L

2017 PSE Integrated Resource Plan

Electric Energy Storage

This appendix describes PSE's experience with energy storage policy and technology, the services that energy storage can provide, and briefly reviews energy storage technologies and key development considerations.

Contents

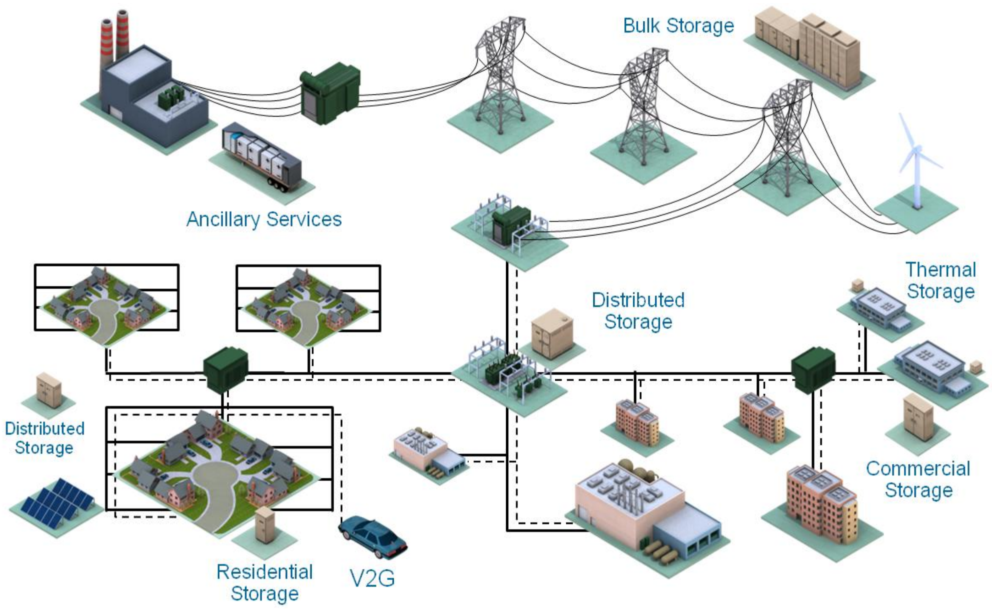
1. OVERVIEW

Electric energy storage (also simply called "energy storage") encompasses a wide range of technologies that are capable of shifting energy usage from one time period to another. In this chapter, we discuss developments in newer forms of energy storage, mainly batteries.

The most widespread traditional forms of energy storage include dams to hold water and underground or LNG storage for natural gas; however, dams must be built by rivers and underground storage requires special geologic formations. Batteries are different. They can be placed wherever needed and may be sized to fit. Evolving battery technologies could deliver important benefits to electric utilities and their customers, since the electric system currently operates on "just-in-time" delivery, which requires generation and load to be perfectly balanced at all times to ensure power quality and reliability. Strategically placed energy storage resources have the potential to increase the quality and efficiency of services provided by utilities. This includes being able to more effectively balance supply and demand, to provide backup power when primary sources are interrupted, to assist with the integration of intermittent renewable generation, and to delay costly upgrades and repair to the transmission and distribution grids. Energy storage is capable of benefiting all parts of the system – generation, transmission and distribution, and customers (see Figure L-1).

Throughout this appendix, energy storage resources will be described in terms of their nameplate power rating and their energy storage capacity. For example, a 10 MW/20 MWh storage system is capable of delivering 10 megawatts of AC power for two hours, for a total of 20 megawatt-hours of energy delivered to the grid (10MW x 2 hours = 20 MWhs). Systems can be as large as pumped hydropower facilities that provide hundreds of megawatts of power for many hours or as small as off-grid battery systems that support electric service for small, remote residences and facilities. This flexibility is one of its attractive qualities.

Figure L-1: Overview of Energy Storage Roles on the Electric Grid



Source: EPRI

PSE Experience

PSE has acquired considerable experience with energy storage technology, policy and services through research and pilot projects. The technology has been considered in both the 2013 and 2015 PSE Integrated Resource Plans.

PSE completed installation of its Glacier Battery Storage Project in the fall of 2016. This partnership with the Washington Department of Commerce is PSE's first grid-connected battery storage project. To ensure the safe operation of the 2 MW/4.4 MWh lithium-ion battery, PSE selected optimal technology and local energy storage service providers to upgrade substation, distribution and controls infrastructure. We continue to collaborate with project partners to study how battery storage can be used to improve the reliability of electricity for our customers. The Glacier Battery Storage Project is described in more detail at the end of this appendix.

In recent years, PSE has actively participated in the ongoing regulatory rulemaking process with the Washington Utilities and Transportation Commission (WUTC), other investor owned utilities (IOUs) and state and industry stakeholders, to help identify a viable model for energy storage in electric utility planning and procurement. The WUTC is currently examining these issues through Dockets UE-151069 and UE-161024. By properly valuing the unique flexibility of energy storage to act as either load or generation, PSE and other stakeholders continue to remove barriers to the inclusion of energy storage in traditional resource planning.

PSE also continues to monitor industry and technology developments associated with batteries and other energy storage technologies. Collaboration with other stakeholders involved in energy storage technology and services has been key to furthering standards for controls, communication and operation of energy storage. Recent industry developments and the implications they have for PSE are described in the following section.

Recent Industry Developments

The energy storage industry has made significant progress since PSE's 2015 IRP. Among the most notable developments are the following.

Policy and Regulatory Environment

Federal and state legislatures and regulatory bodies have used incentives, regulation and policy to reduce barriers to entry for energy storage. Specifically tailored policies have been designed to create frameworks for evaluating the costs and benefits of the technology and a broader market for its adoption. PSE continues to monitor other states' progress in this area, since well-crafted policy is crucial to optimal design of services and clear rules for operation.

