

# Energy Storage and the Law of Averages

How Storage Can Make Electricity  
More Affordable

March 2026

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## Abstract

The electric grid is planned, built, and operated to satisfy peak demand. But because peak demand only occurs for a few hours per year, customers end up paying full price for grid infrastructure that is only used for a small fraction of the year—an increasingly expensive proposition as peak demand continues to grow and more infrastructure is required to meet it. The emergence of cost-competitive energy storage technologies in recent years, however, offers the potential for a grid that is planned, built, and operated based on average demand. By strategically siting and operating energy storage throughout the electric grid, excess generation in low-demand periods can be captured and stored near customers, which then reduces the amount of electricity that needs to be generated and moved through the transmission and distribution systems during high-demand periods. This paper describes these potential benefits, supported by real-world examples of energy storage projects that have created cost savings, which points to the potential for profound and far-reaching reductions in the cost of electricity if energy storage technologies are deployed at scale throughout the electric grid. These examples will be of use to system planners and operators, utility regulators, decision makers, and stakeholders in those processes as they look for opportunities to reduce the cost of electricity in their respective systems and jurisdictions.

## Acknowledgments

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## Acronyms and Abbreviations

APS	Arizona Public Service
BTM	Behind-the-meter
CAISO	California Independent System Operator
CVR	Conservation Voltage Reduction
DG	Distributed Generation
EIA	Energy Information Administration
GMP	Green Mountain Power
GW	Gigawatt
kW	Kilowatt
MISO	Midcontinent Independent System Operator
MW	Megawatt
MWh	Megawatt-hour
NERC	North American Electric Reliability Corporation
SCE	Southern California Edison
WECC	Western Electricity Coordinating Council

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## 1.0 Introduction

Imagine for a moment that all the groceries you buy have a shelf life of one day. Whether you store them in a pantry, refrigerator, or freezer, everything goes bad by the end of the day, so you have to plan and buy each day's food the night before.

The good news in this thought experiment is that grocery prices include delivery; you just put in your order each night, and it is delivered the next day at no additional charge. The bad news is everyone else does this as well and the roads are clogged with delivery vehicles at times.

Most of the challenges in this scenario fall on grocery stores, which are responsible for meeting whatever demands come in each night. Failure to do so means lost revenue, fines, and maybe lost customers. So, to make sure they have the means to meet each day's demands, grocery stores contract with a wide range of suppliers to make sure they can meet customer needs, even if it's securing a year-round contract with a large turkey farm just to meet customer demand on Thanksgiving Day. Of course, this means that there must be enough food producers to meet each day's demand for all grocery stores and that each grocery store must have its suppliers reasonably close by. In summary, there needs to be a significant number of food production facilities—such as farms, dairies, mills, and factories. And once all that supply is developed and contracted, grocery stores must still manage the logistics of shipping in their supplies each night, which requires each store to maintain its own fleet of large trucks.

In some regions of the country, large trucking unions have come together to coordinate shipments, ensure enough trucks are on the road, and plan for new roadways. But people need to eat, and the growing demand for food, roads, and vehicles is getting expensive. Figuring out where to put new roads is becoming an increasingly costly and time-consuming process, and in some places, people tired of giving space to roads are starting to oppose their construction.

Meanwhile, some people have started growing their own food to reduce costs and help the system, though matching their production to their needs is challenging, and it can be difficult to sell their excess production or find a driver to deliver it. Figure 1 illustrates this system:

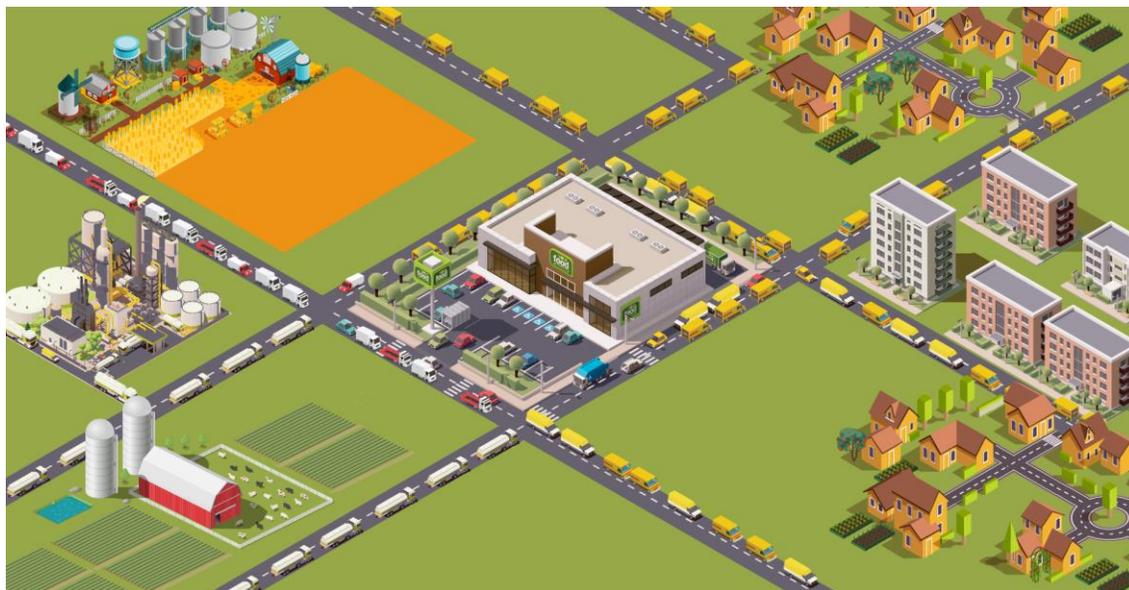


Figure 1: What the world might look like if groceries could not be stored

## 1.1 From the Grocer to the Grid

The preceding scenario is admittedly extreme when applied to groceries. But there is something we all buy every day that does operate in a world of real-time production and delivery: electricity. Of all the things we buy—food, water, gas, electronics, clothing—electricity is the only thing that doesn't have storage built into its supply chain. Where other products can be stored in warehouses, freezers, tanks, and granaries, electricity is unique in that it is produced, shipped, and consumed in real time. Thus, just as in the example above, the electric grid requires a large and diverse amount of production (generators), a trucking fleet to bring in production (the transmission system), delivery drivers to carry products to customers (the distribution system), and a company to manage those processes (a utility).

It helps that electricity can be produced and delivered at nearly the speed of light, which makes it possible to balance supply and demand in real time. But this balancing act is expensive. It requires construction and maintenance of enough generators and wires to meet the highest level of customer demand, even if that demand only happens for a few hours a year. To ensure demand is met even in the event of routine interruptions, redundancy must be built into both the generation and delivery systems, which requires additional resources and expenses.

