

PENNSYLVANIA ENERGY STORAGE ASSESSMENT: STATUS, BARRIERS, AND OPPORTUNITIES



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Pennsylvania Energy Storage Assessment: Status, Barriers, and Opportunities

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Executive Summary

Energy storage deployment has grown rapidly across the United States over the last decade and can address many priorities and challenges currently facing the energy sector. Energy storage can help integrate increasing levels of renewable energy into the grid and reduce the environmental impacts of electricity production. Additionally, energy storage can improve the resilience of the electrical grid, ensure reliable service, and decrease costs to ratepayers. Recognizing these potential benefits, the Energy Programs Office (EPO) of the Pennsylvania Department of Environmental Protection (DEP) retained Strategen Consulting, LLC to consider the role that energy storage may play in the state's future power system. To that end, this assessment aims to survey the current landscape of energy storage in Pennsylvania, explore the potential applications and benefits of energy storage, identify barriers to further deployment, and provide recommendations to enhance the market for energy storage in the state.

This assessment is organized into five chapters.

Chapter 1: Energy Storage Technologies and Markets briefly explains the diverse array of technologies included in the term “energy storage,” each of which has different performance characteristics and costs. This chapter highlights key energy storage trends in markets in the United States, including a summary of energy storage policies and incentives adopted in other jurisdictions. This report focuses on battery energy storage systems, such as lithium-ion batteries, which have experienced the fastest growth and most significant cost declines over recent years. Nonetheless, many of the applications, barriers, and recommendations are technology-agnostic.

Chapter 2: Energy Storage Applications discusses the potential value streams and services that energy storage can provide across the electricity supply chain: from the bulk-power system, to distribution utilities, to retail customers. Energy storage systems can be customized and sized to meet a variety of purposes and needs.

Chapter 3: Energy Storage in Pennsylvania Today surveys the amount of energy storage currently deployed in Pennsylvania. While Pennsylvania is home to several traditional energy storage projects in the form of pumped hydropower, the deployment of more advanced, grid-connected storage technologies is still in its early stages. This chapter considers several recent policy developments in the state, such as proceedings before the Public Utilities Commission (PUC), as well as opportunities for storage to benefit from existing policies and initiatives. The chapter also surveys the economic impact of storage activities in the state from battery manufacturers, jobs in energy storage, and research and development efforts.

In **Chapter 4: Analysis of Energy Storage Potential in Pennsylvania**, Strategen performed economic analyses of energy storage under two scenarios: 1) utility-scale hybrid “solar-plus-storage” systems to serve the grid, and 2) standalone behind-the-meter (BTM) storage systems to provide electricity customers with direct bill savings. Both analyses were conducted using Pennsylvania-specific customer rates and economic conditions.

The first scenario identified the potential for solar-plus-storage projects to provide significant economic and environmental benefits, particularly if supported by public- or ratepayer-funded investments to buy down the incremental costs of adding storage to solar power purchase

agreements. Approximately \$65 million of public investment in energy storage could be used to leverage private investment and yield \$545 million annually in grid and environmental benefits.

In the second scenario, the analysis showed that, under current retail rate structures, energy storage provides very limited value to customers in the form of direct bill savings. The analysis considered multiple configurations of storage systems with different sizes and durations and found that most configurations resulted in a negative payback.

The results of these analyses informed the discussion of barriers and recommendations in **Chapter 5: Barriers to Energy Storage Deployment and Policy Recommendations**.

While there are meaningful benefits to energy storage deployment, there are also many barriers that may limit these benefits from being realized under today's conditions. Chapter 5 identifies barriers and suggests recommendations across state policy, retail tariff design and customer programs, distribution utility planning and procurement, permitting and interconnection, wholesale markets, and technology. Each recommendation is characterized by the estimated time needed for implementation.

These recommendations are intended to encourage the growth of Pennsylvania's energy storage industry, enhance resilience, and provide environmental benefits, while balancing costs and economic equity concerns. These recommendations were informed by Strategen's analysis and the experiences of other states around the country. Following a similar approach as in Chapter 4, the recommendation to "establish a storage procurement goal or target" suggests distinct targets for large-scale solar-plus-storage systems and for customer-sited BTM storage. A storage deployment target could facilitate the target proposed in "Pennsylvania's Solar Future" Plan to get 10% of the state's electricity (or 11 GW) from solar energy by 2030. For example, a storage deployment goal linked to 25% of the Solar Future Plan goal would equate to 1,500 MW of storage by 2030. Under this scenario, the total benefit is estimated to be approximately \$273 million per year. A parallel target could be adopted for BTM storage that builds upon existing peak reduction targets overseen by the Pennsylvania Public Utilities Commission.

Recommendations	Near-term (0-2 years)	Medium-term (2-5 years)	Long-term (5+ years)
1. Establish a storage procurement goal or target			
2. Convene a statewide “Storage Issues Forum”			
3. Designate public funding to accelerate storage deployment			
4. Seek wholesale market improvements by participating in PJM stakeholder processes			
5. Consider changes to resource adequacy rules and oversight			
6. Develop a strategic plan to accelerate microgrid deployment at critical facilities			
7. Develop a tariff for distribution-connected solar-plus-storage facilities			
8. Establish direct incentive programs for storage projects			
9. Adopt a multiple-use application framework			
10. Update the interconnection process for distributed energy resources			
11. Enhance distribution planning and procurement processes			
12. Enact retail rate reforms			
13. Expand retail customer programs			
14. Streamline permitting on state and local levels			
15. Support research and development of new energy storage technologies			

Figure 1. Timeline of recommendations to support energy storage adoption in Pennsylvania

Purpose Statement

Energy storage is a timely topic in Pennsylvania’s energy sector. In recent years, the market for advanced energy storage technologies has grown substantially globally and in the United States, primarily due to falling technology costs and state-led policies and initiatives. It is important to understand what potential lies in the state for energy storage, as energy storage technologies and services have the potential to impact virtually every aspect of the electricity supply chain. Subsequently, this report seeks to explore how these resources can help achieve Pennsylvania’s policy goals and deliver clean, reliable, high-quality electric service.

Renewable Energy Integration

Solar and solar-plus-storage projects have shown remarkable growth in Pennsylvania and the region. The use of grid-connected storage will become increasingly important as a tool to integrate renewable energy into the grid while maintaining reliability of the power system. Energy storage is particularly important for variable sources of energy, so that it stores energy for later use during times of need, and not just at times of generation. Pennsylvania’s current fossil fuel energy systems offer storage capacity for days of higher demand or during natural disasters, but the electric grid is instantaneous and, for the most part, lacking electric storage capacity. Subsequently, Pennsylvania’s August 2020 Clean Energy Program Plan recommended undertaking an “Energy Storage and Batteries Plan” to develop and market an analysis of the needs and capabilities of Pennsylvania to fulfill the future battery storage marketplace of both the state and the region.¹

Clean Energy Policy Goals

Energy storage and batteries will be a key component to achieving policy goals toward clean energy and reductions in greenhouse gas emissions from fossil fuel electricity generation. Pennsylvania’s Solar Future Plan sets a target of increasing in-state solar-powered electricity generation from its current level of 0.1% to 10% (or 11 GW) by 2030. With this ambitious solar generation target, the state is poised to benefit from deployment of advanced solar-plus-storage technologies with standalone battery energy storage systems connected to the grid or directly at an end user’s location.

Resilience

Energy storage can support the resilience of Pennsylvania’s critical facilities, businesses, institutions, and overall electric grid. Several developments in the state in 2020 opened the door for discussions of energy storage. Pennsylvania’s Clean Energy Program Plan emphasized the need for improved energy resilience, such as through the deployment of microgrids,² and the Pennsylvania Public Utilities Commission initiated a proceeding to investigate how to enhance reliability and resilience on the electric distribution system through the use of energy storage.³ To that end, this report intends to inform and facilitate this recent focus on reliability and resilience.

¹ Pennsylvania Department of Environmental Protection Energy Programs Office (2020), “Clean Energy Programs Plan.”

² *Ibid.*

³ Pennsylvania Public Utility Commission (2020), “Docket No. M-2020-3022877.”

Chapter 1: Energy Storage Technologies and Markets

1.1 Overview of Energy Storage Technologies

The term “energy storage” applies to a diverse set of technologies that can store energy at one time and make it available during another. Storage technologies range in their physical and performance characteristics, economic propositions, and applications.

Storage technologies can generally be classified into five categories:

1. Mechanical storage
2. Electrochemical storage
3. Thermal storage
4. Electrical storage
5. Chemical storage

This report focuses primarily on the first three of these categories, particularly on electrochemical storage, more commonly referred to as batteries.

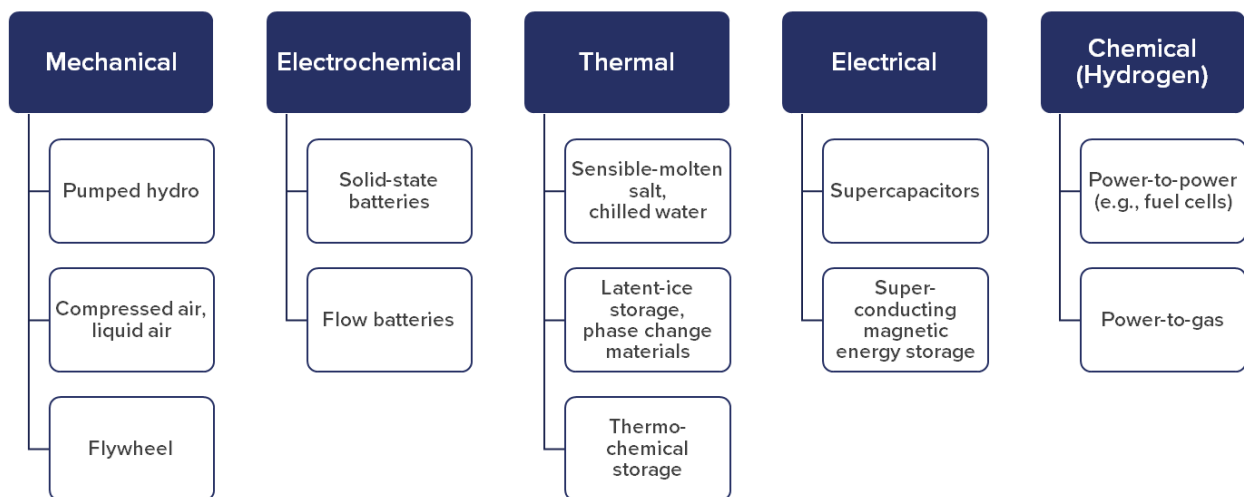


Figure 2. Energy storage technology categories⁴

Energy storage systems offer a variety of physical characteristics and chemistries, economic propositions, and applications. Each energy storage technology has different electrical and operational performance characteristics, such as its size, modularity, application, cost, time to construct, locational flexibility, storage duration provided, and grid services offered. See Appendix C: Energy Storage Technologies for additional details and examples.

Two important performance considerations are the amount of energy the technology can hold – its round-trip efficiency – and how much of that energy can be released in a short time – its discharge time and duration.

⁴ Adapted from Government of Massachusetts (2019), “State of Charge: Massachusetts Energy Storage Initiative Study.”

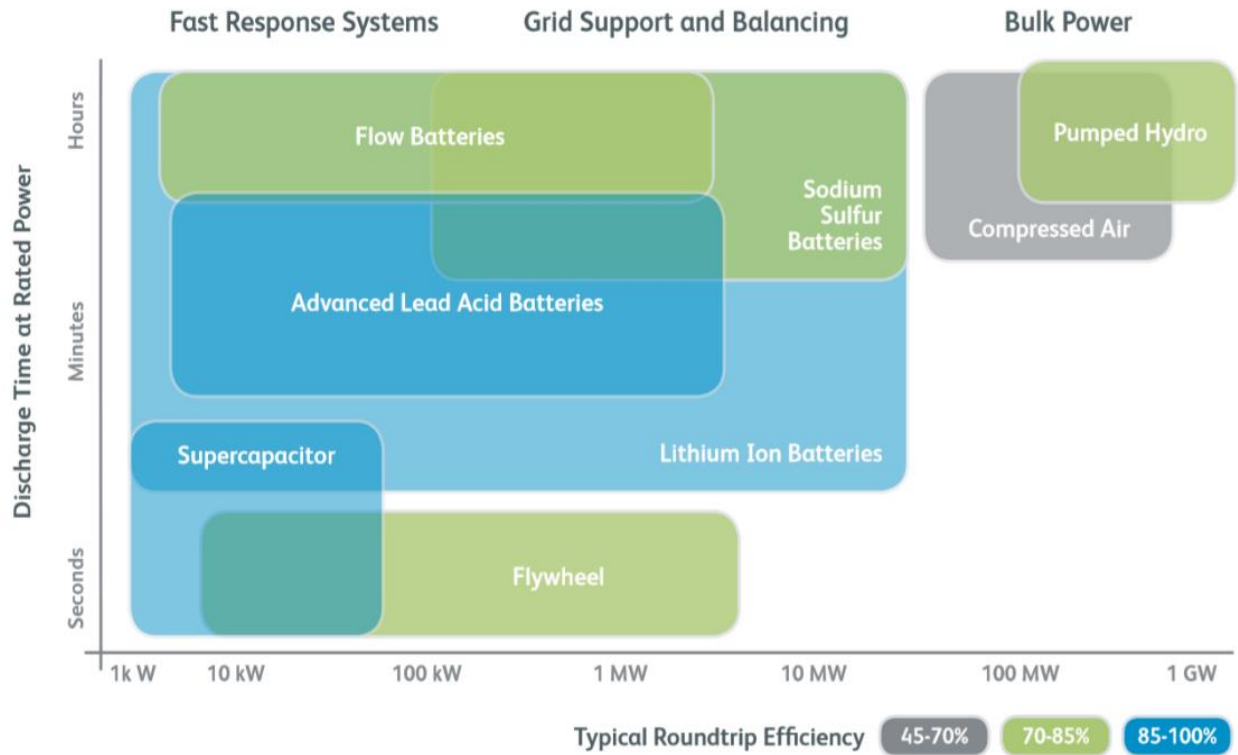


Figure 3. Typical size and duration of energy storage technologies⁵

Storage can provide a myriad of grid services. Some technologies may be better suited to function in specific locations, provide certain grid services, or be better suited to customer-side applications. Energy storage technologies can be integrated in multiple locations across the entire energy value chain: generation, transmission, distribution, ancillary services, and customer applications. These value streams are discussed more thoroughly in Chapter 2: Energy Storage Applications.

1.1.1 Electric Vehicles and Energy Storage

Although electric vehicles (EVs) are not the focus of this report, it is important to note their potential impact on the electricity system and the storage market. For example, passenger EVs are estimated to constitute 80-90% of the global demand for lithium-ion batteries through 2030.⁶ EVs can also function as grid-connected storage resources by dynamically modifying the rate and timing of charging and discharging. These interactions between EVs and the grid are collectively referred to as vehicle-grid integration (VGI). Unidirectional VGI or “smart charging” modulates charging activities so that they are consistent with efficient grid operations. Bidirectional VGI enables EV batteries to discharge to the grid as a generation resource when needed.

Across the country, the vehicle mix continues to shift towards EVs. Research and analytics firm IHS Markit estimates that the share of EVs sold in the U.S. will increase to 7% of the market in 2025.⁷ This

⁵ AECOM (2015), “Energy Storage Study: Funding and Knowledge Sharing Priorities.”

⁶ International Energy Agency (2019), “Global EV Outlook 2019.”

⁷ IHS Markit (2019), “U.S. Electric Vehicle Loyalty and Volumes Reach Record Highs.”

growth will be fueled in part by the introduction of new EV models by nearly every major automaker. Because the rate of EV adoption may vary significantly from one community to the next, the impact of EVs on the electric distribution system is likely to vary in timing and scale.

1.2 Costs of Storage

Over the past decade, most energy storage technologies have experienced cost declines, with lithium-ion technologies leading the way. Bloomberg New Energy Finance reported a 76% drop in cost of lithium-ion cells between 2012 and 2019, largely driven by increases in manufacturing capacity to serve the needs of consumer electronics, EVs, and grid-connected storage.⁸ Figure 4 demonstrates the historical levelized cost of energy (LCOE) for storage technologies and renewable energy.

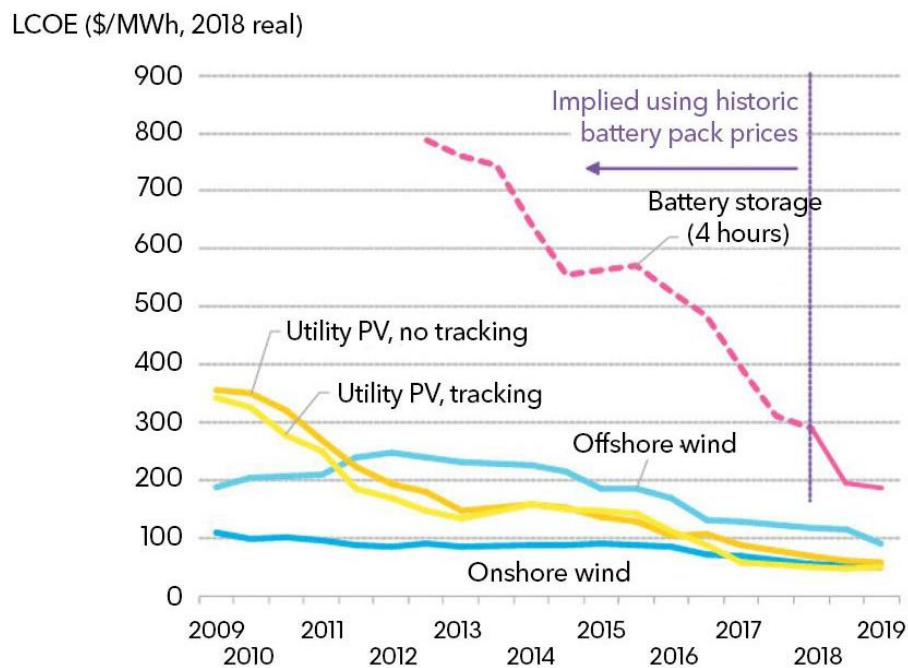


Figure 4. Technology cost benchmarks for battery storage and renewables⁹

The levelized cost of storage (LCOS) varies by the technology and the application, as shown in Figure 5. Most of the barriers to lowering costs further are associated with the non-battery systems costs, such as engineering, procurement, and construction and inverter costs, among others.

⁸ Bloomberg New Energy Finance (2019), “Battery Power’s Latest Plunge in Costs Threatens Coal, Gas.”

⁹ *Ibid.*

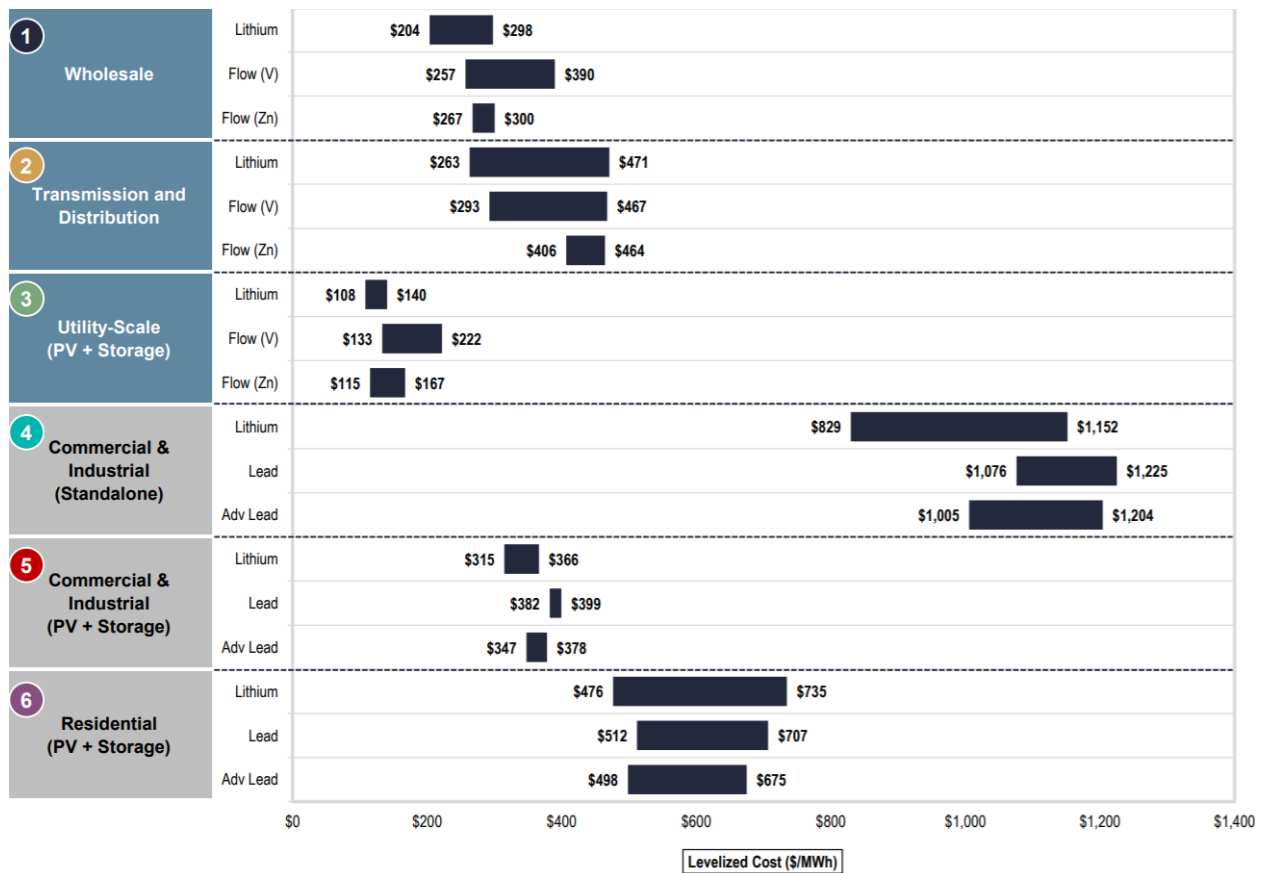


Figure 5. Unsubsidized levelized cost of storage (LCOS) in the U.S.¹⁰

While most analysts expect continued cost declines for lithium-ion technologies, recent analyses have revealed that tight supplies of input commodities carry some risk of cost volatility and could limit the scale of the energy storage market with current technology.¹¹ Cobalt, a rare earth metal, is an especially problematic input to lithium-ion batteries. Global demand for cobalt, driven largely by the demand for batteries, is projected to outpace supply by 2023 and is expected to quadruple in the next 40 years.^{12,13} The supply chain is highly concentrated, leading to increased risks and price volatility, and although alternative sourcing is possible, it could present an increased cost. Manufacturers are also developing lithium-ion battery chemistry to be less reliant on rare earth metals like cobalt and subsequently remove some of the associated price volatility.

¹⁰ Lazard (2020), “Levelized Cost of Storage.”

¹¹ Lazard (2018), “Levelized Cost of Storage.”

¹² Bloomberg New Energy Finance (2018), “Lithium Market Overview.”

¹³ Brink, Susan van den, et. al. (2020), “Identifying Supply Risks by Mapping the Cobalt Supply Chain.” Resources, Conservation and Recycling, vol. 156, p. 104743.

1.3 Energy Storage Deployment in the United States

As of 2020, the U.S. energy storage capacity was approximately 24.5 GW by rated power.¹⁴ The primary form of storage is pumped hydro, comprising 92% of total capacity across the country. The remaining 8% is comprised of thermal storage, CAES, flywheels, and batteries.¹⁵

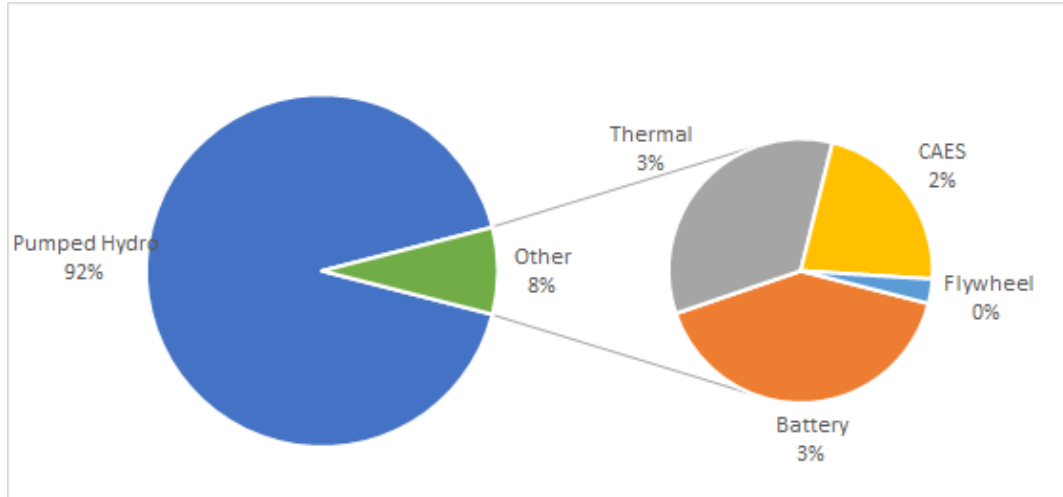


Figure 6. Energy storage capacity in the U.S.¹⁶

While energy storage deployment across all technologies in general have grown rapidly in the last decade, electrochemical – i.e. battery – storage technologies have experienced the most rapid growth. By the end of 2018, the total large-scale battery storage capacity in operation (by energy rating) was 1,267 MWh. Lithium-ion batteries provided 100% of new large-scale battery storage capacity in 2018.¹⁷

As shown in Figure 7, the California Independent System Operator (CAISO) led the wholesale markets in storage deployment between 2016-2018, both in terms of power capacity and energy capacity.¹⁸ Note the initial rise in deployment of battery energy storage in PJM starting in 2014 and subsequent decline in 2016. This was due to a rapid increase in storage deployment due to favorable treatment under a PJM market rule change establishing a market for fast frequency regulation (“RegD”). Subsequent rule changes limited storage’s participation as a RegD resource, leading to the decline in later years. This is further explored in detail in Appendix D: Energy Storage in PJM Wholesale Markets.

¹⁴ U.S. Department of Energy (2020), “Energy Storage Database.”

¹⁵ U.S. Department of Energy (2017), “Energy Storage Database.”

¹⁶ *Ibid.*

¹⁷ U.S. Energy Information Administration (2020), “Battery Storage in the United States: An Update on Market Trends.”

¹⁸ Note: Power capacity is the maximum instantaneous amount of power output measured in units such as megawatts (MW). Energy capacity is the total amount of energy that can be stored or discharged by a battery storage system, measured in units such as megawatt-hours (MWh).

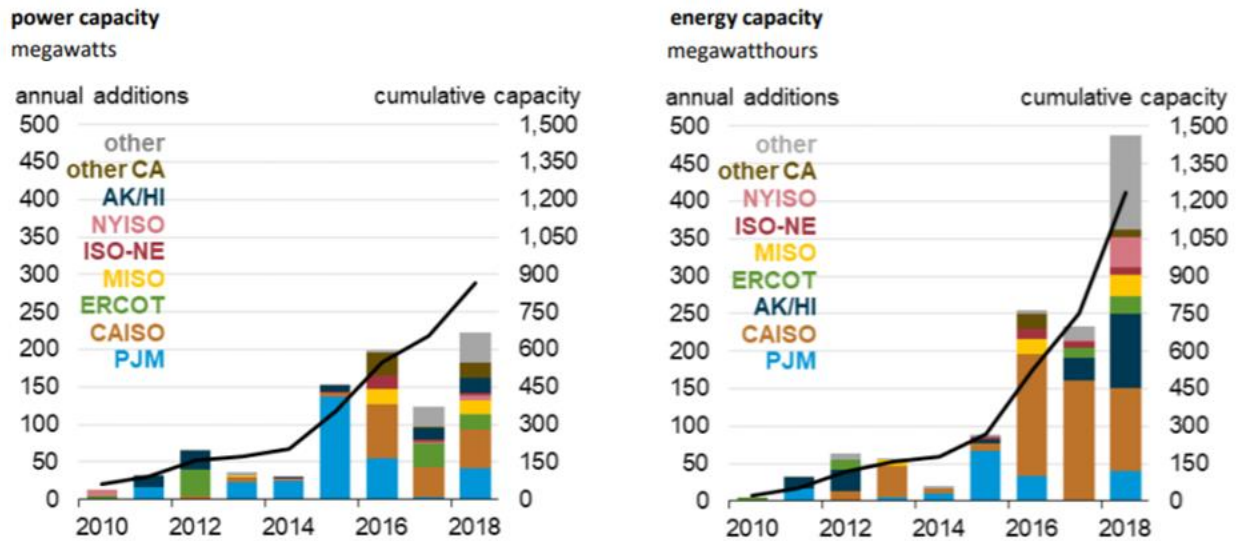


Figure 7. Deployments of battery energy storage in the U.S by power capacity & energy capacity¹⁹

1.3.1 State Energy Storage Policies

Many states, including several of Pennsylvania’s neighbors, have adopted storage-specific policies, targets, and incentives. These states have cited benefits such as economic resource optimization, grid resilience, system efficiency, system flexibility, renewables integration, and greenhouse gas (GHG) reductions. Many of these states have also conducted energy storage studies and/or have started to integrate the technology class into their planning processes.

Seven states, including New York and New Jersey, have statewide targets for energy storage deployment. Most recently, Virginia enacted legislation in April 2020 to establish a goal of 3,100 MW of storage by 2035.²⁰ Additionally, seven states have statewide incentives for energy storage, including New York, New Jersey, and Maryland. Utilities in an additional three states offer direct incentives.

Examples of direct incentive programs include:

- California’s Self-Generation Incentive Program (SGIP), a ratepayer-funded rebate program available to customers of four California investor-owned utilities (IOUs), supports existing, new, and emerging distributed energy resources (DERs).²¹
- New Jersey’s Renewable Electric Storage Program provides financial incentives for non-residential customers for energy storage integrated with BTM renewable energy projects.²²

¹⁹ U.S. Energy Information Administration (2020), “Battery Storage in the United States: An Update on Market Trends.”

²⁰ Database of State Incentives for Renewables & Efficiency (2020), “Virginia Energy Storage Target Program Overview.”

²¹ California Public Utilities Commission, “Self-Generation Incentive Program.”

²² New Jersey Clean Energy Program, “Renewable Electric Storage.”

- Maryland’s Game Changer competitive grant program provides funding to energy storage projects that provide a quantifiable reliability or resilience benefit, demonstrate an innovative application, and drive economic development.²³
- Massachusetts’s Advancing Commonwealth Energy Storage program provides financial awards to innovative, broadly replicable storage use cases/business models with multiple value streams.²⁴

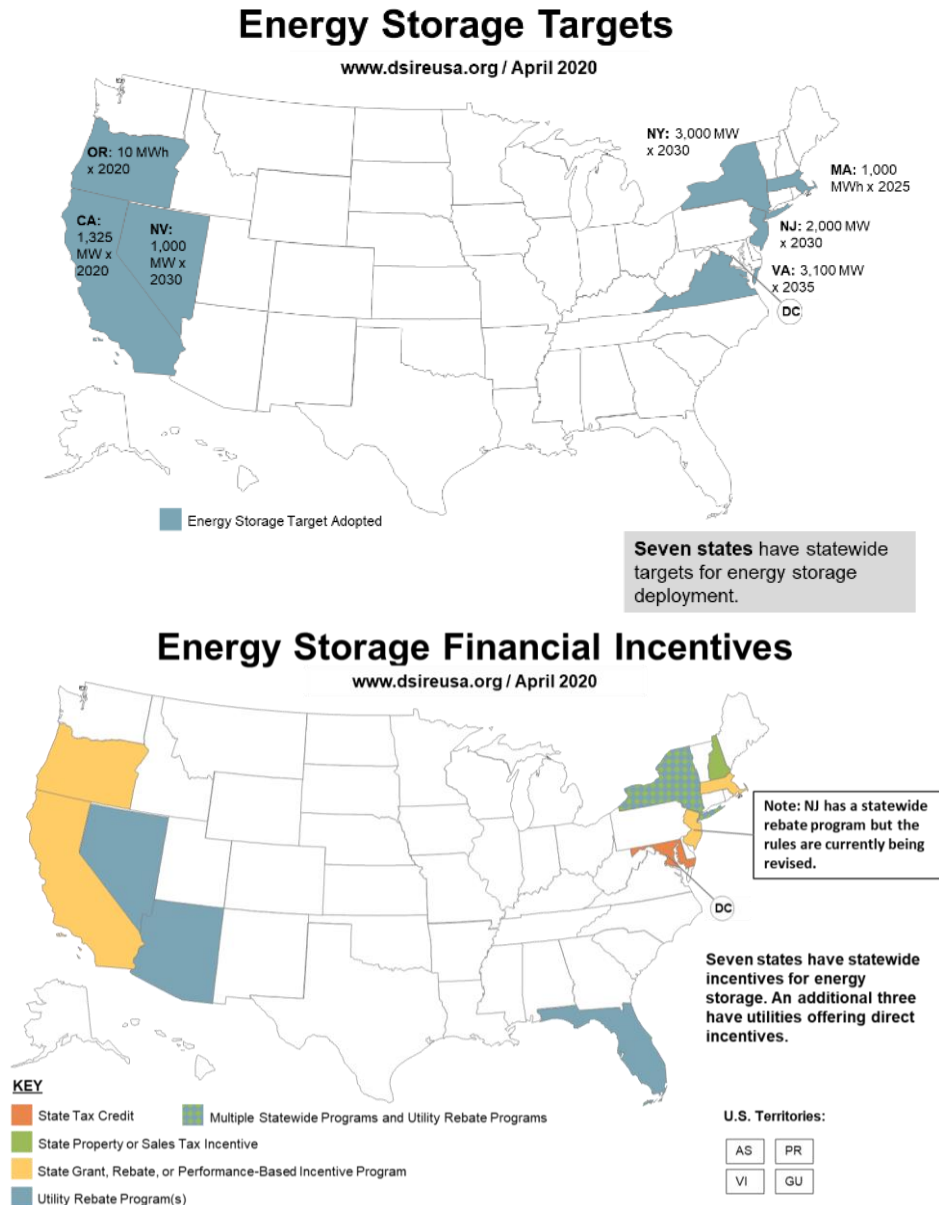


Figure 8. Energy storage targets and financial incentives²⁵

²³ Maryland Energy Administration, “Game Changers Program.”

²⁴ Massachusetts Clean Energy Center, “Advancing Commonwealth Energy Storage.”

²⁵ Database of State Incentives for Renewables & Efficiency (2020), “Detailed Summary Maps.”