- The second energy storage mandate in the U.S. was authorized in June 2015. Oregon House Bill 2193 required the state's investor-owned utilities (Portland Gas & Electric and PacifiCorp) to have a minimum of 5 MWh of energy storage in service by the end of 2019.
- Massachusetts launched the Energy Storage Initiative (ESI) in May 2015 to advance the energy storage segment of the state's clean energy industry.[1] Based on its funded research, ESI has advocated adding up to 600 MW of advanced energy storage technologies on the state's grid by 2025, which would result in over $800 million in cost savings to ratepayers.[2] Subsequently, the Massachusetts state legislature passed bill H. 4568 in August 2016; this bill gave the Department of Energy Resources until the end of 2016 to decide whether or not to set a procurement target for electric companies to procure "viable and cost-effective energy storage systems."[3] Adoption of such targets is expected by July 1, 2017. This legislation is the third energy storage mandate in the U.S.
- Arizona Public Service (APS) and Salt River Project (SRP) imposed residential demand charges that have made solar-plus-storage systems an increasingly viable option for customers in Arizona to reduce their peak electricity consumption from the grid.[4]
- Hawaiian Electric Company (HECO) closed its net energy metering program and introduced new tariffs to support customer interconnection of distributed energy resources to the grid in October 2015. While the newly introduced "self-supply" tariff would prevent exports of excess energy to the electric grid, it would ensure that

---

1 / Commonwealth of Massashusetts. Energy and Environmental Affairs: Energy Storage Initiative. http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/energy-storage-initiative/. Accessed 11/21/2016.
2 / Massachusetts Energy Storage Initiative Study. "State of Charge," September 2016. http://www.mass.gov/eea/docs/doer/state-of-charge-report.pdf. Accessed 11/17/2016.
3 / Ibid
4 / Greentech Media. "The Growing Opportunity for Residential Energy Storage in the US," 6/9/2016. https://www.greentechmedia.com/articles/read/The-Growing-Opportunity-for-Residential-Energy-Storage-in-the-US. Accessed 11/28/2016.

customers installing PV systems with energy storage are eligible for an expedited review and approval of their systems in areas of high PV penetration.[5]

- California continues to pass legislation to accelerate the adoption of energy storage resources. In October 2013, the California Public Utilities Commission (CPUC) adopted procurement targets in accordance with AB 2514 that order the three investor-owned state utilities – Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E) – to install 1,325 MW of storage capacity by 2024. Subsequently, in September 2016, AB 2868 directed utilities to deploy up to 500 MW of additional storage capacity, primarily grid-scale. Further, AB 1637 authorized the CPUC to double its budget for the Self Generation Incentive Program (SGIP) over the next three years, adding an additional $249 million in funding for distributed energy resources. The revised SGIP will allocate 75 percent of program funds for energy storage, including 15 percent to residential projects.
- The state of New York embarked on Reforming the Energy Vision (REV) in 2015, tasking the state's energy industry stakeholders to achieve a cleaner, more resilient and more affordable energy system by upgrading and reforming its infrastructure and business model framework. In response, several demonstration projects inspired by REV intend to integrate energy storage technology into New York's current grid infrastructure. Further, New York City is trying to build upon the 96 MW of solar power installed since 2013 by setting new targets for both energy storage and solar capacity; this includes 100 MWh of energy storage by 2020 and 1 GW of solar capacity by 2030.[6]

Standards

Standards establish a level of quality, performance and reliability for energy storage; they dictate how energy storage systems interact with the grid and each other with regard to operation, communication and safety. PSE's collaboration with stakeholders and adherence to industry-driven standards of operation are integral to designing reliable energy storage systems that are tailored to the unique demands of our grid and our customers.

- The Modular Energy Storage Architecture (MESA) Standards Group released the first draft of a protocol for communications between utility control centers and energy storage systems (ESS) in November 2016. The open, non-proprietary specification, referred to as MESA-ESS, provides a standard framework for utility-scale ESS data exchanges. PSE is a founding member of this group, which includes a national network of electric utilities and energy storage service providers.

---

5 / HECO. Producing Clean Energy: Customer Self-Supply and Grid-Supply Programs. https://www.hawaiianelectric.com/clean-energy-hawaii/. Accessed 11/29/2016.

6 / City of New York. "Climate Week: Solar Power In NYC Nearly Quadrupled Since Mayor de Blasio Took Office and Administration Expands Target," 9/23/2016. http://www1.nyc.gov/office-of-the-mayor/news/. Accessed 11/21/2016.

- Underwriters Laboratories (UL) issued its first certification for a complete home energy storage system in November 2016. The UL 9540 certification was announced for Enphase Energy's AC Battery. Tesla's second-generation Powerwall and Powerpacks and UniEnergy Technologies (UET) ReFlex energy storage systems have also been UL 9540-certified, and other leading vendors are expected to follow.

Market Structure

The structure of specific energy markets defines the role of energy storage and how competitive it can be relative to other technology and programs, so it's important for PSE to monitor the market structures created by its utility and and industry peers. Understanding these designs is critical to our contributions to local and regional efforts to establish transparent guidelines for the participation and compensation of energy storage services.

- The Pennsylvania-New Jersey-Maryland Interconnection (PJM) was the first independent system operator to offer higher payments for fast-responding assets, including energy storage.[7] (The PJM is comprised of thirteen mid-Atlantic and Midwestern states.) This market design has been a major driver of storage development in the region. As a result, several energy storage projects are operating or under construction in order to take part in PJM's frequency regulation services market. Recent projects have included 31.5 MW of energy storage projects in Illinois and West Virginia (respectively) in 2015, and a 7 MW solar-plus-storage project in Ohio that was completed in 2016. The PJM Interconnect supported 74 percent of the utility-scale battery deployments in the U.S. from 2013 through Q3 2016.[8]
- Indianapolis Power and Light (IPL) began commercial operation of the first grid-scale, battery-based energy storage system in the fifteen-state Midcontinent Independent System Operator (MISO) in July of 2016. The 20 MW energy atorage project was designed to deliver enhanced grid reliability and ancillary services, including frequency response, and to increase the ability to balance intermittent resources such as wind or solar energy.[9] Removing barriers to energy storage market participation has become a higher priority in MISO stakeholder discussions since IPL's first energy storage project was placed in service.

