advisory Committee (EAC), where members assess and advise the U.S. DOE every two years on progress of domestic energy storage goals.[22]
- In 2010, California approved Assembly Bill 2514, requiring the California Public Utilities Commission (CPUC) to set and meet energy storage procurement targets for investor-owned utilities, totaling 1.33 GW of storage capacity completed by 2020 and implemented by 2024.[27]
- In July of 2013, the U.S. Federal Energy Regulatory Commission (FERC) issued Order No. 784, which revises the accounting and reporting requirements for public utilities to better account for the use of energy storage devices.[28] This enables utility customers to take advantage of lower-cost and more precise ancillary services and provides opportunities for developing energy storage technologies.[29]

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