Case Studies: New York and California

California and New York, two early movers, provide useful case studies for policy implementation and advanced frameworks for incorporating storage assets. In 2018, New York set a statewide target of 1,500 MW by 2025 and the state's Public Service Commission subsequently adopted a requirement of 3,000 MW by 2030.²⁶ In addition to this deployment target, New York, under the umbrella of the Reforming the Energy Vision (REV) process, has adopted a robust process of distributed system implementation plans which has led the state's utilities to develop harmonized models for integration of DERs. Each utility is also required by the Public Service Commission to launch two energy storage projects, with the intent to use these as models for additional non-wires alternatives (NWAs).²⁷ Competitive solicitations for NWAs have been conducted and more are expected going forward as a means of addressing local system needs in lieu of traditional capital expenditures (e.g. reconductoring, substation upgrades, etc.).

In 2013, California adopted a mandate to procure 1,325 MW of storage capacity by 2020 and in 2016 added a deployment target of 500 MW of distributed energy storage, bringing the total to 1,825 MW.²⁸ However, the additional 500 MW target is not subject to the 2020 deadline. California has three major IOUs: Pacific Gas & Electric, San Diego Gas & Electric, and Southern California Edison. As the cost of storage has declined, all three have exceeded their share of California's 1,325 MW energy storage procurement target. The state's focus on reducing regulatory barriers, enhancing wholesale market participation options, improving end-use customer rate design, and enabling multiple-use applications (MUA) for storage have helped energy storage technologies to participate on a level playing field with conventional resources in the state and have unlocked new applications for nontraditional technologies, such as distribution deferral and power quality applications, that are helping the grid to operate more efficiently and reduce costs to California's energy consumers. Additional details on California's Multiple-Use Application Framework can be found in Section 2.4.1 California's Multiple-Use Application Framework.

The primary application driving deployment of bulk storage in California is to ensure system and local capacity (also called "resource adequacy") as fossil plant retirements continue to grow and long-term capacity is secured through bilateral contracts between developers and utilities. These contracts generally allow new storage facilities to provide other grid services on a merchant or contracted basis so long as they meet the market participation requirements established in their bilateral capacity contracts.

Storage has also been procured in California on an emergency basis due to localized grid constraints. For example, 99.5 MW of energy storage was acquired and operational within 6 months to address reliability issues stemming from the Aliso Canyon gas storage facility leak, which severely curtailed natural gas import capacity into the Los Angeles basin.²⁹

²⁶ New York State Energy Research and Development Authority (NYSERDA) (2019), "Energy Storage."

²⁷ REV Connect (2019), "Non-Wires Alternatives."

²⁸ California Legislature (2016). "Assembly Bill No. 2868."

²⁹ California Energy Storage Alliance (2020), "Compilation of AB 2514 compliance filings and applications for approval."

1.3.2 Federal Investment Tax Credit

The federal Investment Tax Credit (ITC) is one of the most significant federal policy mechanisms to support the growth of solar energy and storage in the U.S. The ITC is a tax credit for solar systems – and potentially storage – on residential and commercial properties. The commercial credit can be applied to both customer-sited commercial solar systems and large-scale utility solar farms.

The ITC is based on the amount of investment in solar property. Congress passed a two-year delay of the ITC phasedown in 2020. The residential and commercial ITC are currently equal to 26% of the amount that is invested in eligible solar property. The ITC then steps down according to the following schedule:

- 26% for projects that begin construction in 2021 and 2022,
- 22% for projects that begin construction in 2023,
- After 2023, the residential credit drops to zero while the commercial credit drops to a permanent 10%.³⁰

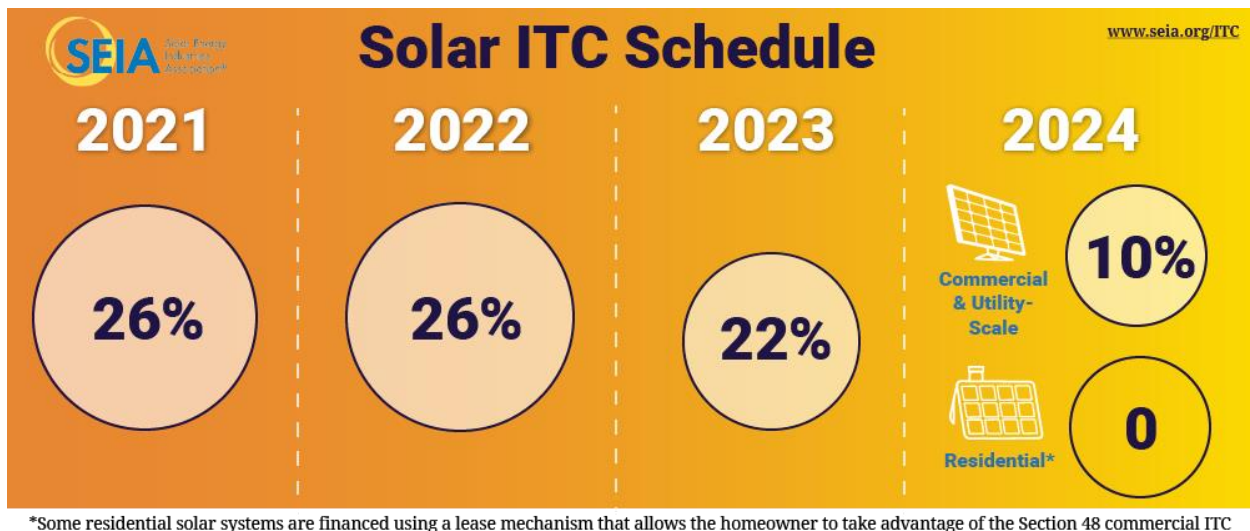


Figure 9. Solar ITC Schedule³¹

In many cases, the ITC can also be applied to the cost of installing a battery in addition to a solar energy system. For residential systems, energy storage is eligible for a credit under the ITC if the battery is charged exclusively by an on-site renewable energy system like solar. In other words, in order to qualify for the ITC, a residential storage system cannot charge from the grid. For commercial storage, the system may be eligible for a credit under the ITC as long as the battery is charged by a renewable energy system at least 75% of the time. The exact value of the federal tax credit for batteries depends on how frequently the battery is charged by a renewable energy system. To claim the full value, the battery needs to be charged by renewable energy 100% of the time. Otherwise, the credit is based on the portion of renewable energy it receives.³²

³⁰ Solar Energy Industries Association, "Solar Investment Tax Credit (ITC)."

³¹ *Ibid.*

³² EnergySage (2021), "Using the solar investment tax credit for energy storage."

Chapter 2: Energy Storage Applications

Energy storage is a versatile resource that can be deployed to provide a diverse range of services for the modern grid due to the variety of operational modes and potential locations where it can be sited. The services that an energy storage resource (ESR) can provide depend on the location of the storage on the and where it is sited. If storage is sited on the utility side of the meter, it is referred to as in-front-of-the-meter or front-of-meter (FOM). If storage is on the customer side of the meter, it is referred to as behind-the-meter (BTM).

As illustrated below, storage can provide up to 13 distinct, general services to the transmission grid and wholesale markets, distribution systems and utilities, and retail customers. This framework provides a basis for considering the applications and benefits of ESRs in Pennsylvania.

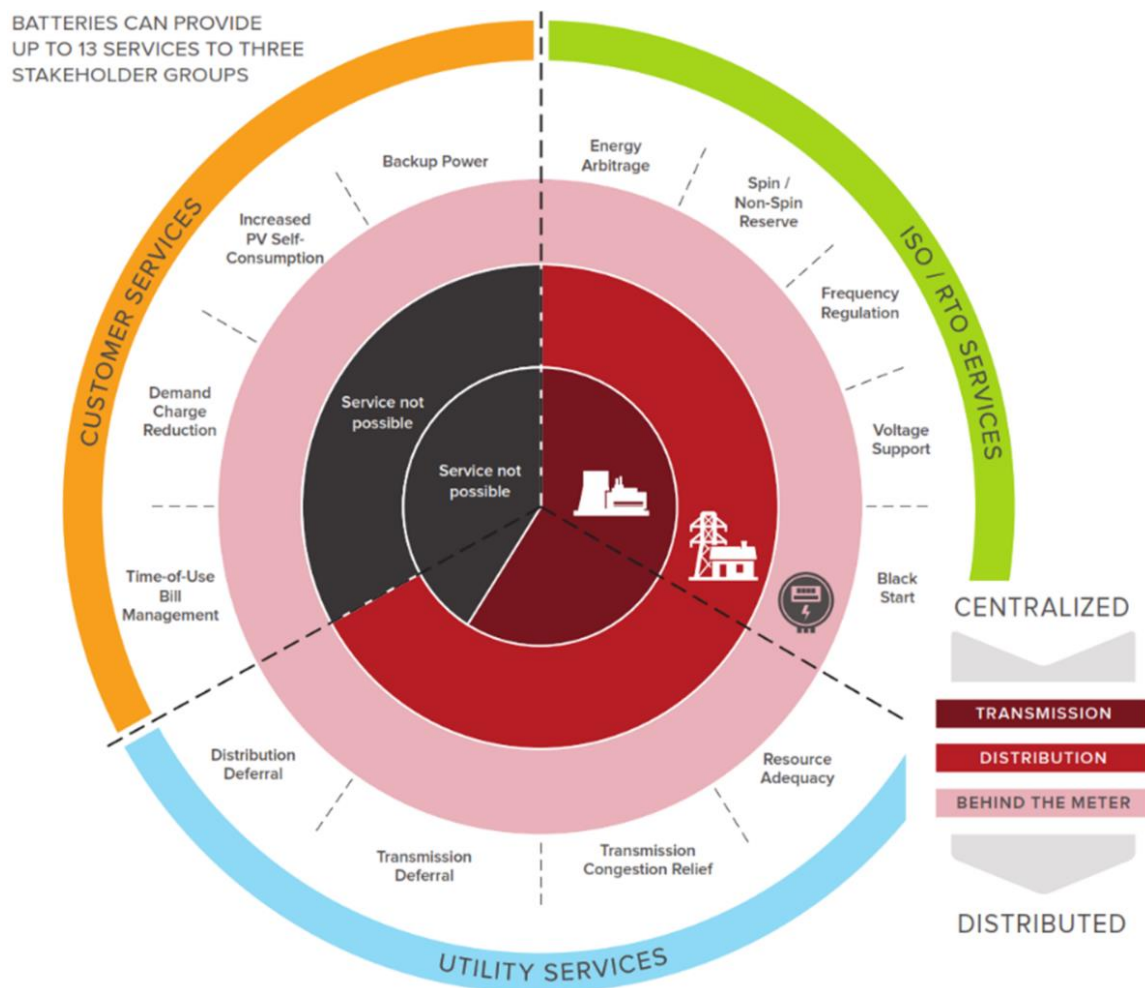


Figure 10. Energy storage services³³

³³ Rocky Mountain Institute (2015), "The Economics of Battery Energy Storage: How multi-use, customer-sited batteries deliver the most services and value to customers and the grid."

The ability of an energy storage system to meet a particular need is dependent on several parameters, including its power and energy requirements, location requirements, frequency requirements, and fungibility of the asset. In this context, fungibility refers to whether there are substitute resources that could be deployed if the energy storage is unavailable. This is particularly relevant if storage is to be deployed as an alternative transmission or distribution solution.

See Appendix B: Glossary of Energy Storage Terms for definitions and descriptions of terms related to storage performance and costs.

2.1 Bulk-Power System Services

Energy storage can enhance the efficiency and flexibility of the bulk-power system operated by independent system operators (ISOs) and regional transmission organizations (RTOs). Storage can be deployed as standalone grid resources or paired with generation resources. In addition to firming the output of variable generation, such as solar and wind, storage can also enhance the performance of traditional generation through hybridization. Bulk storage can lower electricity generation costs by storing energy during times with lower energy costs and using it later, thereby reducing the need to dispatch higher-cost generation resources. Additionally, storage can act as an alternative transmission or distribution resource by reducing peak demand, managing circuit loading, and providing volt/VAR support. Storage can improve grid reliability by providing ancillary services such as fast-responding frequency regulation, spin reserves, and non-spin reserves. Storage can also act as a system capacity resource.

Large ESRs can provide peak capacity when it is needed, which is typically in the late afternoon and early evening during summer and/or winter months. Additionally, unlike traditional peaking units, energy storage can provide valuable grid services like ramping, voltage support, energy arbitrage, congestion relief, regulation, and frequency response when they are not needed for peak capacity. Energy storage assets have low marginal costs for providing these services outside of peak hours because they would be charging with off-peak energy (a strategy known as “energy arbitrage,” discussed below). Unlike thermal generation, energy storage systems are always on and connected to the grid and do not have start-up and shut-down costs. To provide other services outside of their capacity obligations, system operators must identify the hours during which the resources must be available to fulfill their capacity obligations.

See Appendix D: Energy Storage in PJM Wholesale Markets for additional details about energy storage participation in PJM wholesale electricity markets.

2.1.1 Energy Arbitrage

Energy storage can provide value through energy arbitrage by directly participating in PJM’s wholesale electricity markets. It is profitable for ESRs if the price differential between peak and off-peak periods is adequate to make up for the efficiency losses experienced when cycling the storage asset. In wholesale energy markets, significant price differences can result between periods of relatively low demand and periods of relatively high demand. Because operating ESRs is premised on charging and discharging cycles, it is possible to time these cycles such that a resource is charging when the price is low (during off-peak periods, generally during the night), and discharge when the price is high (during peak periods, generally during the day). This is known as energy arbitrage.

Energy arbitrage has long been the business model for pumped-hydro resources in the U.S., generally by taking advantage of daily peak and off-peak prices. However, new storage technologies like batteries are creating additional opportunities for arbitrage. They can easily be co-located with load, and therefore can serve as a hedge against high congestion, reducing locational marginal prices in constrained areas. In the past, this was only possible by purchasing financial transmission rights in PJM. Using new storage technologies to reduce peak consumption in load pockets, allows load-serving entities to hedge against congestion costs by arbitraging energy for their customers. This creates more reliable predictions of congestion costs. Additionally, new storage technologies are able to move from charge to discharge mode very quickly, so there is more opportunity to arbitrage prices in real time. As wholesale prices change in five-minute increments, batteries are able to respond immediately.

To better understand the energy arbitrage potential within the Pennsylvania context, we first looked at historical energy prices in PJM’s Day-Ahead and the Real-Time Energy Markets which have similar price patterns. Figure 11 and Figure 12 below show the average hourly locational marginal price (LMP) for PPL in 2019 in the Real-Time Energy Market and the Day-Ahead Energy Market, respectively. As seen in the tables, high prices are observed in the afternoon during summer, and the morning and evening during winter.

	January	February	March	April	May	June	July	August	September	October	November	December
0	29	24	23	19	18	17	19	17	16	16	21	19
1	30	24	23	19	17	16	18	16	15	15	20	18
2	26	22	23	19	16	15	17	15	15	14	21	19
3	25	23	23	19	16	15	16	14	14	14	21	18
4	25	23	20	19	16	14	16	14	14	15	21	19
5	27	27	26	21	16	15	17	15	16	16	23	20
6	33	29	39	25	16	15	17	16	19	23	35	25
7	37	29	38	43	19	16	18	16	17	21	37	32
8	31	27	29	26	21	18	20	17	17	20	26	24
9	29	28	28	26	21	19	22	19	21	21	25	23
10	32	25	26	27	22	19	26	20	20	19	26	24
11	30	24	25	25	21	20	32	21	20	20	23	22
12	29	25	24	24	21	21	29	22	23	19	23	22
13	27	27	24	25	23	24	30	24	24	19	23	21
14	25	23	25	22	22	22	31	24	28	26	18	21
15	25	23	26	23	23	23	35	27	41	32	10	22
16	30	24	23	23	24	25	49	33	48	28	15	33
17	41	29	24	24	26	26	48	31	40	29	29	42
18	38	33	25	24	22	25	32	26	24	24	26	30
19	33	30	36	29	24	22	28	23	27	25	23	28
20	35	28	33	31	25	21	25	23	25	21	24	32
21	31	26	28	25	24	22	24	20	20	18	23	26
22	26	23	29	22	19	19	21	17	18	17	21	21
23	25	21	22	20	17	17	20	17	17	17	21	19

Figure 11. Mean hourly prices (\$/MWh) for PPL in the PJM Real-Time Energy Market in 2019³⁴

³⁴ Data from PJM (2019), “Energy Market.”

	January	February	March	April	May	June	July	August	September	October	November	December
0	27	23	23	20	18	17	19	17	16	16	20	19
1	27	22	23	19	18	16	18	16	15	15	20	19
2	27	22	23	19	17	15	17	15	14	14	20	18
3	27	22	23	19	17	15	16	14	14	14	20	18
4	28	22	23	19	17	15	16	14	14	15	20	19
5	30	24	25	21	18	15	17	15	15	16	22	20
6	35	28	31	27	18	16	18	16	17	20	27	25
7	39	30	34	28	20	17	19	17	17	21	28	27
8	35	28	30	26	20	18	20	17	17	21	26	24
9	33	27	29	27	21	18	22	19	18	21	25	23
10	34	27	29	27	22	20	24	21	19	20	24	22
11	32	25	27	26	22	20	27	23	20	20	23	21
12	30	24	26	26	22	21	30	25	22	20	22	21
13	29	24	25	26	23	23	32	26	24	20	22	20
14	28	23	24	24	23	23	33	28	25	21	21	20
15	28	23	23	24	23	24	35	30	27	22	22	20
16	31	24	24	24	25	26	39	33	31	23	25	23
17	39	27	26	25	25	26	39	32	30	24	31	29
18	39	30	29	25	24	23	33	27	25	26	28	26
19	37	28	34	27	23	22	29	25	26	27	26	25
20	35	27	33	31	25	22	28	25	24	23	26	24
21	33	25	28	27	23	21	26	22	20	20	24	22
22	30	23	26	22	20	19	22	19	18	18	22	20
23	28	22	24	21	19	17	21	17	16	16	21	19

Figure 12. Mean hourly prices (\$/MWh) for PPL in the PJM Day-Ahead Energy Market in 2019³⁵

The concept of scarcity pricing can significantly increase the revenue potential of a storage asset. While these figures provide average prices in the Day-Ahead and Real-Time Energy Markets, individual prices might deviate in any given hour. For example, on April 8, 2019, at 7:00 AM, the Real-Time LMP spiked to \$469/MWh, the highest price experienced in the year.

The graph below shows the annual average value for the maximum difference between any two prices during a day, based on 2019 Day-Ahead and Real-Time Energy Market prices. The results presented in the graph are based on historical prices and reflect the maximum difference between the highest and lowest priced hour in every day during a year. A storage asset with a single hour duration could theoretically have an average daily revenue equal to this difference per MW (de-rated by efficiency losses). A longer duration asset could capture additional value, although such value would be diminishing as remaining price differences during the day are lower.

³⁵ *Ibid.*

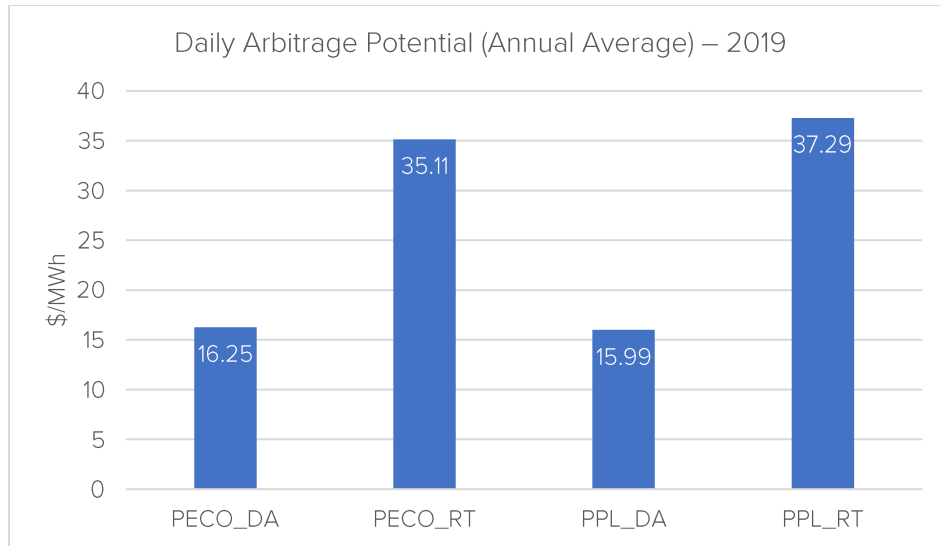


Figure 13. Energy arbitrage potential in Day-Ahead and Real-Time Energy Markets in the PPL and PECO load zones³⁶

2.1.2 Capacity

PJM’s capacity market, called the Reliability Pricing Model (RPM), ensures long-term grid reliability by procuring the appropriate amount of power supply resources needed to meet predicted energy demand three years in the future. Storage can participate in the capacity market, but its valuation is limited by PJM’s proposal that a minimum of 10-hour duration should be maintained to participate in the capacity market.³⁷

2.1.3 Ancillary Services

Ancillary services help balance the transmission system as it moves electricity from generating sources to retail consumers. PJM operates markets to procure two important ancillary services: regulation and reserves. Reserves help to recover system balance by making up for generation deficiencies if there is loss of a large generator. Regulation is used to control small mismatches between load and generation.

The markets for reserves do not typically offer attractive prices for participating resources. Although the market for regulation is lucrative, but shallow and quickly saturated. A storage asset can bid in the regulation market in consecutive hours, which is the reason that a storage asset participating in both energy and ancillary services markets might choose to forego high arbitrage opportunities to maintain its state of charge and be active in the regulation market. PJM has a regulation requirement of 525 MW during non-ramp hours and 800 MW during ramp hours, which consist of both RegA and RegD. Energy storage can provide dynamic regulation (RegD), but as of 2018 PJM seems to have

³⁶ *Ibid.*

³⁷ PJM (2018), “Electric Storage Participation Straw Proposal.”

enough qualified storage MW to satisfy the requirements.³⁸ Nevertheless, regulation prices are high, and the market remains attractive for more investment in storage.

The optimal revenue that a one-hour storage asset participating in the PJM ancillary services market in 2017 could get was over \$100 per kW for the year. This number is calculated based on optimal bidding in both the energy and ancillary services markets³⁹ and informs the study's marginal regulation benefit of the first deployed MW of storage in Pennsylvania. Although the battery can bid in both energy and ancillary services markets, it is much more profitable to bid in the regulation market and only shift energy during extreme price spikes. However, that revenue could quickly disappear as more storage comes online. As regulation is being drafted at a PJM-wide level, Pennsylvania assets will be competing with resources from other states and could be offering regulation exceeding the needs of the state's load. For that reason and although the state's load represents about 20% of the PJM load,⁴⁰ within this study it is assumed that the marginal regulation benefit approaches zero when additional storage within Pennsylvania reaches 25% of the PJM requirement.

In addition to other factors, the amount of regulation required by the PJM system is highly dependent upon the amount of wind and solar production at that time. According to a recent renewable integration study, it was recommended that PJM develop a method to determine regulation requirements based on forecasted levels of wind and solar production.⁴¹ The study's main conclusion is that the PJM system could operate reliably under this higher renewable energy scenario if up to additional 1,500 MW of regulation reserves are also included.

2.1.4 Generation Cost Avoidance

In addition to avoided PJM wholesale capacity costs, storage can preempt the need for utilities to invest in new generation resources. The costs of these resources are generally recovered through a rider mechanism on retail customer bills. Combustion turbines are generally designed to operate for a very limited subset of peak hours during the year and have fast ramping times that can help address fluctuations in generation associated with renewable resource variability. Similarly, advanced energy storage systems can provide energy during a limited number of peak hours and can have near-instantaneous ramping capability, which can aid with renewable resource integration. To the extent that energy storage could provide a similar capability to or nearly equivalent capabilities to a combustion turbine, it could be considered as an alternative to new combustion turbine generation additions. Additional evaluation may be helpful to determine the suitability of storage as an alternative in terms of its capabilities and cost-effectiveness.

Additionally, energy storage can be critical in serving peak load, and shifting renewable generation to peak hours, thereby eliminating the need for seldom used peaking plants and better integrating renewables. For example, Figure 14 below depicts the locations and relative size of gas- and oil-fired

³⁸ PJM (2018), "Regulation Update."

³⁹ Storage revenue in the regulation market was modelled according to: Byrne et. al. (2015), "Estimating Potential Revenue from Electrical Energy Storage in PJM."

⁴⁰ Monitoring Analytics (2019), "Percentage of PJM Load by State."

⁴¹ PJM (2016), "Renewable Integration Study Reports."

peaking power plants in Pennsylvania with capacity factors of 15% or less. While these seldom run, they often have very high emissions rates (e.g. over 0.5 lbs/MMBTU NOx emissions in some cases).

And because this is a peak load service, these benefits can often be realized using the same resources that are providing transmission and distribution (T&D) investment deferral/avoidance because their operational profiles are similar. As renewable generation increases, designing portfolios of utility-scale FOM storage assets that can be aggregated and dispatched to absorb renewable generation and discharged to displace peak capacity requirements will prove increasingly valuable.

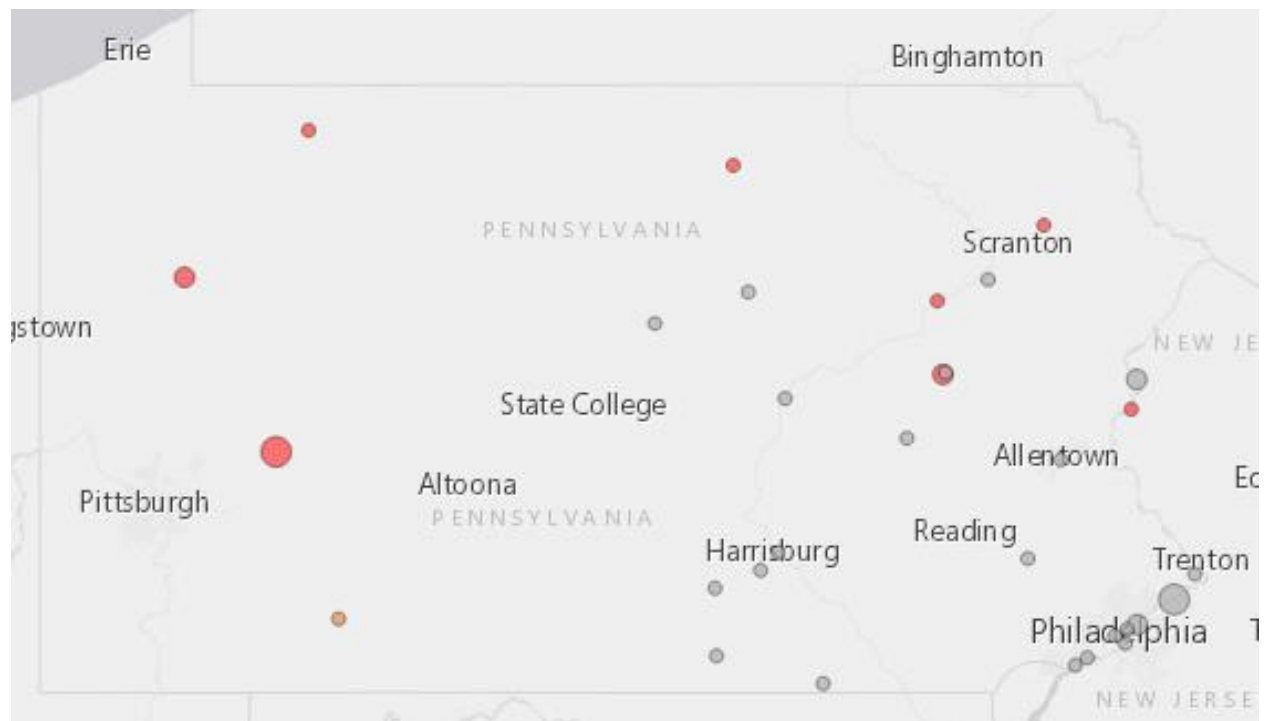


Figure 14. Peaking power plants in Pennsylvania⁴²

There may also be opportunities to offer excess storage capacity into the PJM markets, but this is somewhat dependent on how the utility procures the asset. While the Federal Energy Regulatory Commission (FERC) made clear that it is possible for ESRs that receive cost-of-service rates to also participate in the wholesale markets, there are concerns about over-recovery of costs and the operation of the asset. PJM has not created any official market rules for such assets, and limited precedent exists, so it is unclear how such hybrid cost-based and market-based cost recovery would work. Obtaining clarity from FERC and PJM on this issue could help add value to utility-owned ESRs.

Additional legislation that encourages or requires additional utility deployment of ESRs as a means of integrating renewables or as an alternative to future peaking power requirements could be helpful for realizing the value of storage in Pennsylvania.

⁴² Note: Each dot represents one power plant. Red dots represent gas-fired plants, and grey dots represent oil-fired plants. The size of a dot corresponds to a plant's capacity. S&P Global Market Intelligence (2020).

2.1.5 Merchant Wholesale

Pennsylvania's electric distribution companies (EDCs) are members of the PJM Interconnection, an RTO that operates wholesale capacity, energy, and ancillary service markets. ESRs are able to participate in all of these markets; however, due to the operational characteristics of storage and some elements of PJM's market design, there are relatively limited opportunities for ESRs, particularly new technologies like batteries, to depend on wholesale market revenues alone as a business model. Nonetheless, opportunities do exist for ESRs to generate revenues in the wholesale markets.

Merchant resources are those that are financed and built completely based on their anticipated revenues from PJM's capacity, energy, and ancillary service markets. PJM thus far has the largest market in the world for merchant standalone energy storage projects. The best opportunities for demand response (DR) participation in Pennsylvania are in the PJM wholesale markets. In PJM end-use electricity, customers can be compensated by curtailment service providers that aggregate retail customers and offer their combined load reductions into the PJM markets. PJM has an economic DR program where curtailment service providers can participate in the day-ahead or real-time markets on behalf of the customers they represent. Curtailment service providers are also able to participate in the capacity market as a capacity performance resource if they can reduce their load during capacity performance events throughout the entire year. PJM also enables demand resources to participate and submit bids for reductions in the Synchronized Reserve, Regulation and Day-Ahead Scheduling Reserves markets.⁴³

In 2013, when PJM redesigned its regulation market to comply with FERC Order 755, it began paying regulation resources for their performance and created its RegD signal for faster resources like battery storage and flywheels. Hundreds of megawatts of energy storage projects were financed and built based on this new construct. However, the large influx of ESRs and flexible natural gas generation have lowered regulation prices and some fundamental changes to the market design have made it less economic for short-duration ESRs – systems that can discharge for less than 10 hours at their rated power – to compete. As a result, no additional merchant ESRs have been built in recent years.

Outside of the regulation market, the opportunities for merchant revenue for shorter duration energy storage are somewhat limited. The duration requirements in the capacity market limit the ability of ESRs like batteries to participate at their full rated capacity, and price convergence and decreased volatility in the energy markets have made arbitrage opportunities a relatively unreliable source of revenue for new projects.

However, there are emerging opportunities to pair energy storage with generation resources in the markets. Co-locating energy storage with solar and/or wind installations can assist with renewable integration by better aligning renewable output with load. This is effectively a form of arbitrage and improves earnings for developers by absorbing the clean energy in real time and then selling it into the markets during peak hours when the price for energy is the highest. By controlling the output of these hybrid assets, it is also possible to mitigate intermittency and improve local power quality issues that can arise due to fluctuations in renewable output. While it is possible to offer these

⁴³ PJM (2017), "Demand Response."

resources into the market as a merchant asset, it is more likely for them to be contracted with a utility on a long-term basis as a clean energy asset and/or as an alternative to peak generation units.

Energy storage can also be paired with thermal generation to improve its operational efficiency. Generators often must maintain headroom (i.e. the ability to increase output), to provide load-following and ancillary services, which can result in sub-optimal operation of the generator. If energy storage assets co-located with the generator are dispatched to follow load and provide ancillary services, then generators can operate at a constant, optimal output which reduces wear and tear, outages, operating and maintenance costs, and emissions. It is also possible for the storage asset to be used to improve the efficiency of thermal generation.

2.1.6 Large-Scale Hybrid Solar-plus-Storage Power Purchase Agreement

One of the most common methods for large-scale storage to be deployed today is through a bilateral contract with a specific off-taker, such as a load-serving entity (LSE) or an EDC. This is similar to the manner in which many recent renewable energy projects have been financed through power purchase agreements (PPAs). For standalone storage purchases, this may take the form of a contract for resource adequacy capacity (rather than for energy) since capacity is being purchased rather than energy. In recent years, several PPA for renewable energy have also included energy storage as an optional addition. For example, the Los Angeles Department of Water and Power (LADWP), one of California's largest utilities, recently executed a PPA for a solar photovoltaic (PV) resource that included battery storage options as shown below.

	Eland Phase 1	Eland Phase 2
Solar Technology	Single Axis Tracking Solar PV	
Term	25 Years	
Total Capacity	200 MW	
Solar Price	\$19.97/MWh	
BESS Size	100MW/4-hour (400MWh)	
BESS Price Adder	\$13.00/MWh	
LADWP Share:	87.5%	100.0%
Glendale Share	12.5%	N/A
RPS % in 2025	3.1%	3.5%
Early Buyout Option (EBO)	15, 20, and 25 year anniversary of Commercial Operation Date	
EBO price	Based on Fair Market Price	



Battery Option for each project to increase to 150MW/4-hour (600MWh)		
Price Adder	\$6.65/MWh	
RPS Percentage in 2025	3.3%	3.8%



4

ladwp.com

Figure 15. LADWP Eland Solar-Plus-Storage Project⁴⁴

While Pennsylvania does not have the same quality of solar resources as California or Nevada and is unlikely to see pricing as favorable for the solar PV portion, it still has a robust solar resource and could see very competitive offers for solar-plus-storage projects. Meanwhile, the storage portion is less geographically dependent.

Since Pennsylvania has a restructured market for generation, its distribution utilities are not vertically integrated and may have fewer options to build or contract for these types of projects directly, absent specific policy changes. However, there may be near term opportunities for specific retail customers or power marketers to do so through long-term bilateral contracts, which could also benefit from supportive policies.

2.2 Distribution Utility Services

ESRs deployed on the distribution system can be a flexible tool to provide multiple services including managing peak demand, integrating renewable energy, providing voltage regulation, and mitigating power outages among other capabilities.

⁴⁴ Weaver, John (2019), "Los Angeles says 'Yes' to the cheapest solar plus storage in the USA," *PV Magazine*.

In addition to direct participation in the wholesale markets, ESRs can also be used by EDCs in lieu of traditional investments in infrastructure and should be considered in planning processes for the cost-saving and operational benefits that they can provide. However, obstacles remain for effectively integrating energy storage into utility planning. Emerging storage technologies are not familiar investment options for utility planners, so the initial obstacle is to ensure that they are being considered on an equal basis with all other potential solutions. Storage should be considered as an alternative to traditional capital investments based on the latest assumptions for its cost and capabilities, particularly for those investments that are being developed to serve peak demand. Adopting this approach in Pennsylvania could leverage lessons learned from other states with non-wires solutions frameworks such as California and New York (see Section 1.3.1 State Energy Storage Policies).

Due to the rapidly declining cost of storage technologies, any assumptions made during planning analyses need to be updated on a frequent basis. Additionally, any planning analyses conducted should reflect the full capabilities of storage devices, including the bidirectional capabilities and fast response times of inverter-based technologies.