The result is an electric system that is designed and built around peak demands; a system that is underutilized most of the time but that must still be paid for all the time. Figure 2 illustrates this point using a load duration curve, which plots the total electric demand in the U.S. during every hour of 2024 and then organizes those hours from the highest to the lowest.

As Figure 2 demonstrates, average hourly electric demand in the U.S. in 2024 was 477,774 megawatts (MW), and maximum demand was 745,020 MW (EIA 2025a). If electricity were like any other commodity with storage in its supply chain, then 477,774 MW of generation would have been sufficient to meet all electric demand over the year, with excess production during low-demand periods stored for usage during high-demand periods. Since electricity is not like other commodities, 745,020 MW of generation—a 56% increase over the average—were needed to meet demand. That difference of 267,246 MW between the average and peak demands is the equivalent of building Plant Vogtle—the largest nuclear plant in the country at about 4,700 MW—57 times.



Figure 2: U.S. Load Duration Curve, 2024

A similar issue arises in the transmission system, which must also be built large enough to deliver electricity during peak periods, even though those periods only last for a few hours per year. The Western Electricity Coordinating Council (WECC), which oversees electric reliability in the Western U.S., measures transmission utilization in its region using three tiers: how often a line exceeds 75 percent of its rated capacity, how often it exceeds 90 percent of its rated capacity, and how often it exceeds 99 percent of its rated capacity. Recent third-party analysis

of projected 2030 demand on five major transmission pathways in WECC concluded that those five pathways would exceed 75 percent of their rated capacity between 0 and 33 percent of the time and would exceed 90 percent of their rated capacity between 0 and 19 percent of the time. None of them would ever exceed 99 percent of their rated capacity (Oikonomou et al. 2024).

A similar analysis by WECC took a longer-term view of how seven major transmission pathways would be used in 2044. That analysis concluded that those pathways would still operate at less than 75 percent of their rated capacity for most of the year (between about 57 and 98 percent of the time, depending on the line). However, the analysis also found that sustained periods of extreme heat or extreme cold would require four of those seven paths to operate at or near their maximum capacity for extended periods (WECC 2024).

From the generators that produce electricity to the wires that deliver it, the electric grid was planned and built based on peak demand. A grocer can store inventory to create a buffer between supply and demand, thereby supporting a steady stream of production and delivery from suppliers while allowing customers, who can also store groceries at home, to shop when they want. An electric utility, on the other hand, must acquire enough electric generation to meet all its customers' demands, even if it must contract with generators that it only uses for a few hours per year (like the turkey farm in our thought experiment above). After all those generation resources are contracted, the utility must then build a grid large enough to ensure that the electricity they generate can be delivered to customers at any time, which is ensured by planning and building a grid large enough to meet peak demand.

The electric grid had to be built this way because the technologies to store electricity were not readily available at the time. Even though pumped storage hydropower has been around since the earliest days of the U.S. electric grid, its scale and geographic requirements only allowed energy to be stored at a few, limited points. It was not until the last decade, with the arrival of commercially available battery technologies that can be flexibly sited throughout the grid, that the potential for widespread storage across the electricity supply chain became possible.

Adding storage throughout the electric supply chain allows for a fundamental shift from a grid that is designed and built based on **peak** demand to a grid that is designed and built based on **average** demand. In this way, energy storage has significant potential to reduce the cost of electricity by reducing the amount of infrastructure required to produce and deliver it. Just as the ability to store groceries across the supply chain means fewer producers, less shipping, and fewer delivery drivers are needed, the widespread deployment of energy storage on the electric grid means less generation, transmission, and distribution will have to be built. This creates the potential for profound, widespread reductions in electricity costs.

This paper will explore the ways in which energy storage is already reducing electric costs, drawing from real-world examples, and then discuss the potential for deeper and more widespread savings if energy storage technologies can proliferate throughout the grid. It will explore how energy storage can average out power production by shifting low-cost, excess generation in low-demand periods to displace higher-cost generation during high-demand periods (Section 2). It will then discuss how adding storage throughout the transmission system (Section 3) and distribution system (Section 4) can average out power flows to reduce the amount of electricity that needs to be delivered during peak periods, thereby reducing the amount of transmission and distribution infrastructure needed. Finally, it will discuss how electric consumers can use storage to average out their own usage, creating bill savings and increased resilience in the process (Section 5). Section 6 will summarize and conclude.

## 2.0 Generation

Electricity demands vary minute by minute, hour by hour, and day by day. While their magnitude changes by season and region, these variations in demand are constant. Power plants meet these demands through designed performance for one of three load ranges: baseload, or meeting a minimum amount of electricity demand over a period of 24 hours; intermediate load, or meeting the daily load increase that typically occurs from mid-morning until evening; and peaking, or meeting short-term periods of high demand. Figure 3 illustrates this relationship, showing how these different resource groups are dispatched throughout the day as load (curving line) changes. Utilities and power producers typically dispatch intermediate and peaking resources on a cost-based basis, meaning that the most expensive resources are dispatched only to meet peak demand and meeting peak demand therefore has a disproportionately expensive overall cost.

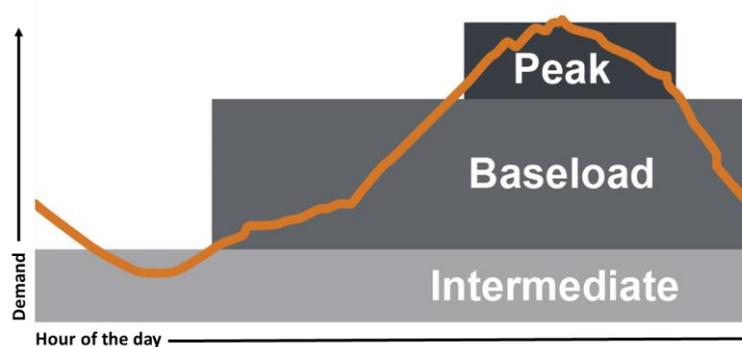


Figure 3: Energy Generation Classes

Because of this, retail electricity prices are heavily influenced by the cost of just a few hours of annual peak demand. As *peak* prices climb, so do *overall* prices, and the ability to offset this peak cost could disproportionately reduce overall electricity costs. To use our previous grocery analogy, battery storage can serve as a pantry, allowing us to purchase in bulk when prices are low and use those reserves, instead of purchasing during peak demand, when prices are high.

Energy storage performs one simple function: shifting energy from one point in time to another. By performing this action with different quantities of energy and over different time scales, storage systems can help reduce generation costs in four ways: ancillary services, energy arbitrage, peak shaving, and avoided construction of peakers. This section will describe and illustrate each of these applications in greater detail.