7 / Greentech Media. "Faster Frequency Regulation Triples in PJM," 11/8/2013. https://www.greentechmedia.com/articles/read/faster-frequency-regulation-triples-in-pjm. Accessed 11/22/2016.
8 / Greentech Media. "U.S. Energy Storage Monitor: Executive Summary, Q4 2016," 12/6/2016.
9 / IPL. "IPL Announces Commercial Operation of Battery-Based Energy Storage Array During White House Summit on Renewable Energy and Storage." https://www.iplpower.com/Our_Company/Newsroom/2016. Accessed 11/28/2016.

Major Procurement Efforts

Procurement efforts by energy industry stakeholders create a pipeline for energy storage development by setting targets for electric utilities and power-generating companies to find, acquire and develop an ever-increasing fleet of energy storage systems that meet the needs of the electric grid. These major procurements provide a valuable reference and benchmark that PSE can leverage in soliciting and selecting energy storage technology as solutions for grid services.

- The White House hosted a "Summit on Scaling Renewable Energy and Storage with Smart Markets" in June 2016 that brought together regulators, power companies, municipalities and energy developers to promote greater integration of flexible resources such as energy storage. The Obama administration also announced new executive actions and 33 state and private sector commitments to accelerate the integration of renewable energy and storage. Altogether, these totaled at least 1.3 GW of additional energy storage procurement or deployment in the next five years.[10]
- In summer 2016, Con Edison awarded contracts to ten service providers for an aggregate of 22 MW of peak demand reductions, including 897 kW of distributed battery storage by the summer of 2018.[11] The contracts were awarded as part of Con Edison's proposed Neighborhood Program (formerly known as the Brooklyn Queens Demand Management plan); they were approved by New York state regulators in 2014, with the goal of deferring more than $1 billion in substation upgrades.
- PG&E issued a request for offers (RFO) for up to 74 MW of energy storage resources in December 2014 pursuant to AB 2514 that drew applications totaling 5,000 MW of energy storage. PG&E subsequently announced contracts for 75 MW of energy storage. These included 20 MW of flywheels, 10 MW of zinc-air batteries and a collection of lithium-ion battery projects.[12]
- SCE's first procurement of 250 MW of energy storage includes contracts for lithium-ion and thermal energy storage projects; the first deployment deadlines are scheduled for the end of 2016. The procurement was announced in November 2014 as part of the utility's "Local Capacity Requirement" RFO to fulfill capacity required to meet established reliability criteria in targeted areas of SCE's grid. In September 2016, SCE signed contracts for 125 MW of power that include an assortment of preferred renewable and

10 / The White House. "FACT SHEET: Obama Administration Announces Federal and Private Sector Actions on Scaling Renewable Energy and Storage with Smart Markets," 6/16/2016. https://www.whitehouse.gov/the-press-office/2016. Accessed 12/7/2016.
11 / Utility Dive. "ConEd awards 22 MW of demand response contracts in Brooklyn-Queens project," 8/8/2016. http://www.utilitydive.com/news/coned-awards-22-mw-of-demand-response-contracts-in-brooklyn-queens-project/424034/. Accessed 11/22/2016.
12 / PG&E. "PG&E Presents Innovative Energy Storage Agreements," 12/2/2015. https://www.pge.com/en/about/newsroom/newsdetails. Accessed 11/22/2016.

alternative technologies, including battery storage. The project, known as the "Preferred Resources Pilot," will go online between 2019 to 2020 and test the capability of distributed resources and the grid to work together to reliably serve approximately 250,000 residential customers and 30,000 businesses in Orange County.[13]

- SDG&E announced in March 2016 that it is seeking up to 140 MW of new "preferred energy resources" to comply with AB 2514. These include energy storage and other renewable and distributed resources.[14] Altogether, and based on targets set by AB 2514, SDG&E must procure at least 165 MW of energy storage by 2020.
- HECO received more than 60 proposals for "one or more large-scale energy storage systems able to store 60 to 200 MW of energy storage for up to 30 minutes" in response to an RFP in early 2014. HECO is still working to file agreements with the HPUC, so the expectation for services from the storage devices has been pushed back to 2018.[15]

Commercial Deployments and Demonstration Projects

Deployments and demonstration projects utilize energy storage systems (in various scales, technology and configurations) to test the value and optimal use of energy storage on the grid. These specifically designed projects provide energy storage stakeholders with measurable data about services to use for study and analysis of the benefits of energy storage to customers and the grid. PSE monitors the progress of these projects and announcements closely in order to assess the opportunity for similar deployments and customer programs, as well as to guide the tailoring of unique configurations that can better address local obstacles to reliable grid operation.

- The U.S. installed 221 MW of energy storage resources in 2015, a 243 percent increase from 2014. Overall, total installed energy storage for 2016 is anticipated to finish at 260 MW, a 15 percent increase from 2015.[16]
- In Vermont, Green Mountain Power began to install its first residential customer-sited energy storage systems in May 2016. Sales of the 500 energy storage systems began in December 2015. Customers could lease a system, purchase a system directly for $6,500, or purchase "shared access" that would result in a bill credit from the utility. These storage systems are intended for emergency backup power during multi-hour power outages.

---

13 / Edison International. "O.C. Pilot Tests Whether Clean Energy Resources Can Meet Growing Needs of Major Metro Area," September 2016. http://insideedison.com/stories/orange-county-pilot-tests-whether-clean-energy-resources-can-meet-major-metro-needs. Accessed 11/22/2016.

14 / SDG&E. "SDG&E's Energy Storage 201, "Procurement Plan Application," 4/5/2016. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=10691. Accessed 12/14/2016.

15 / Pacific Business News. "Hawaiian Electric pushes back major energy storage plan by a year,"06/30/2015. http://www.bizjournals.com/pacific/news/2015/06/30. Accessed 11/28/ 2016.

