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INSTITUTE ON THE
ENVIRONMENT

Community-Scale Energy Storage GUIDE

How Community Groups and Small Businesses
Can Employ Energy Storage to Save Money and
Contribute to Minnesota's Clean Energy Transition



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Introduction

In recent years, the technology to harness renewable energy, such as wind or solar, has become increasingly affordable and more widespread – including at the community scale – powering homes, churches, schools, businesses, and other buildings. Yet without the ability to store that energy for future use, communities powered by renewable energy are limited in what they can capture – and remain dependent on the existing power grid and utilities. With the rise of new energy-storage battery technologies, however, all of that is changing.

This guide is for people who have or are interested in investing in renewable energy to power their home, business, or community space. In it, we'll walk

you through how the US electricity grid operates, how renewable energy generated by homes and buildings works alongside it, and how investing in battery storage for renewable energy can optimize resources and help protect communities against power outages. We'll also overview the different technologies available for storing renewable energy for future use and the partners, costs, and steps involved with installing an energy storage battery. Recent case studies from three sites in Minnesota, a state without fossil fuel reserves yet rich in renewable resources, illustrate how energy storage batteries help aid in the resilience of communities and, by reducing reliance on fossil fuels, the health of the planet.



UNDERSTANDING THE ELECTRICITY GRID

Since its development in the early 20th century, the US electricity grid has been a means of moving energy *through space*. To do so, it relies on large, centralized power plants, which generate vast amounts of electricity, and on transmission and distribution networks, which transport and deliver that electricity to utility customers.

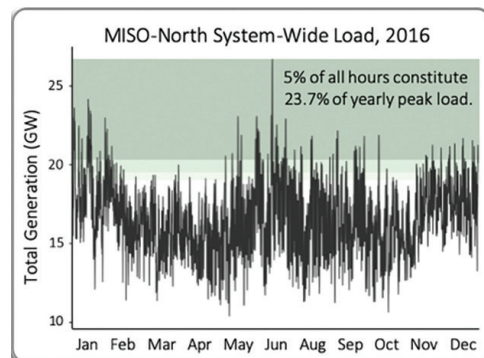
The increasing popularity and decreasing cost of distributed generation resources (i.e. residential- or community-scale solar) has led to a more multi-directional flow of electricity within distribution networks. Still, in order to maintain proper grid frequency and ensure stability, the amount of electricity generated must match with the system load (the total demand for energy across the grid). Energy storage technology, however, has the potential to revolutionize the way that electrical utilities provide services to their customers. It also gives customers greater control over the renewable energy they produce as well as the ability to safeguard against power failures. In other words, energy storage batteries have the ability to preserve and move energy *through time*, potentially freeing utilities from the restrictions of generating power to match load.

How Customer-owned Renewables Work With the US Electricity Grid

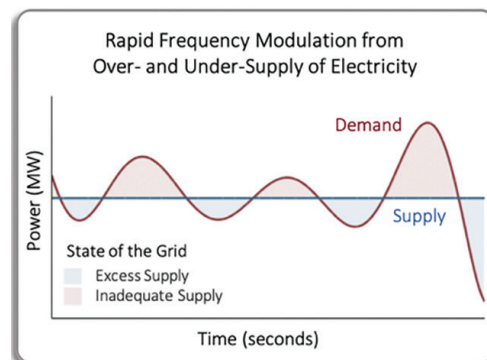
With renewable energy technologies, including solar panels, people can generate the energy to power their homes and buildings, allowing them to rely less on the larger US electricity grid. However, many remain connected to and effectively dependent on the grid because this ability to generate energy is tied to weather - and they'd be left without power when when their renewables can't meet their needs. (Solar panels, for example, generate more power on sunny days than on cloudy days.) Likewise, without the help of an energy-storage battery, people are unable to store any excess power they generate and instead must return it to the grid.

FIGURE 01

Three aspects of electricity provision and grid design that energy storage has the potential to improve are efficiency, stability, and resiliency. Each figure and corresponding description depicts one representative application in each category. Image Source: Institute on the Environment, University of Minnesota.



EFFICIENCY Peak load events contribute to overdevelopment of grid infrastructure.



STABILITY Rapid fluctuation of load relative to generation threatens system frequency and power quality.



RESILIENCY Centralized, one-directional grid design amplifies risk related to generation or transmission failure.

Background

CURRENT GRID VULNERABILITIES

Restrictions associated with traditional, centralized electric grid operation (i.e. matching generation to load) present utilities and grid operators with a number of challenges in regard to three categories: efficiency, stability, and resiliency (Figure 1). Each can pose challenges for utilities to meet the needs of their customers. Furthermore, each can directly affect customers by impacting power quality, elevating electricity costs, and, at times, threatening customer access to electricity altogether. Energy storage, however, has the potential to mitigate challenges in each of these categories, benefiting customers, utilities, and grid operators alike.

EFFICIENCY

Depending on time of year, time of day, and other factors such as the weather, demand for electricity can vary significantly. Meeting demand at times of high use requires utilities to build and maintain generation and transmission infrastructure that may be employed for only a few hours each year – an inefficient use of resources that can lead to higher customer rates. Employing energy storage batteries (both at the utility and “behind-the-meter,” a.k.a. owned by a residential or commercial customer) can redistribute when generation needs to occur, mitigating peak load and generation events, and potentially reducing the need for expensive peaking resources.

STABILITY

Another challenge utilities face is providing appropriate generation to maintain grid stability since system-wide load can vary significantly and rapidly in ways both predictable, such as an increase in air-conditioning use in hot summer months, and unpredictable weather, such as an unexpected winter storm. These fluctuations can include small second-to-second variations in load or larger trends, such as rapid load increases on hot summer afternoons. Again, energy storage has the potential to play a key role in addressing these



challenges. Large-scale energy storage designed for rapid response can modulate supply on a second-to-second basis to match demand, while customer-sited solar-plus-storage installations can mitigate the rapid ramp rate on summer afternoons and evenings by discharging stored energy, thus decreasing the burden on utilities and grid operators.



RESILIENCY

Finally, the highly centralized structure of traditional grid design has proven vulnerable to transmission and distribution failures or interruptions. One notable recent example of transmission infrastructure challenges is Pacific Gas and Electricity (PG&E), a utility in northern California, which in 2019 voluntarily shut off transmission lines during times of dry weather and high winds, denying power to nearly 600,000 customers.¹ The utility took this course of action (which reportedly cost \$65 million) in order to minimize wildfire risks after the utility had been made to pay over \$20 billion

in damages and settlements for wildfires that had been ignited by transmission equipment in 2017 and 2018.² Distribution-sited or behind-the-meter, customer-owned energy storage can stockpile energy on the customer side of the transmission network, providing power even when a transmission line or generation facility must be taken offline. This can both provide power to customers who would otherwise experience outages as well as decrease the burden on any remaining transmission lines, potentially avoiding cascading outage events such as the historic 2003 Northeast blackout.³

Background

HOW DISTRIBUTED AND BEHIND-THE-METER ENERGY STORAGE CAN HELP

While large, utility-scale storage installations benefit from economies of scale and have lower per-kilowatt and per-kilowatt-hour costs on average than smaller residential or community-scale devices, distributed residential and community-scale energy storage can perform additional services and provide additional value for customers.

