The Evolution of Energy Grid Storage

What is it? Where is it at? Where is it Headed?

By Martin Flusberg
February 28, 2023

Image courtesy of Northwest National Research Laboratory

Energy Grid Storage

In a September 2022 report, the Paris-based International Energy Agency (IEA) states that "Grid-scale storage plays an important role in the Net Zero Emissions by 2050 Scenario, providing important system services that range from short-term balancing and operating reserves, ancillary services for grid stability and deferment of investment in new transmission and distribution lines, to long-term energy storage and restoring grid operations following a blackout".

The US Department of Energy (DOE) says that: "Grid energy storage is a critical step on the path to getting more renewable power on the system, supporting a growing fleet of electric vehicles, making the grid more reliable, and securing the clean energy future. Accelerating the development and testing of new energy storage technologies that are more cost-effective, safe, and durable is crucial to meeting the goal of providing clean, affordable, and resilient energy to everyone, everywhere, anytime". DOE is working on building a National Grid Energy Storage Research and Development facility in Richland Washington, scheduled to start operations in 2024.

Energy Grid Storage refers to the process of converting electrical energy into a stored form that can later be converted back into electrical energy when needed. The first large-scale energy storage facility in the

US was the Rocky River Pumped Storage plant which opened in 1929 on the Housatonic River in Connecticut. As of Q4-2022 there were approximately 170 Gigawatts of Energy Grid Storage in the US.

Until fairly recently, Energy Grid Storage has been used primarily to provide back-up power as needed and to store energy during periods of low demand that can then be used in periods of high demand – helping reduce the need for additional generating sources. As noted by DOE above, a key force driving the current growth in Energy Grid Storage is the corresponding growth in the intermittent renewable energy sources solar and wind for energy generation. Since the sun does not always shine – and the winds do not always blow – being able to store energy when they do and then use the energy when they don't is critical to the widespread rollout of renewable energy. In 2022, solar and wind combined were responsible for about 12% of the electricity generated in the US, with wind more than 3 times the size of solar, but their contribution is growing rapidly. In 2021 solar generation grew by about 32% in the US and wind grew by about 13%.

While the growth in renewable energy sources are expected to have the largest impact on the growth in grid storage in the coming years there are potentially other reasons for developing Energy Grid Storage. For example, regional transmission organizations (RTO) and independent system operators (ISO) have begun discussing how best to incorporate storage into transmission system planning and operation. *Storage-as-transmission* (SAT) refers to the use of energy storage to support transmission system reliability. By integrating a storage resource into transmission equipment, SAT can inject or absorb electricity to facilitate power flows on transmission lines over a certain period of time. Used in this way, storage can enhance existing transmission lines or even serve as an alternative to building new transmission projects.

As an example of how SAT adds to reliability, if a transmission circuit or transformer experiences a fault that would ultimately lead to an outage, storage could be used to absorb or inject electricity rapidly to stabilize power flows. Storage also offers an alternative transmission solution for relieving congestion by effectively replicating power line flows along a congested corridor.

SAT can be deployed relatively quickly, since all aspects of the SAT implementation process - including project assessment, procurement, build time, and regulatory approvals such as easement, permitting, siting, and rights of way - can occur on a much faster timeline than traditional transmission systems. With a significantly smaller physical footprint compared to traditional transmission systems they also have smaller environmental impacts and are less likely to generate community pushback. An additional positive feature of SAT is its scalability; it can be augmented over time as well as repurposed and/or relocated if grid needs in a particular area change. This reduces the likelihood of stranded assets if grid conditions change storage is no longer needed in its original location.

Examples of where and how SAT is being used in the U.S. include:

- ERCOT Presidio: In 2010, American Electric Power (AEP) installed the first battery storage system in Presidio, Texas to improve power quality and reduce momentary outages due to voltage fluctuations, therefor improving transmission reliability.

- APS Punkin Center: In 2017, Arizona Public Service (APS) deployed a 2 MW, 4-hour duration storage system in rapidly growing Punkin Center, AZ at a much lower cost than upgrading 20 miles of transmission and distribution line. The unit also delivers local voltage regulation, system-level ramping management, and flexibility for incremental storage additions over time.

