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Integrated Energy Storage in the United States

By Ben Bovarnick December 2015

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Introduction and summary

Whether powering cellphones or keeping laptops charged, energy storage has become a daily function in our lives. Now, these storage systems are poised to help supply power to homes, cars, and power plants. The rapidly falling cost of energy storage technologies in recent years is encouraging wider adoption by utilities, commercial business, and homeowners, and it is important that policymakers proactively drive greater integration of energy storage within the broader electricity grid.

The term "energy storage" describes a broad slate of technologies that primarily store electrical energy for later use, allowing utilities and electricity consumers to access it when most needed. Although cellphone and laptop batteries store and discharge energy in the same way as many commercial and utility-scale energy systems, these large systems can hold thousands to millions of times more energy in reserve. These storage systems are used to improve the efficiency of electric utility operations, support electric grid stability, and save extra electricity to meet peak demand.

Energy storage is a relatively small but emerging market in the electric industry.[1] In recent months, new energy sector announcements have focused additional attention on battery storage and the range of benefits energy storage technologies can provide the electric grid.[2] Tesla, the electric vehicle and energy storage company, recently announced that it will sell its Powerwall system for residential storage and its Powerpack utility-scale lithium-ion batteries at significantly lower prices than market analysts predicted.[3] In fact, recent projections for large-scale battery storage through 2020 suggest costs will fall 40 percent to 60 percent from the 2015 price point, driving significant growth in energy storage markets.[4]

Likewise, there has been movement on the policy side at both the state and federal level. California adopted an energy storage mandate in 2014 to require utilities to provide the state with 1.3 gigawatts, or GW, of energy storage capacity by 2022—a mandate that state utilities are already beginning to meet.[5] New York is reforming its regulatory environment and incentives to finance energy storage projects through the state's Reforming the Energy Vision initiative, which will support a new market for energy storage.[6] Momentum can be seen at the federal level too, with Reps. Chris Collins (R-NY) and Mark Takano (D-CA) launching the congressional Battery Energy Storage Caucus last October.[7]

Historically, energy storage has primarily served as temporary backup power for large commercial buildings, such as hospitals, or cellphone towers—often using lead-acid batteries—or has been used to increase electric grid capacity in the form of large pumped hydroelectric storage, or PHS.[8] Yet with the exception of new PHS projects, U.S. energy storage capacity remained mostly flat throughout the 20th century. However, spurred by cost declines and technical advances, energy storage—excluding PHS—has grown more than 1,200 percent in the past 15 years.[9] Much of this growth has been spurred by utilities, which have installed 85 percent of new energy storage capacity in U.S. markets since 2013. By comparison, 1.2 percent of new energy storage capacity came from residential installations.[10]

The concentration of energy storage within utility projects is partly due to the high capital costs, but also because energy storage offers clear benefits for electric generators and grid operators. Energy storage can help electric utilities meet peak-capacity demand by holding energy in reserve and releasing it when it is most needed, balance electricity levels flowing through the grid to preserve grid reliability, and defer costly investments in new transmission or distribution systems. Additionally, energy storage can reduce emissions associated with electric generation by helping renewable energy generators extend the length of time they can provide energy and reducing the amount of electricity that utilities must purchase from inefficient natural gas peaking plants.

As the costs of energy storage technologies generally—and battery storage in particular—continue to fall, these projects are likely to become increasingly important resources in U.S. electricity markets. Yet many states do not have established policies for incorporating energy storage into electric markets or to encourage its usage. This nascent market offers policymakers and industry leaders the chance to consider how states and utility regulators can reduce barriers to deployment and increase opportunities for energy storage in order to provide low-cost, high-value services to support utility operations, reduce consumer electricity demands, and bolster state electric grid efficiency. As energy storage costs fall, policymakers should take steps to ensure these technologies play an integral role in offering flexible utility solutions that maximize reliability while limiting long-term electricity costs.

Key terms

Capacity: The maximum energy that can be stored or generated and provided for use under specified conditions

Cycling: The repeated process of storing and releasing energy, often used to describe the charging and discharging of batteries

Gigawatt, or GW: 1,000 megawatts, often used to refer to the capacity of large power plants

Frequency regulation: Increasing or reducing the supply of electricity to maintain the alternating current, or AC, frequency on an electric grid

Kilowatt, or kW: A standard measurement of electric capacity

Kilowatt-hour, or kWh: A unit of measurement for the amount of electricity used continuously for one hour. The typical American home uses 7,200 kilowatt-hours, or kWh, of electricity per year.[11]

Kilowatt-year: A unit of measurement that quantifies the cost of a number of kilowatts of electricity available for use in a single year

Levelized cost: The cost of electricity over an electric generator or storage system's lifetime, based on installed price, fuel costs, operations and maintenance, and electricity production

Load following: Dispatching electric storage or generation capacity to allow the grid to ramp instantaneously and smoothly

Megawatt, or MW: 1,000 kilowatts, often used to refer to the capacity of power plants and other large sources of electricity.

Megawatt-hour, or MWh: 1,000 kilowatt-hours, a unit of measurement for the amount of electricity used continuously for one hour, often used to describe output from electricity generation sources

Peak shaving: Reducing the amount of energy generation needed to meet peak demand through storage or demand reductions

Ramping: Increasing or decreasing the electric voltage of a system by adding or reducing electric power to regulate the frequency of a grid and avoid system wear or blackouts

Transmission deferral: The act of postponing or avoiding investment in new electric transmission to replace components that have worn out or are insufficient to meet demand by extending the life of existing infrastructure or replacing it with more cost-effective options, such as energy storage

Voltage support: The capability to produce or absorb electricity to maintain the voltage of an electric system

Storage technologies and applications

The primary role of energy storage is to hold electricity in reserve until called upon to inject it back into the grid. Therefore, storage systems are typically valued based on their power capacity, how quickly and efficiently they can discharge this stored energy, and their ability to withstand repeated charge and discharge cycles. Energy storage can serve as a fast-response grid support tool or provide bulk storage to collect energy when generation is high and release it when demand spikes or supply is low. These storage technologies can range in capacity from kilowatts—1,000 watts—to gigawatts—1 billon watts—depending on the needs they are designed to meet and can send electricity to the grid within seconds or minutes of demand.