16 / Greentech Media. U.S. Energy Storage Monitor, Q4 2016. https://www.greentechmedia.com/research/subscription/u.s.-energy-storage-monitor. Accessed 12/6/2016.

- Con Edison completed contracts for a distributed resources pilot program, known as the Virtual Power Plan, in 2016. This REV demonstration project will outfit 300 homes in Brooklyn and Queens with leased, high-efficiency solar panels and lithium-ion battery storage systems to explore the revenue streams made possible by software-enabled aggregation of energy storage.[17]
- In June 2016, the Arizona Corporation Commission (ACC) ordered APS to spend up to $4 million to develop a residential battery storage program to facilitate energy storage technologies through demand response or load management. The two programs would be introduced as part of APS's energy efficiency "Demand Side Management Plan."[18]
- Texas municipal utilities Austin Energy (Austin, Tex.) and CPS Energy (San Antonio, Tex.) have ongoing pilot initiatives supported by the state. Austin Energy's SHINES program received a $1 million award from the state of Texas in June 2015 to develop a pilot energy storage system paired with a community solar array, and another $4.3 million award in February 2016 to pilot a technology platform supporting the integration of distributed energy resources.[19] CPS Energy was awarded $3 million in grants to kick off its solar-plus-storage program; this will be the largest energy storage system in Texas, and will shift clean energy peak demand periods when completed in 2018.[20]
- PG&E announced the launch of multiple technology demonstration projects aimed at unlocking benefits at the edge of the grid in July of 2016. PG&E will demonstrate a distributed energy resource management system (DERMS) that includes installing and testing smart inverters and battery storage systems for up to 150 residential customers and 20 commercial customers. The battery storage systems used in the DERMS demonstration will evaluate whether customer-sited energy storage can be used to support the grid operationally during periods of high electric demand.[21]
- SDG&E has proposed a number of programs as part of the DER Integration Plan it filed with the CPUC in July of 2015. They include a pilot project leveraging residential energy storage and testing a new business model that would rely on third-party-owned distribution infrastructure; the goal is to find out if this could defer circuit upgrades. The pilot would also introduce an energy storage tariff rate.[22, 23]

---

17 / New York State Department of Public Service. Reforming the Energy Vision: Demonstration Projects. http://www3.dps.ny.gov/W/PSCWeb.nsf/All. Accessed 11/21/2016.

18 / ACC. "Commission Approves Energy Efficiency Programs that Save APS Customers Money," 06/15/2016. http://azcc.gov/Divisions/Administration/news/2016Releases. Accessed 11/28/2016.

19 / Austin Energy. Austin SHINES. http://austinenergy.com/wps/portal/ae/green-power/austin-shines/austin-shines-innovations-energy-storage/. Accessed 11/28/2016.

20 / CPS Energy. "CPS Newsroom: TCEQ awards CPS Energy $3 million grant for solar battery storage program," 6/17/2016. http://newsroom.cpsenergy.com. Accessed 11/28/2016.

21 / PG&E. "PG&E Launches Distributed Energy Resource Projects Testing Technology to Unlock Benefits of the Grid," 7/12/2016. https://www.pge.com/en/about/newsroom/newsdetails. Accessed 11/22/2016.

22 / SDG&E. "Application of SDG&E (U 902 E) for Approval of Distribution Resources Plan," 7/1/2015. https://www.sdge.com/sites/default/files/regulatory/A_15-07-SDG&E_DRP_Application.pdf. Accessed 11/22/2016.

- HECO has more than 17 energy storage projects underway or planned for Hawaii at the end of 2016. These projects are intended to (variously) provide grid services, maintain reliable service for customers and explore the technology's ability to support the use of more renewable energy.[24] In March 2016, HECO announced an agreement to launch a 10-unit pilot program to enable more customers to interconnect rooftop photovoltaic (PV) systems paired with energy storage systems on the island of Molokai.
- Avista continues to operate its 1 MW/3.2 MWh vanadium redox flow battery system at the Schweitzer Engineering Lab in Pullman, Wash. The $7 million project included a $3.2 million grant from the State of Washington's Clean Energy Fund. As of Q4 2016, the project is the largest vanadium redox flow battery storage project in operation in the U.S.
- Snohomish PUD's (SnoPUD) most recent energy storage project, MESA 2 is a 2.2 MW/8.8 MWh vanadium flow battery project located in Everett, Wash.; it is also funded in part by the State of Washington's Clean Energy Fund. Installation of the flow battery project was completed in early 2017.[25]

23 / SDG&E. "Application of SDG&E (U 902 E) for Approval of Distribution Resources Plan," 7/1/2015. https://www.sdge.com/sites/default/files/regulatory/A_15-07-SDG&E_DRP_Application.pdf. Accessed 11/22/2016.
24 / HECO. Reliability: Energy Storage. https://www.hawaiianelectric.com/clean-energy-hawaii/producing-clean-energy/other-routes-to-clean-energy/energy-storage. Accessed 11/28/2016.
25 / Snohomish PUD. Current Energy Storage Projects. http://www.snopud.com/PowerSupply/energystorage/projects.ashx?p=2800. Accessed 11/23/2016.

2. POTENTIAL ELECTRICITY STORAGE SERVICES

Terminology and definitions for energy storage grid services are not yet uniform, but the 2015 U.S. Department of Energy (DOE)/Electric Power Research Institute (EPRI) Electricity Storage Handbook provides the following list (Figure L-2).