Lastly, EDCs under cost-of-service regulation need to be incentivized to look at storage as an alternative to other more expensive investments. Storage is often capable of deferring or completely substituting for investments in more traditional wires infrastructure, but unless EDCs are required to evaluate all options and to select the solution with the highest benefit-cost ratio inclusive of MUAs, then it is generally in the EDC's interest to opt for more expensive conventional projects as they offer greater returns to their investors.

2.2.1 Transmission Congestion Relief

The cost for distribution utilities to serve their customer load goes up during peak hours partly because the transfer capabilities of the transmission system can be pushed to its limits, increasing wholesale energy prices. However, these costs can be mitigated by relieving congestion on transmission lines that serve urban areas or other parts of the grid with limited transmission capacity. Mitigating congestion can be a form of energy arbitrage for the downstream purchaser of energy. Alternatively, it could be part of a planning approach that helps a utility effectively serve load, while hedging price risk. Operationally, it is accomplished the same way – the storage asset is co-located with load, charged when energy demand and prices are low and the transmission system is not congested, and then discharged when energy demand and prices are higher and the transmission lines are congested. Moving energy into the load pocket with storage during times when the system is not stressed can significantly reduce the cost of serving load during peak demand. The small footprint, short development timelines, and minimal environmental impact of storage also allows it to be deployed quickly and very close to load which can be particularly advantageous for any near-term reliability concerns emerging from line congestion. This is more likely to occur in more congested urban areas.

While congestion relief has a clear economic valuation at the transmission level as described above, congestion also exists at the distribution level as well. The following section describes how distribution system costs can be avoided which could include those related to relieving congestion.

2.2.2 Transmission and Distribution Cost Avoidance

One of the primary applications of ESRs is siting energy storage downstream of congested infrastructure, generally at a substation, to defer or avoid investments in system upgrades. This can be accomplished through both utility-owned storage resources and contracted resources owned by third parties. ESRs can be deployed more easily and more rapidly on an incremental basis, which can mitigate the uncertainty of supply and demand forecasting and help avoid major investments in infrastructure.

If a storage system is connected to the distribution system, then it would likely be contracted with the local EDC and fall under the oversight of state-level regulators. PJM maintains frequency and voltage on the bulk-power system and has control over the resources that are interconnected to it, but it does not have visibility into the distribution system or the ability to control distributed energy resources that are not transacting in the PJM markets. Therefore, these services would be contracted with the local EDC on an as-needed basis to keep the distribution system within acceptable tolerances. Storage would need to be considered in the EDCs' planning processes for these services as an alternative to more traditional resources like capacitors, synchronous condensers, and local generation. EDCs have different accounts for different types of assets that determine the rate of return that they will receive, and to be counted as an infrastructure project, energy storage would have to be proposed and approved as a distribution system upgrade to receive such regulatory treatment.

For T&D infrastructure that is persistently congested, aging, or otherwise experiencing voltage problems or thermal overloads, the most common mitigation strategy is to either upgrade or replace those components of the grid. However, upgrading or replacing utility infrastructure can require expensive capital investments. Deferring or avoiding those investments can reduce overall costs for the utility and its customers, especially if other value streams can be monetized. These cost-saving strategies can present a viable business case for energy storage investments and are the major reason why storage needs to be considered on an equal basis with all other T&D infrastructure. By placing storage downstream of transmission or distribution wires and operating it for congestion relief, as described above, it can reduce loading on wires and remove the need to upgrade their capacity or replace aging infrastructure. Additionally, storage can be located at substations or along transmission corridors to help maintain frequency and voltage on the system, reducing the need for capacitors, synchronous condensers, or other substation upgrades and helping generators on the system run more efficiently as they are relied on less for such services.

Transmission Services

Although storage and NWAAs can provide services on both the transmission system and distribution system, there are some key differences between the applications. The high-voltage transmission system is FERC jurisdictional, so using storage for transmission deferral or avoidance will require a resource to be selected in a local or possibly regional transmission planning process and be subject to FERC approval and associated transmission rates. At the transmission level, there are both regional transmission planning processes, conducted by public utility transmission providers such as PJM, as well as local transmission planning processes that are conducted by the transmission owners.

The regional processes are geared toward identifying transmission or non-transmission alternative projects that provide benefits to the region and having their costs allocated commensurately. FERC Order 1000 also aimed to create more competition in this space by removing barriers to the participation of non-incumbent transmission providers in regional planning processes and requiring that projects be chosen on a non-discriminatory basis to provide the most efficient and cost-effective outcomes for the region. While there are some barriers to effectively selecting energy storage as transmission or non-transmission alternatives, the framework exists for these types of projects to be proposed and selected to serve regional transmission needs.

At the local level, transmission owners such as PPL and PECO identify the necessary transmission investment for their system, include them in their local transmission planning processes, and ultimately file those plans with FERC for approval. While it is possible for energy storage to be proposed in these local plans as well, there are no requirements for competition from non-incumbents, no requirements to consider non-transmission alternatives, and limited consideration of alternative technologies like energy storage. Thus, while some utilities are considering energy storage and distributed energy resources as alternatives to expensive transmission investment, such as Con Edison's Brooklyn-Queens Demand Management program in New York, regulatory changes at the federal and state level may be necessary to promote the use of energy storage as a transmission asset.

Additionally, transmission costs in PJM are allocated based on Network Integration Transmission Service, which is the mechanism by which transmission owners recover their annual transmission costs, and Transmission Enhancement Charges, which are how the cost for regional transmission projects are recovered. These costs are generally assessed to PJM network customers based on their load coincident with the annual peak load of the transmission zone that they are located within. Because these charges are assessed based on coincident peak, it is possible for network customers to reduce their transmission charges by dispatching ESRs during their coincident peak, thereby reducing their need for transmission service.

Distribution Services

NWA projects allow utilities to defer or avoid conventional infrastructure investments by procuring DERs such as energy storage that lower costs and emissions while maintaining or improving system reliability. EDCs' DR programs that target particular circuits or distribution feeders are another effective means of using energy storage to avoid infrastructure investments. While these types of resources avoid investments in infrastructure, they also reduce peak electricity demand for distribution utilities. Such benefits should be factored into their evaluation. However, while ESRs can in theory be a more cost-effective alternative to major distribution infrastructure investments, utilities may not pursue lower cost options due to the incentive to increase overall capital expenditures under cost-of-service regulation. In general, distribution utilities operating under a cost-of-service model have an inherent incentive to pursue additional capital investments, which these NWAs would be displacing. An incentive or requirement for utilities to invest in these alternatives may be needed, which may necessitate regulatory or legislative reforms.

2.2.3 Renewable Energy Integration

The variability of some renewable generation resources, like wind and solar, pose new challenges, while the advanced capabilities of inverter-based generation create new opportunities for

enhancing grid reliability. Some of these challenges and opportunities must be addressed by fast-acting energy storage. At the transmission level, it is expected that PJM's ample supply of regulation and operating reserves should be able to accommodate this variability for the foreseeable future. However, to the extent that solar resources are interconnected at the distribution level, different challenges might arise. Two of these are described below. Additionally, coupling storage with renewable resources can provide certain benefits which are also described below.

Reverse Power Flow

As renewables continue to grow in Pennsylvania, utilities can also use storage to manage the intermittent output of distributed solar and avoid reverse power flows at the substation. Certain locations on the T&D system were originally designed for power to flow only in one direction – that is, from central power plants to the high voltage transmission, and ultimately stepped down to lower voltage substations and feeders. With the advent of distributed generation, such as solar PV, there is now the possibility that power would flow in the “reverse” direction. While much of the underlying infrastructure can accommodate this reverse flow, there may be instances where this is not the case. For example, special protection schemes installed at substations transformers may not be equipped to handle reverse power flow conditions that could occur on high solar penetration feeders. As such the protection scheme would need to be upgraded or the conditions mitigated through other means, such as with energy storage). Generally, these conditions have been rare to date, even in higher penetration states as the amount of energy injected by solar PV typically does not exceed load at higher voltage levels. However, there is an increased likelihood this could occur at large solar installations located in more remote areas where there is little to no load. As solar and DERs continue to grow in Pennsylvania, a dynamic hosting capacity analysis can be conducted to identify locations on the distribution system where limits are being approached more quickly than others.

Voltage Regulation

The addition of distributed resources can also increase the frequency of voltage fluctuations. Thus, as distributed solar penetration increases, its variable output could increase the usage of distribution system equipment such as load tap changers, switching capacitor banks, and line voltage regulators. Recent studies of high penetrations of PV in California have indicated that these devices can support high penetrations of PV on many feeders without voltage violations. However, increased switching needs could cause these devices to wear more quickly and lead to higher distribution system maintenance costs. It is not anticipated that these costs will be very large; recent studies of a 100% solar PV scenario in California have indicated that the increase in annual utility operations and maintenance costs due these fluctuations would be on the order of 0.01%.⁴⁵ However, to the extent these costs do exist, they could be mitigated with storage. As inverter-based resources, battery storage is generally capable of providing reactive power and voltage regulation services. It is worth noting that the level of DER penetration in Pennsylvania is currently modest.

⁴⁵ Energy Institute at Haas (2015), “Economic Effects of Distributed PV Generation on California's Distribution System.”

Hybrid Resources

In addition to these challenges, the anticipated deployment of solar creates an opportunity for investments in paired, “hybrid” resources. This can be advantageous for a few reasons. First, ESRs that are directly coupled and charged by renewable energy can take advantage of the federal investment tax credit (with certain limitations). Second, there may be cost advantages to collocating these resources due to shared power conversion systems. Finally, for paired resources that are DC-coupled, energy that would otherwise be “clipped” due to inverter limits can be stored for later use, thus increasing the facility’s output by a small amount.

2.2.4 Transportation Electrification and Electric Vehicle Integration

In addition to those services described above, storage may have other potential benefits for distribution utilities. For example, with the advent of EVs, there may be substantially increased loads in locations with a high penetration of EV chargers. To the extent this increases peak demand on the distribution system, it could necessitate certain equipment upgrades. Energy storage could be added near high-penetration EV charger locations to help defer the need for these additional upgrades. There are now several utilities across the U.S. that have begun to implement transportation electrification plans, which can provide a variety of lessons learned. For example, LADWP’s challenges in electrifying its public transportation sector may be worth reviewing in greater detail.

Trends in Pennsylvania EDCs’ reliability are discussed further in Chapter 3: Energy Storage in Pennsylvania Today.

2.3 Customer Services

BTM storage owners can realize significant energy management benefits when they install energy storage either by itself or paired with generation assets. In BTM contexts, energy storage can lower customer bills by enabling customers to manage their demand charges and reduce peak energy usage. It can also enhance community resilience when deployed in microgrid applications or as a resource that can “island” during power outages.

2.3.1 Time-of-Use Bill Management

As the total demand on the system increases relative to supply, the price of the wholesale energy that utilities must buy to serve their customers also increases. This creates an incentive for utilities to reduce their total consumption during peak demand. Time-of-use (TOU) tariffs are retail billing plans that allow customers to manage their bills by offering different rates based on the time of day, day of the week, and/or season of the year, with higher prices for customers corresponding to when the EDC’s costs of serving its load are highest. By offering a rate structure that is reflective of the utility’s costs, they encourage efficiency amongst their customers during periods of peak consumption.

Similar to arbitraging wholesale energy prices, customers on TOU tariffs can deploy energy storage to charge and store energy during off-peak periods when the price of electricity is low and discharge it when the price of electricity is high, thus reducing grid consumption during peak periods and reducing a customer’s electricity bill. Customers would need to consider the difference between peak and off-peak prices, as well as the efficiency of the storage system and its expected useful life

to determine whether shifting their consumption from peak to off-peak periods with energy storage would be economic.

Storage could also be paired with on-site generation such as rooftop PV to increase solar self-consumption. Utility net metering rates in Pennsylvania do not currently incentivize such behavior, but these combined systems are eligible for the solar ITC. It would be prudent for Pennsylvania policy makers to continue to ensure that retail rates, including any TOU or net metering components are representative of the value that can be provided by ESRs to the grid.

Storage can also be paired with combined heat and power (CHP) systems and used to increase their efficiency by reducing the need to vary the energy output of the CHP system to match the real-time changes in demand. By smoothing the peaks, a smaller CHP system can be operated more efficiently, reducing costs and emissions. Adding storage to onsite generation can also make the facility more resilient, reducing the possibility of generators shutting down during grid outages, and providing back-up power if the generator is not available.

Not only do commercial and industrial (C&I) use cases provide benefits to the customer, but they can also reduce production costs for the system, because they reduce peak requirements in terms of both the amount of energy that has to be generated and the T&D infrastructure needed to transport it. Reducing system peaks can also decrease ramping needs and system variability which can reduce ancillary service requirements.

2.3.2 Demand Charge Reduction

Demand charges are typically based on the maximum instantaneous demand of a customer at any given point during a billing cycle. Retail demand charges are generally calculated by taking the highest level of usage at every 15-minute interval during a billing period. Some demand-based tariffs limit demand charges to the maximum demand during peak-use periods. If managed improperly, demand charges can significantly drive up customer bills. Energy storage can help mitigate these charges by discharging electricity during periods of high customer demand and storing electricity during periods of low demand.

2.3.3 Demand Response Programs

DR programs pay electric customers to reduce their consumption, generally during peak times when energy consumption and wholesale prices are high, and the grid is under significant stress. Because there is a need to balance supply and demand on the grid, decreasing consumption can be just as, if not more valuable than increasing generation because it helps bring the system back to equilibrium without having to start up additional peak generation facilities which often run on oil or gas. Providing incentives to participate in DR programs therefore provides economic and environmental benefits for all stakeholders.

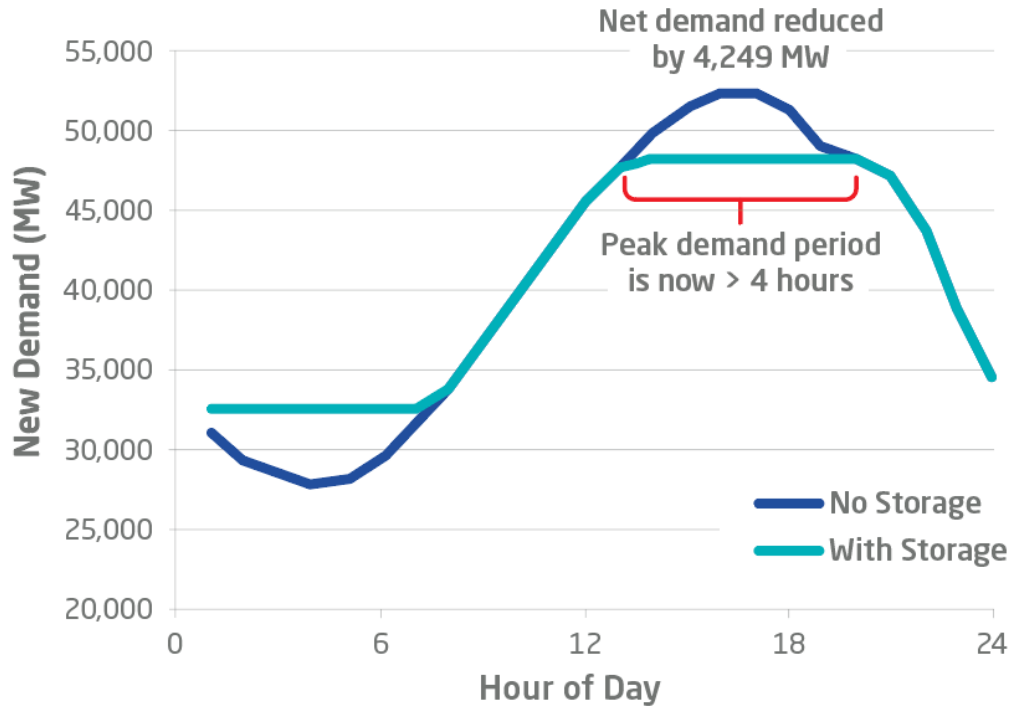


Figure 16. Impact of 4-hour storage dispatch on net load on the peak demand day in 2011⁴⁶

DR is generally measured as the difference between metered consumption during a DR event and a customer’s baseline consumption during comparable hours when they were not called on to reduce consumption. The customer is then compensated based on the reduction in consumption below their baseline. While real-time reduction in electricity consumption is one way to participate in DR programs, demand reductions can also be effectuated by behind-the-meter energy storage which shifts a customer’s consumption to off-peak hours (i.e. the customer charges the ESR during off-peak hours, and then discharges it to serve its co-located load during peak hours, reducing that customers metered load).

Opportunities for retail customers to partially defray the costs of storage systems are also emerging as PJM considers ways to better integrate these resources into their markets. There are already aggregations of grid-integrated water heaters and VGI systems participating in the PJM markets, and they are also considering new models for DER aggregations. As market opportunities emerge for customer-sited assets, these revenue streams can help reduce the cost of ownership of these systems, making them attractive to customers that did not assign sufficiently high value on back-up power or solar self-consumption to invest in them. Additionally, it is possible for utilities to create customer programs to dispatch BTM storage resources to reduce their peak requirements, as has already been done in Green Mountain Power in Vermont⁴⁷ and Liberty Utilities in New Hampshire.⁴⁸

⁴⁶ Denholm, Margolis, (2018), “The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics.”

⁴⁷ Green Mountain Power, “Tesla Powerwall.”

⁴⁸ Liberty Utilities (2019), Liberty Utilities Home Battery Storage Pilot Approved.”

2.3.4 On-site Power Consumption

To save money on their utility bills and generate clean, local electricity, an increasing number of retail customers are electing to install their own solar PV generation. In addition to the federal ITC, Pennsylvania customers may also be eligible for net metering tariffs, solar purchase programs, and solar property tax exemptions that reduce the cost of installing solar generation. Pairing BTM storage such as lithium-ion batteries with PV generation can allow a customer to consume more of the energy that their PV system is generating by shifting that generation to the times when the customer needs it, possibly offsetting higher TOU rates.

By pairing solar with storage systems, the entire hybrid system becomes eligible for the federal ITC, but the customer also becomes less reliant on the utility for their energy. In some cases, customers can rely upon this hybrid system for backup power, provided that technical restrictions do not preclude the system from operating when there is an outage. However, even when the grid is functioning normally, there can be benefits to greater self-consumption. Depending on how utility net metering and tariffs are structured, it may be more economical for customers to consume the PV energy they are generating when they need it, rather than send any of the electricity back to the grid.

2.3.5 Wholesale Market Participation

Customer-sited ESRs are also able to participate in the PJM markets, either on a standalone basis or aggregated with other resources to meet the minimum size requirements. Currently, those resources are required to participate as DR and make their largest contribution in the regulation market. Batteries provided 65% of DR participation in the regulation market in 2018, and grid-integrated electrical water heaters contributed the remaining 35%. Although their participation has been limited thus far, these ESRs that are registered as economic DR are also eligible to participate in PJM's capacity, energy, and reserve markets.

While PJM's DR constructs are currently the only means for customer-sited energy storage to reach the wholesale markets, PJM is developing a participation model that could improve the ability of BTM storage to combine its capabilities with other assets like rooftop solar and participate in PJM's capacity, energy and ancillary service markets. FERC is also considering broader market reforms for DER aggregations, but as currently framed, PJM's model for DER aggregations would allow a group of DER to be joined virtually into a single resource as long as all of the DER are within one utility's service territory and the aggregate resource is less than one megawatt. However, this would not be limited to BTM resources, as PJM defines a DER as any generation or electric ESR connected to the distribution system and/or behind a load meter. PJM is also working on a metering and accounting framework as part of implementing the requirements of Order 841 that will help distinguish between wholesale and retail actions for distributed ESRs.

2.3.6 Resilience and Backup Power

Outages can be caused by weather, animals, equipment failures, or tampering (e.g., vandalism or terrorism), among other factors. Energy storage can provide backup power to customers during outages, reducing loss of critical loads and/or avoiding financial losses to customers. Energy storage

can provide enhanced service and resilience⁴⁹ to certain types of customers by providing improved power quality and backup power. The function of providing backup power could be an especially important consideration for certain critical load facilities (e.g., hospitals, schools) under emergency conditions. Outages can negatively impact critical loads – such as hospitals, schools, and military bases – or cause financial losses to customers with a high need for reliability and resilience. Energy storage could assist with emergency preparedness by pairing solar-plus-storage on police, fire stations, and buildings that serve as emergency shelters. Additionally, energy storage could be beneficial for community centers and other buildings that serve as “resilience hubs” within neighborhoods serving vulnerable communities, such as those areas susceptible to storm damage from hurricanes or other extreme weather events. Because the value associated with backup power services can vary widely, back-up power energy storage systems are designed not only based on anticipated outages on a particular utility’s system but are also tailored such that the back-up power capability corresponds to individual customers’ reliability needs.

2.3.7 Microgrids

Backup power can also be provided within the context of a multi-customer microgrid. Microgrids are local energy grids with the option of operating autonomously by disconnecting from the main grid with on-site/local energy generation. Typically paired with distributed renewable or diesel generation, energy storage in a microgrid application can enable the capability to “island” and operate without grid connectivity for extended periods of time. Some cities have also recently explored programs for deploying storage or solar-plus-storage systems at critical load facilities like hospitals or schools. This can provide a clean source of backup power in case of a natural disaster, such as a hurricane, while also still offering some ability to offset customer load and reduce costs. An example is the City of San Francisco’s recent Solar Resilient program.⁵⁰

Pennsylvania’s August 2020 Clean Energy Program Plan emphasized the need for improved energy resilience, such as through the deployment of microgrids.⁵¹ A microgrid is a collection of generation assets and other distributed energy resources and loads within a defined boundary that can operate in grid connected mode or separate, as an “island”, from the broader electricity grid. Energy storage is a critical part of any microgrid that is reliant on non-dispatchable renewable generation as it gives the operator flexibly to manage its generation and load. Additionally, storage can provide benefits when the microgrid is connected to the grid. When the microgrid is connected to the “macrogrid” the storage asset is operated much like a utility would operate a traditional energy storage asset, by providing infrastructure support, reducing peak requirements, mitigating impacts of intermittency of renewable generation, and providing services back to the macrogrid. When the microgrid is islanded, the storage asset is relied on for its balancing services in a smaller local area, helping to

⁴⁹ Note: Resilience has many definitions, but commonly is understood to align generally with the definition in Presidential Policy Directive 21: “The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.”

⁵⁰ SF Environment (2017), “Solar and Energy Storage for Resiliency.”

⁵¹ Pennsylvania Department of Environmental Protection Energy Programs Office (2020), “Clean Energy Programs Plan.”

maintain frequency and voltage on the system, charging during times of excess generation, and discharging during times of generation deficits.

Resilience is an important key benefit of a microgrid. The costs of power outages can be high to C&I customers, and maintaining power supply to first responders, hospitals, universities, military installations and other critical infrastructure is crucial during natural disasters and emergencies. As the costs of microgrids are coming down and their capabilities are going up, Pennsylvania should not only ensure that there are adequate incentives in place to protect its critical infrastructure, but also to fully value the capabilities of microgrids when they are connected to the grid and able to provide services to the wholesale markets.

Pennsylvania is home to many U.S. Department of Defense (DoD) facilities and military installations, including Carlisle Barracks, the nation's second-oldest army installation.⁵² In order to enhance energy security and resilience, DoD's installation energy strategy includes expanding on-site energy, storage, and advanced technologies.⁵³ Subsequently, there are a number of DoD initiatives examining microgrids, including concepts such as microgrid-as-a-service or resilience-as-a-service products being offered by third-party implementers.⁵⁴ These implementers could potentially seek value by using microgrid assets to participate in wholesale markets as an additional revenue source. Local utilities may also be able to participate by installing make-ready infrastructure, such as controls and switchgears, to enable microgrid functionality.

2.4 Multiple-Use Applications

MUAs for ESRs generally describe business models where the resource provides more than one service, thereby increasing the overall value of the asset. These services can include any incremental benefits provided to the wholesale market, distribution grid, transmission system, and customers. While the versatility of ESRs and the software that controls them enable such applications, there are often regulatory obstacles that can limit their potential. As a result, energy storage cannot realize its full economic potential. Therefore, it is necessary for policymakers to develop rules and guidance related to MUAs that allow storage to deliver multiple services in multiple domains. These types of applications will not only enhance the economic viability and cost-effectiveness of storage but will also enhance reliability and reduce production costs for the power system.

⁵² MilitaryINSTALLATIONS (2020), "Pennsylvania Installations."

⁵³ Office of the Assistant Secretary of Defense for Sustainment (2020), "Installation Energy."

⁵⁴ Casey, Tina (2020), "3 Signs That US Defense Dept. Is Gung Ho For Renewable Energy + Microgrids," *CleanTechnica*.

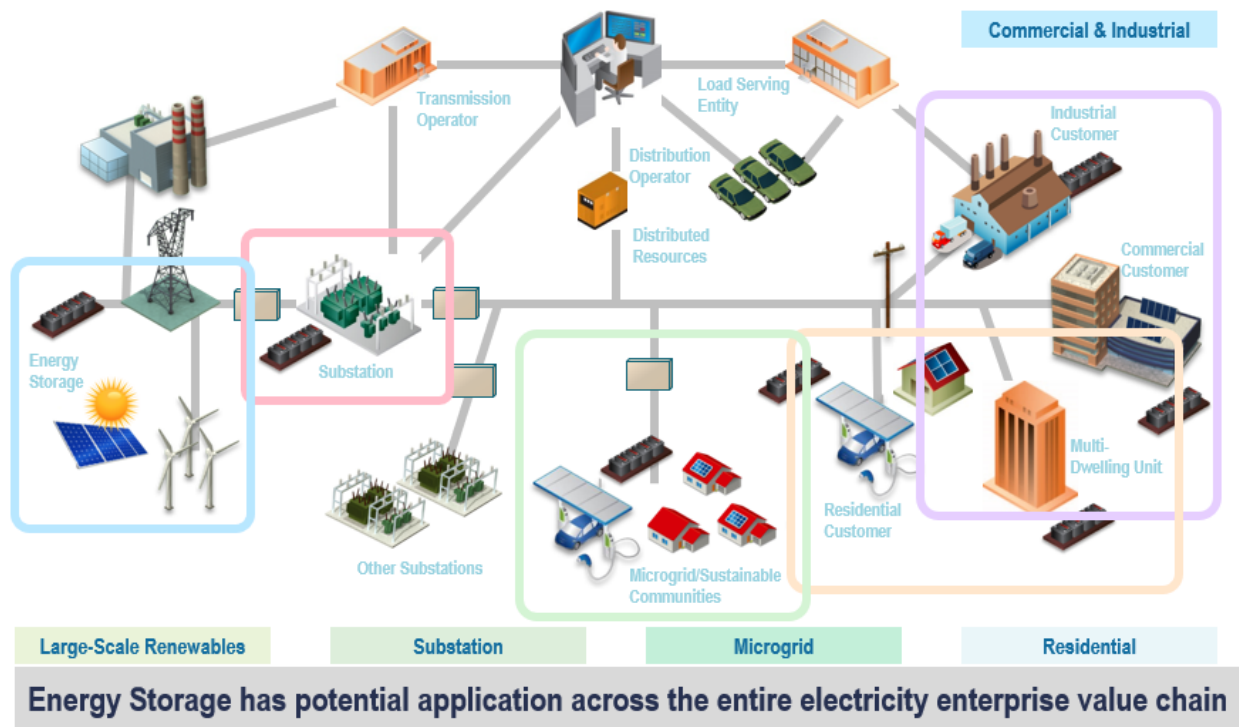


Figure 17. Applications of energy storage in the electric power system⁵⁵

In some instances, there may be value categories that cannot be simultaneously delivered due to conflicting requirements. For example, a storage device dispatched for distribution deferral might or might not exactly match bulk system capacity resource requirements. In other cases, benefits may not necessarily be additive and could lead to double-counting. For example, retail electricity rates should, in theory, be inclusive of wholesale energy costs, even if the retail rates have less temporal granularity. Additionally, today’s market mechanisms may not fully compensate ESRs for all potential value streams. To the extent that there are insufficient revenue streams to incent beneficial storage deployment, additional policies, programs, or incentives may be needed to account for the gap between the cost and full value of storage.

A perennial challenge for energy storage is the fact that it can provide a variety of value streams simultaneously, yet, in general, no single value stream is sufficient on its own to justify the cost. However, if these values are combined, or “stacked,” then the value is more likely to exceed the cost.

⁵⁵ Electric Power Research Institute (2015).

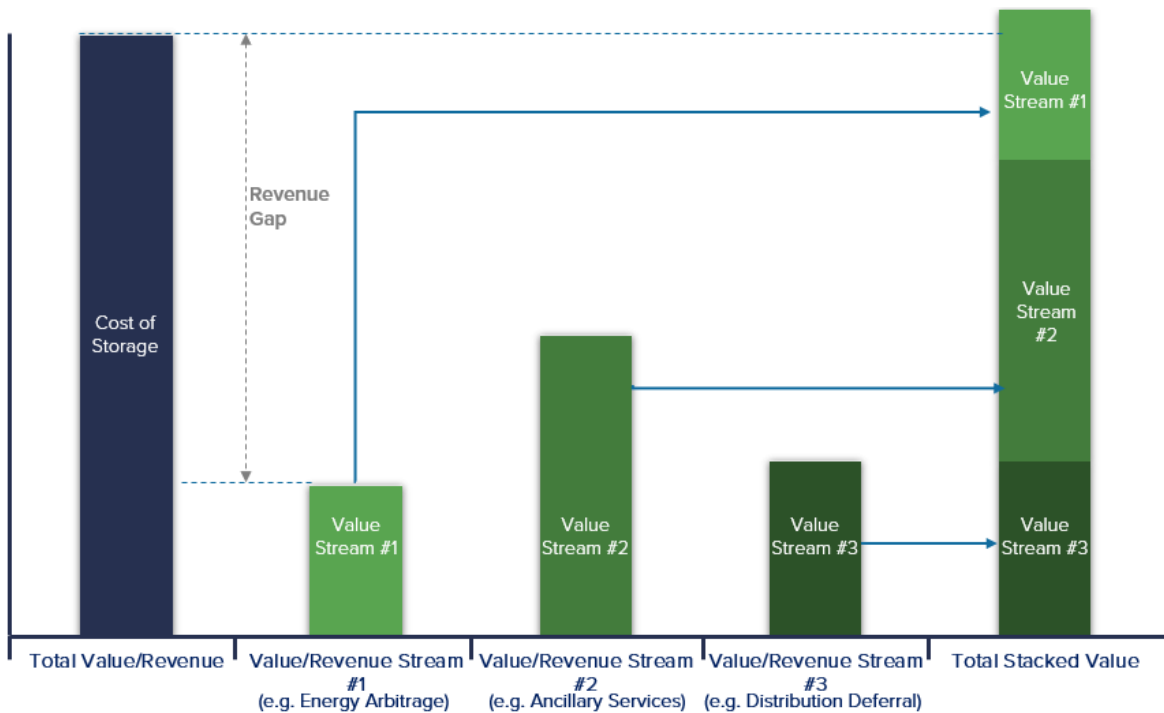


Figure 18. Illustration of cost and potential “value stacking” of energy storage⁵⁶

Because Pennsylvania has not yet established an MUA framework for storage, any dual participation limits that arise from such a framework would constrain the overall number of benefits that a single storage resource can deliver.

2.4.1 California’s Multiple-Use Application Framework

Currently, California is the only state that has performed a comprehensive analysis of MUAs for energy storage.

In the MUA Framework, the California Public Utilities Commission (CPUC) established five service domains for storage: customer, distribution, transmission, wholesale, and resource adequacy. The CPUC defined reliability and non-reliability services that storage could provide in each domain and established a set of rules to determine what resources are able to provide which services and what service must be prioritized over other services. For example, resources interconnected in the customer domain can provide services in in any domain, reliability services must always have priority, and ESRs must not contract for multiple reliability services if one of them could render the resource unable to perform the other. While several related implementation issues are now being discussed in a working group, this initial rule provides a useful framework for the realization of MUAs in California, as well as a starting point for policymakers in other states to start exploring the barriers to energy storage in their states.

⁵⁶ Lazard (2018), “Levelized Cost of Storage.”

<i>Domain</i>	Reliability Services	Non-Reliability Services
<i>Customer</i>	None	TOU bill management; demand charge management; increased self-consumption of on-site generation; back-up power; supporting customer participation in DR programs
<i>Distribution</i>	Distribution capacity deferral; reliability (back-tie) services; voltage support; resilience/microgrid/islanding	None
<i>Transmission</i>	Transmission deferral; inertia [†] ; primary frequency response [†] ; voltage support [†] ; black start	None
<i>Wholesale Market</i>	Frequency regulation; spinning reserves; non-spinning reserves; flexible ramping product	Energy
<i>Resource Adequacy</i>	Local capacity; flexible capacity; system capacity	None

[†]Voltage support, Inertia, and primary frequency response have traditionally been obtained as inherent characteristics of conventional generators, and are not today procured as distinct services. We include them here as placeholders for services that could be defined and procured in the future by the CAISO.

Figure 19. Reliability services and non-reliability services under California’s MUA Framework⁵⁷

In conjunction with the MUA Framework, the CPUC adopted the following interim rules which may be further refined through the working group process:

- Resources interconnected in the customer domain may provide services in any domain.
- Resources interconnected in the distribution domain may provide services in all domains except the customer domain, with the possible exception of community ESRs.
- Resources interconnected in the transmission domain may provide services in all domains except the customer or distribution domains.
- Resources interconnected in any grid domain may provide resource adequacy, transmission, and wholesale market services.
- If one of the services provided by a storage resource is a reliability service, then that service must have priority.
- Priority means that a single storage resource must not enter into two or more reliability service obligation(s) such that the performance of one obligation renders the resource from being unable to perform the other obligation(s). New agreements for such obligations,

⁵⁷ California Public Utilities Commission (2018), “Decision 18-01-003: Order Instituting Rulemaking to consider policy and implementation refinements to the Energy Storage Procurement Framework and Design Program (D.13-10-040, D.14-10-045)” and related Action Plan of the California Energy Storage Roadmap.

including contracts and tariffs, must specify terms to ensure resource availability, which may include, but should not be limited to, financial penalties.

- If using different portions of capacity to perform services, storage providers must clearly demonstrate, when contracting for services, the total capacity of the resource, with a guarantee that a certain, distinct capacity be dedicated and available to the capacity-differentiated reliability services.
- For each service, the program rules, contract, or tariff relevant to the domain in which the service is provided, must specify enforcement of these rules, including any penalties for non-performance.
- In response to a utility request for offer, the storage provider is required to list any additional services it currently provides outside of the solicitation. In the event that a storage resource is enlisted to provide additional services at a later date, the storage provider is required to provide an updated list of all services provided by that resource to the entities that receive service from that resource. The intent of this Rule is to provide transparency in the energy storage market.
- For all services, the storage resource must comply with availability and performance requirements specified in its contract with the relevant authority.
- In paying for performance of services, compensation and credit may only be permitted for those services which are incremental or distinct. Services provided must be measurable, and the same service only counted and compensated once to avoid double compensation.