Fast-response energy storage, such as lithium-ion batteries, can provide electricity immediately to help utilities and grid operators manage electric grid stability, as well as provide backup power for homeowners and commercial customers. These rapid-response storage systems can play an essential role in the electric grid because grid stability requires electric generation and consumption to be consistently in balance. This moment-to-moment balance is typically managed by an independent electric grid operator—an independent service operator, or ISO, or a regional transmission operator, or RTO—that procures ancillary services, which are dedicated operations to maintain grid stability through frequency regulation, load following, and voltage support from utilities and third-party providers.[12] If the electrical flow of a grid falls out of balance, damage will occur, resulting in degradation of electrical components or system overloads, which can cause blackouts. Therefore, energy storage assets that provide frequency regulation, load following, and voltage support must be able to quickly respond to grid signals to rapidly deliver electricity or absorb excess energy from the grid. This process of charging and discharging, known as cycling, can occur dozens of times per day, subjecting systems to wear and degradation over time.[13]

By contrast, bulk energy storage systems, such as pumped hydroelectric facilities, are used by electric generators and grid operators to conserve electricity supply and release it to the grid when needed to meet demand.[14] These large-scale assets can balance electric load over time by storing large amounts of electricity at night when electricity is cheap and then releasing it over a period of several hours during the day when there is higher demand.[15] This energy arbitrage moderates the peaks and valleys that spring from demand fluctuations over the course of a day. Typically, electricity demand ramps up in the morning when people are waking up and peaks in the early evening as people return home from their offices before falling later in the evening as they go to bed. With the dawn of a new day, the cycle repeats. It is up to electric generators and grid operators to ensure that they have electricity available to meet peak demand, or they risk blackouts. Energy storage is a crucial tool to help alleviate the strain of some peaks or limit their duration.

TABLE 1

Selected energy storage technologies

Applications, costs, and technical parameters of storage systems

Storage system	How electricity is stored	Users*	Applications	Levelized cost of energy (in 2014 dollars per kWh)**	Capacity (in MWh)	Response time	Discharge time	Efficiency	Lifetime years and cycles
Lithium-ion batteries, or li-ion	Electrochemical storage of electricity at low temperatures	Utilities; commercial businesses; residential customers	Providing electricity at a moment's notice for frequency regulation, peak shaving, time shifting of renewables, backup power, and off-grid energy	$347 to $739	0.004 to 10	20 milliseconds to seconds	Minutes to hours	85% to 95%	8 to 15 years; 1,000 to 10,000 cycles
Flow batteries	Electrochemical storage of electricity at low temperatures	Utilities; industrial customers	Storing renewable energy integration and time shifting storage; peak shaving; distribution line upgrade deferral; voltage support; load balancing; providing standby power; and providing off-grid electricity	$290 to $892	2 to 60	Seconds to minutes	Seconds to 10 hours	60% to 85%	10 to 20 years; 12,000 to 14,000 cycles
Pumped hydroelectric storage, or PHS	Mechanical storage of electricity by pumping water to a higher elevation	Utilities	Storing large amounts of energy to provide peak load generation, a black start of electricity grids after power outages, and some grid frequency control	$188 to $247	500 to 8,000	Seconds to minutes	Minutes to hours	70% to 85%	50 to 100 years; 500+ cycles

Storage system	How electricity is stored	Users*	Applications	Levelized cost of energy (in 2014 dollars per kWh)**	Capacity (in MWh)	Response time	Discharge time	Efficiency	Lifetime years and cycles
Compressed air energy storage, or CAES	Mechanical storage of electricity by compressing air in a confined space	Utilities	Storing large amounts of energy to align energy supply with demand	$192	Very different for large and small scales	1 to 15 minutes	Seconds to minutes	40% to 75%	25 to 40 years; no cycle limit
Flywheel	Mechanical storage of electricity through a spinning wheel	Utilities	Providing electricity at a moment's notice for frequency regulation	$276 to $989***	0.0052 to 5	4 milliseconds to seconds	15 seconds to 15 minutes	70% to 95%	Less than 20 years; 20,000 to 100,000
Advanced lead-acid batteries	Electrochemical storage of electricity at low temperatures	Utilities; commercial businesses	Providing electricity at a moment's notice for voltage regulation or to displace diesel generation for backup or uninterrupted power	$461 to $1,429	0.001 to 40	5 milliseconds	Minutes to hours	75% to 90%	3 to 15 years; 3,000 cycles
Sodium-sulfur batteries or molten salt storage	Electrochemical or thermal storage of electricity at high temperatures	Utilities; industrial customers	Integrating renewable energy by time shifting electricity, peak shaving, transmission upgrade deferral, voltage support, load balancing, and providing backup electricity	$396 to $1,079****	0.4 to 244.8	1 millisecond	Seconds to hours	70% to 90%	12 to 20 years; 2,500 to 4,400 cycles

* This category refers to end users of energy storage functions, not necessarily intermediate storage providers.

** Cost estimates by Lazard. They reflect transmission system applications unless otherwise indicated.

*** Cost estimate for use in frequency regulation.

**** Cost estimate for sodium-sulfur batteries only.

Sources: Arup, "A five minute guide to electricity storage," available at http://www.arup.com/Home/Publications/5_minute_guide_to_electricity_storage.aspx (last accessed November 2015); Dan Rastler, "Electricity Energy Storage Technology Options" (Palo Alto, CA: Electric Power Research Institute, 2010), available at http://large.stanford.edu/courses/2012/ph240/doshay1/docs/EPRI.pdf; Daniel H. Doughty and others, "Batteries for Large-Scale Stationary Electrical Energy Storage," *The Electrochemical Society Interface* (2010): 49–53, available at http://www.electrochem.org/dl/interface/fal/fal10/fal10_p049-053.pdf; Deloitte, "Energy Storage: Tracking the technologies that will transform the power sector" (2015), available at http://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-energy-storage-tracking-technologies-transform-power-sector.pdf; Energy Flagship, "Electrical Energy Storage: Technology Overview and Applications" (2015), available at http://www.aemc.gov.au/Major-Pages/Integration-of-storage/Documents/CSIRO-Energy-Storage-Technology-Overview.aspx; Lazard, "Lazard's Levelized Cost of Storage Analysis—Version 1.0" (2015), available at https://www.lazard.com/media/2391/lazards-levelized-cost-of-storage-analysis-10.pdf; Xing Luo and others, "Overview of current development in electrical energy storage technologies," *Applied Energy* 137 (1) (2015): 511–536, available at http://www.sciencedirect.com/science/article/pii/S0306261914010290.

