The expansion of renewable generation spurs investment, innovation in long-duration energy storage

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ByClarion Energy Content Directors


A rendering of Form Energy's iron-air battery. Image: Form Energy

By Drew Robb

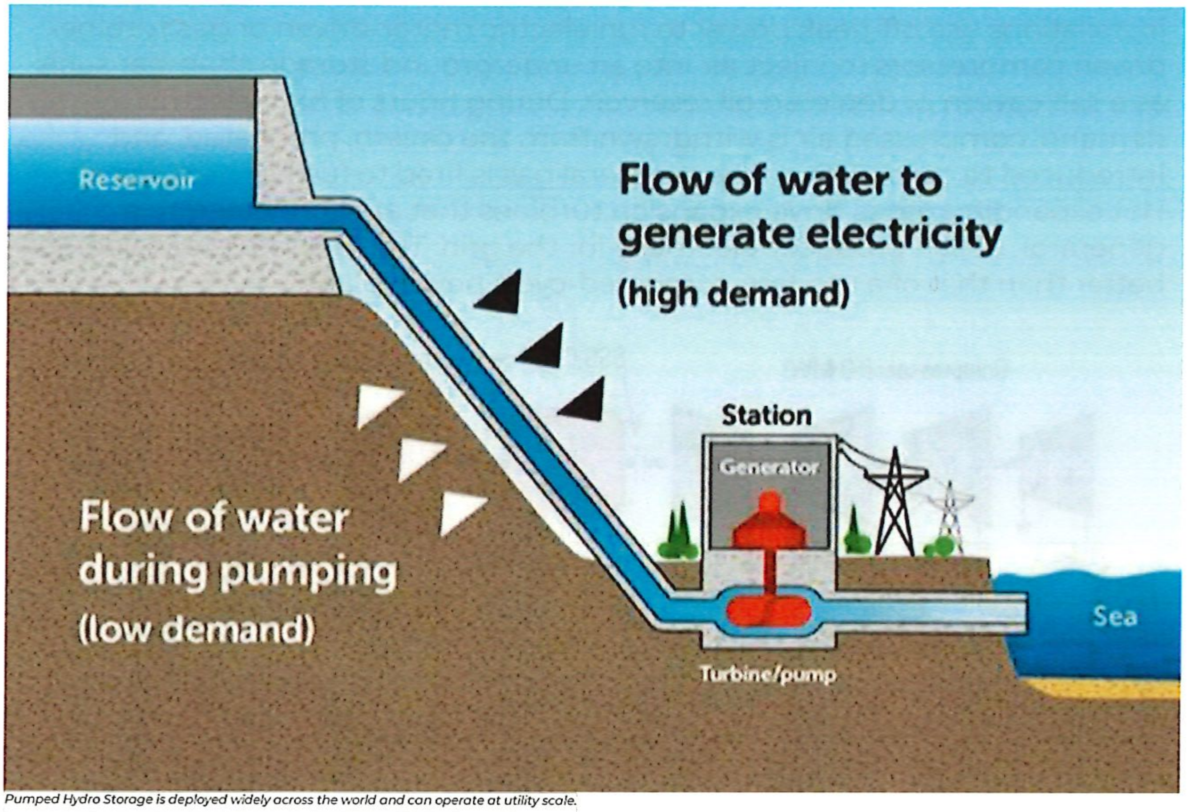
The U.S. Department of Energy (DOE) estimates that the U.S. will need 700 to 900 GW of additional capacity to reach net-zero emissions by 2050. As well as natural gas and nuclear, a lot of that will come from renewables. Without energy storage, though, a significant portion of wind and solar energy will be wasted.

According to the U.S. Energy Information Administration (EIA), utility-scale generation of solar electricity averaged 63.1 Gigawatt hours (GWh) between 10:00 a.m. and 6:00 p.m. each day in the lower 48 states in August of 2024. That's 36% more than for the same hours in August of 2023. Unsurprisingly, California, Texas and Florida make up the bulk of new installations. However, these states often generate more solar energy than the grid can accept. Some solar operators are being told to curtail production, and not by a paltry amount. During 2024, California curtailed over 3 million MWh of solar energy. And the situation appears to be worsening. The quantity of solar power lost in 2024 is double what it was in 2021. There is so much excess power, at times, that it is even being shut off during the hottest parts of the day when demand is high.