Distributing energy assets such as storage or generation capacity across the grid disperses the risk of failure across multiple units as well as reduces reliance on transmission infrastructure.

If a regional grid's generation or storage capacity is centralized in a few large facilities, the risk of grid-wide impacts depends on the failure rate of those few units; however, if the capacity is distributed across many smaller facilities, the risk of any one site failure has a much less significant impact on the grid.

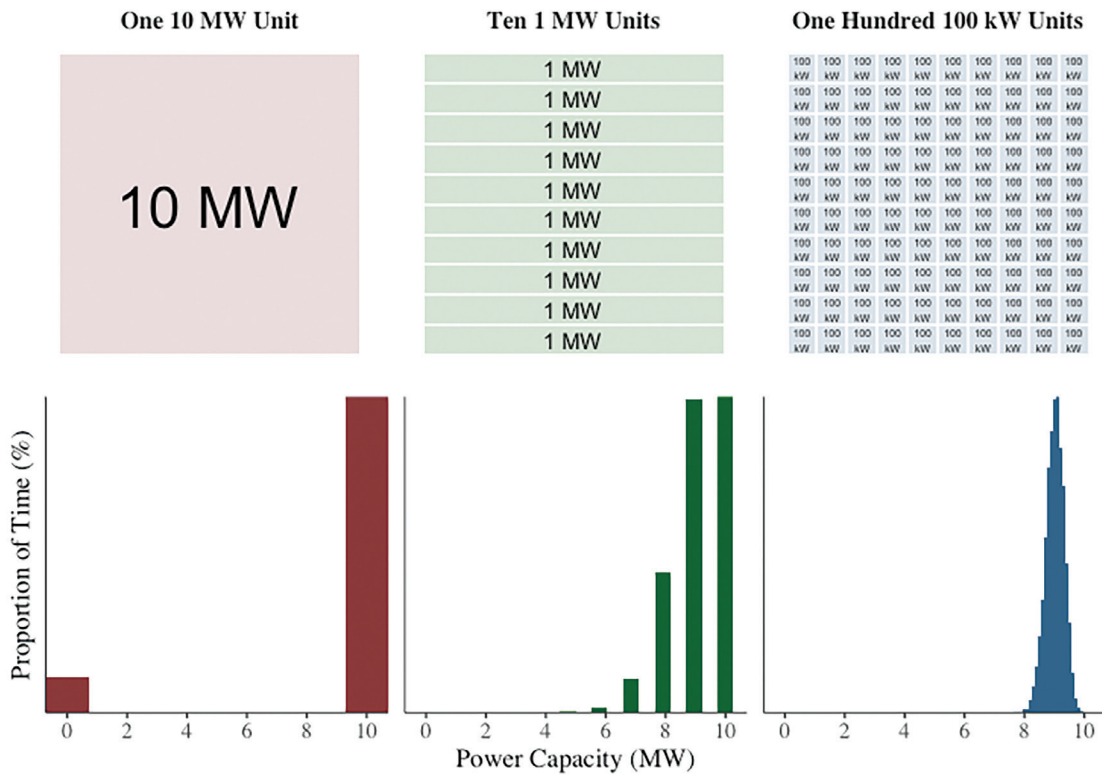


FIGURE 02

Unit diversity describes the distribution of risk across multiple units to decrease downtime and the risk of system-wide negative impacts. Here, generation or storage units with a failure rate of 10 percent demonstrate the mitigation of system-wide risk through the distribution of capacity across many smaller units. Risk is measured by the average proportion of time spent at reduced power capacity. Image Source: Institute on the Environment, University of Minnesota.

Distributing energy resources geographically across the grid reduces the impact of transmission line failures because a smaller geographic area is likely to be reliant on each line for their energy service. Transmission line problems, such as cascading failures – where one transmission line fails, creating an overload on another line that causes it to fail, and so on – are a major contributor to many widespread blackouts, such as the Northeast blackout of 2003, which affected roughly 55 million people,⁴ and the 2021 Texas power crisis, which left more than 4.5 million homes and businesses without power and reliable access to water, heat, and food,⁵ and yet others with exorbitant electricity bills. (Since the electricity grid crosses state lines, a price spike caused by the 2021 Texas power outage left Minnesotans with an \$800 million bill that will increase most individual customers' heating bills by several hundred dollars. This will likely continue to affect consumers across the country for the next few years.⁶)

Geographic distribution of energy resources, including energy storage batteries, can reduce reliance and stress on large transmission infrastructure during events such as these, improving grid reliability and resiliency to large-scale outages. It can also help prevent spikes in electricity bills.

Distributed, behind-the-meter energy resources give people and organizations greater management over their energy consumption and of the flow of energy more broadly. Energy storage has the potential to enable organizations and entities, such as Tribal nations, to achieve energy sovereignty, because it creates a pathway to independence from electric utilities. Furthermore, other consumers who are able to store energy could potentially agree to sell that energy to others in distributed, deregulated markets, democratizing energy markets by enabling broader market access. Additionally, energy storage located behind the meter is able to provide more services to its owner/operator than devices located on the distribution or transmission grids. [Read a detailed overview of energy storage use cases on page 28.]



Benefits of Energy Storage

As discussed in the Background section, the current electricity grid relies on large, centralized power plants in addition to large transmission and distribution networks. There are vulnerabilities in this system that energy battery storage can help to mitigate. However, there are even more benefits for customers who invest in renewable energy.

BACKUP POWER AND RESILIENCE

Energy storage is an emerging option for residential and commercial customers who want to ensure that they have backup power in the event of an outage to the power grid. Historically, backup-power options,

particularly for residential and small commercial customers, were mostly petroleum-fueled generators. However, these devices emit carbon emissions and other airborne pollutants, which can cause adverse health effects.

Additionally, although distributed solar installations are often capable of generating electricity during an outage, they must be turned off to reduce risk to power-line technicians working to restore service. Yet when battery storage devices are installed in a way that allows customers to disconnect from the distribution grid, they can continue to use any backup power stored in their batteries as well as to recharge the batteries with solar generation during power-restoration work.

