Making Sense of Energy Storage

How Storage Technologies Can Support a Renewable Future

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Executive Summary

America must shift away from fossil fuels and towards clean, renewable sources of energy in order to protect our air, water and land, and to avoid the worst consequences of global warming. Renewable energy sources, such as wind and solar power, are virtually unlimited and produce little to no pollution. With renewable energy technology improving and costs plummeting, it is now possible to imagine a future in which all of America's energy comes from clean, renewable sources.

The availability of wind and solar power, however, varies by the hour, day and season. To repower our economy with clean energy, we need an electric grid that is capable of incorporating large volumes of variable renewable resources.

Energy storage technologies can be an important part of that electric grid of the future, helping to assure reliable access to electricity while supporting America's transition to 100 percent renewable energy. To get the most benefit out of energy storage, however, policy-makers and the general public need to understand how energy storage works, where and when it is necessary, and how to structure public policy to support the appropriate introduction of energy storage.

Energy storage can make a valuable contribution to our energy system.

- Energy storage can capture renewable energy produced in excess of the grid's immediate needs for later use. In California, solar and wind energy plants were forced to halt production more than one-fifth of the time during 2016 because the power they produced was not needed at that moment.[1]

- Energy storage can help utilities to meet peak demand, potentially replacing expensive peaking plants.

- Energy storage can extend the service lifetime of existing transmission and distribution infrastructure and reduce congestion in these systems by providing power locally at times of high demand.

- Energy storage can improve community resilience, providing backup power in case of emergency, or even allowing people to live "off the grid," relying entirely on clean energy they produce themselves.

- Energy storage can provide needed ancillary services that help the grid function more efficiently and reliably.

Energy storage is likely to be most effective when used as part of a suite of tools and strategies to address the variability of renewable energy. Other strategies include:

- **Widespread integration of renewable energy into the grid:** Increasing the number and geographic spread of renewable generators significantly reduces their collective variability by making it likely that a temporary shortage of generation in one area will be balanced by solar or wind energy production elsewhere.

- **Weather forecasting:** Having advance knowledge of when wind and solar availability is likely to rise or fall allows energy providers to plan effectively. New England's Independent System Operator (ISO) lists having access to detailed wind speed forecasts five minutes ahead as one of three requirements for making wind energy entirely dispatchable throughout the region.[2]

- **Energy efficiency:** Using less energy, particularly during times of greatest mismatch of renewable energy supply and demand, can reduce the need for backup energy sources. The American Council for an Energy-Efficient Economy has found that if a utility reduces electricity consumption by 15 percent, peak demand will be reduced by approximately 10 percent.[3]

- **Demand response:** Systems that give energy companies the ability to temporarily cut power from heaters, thermostats and industrial machinery when demand peaks – and provide financial incentives for consumers who volunteer to have their power curtailed – can reduce the risks posed by variability.[4] Studies have found that demand response can maintain the reliability of highly intermittent 100 percent renewable energy systems, often at a fraction of the cost of batteries.[5]

- **Building for peak demand:** Much like grid operators have done with conventional combustion power plants, it may make sense to build more renewable energy capacity than is typically needed in order to meet energy needs during times of highest demand. One research study found that the most affordable way to meet 99.9 percent of demand with renewable sources involved generating 2.9 times more electricity than average demand, while having just enough storage to run the grid for nine to 72 hours.[6]

  A number of researchers have outlined ways that the U.S. can be mostly or entirely powered by renewable energy. Energy storage figures into these different scenarios in a variety of ways. (See Table ES-1.)

Many types of energy storage technologies can help integrate renewable energy into America's energy system.

- **Thermal storage** stores energy in very hot or very cold materials. These systems can be used directly for heating or cooling, or the stored thermal energy can be released and used to power a generator and produce electricity. Even pre-heating hot water during periods of high renewable energy production or low demand can be considered a form of thermal storage.

- **Utility-scale batteries** can be located along the electricity distribution or transmission system, providing power during times of peak demand, aiding with frequency regulation on the grid, and absorbing excess renewable energy for later use.

- **Residential and commercial batteries** located "behind-the-meter" can provide backup power during power outages, and have the potential to be aggregated into a larger network and controlled by a utility to support the reliability of the grid. Electric vehicle batteries could also someday be integrated into the grid, charging at times when renewables are available and powering homes and businesses at times when demand is high.

- **Pumped-storage hydropower,** currently the most common and highest capacity form of grid-connected energy storage, works by pumping water from a lower reservoir, such as a river, to a higher reservoir where it is stored. When electricity is needed, the water in the higher reservoir is released to spin turbines and generate electricity.

- **Compressed air energy storage** works by compressing air and storing it in underground reservoirs, such as salt caverns. When electricity is needed, the air is released into an expansion turbine, which drives a generator.

- **Flywheels** use excess electricity to start a rotor spinning in a very low-friction environment and then use the spinning rotor to power a generator and produce electricity when needed. These systems have a variety of advantages – they require little maintenance, last for a long time and have little impact on

Table ES-1. The Role of Energy Storage in Various High Renewable Energy Blueprints

Author	Year	Scenario	Energy Sources Included	Role of Energy Storage	Stratеties Used Other than Storage
The White House[7]	2016	80% reduction in U.S. GHG emissions compared to 2005 levels, by 2050 (no carbon capture scenario)	Wind, solar, biomass, hydropower, geothermal (plus nuclear and natural gas)	Highlights reducing the cost and increasing the storage capacity of batteries as an important goal. Storage also plays a role in increasing grid flexibility.	Energy efficiency, demand response
MacDonald, et al.[8]	2016	U.S. electric grid is roughly 63% renewable, 30% natural gas and 7% nuclear in 2030 (low cost renewables case)	Wind, solar, hydropower (plus nuclear and natural gas)	Not included in model, due to cost.	Geographic diversification – electric grid is modeled as one system across the continental U.S. instead of regionally divided systems
Jacobson, et al. – two studies[9]	2015	100% renewable energy use in the U.S. in 2050	Wind, solar, geothermal, tide, wave, hydropower	Concentrating solar power (CSP) storage, pumped-storage hydropower, hydrogen, and thermal storage are used in all sectors. Batteries are only relied on for transportation, to reduce costs.	Energy efficiency, demand response
Greenpeace[10]	2015	100% renewable energy use globally in 2050	Wind, solar geothermal, biomass, ocean, hydropower	Hydrogen and synthetic fuels used as fuel sources; CSP built after 2030 incorporates storage; a combination of other types of energy storage used to store excess production and provide backup during shortages.	Energy efficiency, demand response, weather forecasting
Williams, et al.[11]	2015	U.S. electric grid is >80% renewable in 2050 (high renewables case)	Wind, solar, geothermal, hydropower	Used minimally to help balance supply with load. Hydrogen and synthetic natural gas are most used for balancing.	Energy efficiency, demand response
Budischak, et al.[12]	2012	Electric grid equivalent to 1/5 of U.S. electricity demand is 99.9% renewable in 2030	Wind, solar	Uses three types of energy storage: batteries, hydrogen and grid-integrated vehicles. They only need enough of these technologies to run entirely on storage for 9 hours, 72 hours, and 22 hours respectively.	Overbuilding renewables

the environment – but have limited power capacity.

Developing technologies, including hydrogen and synthetic natural gas, have the potential to offer unique benefits and may become important tools in the future for energy needs that are currently difficult to serve with electricity.

Energy storage has been growing rapidly in recent years and that growth is projected to continue.

- There is six times more energy storage capacity (excluding pumped-storage hydropower) in 2017 than in 2007 (see Figure ES-1).[13]

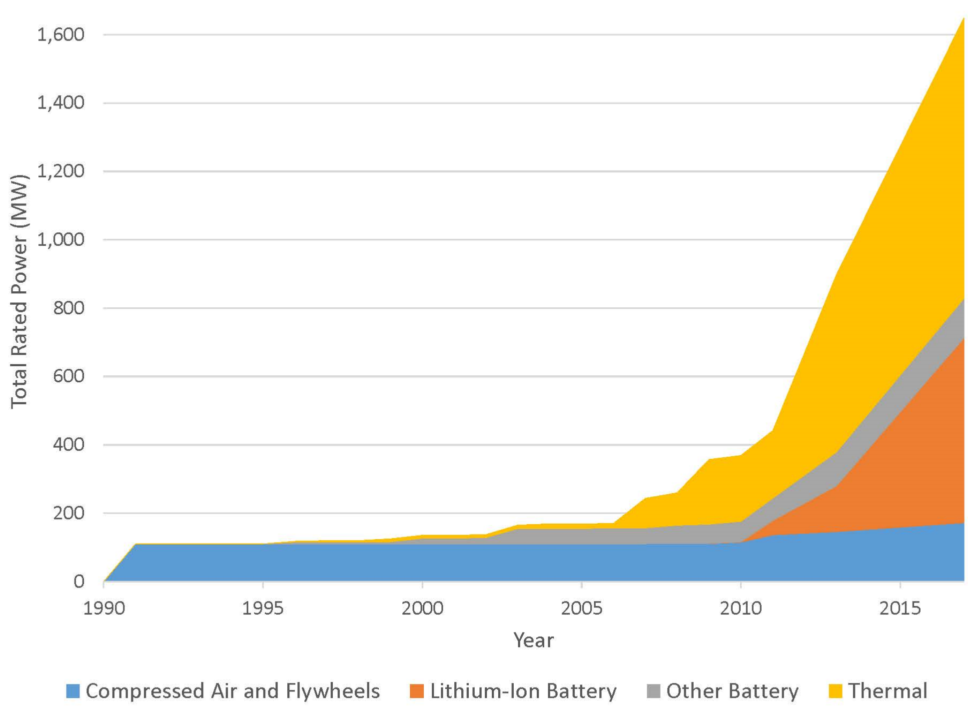
- GTM Research, an electricity industry analysis firm, predicts that the energy storage market will be 11 times larger in 2022 than it was in 2016.[14]

Energy storage is likely to become increasingly important and valuable in the years ahead, as a result of:

- **Falling costs:** The cost of energy storage has been declining rapidly, and this trend is expected to continue. Over the next five years, average costs are projected to fall 19 to 49 percent for batteries, and 23 to 37 percent for flywheels.[16]

- **Increasing renewable energy adoption:** The U.S. Energy Information Agency (EIA) expects that solar and wind capacity will increase by almost 20 percent in the two-year period from 2017 to 2018.[17]

Figure ES-1. Total Stacked Capacity of Operational U.S. Energy Storage Projects over Time, Excluding Hydropower[15]



- **New grid service markets:** Utilities are starting to recognize the value that energy storage can offer for purposes other than renewable energy integration.