No wonder there is so much attention on the funding of lithium-ion battery energy storage systems (BESS). The DOE announced over $3 billion in BESS grants in 2024 for 25 selected projects across 14 states. BESS provides up to four hours of energy storage. That's a good start. But longer-term forms of storage are urgently needed to increase the efficiency of a renewable-heavy grid. Here are some of the main options for long duration energy storage (LDES).

Mechanical energy storage

Mechanical energy storage solutions are among the most mature of the LDES options. This category includes two primary forms of mechanical technologies: compressed air energy storage (CAES) and pumped hydro systems. In addition, there are a collection of other alternatives, many of which are a variant of CAES. These include liquid air energy storage (LAES), thermal storage, CO2 cycle and gravity-based systems. The basic idea is to convert electrical energy into potential or kinetic energy that is later converted back to electricity.



Pumped Hydro Storage is deployed widely across the world and can operate at utility scale.

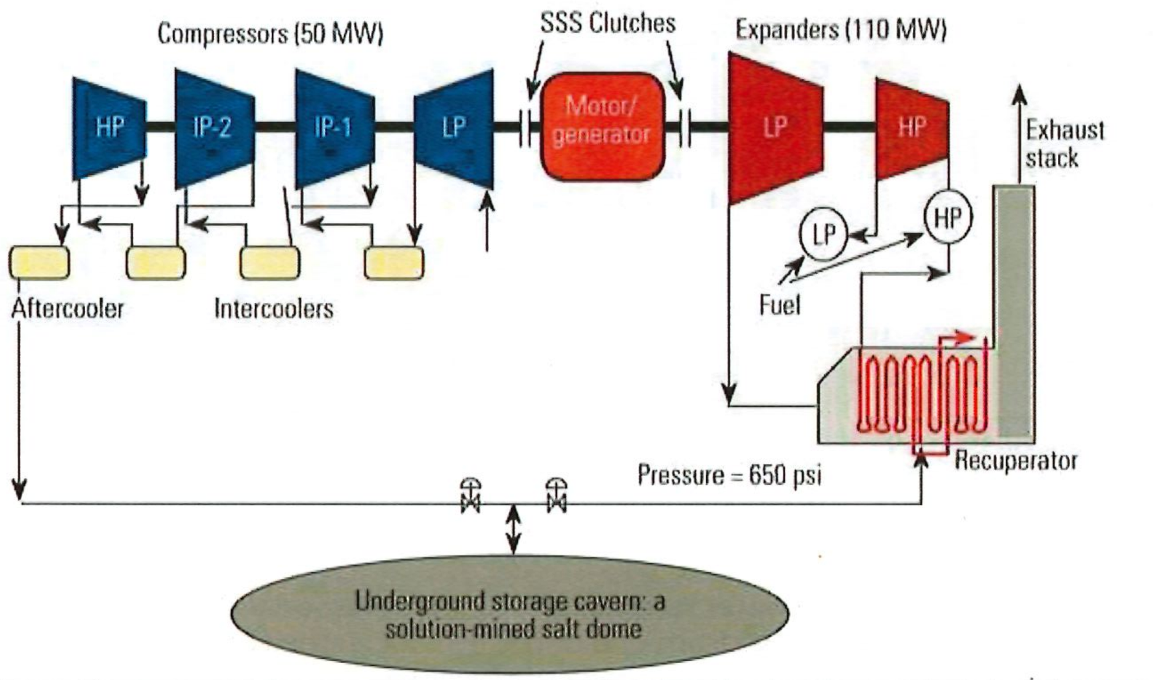
Pumped hydro

Pumped hydro uses two water reservoirs at different elevations to generate power as water moves down from one to the other. Electricity is produced via turbines in the same way as in hydroelectric facilities. The water is recovered in the lower reservoir and pumped up to the top for reuse. About 50 pumped hydro facilities exist in the U.S., adding up to 22 GW. The DOE is funding new projects, including one in Kentucky with EDF. Countries like Australia and Portugal have been adding facilities in recent years.

Compressed air energy storage

"CAES uses pressurized air and can provide efficiency rates as high as 80% in some advanced applications," said Megan Reusser, Hydrogen Technology Manager at Burns & McDonnell. "It is scalable, requires suitable underground storage, and has an emissions profile due to the use of natural gas combustion to generate power from the compressed air."

A handful of CAES plants are currently running: Huntorf, Germany (320 MW); McIntosh, Alabama (110 MW), and a couple of recent additions in China. These installations use off-peak power to run electric motor-driven or gas turbine-driven compressors to inject air into an underground storage chamber such as a salt cavern or depleted oil reservoir. During hours of high electric demand, compressed air is withdrawn from the cavern, preheated, and introduced to combustors where natural gas is fired to further heat the air. Hot expanding gases drive expansion turbines that are connected to a generator, which produces electricity for the grid. The fuel rate is considerably better than that of a modern combined-cycle power plant.