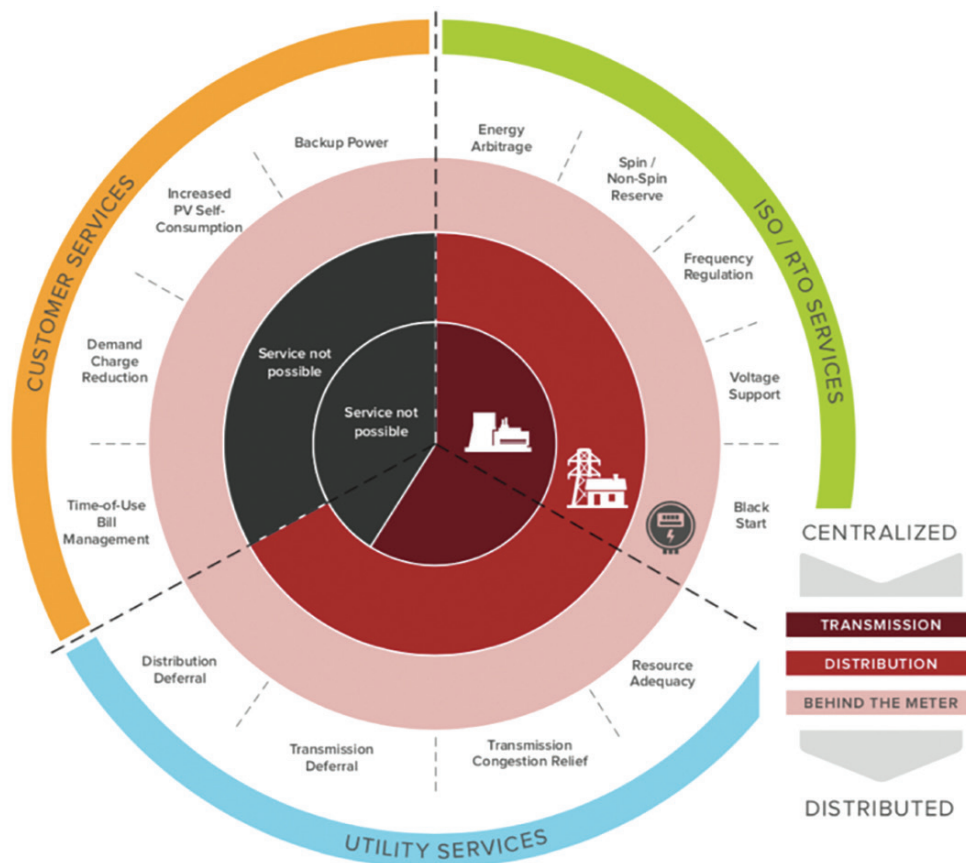


FIGURE 03

Thirteen applications of energy storage devices. These use cases are organized by their primary beneficiary (outer circle) and on the position in the electricity grid from which they can be provided (inner circles). Image Source: Rocky Mountain Institute.

OPTIMIZATION OF DISTRIBUTED GENERATION

The last decade has seen a rapid expansion in the installation of distributed, roof-top solar PV generation. The improving economics of batteries for energy storage have promoted the role of these devices as a mutually beneficial partner for behind-the-meter solar arrays. The value of solar and storage can be greater than the sum of each part through a number of different applications, including the use cases described below.

Net Metering and Service Monetization

The most commonly employed purpose for pairing behind-the-meter solar and storage is to optimize the operation of the generation resource. Solar installations are often oversized in terms of nameplate capacity relative to the average load of the building they're connected to. Given their generation behavior (i.e. idle at night, generating during the day), this typically means that solar installations over-generate during the day and export energy back to the grid. The customer then must draw energy back from the grid at night, when the panels are idle. Energy storage batteries can decrease or eliminate these transactions by storing over-generation during the day and discharging that energy at night (Figure 5).

For customers with retail-rate net metering, which Minnesota employs, each unit of energy returned to the grid is compensated at a rate similar to the customer's retail rate (which is determined by the previous year's electricity rates). Under this rate structure, increasing the on-site use of solar generation (rather than selling back to the grid) produces no monetizable value for the device's owner.* On the other hand, customers can save money if the energy returned to the grid is compensated below the retail rate and they instead store each unit of energy for later use.

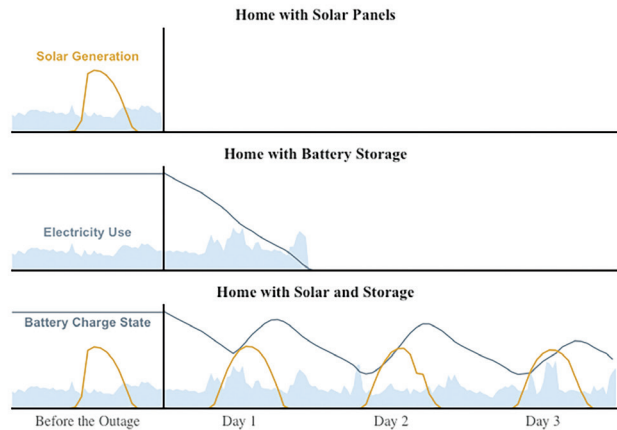


FIGURE 04

Comparison of a home's response to a power outage using behind-the-meter solar generation, battery energy storage, or a combination of the two technologies. The simulated outage begins at the vertical black line and continues across the right side of the figure. Image Source: Institute on the Environment, University of Minnesota.

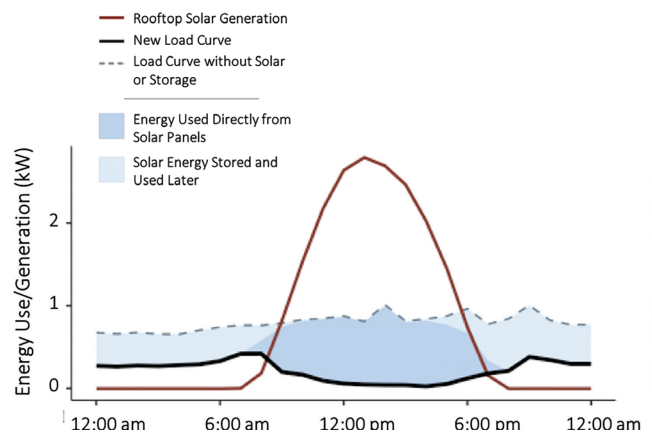


FIGURE 05

This load curve (a chart depicting variation in demand/electrical load over time) illustrates the effects of behind-the-meter solar and storage for a residential customer (depicted as a monthly average). The light blue area represents the value added from the storage device in terms of electricity that would be returned to the grid but is stored and used onsite instead. Image Source: Institute on the Environment, University of Minnesota.

*While retail rate net metering applies to residential on-site solar installations, there are exceptions for community solar projects which serve residential customers, which may receive different compensation. Under Minnesota Statute §216B.164 Subd. 3, net metering for customers of cooperative and municipal utilities is limited to installations less than 40 kW, while for customers of investor-owned utilities, the upper limit is 1 MW.

Benefits of Energy Storage

Ramp Rate / Duck Curve

As distributed solar deployment expands, one potential consequence is an increase in the ramp rate of electricity demand in the afternoon. This occurs due to a dip in overall load during the day due to high penetration of distributed solar, followed by a sharp decline in solar generation that coincides with an increase in electricity use, or building load, in the evening. Energy storage batteries charge during the day when there is overgeneration of solar power; electricity users can draw on this stored power in late afternoon and evening when solar power is not generated.

Islanding and Microgrid Capabilities

For those wishing to rely exclusively on their own power generation, whether connected to the distribution grid or not, solar photovoltaic (PV) generation presents both challenges and opportunities. Solar is the most economically viable means for small-scale generation but generates well below full capacity for the majority of each day. Long-duration storage can provide the ability to store all excess generation, which can then be used when the sun is not shining.