- **Public policies:** The federal Investment Tax Credit for residential solar system can be applied to energy storage installed at the same time, and a new bill introduced in the Senate would create a tax credit for standalone storage as well.[18] A number of state policies supporting energy storage have been adopted in recent years: California, Oregon and Massachusetts have all passed laws setting energy storage targets, and similar proposals were passed by state legislatures in New York and Nevada in 2017.[19]

Smart policies will be key to allowing the energy storage market to continue to grow and support the nation's transition to a clean energy future. Policymakers should:

- Clarify existing grid connection and permitting policies to remove barriers to installation and deployment of energy storage;

- Design energy markets to capture the full value of energy storage and all the services these technologies can provide;

- Incentivize homes and businesses to adopt storage, which can increase resilience and provide benefits to the grid as a whole;

- Set storage benchmarks and encourage utilities to build and utilize energy storage throughout their system.

Introduction

Renewable energy is growing by leaps and bounds. America produces 43 times more solar power than we did a decade ago and seven times as much wind energy.[20] The cost of renewable energy is continuing to decline, renewable energy technologies are continuing to improve, and advances in technologies like electric vehicles are making it possible to repower new segments of our economy with clean energy.

The emergence of renewable energy creates new opportunities for America to reduce the harm that fossil fuels do to our environment, our health and our climate – bringing a future in which we receive 100 percent of our energy from clean sources within closer reach.

Solar and wind power are not, however, available on demand – varying in their ability to produce power on a minute-by-minute, daily, and seasonal basis. To fully repower our economy with renewable energy, we need to enhance our ability to match energy supply with demand. Energy storage technologies can play an important role in achieving that goal.

Energy storage technology is evolving rapidly and declining in cost. Storage projects are already economically competitive with conventional alternatives in many circumstances. But these rapid changes create the need for better understanding about why energy storage is needed, the roles storage can play in the energy system, and the current status and future prospects of storage technologies. This white paper aims to make sense of why and when energy storage is used, what it currently looks like, and what policymakers and the public can do to get the most benefit from energy storage.

Why Store Energy?

America and the world need to shift our energy system away from fossil fuels and towards clean, renewable sources. This change requires modernizing our electric grid, including building new capacity to store energy for later use.

Energy Storage Can Support the Electric Grid

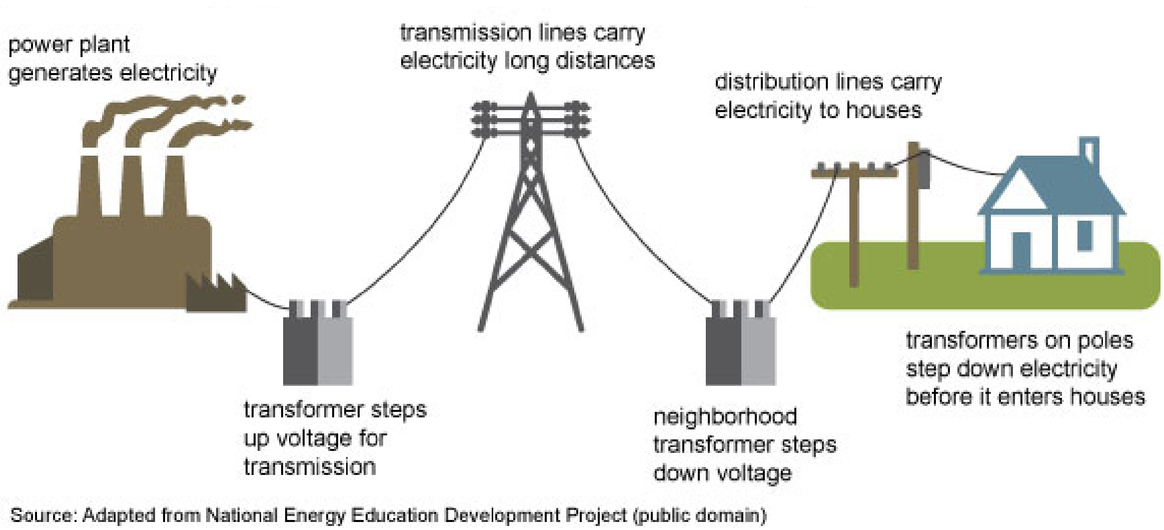
To understand how new technologies can fit into our energy system, we first need to understand how the current system operates. The electric grid consists of four stages: generation, transmission, distribution and use.[21]

Generation occurs in the facilities that produce electricity, from fossil fuel power plants to wind turbines and solar panels. This electricity is often *transmitted* across great distances on a network of high-voltage power lines. Transformers on both ends of the transmission lines increase the electricity's voltage before transmission and then decrease it before *distribution* to homes and businesses, where people can instantaneously draw enough electricity to power *end uses*.

Energy storage can fit into the electric grid at any of these points:

- Energy storage can aid **generation** by helping to meet peak demand. To ensure that they

Electricity generation, transmission, and distribution



Electricity flows through the grid from a generator, through the transmission and distribution systems, to an end user. Credit: U.S. Energy Information Administration can always meet demand, grid operators currently employ “peakers” – combustion plants that only operate at times of highest demand. Peaking plants operate for just a couple hundred hours per year, and typically produce more expensive electricity and emit more greenhouse gases than baseload plants.[22] Storage systems with rapid response times have the potential to serve as cleaner, more efficient replacements for peakers.

- Energy storage can support the **transmission** and **distribution** network by replacing existing infrastructure, extending the service lifetime of existing power lines, and reducing line congestion. Storage can help grid operators avoid building entirely new transmission or distribution lines when demand only slightly outpaces capacity. In Punkin Center, Arizona, for example, local utilities are installing 8 megawatt-hours of battery storage, just enough to meet peak demand during the 20 to 30 highest demand days per year.[23] This investment will allow the utility to avoid building 20 new miles of transmission lines that would be unnecessary more than 90 percent of the time. Energy storage can also reduce strain on the transmission network during midday hours when many solar panels are providing electricity to the grid by retaining some electricity near the load until later in the day, when solar production decreases and congestion on the transmission system dissipates.[24]

- Energy storage can help **users** by limiting demand charges and offering a supplement to the grid. Customer-sited storage can serve as an energy source during a utility’s busiest times. This practice, known as peak-shaving, can help consumers avoid their utilities’ expensive demand charges.[25] Residential and commercial battery storage can also provide backup power in case of emergency, or even allow customers to go entirely “off grid,” relying on energy they produce themselves.

In addition to supporting generation, transmission and distribution, storage technologies can provide ancillary services, which ensure that the grid operates reliably.

One ancillary service that energy storage is particularly well suited for is **frequency regulation**, the second-by-second changes in electricity supply that are needed to meet instantaneous peaks and dips in demand. Generation plants have typically been used for this service, but storage technologies have the potential to work up to twice as efficiently.[26] This is because technologies that can both charge and discharge simultaneously can regulate frequency in two ways at the same time – by adjusting both the rate at which they are charging and the rate at which they are discharging.[27]

Ramping is an ancillary service that will become more important as renewable energy becomes more common. Because solar and wind energy have variable availability, other energy sources need to ramp up or down over seconds or minutes to counter the changes in these renewable sources and maintain the needed level of net energy output. As with frequency regulation, electricity generators have been filling this role, but the rapid response time that some storage technologies offer make them well suited for this service.[27]