Figure 4 illustrates the relationships between these benefits in relative terms of duration (how much energy is stored overall, or MWh) and how much storage there is (the overall size of the storage fleet, or MW). As more storage is added to the grid and provides service over longer periods of time, the values it can provide for the generation system change.

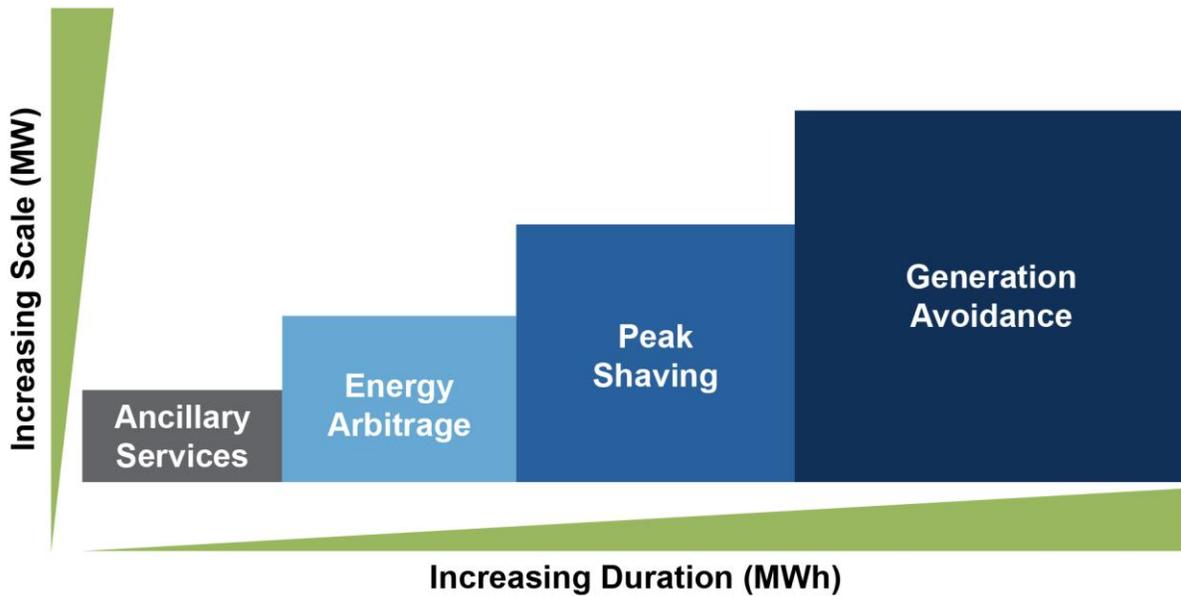


Figure 4: Generation benefits of energy storage

## 2.1 Ancillary Services

Safe and reliable operation of the electric grid requires generation and load to be kept in near-perfect balance. But because both sides of that equation are constantly changing, the grid needs energy resources that can quickly change their output to correct imbalances between generation and demand. Because battery energy storage assets can instantly respond to changes in grid conditions and can both inject and withdraw electricity, they are well-suited to provide ancillary services more effectively and at a lower cost than the generators that have historically provided these services.

As an additional benefit, using energy storage for ancillary services frees up generation resources to provide other valuable services. For example, when temperatures dropped in Texas in January 2024, the state's growing battery storage fleet stepped in to meet ancillary service needs, which released 3 GW of gas generation to meet high demand and saved \$750 million in day-ahead energy market costs (Aurora Energy Research 2025a).

The following case study illustrates how PJM, the largest regional energy market in the U.S., reduced costs when it became an early adopter of energy storage in its ancillary service markets.

## Ancillary Services in PJM

### Case Study



**Summary:** PJM updated its market rules in 2012 to allow energy storage to participate in ancillary service markets for frequency regulation and be paid based on their performance instead of their nameplate capacity.

**Benefits:**

- Reduction in ancillary service costs: \$1.2 million in first year
- Released generators to participate in capacity and day-ahead energy markets (not quantified)

**Outcome:** The increased efficiency of energy storage for providing ancillary services reduced the amount of MWs that PJM needed from about 1,600 MW in 2011 to 700 MW by 2013 (Wolff 2014).

## 2.2 Energy Arbitrage

Where ancillary services involve short-term periods (seconds to minutes), battery storage can also reduce power costs by storing electricity when prices are low and discharging over several hours when prices are high in day-ahead and real-time markets. When providing this service, arbitrage delivers savings by reducing fuel costs for generation by less efficient, higher-cost plants. Of the installed, utility-scale battery energy storage systems in the U.S., 57 percent support reduced power costs through arbitrage and an even greater number are in the planning stage for arbitrage use (U.S. Energy Information Administration 2025a).

When providing arbitrage, energy storage can increase the utilization of low-cost baseload generation, reduce the amount of variable generation that would otherwise be curtailed, and reduce market costs overall (Ölmez et al. 2024). Additionally, because ancillary services like frequency regulation require momentary changes in output, and energy storage technologies can instantly change their output, energy storage projects can provide both arbitrage and ancillary services simultaneously, providing the opportunity for further savings.

The following case study illustrates how energy storage can provide significant savings, even through short-term arbitrage windows.

## Energy Arbitrage in Texas

### Case Study



A heat wave in August 2023 pushed electric demand in Texas to the system's limits. In response, electricity prices rose to their statutory limit of \$5,000 per kilowatt (kW). In response, the market operator dispatched 1.8 GW of battery storage and prices immediately fell by almost 50 percent, saving ratepayers millions of dollars in one day (Gonzales 2024).

## 2.3 System Peak Shaving

Arbitrage provides short-term savings on fuel costs and market purchases. But when large quantities of energy storage regularly inject large amounts of energy during high-demand periods, they provide a service called peak shaving that offers another level of savings. Of the installed, utility-scale battery systems in the U.S., 42 percent support reduced power costs through peak shaving and the number of plants providing this service is expected to grow by 50 percent in the next few years (U.S. Energy Information Administration 2025a).<sup>1</sup> Peak shaving is particularly relevant in regional energy markets that allocate the cost of energy resources to different utilities and their customers based on each utility's total demand during peak periods. Several regional energy markets use this approach, as do many utilities that serve customers in different states.

By using energy storage to reduce demand during peak periods, utilities and their customers subject to this kind of regional allocation can reduce both the overall generation costs for all customers in the region, while further reducing their share of the remaining costs. Predictable, long-term peak shaving by energy storage can also have positive long-term effects on energy system prices. For example, one study found that adding 11 GW of battery storage within the Midcontinent Independent System Operator (MISO) footprint could save up to \$4.5 billion in power costs between 2025 and 2035 (Aurora Energy Research 2025a). The analysis projected hourly generation process through 2035, projecting that inclusion of battery storage could reduce the peak daily price from \$245.30/MWh to \$86.90/MWh, a difference of \$159/MWh on peak demand days. The study also found average planning resource auction price reductions of \$35/MW-day by 2030 as the result of battery storage.