- National Grid Nantucket: The island of Nantucket, MA traditionally receives its electricity from undersea supply cables from the mainland. To ensure electric reliability for customers during peak summer months when the population has skyrocketed - and defer the need for an additional expensive underwater cable to the island - National Grid installed a 6 MW/ 48 MWh battery storage system. This is presently the largest battery storage system in New England.

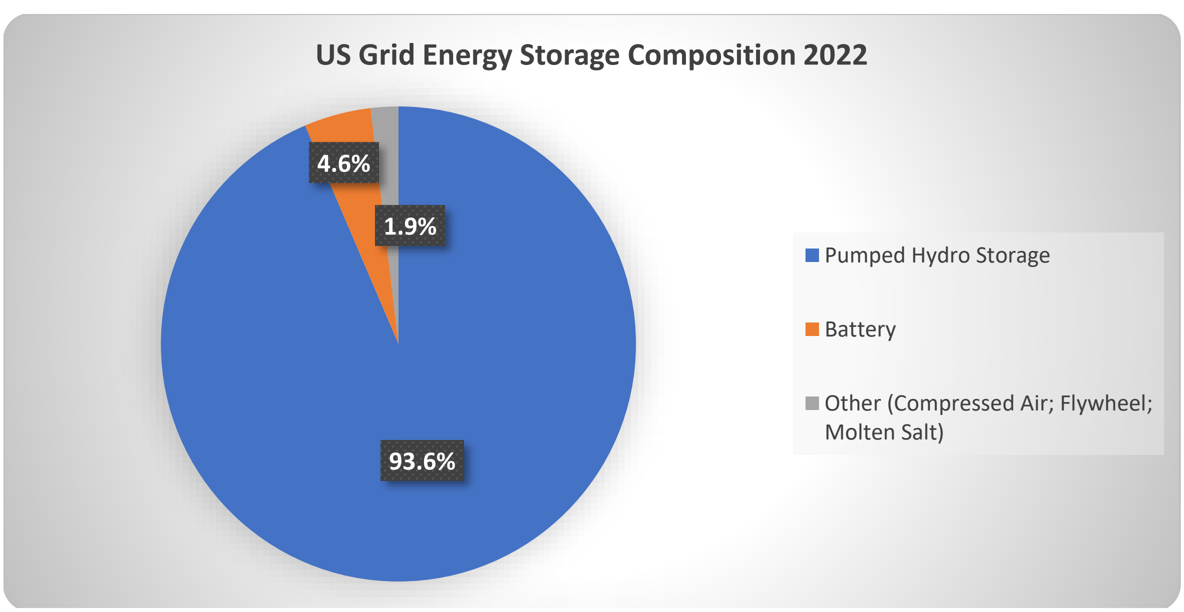
- Oakland Clean Energy Initiative (OCEI): In 2021, PG&E entered into 2 agreements for third-party owned energy storage projects (totaling 43.25 MW and 173 MWh) as a part of the OCEI. These projects are alternatives to traditional transmission systems and will replace fossil generation with clean energy in an area identified by the California EPA as having one of the worst pollution problems in the Bay area.

One issue that may limit SAT is that many RTOs and ISOs have planning and regulatory frameworks that may inhibit storage from being used as a transmission solution; as s a result, RTOs and ISOs may not choose SAT even when it is cost-effective. (More on the relationship between transmission and storage will be addressed later).

Finally, another development that will impact energy storage, as referenced in the DOE quote, is the rapidly growing number of electric vehicles (EVs) in the US. While currently much of these vehicles' charging occurs at night and during weekends when electricity demand is lower, that will change as more people without home charging options purchase EVs. This will increase peak load on the grid which will increase the established rationale for grid storage. Of course, EVs can be part of the solution as well as part of the problem. An increase in the number of EV and EV charger models' support for 2-way charging will enable the long-discussed but barely implemented Vehicle-to-Grid (V2G) opportunity to occur. With V2G, EVs provide power directly to the grid – or to storage systems – during periods where the cars are parked and connected to chargers.