Chapter 3: Energy Storage in Pennsylvania Today

3.1 Overview of Pennsylvania’s Electricity Sector

3.1.1 Electricity Resource Mix

Pennsylvania has plentiful energy resources, with a long history of coal mining and nuclear power generation. The more recent innovations of hydraulic fracturing and horizontal drilling have enabled the state to tap into shale gas resources, particularly the Marcellus Shale field. As a result, Pennsylvania consistently ranks in the top three of the nation’s largest gas producers, coal producers, and electricity exporters.⁵⁸

In 2019, Pennsylvania’s electricity generation mix was comprised of 43% natural gas, 36% nuclear, 16% coal, 2% nonhydroelectric renewables, and 2% hydroelectric.⁵⁹ The state’s load growth is expected to remain relatively consistent over the next 10 years, with forecasted changes remaining within $\pm 1\%$ of current load.⁶⁰ Although load is forecasted to remain constant, the generation mix is expected to continue to shift. For example, solar generation has grown tenfold in the last decade, and natural gas-fired power plants surpassed nuclear power as the largest provider of in-state electricity for the first time in 2019.^{61,62}

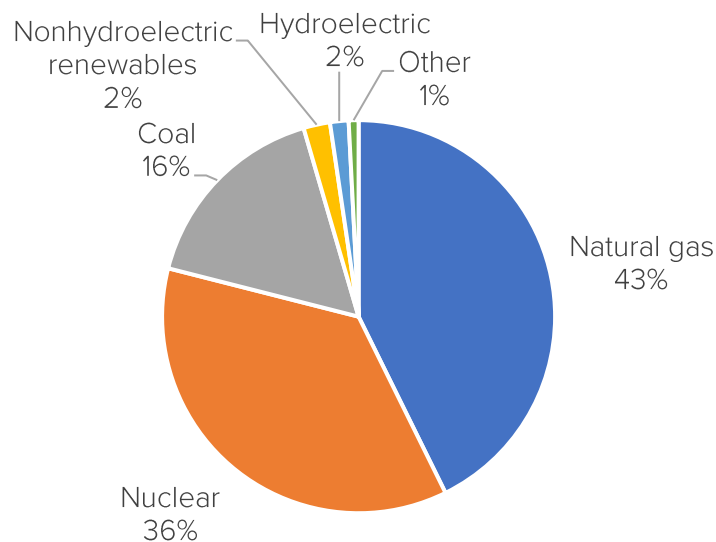


Figure 20. Pennsylvania’s electricity generation mix, 2019⁶³

⁵⁸ U.S. Energy Information Administration (2019), “Pennsylvania Electricity Profile.”

⁵⁹ U.S. Energy Information Administration (2020), “Electric Power Monthly.”

⁶⁰ PJM (2019), “2018 Pennsylvania State Infrastructure Report.”

⁶¹ U.S. Energy Information Administration (2019), “Pennsylvania Electricity Profile.”

⁶² *Ibid.*

⁶³ *Ibid.*

3.1.2 Operating & Planned Energy Storage Resources

The U.S. Department of Energy (DOE) Global Energy Storage Database lists 22 operational or announced energy storage projects in Pennsylvania. The technologies utilized include ice and chilled water thermal storage up to 6 MW, thermal storage up to 2 MW, lithium-ion batteries up to 18 MW, lead acid batteries up to 3 MW, lead carbon batteries up to 12.5 MW, and pumped hydro storage up to 1.07 GW.

Pumped hydropower, in particular, has a long history of contributing to Pennsylvania's energy system. For example, the 435 MW Seneca Pumped Storage Generating Station began commercial operation in 1970.⁶⁴ The 1,070 MW Muddy Run Pumped Storage Facility has provided power to the regional transmission system since 1966; at that time, it was the largest pumped storage hydroelectric power plant in the world.⁶⁵ Muddy Run contributes critical output to offset peak electricity demand on hot summer afternoons.⁶⁶ Pumped hydro storage plays an important role in meeting the requirements of Alternative Energy Portfolio Standards Act (AEPS), discussed below, making up 38.8% of the Tier II alternative energy credits retired in Pennsylvania for the 2019 reporting year.⁶⁷

Approximately 7,000 MW of energy storage capacity across 98 projects are currently in PJM's interconnection queue, although the requested network capacity is much less.⁶⁸ As of February 2021, the PJM transmission interconnection queue showed 64 solar-plus-storage projects across 26 Pennsylvania counties, totaling over 2,300 MW. This trend reflects a growing recognition of the value of solar-plus-storage hybrid projects. This would not include any potential projects interconnected directly to the distribution system of Pennsylvania's EDCs.

⁶⁴ U.S. Department of Energy (2020), "Global Energy Storage Database."

⁶⁵ Exelon, "Hydroelectric."

⁶⁶ U.S. Department of Energy (2020), "Global Energy Storage Database."

⁶⁷ Pennsylvania Public Utility Commission (2020), "Alternative Energy Portfolio Standards Act: Compliance for Reporting Year 2019."

⁶⁸ PJM (February 2021), "New Services Queue."

Pennsylvania County	Solar-plus-Storage in the PJM Interconnection Queue (MW)	Pennsylvania County	Solar-plus-Storage in the PJM Interconnection Queue (MW)
Adams	5	Lawrence	175
Allegheny	37.5	Luzerne	80
Armstrong	150	Mercer	212.1
Bedford	15	Monroe	18.17
Bradford	20	Potter	40
Clearfield	472.4	Schuylkill	50
Columbia	40	Snyder	60
Crawford	47.8	Somerset	160
Cumberland	20	Venango	100
Erie	170	Warren	35.53
Fayette	1.17	Washington	40
Franklin	150	Wayne	5
Huntingdon	180.4	York	20
		Total	2,305.07

Figure 21. Solar-plus-storage in the PJM interconnection queue⁶⁹

3.1.3 Retail Electricity Landscape

Pennsylvania permits retail choice in its electricity market, which allows consumers to choose their own electricity provider and generation options. This market arrangement is sometimes referred to as a “deregulated” market. The Pennsylvania PUC has jurisdiction over 11 EDCs serving most of the Commonwealth.⁷⁰ The state’s largest EDCs are PECO Energy Company, PPL Electric Utilities, and Duquesne Light Company, which serve approximately 1.6 million electric customers, 1.4 million customers, and 600,000 customers, respectively. The Commonwealth’s seven largest EDCs serve over 95% of electricity usage that is regulated by the Commission. Pennsylvania’s rural electric cooperatives, which serve approximately 230,000 households, and most municipal utilities are not regulated by the Commission.

Pennsylvania’s utilities are each individually responsible for procuring adequate generation resources to serve customer load for those who choose to remain on default service with their utility instead of shopping for a competitive electricity supplier. Utilities recover the cost of procuring and delivering electricity through retail electricity rates, which – for regulated EDCs – are designed and adjusted through rate design proceedings at the Commission.

While all retail electricity rates are designed to recover the costs associated with procuring and delivering power, some may enable the use of energy storage more than others. For example, time-varying rates offer higher prices during peak times and lower prices during off-peak times. Demand

⁶⁹ PJM (February 2021), “New Services Queue.”

⁷⁰ Note: EDCs are distinct from electric generation suppliers (EGSs).

charges, which are assessed for C&I customers, may also provide revenue opportunities for customer-sited energy storage.

Transmission owners that serve load in Pennsylvania (e.g. PPL, PECO) are also members of the PJM Interconnection.

3.2 Energy Policies and Programs in Pennsylvania

Although renewable energy and storage account for a small share of Pennsylvania's energy resources, their usage has grown as they become more cost-effective and as policy supports more clean generation. In 2004, the governor signed the AEPS, which requires EDCs to supply at least 18% of generation from alternative energy resources by 2021. Of this 18% requirement, 8% must come from Tier I renewable resources, which include solar PV, solar thermal, wind, low-impact hydro, geothermal, biomass, biologically derived methane gas, coal mine methane, and fuel cell resources. The additional 10% must be derived from Tier II resources, which include waste coal, municipal solid waste, and large-scale hydropower, alongside demand-side management and DER. As of the most recent compliance report, Pennsylvania appears on track to achieve its AEPS targets.⁷¹

Act 129 of 2008 established the Energy Efficiency and Conservation Program, requiring EDCs with over 100,000 customers to reduce energy consumption and demand levels in their service territories. Every five years, the PUC must evaluate the costs and benefits of the program, the potential for further peak demand reductions, and adopt additional incremental reductions if the benefits outweigh the costs. In its most recent study, the PUC examined BTM battery storage as one of the DR strategies and determined it to not be the most cost-effective strategy.⁷² However, in June 2020, the PUC ordered new consumption and demand reduction targets for the fourth phase of the program, which runs from 2021 to 2026. The five-year consumption reduction targets range from 2.4-3.5% of 2009-2010 retail load for the various EDCs, while the peak demand reduction targets range from 2.2-3.8% of 2007-2008 system coincident peak demand. Utilities across the state may deploy additional storage to meet this directive.

"Pennsylvania's Solar Future" Plan, published in 2018 by the DEP, identified 15 strategies to achieve a 10% increase in solar generation by 2030.⁷³ Several strategies, such as investigating opportunities for grid modernization, have been implemented or are currently in progress.⁷⁴ The Solar Future Plan outlines strategies that would meaningfully support the deployment of not only solar energy, but also energy storage. For example, cross-cutting strategies related to carbon pricing, state tax incentives, support for developers looking to leverage federal incentives on the tax equity market, siting and land use, and guidelines for use of long-term contracts would all promote energy storage growth in the state. The Plan identifies barriers related to community solar, virtual net metering, alternative financing, and interconnection. By addressing these issues, Pennsylvania could

⁷¹ *Ibid.*

⁷² Pennsylvania Public Utility Commission (2020), "Energy Efficiency and Conservation Program."

⁷³ Pennsylvania Department of Environmental Protection (2018), "Pennsylvania's Solar Future" Plan.

⁷⁴ See, for example, Pennsylvania Public Utility Commission Docket No. P-2019-3010128 "Petition of PPL Electric Utilities Corporation for Approval of Tariff Modifications and Waivers Necessary to Implement its Distributed Energy Resources Management Plan."

meaningfully facilitate growth in both grid-scale and distributed solar deployment, which can be integrated using energy storage.

The table below, excerpted from the Solar Future Plan, illustrates two potential scenarios for achieving the 10% solar generation goal. In either case, energy storage could be coupled with solar deployment to further leverage the value of these investments to customers and to the grid.

	Reference	Solar A	Solar B
Target for in-state solar	0.5% by 2020	10% by 2030	10% by 2030
Total solar capacity in 2030	1.2 GW	11 GW	11 GW
Distributed capacity in 2030	0.6 GW	3.9 GW (35% of total) 50% residential 50% commercial	1.1 GW (10% of total) 50% residential 50% commercial
Grid scale capacity (>3MW) in 2030	0.6 GW	7.1 GW (65% of total)	9.9 GW (90% of total)

Figure 22. Solar scenarios in Pennsylvania’s Solar Future Plan⁷⁵

For example, if half of the solar deployments envisioned were coupled with storage at 50% of the nameplate capacity with two- to four-hour duration of storage, it would equate to approximately 2,750 MW/8,250 MWh of energy storage deployment. This would be comparable to recent storage deployment targets set in nearby states such as New York and Virginia, which have deployment targets of 3,000 MW by 2030 and 3,100 MW by 2035, respectively.

3.2.1 Recent Storage Policy Developments

Pennsylvania’s August 2020 Clean Energy Program Plan recognized that energy storage and batteries will be a key component to achieving clean energy policy goals through enabling intermittent renewable resources. Some energy systems technology innovations have already accelerated, with new clean energy products and services being made available such as grid-enabled building technologies or energy storage. Each new technology and service has the potential to change the focus areas of the EPO’s program areas by altering program effectiveness or uptake. Subsequently, the Plan recommended undertaking an “Energy Storage and Batteries

⁷⁵ Pennsylvania Department of Environmental Protection (2018), “Pennsylvania’s Solar Future” Plan.

Plan” to develop and market an analysis of the needs and capabilities of Pennsylvania to fulfill the future battery storage marketplace of both the state and the region.⁷⁶

Pennsylvania EDCs have recently been facing reliability challenges. As seen in Figure 17, five of Pennsylvania’s seven large EDCs demonstrated a decline in reliability service between 2015 and 2019. PECO, PPL, Met-Ed, Penelec, and Penn Power did not achieve standard metrics for CAIDI, SAIDI, and/or SAIFI in at least one quarter of 2019.⁷⁷ To contrast, all seven large EDCs achieved standard scores for all metrics in every quarter of 2015.

2019 EDC Performance Scorecard											
Metrics achieved GREEN		Benchmark Metrics not achieved YELLOW					Standard Metrics not achieved RED				
		Rolling 12-Month									
		Benchmark Score					Standard Score				
EDCs	¹ Metrics	² BM	Q1	Q2	Q3	Q4	³ STD	Q1	Q2	Q3	Q4
Large EDCs											
Duquesne Light	CAIDI	108	106	109	100	106	130	106	109	100	106
	SAIDI	126	92	107	98	106	182	92	107	98	106
	SAIFI	1.17	0.87	0.99	0.98	1.01	1.40	0.87	0.99	0.98	1.01
PECO	CAIDI	112	112	138	149	189	134	112	138	149	189
	SAIDI	138	117	145	156	205	198	117	145	156	205
	SAIFI	1.23	1.05	1.05	1.05	1.08	1.48	1.05	1.05	1.05	1.08
PPL	CAIDI	145	177	152	155	176	174	177	152	155	176
	SAIDI	142	161	131	123	150	205	161	131	123	150
	SAIFI	0.98	0.91	0.86	0.79	0.85	1.18	0.91	0.86	0.79	0.85
Met-Ed (FirstEnergy)	CAIDI	117	145	150	151	164	140	145	150	151	164
	SAIDI	135	200	230	211	253	194	200	230	211	253
	SAIFI	1.15	1.37	1.54	1.40	1.54	1.38	1.37	1.54	1.40	1.54
Penelec (FirstEnergy)	CAIDI	117	115	122	136	147	141	115	122	136	147
	SAIDI	148	209	233	241	252	213	209	233	241	252
	SAIFI	1.26	1.82	1.91	1.77	1.72	1.52	1.82	1.91	1.77	1.72
Penn Power (FirstEnergy)	CAIDI	101	126	138	131	129	121	126	138	131	129
	SAIDI	113	143	179	163	178	162	143	179	163	178
	SAIFI	1.12	1.13	1.30	1.25	1.38	1.34	1.13	1.30	1.25	1.38
West Penn (FirstEnergy)	CAIDI	170	169	162	155	165	204	169	162	155	165
	SAIDI	179	209	195	169	196	257	209	195	169	196
	SAIFI	1.05	1.24	1.20	1.09	1.19	1.26	1.24	1.20	1.09	1.19

Figure 23. 2019 reliability performance scorecard for large EDCs in Pennsylvania ⁷⁸

⁷⁶ Pennsylvania Department of Environmental Protection Energy Programs Office (2020), “Clean Energy Programs Plan.”

⁷⁷ Note: CAIDI (Customer Average Interruption Duration Index) measures average power restoration time in minutes for every customer who lost power during the year. SAIDI (System Average Interruption Duration Index) measures average outage duration time in minutes for every customer served during the year. SAIFI (System Average Interruption Frequency Index) measures average frequency of power interruptions for every customer served during the year.

⁷⁸ Pennsylvania Public Utility Commission (2020), “Electric Service Reliability in Pennsylvania.”

Energy storage could help address this stark decline in reliability. EDCs are just beginning to deploy storage for this purpose; for example, in 2019, PPL installed its first battery storage system as a redundant power source designed to keep customers in-service until repairs can be completed. The system was used twice in 2020 to power customers while restoration was in process.⁷⁹

To address this issue, in November 2020, the Pennsylvania PUC initiated a proceeding to examine how to enhance reliability and resilience on the electric distribution system, including using new resources such as energy storage for distribution assets for EDCs as an option that will have a less significant rate impact than other, more conventional restoration or improvement investments.⁸⁰ The PUC is considering input on what thresholds, if any, would classify storage as a generation resource and thus be outside permitted distribution ratemaking and recovery. The Commission is also considering whether it would be prudent for regulated EDCs to include electric storage in their distribution resource planning and, if so, where and under what circumstances.⁸¹

Pennsylvania does not currently have an energy storage target. Legislation was introduced in the 2019-2020 regular legislative session that would direct the PUC to determine appropriate energy storage deployment targets for each EDC; however, this legislation was not enacted.⁸²

Energy storage is also receiving increasing attention at the federal levels. For example, in December 2020, the DOE released the Energy Storage Grand Challenge Roadmap, the Department's first comprehensive energy storage strategy with a goal to develop and domestically manufacture energy storage technologies that can meet all U.S. market demands by 2030.⁸³ That same month, Congress passed the Energy Act of 2020 as part of a coronavirus relief and government funding package. The first major clean energy update to U.S. energy policy in over a decade, the Act addresses multiple energy storage topics, including microgrids, R&D, technical assistance, and recycling.⁸⁴

3.2.2 Additional State Policies and Programs

There are several opportunities for energy storage to be supported by existing programs and policies in Pennsylvania, such as those administered by the EPO and the Department of Community and Economic Development. For example:

- The *Solar Energy Program* provides grant and loan funds that may be used to pay for energy storage costs directly related to the storage of electricity produced by a solar energy system.⁸⁵

⁷⁹ *Ibid.*

⁸⁰ Pennsylvania PUC (2020), "Utilization of Storage Resources as Electric Distribution Assets," Docket M-2020-3022877.

⁸¹ Andrejasich, Kelly (2020), "Pa. commission to examine role of storage in boosting distribution reliability," *S&P Global Market Intelligence*.

⁸² Senate Bill 600 P.N. 655, House Bill 2778 P.N. 4243, Senate Bill 630 P.N. 800.

⁸³ U.S. Department of Energy (2020), "Energy Storage Grand Challenge Roadmap."

⁸⁴ U.S. Senate (2020), "Energy Act of 2020: Section-by-section."

⁸⁵ Pennsylvania Department of Community and Economic Development (2017), "Solar Energy Program Guidelines."

- The *Green Energy Loan Fund*, a revolving loan fund administered by DEP, funds energy efficiency (EE) or renewable generation projects for buildings. If coupled with an EE project, energy storage might qualify for financing as part of an on-site renewable generation system.⁸⁶
- The *Pennsylvania Energy Development Authority* helps finance energy projects by awarding grants, providing loans and loan guarantees, and by issuing revenue bonds or notes. The Authority includes energy storage as an approved project type, although there have been only a small number of applications for storage projects to date.
- The *Energy Efficiency, Environment & Economics* initiative focuses on technical assistance, including contracted on-site EE assessments, and implementation of training programs.
- The *Alternative and Clean Energy Program* provides financial assistance in the form of grant and loan funds that will be used by eligible applicants for the utilization, development, and construction of alternative and clean energy projects in the state.⁸⁷
- In the state’s Clean Energy Program Plan, released in August 2020, many ideas that were not included in the final set of recommendations could theoretically apply to storage.⁸⁸ If these recommendations are implemented in the future, energy storage could be explicitly considered.

Additionally, storage has not been a focus of marketing and outreach for these programs but could be included in these efforts for existing and any future initiatives.

3.3 Energy Storage Equipment Manufacturers in Pennsylvania

Several storage companies are actively developing energy storage products in Pennsylvania. For example, some battery energy storage manufacturers with a prominent presence in Pennsylvania include:

- *East Penn Manufacturing Company*: a battery manufacturer with a 520-acre manufacturing facility in Lyon Station, PA, a nearby wire and cable accessories plant, and a battery recycling program that processes over 30,000 batteries a day and processes nearly 100% of each spent battery.⁸⁹ In 2010, DOE awarded East Penn a \$2 million grant for a demonstration project of grid-connected battery storage that could provide ancillary services, such as frequency regulation, to PJM.⁹⁰
- *EnerSys*: the largest industrial battery manufacturer in the world, with worldwide and American headquarters in Reading, PA.⁹¹

⁸⁶ Pennsylvania Department of Environmental Protection, “The Green Energy Loan Fund.”

⁸⁷ Pennsylvania Department of Community and Economic Development, “Alternative and Clean Energy Program.”

⁸⁸ Pennsylvania Department of Environmental Protection Energy Programs Office (2020), “Clean Energy Programs Plan.”

⁸⁹ East Penn, “Facilities.”

⁹⁰ U.S. Department of Energy (2015), “East Penn Manufacturing Delivers New Battery Technology for Electrical Grid Support.”

⁹¹ EnerSys, “Company Info.”

- *C&D Technologies*: a battery manufacturer headquartered in Blue Bell, PA.⁹²
- *Eos*: in partnership with Holtec International, a 1 GWh aqueous zinc battery production facility for industrial-scale energy storage in Pittsburgh, PA in January 2020.⁹³
- *Fortress Power*: a Pennsylvania-based lithium battery manufacturer.⁹⁴
- *Arkema*: a chemicals and battery manufacturer located in King of Prussia, PA. In February 2020, Arkema was awarded \$5 million from DOE to develop innovative lithium-ion energy storage manufacturing processes.⁹⁵

3.4 Energy Storage Research & Development

Several R&D initiatives are underway in Pennsylvania, including:

- The *Battery and Energy Storage Technology (BEST) Center at Penn State* has been home to world-class researchers facing the latest challenges in energy storage materials, cells, and systems since 2011.⁹⁶ The BEST Center utilizes several Penn State facilities including the battery manufacturing and testing labs. The BEST Center’s research includes new materials and cell development, cell, pack, and system modeling and design, and reduced order modeling, state of charge estimation, and smart battery management systems.
- The *Energy GRID Institute at University of Pittsburgh* leverages public and private partnerships to advance electric power utility scale research, including an improved understanding of battery storage life.⁹⁷
- In 2019, PPL partnered with the Electric Power Research Institute for research related to energy storage, distribution systems, integration of DERs and crisis communications.
- In May 2020, the U.S. Department of Energy awarded \$2.2 million spread over 11 grants to support research related to various energy technologies, including thermal energy storage, at small businesses throughout York, Lancaster, Allentown, Reading, Pittsburgh, Landisville, Pipersville, and State College.⁹⁸

3.5 Energy Storage Jobs in Pennsylvania

The 2020 Pennsylvania Clean Energy Employment Report reported that the clean storage⁹⁹ segment of the industry had 1,770 employees in 2019 and had grown by 9.2% between 2017 and 2019.¹⁰⁰ While the focus of this report is on stationary storage that can be discharged to the power grid, it is worth noting that EVs can function in a similar manner if configured to provide VGI

⁹² C&D Technologies, “Our Legacy.”

⁹³ Eos, “About.”

⁹⁴ Fortress Power, “Home.”

⁹⁵ U.S. Department of Energy, “DOE 301 Congressional Notification Table.”

⁹⁶ Battery and Energy Storage Technology Center, “Battery and Energy Storage Technology at Penn State.”

⁹⁷ University of Pittsburgh, “District Energy: The Grid of Microgrids.”

⁹⁸ Danahy, Anne (2020), “ Pa. businesses to get \$2.2M in Department of Energy research grants,” *StateImpact Pennsylvania*.

⁹⁹ Note: This includes pumped hydropower storage, battery storage, mechanical storage, thermal storage, biofuel storage (including ethanol and biodiesel), and nuclear fuel storage.

¹⁰⁰ Pennsylvania Department of Environmental Protection (2020), “2020 Pennsylvania Clean Energy Employment Report.”

capabilities. Job growth in the EV sector is significant. For example, the workforce around plug-in hybrid vehicles (which have an electric motor powered by rechargeable batteries or another energy storage device) grew by 26.6% between 2017 and 2019, creating 332 new jobs in Pennsylvania.

Chapter 4: Analysis of Energy Storage Potential in Pennsylvania

4.1 Overview & Objectives

To better understand barriers and identify opportunities for energy storage, Strategen analyzed the benefits and costs of storage under two scenarios.

This section attempts to quantify reasonable estimates for what the value of energy storage could be to Pennsylvania by comparing the potential benefits and costs of deploying storage under two different scenarios: a large-scale hybrid solar-plus-storage project, and a BTM storage system for a C&I customer.

For the analysis of a large-scale hybrid solar-plus-storage project, Strategen attempted to quantify the overall benefit that storage could provide to developers of solar PV projects in Pennsylvania and their potential off-takers. It is anticipated that a large amount of grid-scale solar PV projects will be completed in the state in the next few years. Some of these could potentially be coupled with energy storage as a means to provide additional value streams and system benefits. Over the long-term, storage will be crucial for integrating larger amounts of renewable energy onto the Pennsylvania grid by providing operational flexibility and firm capacity to maintain system reliability.

BTM energy storage systems are those that are deployed on the customer's side of the meter – “behind” the meter from the perspective of the utility. For this portion of the analysis, Strategen attempted to quantify the value that storage could provide to end-use customers. Today, this value is driven primarily by bill savings under prevailing retail rates, although it is anticipated that revenues could increasingly come from other sources, such as customer programs that target specific system benefits, direct access to the wholesale market (e.g. through aggregation), or incentive programs.

Strategen's detailed methodology and results can be found in Appendix E.

4.2 Analysis of Large-Scale Hybrid Solar-Plus-Storage

A growing trend in the grid-scale energy storage industry has been to couple battery storage with solar PV systems. The analysis in this report attempts to identify what remaining gaps there are in terms of deploying hybrid systems, rather than standalone solar PV and what additional support may be needed to encourage near-term solar-plus-storage development.

However, the benefits of storage may not always be aligned with the incentives of large off-takers who are simply seeking to procure low-cost renewable energy, which has historically been tracked through MWh-based renewable energy credits (RECs). System reliability characteristics are not necessarily supported by voluntary REC purchases or associated PPA contracts.

However, despite this high level of interest from developers these projects are by no means guaranteed and may still face barriers to be successfully developed with the storage component included. Building upon Pennsylvania's ambitious Solar Future Plan, which anticipates the addition of 11 GW of new solar PV capacity, Strategen recommends that the Commonwealth consider possible options for leveraging that planned solar deployment to simultaneously scale up energy storage deployment through targeted support for solar-plus-storage projects.

There are several advantages of pursuing hybrid solar-plus-storage projects including:

- The ability for the storage component to take advantage of the federal ITC solar (as long as the storage device meets certain operating criteria).
- The ability for collocated solar and storage systems to share power conversion equipment, thereby contributing to economies of scale.
- The ability for the storage system to absorb solar energy that would otherwise be curtailed (due to inverter sizing), thereby increasing the overall usable energy production from the solar system.
- The ability for the storage component to time shift the energy production of the solar output to more valuable on-peak hours.
- Enhanced contribution to the capacity value of the combined solar-plus-storage system (relative to standalone solar).
- The potential to provide additional ancillary services capabilities without pre-curtailling solar production.
- The ability to interconnect using a single resource ID which can streamline development and market participation activities.

There are many potential pathways that Pennsylvania could consider for encouraging solar-plus-storage. Strategen has highlighted three potential options for consideration:

1. Option 1: AEPS solar-plus-storage carve out
2. Option 2: Distribution tariff-based, step-wise procurement
3. Option 3: Time-matched renewable power program

Strategen performed further analysis on Option 3, which reflects an innovative approach that Pennsylvania could pioneer and would be aimed at fostering a robust market for solar-plus-storage through corporate and institutional PPAs.

4.2.1 Option 1: AEPS Solar-plus-Storage Carve Out

The goal of this approach would be to build upon the existing 2004 AEPS framework and the solar target within that framework. Under the AEPS, Pennsylvania's EDCs are required to supply 8% of their electricity from "Tier I" energy sources by 2021. Tier I resources are defined to include solar PV, solar thermal, wind, low-impact hydro, geothermal, biomass, biologically derived methane gas, coal-mine methane, and fuel cell resources. As an additional requirement within the Tier I obligation, 0.5% of electricity must come from solar PV systems, effectively creating a "carve out" for solar. Going forward, the state could choose to increase overall AEPS requirement and/or the solar carve out. However, for solar projects developed to meet AEPS requirements, the compliance has traditionally been based solely on the energy delivered in MWh, with no differentiation between time of energy delivery or whether storage was used to shape the solar output profile. Although storage could facilitate delivery of energy during "high value" peak periods, and perform other grid functions, there is no mechanism within AEPS (or any successor) to value these additional benefits or otherwise incentivize storage deployment. If the AEPS is expanded (or a successor adopted), a portion of the AEPS portfolio could specify a new carve out for solar-plus-storage resources that meet certain eligibility criteria. This could be in addition to (or in lieu of) any existing or expanded solar PV carve out. For example, if the solar PV requirement under AEPS were increased from 0.5% to 10% of total electricity supplied, a parallel solar-plus-storage requirement could be set equivalent to 2.5% of total electricity supplied (thus representing 25% of the solar carve-out). It is recommended that this be

accompanied with certain criteria for the storage operation (e.g. number of cycles, time of delivery, marginal power plant emissions, etc.) to ensure these systems are maximizing benefits to Pennsylvania electricity customers.

4.2.2 Option 2: Distribution Tariff-based, Step-wise Procurement

This option would build upon the experience of programs in other jurisdictions such as the Solar Massachusetts Renewable Target (SMART) program, which requires the local EDCs to establish a new tariff-based mechanism to compensate solar PV developments connected to the distribution system of 5 MW or less. It is a successor to the solar renewable energy credit (SREC) program that Massachusetts had employed in previous years. The SMART compensation mechanism is structured as a fixed payment stream for 10 or 20 years (depending on the type of system), that declines over time for new projects as additional MW “tranches” of solar PV capacity are added to the system. The chart below illustrates these components showing the underlying energy commodity value in blue and the SMART incentive payment in red.¹⁰¹ The incentive payment is funded through a retail rate surcharge collected from all EDC customers.

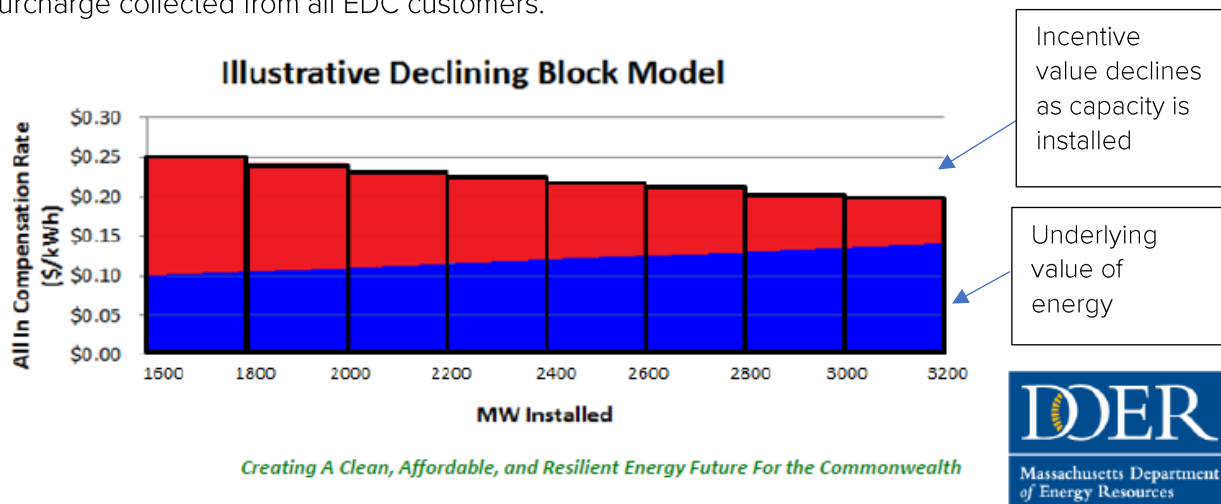


Figure 24. Illustrative declining block model¹⁰²

The starting price of the compensation rate was set through an initial competitive solicitation process. In addition, the base payment was supplemented with specific adders to achieve additional policy goals, such as brownfield development, and community shared solar. One of the adder mechanisms was targeted at encouraging solar with storage and was determined through a formula linked to the configuration of the storage system relative to the solar. The base storage adder value was set at \$0.045/kWh, and additional incentive values were applied for longer duration or higher capacity systems.¹⁰³ The table below illustrates the storage adder value for various configurations.

¹⁰¹ Massachusetts Department of Energy Resources (2017), “Solar Massachusetts Renewable Target Final Program Design.”

¹⁰² *Ibid.*

¹⁰³ Massachusetts Department of Energy Resources (2017), “Solar Massachusetts Renewable Target Program Summary.”

Storage kW as % of Solar	Storage Hours @ Rated Capacity								
	Minimum	2	2.5	3	3.5	4	4.5	5	5.5
25%	\$0.0247	\$0.0271	\$0.0291	\$0.0307	\$0.0321	\$0.0334	\$0.0345	\$0.0356	\$0.0365
30%	\$0.0321	\$0.0352	\$0.0377	\$0.0399	\$0.0418	\$0.0434	\$0.0449	\$0.0462	\$0.0474
35%	\$0.0382	\$0.0419	\$0.0450	\$0.0476	\$0.0498	\$0.0517	\$0.0535	\$0.0551	\$0.0565
40%	\$0.0428	\$0.0470	\$0.0504	\$0.0533	\$0.0558	\$0.0579	\$0.0599	\$0.0617	\$0.0633
45%	\$0.0460	\$0.0504	\$0.0541	\$0.0572	\$0.0599	\$0.0622	\$0.0643	\$0.0663	\$0.0680
50%	\$0.0481	\$0.0527	\$0.0565	\$0.0598	\$0.0626	\$0.0650	\$0.0673	\$0.0692	\$0.0711
55%	\$0.0494	\$0.0542	\$0.0581	\$0.0614	\$0.0643	\$0.0668	\$0.0691	\$0.0712	\$0.0730
60%	\$0.0502	\$0.0551	\$0.0591	\$0.0625	\$0.0654	\$0.0680	\$0.0703	\$0.0724	\$0.0743
65%	\$0.0507	\$0.0557	\$0.0597	\$0.0631	\$0.0661	\$0.0687	\$0.0710	\$0.0731	\$0.0750
70%	\$0.0511	\$0.0560	\$0.0601	\$0.0635	\$0.0665	\$0.0691	\$0.0715	\$0.0736	\$0.0755
75%	\$0.0513	\$0.0562	\$0.0603	\$0.0638	\$0.0667	\$0.0694	\$0.0717	\$0.0739	\$0.0758
80%	\$0.0514	\$0.0564	\$0.0605	\$0.0639	\$0.0669	\$0.0696	\$0.0719	\$0.0740	\$0.0760
85%	\$0.0515	\$0.0565	\$0.0606	\$0.0640	\$0.0670	\$0.0697	\$0.0720	\$0.0742	\$0.0761
90%	\$0.0515	\$0.0565	\$0.0606	\$0.0641	\$0.0671	\$0.0697	\$0.0721	\$0.0742	\$0.0762
95%	\$0.0515	\$0.0566	\$0.0607	\$0.0641	\$0.0671	\$0.0698	\$0.0721	\$0.0743	\$0.0762
100%	\$0.0516	\$0.0566	\$0.0607	\$0.0641	\$0.0671	\$0.0698	\$0.0722	\$0.0743	\$0.0763

Figure 25. Energy storage adder matrix

Pennsylvania could opt to develop a similar program, which would require the EDCs to develop tariffs for PUC approval both to spell out the terms of the solar-plus-storage compensation rate, as well as to collect revenues from EDC customers to fund the program.