The following case study illustrates how California is reducing electricity costs through the coordinated operation of customer-owned energy storage systems to shave system peaks.

### Peak Shaving in California

### Case Study



Through various programs, California has assisted customers with the installation of energy storage systems for many years. In 2025, one of those programs, the California Demand Side Grid Support Program, tested its potential by calling on all participating customers, who collectively owned about 700 MW of energy storage, to discharge their systems at the same time.

Of the 700 potential MW, 539 MW responded, reducing peak demand by about 1.9 percent. When the program reaches its expected peak of 1,300 MW in 2028, the program is expected to deliver between \$28 and \$206 million in net savings (Hledik et al. 2025).

<sup>1</sup> EIA allows energy storage project owners to select multiple use cases; many projects are providing multiple services, so the use case percentages described in this section add to more than 100 percent.

## 2.4 Generation Construction Avoidance

When energy storage systems can provide peak shaving on an extended and predictable basis, they create additional savings by avoiding or deferring the construction of peaking electricity plants. As previously discussed in this section, the highest levels of electric demand are usually met with peakers—power plants fueled by natural gas or refined oil and designed to quickly come on and offline for a few hours at a time. But this flexibility comes at a cost; these units generally have much higher heat rates than other power plants, meaning that they require more fuel to generate a unit of electricity. When battery storage provides peak shaving at scale, it can avoid or defer the need for additional peaker plants, creating savings in both the capital cost of building the plants as well as their long-term fuel and operational expenses.

Energy storage technologies can provide many services, but the ability to defer or displace investment in marginal, high-cost energy generation may be the most significant opportunity for energy storage to generate value on the grid (Mallapragada et al. 2020). There are approximately 1,000 peaking power plants in the United States that represent 19 percent of total installed electricity generation capacity in the U.S., but which accounted for just 3.1 percent of annual net generation in 2021 (U.S. Government Accountability Office 2024). Reducing the costs of building and operating these peaking plants has the potential to dramatically improve affordability. In 2024, the average wholesale electric price for the peak 100 production hours was \$342.05—more than 10 times greater than the average electric price across all hours, at \$24.21 (Millstein et al. 2025). The need for affordable strategies to meet energy demand at peak is magnified by a forecasted 5-year increase in peak demand of 90 GW (Institute for Energy Research 2025).

With the decline in battery storage costs, they have become an economical option for meeting peak demand. All-in installation and operation costs of four-hour utility-scale battery storage is now on-par or lower than similar costs for gas peaking plants, creating the opportunity to consider battery storage in addition to peaking plants as an affordable way to meet peak power needs (Robinson et al. 2021).

### 3.0 Transmission

Studies have shown that the United States needs to build many more new transmission lines to meet the grid's changing needs and accommodate load growth. A 2023 Department of Energy study identified a need to build at least 5,000 miles of new transmission capacity each year through 2050 to meet grid needs (Shreve et al. 2025; United States Department of Energy 2023). Under higher load growth scenarios, the country may need to double the capacity of its current regional transmission grid by 2035 (United States Department of Energy 2023). However, construction of new transmission infrastructure in the United States has slowed since 2015, and just over 300 miles of new transmission lines were completed in 2024 (Shreve et al. 2025). A recent uptick in data center deployment has accelerated load growth in many parts of the country—load growth from data centers has tripled over the last decade—and is forecasted to continue, accelerating the potential need for new transmission lines to accommodate increased demand (Shehabi et al. 2024).

Construction of new transmission lines is both time-intensive and costly, however. Transmission projects in the United States can take 15 years or more to complete siting and construction (Ansolabehere et al. 2024). Compounding this challenge, the transmission grid must be built with enough capacity to accommodate peak demand and enough redundancy to ensure reliability, according to reliability standards established by the North American Electric Reliability Corporation (NERC) (Firestone 2021; NERC 2025). Deploying technologies and approaches that enable load flexibility—by meeting demand with local energy resources or asking customers to reduce electricity use during these peak demand periods—could enable the grid to accommodate much more load without requiring as much new transmission infrastructure. One study from Duke University estimated that flexibility could enable the addition of 100 GW of new load to the existing transmission grid, equivalent to more than 10 percent of the United States' peak demand (Norris et al. 2025).

Energy storage is one technology that can help enable this flexibility and its associated affordability benefits. Storage has the potential to defer some of these costly and time-intensive new transmission projects, helping to reduce costs for ratepayers. Average residential electricity prices have increased about 13 percent between 2022 and 2025, with even higher increases in some parts of the country (EIA 2025b). While new transmission lines will still need to be constructed as demand grows, energy storage can reduce the immediate need for some new lines (Brown et al. 2023).

To achieve these benefits, storage can be deployed to help accommodate additional load that would otherwise require new transmission to accommodate, and this benefit can be achieved in multiple ways. Some energy storage projects can act as part of the transmission system by managing power flows to protect transmission infrastructure and prevent disruptions that could otherwise lead to outages. In other cases, storage, often paired with generation, can inject additional capacity onto the grid during peak load events as an alternative to building new transmission infrastructure to provide that capacity (Twitchell et al. 2022). In these scenarios, energy storage can generally be built much more quickly than transmission and can be a more cost-effective option for ratepayers as compared to new lines.

For example, one study of the MISO grid identified additional cost-saving opportunities associated with energy storage deployment to help reduce costs during periods of peak demand. Batteries can help reduce peak electricity costs throughout MISO territory by charging during low-demand, low-cost periods and discharging electricity onto the grid during periods of

highest demand, where electricity is more expensive and capacity on the transmission grid is constrained. The study estimated that using batteries to manage peak demand in this way could save MISO an estimated \$27 billion in overall system costs by, for example, reducing the costs of new transmission investments, or by limiting reliance on more expensive peaker plants that may otherwise be needed to serve peak loads (Aurora Energy Research 2025b). These savings would translate to lower costs for ratepayers, with potential customer savings of \$4.5 billion over the next ten years compared to scenarios with more limited additional storage deployment (Aurora Energy Research 2025a). In one model, peak power prices in MISO territory in 2035 are estimated to be nearly three times higher with limited storage deployment than in scenarios with more batteries on the grid (Howland 2025).

A few notable cases of batteries being used to reduce transmission costs have already been built or deployed in the United States. Some of these examples are described below.

## Summer Peak Contingency Solution for Island Grid

### Case Study



Nantucket, a small island off the coast in Massachusetts, is served by two undersea transmission lines. Summer tourism means that the island's summer peak demand is approximately twice as much as the island's load the rest of the year (Walton 2018). Analysis by National Grid, the utility serving the island, found that if one of these two lines were to fail during a period of peak demand in the summer, the other line would overload, risking outages (Balducci et al. 2019).