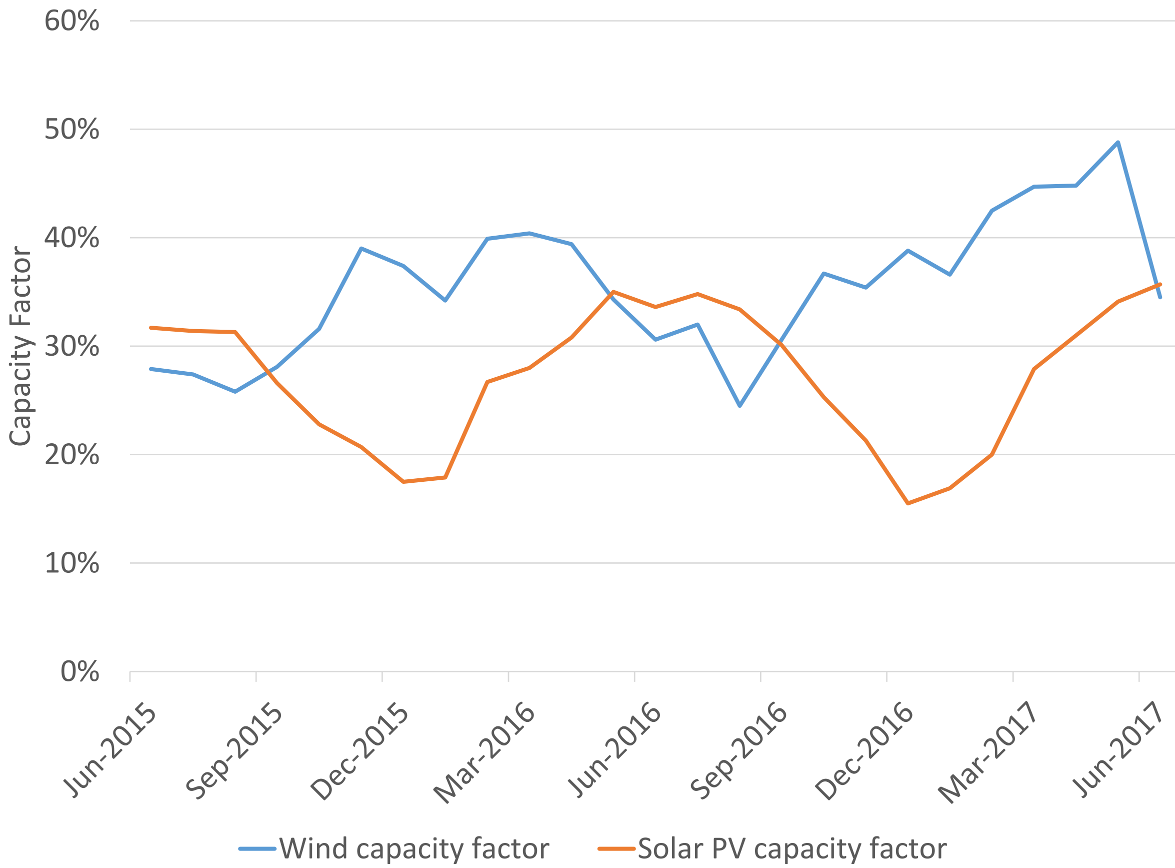
Energy Storage Can Address the Variability of Renewable Energy Sources

Wind and solar energy are not available on demand. The availability of these renewable sources varies on daily and seasonal cycles, and moment by moment in ways that can be more difficult to predict. Sources of electricity that are “dispatchable” – or that can be turned on and off to fill the gaps – such as energy storage, may at times be needed to meet demand.[29]

Seasonal Variability

Both solar and wind power follow known seasonal cycles. Wind power is usually stronger during the winter, while solar energy is more available during the summer (see Figure 1).[30]

Figure 1. Capacity Factors for Wind and Solar Photovoltaic (PV) Electricity Generation Vary Seasonally[31]



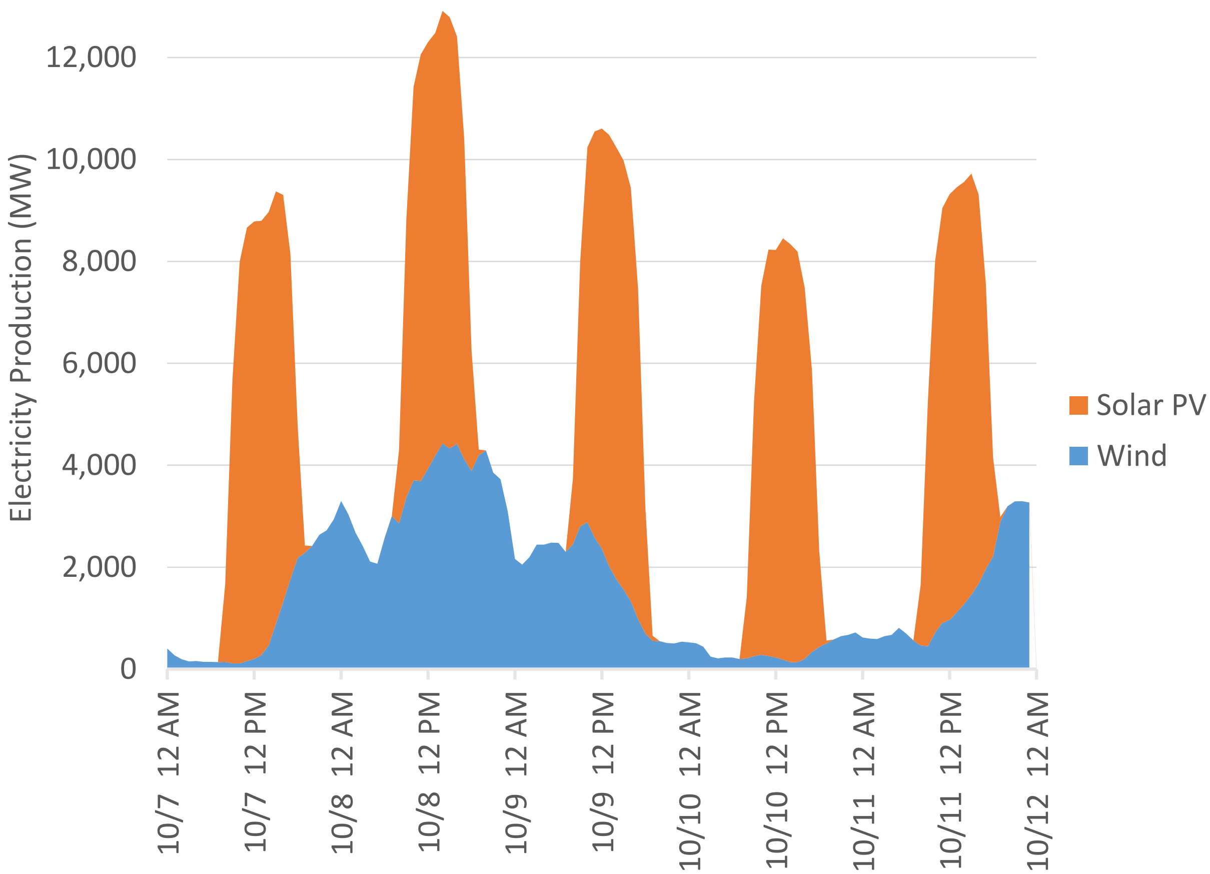
Daily and Hourly Variability

The availability of both solar and wind energy can vary by the hour and day. Because solar power is only produced when the sun is shining, solar PV generation is limited to daylight hours. Some states in the Northeast average less than four hours of peak sunlight per day during the winter months.[32] There is less of a pattern to the daily variations in wind energy, but the variations still have a large magnitude. Over the five days from October 7, 2017 through October 12, 2017, hourly wind power production within California's grid varied from 111 megawatts to 4,426 megawatts, and hourly solar power production varied from 0 megawatts (typically between 8 PM and 7 AM each day) to 8,585 megawatts (see Figure 2).[33]

Momentary Variability

Wind and solar energy also pose the threat of experiencing sudden dips in availability for minutes or seconds. Cloud movement can be responsible for reducing solar availability for a few minutes at a time.[35] Second-by-second variation has historically been a concern for wind energy as well. However, while these brief fluctuations are hard to predict days in advance, researchers and energy providers continue to successfully develop models that can forecast these changes in weather minutes in advance.[36] This gives energy operators enough time to adjust electricity supply. Many varieties of energy storage, which have more rapid response times than power plants, are particularly well-suited for supporting these short fluctuations.

Figure 2. Hourly Solar and Wind Power Production within California's Grid, October 7 to October 12, 2017[34]



When Is (and Isn't) Energy Storage Necessary?

The many benefits that energy storage can provide make it a useful tool for modernizing the electric grid and increasing our use of clean, renewable energy. Energy storage is often the most suitable approach for serving the grid's needs. However, there are also situations in which other solutions may be more effective for integrating renewable energy onto the grid.

Energy Storage Can Capture Excess Renewable Energy

When solar panels and wind turbines are producing more energy than is needed, energy storage technologies enable that energy to be retained for future use.

Some countries already produce more renewable energy at certain times than they can use at any particular moment. On their windiest days, Denmark's wind farms produce enough energy to power the entire country and send their excess power to Sweden, Norway and Germany.[37] More locally, during the winter months, California sometimes produces enough excess solar energy that it is sent to Arizona for free.[38]

Unfortunately, because most fossil fuel power plants are slow to turn on and off, renewable energy production is often curtailed when supply is greater than demand. In California, solar and wind energy plants were forced to halt production more than one-fifth of the time during 2016.[39] These curtailments are becoming more common and larger in size. In March 2017, more than

82,000 megawatt-hours of renewable energy generation was curtailed in California – enough to power roughly 147,300 California households for the month.[40] Widespread deployment of energy storage could help limit such curtailments.

Other Strategies Can Also Address Variability

There are a variety of strategies that can be employed on their own or in conjunction with energy storage to support the growth of solar and wind energy across the grid.