Figure L-2: Energy Storage Grid Services[26]

Bulk Energy Services	Transmission Infrastructure Services
Electric Energy Time-shift (Arbitrage)	Transmission Upgrade Deferral
Electric Supply Capacity	Transmission Congestion Relief
Ancillary Services	**Distribution Infrastructure Services**
Regulation	Distribution Upgrade Deferral
Spinning, Non-spinning and Supplemental Reserves	Voltage Support
Voltage Support	**Customer Energy Management Services**
Black Start	Power Quality
Other Related Uses	Power Reliability
	Retail Electric Energy Time-shift
	Demand Charge Management

Source: 2015 DOE/EPRI Electricity Storage Handbook in collaboration with NRECA

These applications, how they relate to PSE, and some of the potential challenges to adoption are described below. It is important to note that not all of the services described below have been demonstrated in residential, commercial or utility settings. The ability of a single storage resource to provide these services depends on many factors, among them:

1. minimum required energy storage power (kW or MW) and energy (kWh or MWh),
2. location requirements,
3. availability requirements (both frequency and duration), and
4. system performance characteristics (response time, ramp rate, etc.).

26 / Sandia National Laboratories. DOE/EPRI 2015 Electricity Storage Handbook in Collaboration with NRECA; February 2015. http://www.sandia.gov/ess/publications/SAND2015-1002.pdf. Accessed 11/28/2016.

Moreover, using storage to provide multiple grid services can be complicated, since use for some services can exclude use for other services. For example, an energy storage system that provides transmission reliability service must reserve its storage capacity for contingency needs during certain time periods, rendering it unavailable for other uses during those periods. Detailed modeling is required to evaluate storage resources intended for multiple uses.

Bulk Energy Services

The term "bulk energy services" refers to all of the ways that energy storage is used to avoid the need to generate additional electricity.

Electric Energy Time-shift (Arbitrage)

In this application, storage resources stockpile energy for later use, typically charging when the cost of electricity is low and discharging when the cost of electricity is high. Alternatively, storage resources can provide similar time-shift services to accommodate excess generation when there is limited or no demand for it, typically from renewable resources such as wind or solar photovoltaic (PV). The stored energy can then be released when it's needed, enabling utilities to avoid renewable curtailments that would result in the loss of production tax credits (PTCs) and renewable energy credits (RECs).

Electric Supply Capacity

In this application, storage resources serve as generation supply capacity resources, similar to peaking plants. Historically, peak load demands – rather than economic conditions – have driven decisions on when to build new power plants. If energy storage can provide reliable peaking capacity, it may enable utilities to postpone or eliminate the need for new peaking power plants. PSE also refers to this service as "Energy Supply Capacity Value."

Ancillary Services

Ancillary services are defined as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."[27] In other words, these services support the reliable delivery of power and energy over the high voltage transmission system.

Regulation (or Frequency Response)

Regulation ensures the balance of electricity supply and demand at all times, particularly over short time frames (from seconds to minutes). Because energy storage can both charge and discharge power, it can help manage grid frequency. Many storage technologies can do this faster and more accurately than other regulating resources. Federal Energy Regulatory Commission (FERC) Order 755 requires that ISOs implement mechanisms to pay for regulation resources based on how responsive they are to control signals. Under the new rules, storage resources with high-speed ramping capabilities receive greater financial compensation than slower storage or conventional resources.

Spinning Reserves, Non-spinning Reserves and Supplemental Reserves

Generation capacity over and above customer demand is reserved for use in the event of contingency events like unplanned outages. "Spinning" reserves are generators that are turned on, idling, waiting for the signal to go and able to ramp up within 10 minutes. Many storage technologies can be synchronized to grid frequency through their power electronics, so they can provide a service equivalent to spinning reserves with minimal to zero standby losses (unlike the idling generators). Energy storage is also capable of providing non-spinning or supplemental reserves, but these services are easier for traditional generators to accomplish cost-effectively.

Voltage Support

This ancillary service is used to maintain transmission voltage within an acceptable range. Advanced power electronics give storage resources with four-quadrant inverters the capability to correct suboptimal or excessive voltage; however, a number of other devices are capable of providing voltage support at low cost, so the value of this service for energy storage is considered to be low.

27 / U.S. Federal Energy Regulatory Commission 1995, Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities, Docket RM95-8-000, Washington, DC, March 29.

Black Start

This service, typically provided by generators, restores the electric grid following a blackout. While energy storage could theoretically provide this service, black start is of minimal value to PSE, because of its many other low-cost, black start-capable generation resources.

Other Related Uses

Additional services include firming of generation resources, typically wind and solar PV, either as a load following or load ramping support. Excess generation can be stored or released in response to rapid or randomly fluctuating load profiles. As a result, the storage resource can prolong output by flexibly addressing the delta between electric supply capacity and the variable load profile.

PSE's Open Access Transmission Tariff illustrates the relative cost for PSE to provide ancillary services:

Figure L-3: PSE Open Access Transmission Tariff [28]

Service	Rate ($/kW-yr)
Reactive Supply and Voltage Control	$0.07533
Regulation and Frequency Response	$126.00
Operating Reserve – Spinning	$111.00
Operating Reserve – Supplemental	$108.00

28 / OATI OASIS. Puget Sound Energy, Inc.: Open Access Transmission Tariff; 09/01/2016. http://www.oatioasis.com/PSEI/PSEIdocs/2016-09-01_PSE_currently_effective_OATT.pdf. Accessed 11/28/2016.

Transmission Infrastructure Services

These services relate to reliability and economics; they enable the electric transmission system to operate more optimally and efficiently.

Transmission Investment Deferral

When a generation resource like energy storage or demand-side resources can cost-effectively defer capital expenditure in the transmission system, it's called "transmission investment deferral." Transmission resources are sized to handle peak capacity during normal operation with all elements in service, but it must be designed to meet capacity requirements even when portions of the network are out of service. It is possible to use energy storage to address capacity constraints created by periods of peak demand or specific contingencies; however, this is difficult due to the networked nature of the transmission system and storage specifications such as location, sizing, regulatory requirements and system controls. Also, deferring investment in transmission capacity projects is not always the best solution, since these projects usually increase system reliability, which is a valuable benefit. Radial transmission lines, where the battery could provide backup power, are an area where energy storage has more value for reliabiliy.