Key uses and benefits of energy storage

The lifetimes of electric infrastructure assets, including power plants, transmission lines, and distribution centers, last many decades. Investments made today will require payoffs over extended timeframes. As the cost of energy storage falls, these technologies—in particular, those used for fast response and load balancing—can increasingly benefit future electric grid efficiency and reliability. Energy storage systems can be used to meet capacity needs instead of costly investments in new peak electric generation or transmission lines and offer ancillary benefits that enhance grid stability.

Storage systems can be installed at a variety of points on the electric grid: at the point of electric generation, in the transmission and distribution system to bolster electric circuits experiencing peak capacity, and behind the meters that are fixed to commercial and residential buildings, where they can reduce electricity costs during peak demand periods or provide backup power in the event of a power outage. In a recently released report, the Rocky Mountain Institute, or RMI, looked at battery storage systems and identified key services they could provide to utilities, grid operators such as ISOs and RTOs, and residential and commercial customers. The report found that by using storage for multiple services, energy storage projects could yield a substantial return even at the current costs of battery storage. However, it is still rare for companies to use energy storage for multiple services today.[16] The primary uses for energy storage currently include:

- Meeting peak-capacity demand by dispatching stored electricity to the grid
- Providing ancillary services to improve electric grid stability and reliability
- Deferring investment in transmission and distribution to reduce utility costs

Meeting peak capacity

One of the primary roles of energy storage pinpointed by RMI and others is peak shaving, or providing electricity to the grid when demand peaks. Electric demand fluctuates throughout the day, and electric grid operators must ensure that sufficient electricity capacity is available to meet peak demand. This means that grid operators must reserve some electricity generation to meet infrequent peak demand. Energy storage can reduce the peak generation capacity that electric grid operators must retain to meet demand.

Currently, this demand is often met through peaking plants—inefficient combustion turbine, or CT, plants that are usually powered by natural gas and can come online within minutes of a demand spike. These plants are cheap to build and operate but produce more greenhouse gas emissions than other fossil fuel electric generators. CT plants must ramp up and down quickly and run far less efficiently than advanced combined-cycle natural gas plants, which increases their carbon dioxide, nitrogen oxide, and sulfur oxide emissions.[17] For example, New York state's peaking plants operate infrequently—averaging less than 250 hours per year despite making up 20 percent of the state's generators—but have much higher energy costs than baseload power plants. The levelized cost of energy from a combined-cycle natural gas plant is $52 to $78 per megawatt-hour, while the levelized cost of energy from a peaking plant is $165 to $218 per megawatt-hour.[18] Although the cost of utility-scale storage is still above this, the falling cost of battery storage suggests that such technologies will be cost competitive in the near future.[19] At a September 2015 analyst conference in New York, NextEra Energy CEO Jim Robo said, "Post-2020, there may never be another peaker [CT plant] built in the United States—very likely you'll be just building energy storage instead."[20]

A recent report by Moody's Investors Service corroborates this prediction, finding that the falling price of battery storage is likely to drive storage applications that will limit the frequency with which utilities need to dispatch peak capacity.[21] In September 2015, *Fortune* magazine reported, "Utilities are starting to buy big battery banks as a way to avoid building and operating new expensive natural gas plants. If they can use battery energy during peak grid times, instead of turning to this expensive so-called [peaker] power plants, they can save money in the long run."[22] In addition to investment by utilities, commercial and industrial users are expected to procure energy storage, which will limit the amount of energy regulated utilities can sell them. However, while electricity demand growth is slowing, peak demand is still on the rise.[23]

Recent installations of peak generators to meet this demand show that while energy storage is beginning to compete, it has not yet achieved cost parity.[24] A study by Sandia National Laboratory concluded that the levelized cost of capacity for a 100-MW natural gas peaking plant with a 5 percent capacity factor is $156 per kilowatt-year, lower than the current cost of fast-response battery storage. The lowest cost for a lithium-ion battery in the Sandia study was more than $200 per kilowatt-year.[25] However, the study noted that storage technologies have fewer constraints and "can reasonably be expected to earn more net revenues than a CT." While energy storage systems currently face a cost disadvantage when competing with supply peak capacity, the additional services these units provide can eliminate this shortfall.[26] By participating in ancillary services markets (see below), energy storage systems can competitively serve the peak-capacity demand currently met by natural gas turbines.

Providing ancillary services

One of the primary ways that energy storage can reap financial benefits is through participation in ancillary services markets. Ancillary services are specific services that help electric grid operators maintain grid stability as demand fluctuates, including frequency regulation, generation reserves, and voltage control.[27] Utilities can provide these services by selling, also known as "bidding," into ancillary services markets operated by RTOs and ISOs. Grid operators utilize these ancillary service markets to bolster the efficiency of their electric grids and maintain grid stability.

Although fast-response energy storage is a relatively new entrant to electricity markets, a variety of storage technologies have found success in the Pennsylvania-New Jersey-Maryland, or PJM, ancillary services market. The PJM market relies on battery storage, flywheels, and electric vehicles for capacity support and bases compensation for its storage services according to system response time and accuracy.[28] When the PJM market needs to increase or reduce electric load on the grid, it calls on companies with stored electricity or available electric capacity to inject or absorb electricity from the grid, improving its stability and efficiency. The grid requires a precise electric balance, and energy storage services that can meet this balance most effectively are more valuable than ancillary service options that cannot perform as precisely. The fast-response nature of batteries or flywheels lets companies that are selling their energy storage capacity respond to grid operator requests within seconds and vary system output from zero to maximum capacity. By contrast, natural gas turbines can take minutes to dispatch and are inefficient until they reach a predetermined minimum output.

In September 2015, energy storage provider Stem Inc. sold the aggregate capacity of its energy storage units into California's ancillary services electricity market.[29] The company owns numerous distributed battery storage systems that provide energy storage to commercial customers. By linking the aggregate capacity of its systems together, Stem was able to sell its capacity in the California ancillary services market and earn additional return on investment for its customers.