Because weather can vary even over small distances, **integrating renewable energy over a broad region** can greatly decrease the variability of energy production. Studies have found that increasing the number of wind turbines in a region and the size of that region can decrease the variability in the amount of energy produced regionally.[41] A similar study found that if a utility draws from 20 different solar plants, it can almost eliminate the instantaneous drops that are a risk with individual generators.[42] Half an hour of cloud cover, for example, could entirely turn off a town's electricity supply if they only draw from a single power station. However, if they're drawing from 20 solar photovoltaic plants across a single county, it's likely that only a handful would be under cloud cover at any single point in time.

Detailed **weather forecasting** allows utilities to predict and respond to dips in power availability before they occur. New England's Independent System Operator (ISO) lists having access to sophisticated wind speed forecasts five minutes ahead as one of just three requirements for making wind energy entirely dispatchable throughout the region (the other two requirements – nonstop communication between windfarms and ISO headquarters and the existence of an algorithm that lets the ISO control each generator remotely – allow the ISO to make use of these forecasts).[43] Additionally, a study from the National Renewable Energy Laboratory found that in regions where wind energy supplies 24 percent of electricity generation, improving wind forecasts by 20 percent could decrease the amount of annual energy shortfalls – instances when there is not enough electricity generation to

One of the most cost-effective ways to increase the impact of renewable energy without relying on storage is with investments in **energy efficiency**. By simply using less energy, the gap between the current capacity of installed renewables and the capacity that will eventually be needed shrinks. Energy efficiency is particularly useful for supporting high renewable energy penetration because it can reduce peak demand. The American Council for an Energy-Efficient Economy found that if a utility reduces electricity consumption by 15 percent, peak demand would be reduced by approximately 10 percent.[45]

Similarly, **demand response** reduces the challenges of variability by curtailing demand from the grid at times when demand exceeds supply. Demand response provides energy companies with the ability to temporarily cut power from heaters, thermostats and industrial machinery – or engage behind-the-meter energy storage – when demand exceeds renewable energy supply.[46] Studies have found that demand response can maintain the reliability of highly intermittent 100 percent renewable energy systems, often at a fraction of the cost of batteries.[47]

Another intriguing way to transition to renewable energy with limited dependence on storage is to **"overbuild" wind and solar plants** – that is, to accept and plan for curtailment of renewable energy during peak periods in order to assure that sufficient renewable energy resources exist to cover electricity demand during periods of reduced generation. This is not a new concept. Grid operators have historically relied on having excess generation capacity to ensure adequacy and reliability. Overproducing wind or solar energy offers those same benefits, and may actually be the most cost-effective way to power the grid almost entirely with renewable sources. A 2012 study by Dr. Cory Budischak of the University of Delaware found that the most affordable way to meet 99.9 percent of demand with renewable sources involved generating 2.9 times more electricity than average demand, while having just enough storage to run the grid for nine to 72 hours.[48]

How Does Energy Storage Fit into a Renewable Energy Future?

An increasing number of researchers have started to outline ways that the U.S. can be mostly or entirely powered by renewable energy. Energy storage figures into these different scenarios in a variety of ways. (See Table 1.)

The two pathways that predict the largest roles for energy storage – one written by Stanford University Professor Mark Jacobson and the other by Greenpeace – use a variety of storage types and include technologies like hydrogen, vehicle-to-grid batteries and synthetic fuels, which, to varying extents, are not currently viable for widespread use. Greenpeace imagines hydrogen primarily as a replacement for natural gas in power plants, while Dr. Jacobson focuses largely on the potential for hydrogen fuel cells to power transportation.

Conversely, researchers like National Oceanic and Atmospheric Administration scientist Dr. Alexander MacDonald and Dr. Budischak of the University of Delaware, who limited storage use or avoided it entirely in their own roadmaps, are mostly concerned with the cost and limitations of battery storage. Even though other technologies can offer more affordable storage, and battery prices have declined dramatically in recent years, these researchers primarily cite the cost of batteries to justify their decisions to limit the use of all storage.

Energy storage is an important tool for helping America and the world obtain 100 percent of our energy from renewable sources. But it is not the only such tool, and using energy storage in concert with other proven and emerging strategies for balancing electricity supply and demand will likely lead to the best results in facilitating a clean energy transition.

Table 1. The Role of Energy Storage in Various High Renewable Energy Blueprints

Author	Year	Scenario	Energy Sources Included	Role of Energy Storage	Stratetics Used Other than Storage
The White House[49]	2016	80% reduction in U.S. GHG emissions compared to 2005 levels, by 2050 (no carbon capture scenario)	Wind, solar, biomass, hydropower, geothermal (plus nuclear and natural gas)	Highlights reducing the cost and increasing the storage capacity of batteries as an important goal. Storage also plays a role in increasing grid flexibility.	Energy efficiency, demand response
MacDonald, et al.[50]	2016	U.S. electric grid is roughly 63% renewable, 30% natural gas and 7% nuclear in 2030 (low cost renewables case)	Wind, solar, hydropower (plus nuclear and natural gas)	Not included in model, due to cost.	Geographic diversification – electric grid is modeled as one system across the continental U.S. instead of regionally divided system
Jacobson, et al. – two studies[51]	2015	100% renewable energy use in the U.S. in 2050	Wind, solar, geothermal, tide, wave, hydropower	Concentrating solar power (CSP) storage, pumped-storage hydropower, hydrogen, and thermal storage are used in all sectors. Batteries are only relied on for transportation, to reduce costs.	Energy efficiency, demand response
Greenpeace[52]	2015	100% renewable energy use globally in 2050	Wind, solar geothermal, biomass, ocean, hydropower	Hydrogen and synthetic fuels used as fuel sources; CSP built after 2030 incorporates storage; a combination of other types of energy storage used to store excess production and provide backup during shortages.	Energy efficiency, demand response, weather forecasting
Williams, et al.[53]	2015	U.S. electric grid is >80% renewable in 2050 (high renewables case)	Wind, solar, geothermal, hydropower	Used minimally to help balance supply with load. Hydrogen and synthetic natural gas are most used for balancing.	Energy efficiency, demand response
Budischak, et al.[54]	2012	Electric grid equivalent to 1/5 of U.S. electricity demand is 99.9% renewable in 2030	Wind, solar	Uses three types of energy storage: batteries, hydrogen and grid-integrated vehicles. They only need enough of these technologies to run entirely on storage for 9 hours, 72 hours, and 22 hours respectively.	Overbuilding renewables

What Types of Energy Storage Can Make a Contribution?

Existing energy storage technologies can provide valuable services to customers and the grid as a whole. Energy storage deployment, however, has been limited thus far. Current regulations and policies are not structured with energy storage in mind, and market analyses are not designed to take into account the full value of the diverse services energy storage can provide, leaving opportunities for beneficial use of storage untapped.

The total capacity of grid-connected energy storage projects in the U.S. is equivalent to 2 percent of the nation's electricity generation capacity.[55] There are 518 grid-tied energy storage projects operating in the U.S. with 24.2 gigawatts of rated power in total.[56] That is about the same capacity as 40 coal-fired power plants.[57]

There are no available estimates of the capacity of non-grid-tied energy storage. There are far more systems that are not attached to the grid than are – more than 3,700 non-grid-tied residential battery systems were deployed in the U.S. in 2016 alone – but these systems tend to be small and therefore make up a limited portion of total U.S. energy storage capacity.[58]

Current Energy Storage Technologies

The current energy storage technologies tied to the U.S. grid are pumped-storage hydropower (PSH), thermal storage, batteries, compressed air energy storage (CAES), and flywheels. (See Figure 3.) Each of these technologies is explained in more detail below.

Thermal Storage

Thermal energy storage systems encompass a wide array of technologies that can store energy daily or seasonally and that can be used in applications ranging from residential to utility-scale. Thermal storage makes up the second-greatest share of U.S. energy storage capacity, with 821 megawatts of capacity installed. Thermal energy systems are also the second most abundant type, with 141 systems tied to the grid, and some types of thermal storage systems are currently economically competitive in certain U.S. markets.[60]

There are three forms of thermal energy storage – sensible, latent and thermochemical. Sensible thermal storage systems heat a medium, like water or salts, and then use the stored heat to

Figure 3. Share of U.S. Grid-Tied Energy Storage Market by Capacity (Left) and Number of Projects (Right)[59]

generate steam and drive a turbine when energy is needed.[61] Latent systems change the phase of a substance, such as by boiling water or a saline solution, and later allow it to change back and release energy. Thermochemical systems use chemical reactions that require energy input and later allow the reverse chemical reaction to take place and release energy.[62]

Thermal energy systems can be used to produce steam for traditional power plants, but they can also be used directly in heating or cooling applications. For example, excess energy can be used to heat up a water heater in advance or create chilled water or ice to air condition a building later. Passive thermal storage is another practice where buildings incorporate materials that store heat well, like concrete floors. These materials, referred to as thermal mass, can absorb the sun's energy during the day and release it to provide heating at night, and can also absorb excess heat to keep the building cool.[63] These direct uses of thermal energy are efficient for heating and cooling because they avoid energy losses incurred in converting the energy back to electricity.[64]

Similar systems can be used seasonally – to store winter cool for air-conditioning in the summer or, more commonly, to store summer warmth or excess solar energy for heating in the winter. This thermal energy can be stored in water in natural aquifers or insulated tanks or pits or in the earth using boreholes drilled deep into the ground.[65] Drake Landing Solar Community, a 52-home subdivision in Alberta, Canada, for example, uses excess solar thermal energy in the summer to heat water, which then circulates

