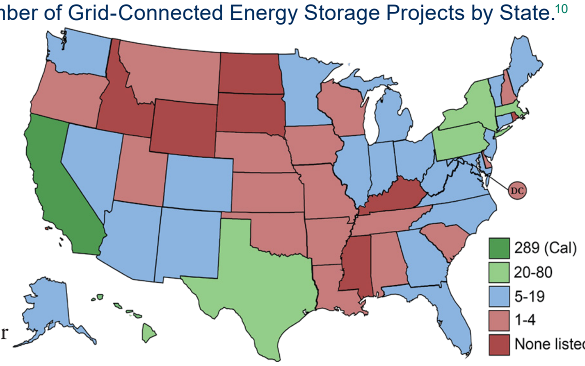
U.S. Grid Energy Storage

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 one of the most common forms of electrical energy storage, ubiquitous in most peoples' lives. The first battery—called Volta's cell—was developed in 1800. 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 resulted in advancements in the cost and performance of rechargeable batteries.[2,4,5] The impact energy storage can have on the current and future sustainable energy grid is substantial.[6]

- EES systems are characterized by rated power in kilowatts (kW) and energy storage capacity in kilowatt-hours (kWh).[7]
- In 2022, the rated power of U.S. EES was 31.6 GW compared to 1,167 GW of total installed generation.[8,9] Globally, the rated power of installed EES was 174 GW.[10]
- In 2021, 1,595 energy storage projects were operational globally, with 125 projects under construction. 51% of operational projects are located in the U.S.[10]
- California leads the U.S. in energy storage with 289 operational projects (5.6 GW), followed by Massachusetts, Texas, and New York.[10]

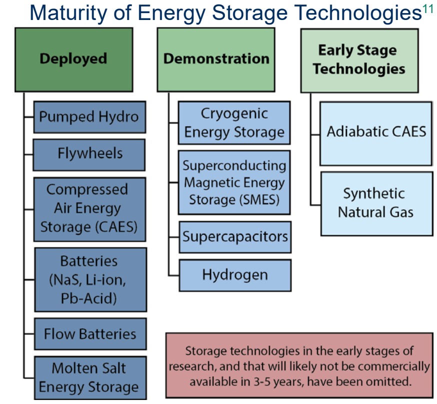
Number of Grid-Connected Energy Storage Projects by State.[10]



Deployed Technologies

Key EES technologies include: Pumped Hydroelectric Storage (PHS), Compressed Air Energy Storage (CAES), Advanced Battery Energy Storage (ABES), Flywheel Energy Storage (FES), Thermal Energy Storage (TES), and Hydrogen Energy Storage (HES).[13] PHS and CAES are large-scale technologies capable of discharge times of tens of hours and power capacities up to 1 GW, but are geographically limited. ABES and FES have lower power and shorter discharge times (from seconds to 6 hours), but are often not limited by geography.[14]

Maturity of Energy Storage Technologies[11]



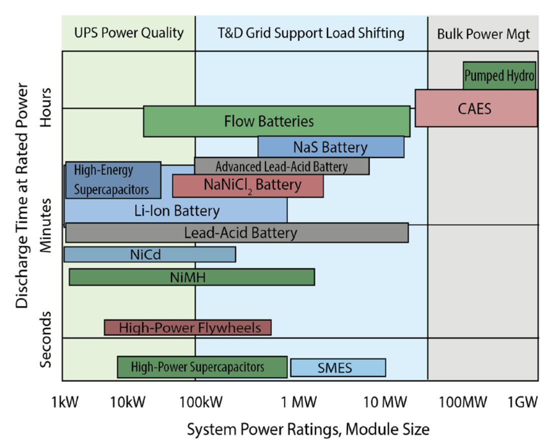
Pumped Hydroelectric Storage (PHS)

- PHS systems pump water from a low to high reservoir and, when electricity is needed, water is released through a hydroelectric turbine, generating electricity from kinetic energy.[14,15]
- Globally, 96% of energy storage is from PHS.[15]
- PHS plants have long lifetimes (50-60 years) and operational efficiencies between 70 and 85%.[14,15]

Compressed Air Energy Storage (CAES)

- CAES systems store compressed air in an underground cavern. The pressurized air is heated and expanded in a natural gas combustion turbine, driving a generator.[16,17]
- Existing CAES plants are diabatic, 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, reduces CO_2 emissions by 40-60%, and enables plant efficiencies of 42-55%.[17]
- As of August 2019, there were 2 CAES plants operating in the U.S. and Germany. The U.S. facility is a 110 MW plant in Alabama.[18]

Characteristics of Energy Storage Technologies[12]



Advanced Battery Energy Storage (ABES)