4.2.3 Option 3: Time-Matched Renewable Power Program

Solar PPAs have become increasingly competitive as a means for large C&I electricity customers to meet their energy demands. For example, recent analysis has shown the typical solar PPA price in PJM is now approximately \$31/MWh. However, many renewable energy off-takers that have supported traditional solar PPAs may be less inclined to pay a premium for solar-plus-storage, without a clear value proposition. For example, off-takers with renewable energy purchase obligations (e.g. through corporate or institutional sustainability goals) often meet these requirements through the simple purchase of bundled or unbundled RECs and do not typically have any additional commitments to ensure that the renewable energy production associated with the RECs is time-matched with the off-taker’s actual end-use load. Meanwhile, the wholesale market value for storage (as a supplement to solar) that can be monetized is constrained; PJM market rules, such as the Minimum Offer Price Rule (MOPR) and the 10-hour duration storage rule, severely limit the ability of clean energy resources and ESRs to access capacity market revenues. As the demand for solar purchases grows, this could ultimately lead to a gap whereby the energy delivered to many solar energy off-takers is not time-matched with their load and there will be diminishing returns to the environmental benefit of solar additions and a substantial remaining need for fossil generation to meet the overall grid’s needs during non-solar hours.

As an illustration of this, the charts below show a depiction of the resources used on two recent days to meet the needs of the grid in California which has a substantially higher penetration of solar

energy resources than PJM, and may be useful for potential challenges PJM may face in the future.¹⁰⁴ While solar overlaps significantly with the peak summer demand hours in July, there is still a substantial period during the evening hours when demand is high, and the remaining load is met predominantly with fossil generation resources (i.e. thermal and imports). In order to achieve further emission reductions over time, it will be necessary to deploy clean energy resources that can meet demand during these evening hours and drive down the reliance on fossil resources during those hours as indicated by the arrow. Solar coupled with battery storage is well suited to perform this role and can help contribute to customer demand that the PJM grid reliability needs at the appropriate time, by “time-shifting” renewable energy delivery to the times when customer demand and fossil fuel energy production on the system are both high.

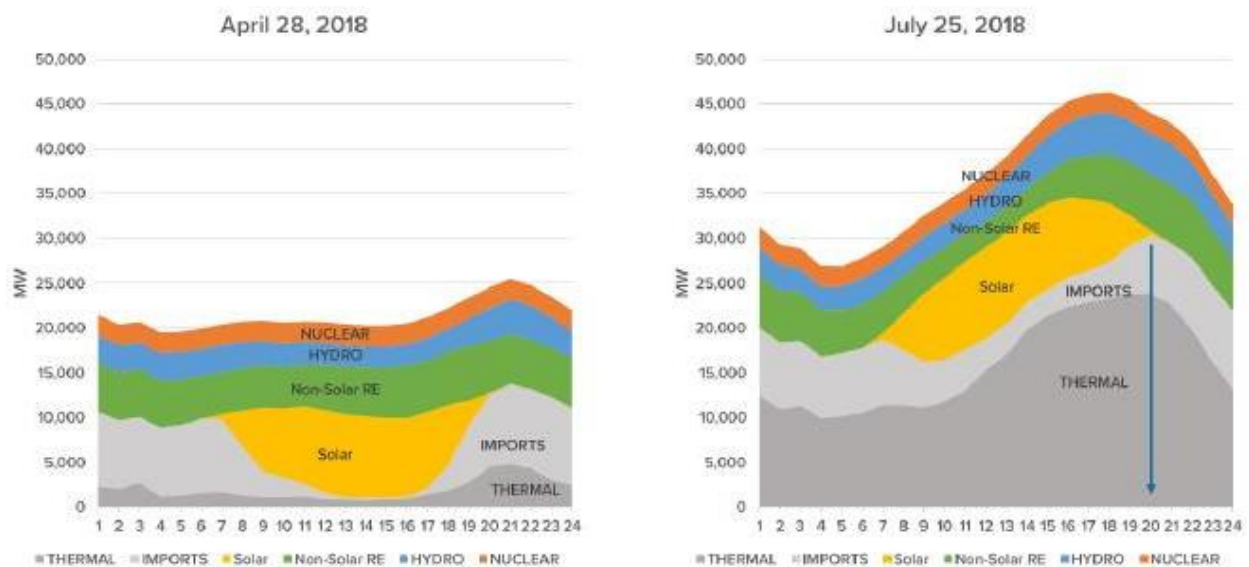


Figure 26. Two days in the life of CAISO

While not all renewable energy buyers are attuned to these grid reliability needs, and their contribution to them, there are some noteworthy exceptions. For example, Google has developed a commitment to transition to time-matched renewable energy, whereby their energy supply purchases must not only be 100% clean, but also coincide with their end-use demand. Google has encouraged RTOs like PJM to develop market products and platforms to facilitate this.¹⁰⁵ While it is possible that additional renewable energy buyers in Pennsylvania could follow Google’s footsteps in considering a time-matched renewable energy commitment, this is not guaranteed. Additionally, the timing and willingness of PJM to develop necessary market platforms is also uncertain. In light of this uncertainty, Pennsylvania could play an active role in encouraging early adoption of this innovative approach through the development of targeted policies and programs that support time-matched solar-plus-storage PPAs, in lieu of traditional REC-based PPAs.

¹⁰⁴ Clean Energy States Alliance (2018), “Energy Storage in the Clean Peak Standard.”

¹⁰⁵ Penrod, Emma (2020), “Google calls for more RTOs, designs 'intelligent platform' to meet 24/7 clean energy goal,” *Utility Dive*.

Low voluntary REC prices in PJM suggest that new solar-only PPAs are now very competitive with contracts for traditional forms of generation. Meanwhile, the wholesale capacity market limitations for storage described above, could prevent any solar-plus-storage systems from being able to access the full suite of market compensation that is offered to traditional forms of generation. As such, state-level policy support may be warranted as a means to help grow the market demand for solar-plus-storage resources that are more closely aligned with Pennsylvania customer demand profiles and the overall grid's needs. This could be done through the development of a "bridge incentive" program to help buy down the incremental cost of the storage component of a new solar-plus-storage systems developed in Pennsylvania for new PPA off-takers in the state. The goal of the bridge incentive would be to accelerate cost reductions in the local storage industry, help standardize the process for procuring solar-plus-storage resources and offset any financial challenges with the phase down of the federal ITC. Programmatic support can be used to attract initial market participants and incentivize early adopters, with the goal of transforming the market over time to the point where programmatic support is no longer needed and solar-plus-storage resource procurement is commonplace. Meanwhile, as battery costs continue to decline, the bridge incentive could step down in a similar fashion to the SMART program described above.

This mirrors the approach taken by other states like New York which through its Energy Storage Roadmap authorized a total \$350 million in bridge incentives to accelerate the energy storage market, including funding for solar-plus-storage projects within the NY-Sun initiative, plus another \$53 million in Regional Greenhouse Gas Initiative (RGGI) funds.¹⁰⁶

4.2.4 Analysis of Option 3

To better understand the potential for solar-plus-storage PPA development in Pennsylvania, this report includes a preliminary analysis of the costs and benefits of a hypothetical program under Option 3. This analysis focuses on estimating the premium associated with the addition of storage to a solar PV system in the state. We assume this incremental storage would be pursued as a means to help large C&I electricity customers move closer to a time-matched renewable energy goal. The figure below provides a simplified view for how a solar-plus-storage project could operate to achieve this objective for a typical day in July.

¹⁰⁶ NYSERDA, "Energy Storage."

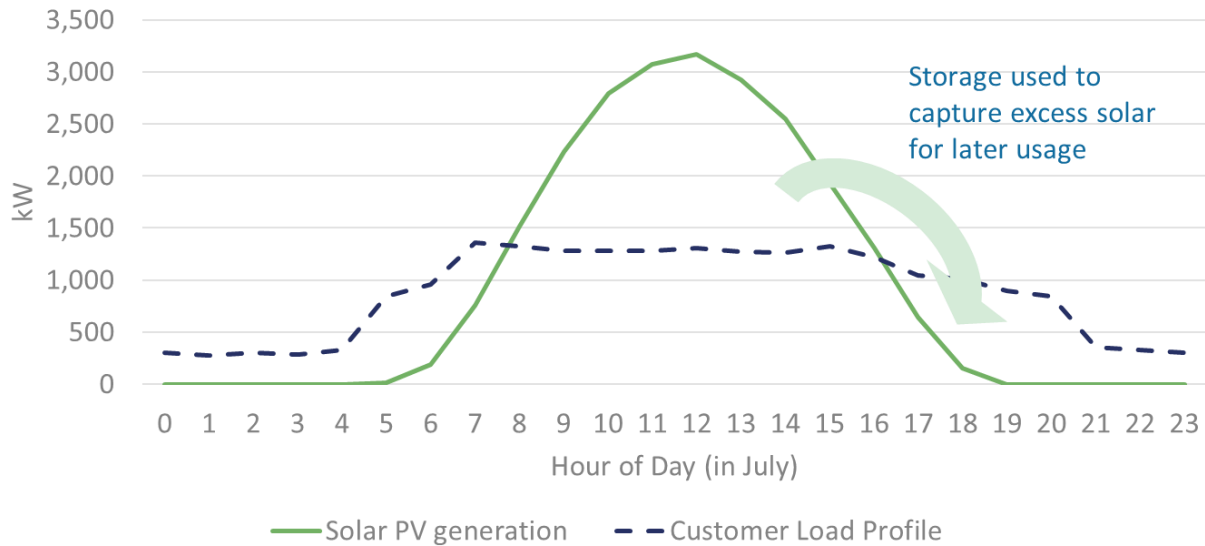


Figure 27. Solar-plus-storage impact on a daily load profile

We use this analysis to benchmark the level of programmatic support that may be required at different levels of deployment (i.e. how many MW of solar-plus-storage deployment could be supported at different levels of bridge incentive funding, including revenue from RGGI if such funding became available). Furthermore, we quantify the power system and environmental benefits that this could provide at these levels of deployment.

To assess the potential to cost-effectively develop a market for solar-plus-storage, this study’s analytical approach begins by addressing the following question: “What is the least-cost storage configuration that transforms a solar-only PPA into a hybrid solar-plus-storage PPA that can approximately time-match a specific customer’s demand?” In other words, if a power customer was seeking to purchase renewable energy (i.e. through a PPA) that approximately matches their load profile through the incremental addition of storage, what is the premium they might expect to pay for that storage?

In conducting this assessment, it is important to recognize that while the addition of storage comes at an incremental cost, it also yields potential benefits both to the purchasing customer, as well as the power system and society at large. More specifically, storage can produce the following incremental benefits from standalone solar:

- Reduce associated wholesale energy costs by optimizing the dispatch of energy produced from solar to better match the specific customer load profile. Solar energy that would be otherwise curtailed can be stored and used at a later time displacing energy from grid resources.
- Reduce wholesale capacity obligations (subject to the limitations of PJM wholesale capacity market participation rules).
- Reduced air emissions from grid fossil resources due to less frequent curtailment of solar energy production.

4.2.5 Key Findings

We found that this results in a 2.9 MW/2.3-hour duration storage system being added to the solar facility, which equates to an incremental cost of approximately \$33 per MWh output from the solar-plus-storage system (or \$61/MWh total).

This accounts for the incremental energy benefits that the storage provides by reducing on-peak energy purchases. However, there are also additional benefits the storage addition would realize due to their contributions to peak capacity. We presume that current rules from PJM would be in effect that require a 10-hour duration storage dispatch to qualify for capacity payments. The optimal storage configuration we identified can be dispatched over a 10-hour period, but in doing so its capacity value would need to be derated to 23% of its nameplate as a result. We also assumed a 44% capacity credit for the solar component, consistent with recent PJM analysis.^{107,108}

In addition to the direct grid benefits of energy and capacity, we also considered the potential societal environmental benefits of the solar PV and solar-plus-storage resources. These benefits are realized by incremental emissions reductions if the storage is used to enhance the total solar energy output in the configuration contemplated, thereby displacing fossil resources on the grid.¹⁰⁹ These emissions reductions were quantified using marginal emissions rate data from PJM as well as the same emissions damage values that were included in the Solar Future Plan (i.e., \$47/ton for CO₂).¹¹⁰

The addition of storage to a solar project yields significant energy system benefits. Additionally, the addition of storage has the potential to enhance the environmental benefits of the solar PV systems, depending upon the configuration. Figure 28 below illustrates these benefits for the hypothetical configuration examined in this analysis.

¹⁰⁷ PJM (2019), “Proposed Changes to PJM Manual 21: Calculation of Capacity Values for Wind and Solar Capacity Resources.”

¹⁰⁸ Note: This presumes that the solar-plus-storage resource is credited at its full capacity value, without necessarily taking into account certain market participation limitations under PJM’s RPM auction.

¹⁰⁹ Note: This assumes a solar-plus-storage system in which the solar PV component is substantially oversized relative to the inverter and would therefore lead to clipping or curtailment. This reflects the trend in recent years towards higher inverter loading ratios for solar. However, coupled storage systems may be able to reduce the amount of curtailed energy by storing it for later dispatch.

¹¹⁰ Pennsylvania Department of Environmental Protection (2018), “Pennsylvania’s Solar Future” Plan.

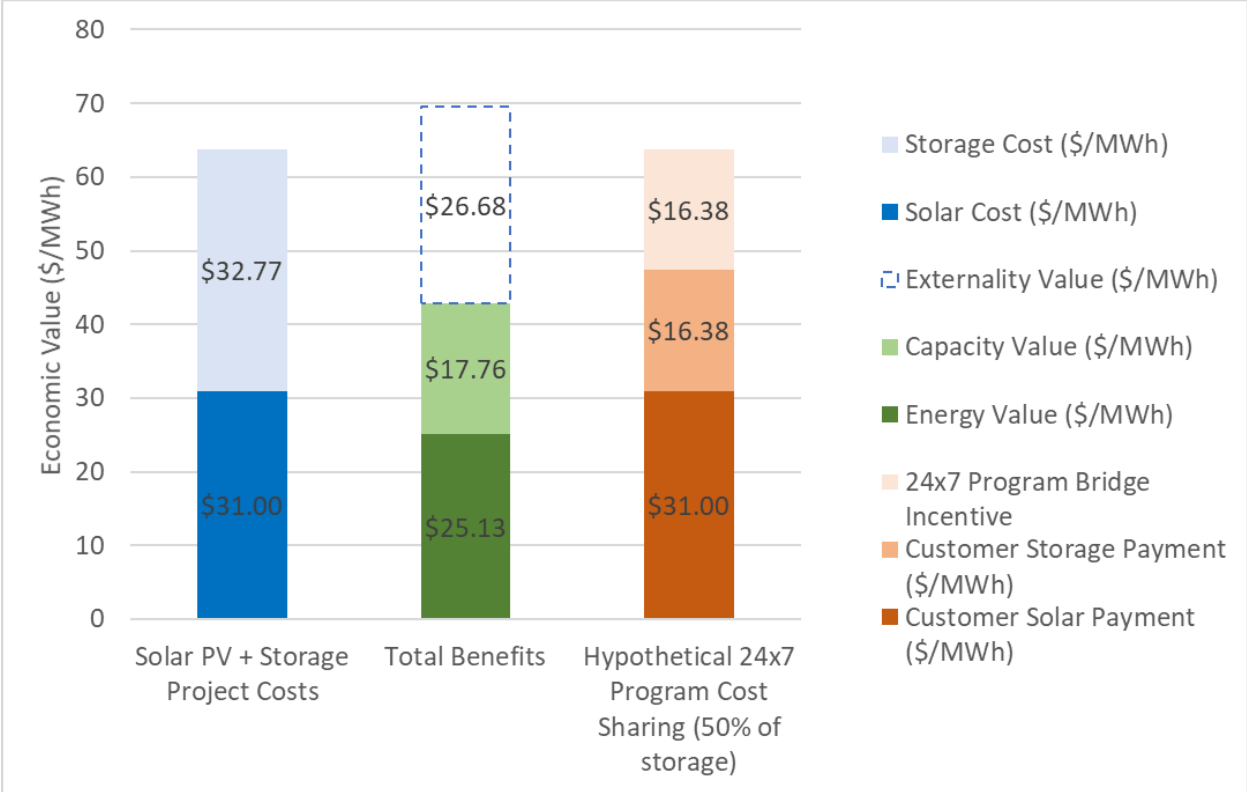


Figure 28. Benefits of time-matched solar-plus-storage projects

Finally, as mentioned the addition of storage comes with incremental costs. However, since Pennsylvania has a policy interest in pursuing the development of energy storage and transitioning to a cleaner energy system, there may be opportunities to share these costs between public and private funding sources. Potential public funding sources could include RGGI auction revenue or EDC direct payment through authorized programs. The table below illustrates various scenarios for storage deployment (using the analysis in this report) at differing hypothetical levels of cost sharing. For example, if Pennsylvania were to pursue this strategy under Scenario 2, this would contemplate 50% of the solar deployment being co-located with storage with a 25%/75% cost sharing arrangement.

	Scenario			
	1	2	3	4
Solar Deployment (GW)	11	11	11	11
Solar Paired with Storage	50%	50%	25%	25%
Co-located Storage (GW)	3.1	3.1	1.5	1.5
Storage Duration (hrs)	2.3	2.3	2.3	2.3
Incremental Cost of Storage Component (\$/kw-yr)	\$84.17	\$84.17	\$84.17	\$84.17
Cost Share	50%	25%	50%	25%
Total Program Cost (\$M/yr)	\$129.6	\$64.8	\$64.8	\$32.4
Total Grid & Environmental Value of Solar + Storage Projects (\$M/yr)	\$545.36	\$545.36	\$272.68	\$272.68

Figure 29. Economic and environmental value of solar-plus-storage projects

The solar-plus-storage projects under this scenario would yield approximately \$545 million annually in grid and environmental benefits and the storage component would be supported by approximately \$65 million through public or ratepayer funded investments (that also leverages private investment). This can be viewed as a conservative “upper limit,” due to the fact that storage costs are likely to decline over time as the 3.1 GW is deployed, and the fact that the program could be structured to reduce the bridge incentive over time.

4.3 Analysis of Standalone Behind-the-Meter Storage

For the purpose of this analysis, Strategen quantified the benefits of BTM storage for a small C&I customer. Strategen developed an optimization model using the Python computer programming language to analyze the impacts from BTM storage on customer bills in Pennsylvania. This model calculates the optimal dispatch (charge and discharge) of the BTM storage to minimize the utility bill. The model was used to analyze the effects of different storage sizes and durations for C&I customers on their bill. Bill savings were used to determine a payback period for storage investments.

The model output demonstrates the effect of the optimized BTM system dispatch on the facility load. Bill savings are achieved both by shifting energy consumption from the grid at off-peak hours (energy arbitrage), as well as by reducing peak load (demand charge mitigation).

The figure below shows a sample of model output representing two days of load under a baseline scenario without storage and under two scenarios with economic dispatch of different storage system sizes. This figure shows the flattening of peaks in the load profile as storage optimally charges and discharges against those peaks. Load increases as storage charges from the grid

during night hours when prices are low and discharges during the late afternoon hours when the price is higher. This way, storage is reducing the overall energy cost by shifting grid energy consumption at off peak periods, as well as lowering peak load and thus demand charges. While storage charges and discharges, there are some efficiency losses which result in a slightly increased energy consumption over the course of the year.

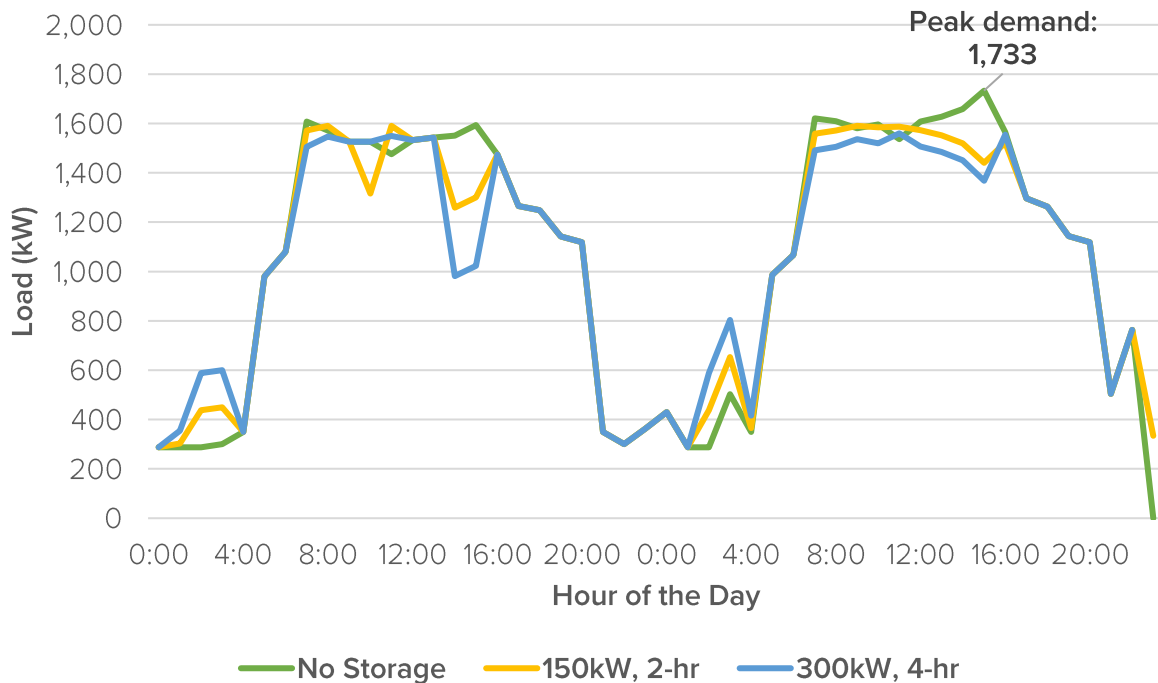


Figure 30. Sample daily load profiles under economic dispatch of storage

4.3.1 Sensitivity Analyses

The analysis included some additional sensitivity cases in order to better understand how sensitive the results and conclusions are to certain parameters. This analysis included a case of reduced installation costs for the energy storage system, a case of different load shape, and a case of increased demand charge in the utility's tariff schedule.

Cost Sensitivity

First, the analysis estimated the cost reduction in the initial investment capital that could result in positive net present value (NPV) and would thus financially incentivize BTM adoption beyond the first adopters. The analysis focused on the smaller systems examined, which were the most attractive from a financial perspective.

A cost reduction higher than 23% results in a profitable investment in a 100 kW, 2-hour BTM system, while a 34% reduction results in a positive NPV for a larger 150 kW, 2-hour system.

	<i>Storage Cost Sensitivity</i>	
<i>Battery size (kW)</i>	100	150
<i>Duration (hours)</i>	2	2
<i>Electricity bill reduction</i>	23%	34%
<i>NPV</i>	0	0
<i>IRR</i>	8%	8%

Figure 31. Cost sensitivity analysis of a BTM system

Batteries have experienced significant cost declines in recent years. If these trends continue, those cost reductions could be achieved in the next years and the payback periods for BTM storage will decrease. Reductions in soft costs, such as from streamlined permitting processes and interconnections, could play a role in greater adoption of BTM storage. Nevertheless, it should be recognized that BTM storage systems have additional benefits that are not currently captured by ratepayers based on the existing tariff schedules. The right regulatory framework could unlock higher revenue streams for BTM systems and thus enable the value that these can bring to the grid.

Demand Charge Sensitivity

A second sensitivity scenario examined the magnitude of the demand charge. High demand charges might incentivize adoption of storage systems, but they come with other considerations and equity concerns. However, this calculation is an illustration of how a different tariff which could include a TOU rate and/or a demand charge could incentivize BTM systems.

For the office load shape, a 100kW, 2-hour battery could result in a positive NPV if the tariff includes a demand charge 1.75 times higher than the existing one.

	<i>Demand Charge Sensitivity</i>		
<i>Battery size (kW)</i>	100	150	150
<i>Duration (hours)</i>	2	2	2
<i>Demand charge multiplier</i>	1.00	1.75	2.00
<i>NPV</i>	(\$37,918.08)	(\$347.76)	\$12,175.65
<i>IRR</i>	2%	8%	10%

Figure 32. Demand charge sensitivity analysis of a BTM system

Load Shape Sensitivity

The analysis also considered a different load shape. Specifically, the same analysis simulating the optimal dispatch of the six storage systems was conducted based on the same tariff but with a different load shape. The new shape was that of a hospital for the same reference location according to the DOE's Commercial Reference Buildings Dataset. This load profile has 1.48 higher yearly demand than the large office. Figure 33 shows the average demand per hour of the day for the month of July for the two load shapes. One can observe that the hospital's electricity needs have lower variation throughout the day.

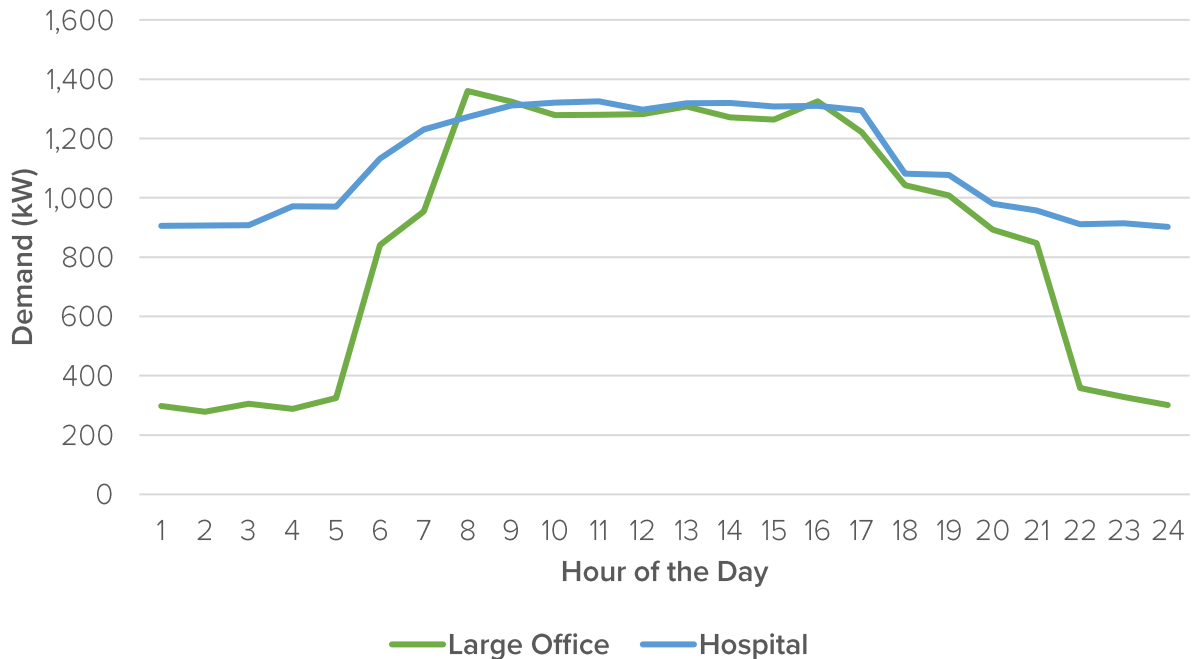


Figure 33: Average load per hour of the day for a hospital and a large office

As the hospital load does not vary as much as the office load, energy storage can be less profitable from intra-day arbitrage or demand charge management. From a bill savings standpoint, the hospital can save less on the bill from installing energy storage, but the BTM system can provide value as local source of backup power, including both the customer-led value of system reliability in outages, as well as the environmental and societal benefits of replacing backup generators utilizing fossil fuels, especially diesel. The value of BTM as a backup power resource, though difficult to quantify in financial terms, cannot be understated, as backup power is often one of the main reasons that customers choose to invest in BTM storage.

4.3.2 Key Findings

Of the energy storage systems analyzed, each scenario resulted in bill savings. However, the question is whether those benefits outweigh the installation costs and provide an incentive for consumers to invest in a BTM system. The BTM analysis focuses on bill savings, however, additional benefits are generated by further deployment of BTM storage including emissions reduction, T&D deferral, and resilience.

Over a 20-year period, three of the four battery systems analyzed resulted in savings that paid back their respective upfront investments. Accounting for the time value of money, however, only one battery system scenario had a positive NPV.

As the size of the storage system increases, the bill savings do not increase at the same rate, but rather at a diminishing marginal rate. This is because the most profitable energy arbitrage opportunities are captured by the initial energy storage kW. The arbitrage opportunities left to be captured by additional storage are smaller. Similarly, storage in a system can reduce the peak thereby flattening the load shape. The new load shape includes a peak with a longer duration, which

means that additional storage needs to be able to discharge for a longer time period to further reduce the peak.

The figure below shows both the demand charge savings for the different storage system configurations under optimal operations every month. For systems with four hours of duration, a smaller system of 100kW can deliver a peak reduction of approximately 100kW, while a larger system of 300kW reduces peak less than 200kW on average. Similarly, increasing the duration of the system, does not result in a proportionate increase of demand charge savings.

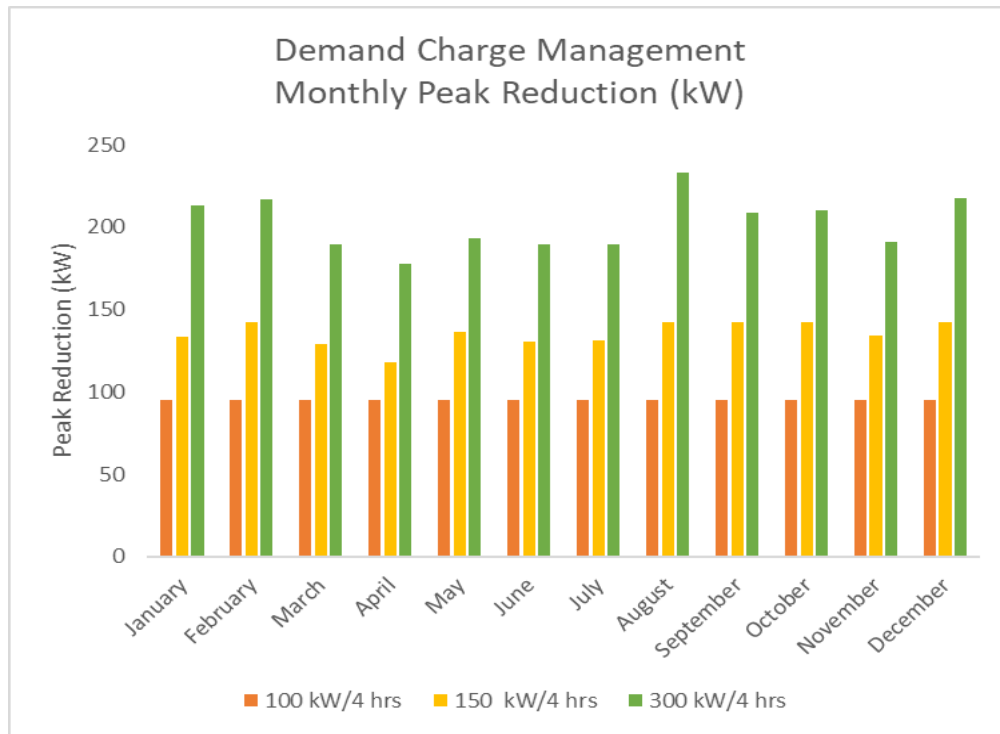


Figure 34. Demand charge savings under different storage configurations

Figure 35 presents the annual results of the analysis for the six different systems, including savings both from demand charge management and energy arbitrage opportunities. The smallest system examined – a 100kW, 2-hour system – results in savings of 2.7% of the original bill on an annual basis, while the largest system examined – a 300kW, 4-hour system – results in a reduction of 7.4% of the original bill. Although the savings increase, they do not necessarily increase at the same rate as the system size and cost.

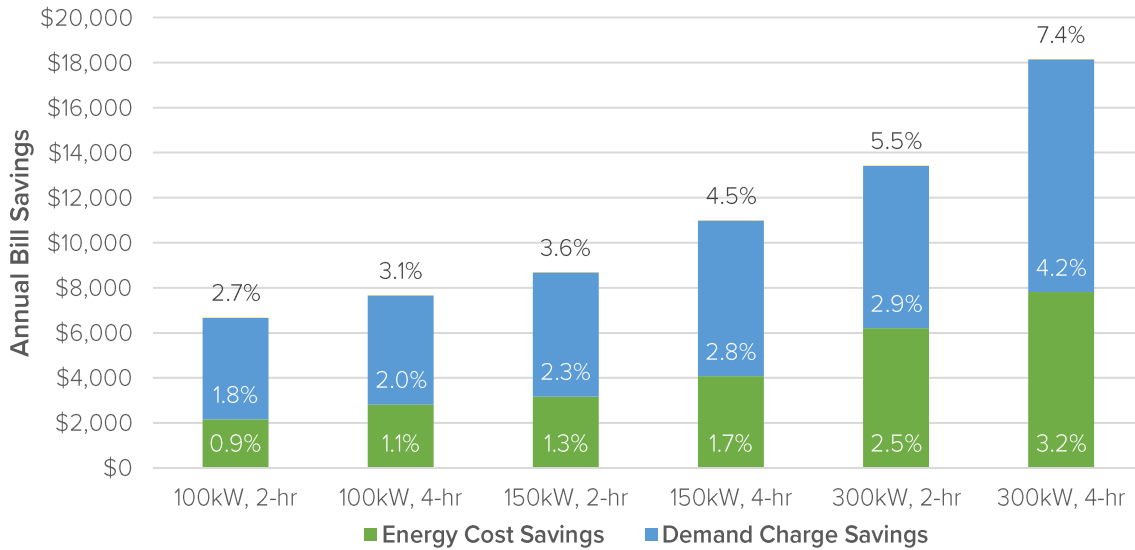


Figure 35. Comparison of annual savings from different storage systems

Next, the analysis evaluates the investment on a lifetime-basis. Bill savings are projected to occur every year during the system’s lifetime and are discounted with an 8% rate. The NPV is calculated based on the annual savings and costs (including operations and maintenance cost, warranty, and augmentation costs), and the initial capital expenditure. The NPV of all systems examined is negative, while the internal rate of return (IRR) takes positive values only for the 100kW, 2-hour system and the 150kW, 2-hour system. The results are summarized in Figure 36.