Deferring transmission investment

In addition to replacing peak generation and providing ancillary services, energy storage can help utilities circumvent the costs associated with new transmission and distribution investments by improving the ability of existing grid infrastructure to meet and respond to peak-capacity loads. In West Virginia, for example, American Electric Power, or AEP, installed sodium-sulfur batteries to avoid building a new 8-mile transmission line to reduce transmission congestion at a cost the could have exceeded $8 million.[30] The 2-MW energy storage system AEP installed, which was partially funded by the U.S. Department of Energy, or DOE, will improve daily reliability and limit power outages.[31]

The Brattle Group found that deferred transmission investments in Texas gained by placing battery storage units near specific locations strained by peak demand were worth approximately $36 per kW-year for deferred transmission investments and $14 per kW-year for deferred distribution investments.[32] These values are based on the finding that investment in energy storage units is cheaper than the cost of improvements to existing transmission. In locations where investments to improve distribution services incorporate energy storage at lower-than-expected costs, the savings could be monetized and returned to consumers or investors to incentivize such investments.

Similarly, electric utility Consolidated Edison, or Con Ed, in New York City has turned to battery storage and demand-side management programs to defer the cost of building a $1 billion substation. Con Ed plans to invest $500 million in programs to limit electricity demand and equipment upgrades, including battery systems, to increase grid flexibility and improve peak-demand response. Battery storage is not subject to many of the siting restrictions associated with the construction location of other electric infrastructure, giving utilities the flexibility to determine placement. Battery storage systems can also be mobile to meet the evolving peak requirements of an electric grid.[33]

Energy storage and the Clean Power Plan

When the Environmental Protection Agency, or EPA, released its final rules for the Clean Power Plan in August, energy storage was not on the agency's list of Best System of Emission Reduction, or BSER, tools for reducing power plant emissions—a list that included solar, wind, and natural gas. The EPA highlighted the potential for energy storage to assist with the integration of renewable energy to mitigate emissions and increase the efficiency of the electric grid, but the agency determined that energy storage would provide only indirect reductions in power plant emissions.[34]

However, that does not mean that states are not able to call upon energy storage technologies as a tool to reach their Clean Power Plan pollution reduction targets. As the costs of energy storage continue to fall, these systems can help meet emissions targets by eliminating the need for fossil fuel generators to respond to peak demand and by aligning renewable energy generation with demand.

In addition to limiting the fossil fuel emissions associated with peak demand, fast-response energy storage systems, such as battery storage, can improve the efficiency of coal-fired power plants and other fossil fuel generators by reducing the need for ramping and load following.[35] The National Energy Technology Laboratory—an energy research laboratory operated by the DOE—found that the average efficiency of U.S. coal plants was 32 percent.[36] Moreover, according to the Congressional Research Service, "Improving the efficiency of existing coal plants could potentially result in significant reductions of CO_2 emissions per unit of electricity produced."[37] One approach to increasing efficiency, particularly in states with significant percentages of coal-based electricity, is to use fast-response energy storage to reduce or eliminate the need for ramping, which can inhibit power plant efficiency and cause damage to system components.[38]

Energy storage would yield efficiency improvements by reducing the ramping power plants must perform to maintain grid stability as demand shifts. Brief fluctuations, for instance, could be met by dispatching energy storage instead of ramping, thus allowing electric generators to run at consistent outputs.[39] Battery manufacturer Alevro estimates that incorporating its batteries into coal plant operations could increase output by 15 percent,[40] improve efficiency by 11 percent, and reduce greenhouse gas emissions by up to 7 percent.[41] Regulators and utilities could incorporate energy storage into state approaches to increase electricity generation and transmission efficiency by reducing peak-demand levels and the ramping of fossil fuel plants.

Recent cost and usage trends

To date, the cost for most energy storage systems has still been too high to be widely competitive with conventional electricity generation and transmission assets. Most lithium-ion battery systems cost between $350 and $750 per kWh.[42] To alleviate this price hurdle, battery storage systems have often been deployed with the support of public funding or as pilot projects to gather data for future usage. In Glacier, Washington, Puget Sound Energy deployed a 2-MW lithium-ion battery system to provide up to 18 hours of backup power during grid outages at a cost of $9.6 million. Puget Sound Energy received a $3.8 million grant from the state of Washington for the system.[43] Similarly, Duke Energy matched a $22 million grant from the DOE to finance 36 MW of battery storage for the company's 153-MW Notrees wind farm in Texas to offset variable generation of the farm and to arbitrage power production in response to demand fluctuations.[44] Furthermore, low natural gas prices in recent years have suppressed the costs of using natural gas generators to provide ancillary services and meet peak demand, undermining the cost competitiveness of energy storage in some markets.[45]

However, as demand for energy storage grows, costs are expected to significantly decrease, particularly for fast-response systems such as batteries. Although price trends for different energy storage technologies vary considerably, the falling costs of battery storage units offer one metric to track costs in the energy storage industry. The per-year cost of the lithium-ion cells used in electric vehicles have decreased roughly 8 percent from 2007 to 2014, and the cost is expected to continue to decline steadily.[46] A recent Brattle Group study predicted that typical storage costs will drop more than 50 percent from 2014 to 2020.[47] Recent declines in battery costs have been compared to the rapid growth of the photovoltaic solar industry, a sector that has experienced massive cost drops in recent years.[48]

Falling costs are already reducing the payback period for energy storage projects and helping these projects compete in certain parts of the country. The S&C Electric Company, which provides the energy storage services that bid into the PJM ancillary services market, could see the investment in its 1-MW system paid back in as little as four to five years.[49] Similarly, battery storage provider Stem Inc., which contracts with California utilities to provide demand-response services, projects a payback period of less than three years for its battery systems.[50]

These falling costs for fast-response energy storage are already leading to increased usage around the country. Excluding pumped hydroelectric projects, the number of energy storage projects commissioned in the United States has increased more than 600 percent in the past five years, primarily through increasing use of battery storage.[51] Most recently, the second quarter of 2015 saw a 900 percent growth in capacity deployment across the United States. The majority of this growth came from the new storage capacity added to the PJM Interconnection grid, which has added 100 MW of storage capacity since the start of 2013.[52] This growth continued in the third quarter of 2015, with 60.3 MW of new storage capacity added.[53] Market analysis firm GTM Research estimates that the energy storage market will reach an annual capacity deployment of 858 MW by 2019—four times more than the total expected to be deployed in 2015.[54]