- ABES stores electrical energy in the form of chemical energy.[19]
- Batteries contain two electrodes (anode and cathode) composed of different materials and an electrolyte that separates the electrodes. The electrolyte enables the flow of ions between the two electrodes and external wires allow for electrical charge to flow.[19]
- The U.S. has over 580 operational battery-related energy storage projects using lead-acid, lithium-ion, nickel-based, sodium-based, and flow batteries.[10] These projects account for 4.8 GW of rated power in 2021 and have round-trip efficiencies (the ratio of net energy discharged to the grid to the net energy used to charge the battery) between 60-95%.[10,20]

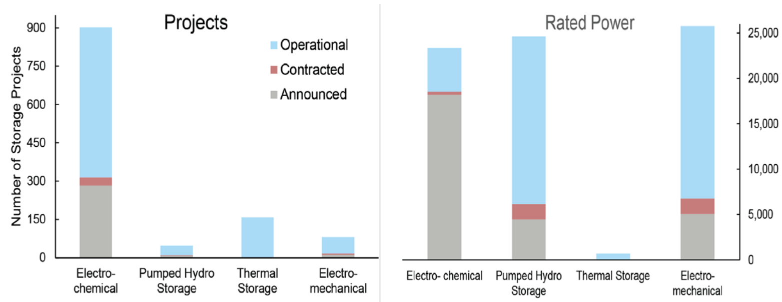
Flywheel Energy Storage (FES)

- FES systems store kinetic energy by spinning a rotor in a low-friction enclosure, and are used mainly for grid management rather than long-term energy storage.[17] The rotor changes speed to shift energy to or from the grid, as needed for grid stability.[14]
- In 2021, flywheels account for 0.10 GW of rated power in the U.S. with efficiencies between 85-87%.[10,20]
- There are two categories of FES: low-speed and high-speed. These systems rotate at rates up to 10,000 and 100,000 RPM (revolutions per minute), respectively, and are best used for high power/low energy applications.[17]

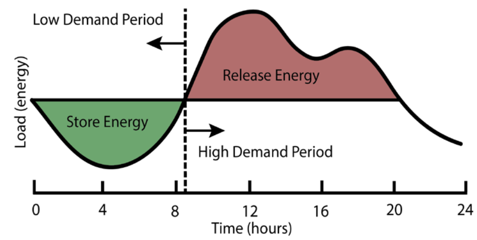
Applications

- EES systems have 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).[22]
- EES can operate at partial output levels with low losses and can respond quickly to changes in electricity demand.[23] Much of the current energy infrastructure is approaching—or beyond—its intended lifetime.[24] Storing energy in off-peak hours and using that energy during peak hours saves money and prolongs the lifetime of energy infrastructure.[21]
- Round-trip efficiency, annual degradation, and generator heat rate have a moderate to strong influence on the environmental performance of grid connected energy storage.[25]
- Energy storage will help with the adoption of renewable energy by storing excess energy for times when renewable energy sources are unavailable.[26]

U.S. Energy Storage Projects by Technology Type in 2021[10]



Daily Energy Storage and Load Leveling[21]



Solutions

Research & Development

- The U.S. Department of Energy (DOE) administered $185 million of the American Recovery and Reinvestment Act (ARRA) funding to support 16 large-scale energy storage projects with a combined power capacity of over 0.53 GW.[27]
- Storage technologies are becoming more efficient and economically viable. One study found that the economic value of energy storage in the U.S. is $228.4 billion over a 10 year period.[23]
- Lithium-ion batteries are one of the fastest-growing energy storage technologies due to their high energy densities, high power, near 100% efficiency, and low self-discharge.[28,29] The U.S. has 1 million metric tons (Mt) of lithium reserves; globally, there are 26 Mt of reserves.[30]
- Long-term (10-100 hours) and seasonal (100+ hours) energy storage are also important areas of research. Hydrogen, compressed air, and hydropower are the most viable technologies for these types of storage.[31]
- When designing EES, ensure system deployment results in a net reduction in environmental impacts.[32]

Five Categories of Energy Storage Applications[23]

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

Policy & Standardization

- The Energy Independence and Security Act of 2007 enabled an Energy Storage Technologies Subcommittee through the Electricity Advisory Committee (EAC), whose members assess and advise the U.S. DOE every two years on progress towards domestic energy storage goals.[27]
- 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.[33] Massachusetts, Nevada, New Jersey, New York, Oregon and Virginia all have similar mandates.[34]
- In 2018, the U.S. Federal Energy Regulatory Commission (FERC) issued Order No. 841, which requires wholesale electricity markets to establish participation models that recognize energy storage's physical and operational characteristics. The order builds on past FERC Orders No. 755 and No. 784.[35]
- The 2022 Inflation Reduction Act was passed to accelerate the clean energy transition. Its provisions include incentives, like the Investment Tax Credit, for energy storage systems.[36]

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