The Crescent Dunes Solar Thermal Energy project in Nevada. The 2.6 square miles of mirrors reflect and concentrate the sun's rays onto the receiver in the center, heating the molten salt it contains. When electricity is needed, the stored heat is used to generate steam and power a turbine, just like a traditional power plant. Photo: U.S. Bureau of Land Management via Flickr, CC BY 2.0.

through underground boreholes and transfers the heat to the surrounding earth. The area containing the boreholes is insulated, so the heat is trapped in the earth until winter, when it is used to heat water, which then circulates up through the homes to heat them. This system provided 100 percent of the homes' heating needs in the winter of 2015 to 2016, and has provided over 90 percent of their needs for the last five years.[66]

Just four large molten salt thermal storage systems in the Southwest make up over half of the grid-tied thermal storage capacity in the U.S.[67] These are all tied to concentrated solar power systems where the sun's rays are reflected off of mirrors and concentrated onto a receiver, thus heating it. In these systems, the heat is stored in molten salts and when electricity is needed, the heat is used to generate steam and power a turbine, just like traditional power plants.[68]

A smaller scale example of thermal energy storage can be found in millions of basements across the country. Electric water heaters, which are responsible for 9 percent of all residential electricity use nationwide, can be used to store thermal energy and aid with peak-shaving and demand response.[69] One study found that using a single electric water heater for energy storage can save almost $200 per year.[70]

Ice thermal storage systems, which use excess or non-peak electricity to make ice, are among the most abundant type of thermal storage, with 108 systems currently connected to the grid. This technology has mainly been used to provide air conditioning for large buildings and energy storage for the grid, but the American company IceEnergy has recently introduced a smaller model of their system to be used in homes. These systems do not degrade the way lithium-ion batteries do and could become competitive in the residential energy storage market.[71]

Utility-Scale Batteries

There are fewer utility-scale batteries than other energy storage systems, but because these systems are large, they have the third-highest total capacity of any type of energy storage in the U.S. Utility-scale batteries can provide the grid with a variety of services and have an advantage over other large-scale projects because they are not location-restricted.[72] These batteries can be located along the grid's distribution system – either on a community- or substation-level – or along the transmission system.

Lithium-ion batteries have reached market maturity in some regions of the U.S. for providing frequency regulation services, but these markets may soon become saturated.[73] Utility-scale batteries have the potential to provide the grid with many other services, including integrating renewables, supporting transmission and distribution infrastructure, and managing demand.[74] Lithium-ion batteries may prove to be the dominant battery type for these uses as well, but zinc-based batteries may be better for larger scale projects requiring a longer duration energy storage source, and could potentially be deployed at the same scales as pumped-storage hydropower (PSH) projects.[75]

Utility-scale batteries are not yet economical in many markets, but costs have been dropping rapidly, and some projects have already been profitable for specific uses.[76] In Vermont, the utility Green Mountain Power built a solar farm and utility-scale battery microgrid that has saved the utility roughly $200,000 per year.[77] Between the microgrid's avoided capacity charges, peak shaving performance, and the frequency regulation services it provides, the cost of this system is expected to be recovered in no more than 10 years.[78]

Behind-the-Meter Batteries

Behind-the-meter batteries are small systems that can be used to store energy for use in homes or other buildings. They are the most abundant type of energy storage system in the U.S. – it is estimated that 4,400 residential battery systems were deployed in 2016 alone – but these units are small, so they make up a small portion of total U.S. energy storage capacity.[79]

There are several types of batteries on the market including lithium-ion, sodium-sulfur, nickel-cadmium, and flow. Lithium-ion batteries, such as Tesla's new Powerwall and Samsung SDI's batteries, are by far the most dominant type of grid-connected battery.[80]

Behind-the-meter batteries provide homeowners, businesses and electric utilities with a variety of benefits, such as providing backup power during outages (see text box). Batteries can also store energy when electricity costs are low for use when demand and costs are high, saving money and reducing peak demand on the grid. Owners can use batteries to store energy when their solar panels are generating excess energy to use when they aren't producing enough energy, helping to integrate and increase the value of renewable energy sources. Larger networks of grid-tied residential and commercial batteries have the potential to be aggregated and controlled by a utility to provide grid functions and services, such as frequency regulation and peak shaving.

Thus far, residential batteries have not been cost-effective for residential customers in many areas of the U.S. However, that is changing quickly. Costs have been dropping steadily, and batteries are often already cost-effective for commercial use. A study by researchers at the University of California, Berkeley projects that residential solar plus storage could become cost-competitive with grid-supplied electricity by 2020.[81] Residential batteries already make economic sense for homeowners in some situations and locations. For example, in Hawaii, where electricity costs are high and solar owners cannot be compensated at retail rate for supplying energy to the grid, it makes financial sense for homeowners to use residential batteries in conjunction with rooftop solar to supply their own power.[82] Current regulations in California and some northeastern states make residential batteries more attractive in these locations, too.[83]

Because the electric vehicle (EV) market is projected to grow rapidly in coming years, utilities are also thinking of ways to use EV batteries as a grid-connected energy storage resource. To ease EV demand on the grid, various strategies are being devised to shift EV charging to low-demand times. There also may be the potential to hook up EVs like a distributed, utility-scale battery that could store excess renewable energy and feed energy back to the grid, primarily for lower-energy services like frequency regulation. This practice, called V2G (vehicle to grid), is not currently economical, but could provide utilities with energy storage services without their having to purchase energy storage systems.[84]

Some utilities are also considering purchasing networks of EV charging stations to use as distributed energy storage. Similar to V2G, the charging stations would be charged during

Batteries Can Increase Resilience During Disasters

Batteries can help lessen the hardship felt during disasters. For example, after Hurricane Irma hit Florida in September 2017, millions of homes were left without power. While many customers had to wait weeks for power to be restored to the grid, some homeowners with rooftop solar panels and residential battery storage were able to produce enough electricity to turn their lights on and use their appliances as soon as the sun came up the next morning.[88] As extreme storms – like the hurricanes that hit Florida, Houston and Puerto Rico in the fall of 2017 – are projected to become more frequent in coming years, microgrids of behind-the-meter batteries may become important safety nets for keeping important facilities like hospitals and shelters operational during disasters.[89] Within weeks of Hurricane Maria, Tesla began installing solar plus storage systems to repower Puerto Rico's grid.[90]

low-demand times or when excess renewable energy is being generated and could also feed power back to the grid when needed.

Cars require high-performing batteries, so EV batteries need to be replaced once their capacity declines past a certain point. These retired batteries can still be useful, though, and car companies like BMW and Nissan already have projects in the works to use their old EV batteries in residential and commercial energy storage systems.[85]

The main drawbacks of batteries are that they require frequent maintenance, can be damaged, and eventually need to be replaced. Many types of batteries, including lithium-ion, contain elements that are often obtained through mining, an environmentally harmful process.[86] Batteries can also leach toxic and hazardous chemicals into the environment if they are not disposed of properly, which can potentially harm human health.[87]

Pumped-Storage Hydropower

Pumped-storage hydropower (PSH) is the oldest form of grid energy storage – the first project was constructed in 1929 and no other grid-connected energy storage technologies were deployed until 1982. There are relatively few PSH installations and only one new project has been built since 1994, but PSH still makes up the vast majority – 93 percent – of total energy storage capacity in the U.S. because these projects are huge.[91]

PSH works by pumping water from a lower reservoir, such as a river, to a higher reservoir where it is stored. When electricity is needed, the water in the higher reservoir is released to spin turbines and generate electricity.

PSH is an attractive energy storage technology because it can be used for long-term storage and can respond to large electric loads within seconds.[92] Traditional PSH projects are hard to site, so firms are starting to design new forms of PSH that use, for example, seawater or underground reservoirs.[93] In a report to Congress in 2015, the Department of Energy proposed building smaller PSH systems in decentralized networks, like streams or existing drinking water pipes.[94] Another technology is being developed that consists of a sphere floating underwater – when there is excess energy, water is pumped out of the sphere, and when energy is needed, water is allowed to flow back into the sphere and powers a generator.[95]

Compressed Air Energy Storage

There are only four compressed air energy storage (CAES) projects currently, but they have a total capacity of 114 megawatts, or about the same capacity as 400,000 solar panels. [96]

CAES works by compressing air and storing it in underground reservoirs, such as salt caverns. When electricity is needed, the air is released into an expansion turbine, which drives a generator. CAES can provide massive energy stores for grid applications, but appropriate sites for CAES are hard to find, so new options, like aquifers and depleted natural gas fields, are being explored.[97]

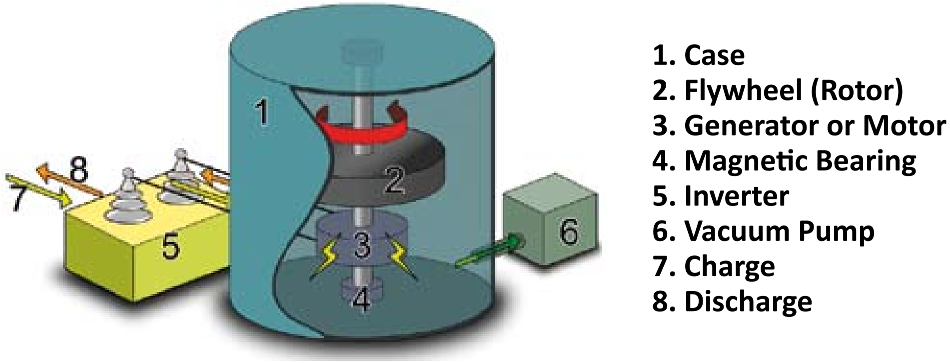
The biggest drawback of CAES is that it is highly inefficient. When air is compressed, it heats up considerably and needs to be cooled before it can be stored. The air then needs to be reheated before it expands and generates electricity. This is usually done using natural gas.[98] Alternative technologies are being explored to solve this problem as well.