Instead of constructing a new undersea transmission line to address the contingency, the utility opted to deploy a 6MW/48MWh battery project alongside a new diesel generator as a more cost-effective solution.

The battery cost approximately \$50 million. With the inclusion of the diesel generator, the cost of the combined project was approximately \$80 million. Because of the high costs of building additional underwater transmission, a new line, by contrast, was estimated to cost \$200 million or more (Gheorghiu 2019; Trabish 2023).

The battery and generator project saved National Grid and its ratepayers approximately \$120 million (Gheorghiu 2019). The project ensured grid reliability on the island even in the case of a transmission line overload contingency event during summer peak demand periods.

In many rural and remote areas, upgrading existing transmission lines or constructing new lines can be particularly costly due to the geography of an area. As an island, Nantucket's transmission lines must be built under the ocean, incurring high costs; in other areas, like Punkin Center, Arizona, transmission lines may need to cross mountainous terrain. In these cases, energy storage can be a viable alternative to meet growing demand or address contingencies as compared to new transmission projects.

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## Transmission Line Deferral in a Rural Area

## Case Study



Punkin Center is an unincorporated community located in a rural and mountainous part of Arizona northeast of Phoenix. The area is served by a 21-kV radial transmission line. (Wamsted 2019). Facing modest but continued load growth forecasts, utility Arizona Public Service (APS) identified a potential need for a transmission line upgrade to meet demand in 2017 (Bade 2017), and decided to deploy a 2MW/8MWh battery project to meet Punkin Center's demand instead of a more costly transmission line upgrade.

While exact numbers are not public, according to the utility, the battery investment cost ratepayers 50% less than a wires-based investment (Potential Benefits of High-Power, High-Capacity Batteries 2020).

APS determined that the battery project would address the community's capacity needs sooner and would represent significant cost savings for ratepayers (Wamsted 2019). The battery is able to defer transmission investment by providing power during peak demand periods, estimated to occur 20-30 days per year (Potential Benefits of High-Power, High-Capacity Batteries 2020).

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Even without the presence of challenging terrain, storage can be a cost-effective solution to transmission capacity constraints by providing voltage support and maintaining reliability during contingency events.

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## Reliability Without a New Transmission Line

## Case Study



In 2019, the Midcontinent System Operator (MISO) identified the area around Waupaca, Wisconsin as a reliability risk. According to the grid operator, interruptions to an individual 115/138-kV transmission line in the area, which could occur due to either planned maintenance work or unplanned events, could cause power outages to several towns in Waupaca County (MISO 2020).

MISO evaluated several proposed solutions to maintain reliability for the Waupaca area and ultimately selected a 2.5 MW/5 MWh battery. The battery was sized to meet 90% of the area's planned loads. Combined with an upgrade to the 69-kV sub-transmission line serving the area, the battery was identified as a more cost-effective reliability solution when compared to more extensive transmission line upgrades (Twitchell et al. 2022).

MISO initially estimated the proposed project would cost approximately \$9 million (in 2019 dollars), as opposed to an estimate of \$12.4 million to rebuild a transmission line instead (MISO 2020).

The project originally had a planned in-service date of 2022. This date was delayed to 2025 as of 2024; as of October 2025, the project was planned for deployment in December (ATC 2025; Dagenais and Vespalec 2024). The current cost estimate for the battery project has risen to \$13.8 million as of late 2025 due to overall cost increases, but remains cost-effective as compared to a line rebuild due to overall price increases (ATC 2025).

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Generation retirements may also trigger a need for new transmission line upgrades to maintain reliability. Once again, energy storage can be a relatively inexpensive alternative to transmission line upgrades to ensure resource adequacy during peak demand in some retirement scenarios.

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## Peaker Plant Retirement Capacity Solution

## Case Study



In 2018, the California Independent System Operator (CAISO) needed to evaluate options to ensure reliability of service in the Oakland area after a planned retirement of a 165-MW peaker plant. According to CAISO's analysis, the loss of the peaker plant meant that the transmission lines serving the area would not have adequate capacity to serve load during certain peak demand scenarios (Twitchell et al. 2022).

Solutions evaluated included transmission line upgrades, new line construction, addition of a new generator to replace the peaker plant, and a project including batteries combined with minor system upgrades. The battery had an estimated cost of just over \$100 million, as compared to approximately \$574 million for the most expensive alternative of a new 230-kV transmission line (CAISO 2018; Twitchell et al. 2022).

**Outcome:** In its 2025 transmission plan, CAISO found that load growth in Oakland had surpassed 2018 forecasts, and meeting demand would require additional transmission upgrades in addition to the proposed energy storage project. However, CAISO confirmed that the addition of storage to the overall project remained more cost-effective than wires upgrades alone, even with the new load growth forecasts (CAISO 2025).

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## 4.0 Distribution

Going back to our thought experiment at the beginning of this paper, the difference between the electric transmission and distribution systems is like the difference between highways and city streets. Like highways, the transmission system operates at high volume (or voltage) over long distances. And like city streets, the distribution system operates at lower volume (or voltage) and connects to every home and business.

To operate reliably, a distribution system must be large enough to meet the peak demand of customers and flexible enough to accommodate constant changes in demand. Like with the generation and transmission systems, utilities have historically ensured sufficient capacity and flexibility on the distribution system by sizing substations, wires, transformers, and other distribution system infrastructure based on peak demand.

As growing levels of self-generation and large customer loads like electric vehicles and air conditioners have made customer energy usage more variable and unpredictable in recent years, utility spending on distribution systems has rapidly increased. From 2003 to 2023, annual utility capital expenditures on new distribution infrastructure grew from about \$20 billion per year to more than \$50 billion per year, which is about as much as utilities spend each year on new generation and transmission infrastructure combined (EIA 2024).

Energy storage can reduce distribution system costs by increasing flexibility and acting as a buffer against varying customer demands, thereby allowing the distribution system to be built to average customer demand rather than peak demand. Specific ways in which storage can average out the demands on the distribution system include managing voltage, meeting local peak demand, and integrating distributed generation.

### 4.1 Voltage Management

Electric reliability standards establish a voltage range within which distribution systems must operate. For the 120-volt systems that power most residential and commercial uses, that range is between 105 and 127 volts. Through a practice known as Conservation Voltage Reduction (CVR), many utilities operate their distribution system near the lower end of the range because doing so requires less electricity to be generated and results in less electricity being lost as it moves through distribution wires. CVR can reduce generation needs by up to 4 percent, creating significant operational savings for the utility and its customers (Schneider et al. 2010).