What is Being Used to Provide Energy Grid Storage

While it appears to be commonly assumed that batteries represent the majority of grid storage today, in fact as of the end of 2022 batteries represented just ~ 8 GW or 4.6% of grid storage in the US. The vast majority of grid storage – over 93% - is provided by Pumped Hydropower Storage.



Pumped Hydropower Storage

Pumped Hydropower Storage (PHS) uses the force of gravity to generate electricity using water that has been previously pumped from a lower source to an upper reservoir. The water is pumped to the higher reservoir at times of low demand (and low electricity prices). At times of high demand - and higher prices - the water is then released to drive a turbine and supply electricity to the grid.

There are two main types of pumped hydro:

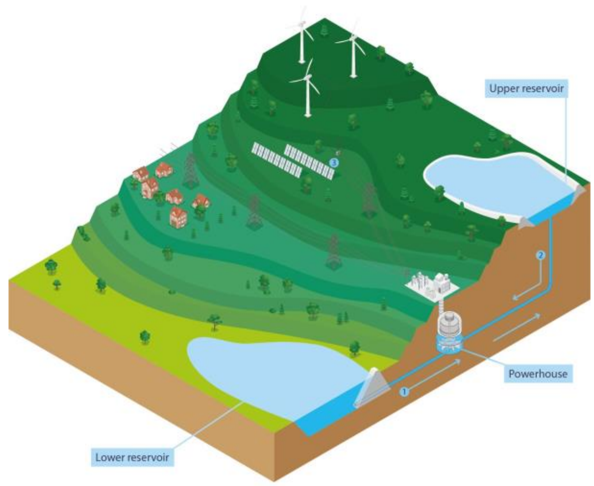


Image courtesy of International Hydropower Association

Open-loop: with either an upper or lower reservoir that is continuously connected to a naturally flowing water source such as a river.

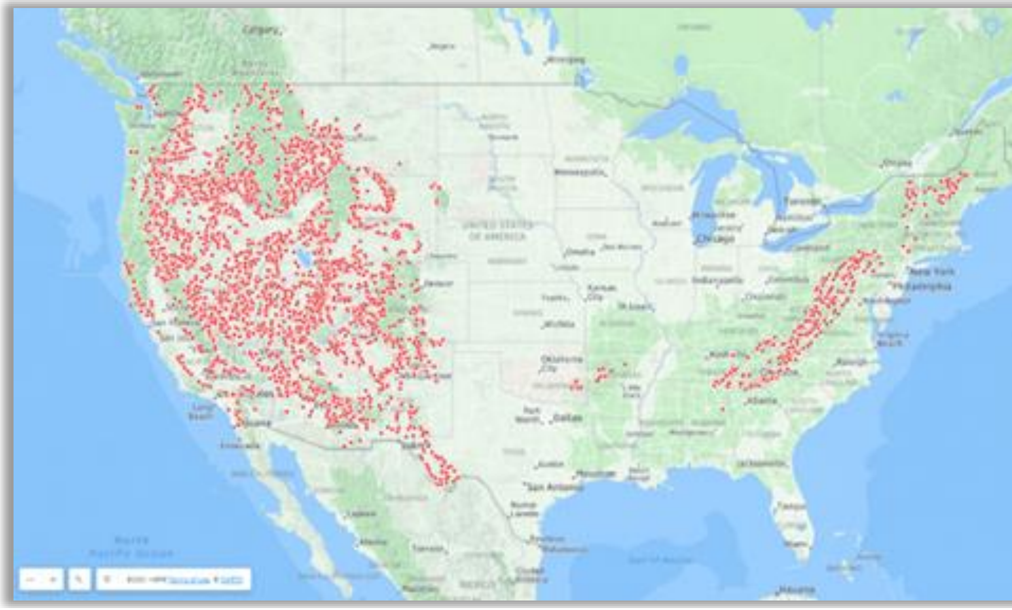
Closed-loop: an 'off-river' site that produces power from water pumped to an upper reservoir without a significant natural inflow.