Flywheels

Flywheels are currently a minor form of energy storage, with only 21 projects currently connected to the grid and a total capacity of 58 megawatts.

Flywheels use excess electricity to start a rotor spinning in a very low-friction environment and then use the spinning rotor to power a motor and generate electricity when needed.[99]

Flywheels are useful for making the grid function better through services like frequency regulation because they have very fast response times, can charge quickly, and are very efficient. Flywheels are also advantageous because they are scalable, store a lot of energy in a small amount of space, require little maintenance, last for a long time, and have little impact on the environment.[100]



Flywheels use spinning rotors to generate and rapidly discharge electricity. Credit: Tosaka via Wikimedia Commons, CC BY 3.0.

Flywheel deployment has been limited, though, because most current flywheels have very short discharge times, so they are not useful for storing large amounts of energy.[101] The discharge time of flywheels is projected to increase, though, and there is already one flywheel currently tied to the grid with a 4-hour duration and another proposed.[102] Flywheel deployment has also been limited because their upfront costs are higher than batteries, but some estimates indicate that they have much lower lifetime costs.[103]

Future Energy Storage Technologies

There are many energy storage technologies that are in various stages of development and could potentially offer unique benefits in the future.

Hydrogen

Hydrogen energy storage works by using excess electricity to split water into hydrogen and oxygen. The hydrogen is then stored and is used in an engine or fuel cell to generate electricity later, when there is greater demand.[104] Hydrogen offers longer-term, higher capacity storage than other technologies, but is inefficient and highly volatile, so deployment has been limited.[105]

Synthetic Natural Gas (SNG)

Synthetic natural gas (SNG) can be made by taking hydrogen (produced in the same manner as described above) and combining it with carbon dioxide.[106] The SNG can then be stored, transported, and burned just like natural gas, using existing infrastructure. The whole process consumes as much carbon dioxide as it produces. This process is inefficient and currently uneconomical, but could provide longer-term energy storage than other technologies, and be used in applications that require more energy-dense fuels until better alternatives are identified.[107]

Other Technologies

There are new energy storage technologies still being developed that could become important in the future, as well. For example, the Gravity Power company has designed a system that consists of two water-filled shafts, one wider than the other, that are connected at both ends. When there is excess energy, water is pumped down the smaller shaft to raise a piston in larger shaft. When energy is needed, the piston is allowed to sink down the wider shaft, forcing water through a generator.[108]

One innovative project currently under construction in Nevada is called Advanced Rail Energy Storage. This system will use excess energy to pull modified railway cars up a special track. When energy is needed, the cars are released down the track and their motion will drive a generator. This system generates more power per height differential than pumped-storage hydropower.[109]

Advantages and Drawbacks of Current Technologies

Each type of energy storage offers its own advantages and limitations. Energy storage can be most useful if we build new projects that use a variety of technologies at a variety of scales, serving the diverse needs of the electric grid and helping to integrate a mix of renewable energy technologies. (See Table 2.)

Similarly, some types of storage are better suited for residential or commercial use, while others are intended to be built and used by utilities (see Figure 4).

Where Is Energy Storage Currently Deployed?

Energy storage projects are mainly clustered in a few areas of the U.S. that have favorable markets and supportive state and regional policies. California has the most grid-tied energy storage both in terms of total capacity and number of projects. States along the eastern seaboard and Michigan have the next-most installed capacity and Hawaii has the second highest number of projects (see Figure 5).[113]

Table 2. A Comparison of All Current Grid-Tied Energy Storage Technologies

Technology	Primary Applications	Current Drawbacks	Cost per kWh[110]	Total Installed Capacity	Number of Grid-tied Projects[111]
Thermal Storage	• Renewables integration • Demand response • Support for transmission and distribution (T&D) infrastructure • Backup during power outages • Additional capacity • Ancillary grid services	• Cost	\$0.23 - \$0.86	821 MW	141
Batteries	• Renewables integration • Demand response (only behind-the-meter batteries) • Support for T&D infrastructure • Backup during power outages • Additional capacity • Ancillary grid services	• Environmental impacts of mining and improper disposal • Cost (although battery costs are dropping rapidly)	\$0.16 - \$2.19	680 MW	314
Pumped-storage hydro	• Additional capacity	• Difficult to site • Limited uses	\$0.15 - \$0.20	22,561 MW	38
Compressed air energy storage	• Additional capacity • Ancillary grid services	• Difficult to site • Limited uses • Low efficiency	\$0.12 - \$0.14	114 MW	4
Flywheels	• Ancillary grid services	• Short discharge time • High cost	\$0.33 - \$1.25	58 MW	21

Figure 4. Typical Power Ratings and Discharge Durations for the Most Common Types of Energy Storage[112]

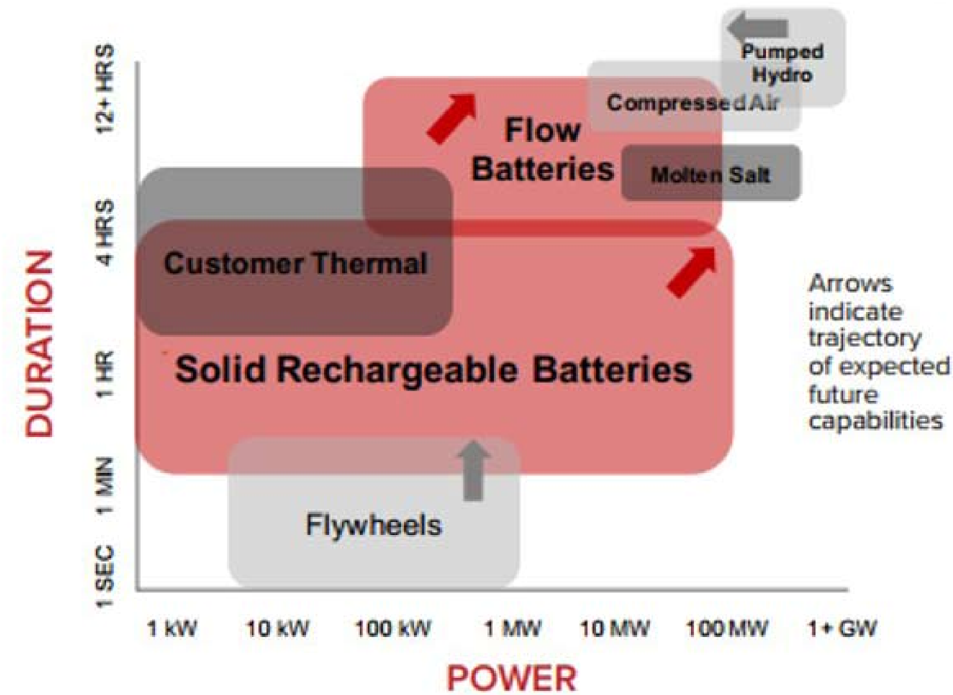
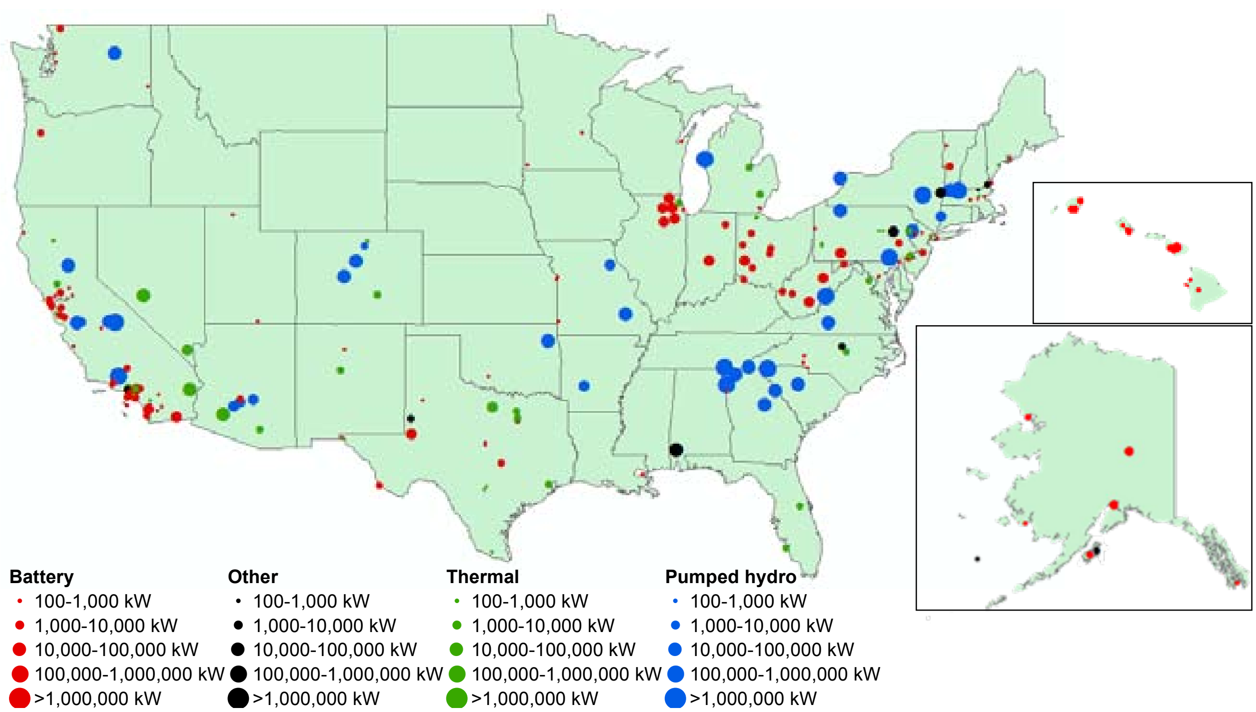


Figure 5. Map of Operational Grid-tied Energy Storage Projects Greater than 100 kW[114]



What Is the Future of Energy Storage?