While CVR can be safely done without damaging system equipment or reducing the quality of service to customers, it creates a small margin of error for the distribution system, as even minor decreases in voltage can quickly push the system out of its prescribed operational range. Energy storage can act as a buffer in that situation, as illustrated in Figure 5:

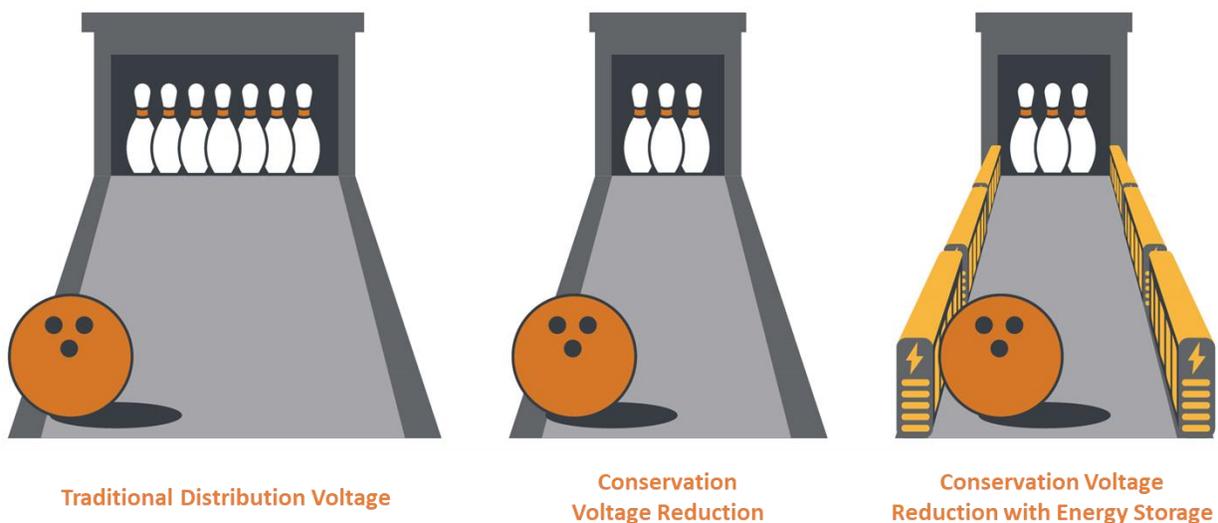


Figure 5: Distribution System Operations and Bowling

As shown in Figure 5, distribution lines are like a bowling alley—the ball (electricity) needs to be delivered to the pins (customer) while staying within the boundaries (voltage). Traditional distribution voltage ranges provide a wide alley to ensure that the target can be met, even if minor errors or unforeseen conditions emerge. Operating a system under CVR, on the other hand, is like bowling on a narrow alley that is just wide enough to accommodate the ball, and even minor miscalculations can result in a gutter ball. In similar fashion, operating a distribution line under CVR is a delicate balance that is further complicated by large customer loads (like electric vehicles or heating and cooling equipment) and customer-owned generation resources that can rapidly come on or offline and push voltage out of bounds.

Adding energy storage to a CVR program is like adding bumper pads to the bowling alley; just as bumper pads keep the bowling ball in the lane, storage can prevent voltage from exceeding its narrow range by automatically and instantaneously correcting voltage fluctuations. In this way, storage provides flexibility for the distribution system to reliably operate near the bottom end of the range even in unpredictable situations. This flexibility can be achieved with relatively small amounts of energy storage, and the resulting savings more than offset the cost of the storage, resulting in a lower total cost of operation (Zhang et al. 2017). The combination of CVR and energy storage in a distribution system can increase the effect of other advanced distribution management techniques, such as demand response, and create further savings (Pamshetti and Singh 2022).

Regardless of whether a utility operates a CVR program, energy storage can help maintain distribution system voltage within necessary ranges. Long distribution lines, which lose voltage the further they get from their generation resource, can particularly benefit from energy storage, as the following case study illustrates:

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## Distribution Voltage Support

## Case Study



PacifiCorp operates a 209-mile distribution feeder in Eastern Utah. In 2004, low voltages on the end of the line that caused frequent outages for customers called for a solution. But the line passed through several protected areas, meaning that engineering, permitting, and building a long-term solution would take years.

To ensure reliable service in the meantime, PacifiCorp deployed a 250kw / 2 MWh vanadium flow battery system near the end of the line. The battery operated until 2009, deferring a \$4 million upgrade for five years.

The battery system cost about \$1 million and provided a capital deferral benefit of about \$1.2 million and \$86,400 in arbitrage benefits over its life. The system had a net positive benefit of about \$300,000 while providing a temporary solution for local reliability issues while a long-term solution was developed (Kuntz 2005; Perry 2014).

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### 4.2 Meeting Local Peak Demand

Electric utilities have an obligation to serve the demands of their customers. Whether usage on an existing distribution line outgrows the capacity of that line or a new customer plans a large, new load (such as a new housing subdivision or large commercial project), the utility is required to expand the distribution system to accommodate the growing demand. Historically, this generally involved one of two options: reconductoring the existing line to increase its capacity or adding another line to serve the new demand. But by deploying energy storage on distribution lines, utilities can charge the storage during low-demand periods and then use the stored energy to help meet local demand during high-demand periods, thereby deferring or displacing the need for additional distribution infrastructure.

On heavily loaded distribution feeders, the values of improved reliability and avoided distribution infrastructure have been shown to roughly offset the cost of an energy storage system, while additional potential revenue streams like CVR and energy market revenues would provide net positive benefits (Inaolaji et al. 2024).

Since 2015, Southern California Edison (SCE) has deployed 10 pilot projects to test various ways in which energy storage can support its distribution system. Many of those projects were designed to meet growing demand without having to build additional distribution infrastructure. In one case, a large commercial customer that was launching a new manufacturing process requested a higher level of service level from SCE—a level that would have exceeded the capacity of the distribution line serving the customer. However, by deploying a 2.4 MW/3.9 MWh energy storage system on the customer's premises, SCE was able to supply the customer's demands without having to do any system upgrades (Chew et al. 2018).

Another of SCE's pilot projects, the Yorktown Battery Energy Storage Facility, has demonstrated the ability of energy storage to manage peak load on the distribution system on a larger scale:

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## Peak Load Management

## Case Study



Load growth was projected to create a near-term reliability issue on a distribution line operated by SCE in Pico Rivera, CA. The initially identified solution was to reconnector about 5 miles of distribution wires through heavily developed urban areas.

In 2024, SCE instead deployed a 3.5 MW/3.9 MWh battery energy storage system at the affected substation. The additional capacity is projected to maintain local reliability while deferring the reconductoring project until at least 2028. When not needed to support the distribution system, the battery participates in wholesale energy markets.