	Without storage	With storage					
		100 kW, 2-hr	100 kW, 4-hr	150 kW, 2-hr	150 kW, 4-hr	300 kW, 2-hr	300 kW, 4-hr
Energy Consumption (kWh/yr)	6,694,518	6,709,091	6,715,204	6,715,828	6,724,785	6,735,045	6,752,434
Peak Demand (kW)	1,733	1,638	1,638	1,591	1,591	1,557	1,500
Energy Cost (\$/yr)	\$162,468	\$160,304	\$159,660	\$159,300	\$158,398	\$156,255	\$154,662
Demand Charge (\$/yr)	\$81,889	\$77,386	\$77,044	\$76,379	\$74,979	\$74,690	\$71,550
Annual Bill (\$)	\$244,357	\$237,690	\$236,704	\$235,679	\$233,377	\$230,945	\$226,212
Storage System Costs (\$)		\$69,400	\$133,200	\$104,100	\$199,800	\$208,200	\$399,600
Savings from Storage		\$6,667.76	\$7,653.03	\$8,679	\$10,980	\$13,413	\$18,146
		2.7%	3.1%	3.6%	4.5%	5.5%	7.4%
NPV		-\$17,261	-\$80,190	-\$37,918	-\$124,827	-\$111,698	-\$284,326
IRR		4%	-3%	2%	-4%	-2%	-7%

Figure 36. Example annual bills with different battery systems

The negative NPV suggests that the current structure of retail rates in Pennsylvania is not necessarily conducive to customer investment in BTM storage. As such, if Pennsylvania seeks to encourage storage investment, certain changes may be needed, potentially including:

- Retail rate reforms to provide better time-varying price signals (including for both energy and demand components),
- Utility programs and incentives targeted at “bridging the gap” while helping transform the market for energy storage in Pennsylvania and buying down the cost of future storage deployments,
- Greater access to wholesale market products such as DR that could provide further incentives.

Chapter 5: Barriers to Energy Storage Deployment and Policy Recommendations

Energy storage in Pennsylvania faces barriers from policy, regulation, wholesale markets, and technology. Despite these barriers, Pennsylvania has many options to create a robust policy environment that fosters energy storage investment and integration.

While policies and programs that specifically target ESRs can help foster the industry, it is also important to align those initiatives with Pennsylvania's other clean energy policies and long-term energy objectives. New storage technologies are versatile, quick-responding, and highly controllable assets. As such, they not only offer performance enhancements over traditional assets, but they can also serve as a precision tool that enables other energy policies such as clean energy integration, grid modernization, enhanced resilience and reliability, better utilization of existing resources, and lower grid operating costs. With this in mind, carefully designed policies for energy storage can support a reliable, efficient, cost-effective power sector that continues to strengthen Pennsylvania's economy.

The following recommendations are classified as near-term, to be implemented in the next two years; medium-term, in the next two to five years; and long-term, to be implemented in five years or more.

5.1 State Policy

Barrier: Lack of Energy Storage or Clean Energy Targets or Requirements

Between state policies and customer interests, there is increasing demand for clean energy resource deployment in Pennsylvania. In many instances, wind and solar are now more economical than other forms of generation, while at the same time eliminating concerns of long-term fuel price volatility and preventing adverse environmental impacts. Moreover, a significant portion of resources proposed for development in Pennsylvania's interconnection queue are wind and solar. To the extent these resources will require additional integration capabilities, additional ESRs may be needed.

Storage procurement requirements and targets, especially coupled with state and federal incentives, have been key factors in the rapid commercialization and growth of the storage market in other jurisdictions. They create certainty of demand for energy storage technology providers and developers that can help to drive down costs of the technology and maximize its value as it reaches full commercial scale.

For many jurisdictions, a major motivation for pursuing energy storage has been the notion that it will help advance a transition to a cleaner energy system. That is, storage is seen as an enabler of other clean energy technologies such as wind and solar. As such, clean energy policies themselves have served as an indirect driver for energy storage deployment.

As discussed in Chapter 1: Energy Storage Technologies and Markets, several states have recently taken this approach. For example, California required its IOUs to procure 1,325 MW of energy storage by 2020 and has since expanded that by another 500 MW. New York established a statewide target for 3,000 MW of storage deployment by 2030 and have adopted a variety of

complementary policies to achieve this. In 2019, Virginia enacted a suite of energy policy laws including an energy storage target of 3,100 MW by 2035. Similarly, Oregon, Massachusetts, and New Jersey have energy storage procurement goals.

Recommendation #1: Establish a Storage Procurement Goal or Target

Near-term

One option to accelerate the market for energy storage systems is to establish a procurement goal or target. If Pennsylvania's goals include the acceleration of the local energy storage industry, then establishing a numerical procurement target would be an effective policy step towards that goal. Ideally the specific numerical target would be linked to an amount of storage determined to cost effective or in the public interest, or that builds upon other policy goals the state has established.

For example, a target could comprise of two components:

1. *Solar-plus-storage*: A storage deployment target could serve as a natural complement to the target of 10% of electricity (or 11 GW) of solar by 2030, identified in Pennsylvania's Solar Future Plan. Based on the analysis conducted in Chapter 4: Analysis of Energy Storage Potential in Pennsylvania, a storage deployment linked to 25% of the Plan's deployment goal would equate to 1,500 MW of storage by year 2030 and could yield significant grid and environment benefits on the order of \$273 million per year.¹¹¹
2. *Behind-the-meter (BTM) storage*: While the analysis focused on large-scale hybrid solar-plus-storage, a parallel target could be adopted for BTM storage that builds upon the peak reduction targets under the Act 129 programs overseen by the PUC. As an example, Arizona's Corporation Commission recently adopted a draft set of energy rules that require utilities in the state to install energy storage systems with capacity equal to 5% of each utility's peak demand by 2035.¹¹²

In addition to setting an overall target, the state should also include other parameters to ensure that the storage being deployed covers a broad range of market segments and that the projects deployed maximize benefits to the Commonwealth. Sub-categories by application (e.g. hybrid solar-plus-storage deployment, NWAs, storage-as-transmission, peaking capacity, peak demand reduction), rather than by point of interconnection, could further target the state's specific values and needs. Building upon guidance on the locations and applications for storage, regulators must also consider potential ownership models and how they may be linked to any obligations under the target (e.g. whether a portion of the target should be met with utility-owned and operated assets versus third-party owned and operated).

Finally, a storage procurement target could also effectively be accomplished by creating a carveout for hybrid resources or by placing a requirement on the time of delivery of existing clean energy programs, such as AEPS. For example, a clean peak standard or time-matched renewable requirements would in turn promote coupled renewable-plus-storage projects. This would ensure

¹¹¹ Note: This assumes the "low-cost" scenario could be achieved by pairing storage with renewables, thus providing federal tax incentives, as well as through technological advances.

¹¹² Wichner, David (2020), "Arizona regulators adopt new clean energy rules without renewable mandate." *Tucson.com*.

that renewable generation is reducing the need for generation to meet peak loads, which can often be more expensive, less efficient, and cause greater environmental impacts. While wholesale markets already put a time value on energy, they do not value the full environmental attributes of energy, nor do they value the additional benefits to the distribution system by avoiding peak demand.

Recommendation #2: Convene a Statewide “Storage Issues Forum”

Near-term

Not only has Pennsylvania attracted significant storage project development interest, but there are many interest groups that have unique insight and visibility into a wide range of issues likely to emerge as the industry evolves. As such, it is recommended that the state convene a “Storage Issues Forum” on a regular basis to allow key stakeholders to identify challenges and opportunities for the storage industry going forward, both within Pennsylvania’s own economy, but also more broadly across the U.S. and internationally. This Storage Issues Forum could be used as an opportunity to revise and update the results of this study, as technologies evolve and system needs change. Moreover, the Storage Issues Forum could work in tandem with PJM stakeholder groups to facilitate communication between the state and regional levels.

Recommendation #3: Designate Public Funding to Accelerate Storage Deployment

Near-/Medium-term

As of this report’s writing, Pennsylvania is currently considering joining RGGI. DEP’s modeling estimates that from 2022 to 2030, participating in RGGI would lead to an increase in Gross State Product of nearly \$2 billion.¹¹³ Revenues from the sale of carbon dioxide allowances under RGGI could potentially be used to support storage market policies and programs.

For example, RGGI revenues could be used to:

- Establish new incentive programs to buy down the upfront costs of energy storage projects.
 - For example, California’s Self-Generation Incentive Program (SGIP) offers incentives for residential and commercial BTM storage systems.
- Establish a new time-matched solar-plus-storage cost-sharing program to encourage renewable energy buyers to incorporate storage into their purchases. This would be similar to the analysis presented in Chapter 4: Analysis of Energy Storage Potential in Pennsylvania.
 - New York used \$53 million in RGGI funds to offer “bridge” incentives for solar-plus-storage.
- Offer technical assistance in the form of training programs on codes, standards, and safety for local jurisdictions.
 - New York works with local governments and first responders to understand, plan for, and site energy storage.
- Reduce required AEPS compliance costs for hybrid resource procurement, such as solar-plus-storage.

¹¹³ Pennsylvania Department of Environmental Protection, “Regional Greenhouse Gas Initiative.”

- Provide funding for EDCs to implement pilots in emerging storage technologies, including VGI demonstrations.
- Reduce the cost of site assessments for storage manufacturers.

Recommendation #4: Develop a Strategic Plan to Accelerate Microgrid Deployment at Critical Facilities

Medium-term

Microgrids can help provide resilience and a means of backup power in the event that there are significant outages, especially for critical infrastructure and emergency services within vulnerable communities. We recommend that Pennsylvania develop a statewide strategic plan for accelerating microgrid deployment, which would necessarily include a significant energy storage component. Part of this strategy could include various “make ready” provisions, whereby utilities could make investments to enable microgrid-specific infrastructure (e.g. interconnection requirements, controls network architecture, grid disconnection protocol) and facilitate microgrid development.

Additionally, this strategic plan would identify critical facilities where storage can help provide resilience benefits. Another key aspect would be providing tools and best practices to local jurisdictions that could develop their own microgrid capabilities.

5.2 Retail Tariff Design and Customer Programs

Barrier: Lack of Retail Programs and Rates Tied to Grid Services

Even in the absence of more retail choice options, the prevailing retail rates in Pennsylvania do not necessarily reflect a robust representation of grid cost drivers – and as a corollary, the benefits associated with avoiding these costs. More sophisticated retail rate options that capture these costs and benefits could facilitate more storage.

Creating a robust market for BTM storage deployment primarily depends on ensuring that retail customers are exposed to price signals that reflect the values that storage can provide to the energy system. Implementing reforms to retail rate designs and/or EDC customer programs may be an avenue to encouraging greater adoption of customer-sited, distributed energy storage.

Barrier: Limited Pathways for Retail Customers to Provide Grid Services through DERs

As discussed in Chapter 2: Energy Storage Applications, BTM storage assets can provide a variety of grid services – both at the wholesale level and at the distribution level – but lack a clear pathway for doing so. At the wholesale level, these likely require some mechanism for aggregation (e.g. through FERC Order 841) either by an EDC or a third party. Existing options are limited in nature and are not specifically tailored to storage. For distribution-level services, the provisions of Order 841 do not apply, and therefore there is not a clear, accessible pathway for customers to provide these services.

Recommendation #5: Establish Direct Incentive Programs for Storage Projects

Medium-term

Direct incentive programs reward early adopters for providing a variety of difficult-to-quantify benefits, such as enhanced grid resilience, and can accelerate broad market acceptance. Direct incentive programs can be financed through a variety of methods, such as by establishing a statewide tax abatement for storage projects, or by implementing an electric bill surcharge or rider.

Several states have established direct incentive programs for DERs and storage to help achieve market transformation and accelerate cost reductions. For example:

- California’s SGIP, a ratepayer-funded rebate program available to customers of four California IOUs, supports existing, new, and emerging DERs.¹¹⁴
- New Jersey’s Renewable Electric Storage Program provides financial incentives for non-residential customers for energy storage integrated with BTM renewable energy projects.¹¹⁵
- Maryland’s Game Changer competitive grant program provides funding to energy storage projects that provide a quantifiable reliability or resilience benefit, demonstrate an innovative application, and drive economic development.¹¹⁶
- Massachusetts’s Advancing Commonwealth Energy Storage program provides financial awards to innovative, broadly replicable storage use cases/business models with multiple value streams.¹¹⁷

Examples of these programs are provided in Section 1.3.1 State Energy Storage Policies.

Programs can also be structured in a variety of ways; for example, the incentive could be tied to specific performance or a system benefit being provided. Key best practices from similar programs include establishing clarity of program goals and objectives, requiring customer or third-party cost share, and providing sufficient funding so the program can help achieve market transformation.

Utilizing performance-based incentives and ensuring program certainty over time, both in terms of per-project incentive amounts and program funding and duration are also recommended. It is recommended that programs include a customer cost share while also including sufficient funding so the program can help achieve market transformation. Importantly, an incentive program should be designed to be temporary in nature and would wind down over time as the market matures. Additional priorities and objectives can also be incorporated, such as specialized incentives for low-income residents.

Recommendation #6: Enact Retail Rate Reforms

Medium-/Long-term

Although retail customers have the option to shop for their electricity supplier, the prevailing retail rate options for customers of the major EDCs, such as PPL and PECO, will have a significant influence

¹¹⁴ California Public Utilities Commission, “Self-Generation Incentive Program.”

¹¹⁵ New Jersey Clean Energy Program, “Renewable Electric Storage.”

¹¹⁶ Maryland Energy Administration, “Game Changers Program.”

¹¹⁷ Massachusetts Clean Energy Center, “Advancing Commonwealth Energy Storage.”

on customer adoption of energy storage. Moreover, the specific design of these rates is critical to ensuring that the operation of BTM storage is aligned with broader grid benefits. There are two main components of typical retail rate designs that are particularly well-suited to encouraging storage deployment and beneficial charging and dispatch behavior:

- TOU volumetric energy rates (typically expressed as cents per kWh)
- Time-varying demand charges (typically expressed as dollars per kW)

Deployment of BTM storage in other jurisdictions has been largely driven by high demand charges that are offset by storage used to reduce consumption during peak hours. In both cases, the rates must be designed in a manner that is sufficiently targeted toward peak demand hours, and that it provides an incentive for customer adoption. In contrast, if for example, a TOU rate has insufficient differential between on and off-peak hours, it will be much less likely to incentivize storage.

As illustrated in Chapter 3: Energy Storage in Pennsylvania Today, Pennsylvania utilities already offer rates for C&I customers that have demand charges. However, even these rate structures may be limited in terms of encouraging deployment of storage at scale. Additional modification of these rates, or incorporation of stronger time-varying price signals beyond what is currently in place in other rate classes may be beneficial for encouraging more energy storage. To accomplish this, the PUC would need to open an investigation into more advanced TOU rates and require that pilot rates be implemented if they are found beneficial.

Additionally, it is crucial that customers can understand their electricity bills, yet more advanced rate designs may be complex and difficult for customers to understand. As rates become more complicated, customer bills must also be designed in a way that is clear, transparent, and user-friendly. Utility bills could be itemized, with line-by-line breakdowns of all demand and energy charges and followed by a supplemental page with more detailed explanations of each charge, the way charges are assessed, and their purpose.

Recommendation #7: Develop a Tariff to Compensate Distribution-Connected Solar-plus-Storage Facilities

Medium-term

While Pennsylvania's restructured power system means that utilities may have limited ability to own or contract for new generation assets, there may be avenues to procure solar-plus-storage at the distribution level. The state's legislature could direct the PUC to investigate this option through a proceeding like that recently conducted for the Massachusetts SMART program. This would necessitate the development of a new tariff to collect revenue and compensate the new solar-plus-storage systems for the energy and other services provided.

Ideally the compensation mechanism would also be structured so that it has a limited but specific capacity procurement target and would step down over time. For example, the Pennsylvania Solar Future Plan's Scenario A calls for approximately 4 GW of distributed solar by 2030. If 25% of this were coupled with storage, that would equate to 1,000 MW of distributed storage, which could be divided into different tranches (e.g. 200 MW each), whereby the compensation would step down as the capacity deployment was exhausted.

Initial compensation levels could be established through a competitive solicitation conducted via reverse auction to ensure the most competitive solar-plus-storage projects are selected.

Recommendation #8: Expand Retail Customer Programs

Medium-/Long-term

In addition to bill savings linked to retail rate design, EDC customer programs can provide an additional source of revenue to reward customers who provide value to the grid by installing and dispatching storage devices.

Pennsylvania EDCs already offer some limited DR programs to their customers, such as PPL's Act 129 Demand Response Program. However, these existing programs focus primarily on delivering wholesale energy and capacity, so not all customers may be eligible to participate. As such, existing programs like these could be expanded or modified to better incorporate ESRs. Additional customer programs could be developed, or existing programs could be modified to allow greater customer participation.

5.3 Distribution Utility Planning and Procurement

Barrier: Lack of Framework and Incomplete Valuation of Storage in Procurement and Planning

In general, EDCs have a disincentive to seek solutions that may lead to lower overall capital expenditures. This is because cost-of-service regulation inherently provides an opportunity for EDCs to earn a stable rate of return on any incremental new capital investments. As such, an EDC may not be motivated to pursue storage options even if they are lower in cost than traditional solutions. Alternatively, EDCs may have an incentive to pursue incremental investments on the distribution system, including storage, for which they are able to take an ownership stake and earn a return on capital. However, there is no specific framework in Pennsylvania for determining when certain storage investments are beneficial and in the public interest.

Evaluation Tools & Processes

In general, modern storage technologies have not played a major part in traditional approaches to evaluating the needs for new generation, transmission, and distribution infrastructure. Many new technologies such as storage can serve the same needs as traditional grid assets. Therefore, it is important to ensure they are being given due consideration in planning processes, and that they are chosen by utilities where they represent more efficient and cost-effective solutions. In some cases, the traditional approaches of value quantification offer an incomplete assessment of the value streams and potential use cases for storage. This means that new tools, methodologies, and processes may need to be developed or implemented to properly evaluate storage for grid planning purposes. This pertains to ESRs considered for both distribution system benefits (e.g. through grid transformation planning) as well as on the generation side (e.g. integrated resource planning).

Recommendation #9: Enhance Distribution Planning and Procurement Processes

Medium-/Long-term

It is recommended that the state establish a process to identify and utilize the distribution system benefits of energy storage. Overseen by the PUC, corresponding procurement and cost recovery

mechanisms would also be needed. This process could occur through grid planning processes, such as grid transformation plans. This section describes some of the elements that could form the basis of a distribution system planning and procurement process that enables storage deployment. Two primary areas of focus within the broader distribution planning paradigm could include NWAs and hosting capacity analysis.

Grid Transformation and Integrated Distribution Plans

In general, the term “grid transformation” refers to investments made in the distribution system that provide enhanced capabilities to utilities and their customers. Ideally, this would include a robust process for identifying needs that storage could address, identifying locations that would best address these needs, and a cost-benefit evaluation of particular project or program proposals. The figure below illustrates an example of the potential elements in an idealized distribution system planning process.

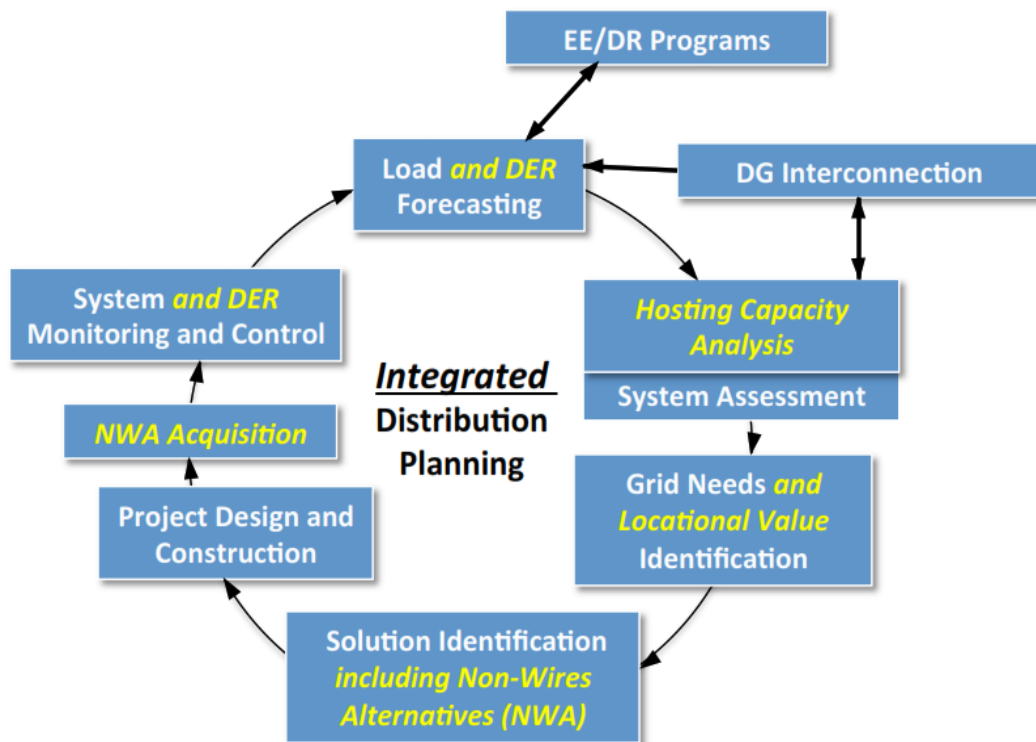


Figure 37. Integrated Distribution System Planning¹¹⁸

As discussed in Chapter 2: Energy Storage Applications, storage can provide benefits by deferring or avoiding distribution system upgrades, thus providing an NWA. However, several steps are needed to ensure successful procurement of NWAs. Pennsylvania could consider adopting some or all of these steps to achieve distribution system benefits from storage as an NWA:

¹¹⁸ New Energy Advisors (2018).

- Develop and implement a distribution system planning process (e.g. through grid transformation plans) that enhances the transparency of distribution planning,
- Improve information and transparency around locational net benefits on the grid,
- Implement screening criteria for the consideration of NWAs,
- Adopt protocols for solicitation and evaluation of NWA projects, and
- Approve standard offer contracts for the procurement of third party-owned NWAs.

As examples of best practices, Pacific Northwest National Laboratories recently compared several distribution system planning modernization initiatives in 16 states throughout the country.¹¹⁹ Three states were identified as leaders in the development of protocols for NWAs to address distribution system requirements: Rhode Island, New York, and California. Several states' approaches included protocols for EDCs to develop planning documents that identify opportunities within their service territories to defer traditional investments with NWAs. These opportunities are screened according to a set of criteria that may include technical and practical considerations, such as cost and implementation timeline. Additional incentive programs have also been considered to ensure that EDCs can be rewarded for selecting the most cost-efficient outcome for consumers, regardless of ownership structure. For example, California proposed a pilot that would provide an incentive to utilities that are able to “cost-effectively displace or defer traditional distribution system investments” through third-party DER providers.¹²⁰

Another component of a robust distribution planning process that could identify opportunities for storage is a hosting capacity analysis. Development of dynamic hosting capacity maps can provide public information to developers about the locational value of storage and other DER deployments. This has been especially important in locations that have high penetrations of rooftop solar PV, such as Hawaii and California, and where there have been limitations on the ability of the distribution system to accommodate additional solar systems. Although this is likely less urgent of a priority for Pennsylvania since there has been limited rooftop solar PV installed to date, it will nonetheless be an important consideration as the penetration of distributed solar increases over time.

Procurement and Cost Recovery

Even if opportunities for beneficial storage are identified in the distribution planning process, they are unlikely to be implemented unless there is a clear mechanism for procurement and cost recovery. For example, utilities may not wish to pursue NWAs over traditional distribution investments if this reduces the overall capital expenditures (and thus reduces investment opportunity for the utility). As such, an incentive or requirement for utilities to invest in these alternatives may be needed, which may necessitate regulatory or legislative reforms. One option would be to establish a requirement to pursue NWAs that are found to be cost-beneficial.

For example, in New York, utilities are procuring NWAs directly as part of their REV Connect program.¹²¹ Distribution utilities have conducted competitive solicitations for NWAs, including storage, to a subset of distribution upgrades identified as part of their distribution system planning

¹¹⁹ Pacific Northwest National Laboratory (2018), “Distribution System Planning- State Examples by Topic.”

¹²⁰ California Public Utilities Commission, “Integrated Distributed Energy Resources.”

¹²¹ REV Connect (2019), “Non-Wires Alternatives.”

process. Pennsylvania could take a similar approach by requiring utilities to issue an RFP for NWA opportunities that meet certain criteria.

Procurement of storage solutions for distribution benefits also necessitates a cost recovery mechanism. For example, the PUC could consider preauthorizing costs of NWAs that meet certain criteria, regardless of whether the underlying asset is owned by the utility itself or procured through a contract with a third-party provider.

Data Limitations

In the absence of detailed data of system loads on the distribution grid, there are inherent challenges to successfully storage as an NWA. However, there are still options worth considering and pursuing despite these limitations:

- Identify what voltage levels load data exists for and target deferral opportunities towards the lowest possible level where such data is collected.
- Identify locations with significant numbers of completed or requested distributed generation interconnections. These may be more likely targets for storage as a means to increase hosting capacity.
- Identify locations that require new or upgraded distribution equipment due to load growth.
- Consider deferral opportunities that could be unlocked if other data collection devices are deployed, such as advanced metering infrastructure or advanced distribution management systems.

5.4 Permitting and Interconnection

Barrier: Cumbersome Local Permitting and Interconnection Processes

All new infrastructure projects must go through some level of permitting and review processes at the local level. However, energy projects, and storage in particular, are often subject to additional levels of regulation that may be unfamiliar and confusing to developers, local officials, and consumers. Subsequently, cumbersome permitting and interconnection processes are perennial barriers for distributed energy resource deployment, and storage is no exception.

Barrier: Limited Local Industry Experience in Advanced Battery Technologies

Aside from pumped hydro and a few small demonstration projects, there has been limited deployment of advanced energy storage technologies in Pennsylvania. Any time an emerging technology such as advanced energy storage attempts to enter a new market, there are often hurdles that are non-technical in nature simply due to lack of overall experience among relevant stakeholders who include developers, financiers, utilities, system operators, regulators, and ratepayers. Overcoming barriers to achieve market transformation can often be more easily resolved through “learning by doing” as well as a careful analysis of what has worked, and more importantly, what has been challenging in other states.

Recommendation #10: Streamline Permitting on State and Local Levels

Medium-term

There are many steps that can be taken at the state level to facilitate the local safety and permitting processes associated with energy storage deployment. Additionally, there is a growing body of best practices and resources from other states' experience that Pennsylvania could adopt. These include the following:

- Amend and adopt a model permit and checklist system, such as that developed by New York. These can be distributed to authorities having jurisdiction and ultimately used to educate them through a special stakeholder session.
- Conduct fire official education courses through the National Fire Protection Association.
- Ensure the PUC has developed sound interconnection rules that do not pose undue barriers to customer storage adoption.
- Adopt the most current version of the National Electric Code. As of the time of this writing, the Code was most recently updated in 2020. Alternatively, the state could adopt only the articles of the Code that pertain to energy storage and let the current code adoption process continue as-is.
- Ensure any utility procurement of storage systems include relevant product safety standards, and that these be demonstrated as part of any competitive solicitation process.

Recommendation #11: Update the Interconnection Process for Distributed Energy Resources

Medium-term

It is recommended that Pennsylvania institute a process to update the interconnection process and rules to ensure that storage-specific issues are adequately addressed. As increasing levels of distributed energy storage are deployed, greater visibility and situational awareness will become increasingly important for both the local EDC and wholesale market operators, especially in cases where resources are providing multiple services across both domains. However, it is also important that interconnection requirements are not overly burdensome, do not impose excessive costs, and do not require unnecessary communications and control features.

5.5 Wholesale Markets

Reforms to wholesale market rules, such as PJM's, fall under FERC jurisdiction. Although Pennsylvania has no direct control over the decisions made by FERC and PJM, the state may be able to play an influential role in shaping these decisions. As such, it is important to recognize any wholesale market barriers that currently exist.

Additional information on PJM and its markets can be found in Appendix D.

Barrier: Restrictive Requirements for Participation in PJM Markets

While ESRs are eligible to participate in PJM's capacity market, and the large, long-duration pumped hydro units have been doing so successfully for years, there are several obstacles to newer, shorter-duration technologies, such as batteries.

Energy

PJM's continuous charge and discharge modes for energy storage and the new physical and operational parameters will make it easier to model and dispatch ESRs in PJM's energy markets. PJM has proposed to optimize ESRs over time and give them a day-ahead schedule. PJM will not benefit from the same full-day optimization that it performs for its large pumped-hydro units, and it will be difficult for ESRs to account for their opportunity costs of discharging energy. Storage resources have to stop and recharge, but if they discharge energy during one hour, it limits their ability to do so in future hours when the price might be higher. Additionally, without a day-ahead schedule, ESRs will not know whether or when they will have wholesale market obligations or what their scheduled revenues are in advance. This is less problematic for ESRs whose business is predicated on wholesale market participation than it is for ESRs who may also want to sell services to a distribution utility or its customers.

Capacity

Storage assets face several challenges in participating in PJM's capacity market, including energy and duration requirements, potential performance penalties, and must-offer obligations. PJM's existing and proposed duration requirements in its capacity market create a barrier to storage technologies like batteries from being able to participate at their full rated capacity. Under the existing construct, ESRs are required to have durations of six or ten hours (depending on how they register) and be available for capacity performance assessment hours which are of unknown times and durations. This means that ESRs must be available at all times for capacity performance and must be longer duration than most new storage technologies are generally designed for. Additionally, they are subject to day-ahead must-offer obligations for the entire operating day, which does not account for their energy limitations because they cannot provide energy 24 hours per day at a reasonable power rating.

Regulation

Although the regulation market that PJM implemented after FERC Order 755 was heralded as a success, the market has since been flooded with ESRs which have driven down regulation prices and led to some operational challenges and ongoing reconfigurations of the market design. The regulation market now represents a highly competitive market with persistent regulatory uncertainty. However, PJM has indicated its interests in moving the market towards a direction that requires longer durations for energy storage and assigns less value to their faster response times. While this will adversely affect the value of storage resources that are already in the market, it also makes it unlikely that new ESRs will be deployed with any significant reliance on regulation revenues until these issues are resolved.

Reserves

PJM's compliance proposal for Order 841 was designed to improve the ability of ESRs to provide reserves as they no longer need an energy schedule to do so, but it still requires them to go through an exception process to be a Tier 1 synchronized reserve resource. Similarly, ESRs must seek an exception to participate in the day-ahead scheduling reserve market, although this is the lowest value reserve product, and it is unlikely that ESRs would benefit from participating in this market.

In 2019, PJM proposed to revise its reserve pricing to account for increasing variability on its system, especially when weather conditions or deviations from load forecasts require additional resources to meet demand.¹²² While the filing may create a better pricing regime by consolidating and better aligning reserve products, and by implementing a demand curve for them that better supports the system needs, the increased penalty factors could create a disincentive for energy-limited resources like storage to provide reserves.

Barrier: Unclear Market Participation Rules

Hybrid Resources

An increasingly common application for storage resources, particularly large-scale batteries, is to be paired with on-site renewable generation. Most common amongst these hybrid resources are solar-plus-storage facilities because, as described in Section 1.3.2 Federal Investment Tax Credit, they are eligible for the ITC if the storage asset is charged exclusively by the on-site solar.

Combining storage with wind or with both wind and solar (“solar-plus-wind-plus-storage”) can also offer advantages over traditional intermittent generation assets. Most of these hybrid resources to date have been contracted to sell their output directly to utilities to provide dispatchable clean energy that is available to serve system peak.¹²³ The declining costs in these technologies and their ability to be dispatched during periods of high wholesale prices are making their business case as a participant in PJM’s markets increasingly attractive.

A weakness in PJM’s markets, however, is the lack of a participation model for these hybrid assets. Rules for intermittent generation exist in PJM’s markets, and the rules for storage are evolving under Order 841, but there remains a structural gap in the market for how these hybrid assets can participate. The uncertainty created by this lack of rules produces a barrier to hybrid resources entering the market. It is unclear whether the proposed rules will apply to intermittent generation, other generation, energy storage or a combination thereof. An example of this is capacity accreditation, where PJM allows wind and solar resources to define their capacity levels by reference to the resource’s output during four summer-peak afternoon hours because they are incapable of being dispatched to a specific level of sustained output. In contrast, PJM has proposed to treat energy storage like fossil or nuclear generation because they can be dispatched to a specific output for a sustained amount of time. Hybrid storage-plus assets, while more dispatchable than traditional wind and solar, are still reliant on the availability of the wind and the sun, therefore making it unclear whether their installed capacity values will be established like intermittent generation, traditional generation, or somewhere in-between.

In addition to determining the capacity value of hybrid storage-plus resources, uncertainty also remains with respect to the participation model that applies to them, what types of physical and operational characteristics need to be considered in PJM’s modeling and dispatch software, what ancillary services they are eligible to provide and how they will provide them, and what

¹²² PJM (Mar. 29, 2019), “Enhanced Price Formation in Reserve Markets of PJM Interconnection, L.L.C.,” Docket No. EL19-58-000.

¹²³ Nevada Power Company and Sierra Pacific Power Company (2018), “Application seeking approval to add 1,001 MW of power purchase agreements and 100 MW of energy storage capacity.” See also: Mai, HJ (2019), “Solar + storage projects to drive utility-scale deployment of batteries: Navigant,” *Utility Dive*.

interconnection rules apply to these resources. In addition to the fundamental rules regarding access to the grid and the wholesale markets, PJM must determine the applicability of market mitigation schemes and offer obligations, transmission charges, metering and telemetry, settlement, and all other rules that will be necessary to facilitate market participation. Moreover, these rules may need to account for the configuration of the assets as well. It is possible for hybrid assets that share a point of interconnection to be tightly coupled so that the storage can only charge off the generation it is paired with and loosely coupled so that the storage is also able to charge off the grid, and market operators will need to consider both. As these resources continue to gain a foothold in the markets, lack of clarity on these issues will continue to constrain their participation in the wholesale markets.

Storage as Transmission

In addition to participating in the organized markets, energy storage is also able to provide infrastructure services to T&D systems. FERC has approved the use of energy storage as a transmission asset in the past,¹²⁴ as well as issued a policy statement that clarified the ability of ESRs that are chosen as a transmission asset and are receiving cost-based rates to also receive market-based compensation.¹²⁵ Additionally, the Energy Policy Act of 2005 included energy storage technologies in its definition of “advanced transmission technologies” and encouraged their use to enhance the reliability, operational flexibility, and power-carrying capability of T&D systems.¹²⁶ FERC also required public utility transmission providers to consider non-transmission alternatives as part of their regional transmission planning processes as part of Order 1000.¹²⁷

While policies exist that encourage the use of ESRs as transmission assets and non-transmission alternatives, these policies lack effective implementation thus far. To be considered a transmission asset or a non-transmission alternative, ESRs must be chosen in a transmission planning process, but it is unclear what services a storage asset must provide to be considered a transmission asset, and there are no existing cost allocation and recovery processes for non-transmission alternatives. Additionally, while PJM’s regional planning process must select most efficient and cost-effective projects, there are no such requirements in local transmission planning processes. This may cause lower cost storage solutions to be overlooked, which may be further exacerbated by a lack of requirements to consider storage in those local processes in the first place.