TIME-OF-USE RATE MANAGEMENT

Historically, the vast majority of electric utility bills for residential customers have been assessed with flat, per-kilowatt-hour rate design. This rate design assigns the same cost to each unit of electricity irrespective of how much energy is being used or when it is consumed. Time-of-use rates, on the other hand, assign different rates depending on the time of day, week, or year in which it is used. Reflecting market conditions, energy used at times of high demand (i.e. summer evenings) is assigned a greater cost than energy used at times of typically low demand (i.e. middle of the night). **[To learn more about time-of-use rate design, refer to “Minnesota Time-of-Use Pilot Program,” page 13.]**

Cost of Electricity

For utilities, not all hours of the day, month, and year are equivalent with respect to cost of energy generation or procurement. At times of peak electricity use, when utilities employ all power generation resources available to them, the average cost of generation increases. That means that low-cost resources such as wind, solar, and combined-cycle natural gas turbines must be supplemented by expensive natural gas or petroleum-fueled peaking plants, which increases costs for customers. (When utilities charge customers the same rate for every kilowatt-hour, they disperse these peak costs throughout the rest of the day by overcharging when generation costs are low and undercharging when costs are high.)

Promoting Energy Efficient Behavior and Shifting Energy Consumption

By creating a price differential between electricity consumed during peak and low-demand times, utilities create incentives for customers to shift their behavior towards using a greater proportion of their electricity during off-peak hours. Common methods for this include using appliances such as washers, dryers, dishwashers, and ovens more during off-peak times and decreasing their use during peak hours. Additionally, reducing air-conditioner use during summer evenings, whether by improving insulation or allowing household temperatures to rise by a few degrees, can reduce peak energy use and save money on monthly bills.

In addition to behavioral changes to reduce peak energy use, employing energy storage to shift electricity consumption from one time to another can allow customers to reduce their energy bills. Customers can charge their energy storage battery during off-peak times or when on-site generation exceeds energy use, and discharge during peak hours. This practice can reduce the average per-kilowatt-hour electricity cost assessed to the utility customer, saving them money on their energy bill.

Minnesota Time-of-Use Pilot Program, a Real-world Example

Xcel Energy proposed a pilot residential time-of-use program in 2017, which was approved unanimously by the Minnesota Public Utilities Commission, an investor-owned utility (IOU), in 2018 and commenced in fall 2020.⁷ The pilot raises rates for weekday peak hours (3 – 8 pm) from \$0.134/kWh to \$0.259/kWh in summer months, and from \$0.117/kWh to \$0.224/kWh in winter months. The pilot also lowers rates to \$0.057/kWh on off-peak hours (12 – 6 am); on all other hours, classified as “mid-peak,” it lowers rates to \$0.121/kWh in the summer and \$0.104/kWh in the winter.

A shift to this rate structure could increase a customer’s bill if much of their energy use falls within peak hours and they are unable to adjust their energy consumption behavior. However, that can change by using an energy storage battery. By charging it during off-peak hours and discharging it during peak hours, customers can potentially save money on utility bills and offset the cost of the battery itself. (Xcel Energy’s time-of-use pilot program is not currently available to customers with energy storage batteries. Potential for savings depends on the availability of time-of-use rates for all interested customers.)

DEMAND-CHARGE MANAGEMENT

Unlike the majority of residential utility customers, most commercial and industrial customers have demand-metered rate designs for their utility bills. With this rate structure, in addition to being charged for every kilowatt-hour of energy used at a set rate, customers are also charged for their highest fifteen-minute sustained load, or electrical use, each month, which is measured in kilowatts. Demand charges are assessed because high-load events disproportionately burden utilities in terms of stress on infrastructure and increased generation

requirements. Commercial and industrial customers generally use much more energy than do residential customers, and typically do so in more predictable and regular ways, thereby contributing much more significantly to utility-wide peak events, when they deviate from their normal operation, raising the cost of service.

For businesses that use a fairly consistent amount of energy throughout the day every month, demand charges make up a minor portion of their energy bills. However, customers who use electricity in an uneven manner, such as places of worship, which use most of their energy on weekends, demand charges can make up a large portion of their energy bills.

Demand-metered customers can employ energy storage batteries to reduce demand charges by time-shifting their energy use to distribute load over time, thus minimizing peak events. Storage devices can be charged when energy use is low and discharged during peak energy-use times, which would shift part of the load to an off-peak time and effectively smooth out the load profile. This approach can be especially effective for customers who have predictable or controllable peak-use events. However, if peaks are unpredictable or simply misjudged, the battery may be discharged too aggressively, draining its capacity before the peak event ends and causing the load to jump back up to the true peak. Because demand-metered rates are judged solely on the single highest peak in the month, mismanagement of a single peak event in the month can negate any potential savings provided by the storage device. For this reason, well-designed battery management systems (BMSs), which provide basic control systems for maintaining key measurements and processes of the device within a safe operating range, are especially critical tools for the success of demand-charge management.

Energy Storage Batteries

Most energy storage technologies commonly used in residential and community-scale applications are electrochemical batteries. This section will describe three of the most common battery classes currently used for storage applications: lead acid, lithium ion, and redox flow. In addition to electrochemical battery methods, thermal energy storage is commonly applied in residential and community-scale situations to great effect. While these options are unable to return the stored energy to electrical energy form upon discharge, they can greatly improve grid efficiency and reduce both energy consumption and the associated emission of air pollutants.