While the exact costs and benefits of the system have not been publicly disclosed, SCE has indicated in regulatory filings that the battery system was cost-effective based on the deferral value alone, while energy market revenues provide an additional benefit (Southern California Edison 2023a, 2023b).

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However, load growth is often uncertain. New customers may request services that utilities are required to provide, but changing economic conditions or finances may cause the underlying project that would create the demand to be delayed or canceled. If a utility builds wires and transformers to meet those needs and then they do not materialize, the utility is left with a stranded asset that may not be fully utilized for years.

Energy storage will not always be a viable option for satisfying growing demand on the distribution system. But in situations in which storage can meet an identified need, it can also provide a financial hedge against load growth uncertainty. If the forecasted load growth doesn't materialize, the storage asset can provide other grid benefits and the utility has only made a 10-year financial commitment (the useful life of a storage system) instead of a 40-year commitment (the useful life of distribution infrastructure). A storage project deployed in Maine illustrated this benefit (Oikonomou et al. 2024):

## Peak Load Management

## Case Study



Surging electric demand during the summer tourist season in the coastal town of Boothbay, Maine was projected to overload a key distribution line. In 2015, utility Central Maine Power deployed a portfolio of distributed generation, energy efficiency, and a 0.5 MW/3 MWh advanced lead acid battery to collectively provide 2 MW of local capacity to meet the forecasted demand growth without having to upgrade the distribution system.

The total cost of the full portfolio of distributed generation, energy efficiency, and energy storage was reported to be about \$6 million. The battery costs were not publicly reported on a standalone basis but were likely about \$1.5 million (PNNL 2024).

The forecasted load growth did not occur, and after participating in energy markets for a few years, the battery was retired in 2018. The \$6 million portfolio of non-wire alternatives saved customers \$12 million and continued to provide capacity and other benefits even when they were no longer need for their original purpose (Chew et al. 2018).

### 4.3 Integrating distributed generation

A confluence of factors—increasing dependence on electricity, aging electric grid infrastructure, growing intensity of natural events, and increasing technology options available at declining costs—have driven an increase in demand for backup generators in the U.S. in recent years (Thompson and Pescaroli 2023). Similarly, the EIA estimates that the amount of installed distributed solar in the U.S. increased from about 7.3 GW in 2014 to 53.2 GW in 2024 (U.S. Energy Information Administration 2025b).

This proliferation of distributed generation (DG) presents both an opportunity and challenges. The opportunity is that the DG resources that customers are purchasing could be harnessed to help meet grid needs during periods of high demand, thereby reducing the amount of generation and transmission that utilities would otherwise need to build to meet that demand.

The challenges are twofold. First, most DG technologies are not readily dispatchable by a utility—a key factor in determining whether those resources can be counted on for grid needs. Solar systems cannot be turned off and on as needed. A utility can curtail the system if there's a problem, but it can't turn it up or down as needed. A backup generator can be turned off and on and ramped up and down as needed, but a utility is unlikely to have the ability to control it.

Second, the distribution system was designed as a one-way delivery system, so if a line has high DG production that exceeds the line's total demand, it can reverse power flows back toward the transmission system, which can disrupt power flows and damage equipment.

Energy storage can resolve both challenges by adding dispatchability to DG assets—the button that a utility can push to activate, deactivate, or alter their output to provide the control necessary to serve grid functions. In this way, storage allows DG production to be averaged out—capturing excess generation in one period and shifting it to another period when it is needed. DG and energy storage, when planned and operated in a coordinated fashion, can improve the reliability of distribution systems while reducing their overall cost (Li et al. 2018).

## 5.0 Customer

The final stage of the electricity lifecycle is customer consumption. Many customers operate under business-as-usual conditions, consuming electricity as needed and paying the corresponding costs. In a world of rising electricity costs, however, consumers are increasingly concerned about managing their energy costs through behavioral changes and investments in energy efficiency, distributed generation, and energy storage systems.

Behind-the-meter (BTM) energy storage systems are privately owned systems that are located on a customer's premises and connected to the customer's side of the utility's service meter. Referring to the grocer analogy, BTM storage is like the customer's fridge, freezer, and pantry; holding energy on their side of the meter for use whenever it's needed. BTM systems offer opportunities for lowering energy costs and mitigating power outages (Zinaman et al. 2020).

### 5.1 Lowering the Cost of Energy for Customers

BTM systems can reduce customers' electricity costs in several ways: peak shaving (Nieta et al. 2021; Mostert and Bekker 2020), reduced demand charges (Neubauer and Simpson 2015; McLaren et al. 2017; Bhattarai et al. 2016), demand response participation (Chandrashekeran 2020; Parrish et al. 2020), and net metering (Inzunza and Knittel 2020; Venning 2019; Uturbey et al. 2024). However, it is important to note that the amount a customer can save depends heavily on the electricity rate structure offered by their electricity provider. Most importantly, the largest value is found in stacking multiple cost-saving measures through joint optimization (Chen et al. 2021; Su et al. 2022).

#### 5.1.1 Peak Shaving

While Section 2 discussed the role of large-scale energy storage systems in providing peak shaving, this benefit can also be achieved by networks of BTM systems operating in coordinated fashion. Peak shaving is a strategy where electricity consumption is shifted from high-cost to low-cost time periods (Nguyen and Byrne 2017). This is possible because the BTM system will charge when the energy costs are low and then use that stored energy in place of grid energy during high-cost periods. Below is a case study of a collaboration between The Irvine Company, Southern California Edison, and Advanced Microgrid Solutions (Mueller 2015; Newsroom 2015; Starkey et al. 2018).

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## BTM Storage for Peak Shaving Case Study



SCE needed new ways to meet growing peak demand. Large commercial buildings in their service area contributed significantly to local peaks but had limited tools to flex their load without disrupting tenants.

In 2015, SCE partnered with Irvine Company and Advanced Microgrid Solutions to deploy Tesla Powerpack battery systems and advanced energy management software at 21 high-rise office buildings. Using real-time information, the BTM systems shift the buildings to battery power when SCE calls for support.

The first phase of installation cost more than \$30 million (Mueller 2015). It decreased peak demand for the included buildings by up to 25 percent, provides 10 MW of load reduction for 4 hours to help SCE balance the grid, reduced the Irvine Company's operating costs by 10 percent (about \$1 million per year), and has had no disruptions for building occupants.

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### 5.1.2 Reduced Demand Charges and Demand Response Participation

A demand charge is a surcharge fee on an electricity bill based on a customer's usage during peak periods. Utilities use it to cover the high cost of generating or purchasing energy during peak demand. BTM storage can also help reduce or eliminate that charge (Neubauer and Simpson 2015). Demand response is a strategy to manage electrical power consumption by responding to pricing signals from utility companies. When customers can opt into demand response programs, BTM reduces usage during real-time high-cost periods. Kaiser Permanente's Richmond Medical Center's Solar-Battery Microgrid is an example of the success of BTM for reduced demand charges and demand response participation (Hemstreet and Baruch 2018; Bliss 2019).