Without clear rules for when storage is transmission and when it is a non-transmission alternative, without due consideration in planning processes, and without cost allocation for non-transmission alternatives, it will remain difficult for storage assets to be chosen to fulfill infrastructure planning needs. These represent the primary obstacles, but once they are resolved, implementation of FERC’s policy statement on utilizing storage for multiple services will even further unlock the potential value of these resources.

¹²⁴ *Western Grid Dev., LLC*, 130 FERC ¶ 61,056 (Western Grid), reh’g denied, 133 FERC ¶ 61,029, (2010).

¹²⁵ *Utilization of Electric Storage Resources for Multiple Services When Receiving Cost-Based Rate Recovery*, January 19, 2017; 158 FERC ¶ 61,051

¹²⁶ “Energy Policy Act of 2005.” 119 Stat. 594; P.L. 109-58; 42 USC 15801.

¹²⁷ Note: Order No. 1000 requires that regional processes must give “comparable consideration of transmission and non-transmission alternatives....” (pg. 155).

DER Aggregation

Creating clear paths for potential sellers to participate in as many markets as possible fosters competition and enhances market liquidity. As DERs proliferate on the grid, market access is critical to maximizing their value. Small distributed storage and generation assets have the same capabilities as their utility-scale counterparts, but ISO/RTO modeling and dispatch software becomes constrained and cannot reach timely solutions if the number of resources it needs to optimize becomes too large. To reduce the number of market participants, but still create opportunities for distributed resources to participate in the ISO/RTO markets, wholesale market operators must establish clear rules for DER aggregations. Such frameworks will enable the participation of resources that cannot by themselves meet the minimum size and/or performance requirements to participate in the PJM markets.

Barrier: Limits on Market Access for Multiple Uses for Storage

A major potential barrier to storage deployment is related to uncertainty regarding the ability of ESRs to benefit from multiple value streams both at the retail and wholesale levels. In Pennsylvania, there are multiple jurisdictional and service domains that ESRs need to navigate. It is possible for storage to simultaneously¹²⁸ provide services in PJM markets, to the high-voltage transmission system, to the distribution system and the utilities that own and operate it, and to end-use customers. Thus, storage devices can function as a wholesale asset and be subject to federal jurisdiction or as a retail asset and be subject to state jurisdiction. Additionally, there are different interconnection requirements depending on the location and application of the storage resource.

Overly cautious approaches to market access can place unnecessary limitations on a resource's ability to provide multiple services. These limitations are necessary to an extent to preserve system reliability, prevent distortions in the markets, and to ensure resources are not receiving conflicting dispatch signals. However, sometimes these limitations are restrictive and unnecessarily prevent the full utilization of ESRs.

Recommendation #12: Adopt a Multiple-Use Application Framework

Medium-term

As discussed in detail in Section 2.4 Multiple-Use Applications, storage can serve many functions under various ownership structures. As energy storage technologies and the control systems that manage them evolve, they are demonstrating increased abilities to provide multiple services both within individual domains and across multiple domains. For example, storage can function as a utility-owned grid infrastructure asset akin to transmission or distribution. It can also provide grid functions through third-party contracting mechanisms or serve as a generation asset. Finally, it can serve as a load modifier, particularly for customer-owned deployments.

Such MUAs are critical to unlocking the value of storage assets and maximizing their cost-saving potential for Pennsylvania ratepayers. As such, it may be important for state regulators to clarify the

¹²⁸ Note: "Simultaneously" in this case refers to the ability to perform multiple functions over several intervals of time. It is not always possible for storage to perform multiple functions at the same instant (though in some cases this may be possible).

regulatory treatment of storage under different use cases and deployment scenarios. In more mature storage markets, such as California), concerted efforts have been made to establish a framework for MUAs. These frameworks can help provide clarity to storage providers about which value streams are able to be delivered at different grid interfaces, when certain value streams can be delivered simultaneously, when conflicts may arise, and what jurisdictions apply to certain capabilities. It will be important for the Pennsylvania PUC, in coordination with PJM, to establish a similar framework to provide greater market clarity and certainty.

Recommendation #13: Seek Wholesale Market Improvements by Participating in PJM Stakeholder Processes

Near-/Medium-term

The Pennsylvania PUC is a member of the Organization of PJM States, Inc. (OPSI).¹²⁹ While this does not make the PUC a member of PJM, it does give the PUC a unique right to participate, deliberate, give input, and engage at all levels of the PJM stakeholder process. Since OPSI is not a PJM member, the organization does not get a vote in PJM decisions, but individual OPSI members may elect to become a PJM member and obtain voting rights.¹³⁰ Hence, for issues that may be important for the state, there are numerous ways for state entities, such as the PUC, to get involved in the PJM stakeholder process, all the way from early-stage issue formation to later stage voting and approval of changes.

To discuss any issues regarding energy storage in the wholesale markets, Pennsylvania and its stakeholders can participate in relevant PJM subcommittees, task forces, or general OPSI and PJM stakeholder meetings. For example, the DER & Inverter-Based Resources Subcommittee is an ongoing subcommittee established by the Market Implementation Committee at its July 8, 2020 meeting.¹³¹ This subcommittee replaced the Intermittent Resources Subcommittee of the Market Implementation Committee and first met on August 3, 2020.¹³² This subcommittee will investigate many of the issues under discussion in this report. For example, the subcommittee has recognized that the various configurations of solar-battery hybrids need their own discussion about how existing business rules may or may not apply to each, and the need for potential clarification or enhancement for certain types of hybrids. Subsequently, the subcommittee is currently considering revisions to PJM business manuals, and if needed, proposed revisions to governing documents and a filing with the FERC. The subcommittee expects to report its findings and may also propose solutions by the end of 2020.¹³³ Additionally, the Capacity Capability Senior Task Force is exploring new methods of calculating how much power resources such as wind, solar, and energy storage may offer into the capacity market.¹³³

Pennsylvania may want to provide input on PJM's ten-hour storage duration criteria for capacity market valuation. For example, the New York ISO (NYISO) recently proposed implementing a longer duration criterion for storage to receive full capacity market credit. This proposal was later revised,

¹²⁹ Organization of PJM States, Inc. (2020), "Home."

¹³⁰ PJM (2019), "Manual 34: PJM Stakeholder Process."

¹³¹ PJM, "DER & Inverter-Based Resources Subcommittee."

¹³² PJM, "Distributed Energy Resources and Inverter-based Resources Subcommittee."

¹³³ PJM, "Capacity Capability Senior Task Force."

and full credit is likely to be given to shorter-duration resources up to a certain level of penetration. This revision was made in part due to additional technical analysis conducted after the original proposal. Similarly, Pennsylvania could support additional technical analysis and seek adoption market rules that provide greater opportunities for shorter duration (e.g. 2-hour, 4-hour, etc.) ESRs to participate in PJM's capacity market.

Additionally, Pennsylvania may want to engage in the implementation of FERC Order 2222, described in more detail in Appendix D: Energy Storage in PJM Wholesale Markets. The deadline for ISOs/RTOs, including PJM, to file compliance plans with the Order is in July 2021.

Recommendation #14: Consider Changes to Resource Adequacy Rules and Oversight

Medium/Long-term

In recent years, several states that participate in PJM have expressed concerns about the RTO's capacity market design. For example, PJM has been reported to have unnecessarily high planning reserve margins that potentially impose undue costs on retail customers. Additionally, FERC recently expanded PJM's MOPR to establish price floors for clean energy resources that are supported by state-level policy. This has led some states to consider options for exercising greater control over their own resource planning decisions, including more explicit criteria for resource adequacy planning, or even considering exiting PJM altogether.

If Pennsylvania wishes to have greater control over the magnitude and composition of its generation capacity mix (including support for energy storage), it could consider options for establishing resource adequacy criteria. For example, Massachusetts recently enacted legislation requiring a "clean peak" standard. Similar types of "clean capacity" or "clean resource adequacy" criteria could be considered for Pennsylvania. While there are many potential approaches, the goal would be for LSEs to meet a portion of their peak capacity and reliability needs from clean energy resources, including energy storage.

Additionally, a proactive approach to resource adequacy planning could help to anticipate and avoid some of the challenges associated with rapid buildout of clean energy. Experience in California, for example, has demonstrated the need to ensure that clean energy resources can meet grid reliability needs in advance, rather than reaching a stage where fossil energy resources must be maintained on an emergency or uneconomic basis due to unforeseen reliability challenges.

5.6 Technology

Barrier: Potentially High Battery Costs and Technical Limitations

Although battery costs are rapidly declining, as described in Chapter 1: Energy Storage Technologies and Markets, batteries still may not be economic under all circumstances. Many battery chemistries still face limitations in cost or performance or are still maturing in the market.

Notably, long-duration electricity storage (LDES) systems – systems that can discharge for 10 hours or more at their rated power – have recently gained attention for their ability to provide "firm" low-carbon energy resources to complement variable renewable generators like wind and solar. While shorter duration energy storage technologies can load fluctuations during the day, longer duration options are needed for periods of low wind or sun that last several days or during extreme weather

events. Longer duration storage can also displace more capital-intensive baseload and load-following plants. Given their unique performance and applications, LDES faces a different set of economic and technical challenges than shorter-duration storage.

Additionally, there are still not widespread, economically viable options for battery disposal and recycling. As a result, create uncertainties for end-of-life disposal and environmental impact.

Recommendation #15: Support Research and Development of New Energy Storage Technologies

Short-/Medium-/Long-term

As described in Chapter 1: Energy Storage Technologies and Markets, there are a variety of energy storage technologies that are continually evolving as the industry's technical knowledge improves and manufacturing capabilities scale up. Pennsylvania's education and research institutions, some of which are listed in Section 3.4 Energy Storage Research & Development, could play a key role in advancing storage technologies, improving battery chemistries, and bringing costs down. Demonstration projects could also serve as a learning opportunity for students and faculty to prepare them for careers in the storage industry. Additional funding and other resources could be allocated towards this effort to help position Pennsylvania as a center for learning and research in energy storage.

Appendix A: Acronyms

AEPS	Alternative Energy Portfolio Standard
AGC	automatic generation control
BEST	Battery and Energy Storage Technology Center
BTM	behind-the-meter
C&I	commercial and industrial
CAES	compressed air energy storage
CAIDI	Customer Average Interruption Duration Index
CAISO	California Independent System Operator
CHP	combined heat and power
CPUC	California Public Utilities Commission
DEP	Pennsylvania Department of Environmental Protection
DER	distributed energy resource
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DR	demand response
EDC	electric distribution company
EE	energy efficiency
EPO	Energy Programs Office
ESA	Energy Storage Association
ESR	energy storage resource/electric storage resource
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
FOM	front-of-meter/in-front-of-the-meter
GHG	greenhouse gas
GW	gigawatt
IOU	investor-owned utility
IRR	internal rate of return
ISO	independent system operator
ITC	Investment Tax Credit
kW	kilowatt
kWh	kilowatt-hour
LADWP	Los Angeles Department of Water and Power
LAES	liquid air energy storage
LCOE	levelized cost of energy
LCOS	levelized cost of storage
LDES	long-duration energy storage
LMP	locational marginal price
LSE	load-serving entity
MOPR	Minimum Offer Price Rule
MUA	multiple-use application
MW	megawatt

MWh	megawatt-hour
NERC	North American Electric Reliability Corporation
NPV	net present value
NWA	non-wires alternative
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
OPSI	Organization of PJM States, Inc.
PJM	PJM Interconnection
PPA	power purchase agreement
PUC	Public Utilities Commission
PV	photovoltaic
R&D	research and development
REC	renewable energy credit
REV	Reforming the Energy Vision
RFP	request for proposals
RGGI	Regional Greenhouse Gas Initiative
RPM	Reliability Pricing Model
RTO	regional transmission organization
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SGIP	Self-Generation Incentive Program
SMART	Solar Massachusetts Renewable Target
SREC	solar renewable energy credit
T&D	transmission and distribution
TOU	time-of-use
VGI	vehicle-grid integration

Appendix B: Glossary of Energy Storage Terms

B.1 Performance Metrics

- **Rated Power Capacity (kW)** – the total possible instantaneous discharge capability of the storage system, or the maximum rate of discharge the storage system can achieve starting from a fully charged state.
- **Energy Capacity (kWh)** – the maximum amount of stored energy the system can hold.
- **Duration (Seconds, Minutes, Hours, Days, etc.)** – the amount of time a storage system can discharge at its rated power capacity before depleting its energy capacity. For example, a storage system with 1 MW of rated power capacity and 4 MWh of energy capacity will have a storage duration of four hours.
- **Energy Density (kWh/L)** – the amount of energy that an energy storage system can store per unit volume occupied by the system.
- **Power Density (kW/L)** – the maximum available power per unit volume.
- **Energy-to-Power Ratio (kWh/kW)** – relationship between energy capacity and rated power capacity in a given application.
- **State of Charge (%)** – represents the storage systems level of charge and ranges from completely discharged (0%) to fully charged (100%).
- **Depth of Discharge (%)** – represents the ratio of discharged energy (kWh) to usable energy capacity (kWh).
- **Cycles Per Day (#)** – the number of times the energy storage system charges and then discharges to a certain depth of discharge (usually 80%) within a 24-hour period.
- **Cycles Per Year (#)** – the number of times the energy storage system charges and then discharges to a certain depth of discharge (usually 80%) over the course of a year.
- **Operational Life (Years)** – the number of years an energy storage system can operate while maintaining its normal cycle rate for its given use case.
- **Round Trip Efficiency (%)** – the ratio of energy output (kWh) to energy input (kWh) of storage system during one cycle. For battery technologies these refer to DC/DC efficiencies while mechanical-based systems are expressed in AC/AC terms.
- **Degradation Factor (%)** – refers to the amount of rated capacity or energy capacity that is lost over time as the components of the system experience wear and tear and/or chemical changes.
- **Theoretical Response Time (Seconds)** – the time in seconds it takes an energy storage system to reach 100% of rated power during charge/discharge or from an initial measurement taken when the system is at rest.
- **Response Time Constrained by Power Conversion System (Seconds)** – the time in seconds it takes an energy storage system to reach 100% of rated power during charge/discharge constrained by technical limits of its power conversion system.
- **Ramp Rate (%/second)** – the rate of change of power delivered to or absorbed by an energy storage over time, expressed in megawatts per second or as a percentage change in rated power over time (percent per second).
- **Black Start Capable** – refers to ability of technology to enable the process of restoring electric power from complete blackout, without relying on an external power source.

B.2 Cost Metrics

B.2.1 Capital Expenditures

- **Storage System** (\$/kWh) – includes costs for components critical to charging and storing energy. For example, electrodes, electrolytes, and separators for a battery system or waterways; reservoirs, pumps, and generators for a pumped storage hydro system.
- **Power Conversion System** (\$/kW) – includes costs for the inverter and packing, as well as container and inverter controls.
- **Balance of Plant** (\$/kW) – includes costs for site wiring, interconnecting transformers, and other additional ancillary equipment.
- **Construction & Commission** (\$/kWh) – also referred to as engineering, procurement, and construction cost and includes costs related to the procurement and transportation of necessary equipment to the project site as well as the costs of labor and parts for installation

B.2.2 Operational Expenditures

- **Fixed Operations and Maintenance** (\$-kW-year) – includes all costs necessary to keep the storage system operational throughout the duration of its economic life that do not fluctuate based on energy usage.
- **Variable Operations and Maintenance** (\$-kW-year) – includes all costs necessary to operate the storage system throughout its economic life and is normalized with respect to the annual discharge energy throughput.

B.2.3 Levelized Cost

- **Levelized Cost** (\$/kWh) – represents the average amount of money per unit of electricity generated that would be required to recover the costs of building and operating an energy storage system plant during assumed financial life and duty cycle. Key inputs include capital expenditures, operational expenditures, financing cost, and utilization factor. Levelized costs are often used to compare the cost effectiveness of energy storage investments.
 - **Levelized Cost of Storage (LCOS)** (\$/kWh) – the aggregate cost of an energy storage investment over its operation life (including financing costs) divided by its cumulative delivered electricity. While consensus has yet to develop on its exact formulation, LCOS is the most common levelized storage metric.
 - **Levelized Lifecycle Costs** (\$/kWh) – the total cost of an energy storage investment over its entire life including raw materials, manufacturing, operations, and decommissioning/end of life divided by its cumulative delivered electricity. While more comprehensive, this metric is used less due to the difficulty of obtaining consistent beginning of life (materials and manufacturing) and end-of-life (decommission and recycling) data.

Source: U.S. Department of Energy (2020), “Energy Storage Grand Challenge Draft Roadmap.”

Appendix C: Energy Storage Technologies

C.1 Mechanical Storage

Mechanical storage technologies store energy by converting kinetic energy to electrical energy. Example technologies include flywheels, compressed air energy storage, liquid air energy storage, and pumped-storage hydroelectric systems.

Flywheels store electric energy as rotational energy by spinning a cylindrical rotor at very high speeds in a nearly frictionless enclosure. The flywheel's rotational speed is reduced in order to convert kinetic energy into electricity via a generator. Vacuum chambers and magnetic bearings are often used to reduce friction further. High tensile strength materials must be used.

Flywheels are characterized by good efficiencies over short timescales, rapid start-up times (typically a few minutes), high cycling capabilities, high energy density, long lifetimes (typically 20 years), limited maintenance, minimal environmental impact, and modularity. They are typically used for power quality, management, and reliability including for reactive power support, spinning reserves, voltage regulation, frequency response, and for short duration ride-through applications. They have also been used to smooth the output power fluctuations of variable generation resources, such as wind.¹³⁴



Figure 38. Flywheels in Hazle Township, PA

Compressed air energy storage (CAES) systems compress and store gas, typically ambient air, under pressure in above-ground storage containers or in suitable underground geologic formations, such as underground salt caverns. Energy is extracted by expanding or decompressing the gas through a turbine that drives a generator. Capacity and discharge times are site-specific, and natural gas is typically required to operate.¹³⁵ Small-scale applications exist in industries like mining, while utility-scale applications are more limited and include deployments in Bremen, Germany, and McIntosh, Alabama. CAES applications can be used for peak shaving, ancillary services, price arbitrage, and seasonal load shifting, among other applications.

Liquid air energy storage (LAES), also referred to as cryogenic energy storage, uses electricity to cool air until it liquefies, stores the liquid air in a tank, brings the liquid air back to a gaseous state (by exposure to ambient air or with waste heat from an industrial process) and uses that gas to turn

¹³⁴ Electric Power Research Institute (2004), "Energy Storage for Grid Connected Wind Generation Applications."

¹³⁵ Sandia National Laboratories (2011), "Potential Hazards of Compressed Air Energy Storage in Depleted Natural Gas Reservoirs."

a turbine and generate electricity. LAES is a long-duration, large-scale technology with long lifetimes of 30 or more years. LAES systems can be located at the point of demand. Although these systems are still relatively novel, they are based on well-established technologies and processes.¹³⁶

Pumped-storage hydroelectric (“pumped hydro”) systems store energy by pumping water against gravity from a reservoir at a lower elevation to one at a higher elevation. Energy is extracted by releasing stored water through a hydroelectric turbine to generate electricity. Systems are considered “open loop” if they connect to a natural body of water, and “closed loop” if they do not. Proposed systems are subject to rigorous environmental review and can take several years to site, permit, and build. Small-scale installations have also been deployed. Depending on size, they are called “micro,” “mini,” “nano,” or “pico” systems.¹³⁷

Pumped hydro is a mature, highly efficient technology. It is the most common type of energy storage system in the world. In fact, pumped hydro accounts for more than 95% of all utility-scale energy storage applications in the United States.¹³⁸ Pumped hydro systems can contribute valuable energy, capacity, and ancillary services, depending on a system’s operational, environmental, and water resource constraints.

C.2 Electrochemical Storage

Electrochemical storage technologies, or simply called “batteries,” are an exceptionally flexible energy storage technology. Numerous battery technologies offer a range of energy density, power performance, cost, and charging durations, among other attributes. Due to their scalability and modularity, batteries can be deployed anywhere from a kilowatt-scale household backup use to gigawatt-scale bulk energy systems to support utility operations. Batteries come in two main categories: solid-state batteries and flow batteries. As the more common category of the two, solid-state batteries are the focus of this report.

C.2.1 Solid-State Batteries

As the name implies, solid-state batteries store chemical energy in solid electrodes. Examples include lead-acid batteries, lithium-ion batteries, sodium-sulfur batteries, and zinc-based batteries.

Lead-acid batteries are a well-established technology dating back to the 1800s. They are supplied by a large, worldwide base of suppliers, and are the world’s most widely used rechargeable battery. They are primarily used as automotive batteries and in the industrial sector for standby applications. “Advanced” lead-acid batteries and carbon composite lead materials continue to mature, allowing for greater depth of discharge and longer battery lifetimes in utility applications.¹³⁹

Lithium-ion batteries include a wide range of battery chemistries characterized by the transfer of lithium compounds between electrodes. They are used primarily by the telecommunications, consumer electronic, and EV industries, and represent the fastest-growing chemical storage

¹³⁶ Energy Storage Association, “Liquid Air Energy Storage.”

¹³⁷ Note: “Micro” systems have a capacity between 5 kW to 100 kW. “Pico” systems have a capacity of less than 5 kW. OpenEI, “Micro/Nano Hydro.”

¹³⁸ U.S. Department of Energy, “Pumped-Storage Hydropower.”

¹³⁹ May, Geoffrey J., et al. “Lead Batteries for Utility Energy Storage: A Review.” *Journal of Energy Storage*, vol. 15, 2018, pp. 145–157., doi:10.1016/j.est.2017.11.008.

technology in the electric utility industry. Utilities are increasingly deploying lithium-ion batteries in grid-scale applications for power management, capacity, arbitrage, and ancillary services.

Sodium-sulfur batteries use metallic sodium and operate at high temperatures, roughly 300 to 350°C. They are characterized by high round-trip efficiencies (around 90%), long discharge properties, and the potential for continuous peak load support. They have been deployed globally at more than 35 locations in order to shave peak, provide backup power, firm wind capacity, and provide ancillary services.¹⁴⁰

Zinc-based batteries are a maturing technology that employ zinc – a readily abundant element – and other chemicals. For example, zinc-air batteries oxidize zinc with oxygen from the air using only one electrode. Zinc-air batteries have very high energy densities but low round-trip efficiencies (around 50%) because the electrolyte does not always deactivate during the recharging cycle. Zinc-air batteries are low-cost, lightweight, and non-toxic. Deployments to date have primarily focused on microgrid applications.

C.2.2 Flow Batteries

Flow batteries are composed of two separate tanks that store fluid electrolytes. The electrolytes are pumped through a common chamber, separated by a membrane that allows electrons to flow between them. These batteries can be reconditioned on-site by replacing the electrolyte to extend their life. Examples of flow batteries include redox, iron-chromium, vanadium redox, and zinc-bromine flow batteries. Vanadium discharges reliably for thousands of cycles but is a rare and costly element; organic compounds may offer an alternative to vanadium. While flow batteries may provide some advantages, particularly for long-duration use cases, they have not had the same commercial success as solid-state batteries.

C.3 Thermal Energy Storage

Thermal energy storage stores energy by cooling or heating a medium – typically water – and releasing the energy at later times. These technologies come in numerous forms and are used for heating, cooling, or power generation.

- *Ice-based technologies*: Ice is made, stored, and used later for cooling, industrial processes, or to cool inlet air for various purposes (e.g. for combustion turbines).
- *Chilled-water thermal storage*: Water is chilled, stored, and used later for cooling, industrial processes, or to cool inlet air for various purposes (e.g. for combustion turbines).
- *Direct load control of water heaters*: electric heat pump water heaters or resistive electric water heaters: Water heating loads are shifted from periods of higher demand to periods with lower demand and energy prices.
- *Pumped heat electrical storage*: Heat is pumped from one medium to another using a reversible heat pump, similar in principle to pumped hydro.
- *Solar hot water storage*: Like a standard water heater tank, water is heated by solar thermal technologies and stored in a tank for later use.

¹⁴⁰ U.S. Department of Energy (2020), “Energy Storage Database.”

- *Molten salt technologies:* Molten salt is heated to high temperatures and circulated through a heat exchanger to create super-heated steam that powers a steam turbine. This technology has been coupled with solar in concentrated solar power applications.

Thermal technologies are utilized around the country at the industrial, commercial, or residential level. Particularly in conjunction with time-differentiated rates, thermal energy storage can be a cost-effective way to shape end-use load and manage the electrical grid. An exception to this is molten salt, which has generally been deployed in utility-scale applications.

C.4 Electrical Storage

Electrical storage systems modify electrical or magnetic fields to store electric energy. Examples include supercapacitor or double-layer capacitor storage systems and superconducting magnetic energy storage systems.

C.5 Chemical Storage

Most notably, chemical energy storage systems produce hydrogen through water electrolysis. Once produced, the hydrogen can be stored and used later to generate electricity via fuel cells or internal combustion.

Appendix D: Energy Storage in PJM Wholesale Markets

D.1 Overview of PJM

The PJM Interconnection, an RTO, operates a competitive wholesale electricity market that manages the reliability of its transmission grid and performs long-term transmission planning. As part of market operations, PJM centrally dispatches generation and coordinates the movement of wholesale electricity in all or part of 13 states – Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia – and the District of Columbia.

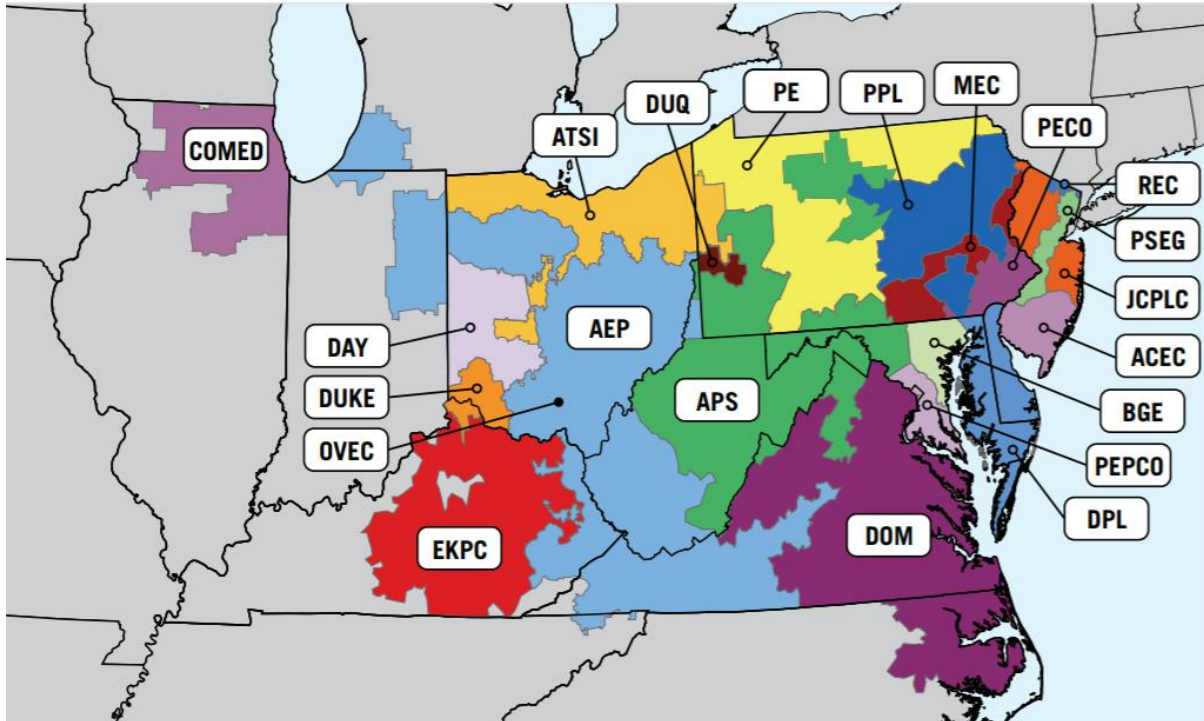


Figure 39. PJM capacity market zones¹⁴¹

PJM operates several competitive wholesale electricity markets:

- a capacity market, called the Reliability Pricing Model (RPM);
- two energy markets: the Day-Ahead and Real-Time markets; and
- four ancillary services markets: the Synchronized Reserve Market, the Non-Synchronized Reserve Market, the Day-Ahead Scheduling Reserve Market, and the Regulation Market.

PJM has a two-tiered governance structure that includes the PJM board of directors and the members committee. The board includes nine independent members who vote on final decisions regarding market changes and new programs before they are filed for regulatory approval. Each member of PJM has one representative on the members committee, which votes on issues and

¹⁴¹ PJM, "PJM Zones."

provides advice to the board.¹⁴² The committee is made up of five sectors representing generation owners, transmission owners, electric distributors, other suppliers, and end-use customers. In addition to the member committee, PJM also has a number of permanent committees, user groups, subcommittees, and task forces that make decisions on individual issues and provide their recommendations to the members committee.¹⁴³

PJM establishes its market rules through a deliberative multi-party stakeholder process. States like Pennsylvania are generally represented in these processes through groups like the Organization of PJM States, Inc. (OPSI). The development PJM's capacity market rules are informed by its own analysis of operational data, including an effective load carrying capability analysis that is impacted by the specific suite of resources available within the PJM footprint. However, there are often differences of opinion among experts on how these technical analyses should be conducted and what conclusions should be drawn to inform market rules. For example, ESA recently solicited its own technical analysis which demonstrated that energy storage systems with durations shorter than ten hours would be able to provide full capacity value up to a certain level of penetration.¹⁴⁴

PJM defines an "energy storage resource" (ESR) as a resource capable of receiving electric energy from the grid and storing it for later injection to the grid that participates in the PJM Energy, Capacity, and Ancillary Services markets as a market participant.¹⁴⁵

D.2 Capacity Market

PJM operates a three-year forward capacity market called the Reliability Pricing Model (RPM) to ensure adequate supply is available to meet forecasted demand plus a reserve margin over a longer time period. PJM accomplishes this by procuring these forecasted capacity requirements three years prior to the resources being required to deliver energy, with the potential for additional incremental auctions. These long-term price signals are intended to attract any needed power supply by helping to cover the capital costs of investing in new electricity generation. Resources that clear the capacity market must be operational entering their performance year (i.e. three years after they clear the capacity market) and must offer into the day-ahead energy market to ensure their availability. However, Intermittent Resources, Capacity Storage Resources, Demand Resources, and EE Resources are categorically exempt from the must-offer requirement.

Beginning with the 2020/2021 delivery year for capacity, new "Capacity Performance" requirements were fully instituted that increased the incentives to meet reliability obligations. Resources that cleared the capacity market must be able to deliver energy and reserves throughout the entire year during system emergencies or pay penalties for non-performance. Bonuses and penalties have an impact on supply offers into the capacity auction because there is an opportunity to earn revenue during emergency events.¹⁴⁶

¹⁴² PJM, "Governance."

¹⁴³ PJM, "Committees and Groups."

¹⁴⁴ Astrape Consulting (2019), "Capacity Value of Energy Storage in PJM."

¹⁴⁵ PJM (2020), "PJM Manual 18: PJM Capacity Market." Sec. 5.4.1.

¹⁴⁶ PJM (2020), "PJM Manual 18: PJM Capacity Market." Sec. 1.5.

Subsequently, ESRs have several options to participate in RPM: 1) participate as standalone resources, risking non-performance based on the expected output; 2) aggregate with other resources to provide the required year-round capability; or 3) participate as seasonal resources.¹⁴⁷

In a 2019 study of the capacity value of energy storage in PJM, Astrapé Consulting simulated the entire PJM electric system plus those of its direct neighbors and found that energy storage systems with duration capability of 4 hours can provide up to 4,000 MW of capacity of equivalent reliability value to that supplied by conventional resources.¹⁴⁸ Storage systems with 6-hour duration can provide up to 8,000 MW of capacity of equivalent reliability value to conventional resources. Within these limits, storage can replace traditional generation megawatt-for-megawatt with no reduction in system reliability.

Thus, a 4-hour duration requirement would correctly represent the capacity value of storage under current market conditions and would remain accurate until the amount of installed storage in PJM increases by two orders of magnitude. The study shows no justification for longer duration requirements, and that, at current levels of penetration, duration requirements longer than 4 hours reduce the capacity value of storage to well below the amount of traditional capacity it provides as equivalent service. The conclusion of the study was incorporated as a sensitivity analysis in this report and leads to significantly higher storage deployment.

In both the main and the reduced required duration analysis, capacity savings are quantified by multiplying the capacity value of storage with forecasted capacity costs and are assumed to be constant for any level of storage deployment within Pennsylvania. The capacity value of a storage system is equal to 10% of the total energy it can store if its duration is shorter than 10 hours and equal to the power rating if the asset has a duration longer than 10 hours.

An alternative to RPM is the Fixed Resource Requirement Alternative, in which an LSE can submit a plan to meet a fixed capacity resource requirement, as opposed to the variable capacity resource requirement included in RPM.¹⁴⁹

D.3 Energy Markets

PJM clears both day-ahead and real-time energy markets where the price for energy is determined by the cost of the last and most expensive resource needed to ensure that all of the demand on the system is met, subject to reliability and transmission constraints. Thus, as demand goes up, so does the price, both on an hourly basis in the day-ahead market and a five-minute basis in the real-time market.

PJM's energy markets ensure that adequate electricity is being generated to meet demand. The Day-Ahead Energy Market is a forward market in which supply-side resources specify the price level at which they are willing to generate electricity and demand-side resources specify the price level at which they are willing to consume electricity. The market clears taking into consideration the different bids, as well as other resource constraints. The hourly locational marginal prices for the next day reflect the cost of generating the electricity, as well as the congestion and losses that occur

¹⁴⁷ PJM (2018), "Intermittent Resource Participation in RPM for 2020/21 and beyond."

¹⁴⁸ Astrapé Consulting (2019), "Capacity Value of Energy Storage in PJM."

¹⁴⁹ PJM (2020), "PJM Manual 18: PJM Capacity Market."

moving that electricity across the transmission system. PJM's Real-Time Energy Market similarly calculates locational marginal prices (LMPs), but is a spot market, meaning that the electricity is procured for immediate delivery and prices are calculated at five-minute intervals based on real-time operating conditions. Resources that clear the day-ahead market receive a schedule and are committed to perform the following day, but because day-ahead load forecasts do not always accurately predict electricity demand the following day, and other changes can occur regarding the availability of generators transmission wires, the real-time market provides a means to reevaluate the system's needs and dispatch resources as cost-effectively as possible.

D.4 Ancillary Services Markets

The ancillary services markets help maintain a balance between supply and demand on the transmission system. Regulation and reserves are the two primary types of ancillary services, although PJM also compensates resources for non-market services.