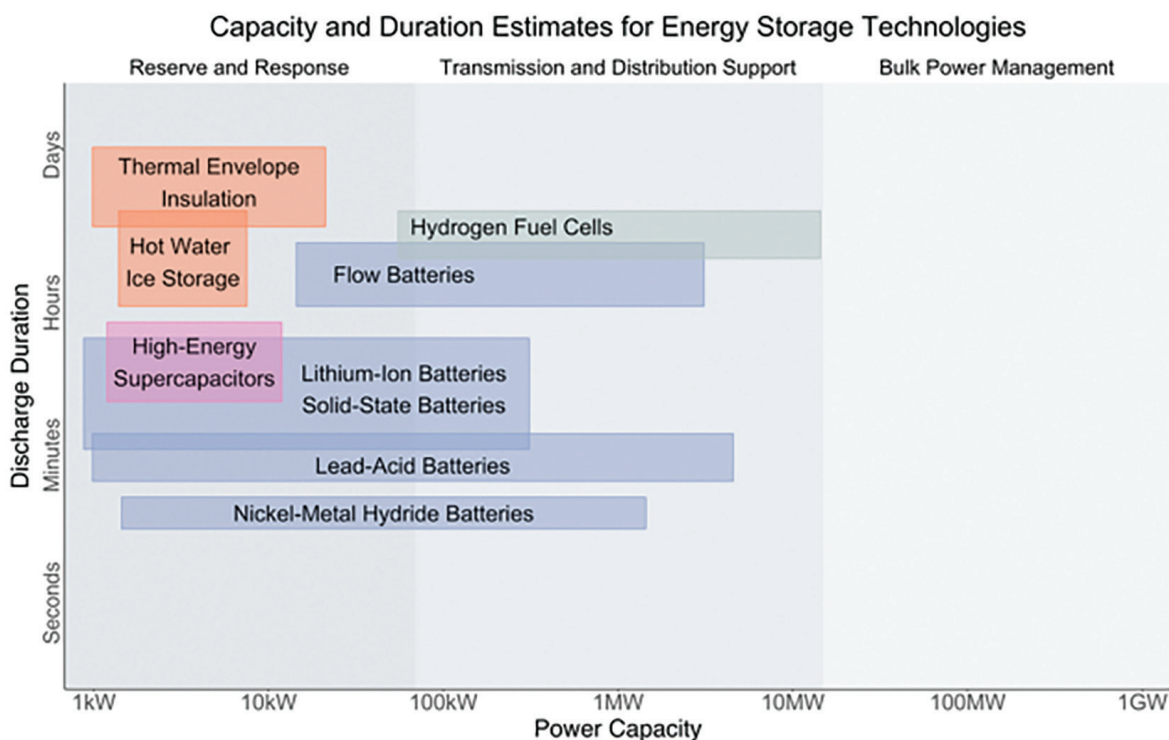


FIGURE 06 Comparison of energy storage applications capable of community-scale installation based on power capacity range and typical duration limitations. Storage technologies which are not considered to be useful or achievable on a community-scale have been omitted from this figure. Image Source: Institute on the Environment, University of Minnesota.

LEAD-ACID BATTERIES

Lead-acid batteries are among the oldest battery technologies in current use.

HOW DO THEY WORK?

Sulfate ions in a sulfuric-acid solution bind with one of two lead electrodes (electrical conductors) to create lead sulfate on the surface of the electrode. On the anode (a negatively charged electrode), this reaction releases two hydrogen ions as well as two electrons. On the cathode (a positively charged electrode), oxygen ions from the lead oxide electrode are displaced by sulfate from the sulfuric acid and form water by combining with the hydrogen ions and electrons from the anode. The hydrogen ions can travel across the barrier in the cell, but the electrodes must travel across the external circuit, generating electricity.

ADVANTAGES:

- o Low cost
- o High power density
- o Fully recyclable and reusable

DISADVANTAGES:

- o Modest round-trip efficiency
- o High self-discharge rate (3 - 20 percent)
- o Low cycle life
- o Low "depth of discharge"
- o Low energy density
- o Presence of toxic lead reagents

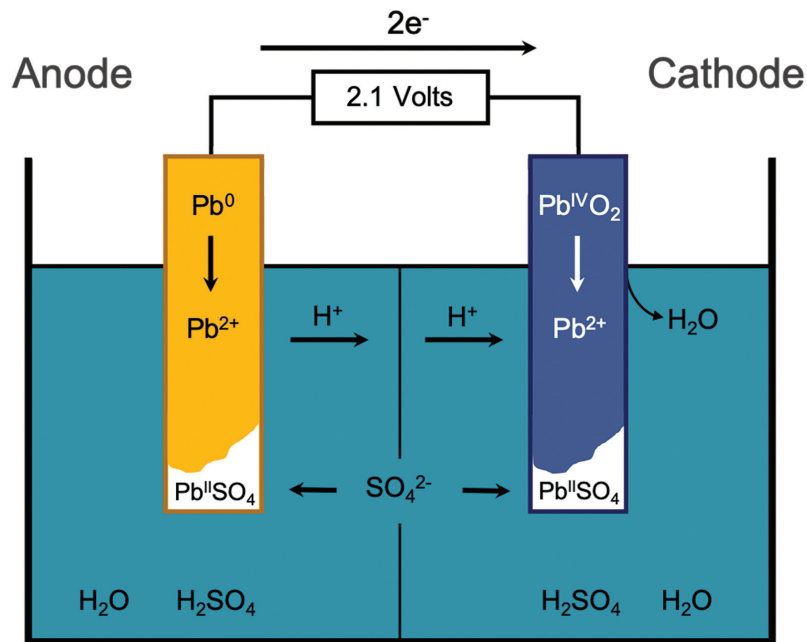


FIGURE 07

Schematic diagram of a lead-acid battery depicts a lead cathode and lead dioxide anode suspended in an aqueous sulfuric acid solution. The battery is shown during discharge with lead (II) sulfate accumulating on the electrodes. When charging, a current is run in the opposite direction between the electrodes, reversing each reaction shown. Image adapted from Jenn-Kun Kuo et al. *Int'l J. Energy Research*, 2015.

Energy Storage Batteries

LITHIUM-ION BATTERIES

Lithium-ion battery technology is currently the most rapidly developing and common type of energy storage battery in use, both for stationary and mobile purposes. It was first commercialized in the early 1990s and has been used in consumer electronics and electric vehicles. The recent surge in electric vehicle sales has driven rapid advances in lithium-ion technology and has contributed to rapidly declining costs. These trends have led this battery chemistry to dominate the stationary energy-storage market as well, most commonly used for residential backup power and utility-scale grid services (i.e. frequency regulation, spinning reserve, etc.).

HOW DO THEY WORK?

Lithium ions can flow between a lithium metal oxide cathode and a graphite anode through an electrolyte barrier. Electrons cannot travel through the barrier, so they are driven through an external circuit by charge repulsion. The lithium ions are more stable in the metal oxide than in the graphite, so it releases energy as electricity when traveling from graphite to

the metal oxide. To move in the opposite direction, it requires energy (ie. charging). Changing the metal oxide can fine-tune the properties of the battery; common chemistries include lithium iron phosphate (LFP), lithium nickel manganese cobalt oxide (NMC), and lithium titanate, among several others.

ADVANTAGES:

- o High energy and power density
- o High round-trip efficiency (esp. long-duration batteries)*
- o Modest price (and rapidly declining)
- o Rapid, virtually instantaneous response

DISADVANTAGES:

- o Sensitive to high and low temperatures
- o Potential for thermal runaway; flammability concerns
- o Limited depth of discharge
- o Self-discharge rate (1.5 - 2.5 percent)
- o Recycling lithium at end of useful life is economically inefficient

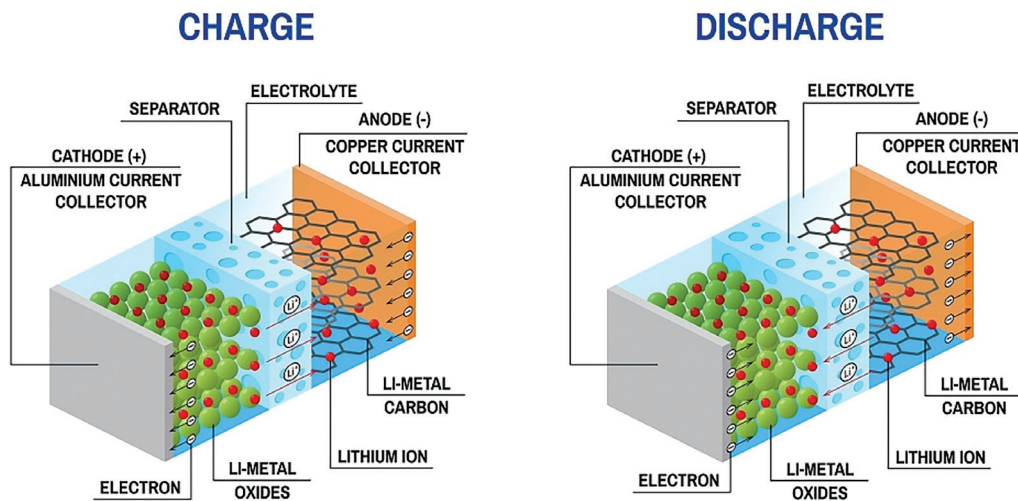


FIGURE 08

Schematic diagrams of a lithium-ion battery during charge and discharge, depicting the direction of lithium ion movement across the separator and corresponding electron motion from one electrode to the other. Image Source: VectorStock.