PHS can be cheaper than other forms of energy storage, especially for very large capacity storage. According to the Electric Power Research Institute, the installed cost for Pumped Hydropower Storage varies between $1,700 and $5,100/kW, compared to $2,500/kW to $3,900/kW for lithium-ion batteries. PHS is more than 80 percent energy efficient through a full cycle**,** and PHS facilities can typically provide 10 hours of electricity, compared to about 6 hours for lithium-ion batteries. Despite these advantages, the challenge of PHS projects is that they are long-term investments: permitting and construction can take 3-5 years each.

The largest PHS facility in the world was built in Bath County Virginia in 1985. It has an output of approximately 3 GW and supplies power to about 750,000 homes.

Recent studies suggest that there is significant potential for scaling up global pumped hydro capacity.

For example, virtually all of the country's currently operating Pumped Hydropower Storage projects are Open Loop. As the need for more energy storage grows, so does interest in Closed Loop PHS. A recent National Renewable Energy Laboratory (NREL) study looked at this technology and its potential in specific regions across the United States. The study identified nearly 15,000 sites where PHS technology can be best deployed in the future.



Potential PHS sites in the contiguous United States identified by NREL

Battery Storage

Saticoy Storage Station - Oxnard, Calif

The Energy Information Administration (EIA) projects battery energy storage increasing from 8 GW in 2021 to 30 GW in 2025. More than 75% of this increased capacity is expected to be installed in California and Texas. This is because of the scale of solar and wind power currently in place and planned for these states. More utility-scale solar capacity – 16.8 GW - is located in California than any other state, and developers expect to add another 7.7 GW of solar generating capacity by 2025. 10.5 GW of utility-scale solar capacity is located in Texas and developers plan to install another 20.4 GW by 2025. In addition, Texas has 37.2 GW of wind power capacity, more than any other state, and developers expect to add 5.3 GW of new wind turbines by 2025[1].

Batteries are the most scalable type of grid-scale storage, and the market has seen strong growth in recent years. Although currently far smaller than pumped hydropower storage capacity, grid-scale batteries are projected to account for the majority of storage growth worldwide in the coming years.

[1] Note that an issue in Texas is that there simply not enough transmission lines to support the level of wind power, which has led to negative wholesale energy prices. This was discussed in a Business Week article in 2022.

Lithium-ion batteries (Li-ion) are by far the most popular battery storage option today and control more than 90 percent of the global grid battery storage market. Compared to other battery options, lithium-ion batteries have high energy density and are lightweight. Based on cost and energy density considerations, lithium iron phosphate batteries, a subset of lithium-ion batteries, are currently the preferred choice for grid-scale storage. 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. (More energy-dense chemistries for lithium-ion batteries, such as nickel cobalt aluminium (NCA) and nickel manganese cobalt (NMC), are popular for home energy storage and other applications where space is limited).

Flow batteries are an alternative to lithium-ion batteries for grid storage. In a flow battery, two liquids are separated by a membrane and circulated in order to enable ion exchange between them. By isolating the liquid electrolytes, flow batteries offer a long cycle life, can make use of their complete discharge range, and have a low internal discharge rate. 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. 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. A 200 MW (800 MWh) flow battery is currently being constructed in Dalian, China. This system will not only overtake the Hornsdale Power Reserve in Australia as the world's biggest battery, but it will also be the only large-scale battery (>100 MW) that is made up of flow rather than lithium-ion batteries. Flow batteries could emerge as a breakthrough technology for stationary storage as they do not show performance degradation for 25-30 years and are capable of being sized according to energy storage needs.

Lead-acid batteries are also used in grid storage but represent a very small and shrinking share.

Because of the expected rapid growth in grid storage, as well as concerns about lithium availability and the impacts of lithium mining, there is significant work being done on alternative forms of batteries and a fair number of companies involved in that process. As examples, here are a couple of well-funded start-ups working on battery technologies specifically for grid storage:

- **Form Energy** has raised $370 million in funding, including a $240 million round in 2022 led by steel company ArcelorMittal. Other investors include MIT's venture fund The Engine and Bill Gates's Breakthrough Energy fund. Form Energy is building batteries that use air and iron.