The History of U.S. Energy Storage

People have been using and storing energy from natural sources for most of human history. For thousands of years, people have lived in stone or clay structures, with the understanding that these materials retain cold during the summer and heat during the winter. Dams are another early example of energy storage. Starting around 1500, builders in Spain and Russia installed dams that blocked rivers from flowing, holding and re-routing the water to power mills.[115] While grid-tied energy storage is much more recent, it is an example of the same concept – storing energy when it is available for use when it is not.

The history of grid-tied energy storage in the U.S. can be split into a few distinct periods.[116]

- **1929 – 1981**: **Pumped-storage hydropower (PSH)** is the only form of energy storage in the U.S., with 30 projects constructed.
- **1982 – 1995**: A few **new technologies are introduced** and connected to the grid (lead-acid batteries, thermal storage and compressed air energy storage), but PSH still dominates, making up eight of the 13 systems deployed.
- **1996 – 2007**: New technologies take over, but **growth is slow**, with only 24 new projects added. About half of these projects are batteries (mostly lead-acid), about half are thermal, and two are flywheels.
- **2008 – 2014**: A period of **rapid growth** with 307 new projects coming online – mostly batteries and thermal systems.
- **2015 – Present**: **Lithium-ion batteries and thermal systems** emerge as the dominant forms of energy storage.

Energy Storage Is Taking Off

Energy storage deployment has been growing rapidly in recent years, both in terms of total capacity and number of projects. Excluding pumped-storage hydropower, there are six times more energy storage capacity and projects connected to the grid than there were in 2007.[118]

The recent dramatic growth in the energy storage market is projected to continue. GTM Research, a market analysis firm that focuses on the electricity industry, predicts that the energy storage market will be 11 times larger in 2022 than it was in 2016.[119]

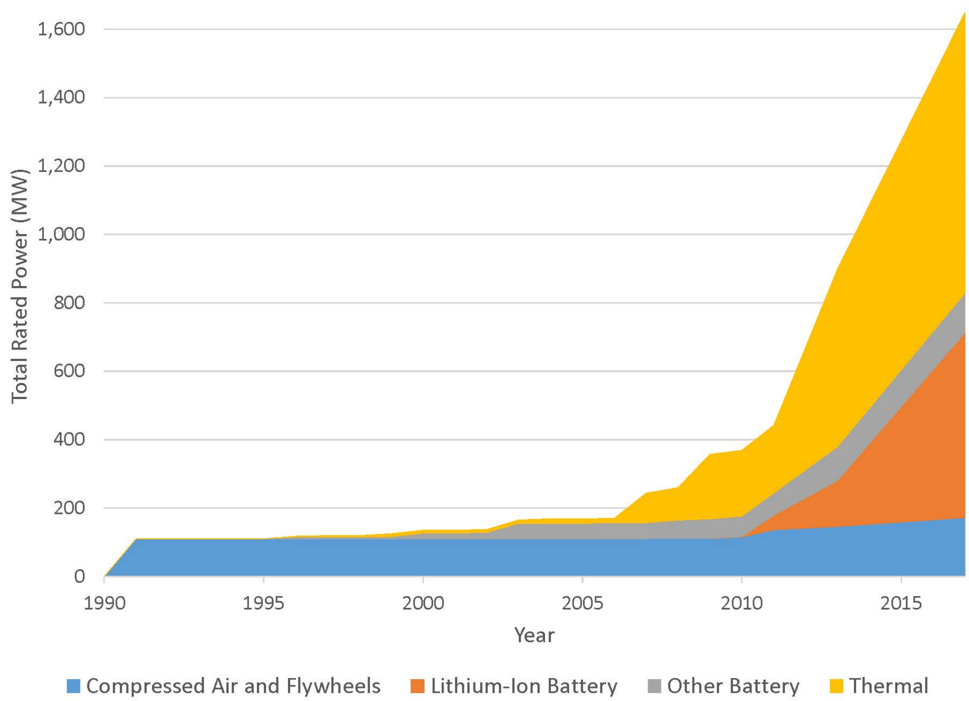
The Value of Energy Storage Is Increasing

Rapid growth in the energy storage market is being driven by falling costs and a variety of factors that are increasing the actual and recognized value of energy storage.

Falling Costs

Energy storage costs are dropping rapidly across the board – for many technologies and uses and at varying scales.[120] The cost of lithium-ion batteries, for example, has dropped from $10,000 per kWh in the early 1990s to a projected $100 per kWh in 2018.[121] These rapidly dropping battery costs could make solar energy systems combined with lithium-ion batteries cost-competitive with grid electricity across the U.S. by 2020.[122] This trend is projected to continue for energy storage technologies in general – over the next five years, average costs are projected to fall 19 to 49 percent for varying battery types, 23 to 37 percent for different flywheel uses, and 4 to 5 percent for PSH, CAES, and thermal technologies.[123] Declining

Figure 6. Total Stacked Capacity of Operational U.S. Energy Storage Projects over Time, Excluding Hydropower[117]



costs will make energy storage technologies more attractive and speed their deployment.

Increasing Renewable Energy Adoption

New renewable energy systems are being installed every day and this expansion is projected to continue. The U.S. Energy Information Agency (EIA) expects that 13 gigawatts of solar and wind capacity will be installed in 2017 and that another 12 gigawatts will be added in 2018 – that's almost a 20 percent increase in capacity in just two years.[124]

As a greater share of energy in the U.S. is provided by increasingly inexpensive variable sources of energy, there will be a greater need for energy storage to balance energy supply and demand. Once renewable sources provide 40 to 50 percent of electricity generation, energy storage will be necessary to maintain the cost-effectiveness of these clean technologies.[125] As renewable energy sources approach that level of penetration in the electricity market, energy storage deployment will likely follow.

New Grid Service Markets

Utilities are starting to recognize both utility-scale and residential energy storage as a valuable resource for maintaining the stability and reliability of the grid. For example, in 2015, the Aliso Canyon natural gas storage facility experienced a methane leak that could have caused power outages across southern California.[126] Multiple battery storage projects were brought online to provide electricity during peak demand times when power plants would have traditionally used the natural gas from Aliso

Canyon. These batteries were brought online in just nine months, whereas traditional "peaker" power plants take years to construct after a need is identified.[127]

Changing Policies and Regulations

Some regulations and policies that were written before many energy storage technologies came online have hindered energy storage deployment. With energy storage becoming increasingly valuable, states are beginning to introduce new policies and regulations, opening up new energy storage markets across the country. In March 2017, 140 state-level policies and regulations were pending or in place across the country that were related to the utility side of energy storage alone.[128]

Energy storage regulations may also change on the national level soon. The federal Investment Tax Credit for residential solar installations can also be applied to energy storage that is set up at the same time.[129] In October 2017, two senators introduced a bill that would also offer a tax credit for storage that is installed independently from home solar.[130] The Federal Energy Regulatory Commission (FERC) issued a proposal in 2016 that would require the nation's grid operators to establish rules that remove barriers and allow energy storage resources to participate in their energy markets.[131] FERC activities were stalled for the first six months of the Trump Administration, as the commission did not have enough members to hold any votes.[132] However, the final two commissioners were appointed in August 2017, restoring quorum, and FERC may revisit the topic of energy storage guidelines.[133]

To help meet their carbon reduction goals, reduce peak load and save ratepayers money, some states are offering incentives to consumers and issuing mandates for their utilities to build energy storage resources. California, most notably, issued a mandate in 2013 requiring the state's three investor-owned utilities to collectively deploy 1,325 megawatts of energy storage by 2024 and another mandate in 2016 requiring them to deploy an additional 500 megawatts "behind-the-meter" – or directly tied to customers' systems.[134] Oregon passed a law in 2015 requiring two utilities to each procure a much smaller 5 megawatt-hours of energy storage by 2020.[135] In June 2017, Massachusetts set a nonbinding energy storage procurement goal of 200 megawatt-hours by 2020.[136] The New York state legislature passed a bill in June 2017 that, once signed by Governor Cuomo, would allow the Public Service Commission to establish a 2030 energy storage target for the state.[137] The Nevada Public Utilities Commission is investigating if it will set an energy storage procurement mandate, and a bill has been introduced in Nevada that would allow energy storage resources to count doubly toward utilities meeting their renewable energy requirements.[138] All of these policies could lead to significant growth in these states' energy storage markets.