* Batteries with a lot of power capacity and low energy capacity are considered "short duration," while batteries with high energy capacity and low power capacity are considered "long duration." "Round-trip efficiency" refers to the amount of energy that can be discharged from a battery relative to the amount of energy that was used to charge it.

REDOX-FLOW BATTERIES

Redox-flow batteries are a relatively newer battery technology with a rapidly expanding niche in the energy storage market. These devices are typically employed for stationary, long-duration applications without strict weight or space restrictions, such as reserve capacity, time-shifting/energy arbitrage, or renewable generation firming. There are several functioning installations across the country, though flow batteries make up a small fraction of overall storage installations. Flow-battery technology is rapidly developing and advancing through research into novel chemical combinations and battery design.

HOW DO THEY WORK?

Solid electrodes are replaced by liquid electrolytes solutions, which are stored in holding tanks and pumped into the cell as needed. In the reaction cell, the two solutions are separated by a semipermeable membrane, which facilitates ion exchange across the barrier. Electrons are driven through charge repulsion, releasing energy as electricity; charging the battery reverses this reaction. Most commercially available batteries use vanadium solutions as electrolytes. More recent developments

have focused on common, inexpensive, and environmentally benign metals such as iron and zinc. Ongoing research is exploring the use of organic (non-metallic) electrolytes.

ADVANTAGES:

- o Long cycle life (20+ years)
- o Long duration potential (4 - 10+ hours)
- o Improved safety and fire resistance
- o Power and energy capacity can be selected independently
- o Electrolyte tanks are stackable to reduce footprint
- o Electrolyte solutions have value after battery's useful life, improving recycling and reuse potential

DISADVANTAGES:

- o Sensitive to high and low temperatures
- o Potential for thermal runaway; flammability concerns
- o Limited depth of discharge
- o Self-discharge rate (1.5 - 2.5 percent)

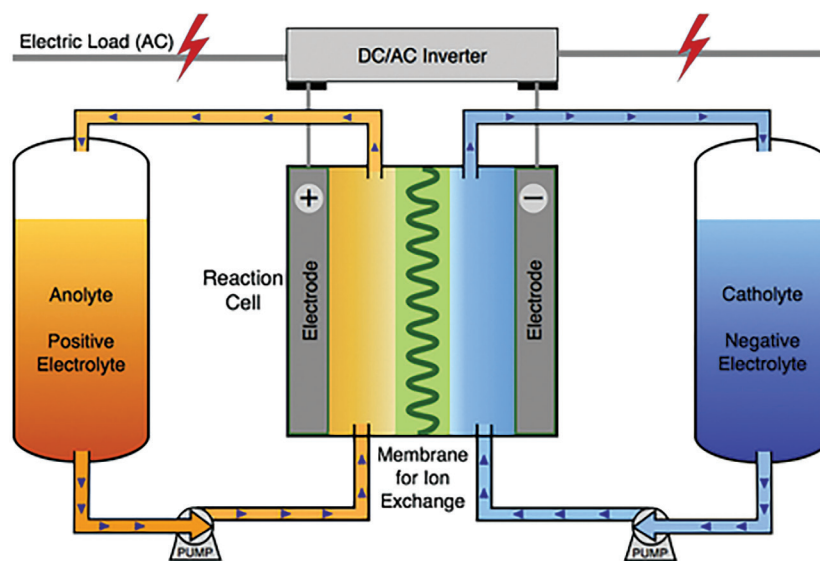


FIGURE 09

Redox-flow battery schematic depicting central reaction cell and separate electrolyte storage tanks.
Image Source: Prof. Werner Antweiler, University of British Columbia.

Energy Storage Batteries

THERMAL STORAGE

(BUILDING ENVELOPES AND HOT WATER)

In addition to the electrochemical energy storage methods detailed above, another key community-scale energy-storage method involves thermal energy and the storage of hot or cold air, water, or other thermal mediums. The fundamental principle of thermal-energy storage is to heat or cool the storage medium (water, for example) before the energy is required, typically when energy costs are lower or when less energy might be required to complete the process. Proper insulation of the thermal storage medium allows it to maintain a temperature differential with its surroundings over time.

The two primary uses for thermal energy storage on a residential or community scale are tank-style

hot water heaters and insulating building envelopes (the physical separation between a building's interior and exterior for climate control; includes doors, windows, insulation, and siding).

When employing a hot water heater for energy storage, the operator typically fills and heats the tank at a time when energy demand is low, such as the middle of the night. With the proper tank size and insulation, that hot water can be used throughout the day without the need to draw power when energy demand increases. If the energy rate design employed sets different energy costs at different times of the day, the customer is also able to save money in addition to reducing