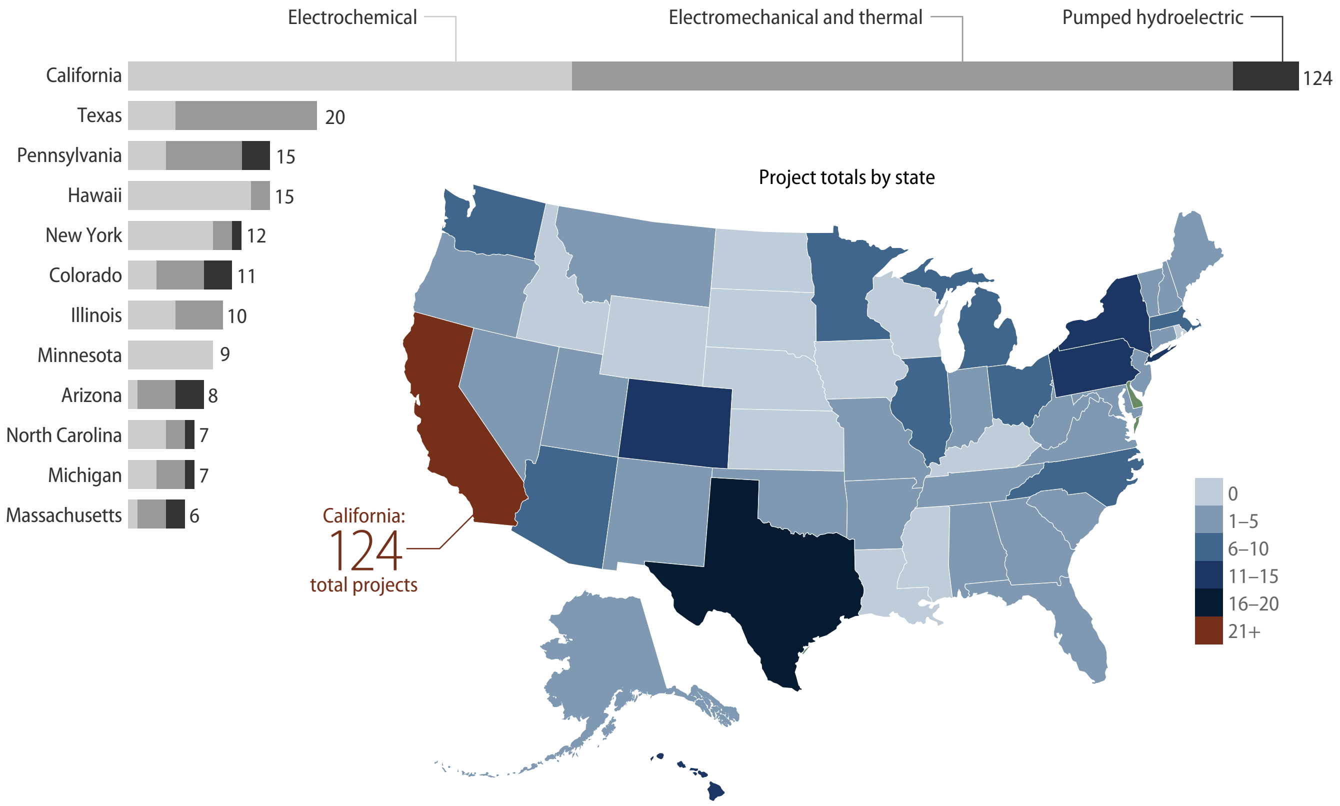
While the number of energy storage projects across the country is increasing—there are currently 325 projects in the United States—energy storage development is greatly outpacing other areas in a few states.[55] For instance, California has installed almost half of the total number of nonhydroelectric storage projects tracked by the DOE. Other state leaders include Texas, New York, Hawaii, Pennsylvania, and Illinois.[56] These projects are concentrated in the California Independent Service Operator, or CAISO, and PJM electric grids. CAISO currently hosts 111 projects that are operating or under construction totaling 215.4 MW, while PJM hosts 45 projects totaling 190.3 MW.

Compared with the recent spike in battery storage, bulk storage systems, such as pumped hydroelectric storage, have experienced more gradual growth throughout the past century. However, these systems contribute significant capacity to the U.S. electric grid. In the past century, 41 PHS facilities have been built in the United States for a total of 22.37 GW, and 36 of these facilities are still operational today.[57] Recent additions to the bulk storage space have come from thermal storage projects, primarily smaller 1-MW to 2-MW projects, but also the 72-MW Nevada Solar One power plant, the 90-MW TAS Texas Cooperative, and the 280-MW Solana solar generating plant.[58] These bulk storage facilities and smaller energy storage systems provide the United States with 24.6 GW of capacity, enough to store 2.3 percent of U.S. electric generation.[59]

FIGURE 1

Energy storage projects in the United States

Storage installations by state through 2015



Source: U.S. Department of Energy, "DOE Global Energy Storage Database: Projects," available at http://www.energystorageexchange.org/projects (last accessed November 2015).

Deployment barriers

In spite of these recent gains, energy storage still faces significant hurdles. Many systems are not yet cost competitive with conventional technologies. Cheap natural gas suppresses the market for peak-load shaving and ancillary services.[60] States lack the regulatory structures necessary to facilitate energy storage deployment or reward utilities for their investments in storage projects. Furthermore, the value of storage often serves many parties, whether or not they all contribute to an investment. This inability to spread the cost of investment among all beneficiaries is another hurdle to overcome.