Compressed Air Energy Storage systems utilize compressors to store pressurized air underground, and turboexpanders and gas turbines to convert that stored resource into energy. SSS Clutches enable the plant to switch between driving the compressor or generating power.

For example, the McIntosh plant in Alabama is owned by utility PowerSouth. It comprises a single machinery train with two Siemens Energy compressors and expanders, a motor generator, and a huge salt cavern. It takes about 40 hours to compress the chambers, after which the generator can provide power at full capacity for about 25 hours. The unit performs emergency starts in nine minutes and the plant runs all year round. Its single powertrain consists of low pressure (LP), intermediate pressure (IP), and high pressure (HP) compressors, LP and HP turbo-expanders, and synchro-self-shifting (SSS) clutches manufactured by SSS Clutch. It is the engagement or disengagement of the clutches that controls whether the motor/generator is used to drive the compressor or generate grid power.

“The plant has been running successfully for more than 30 years,” said Morgan Hendry, President and CEO of SSS Clutch. “85% of the U.S. has geologic sites that could work for CAES. Northern Europe, too, has plenty of potential sites, some of which are already used for natural gas storage.”

In recent times, several CAES variants have arrived on the market:

· Canadian company Hydrostor plans to build the Willow Rock Energy Storage Center in Rosamond, California. This Advanced-CAES project will provide 500 MW of power, using a combination of air and water storage below ground.

· Highview Power has devised liquid air energy storage (LAES) that uses liquefied air instead of compressed air, with pilot projects lined up in Spain with small-scale versions already operating in the UK.

· Just-In-Time Energy offers an optimized LAES process that provides power from hot air expansion and improves project economics. The company is also developing a combined gas and electric storage system (CEGS) that replaces liquid air with liquefied natural gas (LNG). The CEGS system stores excess renewable electric energy as LNG and molten salt, mostly at off-peak times, returning the gas to the pipeline system at peak times while concurrently returning to the grid 95-120% of the power used to produce the LNG and heat the molten salt. The molten salt component allows the opportunistic storage of short bursts of renewable energy often available on sunny windy afternoons.

· Alliant Energy is working on the 20 MW Columbia Energy Storage Project in Wisconsin that will compress CO2 gas into a liquid as the storage medium.

· Corre Energy and Contour Energy are hoping to combine hydrogen and compressed CAES storage for a 280 MW project in Texas.

Other forms of energy storage

There are several other approaches to LDES at various stages of development:

Thermal energy storage systems

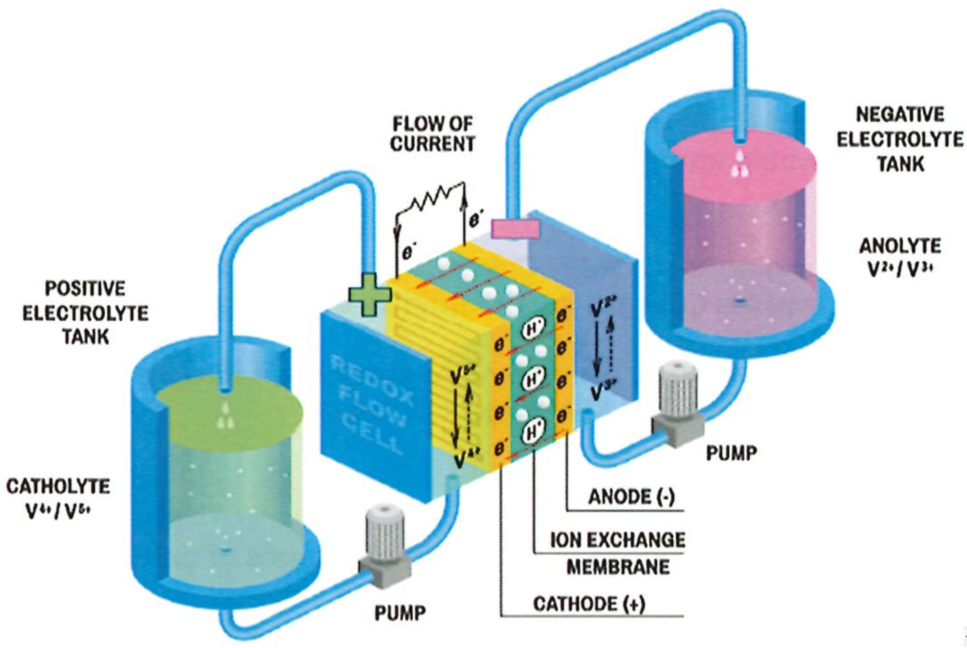
Thermal energy storage systems make use of latent heat, sensible heat and thermochemical processes to store energy as heat. In some cases, a phase change from a liquid to a vapor is involved. For example, heat can be transferred to a working fluid to produce steam via a turbine generator. In other examples, energy is transferred to molten salt or into bricks that retain heat. Such systems can be capital intensive and challenging to implement.