Transmission Congestion Relief

This refers to using storage resources in a geographic area where locational marginal price (LMP) is jointly defined by the wholesale market price of energy and the amount of location-specific congestion in the electric system. The storage resource would optimize its dispatch based on an hourly LMP price signal. Locational marginal pricing was not modeled in prior versions of PSE's IRP since the Pacific Northwest did not use it. However, now that PSE has begun participating in the Energy Imbalance Market (EIM) administered by the California Independent System Operator (CAISO), storage resources can be assessed for their ability to be deployed downstream of congested transmission corridors where they can potentially discharge during congested periods and minimize congestion in the system. PSE studied energy storage as a potential solution to transmission congestion on the east side of King County, but it did not prove feasible. Chapter 8, Delivery Infrastructure Planning, contains a description of that study.

Distribution Infrastructure Services

These services support the physical infrastructure of the distribution system that connects distribution substations to customer meters.

Distribution Investment Deferral

This is similar to transmission investment deferral, but specific to the distribution system. To relieve overloaded distribution transformers, particularly high-cost substation transformers, energy storage can charge during low load periods and "peak shave" the highest load periods. This may postpone the need for a distribution investment. However, an energy storage system may be limited in its ability to deliver the operational flexibility and reliability improvements that traditional distribution infrastructure provides. For example, using storage to defer a new substation may make it harder to take existing substations offline for maintenance or in response to unplanned outages. For each candidate system, the tradeoffs between reliability, operational flexibility, capacity and cost need to be studied.

Distribution Voltage Support

This service maintains power voltage within acceptable bounds, as defined by ANSI standards (+/- 5 percent of nominal). A storage system could provide voltage support on distribution lines and support a conservation voltage reduction scheme, but the value of this service for energy storage is considered low, because other devices are capable of providing low-cost voltage support.

Customer Energy Management

Storage resources placed on the customer side of the meter can also provide direct benefits to customers, such as increased power quality, reliability, the ability to shift consumption to hours with lower energy rates and demand charges. Although not specifically included as part of this study, PSE has assessed each of these services and their potential application.

Power Quality

This service involves using energy storage to protect customers' on-site loads from short-duration events that affect the quality of power delivered by PSE. Energy storage could be used to address poor power quality to downstream customers, including variations in voltage magnitude or primary frequency, low power factors whereby voltage and current are excessively out of phase with each other, or poor harmonics (i.e., the presence of electric currents or voltages at frequencies other than the primary frequency). Instances of poor power quality can range from seconds to a few minutes and the on-site energy storage would be able to monitor the utility power quality and discharges to smooth out disturbances and variations.

Power Reliability

Energy storage can support customer loads in the event of a total loss of power on the grid. During a power outage, the energy storage and customer loads will island and subsequently resynchronize with the utility when power is restored to the grid. The duration of time by which energy storage can mitigate a power outage depends on the energy capacity of the energy storage and the size of the load that it is providing with backup power.

Retail Electric Energy Time-shift

This service involves using energy storage to reduce a customer’s overall cost of electricity. Customers could use their energy storage to charge during off-peak time periods when the retail price of electricity is low, then discharge the stored energy during on-peak time periods when the retail price of electricity increases. Since there are no time-of-use or real-time pricing tariffs in PSE’s service territory, this service is not available to customers and was not considered further for this study or when assessing services from energy storage placed on the customer’s side of the meter.

Demand Charge Management

This service can be used by customers to reduce their overall costs for electric service by reducing their demand during peak periods specified by the utility. As the peak demand can be assessed for the monthly demand charge during any 15-minute interval period, the energy storage must be able to reduce or limit load during all hours of a specified period of time and day. Tariffs will define the peak time of day and days when peak demand charges will be assessed (by kW, whereas the price for electric energy is measured per kWh). The tariffs will also define the time of day and days where no or low demand charges will be assessed, thus providing the optimal time for charging the enegy storage. Pricing tariffs that include demand charges are applicable to non-residential customers and are therefore not further considered for residential customers.

3. ENERGY IMBALANCE MARKET

In October 2016, PSE became the third non-California utility to join the Energy Imbalance Market (EIM), a real-time wholesale energy market administered by the California Independent System Operator (CAISO). The EIM connects multiple balancing authorities and utilities operating in eight western states and enables participants to buy and sell power closer to the time that electricity is consumed. The real-time energy supply market enhances grid reliability, generates cost savings for its participants, supports the reduction of congestion on transmission lines and increases the diversity of generation resources. [29]

As a participant, PSE's transmission system and generators operate on a 15-minute basis to serve either within PSE's own balancing authority area or on behalf of other EIM participants. As a result, PSE is able to reduce reserve obligations and associated costs with readily-available lower-cost resources available via the marketplace. Increased real-time visibility across neighboring grids also enhances PSE's efficient operation and the dispatch of its local generation resources.

Energy storage is a flexible resource that can potentially provide PSE with additional options for participating in the EIM. Primary options include bulk power supply and providing flexible ramping in the EIM. For bulk supply, stored electricity from pumped hydro and batteries (as modeled for the 2017 IRP or in a larger capacity) could be bid into the market. Alternatively, the fast-ramping capability of batteries could provide flexible ramping in the EIM. Storage may also allow PSE to optimize use of its own resources to meet balancing or other needs, thereby freeing up other resources to be provided into the EIM. PSE will look to include new resource types in the future, including storage. PSE may also be able to bid into forward markets in the future and provide the stored electricity as operating reserves for EIM participants seeking to optimize balancing and associated cost. PSE continues to research and analyze the capability of storage resources to qualify and compete as resources in the EIM market.

---

29 / CAISO. EIM FAQ. https://www.caiso.com/Documents/EIMFAQ.pdf. Accessed 3/9/2017.