Market valuation

The diverse value potential of storage systems can impede companies from collecting the full benefits offered by an energy storage project. For example, a transmission and distribution utility that installs an energy storage system instead of constructing new, expensive wires to improve electricity distribution can accrue savings from the cheaper option but not necessarily earn additional profit from the ancillary services or peak shaving their system could offer the grid. [61] This fragmentation of incentives can result in underinvestment in energy storage and affects almost any energy storage use case, not just transmission and distribution deferral.[62]

Energy storage may also be undervalued due to a lack of industry familiarity with new energy storage technologies or applications. While a recent Black & Veatch survey of utilities found that almost two-thirds of respondents felt energy storage would be important for the integration of variable energy resources and 70 percent said one of the most valuable functions of energy storage is meeting peak-capacity requirements, 54 percent of respondents stated that they were not involved in energy storage programs or were unaware of their involvement.[63]

Some hesitation is understandable. For instance, in 2014, a $2 million solar-firming lead-acid battery system—designed to smooth fluctuations in solar output due to shifting weather patterns—on the island of Kauai in Hawaii was almost completely useless after just two years of usage, even though it was expected to last eight years. Repeated deep cycling of the system's batteries had degraded them faster than expected, and the company that sold them later declared bankruptcy.[64]

Newer technologies such as lithium-ion, molten salt, and flow batteries are much less susceptible to these types of problems, but vast differences between storage technologies can make research and procurement a daunting task for companies or their investors. While the energy storage industry is gaining experience, many utilities and developers prefer to watch from the sidelines.

Regulatory restrictions

In addition to market hurdles and competition with conventional energy sources, energy storage projects face regulatory limitations to deployment. The novel nature of fast-response energy storage means that many states do not have a regulatory environment that has sufficiently adapted to support integration of energy storage into existing utility markets. Furthermore, the multiple roles energy storage can play in electricity markets make them more difficult to regulate.[65] Efforts to profit from the multiple services that energy storage systems can provide have been stymied in states that are insufficiently prepared to regulate the versatile characteristics of energy storage systems.

In ISO—independent service operator—and RTO—regional transmission operator—regions, many states lack sufficient clarity on what services energy storage can provide to different electricity markets because they have regulations designed to limit simultaneous participation in wholesale electricity generation markets while providing electricity distribution services. This divide prevents utilities from using electricity rates to recover costs of investment in an energy storage system for transmission services while also generating revenue by bidding the system capacity into ancillary services markets or by selling electricity back to the grid at times of peak demand. Such an arrangement would likely require approval from both the Federal Energy Regulatory Commission, or FERC, and state regulators, which drives project uncertainty and significantly hinders investment.[66]

These regulatory barriers are particularly acute in Texas, where laws for the state's electricity grid, which is outside of FERC jurisdiction, are designed to limit monopoly ownership of electricity assets. In Texas, electric generators are prohibited from owning transmission and distribution assets, while electric transmission utilities are barred from owning electricity-producing systems. This restriction has prevented Oncor, a Texas transmission and distribution utility, from reaping the full value of two battery storage systems the utility deployed to enhance grid reliability. Oncor was limited to using storage to support transmission and distribution and could not use the batteries to participate in competitive power markets.[67] Efforts to reform market rules have been met with resistance from utility and industry groups, and no legislative proposals have been considered to reform the current regulations.[68]

Meanwhile, states with traditional utility regulatory structures have to establish clear valuation of energy storage assets to send strong market signals to electric utilities. In these states, electric utility investment decisions are based in part on the ability of the utility to recover investments through electricity rates. State utility regulators or legislators must offer guidance to utilities on the value of energy storage to provide ancillary services, improve reliability, and offset investments in transmission, distribution or peak generation elsewhere. Additionally, regulators need to consider how these investments might benefit ratepayers at the expense of traditional sources of revenue for utilities, similar to energy efficiency investments. Furthermore, the vertically integrated structure of these utilities limits the opportunities for third-party developers to market energy storage services. In these states, regulators and policymakers may need to reform the rate treatment of energy storage assets in order to reduce regulatory barriers.[69]

Outside of utility investments in energy storage, one significant market for energy storage systems is commercial and residential consumers. These systems—generally known as behind-the-meter, or BTM, systems—are often smaller than utility-scale projects and deployed by third-party companies or utilities. Individually, BTM systems do not necessarily provide the capacity needed to provide measureable value to an electric grid. However, when aggregated with many other systems, they can provide hundreds to thousands of kilowatts of capacity. CAISO has developed rules that allow third-party owners of energy storage to bid aggregate systems into the state's ancillary services market. On September 3, 2015, Stem Inc. in partnership with Pacific Gas and Electric, or PG&E, used this model to bid the capacity of its aggregate units into California's electricity market and generate a new source of revenue for its customers.[70] However, other states have not yet adopted similar rules, hindering the opportunity for owners of BTM systems to profit through the sale of aggregate capacity.[71]

Currently, the market for demand-response technologies is also facing uncertainty while FERC Order 745 is being considered by the U.S. Supreme Court in *Federal Energy Regulatory Commission v. Electric Power Supply Association*.[72]

Order 745 requires ISOs and RTOs to compensate companies for demand-side management response. If upheld, this rule would require wholesale electric market operators to pay companies for reducing their electricity load during high-demand periods at the expense of wholesale electric generators.[73] Energy storage, which can serve similar functions as automated demand response, could be similarly compensated for providing electricity to the grid at times of high demand. However, if the Supreme Court overturns Order 745, the Court could conclude that demand response is part of state regulatory authority or require FERC to establish new rules for demand response, creating additional uncertainty for energy storage investors.[74]

Conclusion and questions for further study

Energy storage is likely to play an increasing role in U.S. electricity markets in the coming decade. Prices are expected to fall, and electric utilities will become more familiar with storage systems and the benefits they can offer. It is important that policymakers, regulators, and industry leaders anticipate the role energy storage will play when planning future investments in electricity generation and transmission.

In order to better understand the role energy storage may play in future investment decisions and what opportunities exist to integrate energy storage systems into the U.S. electricity markets, utilities, regulators, and policymakers should consider the following questions:

- **Maximizing value streams:** How can energy storage provide multiple services simultaneously? How can owners be compensated fully for them?

- **Asset ownership:** Who should own energy storage systems—utilities, third parties, or individuals? How can states ensure that existing or future regulations do not restrict investment by interested parties?

- **Investment planning:** How can states and utilities best plan for a future of low-cost energy storage? How should regulated utilities incorporate energy storage into integrated resource plans?

- **Encouraging deployment:** What policies can support development of the market for energy storage and system price reductions? What state policies are showing the most success?

- **Energy storage and the Clean Power Plan:** How can energy storage systems assist state energy efficiency and help states and utilities comply with Clean Power Plan targets?