"Thermal energy storage makes sense where you need heat even more than power," said Reusser. "Due to costs, these systems are typically limited to large-scale applications."

Electrochemical energy storage systems

Electrochemical energy storage encompasses a variety of alternatives to BESS, such as flow batteries, metal anodes and static batteries. There are about 40 different chemistries of which a vanadium redox flow battery (VRFB) is the most common.

"The advantages of electrochemical storage include scalability, long lifespan, low risk of thermal runaway, and the fact that some use non-toxic materials," said Reusser. "The challenges include high initial costs for components and setup, lower energy density compared to lithium-ion, and the need for regular maintenance of pumps and valves."



Schematic for a flow battery. Courtesy of Burns McDonnell.

For example, Burns McDonnell provided 500kW (2.5MWh) of redox flow battery technology to the GridStar Flow Serial Number One site owned by Convergent Energy + Power in Andover, MA in 2020. The company is also involved in a cold weather flow battery demonstration project with the

University of Minnesota Morris and Ottertail Power for research purposes. When completed, it will provide 1 MW/6 MWh.

"This college is on an isolated microgrid and wants to find battery technology that can operate in cold conditions," said Reusser.

Iron-air batteries are a new approach being developed by Form Energy that are said to offer up to 100 hours of capacity. How does it work? When iron is exposed to oxygen, it rusts and releases electrons, which are used to provide electricity. When there is an excess amount of power, electrons flow back into the battery, and the process is reversed, unrusting the iron and recharging the battery. Form Energy is working with Great River Energy on the Cambridge Energy Storage Project. Located in Cambridge, MN, it will provide 1.5 MW of this experimental form of battery storage.

Chemical storage

Familiar forms of chemical storage involve the formation of ammonia or liquefied natural gas (LNG) via compression. More recently, excess renewable power is being used to create hydrogen via electrolysis. A host of electrolyzer projects are currently under development.

"The goal is to use excess renewable energy to create hydrogen and then store it to use later," said Reusser. "Chemical storage is a good way to transport energy and is often best if there is more interest in the molecule than the electron."

Beyond transportation, electrolysis and energy export, chemical storage is applicable to industrial processes and as a form of backup power. It is very scalable, provides very long durations, high energy density, and a route to decarbonization for hard-to-abate sectors. However, capital costs can be high and systems can be complex.

Choosing the right solution

Every site is different. Each use case needs to weigh the operating conditions, cycling expectations, round-trip efficiency, capacity, expected lifespan, O&M costs, and capital costs.

"Extreme cold means that some options can be taken off the table at once," said Reusser. "You also have to understand whether you are likely to be using stored energy daily, weekly, or monthly as some solutions are more suited to shorter or longer cycles."

For example, liquid air warms so you have to be using it regularly to make it pay. Otherwise, you expend a lot of energy in re-cooling it. Similarly, the volume of energy available over what time period can favor options like CAES. As a rule of thumb, most battery technologies provide up to four hours of storage, mechanical solutions provide ten to 36 hours, thermal and electrochemical up to 160 hours, and chemical can provide the longest durations in the form of hydrogen, ammonia and LNG.

"It may be wise to consider hybrid systems that combine short-duration lithium-ion batteries with a long-duration method for increased performance and cost-efficiency," said Reusser.

The other factor to consider is the rise of AI. Organizations want the benefits of AI now. This is sure to act as a catalyst for all forms of long-duration storage, particularly CAES due to its maturity.

"Growing demand for AI will increase the need for LDES," said Hendry of SSS Clutch. "AI-driven systems require reliable, scalable, and sustainable energy to support their continuous operation, data processing, and integration with renewable energy sources."

About the Author: Drew Robb has been working as a full-time freelance writer in engineering and technology for the last 25 years. For more information, contact drew@robbeditorial.com.