4. ENERGY STORAGE TECHNOLOGIES

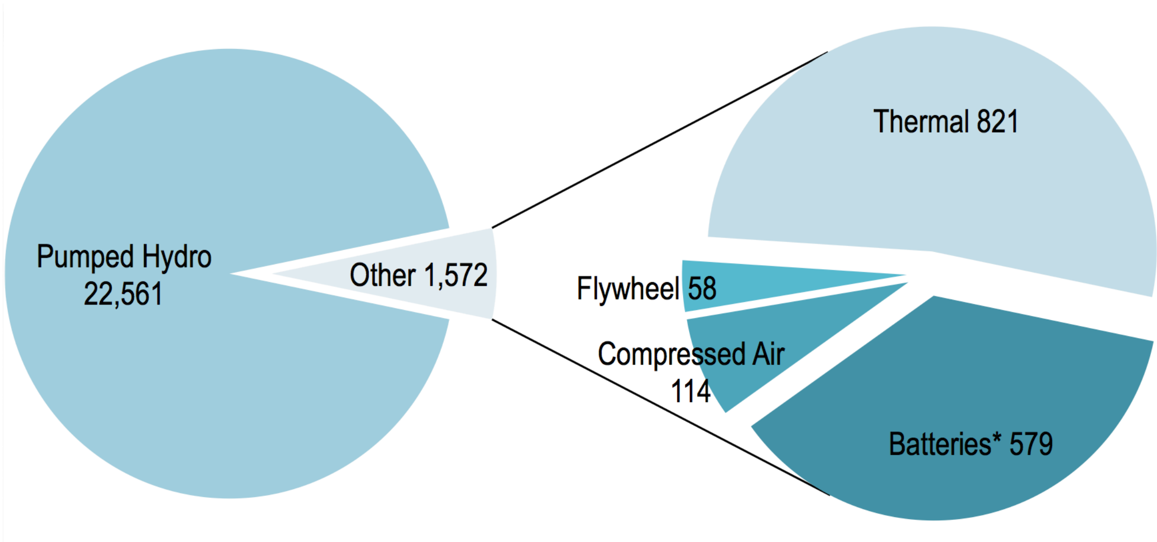
Energy storage encompasses a wide range of technologies and resource capabilities, and these differ in terms of cycle life, system life, efficiency, size and other characteristics. A detailed description of how each technology works, its benefits and limitations, and where it has been deployed is presented in the 2015 PSE IRP in Appendix L. This brief summary focuses on how much of each general type of energy storage has been installed since the 2015 IRP.

Figure L-4: Energy Storage Technology Classes

Technology Class	Examples
Chemical Storage	Batteries
Mechanical Storage	Flywheels, Compressed Air
Thermal Storage	Ice, Molten Salt, Hot Water
Bulk Gravitational Storage	Pumped Hydropower, Advanced Rail/Gravitational Rail

Although battery technology has attracted a great deal of industry attention in recent years, pumped hydro technology still supplies the majority of grid-connected energy storage in the U.S. today (93.5 percent) due to historical investment. The remaining categories combined comprise 6.5 percent of total installed operational capacity as of 2016, but 100 percent of operational capacity installed since 2013.

Figure L-5: Installed U.S. Grid-connected Energy Storage in MW, by Technology, as of 11/2016 [30]

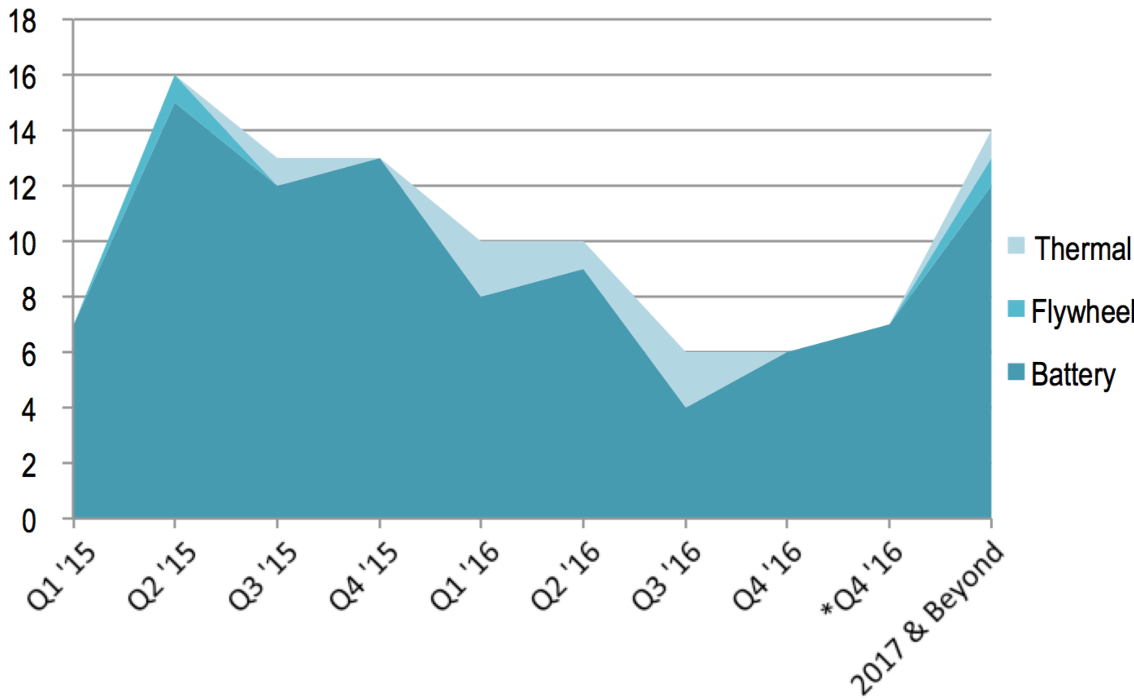


Batteries include lithium-ion, flow, sodium-based, nickel-based, lead acid, electrochemical capacitors and ultracapacitor batteries

Recent installations and contracted or announced projects tracked by the DOE's energy storage database focus exclusively on battery, flywheel and thermal storage technology. The number of projects and grid-connected or contracted MW of energy storage are displayed in Figures L-6 and L-7, respectively.

30 / U.S. Department of Energy Global Energy Storage Database (DOE GESDB), November 2016 http://www.energystorageexchange.org.