As the United States reshapes its 21st-century electric grid, it is important not to let 20th-century thinking drive new investments. Utilities that historically focused on utilizing large-scale baseload power generators should now shift their focus to flexible grid solutions that use resources more efficiently to meet peak electric demand. Many states and utilities are working to reduce peak electricity needs through demand-response programs, and new energy storage technologies will bolster these efforts. With the projected cost declines expected for energy storage in the coming years, it is imperative that policymakers and the private sector consider the roles they can play in offsetting costly investments in conventional generation, transmission, and distribution. Energy storage investments will increase grid flexibility and resilience, while helping utilities defer investment in new generation and transmission to meet peak demands. As energy storage costs fall, policymakers should take steps to ensure these technologies play an integral role in offering flexible utility solutions that maximize reliability while limiting long-term electricity costs.

Appendix: State-specific approaches to energy storage

California: Storage procurement mandate

In 2010, the California Legislature passed A.B. 2514, which directed the California Public Utilities Commission, or CPUC, to determine a process for incorporating utility-scale electricity storage into the state's electric grid. On June 10, 2013, CPUC announced mandatory procurement requirements for the state's three investor-owned utilities, or IOUs.[75] The IOUs must meet increasing procurement benchmarks every two years, totaling 1,325 MW by 2020. Southern California Edison, or SCE, and Pacific Gas and Electric, or PG&E, each must procure 580 MW, while San Diego Gas and Electric, or SDG&E, must procure 165 MW.[76] These procurements will provide utility storage capacity equivalent to 1 percent of California's peak electricity usage in 2020.[77]

The mandate does not prescribe specific technologies or uses for energy storage systems. As a result, utilities can procure storage systems with a variety of functions that serve the grid operated by the California Independent System Operator, or CAISO. These functions include ancillary services; balancing electricity demand; electricity price arbitrage; transmission and distribution services, including peak-capacity support and congestion relief; and customer services, including power-outage mitigation and energy cost management. CAISO requires that systems offer grid optimization services or "greenhouse gas emissions-reducing attributes."[78]

SCE has led California's IOUs in storage investments. The utility, which initially sought to procure 50 MW of storage in 2014, ultimately secured 264 MW through a combination of battery storage and thermal storage. The 264 MW will help SCE replace electric capacity lost to the closure of the San Onofre Nuclear Generating Station.[79] The storage procurements included 100 MW of battery storage built into existing power generation sites; 135 MW of behind-the-meter battery storage used by commercial and industrial customers from two providers; and 25.6 MW of behind-the-meter thermal energy storage through cooling units linked to commercial building air conditioning units, which can reduce daytime energy needs.[80]

Meanwhile, PG&E solicited 74 MW of storage in 2014—50 MW on the transmission system and 24 MW for distribution—and received 500 proposals.[81] The utility submitted 75 MW of energy storage contracts to CPUC for review in December 2015. The projects include 20 MW of flywheel storage, four lithium-ion battery installations totaling 42 MW, and two zinc-air battery projects totaling 13 MW.[82] SDG&E has solicited proposals for 25 MW of storage, with the possibility of expanding the procurement by up to 800 MW.[83] SDG&E is also exploring residential energy storage partnerships that could take advantage of aggregate home energy storage. The utility has proposed a so-called residential energy storage rate that would allow it to draw electricity from customer-owned, behind-the-meter batteries in exchange for reduced electricity rates.[84]

In 2014, CAISO also developed a roadmap to identify the challenges facing the storage sector, anticipating continued energy storage growth in California. This roadmap appears to have been well timed. On September 3, 2015, Stem Inc., in partnership with PG&E, became the first energy storage provider to successfully bid aggregate stored electricity into the CAISO-run electricity market. Stem's systems provide energy storage to commercial facilities, reducing its clients' energy costs by storing electricity onsite when the price is low. By biding stored power into the CAISO market, Stem can generate an additional revenue stream from its systems and reduce the costs of its services.[85]

California's storage market appears poised for growth. The California Energy Storage Alliance, or CESA, recently conducted a study that found solar-plus-storage systems could be valued at up to $0.25 per kWh—a significant value for such systems. The CESA has petitioned CPUC to establish a regulatory track that studies this finding. Edward Burgess, a manager with Strategen Consulting, noted that, "though comparing solar and storage to traditional generation resources is difficult, the $0.25 per kWh levelized avoided cost roughly matches the levelized cost of energy of a natural gas peaker turbine."[86] This is due to the fact that peaker turbines typically operate less than 10 percent of the year, while solar-plus-storage systems can provide electricity at a rate similar to baseload generation. [87]

Hawaii: Market- and Public Utilities Commission-driven uptake

Unlike California, whose electricity can flow relatively freely within the Western Interconnection electric grid, Hawaii is constrained by its island geography. Due to the restricted electric grid and the costs of shipping fuel, Hawaiian electricity prices were 2.5 times higher than the mainland average in 2015—down from 3.2 times higher in 2014.[88] Although Hawaii has invested heavily in solar power, the high concentrations of this intermittent energy source have prompted concerns about grid instability due to fluctuating electric levels.[89] For instance, the Kauai Island Utility Cooperative, or KIUC, can meet up to 95 percent of the island's daytime electric demand with solar power, but this generation can drop 90 percent under cloud cover.[90] In September 2015, KIUC announced it would partner with SolarCity to deploy a solar-plus-storage facility with 52 MWh of battery storage and 13 MW of solar power.[91]

Energy storage procurement in Hawaii has been partially spurred by guidance from the Hawaii Public Utilities Commission, or PUC. The body rejected the 2014 integrated resource plan proposed by the Hawaiian Electric Company, or HECO—Hawaii's largest electricity provider—because it insufficiently demonstrated the company's plan to "become a utility of the future." The PUC called on the utility to "address the growth of distributed generation by increasing flexibility, reducing fossil fuel generation and adopting demand response programs."[92] Immediately following this, HECO issued a request for proposals for 60 MW to 200 MW of energy storage.[93] This move comes as HECO is contending with a rapid influx of rooftop solar systems that are adding energy to the grid. The utility delayed connections for thousands of rooftop solar systems to the grid in 2013 and 2014 amid fears that it could not handle the fluctuations in solar power.[94]