D.4.1 Reserves

Reserves are resources that operate in standby mode so that they may be deployed within a specified timeframe to compensate for the loss of energy assets. PJM operates a synchronized reserve market, non-synchronized reserve market, and a day-ahead scheduling reserve market. Synchronized Reserve Market, the Non-Synchronized Reserve Market, the Day-Ahead Scheduling Reserve Market,

ESRs are eligible to provide reserves in PJM if they are connected to the grid and can provide energy in less than ten minutes, and if they are not connected to the grid but are still capable of providing energy in less than ten minutes. The synchronized reserve market is for resources that are connected to the grid and can be deployed in ten minutes or less. The synchronized reserve market is further divided into Tier 1 and Tier 2 resources, where Tier 1 resources are those that are already online and following economic dispatch but are not operating at full capacity and are able to increase their output. Tier 2 resources are all other resources that cleared the synchronized reserve market.

While these are not highly valuable markets, ESRs that are offering energy will be co-optimized by PJM's market model and may be called upon to provide reserves if their state-of-charge provides adequate ability for them to do so. Additionally, PJM removed the requirement to have an energy schedule to provide synchronized reserves, so it is possible for ESRs to only offer synchronized reserves which gives them added flexibility in how they provide services. However, without an energy offer, they will not get compensated based on their opportunity cost of providing energy, which could further reduce prices in a market that already does not provide significant value outside of shortage events.

Non-synchronized reserves are non-emergency energy resources that are not synchronized to the grid but are able to start up and provide energy within ten minutes. The day-ahead scheduling reserve market is for resources that can provide energy within 30 minutes. Offline and online generation as well as economic DR are eligible to provide day-ahead scheduling reserves.

D.4.2 Regulation

Regulation is the injection or withdrawal of real power by facilities capable of responding to the system operator's automatic generation control (AGC) signal and is used to keep system frequency

within acceptable tolerances as small discrepancies between supply and demand occur. In its regulation market, PJM uses two different signals for resources with different performance characteristics. A traditional signal, called RegA, dispatches slower, sustained-output resources such as steam and combustion resources. A faster signal, called RegD, dispatches faster, dynamic resources, such as battery storage.

PJM procures numerous ancillary services, with organized markets for regulation and reserves, as well as cost-of-service compensation for reactive power and black start. PJM's regulation market, and particularly its RegD signal described above are particularly well-suited for new storage technologies because faster moving resources which are inverter-based, such as batteries and flywheel systems, can very accurately follow AGC signals from PJM. Additionally, the pay-for-performance requirements of FERC Order 755 that now also require compensation for mileage has made participation in the regulation market an attractive revenue stream for ESRs. However, PJM's regulation market design is currently being disputed in settlement procedures at FERC because PJM changed its 15-minute neutral regulation signal to a 30 minute conditionally neutral signal.¹⁵⁰ The rationale for these changes relates to the fact that under the previous design, some RegD providers (including ESRs) were actually working against the needs of the grid.¹⁵¹

D.5 Non-Market Services

In addition to the ancillary services that PJM procures through its organized markets, PJM also compensates resources for providing non-market services, such as reactive power, blackstart service, and frequency response. Storage can provide many of these non-market services.

Reactive power helps maintain voltages within acceptable limits. All resources with a PJM interconnection agreement are required to have reactive power capability and operate within a specified power factor range. The costs of doing so are recovered through a cost-of-service rate in PJM's tariff. Energy storage systems located near areas where high reactance occurs can offset that reactance by generating or absorbing reactive power. All resources, including energy storage, are required to have reactive power capabilities as a condition of interconnection and can recover the capital costs of their reactive power capability through PJM's tariff. ESRs are also eligible to receive compensation for opportunity costs if they are dispatched to provide reactive power and must decrease their real power output to do so.

Black start resources are used to restart turbines after an outage and restore electricity to the grid. PJM selects units to meet black start needs identified in transmission owner restoration plans through an RFP process. Storage resources are eligible to submit proposals in response to such solicitations.

As the regional balancing authority, PJM is responsible for complying with NERC requirements for maintaining adequate primary frequency response on its system.¹⁵² Primary frequency response involves the rapid, automatic, and autonomous actions of generating facilities to arrest and stabilize frequency deviations. Frequency response allows the interconnected grid to maintain frequency

¹⁵⁰ *Energy Storage Ass'n v. PJM Interconnection, L.L.C.*, 163 FERC ¶ 61,157 (2018).

¹⁵¹ Note: More specifically, according to PJM participants they were working against controlling the Area Control Error, which is the measure used to maintain frequency within a specific control area.

¹⁵² NERC, "Standard BAL-003-1 — Frequency Response and Frequency Bias Setting."

within acceptable boundaries following the sudden loss of generation or load.¹⁵³ While FERC enabled market-based sales of primary frequency response in 2015,¹⁵⁴ it also later required all new facilities seeking interconnection service to install, maintain and operate a functioning governor or equivalent controls as a precondition of interconnection and created some accommodations for energy storage based on its energy limitations.¹⁵⁵

Category	2018 \$/MWh	2018 (\$ Millions)	2018 Percent of Total	2019 \$/MWh	2019 (\$ Millions)	2019 Percent of Total	Percent Change
Load Weighted Energy	\$24.65	\$19,498	61.4%	\$17.28	\$13,337	54.3%	(29.9%)
Capacity	\$8.37	\$6,624	20.9%	\$7.13	\$5,506	22.4%	(14.8%)
Capacity	\$8.34	\$6,600	20.8%	\$7.12	\$5,497	22.4%	(14.6%)
Capacity (FRR)	\$0.00	\$0	0.0%	\$0.00	\$0	0.0%	0.0%
Capacity (RMR)	\$0.03	\$24	0.1%	\$0.01	\$9	0.0%	(62.7%)
Transmission	\$6.10	\$4,823	15.2%	\$6.57	\$5,069	20.6%	7.7%
Transmission Service Charges	\$5.67	\$4,483	14.1%	\$6.16	\$4,756	19.4%	8.7%
Transmission Enhancement Cost Recovery	\$0.37	\$292	0.9%	\$0.35	\$270	1.1%	(5.4%)
Transmission Owner (Schedule 1A)	\$0.06	\$48	0.2%	\$0.06	\$43	0.2%	(6.8%)
Transmission Seams Elimination Cost Assignment (SECA)	\$0.00	\$0	0.0%	\$0.00	\$0	0.0%	0.0%
Transmission Facility Charges	\$0.00	\$0	0.0%	\$0.00	\$0	0.0%	0.0%
Ancillary	\$0.51	\$407	1.3%	\$0.46	\$352	1.4%	(11.2%)
Reactive	\$0.26	\$206	0.7%	\$0.28	\$214	0.9%	6.2%
Regulation	\$0.12	\$94	0.3%	\$0.07	\$57	0.2%	(37.6%)
Black Start	\$0.05	\$42	0.1%	\$0.05	\$41	0.2%	0.4%
Synchronized Reserves	\$0.04	\$32	0.1%	\$0.03	\$22	0.1%	(30.9%)
Non-Synchronized Reserves	\$0.01	\$9	0.0%	\$0.01	\$7	0.0%	(13.4%)
Day Ahead Scheduling Reserve (DASR)	\$0.03	\$24	0.1%	\$0.01	\$11	0.0%	(52.2%)
Administration	\$0.32	\$257	0.8%	\$0.32	\$249	1.0%	(0.6%)
PJM Administrative Fees	\$0.30	\$239	0.8%	\$0.30	\$231	0.9%	(1.1%)
NERC/RFC	\$0.02	\$16	0.1%	\$0.02	\$17	0.1%	7.4%
RTO Startup and Expansion	\$0.00	\$2	0.0%	\$0.00	\$1	0.0%	0.0%
Energy Uplift (Operating Reserves)	\$0.15	\$119	0.4%	\$0.07	\$56	0.2%	(52.3%)
Demand Response	\$0.00	\$3	0.0%	\$0.00	\$2	0.0%	(26.8%)
Load Response	\$0.00	\$3	0.0%	\$0.00	\$2	0.0%	(48.8%)
Emergency Load Response	\$0.00	\$0	0.0%	\$0.00	\$1	0.0%	0.0%
Emergency Energy	\$0.00	\$0	0.0%	\$0.00	\$0	0.0%	0.0%
Total Price	\$40.11	\$31,731	100.0%	\$31.83	\$24,571	100.0%	(20.6%)
Total Load (GWh)	791,094			771,929			(2.4%)
Total Billing (\$ Billions)	\$31.73			\$24.57			(22.6%)

Figure 40. Inflation-adjusted total prices in PJM: 2018 and 2019¹⁵⁶

D.6 Relevant FERC Orders

D.6.1 Order 755

FERC Order 755, enacted in 2011, established a two-part compensation model for frequency regulation services in ISOs/RTOs. FERC argued that the previous compensation structure did not adequately compensate for faster-ramping resources such as battery storage and incentivized uneconomical dispatch by ISOs/RTOs. The first part of the structure is capacity-based and reflects opportunity costs of providing the service. For example, generators will be compensated for costs incurred by a storage device that was dispatched at a time when it would have been more

¹⁵³ *Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response*, Order No. 842, 162 FERC ¶ 61,128 (2018).

¹⁵⁴ *Third Party Provision of Primary Frequency Response Service*, Order No. 819, FERC Stats. & Regs. ¶ 31,375 (2015).

¹⁵⁵ *Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response*, Order No. 842, 162 FERC ¶ 61,128 (2018).

¹⁵⁶ Monitoring Analytics (2020), “State of the Market Report for PJM.”

economical to recharge the asset. The second part is performance-based and pays for the impact and accuracy of a resource in responding to the dispatch signal. In response to this Order, PJM created its two signals for regulation: RegA and RegD.

PJM created these two signals in response to FERC Order 755, which required the ISOs/RTOs to pay regulation resources not only for the megawatt range over which they can move (their capacity), but also the amount that they move up and down in response to the AGC signal (their mileage). Since faster moving resources are better at following the AGC signal and do more work in the regulation market, these reforms helped ensure that those resources were being compensated for their superior performance.

D.6.2 Order 841

FERC issued Order 841 in February 2018 to require the ISOs/RTOs to remove barriers to the participation of ESRs in their capacity, energy, and ancillary service markets. As the provision of wholesale services became a more attractive business model for energy storage, some ISOs/RTOs started to revise their tariffs to improve access for ESRs, but the wholesale markets still were not accommodating their full capabilities and benefits. Original ISO/RTO market constructs were designed for centralized thermal generation and one-way power flows, which can create barriers to the participation of ESRs. Even where rules for storage had started to emerge, they often placed limitations on the services that ESRs could provide or were designed for the unique operating characteristics of specific storage technologies, such as pumped hydro. Opening the wholesale markets to emerging technologies so that they can compete on an equal basis with all other resources fosters competition in those markets, thereby helping to ensure efficient market outcomes and cost-effective rates for consumers.

Order 841 defined an “electric storage resource” as a resource capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid. Order 841 required the ISOs/RTOs to create a participation model (i.e. a set of market rules) for all energy storage technologies that recognizes their physical and operational characteristics and facilitates their participation in the ISO/RTO markets. The final rule included five primary requirements related to the participation of ESRs.

First, it required the ISOs/RTOs to ensure that a resource using the participation model for ESRs is eligible to provide all capacity, energy, and ancillary services. While ESRs will still need to meet the minimum technical requirements of providing these services, this reform makes sure the resources have access to the markets and are not unnecessarily prohibited from selling certain services.

Second, the ISOs/RTOs are required to ensure that a resource using the participation model for ESRs can be dispatched and can set the wholesale market clearing price as both a wholesale seller and wholesale buyer. This reform acknowledges the bidirectional characteristics of energy storage. Since energy storage can behave as both a generator and a consumer of electricity, Order 841 ensured that it is able to participate as both supply and demand.

Third, Order 841 requires the ISOs/RTOs to account for the physical and operational characteristics of ESRs in their participation models. The energy limitations and bidirectional capabilities of ESRs distinguish them from other energy assets. To ensure that ESRs are modeled and dispatched in a way that is consistent with their capabilities, ESRs must also be able to submit information about their

physical constraints or operational limitations either as a dynamic part of their market offers or as a static characteristic of the resource. Order 841 established that ISOs/RTOs must account for a list of 13 physical and operational characteristics, including state of charge, maximum charge and discharge rates, minimum charge and discharge rates, maximum state of charge, and minimum state of charge, among other characteristics. The list was intended to be broad enough to acknowledge the potential constraints of all energy storage technologies, but submission of the information was not mandatory if it is not relevant for a particular technology. ISOs/RTOs were also given the option to propose additional characteristics.

Fourth, because several ISOs/RTOs imposed minimum capacity requirements that created a barrier to entry for small ESRs, Order 841 requires that the ISOs/RTOs allow ESRs of at least as small as 100 kW to participate in the new participation models. This was also consistent with the requirement that transmission-connected, distribution-connected, and BTM storage resources be able to participate in the ISO/RTO markets, and the fact that many smaller ESRs are being developed today. However, the ability for greater participation also has the potential to complicate the interconnection, monitoring, and control of storage devices.

Lastly, Order 841 requires each ISO/RTO to ensure that ESRs are able to pay the wholesale price for their charging energy. This requirement extends to all resources that fall under the definition of ESRs in the Final Rule, and not just those that are using the participation model for ESRs. Because charging an ESR to sell electricity back into the wholesale markets is not an end-use of electricity, this qualifies as a wholesale transaction, and therefore the relevant wholesale rate is applicable. However, while wholesale rates are generally lower than retail rates –thus potentially improving the competitiveness of ESRs in the markets – ESRs were not precluded from paying the retail rate for their charging energy, buying it bilaterally, or charging off a co-located generator.

PJM Compliance

To comply with Order 841, PJM originally filed its proposed ESR Participation Model on December 3, 2018, and the revised compliance plan was enacted a year later on December 3, 2019. This participation model will allow ESRs to participate in PJM's capacity, energy, and ancillary services markets.

Because PJM currently only allows ESRs to participate as market sellers, it revised its tariff to ensure that they will be able to also act as market buyers and be eligible to purchase energy or related services from PJM markets. In its energy market, PJM has proposed a construct that it states will allow ESRs to participate and be dispatched as supply and demand and set the wholesale clearing price as both in a way that accounts for the unique characteristics of storage. Specifically, PJM proposes to model ESRs as one continuous resource by accounting for their entire positive (discharging) to negative (charging) range over a given hour. PJM also proposes to allow ESRs to participate in the day-ahead and real-time energy markets under three different modes: (1) continuous mode; (2) charge mode; and (3) discharge mode. Continuous mode allows ESRs to be dispatched along their entire operating range, while charge mode only allows them to participate with a negative dispatchable range, and discharge mode only allows them to participate with a positive dispatchable range. PJM incorporated many of the required physical and operational characteristics into the modeling of ESRs in the energy markets, although it will not be managing the

state of charge of ESRs or optimizing their output over time. The minimum size for all resources in PJM was already 100 kW, so it did not need to make any changes to the size requirements for ESRs.

For its capacity market, PJM proposed to revise the definition of a “Capacity Storage Resource” to include all types of storage technologies. PJM also proposes that the installed capacity megawatt value of Capacity Storage Resources will be based on the level of continuous output that the resource can sustain over ten hours. However, this proposal faces significant opposition in the comments filed by industry, and it is possible that FERC may require a shorter duration requirement that better reflects the output duration of new storage technologies such as batteries and offers a more cost-effective approach for consumers. Additionally, PJM clarified that it will not be changing its must-offer requirement for the day-ahead energy market or its capacity performance requirements for Capacity Storage Resources.

For reserves, PJM proposes that ESRs that are synchronized to the grid and operating in continuous, charge, or discharge mode may participate in the synchronized reserve market, and that they can do so without offering into the energy market and being co-optimized across energy and reserves. This provides some added flexibility in how ESRs can provide reserves and may improve competition in that market. Additionally, PJM clarifies that if an ESR is disconnected from the grid and is capable of providing energy within ten minutes then it may participate in the non-synchronized reserve market. PJM proposes that ESRs that want to participate in the day-ahead scheduling reserve market would need to inform PJM that it would like to be considered and would require an energy schedule.

For regulation service, PJM proposes that an ESR may elect to provide both energy and regulation or regulation only. When the resource is providing regulation and energy, it may be in continuous, charge or discharge mode, and its potential regulation capacity will be determined by the operational limits of the mode it is operating in. While these are relatively minor changes to the regulation market, it is worth noting that ESA filed a complaint against changes that PJM made to its regulation market in 2017 and that the current market design is currently being contested in settlement procedures before FERC.¹⁵⁷ Lastly, PJM clarifies that ESRs are eligible to receive compensation for reactive power capability and dispatch and that they may participate in solicitations for black start service.

PJM’s FERC Order 841 reforms for the participation of ESRs in the capacity market have not improved the market opportunity, and arguably have made it worse. PJM maintained the same capacity performance and must-offer obligation rules and created a ten-hour duration requirement for the ESR participation model. Because increasing the duration of new storage technologies like batteries can drastically increase their costs, it would be prohibitively expensive under current technology prices to design a system that can discharge for ten hours at its maximum output. PJM did clarify that ESRs may de-rate their capacity to meet the ten-hour requirement, which means that a 1MW/1MWh battery could offer 100 kW into the capacity market as that is the quantity that it is able to discharge for ten hours. However, this is only a fraction of the capability of the resources, and numerous arguments were made by commenters on PJM’s filing that the 10-hour requirement goes well beyond what the operator needs to meet peak demand, is significantly longer than the capacity

¹⁵⁷ *Energy Storage Ass’n v. PJM interconnection, L.L.C.*, 163 FERC ¶ 61,157 (2018).

duration requirements in any of the other ISOs/RTOs,¹⁵⁸ is unnecessary and redundant due to the capacity performance requirements and over-procures capacity which raises costs for consumers. Due to the significant pushback on PJM's capacity market proposal, and the other open capacity market proceedings, significant uncertainty exists regarding future opportunities in the capacity market for ESRs.

D.6.3 Minimum Offer Price Rule

On December 19, 2019, FERC issued an order which directed PJM to expand its existing MOPR to nearly all state-subsidized capacity resources.¹⁵⁹ In this context, resources that have been mandated to deploy as part of a state's strategy to decarbonize its electric grid or minimize its carbon and criteria pollutant emissions would be subject to MOPR, significantly limiting their opportunity to economically benefit from the RPM capacity market.

D.6.4 Order 2222

FERC Order 2222, issued September 17, 2020, enables DER aggregators to participate in the regional organized wholesale capacity, energy, and ancillary services markets alongside traditional resources. DERs are defined as small-scale generation or storage technologies that provide an alternative to (or an enhancement of) the traditional electric power system. They can be located on a distribution system, a subsystem, or behind a customer meter.

Building on Order 841, Order 2222 provides an opportunity for energy storage by providing new revenue streams for which they are uniquely suited. This is expected to be a very challenging and complicated process due to the complex nature of DERs and the necessary considerations for their integration.

In their compliance plans, ISOs/RTOs will need to revise tariffs to establish DERs as a category of market participant and set a size requirement for resource aggregations that do not exceed 100 kW. Additionally, compliance plans will include details on export limitations, locational value of DERs, and definitions of market participation for aggregated DERs, and metering and telemetry requirements, among other aspects. The rule also directs the grid operators to allow DERs that participate in one or more retail programs to participate in its wholesale markets and to provide multiple wholesale services, but to include any appropriate, narrowly designed restrictions necessary to avoid double counting.

The deadline for ISOs/RTOs, including PJM, to file compliance plans with the Order is in July 2021.

¹⁵⁸ Note: For example, the CAISO requires a 4-hour capacity duration to fulfill system resource adequacy requirements. Recently, NYISO had also proposed moving from a 4-hour duration requirement to a longer 8-hour duration requirement to receive full capacity credit. After further studies, the NYISO revised its proposal to arrive at a 6-hour duration for full capacity credit, and 90% credit for 4-hour duration.

¹⁵⁹ FERC, Docket Nos. EL16-49-000 and EL18-178-000.

Appendix E: Detailed Methodology and Results of Analysis

E.1 Solar-Plus-Storage Analysis

To conduct the analysis, we first considered a “base case” without storage which consisted of a solar PV system that was sized to produce annual energy (in MWh) equivalent to the overall energy consumption of a large C&I customer. For this we assumed the load profile for a large office building in southeastern Pennsylvania which equates to the energy output of a solar PV system size of 5.2 MW (DC) capacity. Additionally, we assumed a base solar PPA price of \$31/MWh, which equates to recently reported solar PPA prices in PJM.

Next, we considered the incremental storage that could be added to better match the customer’s hourly load profile while limiting charging from the grid to less than 20% of total MWh. This grid charging limitation reflects both a) the necessary requirements to ensure full capture of the federal ITC (which requires charging from solar of at least 75%), and b) a resource that can provide the lion’s share of the customer’s 24x7 need.¹⁶⁰

A least-cost optimization model was then used to determine the optimal configuration of the storage resource needed to deliver the time-matched energy under these constraints. This analysis similarly relied upon historical PJM locational marginal pricing information for Pennsylvania.

Note that this analysis does not include a full assessment of the potential long-term benefits that could be delivered to a solar-plus-storage provider if: a) PJM capacity market rules were changed to allow for more robust solar-plus-storage participation, b) additional grid values were monetized (e.g. T&D upgrade deferrals), or c) or additional externalities were included (e.g. full social cost of carbon values).

The storage resource cost and performance assumptions were similar to those used in the standalone BTM analysis.

E.2 Behind-the-Meter Analysis

The analysis of energy storage potential for standalone BTM applications focuses on the benefits to BTM system owners. As utility customers, these BTM system owners can achieve savings on their utility bills from the controlled dispatch of the BTM system. By selectively charging and discharging the battery, the BTM system can reduce both the demand charges and energy charges by adjusting the electricity required from the utility.

For the purpose of this analysis, Strategen quantified the benefits of standalone storage for a sample C&I customer in Pennsylvania. The analysis considered four different storage configurations of differing capacities and durations:

1. 150-kW capacity, 2-hour duration
2. 150-kW capacity, 4-hour duration

¹⁶⁰ Note: By limiting grid charging to 20%, this results in a minimum of 80% the customer’s full 24x7 energy needs being met by solar energy. While we recognize this is not a complete 24x7 solution, it still represents a substantial step towards that objective, which will be more readily realized as more renewable energy comes onto the PJM system.

3. 300-kW capacity, 2-hour duration
4. 300-kW capacity, 4-hour duration

E.2.1 Model Framework and Optimization

To perform this analysis, Strategen developed a BTM model written in Python, which includes an optimization framework to minimize the electric utility bill. Given a yearly load profile, tariff rate, and BTM system size in power (kW) and duration (hours), the BTM model models the optimal dispatch of the BTM system over the monthly billing period and is repeated for all 12 months of one year.

The model output includes the resulting dispatch profile, peak load, and bill for each month, stored as CSV files. A flowchart of the modelling process is provided below.

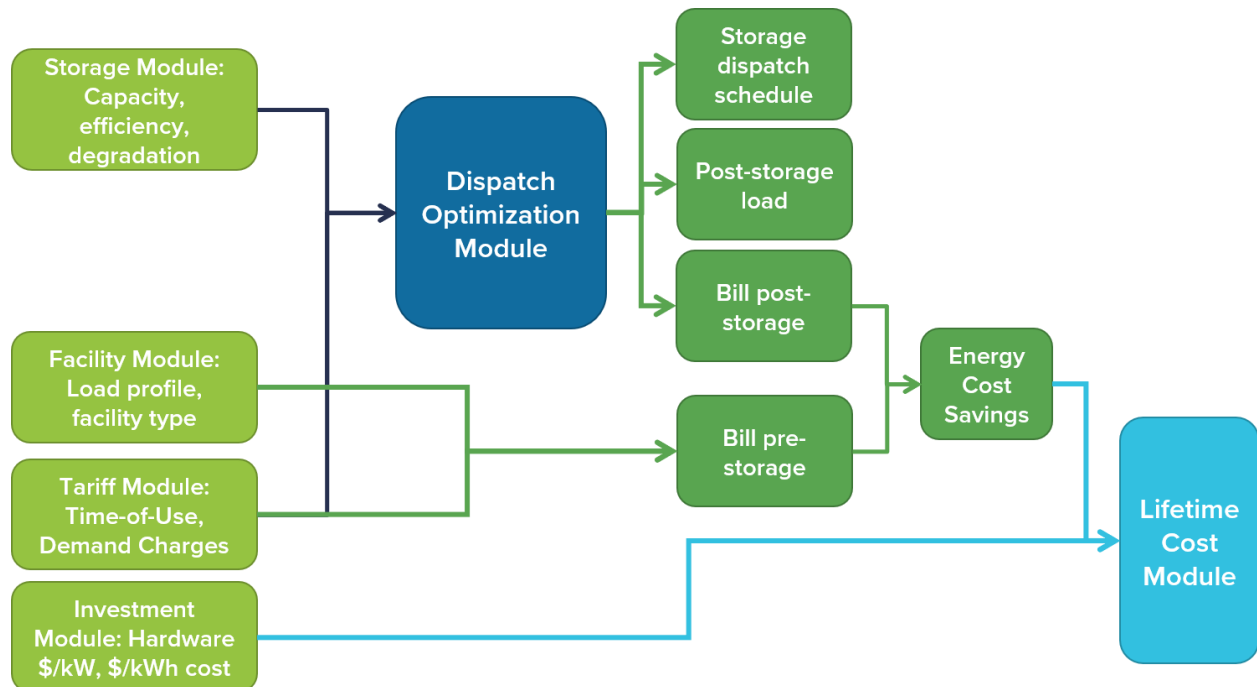


Figure 41. Behind-the-meter model structure

The model output below shows the effect of the optimized BTM system dispatch on the facility load. The new load shows reduced peak load demand during on-peak times with demand charges and increased load charging during off-peak hours.

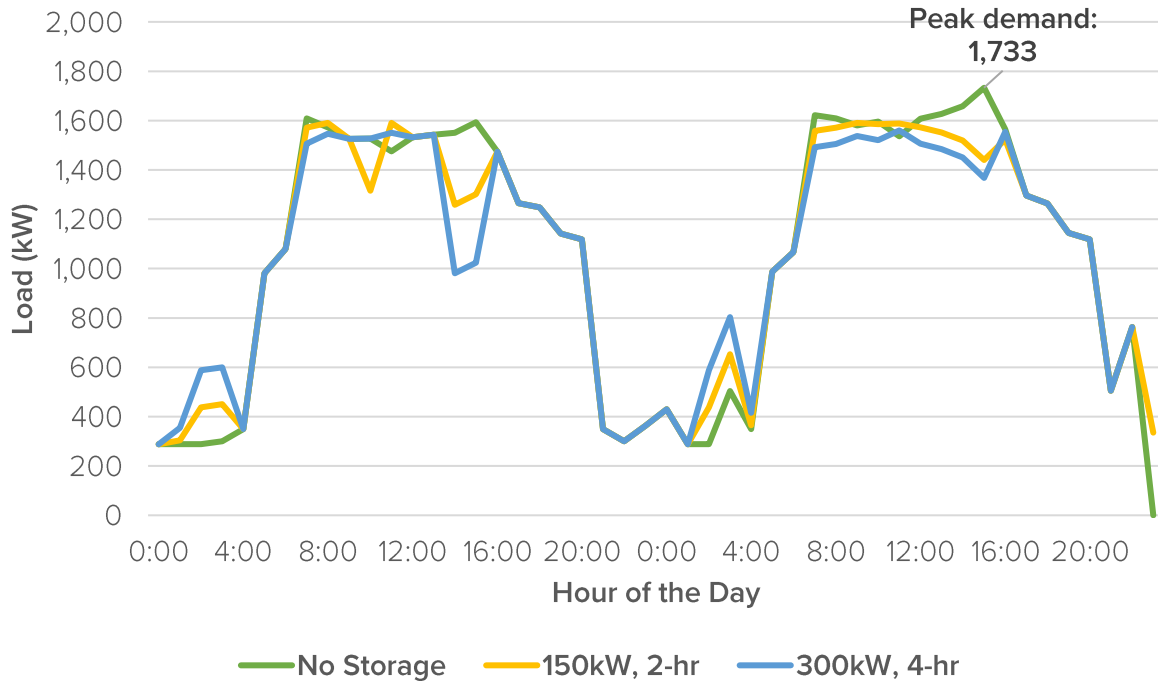


Figure 42. Sample model output for two storage systems

E.2.2 Inputs & Assumptions

Storage Characteristics

The analysis considered four different commercial/industrial, standalone, lithium-ion battery storage systems configurations: a 100-kW/2-hour system, a 100-kW/4-hour system, 150-kW/2-hour system, a 150-kW/4-hour system, a 300-kW/2-hour system, and a 300-kW/4-hour system. All the storage configurations are assumed capable of fully discharging with an efficiency of 95% for both charge and discharge, or approximately a 90% round-trip efficiency.

Facility Load Profile

The BTM benefits analysis was conducted for a typical C&I customer. Strategen did not analyze the potential benefits of storage for residential customers due to the fact that tariffs available to residential customers do not have pricing structures, such as demand charges, that are conducive to storage.

As a customer's utility bill is based on the amount and timing of electricity consumption, the hourly load profile is an important consideration. The analysis considered a simulated load profile from a sample large office building in southeastern Pennsylvania from the DOE's Commercial Reference Buildings Dataset.¹⁶¹

Actual individual customer loads may vary widely from the proxy load used in this analysis, particularly considering the large number of customers on the tariff. In the presence of demand

¹⁶¹ OpenEI, "USA_PA_Philadelphia.Intl.AP.724080_TMY3/."

charges, customers with wider deviations in their demand and higher peak demands may benefit more from energy storage, because storage may have a greater impact in reducing peaks and demand charges. Although these assumptions are not fully representative of actual customer data, they nonetheless allow for general trends and comparisons to be made between different tariffs, loads, and system costs.

In order to properly evaluate the effects of load on BTM system performance, a simulated load profile for a sample large office building in southeastern Pennsylvania was taken from the DOE Commercial Reference Buildings dataset.¹⁶² This simulated load demonstrated an annual peak demand of 1,733 kW.

Retail Tariff

For the purpose of this analysis, Strategen quantified the benefits of storage for a small general service customer (for non-residential service at secondary voltage). Strategen utilized a rate that includes energy charges (\$/kWh) and demand charges (\$/kW), in addition to a monthly fixed distribution charge.¹⁶³

Strategen did not consider customer participation in DR programs in its analysis due to the limited number of customers of these programs. For example, only a small number of facilities, approximately 70, participated in PPL's Demand Response Program in 2019.¹⁶⁴

Strategen utilized one of PPL's tariffs for small general service (GS) customers (for non-residential service at secondary voltage). Under this tariff, customers incur energy charges (\$/kWh) and demand charges (\$/kW), in addition to a monthly fixed distribution charge and several riders. The billing demand is defined as the average kW during the 15 minutes of the billing period with the highest demand. Energy and demand charges are broken out by distribution, transmission, and generation, and, to an extent, are dependent on PJM's real-time LMPs and capacity prices. LMPs and capacity prices were based on 2019 actual data.

Strategen is aware that PPL offers a TOU rate option for GS-1 and GS-3 rates for residential and small C&I customers with peak demand of less than 100 kW. Under this rate, generation charges vary by time of day and season, superseding the portion of the tariff that is dependent on PJM prices.¹⁶⁵ This option was introduced in 2019, and fewer than 20 customers are currently utilizing the TOU option.¹⁶⁶ Because of the limit placed on peak demand for eligibility for this tariff, as well as the limited customer participation, Strategen did not incorporate this tariff into its analysis.

Strategen also examined electric tariffs offered by PECO and found a notable difference between the demand charges in PECO and PPL's tariffs for similar customer classes. For example, PECO's GS tariff includes a distribution demand charge of \$8.59 per kW of billed demand,¹⁶⁷ while PPL's

¹⁶² OpenEI, "USA_PA_Philadelphia.Intl.AP.724080_TMY3/."

¹⁶³ PPL Electric Utilities (2015), "Rate Schedule GS-1."

¹⁶⁴ Cadmus (2019), "PPL Electric Utilities Demand Response Annual Report to the Pennsylvania Public Utility Commission."

¹⁶⁵ PPL Electric Utilities (2020), "General Tariff Rules and Rate Schedules for Electric Service."

¹⁶⁶ PPL Electric Utilities, "PPL Electric's Default Service Program."

¹⁶⁷ PECO Energy Company (2020), "Supplement No. 43 to Tariff Electric Pa. P.U.C. No. 6."

comparable GS-3 tariff includes a distribution demand charge of \$3.985 per kW of billed demand.¹⁶⁸ Under the conditions of this analysis, one of the primary benefits of storage is the avoidance of demand charges; therefore, Strategen utilized PPL's tariffs in order to examine the outcomes based on more conservative circumstances.

Energy Storage System Costs

The cost of each system size was calculated using cost data for a commercial/industrial, standalone, lithium-ion battery system, as reported by Lazard in the most recent levelized cost of storage (LCOS) report. The energy capital cost for standalone batteries ranges from \$319/kWh to \$400/kWh and the capacity capital cost from \$56/kW to \$67/kW.¹⁶⁹ In calculating the cost-benefit analysis, the most conservative (i.e. the highest) costs were utilized for the purpose of this analysis.

E.2.3 Financial Model Results

The resulting utility bills are compared to the utility bill without the BTM system to produce a yearly bill savings for each system size. Using the yearly bill savings and the system cost, the payback period, the NPV, and the IRR are calculated for each system size. A discount rate of 8% was assumed. Battery degradation is not considered for yearly savings and is assumed to operate optimally at full rated capacity throughout the payback period.

E.3 Limitations

While these analyses provide a reasonable initial estimate of storage's potential value in Pennsylvania, we also advise caution on the use of the analysis due to a variety of limitations:

- *Future uncertainty:* The model assumes perfect foresight and, as such, provides a higher bound of the expected savings. Some inputs into the analysis are dependent on historical data or assumptions that contain substantial uncertainty (e.g. PPA prices, load forecasts, etc.). While reasonable projections of these future values were used, there is a possibility that these projections will be inaccurate. Market dynamics may ultimately have a large effect on certain forecasts.
- *Data availability:* Due to limited data availability, certain portions of the analysis were either simplified or generic approximations were used that may not be specific to Pennsylvania circumstances. For example, a sample load profile from a commercial customer in southeastern Pennsylvania was taken from a DOE dataset, rather than a specific or typical PPL or PECO customer's load profile. These inputs should be updated as further analysis is conducted.
- *Unquantified Benefits:* Several benefit categories are more difficult to quantify and were not included within the limited scope of this analysis. However, they may warrant further investigation. Some of these include:
 - Reliability
 - Resilience
 - Voltage control

¹⁶⁸ PPL Electric Utilities (2020), "General Tariff Rules and Rate Schedules for Electric Service."

¹⁶⁹ Lazard (2020), "Levelized Cost of Storage."

- Avoided transmission costs
- Avoided criteria pollutants

Finally, the analysis in this report focuses on standalone energy storage systems. However, it should be recognized that many customers in Pennsylvania are exploring and implementing BTM solar-plus-storage systems, particularly to take advantage of the federal ITC as it steps down.