  Scientists have been trying to develop a practical battery based on iron, which generates an electric current as it rusts, since the 1960s. Such a battery would have high energy density and could be recharged by reversing the current flow and "de-rusting" the iron. It would use nonflammable materials and was expected to be relatively inexpensive to build and potentially last for decades. It was also expected to be able to operate for several days. Research on iron-based batteries languished for years however because of concern that there was no market for such a battery. With the need for backup grid power for solar and wind, interest in iron-based batteries has exploded.

  Form Energy, in cooperation with Great River Energy, is building a pilot facility in Minnesota which is scheduled to open in the coming year. The 40,000-square-foot battery array is designed to power up to 400 homes for up to 100 hours.

- **Ambri** has raised over $200 million, including a $144 million round last summer. Ambri's solution is based on battery technology developed by MIT materials scientist Donald Sadoway that uses calcium and the metal antimony. These are safe, stable chemicals that won't catch fire and cost less than lithium and other minerals found in lithium-ion batteries. While lithium batteries lose their ability to hold a charge after a few years, Ambri's battery is designed to have a 20-year lifespan, even if it's fully discharged and recharged every day. Ambri will shortly begin testing its system at a major data center and is expected to roll out its first grid storage system later in 2023.

Other Current Types of Grid Storage (less than 2% of total facilities)

- **Molten Salt (Thermal).** Thermal energy storage facilities use temperature to store energy. When energy needs to be stored, salt, or other materials including rock or water, is heated and kept in an insulated environment. When energy needs to be generated, the thermal energy is released by pumping cold water onto the hot salts or hot water or other materials in order to produce steam, which then spins turbines. Thermal energy storage can also be used to heat and cool buildings instead of generating electricity. 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.

- **Flywheels.** Flywheels are not suitable for long-term energy storage but are 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. The Stephentown Spindle in Stephentown, New York, which began operation in 2011 with a capacity of 20 MW, was the first commercial use of flywheel technology for grid storage in the US. Several other flywheel facilities have since come on-line.

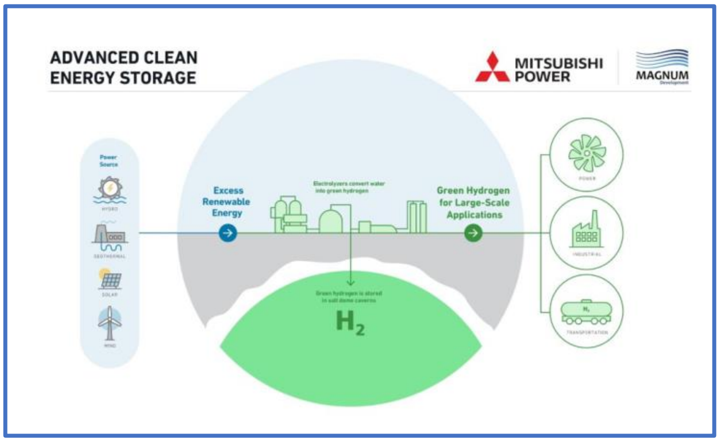
- **Compressed Air Energy Storage (CAES).** With compressed air storage, air is pumped into an underground hole, most likely a salt cavern, during off-peak hours. When energy is needed, the air from the underground cave is released back up into the facility where it is heated, and the resulting expansion 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 is only 1 operating CAES facility in the US in McIntosh, Alabama. The McIntosh plant, which was built in 1991, has 110 MW of storage. A 317 MW CAES plant is under construction in Anderson County, Texas.

Potential Grid Storage: Hydrogen

One potential form of clean grid storage that is getting a lot of attention is hydrogen.

Electricity can be converted into hydrogen by electrolysis. The hydrogen can be then stored and eventually re-electrified. The overall efficiency of hydrogen today is lower than other storage technologies. Despite this low efficiency the interest in hydrogen energy storage is growing due to the much higher storage capacity compared to batteries (small scale) or pumped hydro (large scale).

The “round-trip efficiency” of converting electricity to hydrogen, then burning that hydrogen to generate electricity, is only about 33 percent. In other words, for every megawatt-hour of output 3 MWh are consumed. But that becomes much less of an issue if the objective is long-duration storage measured in weeks or even months vs. short-term storage measured in hours.