Statewide incentive programs also make it easier for consumers to install their own storage. California runs a Self-Generation Incentive Program aimed at industrial, residential and commercial users. This rebate program, which covers renewable energy generation as well, pays $1.31 per watt for advanced energy storage systems, covering up to $5 million or 60 percent of the installation costs.[139] Maryland offers a 30 percent tax credit towards the cost of installing residential or commercial storage.[140] This program can offer up to $750,000 in tax credits annually, a total that would support $2.5 million in new storage projects across the state each year.[141]

Thermal and Battery Storage Are Growing Fastest

The major energy storage technologies, other than PSH, are all projected to grow rapidly in the next several years. These technologies are expected to continue to make up roughly their current share of the market in the future – thermal storage will continue to be the dominant technology, followed by batteries, CAES, and flywheel systems.[142]

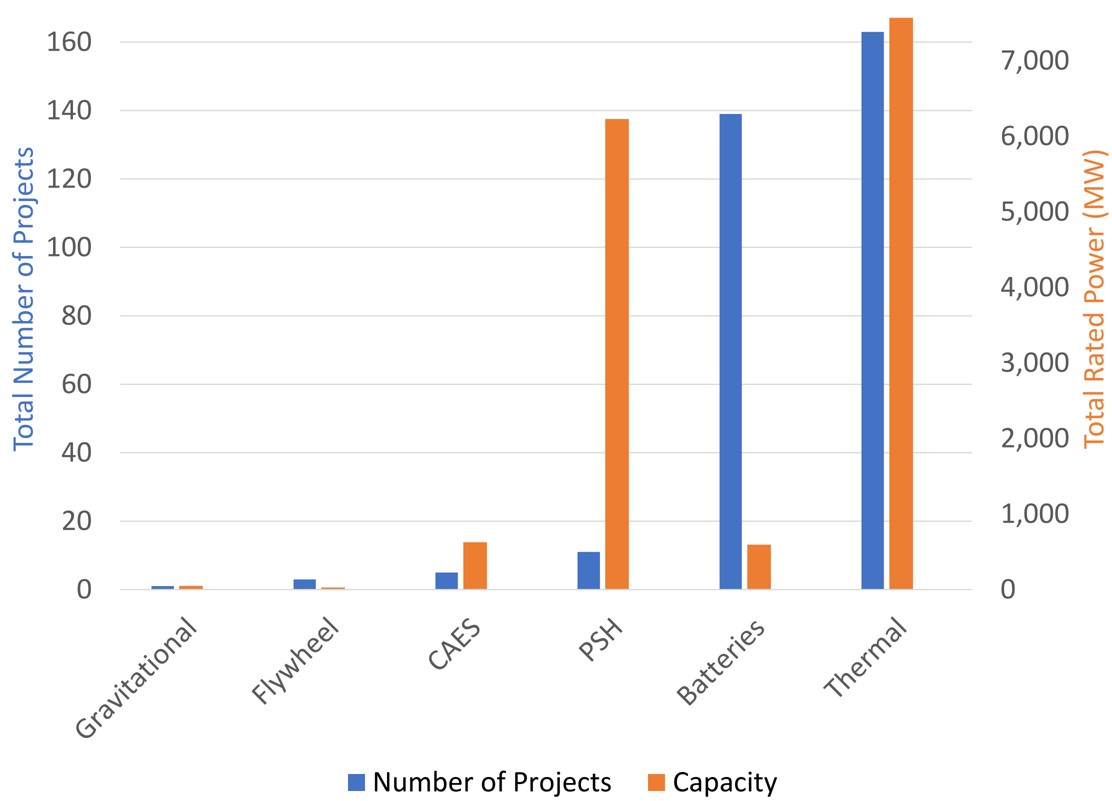
There are more thermal storage systems announced, contracted or under construction to be connected to the grid, with a higher total capacity, than any other storage type currently.[143] The thermal storage market is projected to quadruple in value by 2022 and to continue to have the greatest total capacity after PSH.[144]

Batteries are the second most common grid-tied energy storage systems in the works and many of these are lithium-ion batteries. Lithium-ion deployment increased exponentially in 2015 and was largely funded through private investment, showing that this technology is now economically viable in some markets.[145] Lithium-ion batteries have even saturated the frequency regulation market in some places.[146] Lithium-ion and other batteries are being developed for new grid services, markets are opening up in new locations, and the residential energy storage market is growing. All of these factors will allow battery deployment to keep expanding.

Flywheels and compressed air projects are also projected to grow exponentially in the coming years, but both will continue to make up only a small share of the energy storage market.[147] Other new technologies may also become increasingly important in the future.

Though PSH is projected to grow slowly while other technologies are taking off, PSH will continue to make up the bulk of energy storage capacity in the U.S. for some time. This is because there is currently 27 times more grid-tied PSH capacity than the next most abundant type – thermal. Also, though there are few PSH projects in the works, their total planned capacity is the second highest after that of thermal systems. Because the most well-suited locations have already been developed, the U.S. EIA projects that less than 4 percent of available PSH potential will be developed by 2040, showing that other technologies will begin to out-compete PSH for economic and operational reasons.[148]

Figure 7. Planned Grid-Tied Energy Storage Projects by Category[149]



Where Will Energy Storage Grow the Fastest?

Energy storage will take off the fastest in states and energy markets with strong policy frameworks, including storage mandates and incentives. High electricity prices additionally provide a powerful incentive to consider energy storage.

California is far ahead of other states in deploying energy storage and will continue to be the energy storage leader over the next few years.[150] This is because California was the first state to set a mandate for their utilities to procure energy storage resources and to alter their regulations and policies to be favorable for energy storage.

Hawaii, Massachusetts, New York, Arizona and Texas are all vying to develop the second-largest energy storage market in coming years because of enacted or proposed mandates and regulation and policy changes.[151]

There are states in all regions of the U.S. with significant amounts of energy storage projects operating or planned, though. After California, the states with the most energy storage capacity currently installed are Virginia, South Carolina, Georgia and Michigan, and Nevada, Montana, Texas, Pennsylvania and Oregon have the highest capacity additions planned.[152]

Policy Recommendations

Energy storage is on the rise. Installed capacity is increasing, costs are falling, and people are starting to recognize the big role it can play in supporting the grid and getting us to a clean energy future. However, there are hurdles preventing utilities and consumers from fully embracing energy storage.

In spite of the looming need for energy storage and the immediate benefits it can provide, growth has been limited for a few reasons. Many electricity providers are not fully aware of the many uses and benefits of energy storage and, therefore, don't consider it when grid management needs emerge. Additionally, many commercial customers are unaware of the current energy storage market, and therefore don't consider it when planning energy investments. Thirdly, energy market policies and regulations written before energy storage technologies were developed can artificially undervalue energy storage or even prevent energy storage from participating in the market or attaching to the grid.

To remove these barriers and ensure that energy storage is deployed in the most beneficial manner, policymakers should enact the following changes.

Remove Barriers to Energy Storage

In most states, existing policies and regulations either explicitly exclude energy storage, or do not sufficiently consider and address energy storage's unique attributes, thus restricting it from connecting to the grid or participating in energy market opportunities.[153]

States can help remove these barriers by clarifying their existing grid connection policies to specify that storage is allowed to be connected to the grid and lifting requirements that require generators to be able to provide power for a certain amount of time to participate in the energy market. Federal regulators can facilitate this by requiring the nation's grid operators to allow energy storage to participate in their energy markets.

Design the Markets to Fully Value Energy Storage

Currently, energy regulators and utilities assign value to energy systems based on their categorization as either a generation, transmission and distribution, or end use resource. This categorization works well for traditional energy systems, but energy storage falls into all three categories. Because energy storage can only currently be valued as one resource type, it is artificially undervalued. FERC, nationally, and the nation's regional transmission organizations (RTOs) and independent system operators (ISOs), regionally, should structure their regulations to allow energy storage systems to be fully valued. This would include allowing storage to participate in both wholesale and capacity markets, and considering the stacked value of all the grid services that storage provides.

Require Utility Storage

Energy storage is a multi-functional resource that utilities can use to support increasing renewable power generation and avoid more costly investments in grid infrastructure. Energy regulators – FERC, RTOs, ISOs and state public utilities commissions – should enact policies and regulations that encourage energy storage adoption now to ensure that the grid is stable in the future. States can aid in this by incorporating energy storage into their renewable portfolio standards, or by establishing stand-alone energy storage procurement mandates.[154] State mandates should prioritize energy storage technologies that not only help to integrate renewables and level demand peaks, but also increase resiliency by providing power during outages.[155]

Incentivize Residential and Commercial Storage

Energy storage is valuable in different ways depending on where it is attached to the grid. To reap the full benefits of energy storage, state mandates can require that a certain amount of energy storage capacity be deployed behind the meter, or directly attached to customers' facilities.[156]

Since behind-the-meter storage systems offer unique benefits both to the grid and to the user, states should incentivize businesses and homeowners to install energy storage systems. This can be done by offering tax incentives or by incorporating storage into new or existing renewable energy or energy efficiency incentive programs.[157]

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