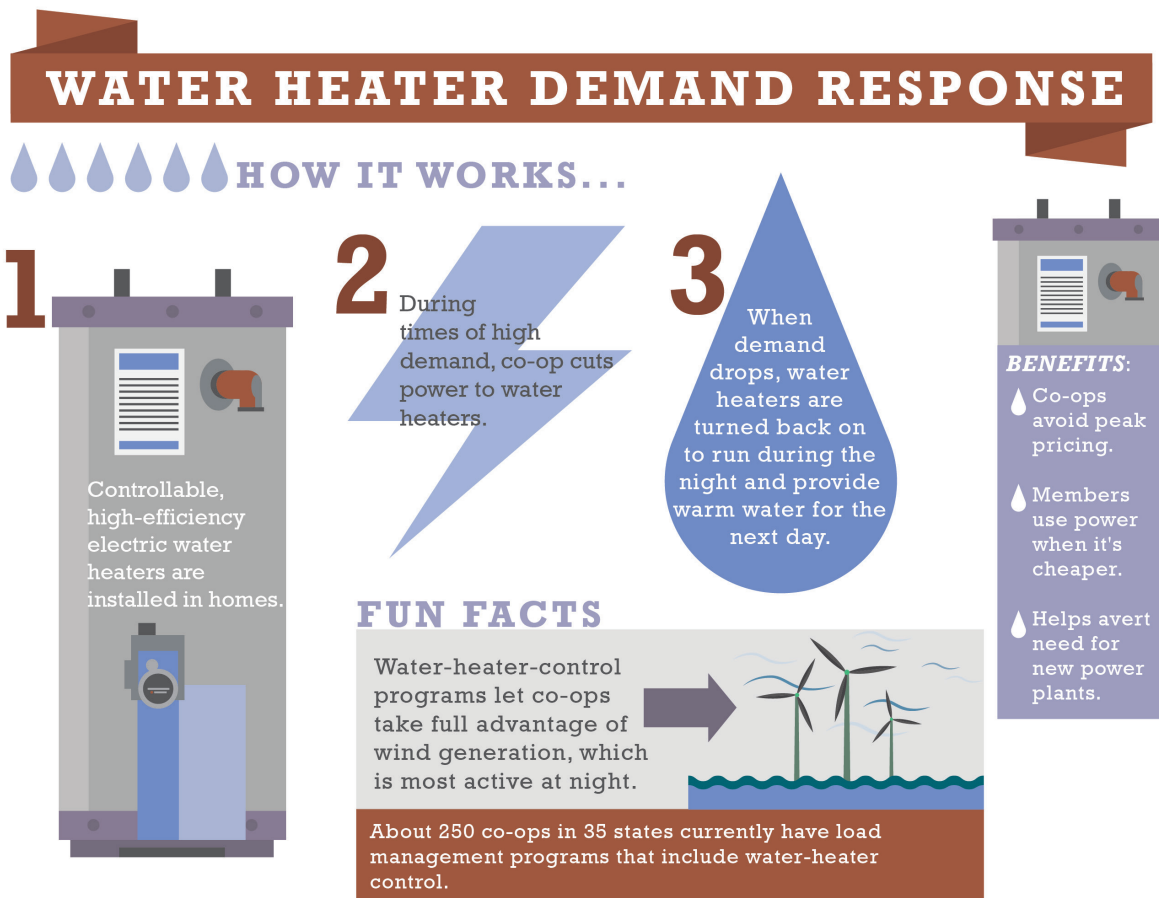


FIGURE 10

Many cooperative utilities employ grid-integrated water heating programs as demand response to provide grid flexibility and lower energy costs for consumers. Image Source: Rural Electric Magazine.

Energy Storage Batteries

distribution system congestion and mitigating energy peak events. Furthermore, many utilities operate Grid-Integrated Water Heating (GIWH) programs that aggregate many residential and commercial hot water heaters as a thermal energy storage system to facilitate flexibility to their distribution system for the purpose of mitigating system peaks and/or steep ramp rates.

The insulation of building envelopes operates similarly to hot water storage, except that the storage medium (conditioned air, for example) cannot be deployed at will; rather, it is perpetually in use. During warm days, for example, a building can be cooled at night when the outside temperature

is relatively low. (If the external temperature is adequately low, the internal temperature can be set without using any electricity.) When the external temperature rises during the day, a sufficiently insulated building will require less electricity - if any - to maintain a lower internal temperature. The opposite situation can apply during cold weather (i.e. storing warm air inside the building). While, similar to hot-water energy storage, this storage technique can shift energy use from times of high demand to times of lower demand, it has the added benefit of reducing the amount of energy used overall by limiting energy losses from leaks and reducing the frequency and extent of the use of climate control systems.



Getting Started: Bringing Energy Storage To Your Home Or Community

There are many steps to bringing an energy storage battery to your home or community space. Here we break down the primary considerations to take into account when beginning the process

1. DETERMINE YOUR USE CASE

There are a number of different things to consider when researching or considering an energy storage battery in order to maximize the value that it can provide. The starting point of these considerations should be to clarify which purpose(s) the device is intended to serve. Is the intent to save money on electrical bills by shifting when and how much electricity is being drawn from the grid? Do you have a renewable energy system like solar panels and want to get more value from them? Are you intending to improve the reliability of your electric service or provide resilience in the event of power outages? Do you intend to reduce your greenhouse gas emissions or contribute to the decarbonization of Minnesota's energy sector? Or is the goal to disconnect from the grid entirely? Identifying the underlying intent and purpose of an energy storage battery has a huge impact on selecting the type and size of the device, the manner in which it is installed, and the way in which it is operated. One storage device can be used to fulfill two or more purposes, and stacking these value streams can help the cost-effectiveness of the battery. However, with multiple functions the size requirements may increase and/or the effectiveness of fulfilling each of these individual purposes may decline.

Once the purpose has been identified, you can select the use case, or the way in which the device will be operated. If the intent of installing energy storage is to save money, then it is important to consider the rate design, or the method that your utility uses to calculate your bill. If you have a time-of-use or demand-metered rate design, then time-of-use management or demand-charge

management, respectively, can be used to reduce your electric bills [[learn more on pages 6 and 8](#)]. If, on the other hand, your utility charges a flat rate per kilowatt-hour used, it is currently unlikely that an energy storage battery will do much to change your bill. Contact your utility to learn what rate design options are available for your customer type and whether any can provide monetary value for behind-the-meter energy storage.

If the purpose that you have identified is to provide resiliency in the event of power outages, you will employ the backup-power use case [[see pages 30 - 31](#)]. And if you are interested in reducing your greenhouse gas emissions and already have or plan to have a renewable generation resource on your premises (typically solar photovoltaic), or if you are looking to disconnect from the grid entirely, the appropriate use case is optimization of distributed generation [[see page 6](#)]. With respect to facilitating

QUESTIONS TO ASK:

1. What purpose(s) should the device serve? Which purpose(s) is/are most critical to my home/community? (Ex: Am I dissatisfied with the reliability of my electric service due to frequent or significant outages?)
2. Do I have other energy devices (i.e. solar panels) that should be considered when planning an energy storage system?
3. Considering the use case(s) I've identified, which features are most important for the battery to have? (Ex: Should I prioritize reduction of energy costs or attributable carbon emissions?)
4. What is my rate design? (How does my utility calculate my energy bill?)

Minnesota's transition to renewable and carbon-free energy resources, each of these use cases contributes to Minnesota's energy goals in some way.

2. SELECT THE RIGHT BATTERY

The type and size of an energy storage battery has a huge impact on its ability to perform the intended use case. Selection of a particular battery chemistry can come down to a number of factors.