Advanced Clean Energy Storage Delta is building an energy storage facility in Utah which is designed to store hydrogen for months. The facility will convert excess solar and wind power generated by an increasingly renewable Western U.S. grid to green hydrogen[2] during the spring and fall and save it to generate electricity to cover shortfalls in renewable power supply during summer heat waves and droughts and cloudy and/or windless winter months. The developer received a loan of $500 million from the US Department of Energy for the project.

The other major hydrogen storage project in the US is being undertaken by Pacific Gas & Electric in coordination with energy storage company Energy Vault[3] in Calistoga, California. The project, being referred to as a *Long-Duration Energy Storage System,* integrates a short duration battery system for “grid forming/black start capabilities” (in the event of a black out) with a long duration fuel cells plus green liquid hydrogen storage for situations as described earlier.

The hydrogen storage option appears to be further along outside the US in countries such as Germany, Denmark, and Australia.

Other technologies in various stages of development include Cryogenic Energy Storage, Superconducting Magnetic Energy Storage, and Supercapacitors, but they are at earlier stages than the technologies outline here.

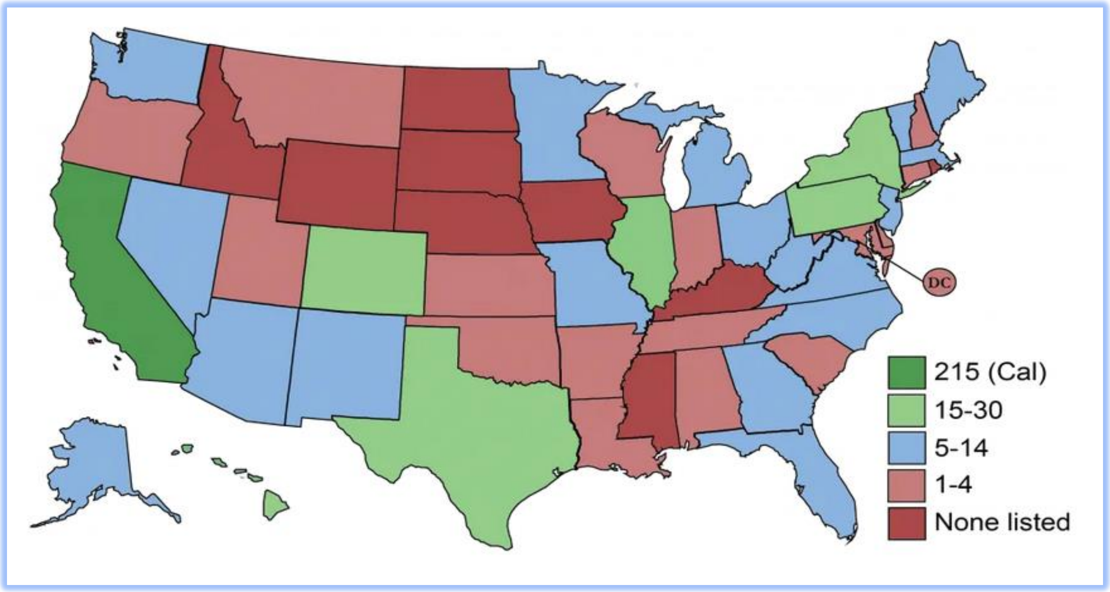
Growth in Energy Grid Storage

The total number of Energy Grid Storage projects is currently growing rapidly across the US and elsewhere. The worldwide growth rate in 2022 was close to 30%.

As noted earlier, that growth is far from uniform across the US. Below is a map that shows the number of Grid-connected energy storage projects by state.

[2] Green hydrogen is hydrogen produced by splitting water via electrolysis. This produces only hydrogen and oxygen, and the oxygen can then be vented into the atmosphere.
[3] Energy Vault, based in Switzerland, offers a short-duration storage product using lithium-ion batteries and a long-duration – which they define as 4 or more hours – option based on a proprietary gravity-based technology that lifts and lowers composite blocks to store and discharge energy.