Most recently, the PUC announced it would end net-metering rebates for rooftop solar systems—a system in which rooftop solar owners can sell electricity to the utility at the same retail rates at which they purchase it—and replace the rebates with two optional electric rate structures to integrate future residential solar installations into the electric grid. The two options are known as a self-supply tariff and a grid-supply tariff. The grid-supply tariff would compensate rooftop solar owners for electricity sent back to the grid at the wholesale rate of electricity—less than the retail rate systems receive through net metering. The self-supply tariff would limit the amount of electricity owners could dispatch to the grid and would not compensate them for it, but homeowners who choose this option would receive an expedited review to install their systems.[95] This self-supply rate structure will likely improve the value proposition of solar-plus-storage systems. Solar energy stored during the day and consumed at night could cut a system owner's electricity bills more than the bills of a homeowner who uses the grid-supply rate to earn wholesale prices from solar power during the day but has to purchase electricity at night.[96] This rate structure appears to be designed to encourage solar owners to consume electricity generated onsite, rather than exporting it to the grid, and could ultimately lead consumers to forgo grid access completely.[97]

New York: Reforming the grid with storage

In 2014, the state of New York launched Reforming the Energy Vision, or REV.[98] The REV initiative is designed to advance a market and regulatory environment that favors energy efficiency, increased renewable energy usage, development of microgrids, demand-side management, and deployment of energy storage.[99] As part of REV, the state's public utility commission is working with the New York State Energy Research and Development Authority, or NYSERDA, to support energy storage projects. In June 2015, NYSERDA announced funding for seven companies with energy storage prototypes that feature a variety of battery and other storage technologies.[100] In September 2015, New York City utility Consolidated Edison announced it would invest in 1.3 MW of energy storage composed of two battery systems designed to support grid resilience and replace backup diesel generators.[101] The investment is part of a $500 million proposal to defer construction of a $1 billion substation through investments in demand-side management and electric grid upgrades.[102]

Oregon: Legislating the first steps

In June 2015, the Oregon Legislature passed H.B. 2193-B, a bipartisan bill requiring state utilities to procure energy storage systems and prompt the Oregon Public Utility Commission, or PUC, to establish guidelines and stakeholder engagement processes to incorporate energy storage into Oregon's long-term energy plans.[103] The bill requires Oregon's two investor-owned utilities, Portland General Electric and PacifiCorp, to procure storage with capacity between 5 MWh and 1 percent of their peak load by 2020.[104] The upper limit is necessary to exclude larger energy storage systems because the bill permits utilities to recover system costs through electric rates, "including any above-market costs associated with procurement." The bill also instructs the PUC to adopt guidelines to evaluate proposals for energy storage procurement by 2017.[105] The sponsors of the bill hope to catalyze utility-scale energy storage in Oregon by encouraging the PUC and utilities to fill the knowledge gaps that persist in the integration of fast-response energy storage within the state's electric grid.

New Jersey: Grants for solar plus storage

In the wake of Hurricane Sandy, 2.6 million New Jersey residents were left without power, and many municipal buildings were forced onto backup generators, some of which exhausted their fuel supplies before power could be restored.[106] In 2014, New Jersey solicited $3 million worth of funding proposals for energy storage systems to enhance electrical resilience at critical facilities, such as schools and wastewater treatment plants, throughout the state.[107] The state awarded funding to 13 solar-plus-storage projects at an average of slightly more than $900,000 per project. The projects each have a capacity of 250 kW to 1.5 MW, totaling 7.75 MW.[108]

Massachusetts: $10 million for storage

The $10 million Massachusetts Energy Storage Initiative, sponsored by the Massachusetts Department of Energy Resources, or DOER, is working to encourage the development of an energy storage industry in the state.[109] The state's storage initiative programs include a statewide study of energy storage deployment, an assessment of the market forces driving the electricity storage interest that stakeholders experience, and support for demonstration projects.[110] Previously, the DOER had issued two rounds of funding awards as part of the Community Clean Energy Resiliency Initiative to support energy storage for backup power.[111]

Texas: Barriers to ownership

In contrast with the accommodating regulatory environment afforded to energy storage in California and Hawaii, the Texas electricity market presents barriers to energy storage deployment. When Texas deregulated its electricity sector in 2002, it restricted electric generators from owning transmission and distribution assets, and vice versa. This means that electric transmission companies can only use energy storage to enhance grid functions and reliability, while electric generators can use storage to accommodate the variability of renewable energy or as demand-response assets.

This divide hindered the efforts of Texas electric utility Oncor to acquire energy storage assets that would support integration of renewable electricity generation and grid reliability. A Brattle Group analysis suggested that Oncor and other utilities could deploy 3 GW to 5 GW of electricity storage at $350 per kWh for cost-effective integration of renewable energy.[112] However, as a transmission utility, Oncor cannot sell battery storage services to electric generation markets. Oncor proposed the option to "own and operate the batteries" but auction off excess storage capacity to third parties, which could then bid the capacity in the generation market.[113] However, under Texas' current utility regulatory structure, Oncor may still not be able to own and operate the batteries itself.

In spite of these hurdles, Oncor has deployed 225 kW of lithium-ion batteries[114] for microgrid systems at its service facilities to enhance reliability, spinning reserve capacity, and onsite renewable generation shifting.[115] In the first six months since the systems were commissioned, the batteries have reportedly saved Oncor more than 900 minutes of outages.[116]

In addition to the two systems owned by Oncor, Texas has 18 energy storage systems deployed, for a total of 160 MW of energy storage capacity, and more energy providers are seeking storage opportunities as well.[117] Duke Energy and OCI Solar Power have both procured battery storage systems to better integrate their solar and wind generation with the electric grid and to stagger the delivery of renewable electricity in order to increase its value.[118] Austin Energy is similarly considering procurement of a 1.6-MW battery storage system to augment a 2.5-MW community solar plant the utility is constructing. The battery system will likely support utility efforts to meet peak capacity during unusually high-demand periods.[119]

Although energy storage is gaining ground in Texas, it still faces persistent barriers. The Texas electricity market—the Electric Reliability Council of Texas, or ERCOT—does not have a clear value for capacity, in contrast with CAISO or PJM. ERCOT also lacks demand-response incentives that would compensate utilities for a reduction in electricity delivered due to improvements in efficiency, despite the savings energy storage could yield. There is unlikely to be broad support for the removal of these systemic barriers. A report by the Brattle Group found that Texas electric generators are likely to oppose perceived competition from transmission and distribution utilities in the generation market and would resist legislative changes to the current regulatory compact.[120]

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