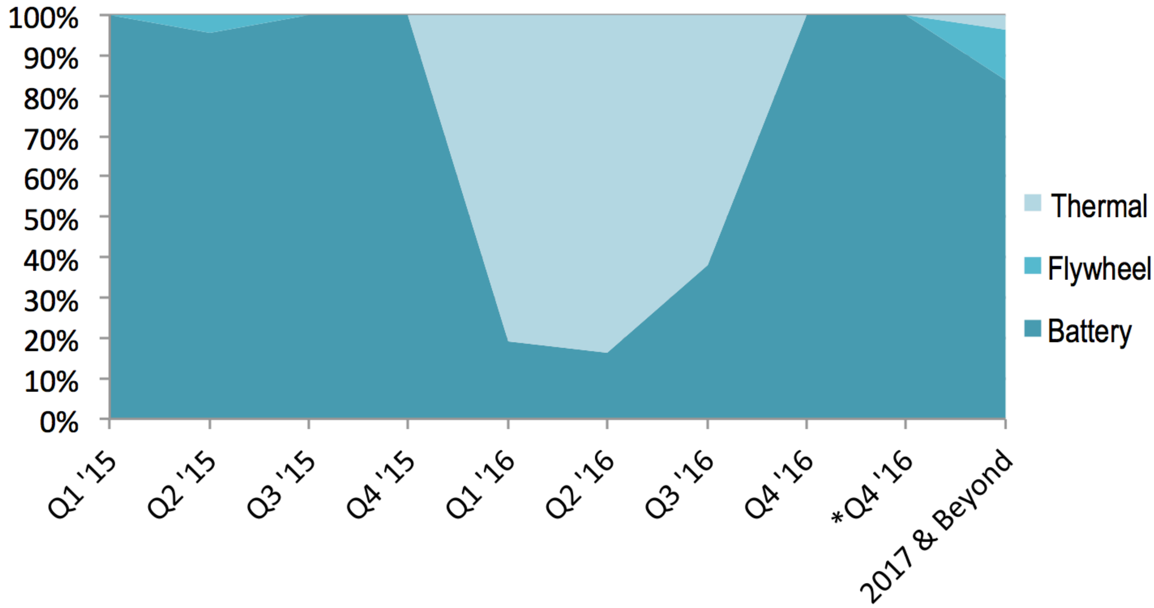
Figure L-6: Number of U.S Grid-connected Energy Storage Projects Installed or Contracted Since 2015, by Technology [31]



NOTE: Information from the DOE's energy storage database is as of 11/2016, therefore Figure L-6 separates the number of U.S. grid-connected energy storage projects installed as of 11/2016 and those projects anticipated to be installed by year-end 2016.

31 / U.S. Department of Energy Global Energy Storage Database (DOE GESDB), November 2016 http://www.energystorageexchange.org

Figure L-7: Percentage Share of the MWs of U.S. Grid-connected Energy Storage Projects, Installed or Contracted Since 2015, by Technology [32]



NOTE: Information from the DOE's energy storage database is as of 11/2016, therefore Figure L-7 separates the number of U.S. grid-connected energy storage projects installed as of 11/2016 and those projects anticipated to be installed by year-end 2016.

32 / Ibid

5. DEVELOPMENT CONSIDERATIONS

The siting of an energy storage resource is an important consideration for development feasibility; it affects both costs and benefits. Some resources, like pumped hydro, must be located in areas with specific geology, water access and transmission lines. Natural gas combustion turbines have similar constraints, plus they face air emissions constraints in many locations as well. Many forms of storage, particularly batteries and ice energy, are more flexible when it comes to sizing and siting. Battery resources can be sized from as small as 1 kW to as large as 1,000 MW and sited at the customer's location or interconnected to the transmission system. Other factors may also limit where storage can be located, among them space availability, permitting and interconnection upgrade requirements. A few examples of different siting options for battery storage resources follow.

54 kW/54 kWh commercial customer-sited lithium-ion battery.

7 kW/14 kWh residential customer-sited lithium-ion battery.

1 MW/2 MWh customer-sited lithium-ion battery.

1 MW/3.2 MWh distribution-connected vanadium redox flow battery.

Proposed 100 MW/400 MWh transmission-connected battery.

6. GLACIER PILOT PROJECT

In partnership with the Washington State Department of Commerce, PSE commissioned a battery storage pilot project in Glacier, a small town east of Bellingham, Wash. The project included the installation of a 2 MW/4.4 MWh lithium-ion battery system that was interconnected to the 12.5 kV distribution system near Glacier's existing substation during October 2016.

Glacier is served by a radial transmission and distribution line that runs along a heavily forested scenic highway, and the town experiences frequent and lengthy outages because of how challenging it is for repair crews to reach and repair the lines during storms. The project is funded in part by a $3.8 million Smart Grid Grant from the Washington Department of Commerce; PSE's investment is estimated at $7.4 million.[33]

33 / PSE. PSE Innovation Project: Glacier Battery Storage Project. https://pse.com/inyourcommunity/pse-projects/system-improvements/Pages/Glacier-battery-storage-project.aspx.

The Glacier project tests three primary use cases:

- Outage mitigation
- System-wide peaking (supply capacity)
- System flexibility

Several project locations along PSE's electric grid were considered in addition to Glacier, including Baker River, Crystal Mountain, Frederickson, Lake Holm and Wild Horse. Similar to Glacier, each project site provided a combination of present issues, including a history of recurring outages and potential grid benefits that could result in measurable upgrades to reliability. Ultimately, Glacier was selected as the project site based on its superior combination of economic cost benefit, comparably lower development complexity and costs, and few other options to address the existing reliability concerns.

Pacific Northwest National Laboratories (PNNL) will conduct four to six months of testing and evaluation. Identifying the performance and economic benefits of the project will help PSE determine whether future applications of this technology are feasible and cost effective.

For more information on the Glacier Battery Storage project, please visit: http://pse.com/inyourcommunity/pse-projects/system-improvements/Pages/Glacier-battery-storage-project.aspx.