Number of Grid-Connected Energy Storage Projects by State



Source: Center for Sustainable Systems – University of Michigan

One of the factors that is expected to increase investment in Energy Grid Storage is the Inflation Reduction Act (IRA). The IRA may significantly improve the economics for large-scale battery storage projects. For the first time, standalone storage systems will be eligible for a 30 percent investment tax credit - and up to 70 percent with additional incentives. Previously, federal tax credits were only available for storage when it was paired with renewable generation.

Rather than renewing investment and production tax credits for only a year or two, as Congress has repeatedly done in the past, the IRA locks the incentives in place through 2032. This gives investors and developers a generous timeline for generating returns. In addition, the new law expands the limits of what can be included in calculating total project costs. The tax credit will now cover interconnection, microgrid controllers and a broader scope of components often used in clean energy systems.

If projects meet certain requirements related to wages and apprenticeships they can potentially boost the tax credit to as high as 70 percent through three potential further incentives – domestic content (projects constructed with equipment and material produced in the US); energy communities (defined as a brownfield site; the site of a coal mine or coal-fired power plant; or an area that has or had direct employment or local tax revenue related to oil, gas, or coal activities) and low-medium income location projects.

However, projecting the exact rate of growth over the coming years is complicated by the fact that the forecasts for growth are all over the place.

Transparency Market Research recently released a report that projected worldwide growth of grid battery storage at 26.5% annually (CAGR) through 2031. A few months earlier Vision Gen projected a CAGR in the same market through 2032 of 15.6%. Market Research Future pegged the CAGR at 32%. Precedence Research predicted a CAGR of 8.4% in overall grid storage, with a 14.2% rate for battery storage. BloombergNEF predicted a 15-fold increase of overall storage (which includes residential, commercial, and industrial, not just grid storage). That's a CAGR of over 40%.

Not to be outdone, IEA reports that grid-scale battery storage needs to grow 44-fold from 2021 to 2030 for the Net Zero Scenario.

On the other end of the spectrum, NREL projected a 5-fold increase in overall US grid energy storage from 2021 to 2050. That's a CAGR of approximately 6%.

Well, the growth rate is clear then, isn't it?

Another factor impacting the growth of both the level of new storage and renewable energy generation being added to the grid was the focus of a very recent article in the NY Times (NYT): "The U.S. Has Billions for Wind and Solar Projects. Good Luck Plugging Them In". The article points out that the volume of projects has overwhelmed the nation's antiquated systems for connecting new sources of electricity to homes and businesses. So many projects are seeking approval that the approval delays can drag on for years. The NYT reports that there were 8,100 energy projects - the vast majority of them wind, solar and battery storage - waiting for permission to connect to electric grids at the end of 2021, up from 5,600 the year before. It now takes roughly four years on average for developers to get approval. And, when many of the projects are finally reviewed, they often face another hurdle: the local transmission system is at capacity, and there may be further delays until new transmission lines can be built. The NYT article further reports that, according to research from Lawrence Berkeley National Laboratory, fewer than one-fifth of solar and wind proposals actually make it through this so-called interconnection queue.

Given the amazingly wide range of forecasts on grid storage growth, and the impact of the application process and the transmission/distribution grid on the growth rate of both renewable energy generation and storage, it is quite a challenge to predict what we might see in a few years.

But a few observations are possible:

- Energy Grid Storage is going to continue to grow – and we can expect it to be significantly larger than it is today in the near-term.

- The percentage of total grid storage represented by batteries will continue to grow, although it will take quite a while for battery storage capacity to exceed hydropower storage. Even if battery storage in the US grew at 3 times the rate of hydropower storage – e.g., 30% vs. 10% annually - it would take until 2040 for battery storage to overtake hydropower storage.

- It is also hard to project the mix of battery types, although it is safe to say that lithium-ion batteries will remain in the lead for the next several years at least.

- There are few forecasts of what hydrogen storage will look like by 2030, but it should be significantly higher than it is today.

The bottom line: while it is very difficult to accurately predict the level of Energy Grid Storage we will see in the US in 2030 – let alone 2050 – it will definitely be considerably larger than it is today, and Energy Grid Storage will play a key role in the energy transition.