## BTM Storage for Demand Charge and Response

### Case Study



At Kaiser Permanente’s Richmond Medical Center, peak demand charges made up as much as 45% of the summer electric bill. To reduce that cost, Kaiser Permanente installed a solar system and a 1-MW/1-MWh BTM system with a microgrid controller. The controller automatically discharges the battery to reduce peak loads and participate in demand response events, thereby lowering demand charges.

The project was funded by a \$4.77 million grant from the California Energy Commission’s EPIC program to Charge Bliss, which developed, designed, and engineered the microgrid in partnership with Kaiser Permanente. (Total installed cost beyond the grant is not specified.)

The system provides up to 140 kW of demand reduction, roughly a 25 percent reduction in peak load; demand charge reductions of up to \$394,000 per year, and demand response payments of \$40,000-\$80,000 per year.

This project has demonstrated that BTM storage can be used to cut demand charges and participate in response programs. This microgrid solution generated strong interest among regulators and illuminates a path for hospitals, developers, investors, and regulators to collaborate and expand microgrids for hospitals in California (Bliss 2019).

## 5.2 Reducing Power Outages

BTM storage also provides customers with reliable power access during grid disruptions, keeping energy available locally when the wider grid fails (Marqusee 2025; Anderson 2023; Chatterji and Bazilian 2020; Munankarmi et al. 2023). In some cases, BTM systems support only essential services, such as lighting or refrigeration. One such successful example of this is the Parkway Overlook Apartments, an affordable housing redevelopment project owned and operated by the Washington, DC, Housing Authority, where a BTM system helps lower energy costs but also maintains community services during outages (Executive Office of the Mayor, Washington, DC 2018; GRID Alternatives Mid-Atlantic 2021; Muller 2019; Southway Builders 2019; DC Housing Finance Agency 2018).

Other systems are designed to fully support critical infrastructure, such as hospitals (Lazo et al. 2023; Islam et al. 2022; Sibai et al. 2024), or critical community services such as police departments, telecommunications services, and fire stations (Cabrera-Tobar et al. 2023; Kwasinski 2016; Ferraro et al. 2020). For example, the Sterling Municipal Light Department (SMLD) in Massachusetts successfully launched a BTM system in 2016 to isolate the police station and dispatch center from the main grid during power outages and provide emergency backup power (DeMaina 2017; Kauth and Hellerstein 2019; Sterling Municipal Light Department 2021; Byrne et al. 2017).

### 5.3 Joint Optimization

The greatest cost savings from BTM are achieved through joint optimization, where the system dynamically coordinates all available services so that, at any given moment, it is deployed to the highest-priority, highest-value purpose, subject to technical and contractual constraints. Rather than using a single BTM for a single purpose, joint optimization incorporates all the strategies on a larger scale. An example of this approach is Green Mountain Power's Vermont Powerwall and Bring Your Own Device programs (Leah 2021; Jay 2017; Leah 2023a; GMP 2025). By aggregating a fleet of BTMs into a virtual power plant, GMP can deliver savings on customer bills (Green Mountain Power 2025). The success of these programs led to the launch of GMP's 2030 Zero Outages Initiative (Leah 2023b), which extends this model to a broader system-wide resilience strategy.

#### Joint Optimization – Green Mountain Power

#### Case Study



Green Mountain Power (GMP) faced rising costs driven by peak demand and maintaining grid reliability in a rural area. To address those challenges, GMP designed a residential BTM storage program that provided participating customers with BTM storage systems for their homes for 10 years.

In return, GMP controls the batteries and can dispatch them during peaks and other grid events. Due to strong interest, GMP expanded the concept to a “Bring Your Own Device” option, where customers can install qualified storage devices with a payment from GMP in exchange for allowing GMP to operate them as part of its virtual power plant.

GMP Estimates that its total costs per residential battery system are \$16,212, with a net benefit of \$7,102 after the first three years (Green Mountain Power 2025).

During regional peaks, GMP aggregates thousands of BTM storage as a virtual power plant to reduce peak demand and associated transmission charges, resulting in more than \$3 million saved system wide. During outages, customers retain backup power.

GMP's programs demonstrate that a residential BTM network can be cost-effective at the system level: avoided charges and deferred infrastructure costs exceed the cost of the battery program and customer incentives, providing savings for all GMP customers. GMP has committed to investing \$30 million in energy storage to maintain reliability and keep customers connected during extreme weather.

## 6.0 Summary

By acting as a buffer between supply and demand, storage allows producers to meet fluctuating demand with steady, average production levels. As a result, the things we buy—food, water, gasoline, clothing, and just about everything else—are more affordable and accessible. It's why we don't have to buy groceries every day and why roads aren't clogged with vehicles making daily grocery runs for every household. It's why we can build fewer production facilities and schedule shipping to occur at regular intervals.

Unfortunately, electrical energy storage technologies were limited when the electric grid was built, so the grid was generally built without the ability to store its product. And without that capability, it had to be built large enough to meet the highest demands. The result is an oversized electric system, one with gigawatts of generation capacity that sit idle for most of the year and transmission and distribution lines that are underutilized for almost the entire year. And because costs are the only thing about the electric system that do get averaged out (in customer rates), customers are paying for all those assets year-round, even if they are only being used for a few hours. As a result, electric bills are high—and will only continue to grow as peak demand increases and more infrastructure is required to meet it.

But with the growth of energy storage technologies, this oversized grid offers an opportunity. Retrofitted with energy storage technologies, the electric grid can shift from its current, peak-driven model to a one designed around averages. By absorbing excess energy during low-demand periods and shifting it to high-demand periods, energy storage can average out production and reduce the need for new generators, particularly high-cost peakers. By strategically siting storage resources closer to end-use customers, storage can average out the amount of energy that needs to be sent over transmission and distribution lines, reducing infrastructure needs. And when sited on customer premises, storage can average out customer usage to provide bill savings and backup power.

Energy storage cannot solve every grid need, of course. There will still be a need for new generation to meet rising demand and new transmission and distribution lines to connect new generators and customers to the grid. But with strategic placement and operation of energy storage, those investments can be optimized and minimized, creating real savings for customers. This paper has provided 13 case studies that collectively have improved grid reliability while saving customers millions of dollars.

The examples in this paper of energy storage projects that have reduced costs of electrical generation, transmission, distribution, and consumption are indicative of the potential for deep and widespread reductions in electric system costs if storage is deployed at scale throughout the electric grid.

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