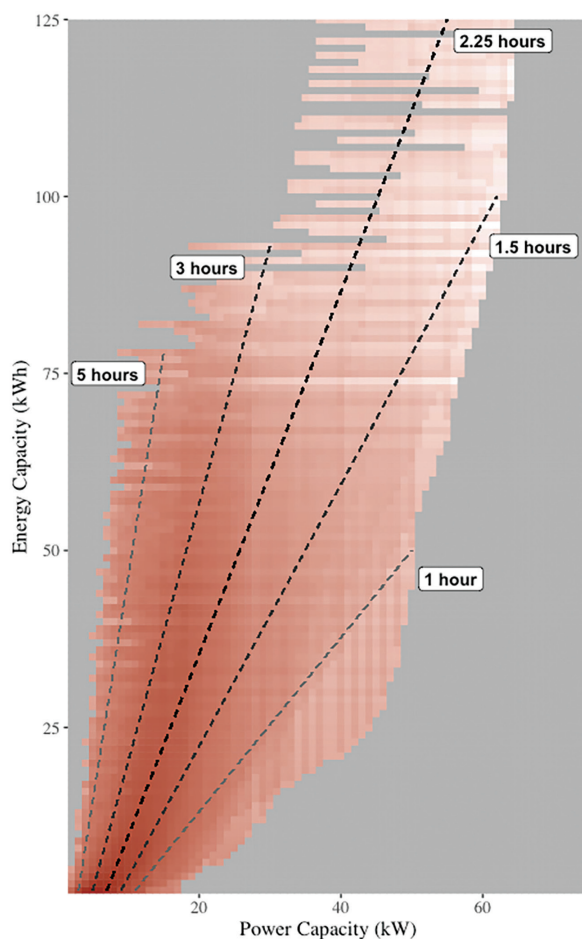


FIGURE 11
Example battery capacity analysis for demand-charge management application. Darker color indicates greater marginal value, while grey area indicates no marginal value. Image Source: Institute on the Environment, University of Minnesota.

Lead-acid batteries are by far the least expensive option but may require ongoing monitoring to ensure optimal function; they also may need to be replaced after a few years. If limited funds are available, or if the device is only needed or wanted for a few years, then lead-acid may be a good choice – particularly one of the newer designs. Additionally, if circular material flow and recyclability are significant concerns for you or your organization, lead-acid has a long history of recycling and reuse of battery materials. Lead-acid batteries have long been used for off-grid operation or emergency backup power and would also fit well with an application that does not require frequent cycling or deep discharging, such as demand-charge management, potentially extending the battery's useful life.

Lithium-ion technology is currently the most common battery chemistry for stationary energy-storage installations. This can be attributed to its advantageous mix of modest cost, high energy density (small footprint), and moderately long functional life. These balanced properties make lithium-ion batteries suited to a wide range of use cases and applications, including all four described herein. Continued research and development in the electric vehicle industry have greatly contributed to the declining costs of lithium-ion batteries and are expected to continue to drive lower costs and improved performance.

Redox-flow batteries are a much newer technology than others in widespread use. As such, they make up a much smaller share of the energy storage market and typically have higher costs per unit of battery capacity. One particular advantage of flow batteries is the ability to select the power and energy capacities independently of each other. This enables batteries of longer duration than other technologies can typically achieve, which makes flow batteries advantageous in cases which benefit from long duration storage, such as integration of distributed renewable generation resources, backup power, or time-of use management.

Getting Started

BATTERY SIZE

In addition to the selection of battery chemistry, determining an appropriate battery capacity to meet the requirements of the selected use case(s) is critical to achieve the objectives of the storage application in an efficient, cost-effective manner. A device which is sized too small would be unable to provide the level of services necessary to meet project goals; meanwhile, one that is too large would be more expensive than necessary and likely would not generate the value necessary to offset the capital expense of the installation. Additionally, the ratio of power capacity to energy capacity can greatly influence the effectiveness of the battery in executing a particular use case.

Batteries that are intended to optimize solar generation should be sized with consideration for the scale of the solar array and the typical amount of energy generated in excess of building demand. If the battery is intended to charge only from the solar array, any energy over and above the expected excess generation is unlikely to be used. Likewise,

HOT TIP

Most vendors of energy storage batteries or battery management systems are able to assist in the selection of use case(s) and to appropriately size a battery storage system to maximize the potential value of the installation.

power capacity should be determined with an eye toward the largest amount of over-generation expected, in order to ensure that the battery can use as much over-generated electricity as possible rather than exporting it to the grid.

Finally, when sizing a battery that will be used in part or primarily as a backup power supply, it is important to take account of the electricity needs of the building. In most cases, planning to supply 100 percent of a building's load during an outage is impractical and unnecessary. One should instead take a critical load inventory to determine which loads must be supplied during an outage and which are not necessary. Critical loads may include refrigeration, space heating, and powering communication devices, among others. These loads can be wired together to form a critical-load circuit within the building's electrical system, which will be powered by the battery when an outage occurs. (All non-critical outlets or wires will be without power.) Once this critical load is met, the energy capacity will determine how long the backup power will last.

Figure 11 (page 21) depicts a value estimation analysis of a theoretical battery engaged in demand-charge management on a particular load curve. The shade of each colored tile represents the relative marginal value for each added unit of battery capacity. Darker shades represent greater additional value for each additional unit. The gray region of the plot represents ranges of power to energy ratios in which additional units of either power or energy capacity represent no added value. The shape of this plot is highly dependent on the characteristics of each individual load curve and on the use case being applied.

QUESTIONS TO ASK:

1. What is my site's use case? What objectives are most important to me/my community in making a battery storage decision (e.g., cost, recyclability, duration, etc.)?
2. Are there environmental factors to consider regarding the site of the battery (ex: placed in a residential vs. warehouse setting)?
3. What power source will the battery be linked to? What are the electricity needs of the building where the battery will be installed?
5. On average, how many years do I/we need the battery to last?
6. What capacity is there for ongoing maintenance?

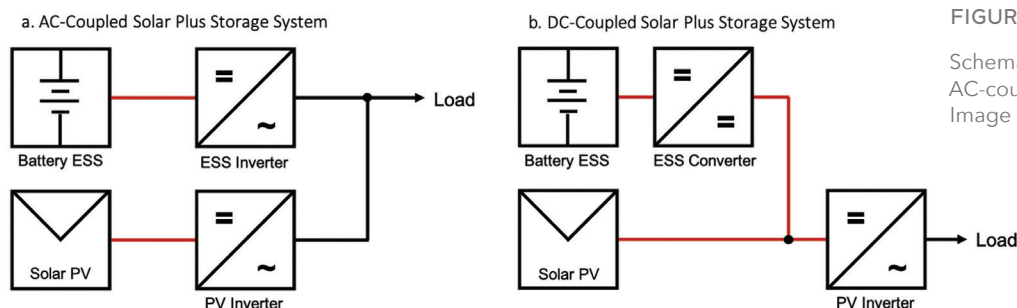


FIGURE 12

Schematic depiction of DC- and AC-coupled solar plus storage systems. Image adapted from Dynapower.

Based on the factors illustrated in Figure 11, it is critical to select a battery with characteristics that suit the particular application. Most vendors of energy storage batteries or battery management systems are able to provide detailed analysis to assist in the selection of use case(s) and to size a battery storage system appropriately to maximize the potential value of the installation.

3. RESEARCH ADDITIONAL EQUIPMENT REQUIREMENTS

In addition to the energy storage battery itself, additional equipment is needed for the device to function properly. Selection of these components can have profound effects on the overall performance of the battery. These equipment requirements include the following:

BATTERY MANAGEMENT SYSTEM (BMS)

Batteries typically contain basic control systems which maintain key measurements and processes within a safe operating range, preventing it from inflicting damage on itself through overcharging, overheating, or some other detrimental behavior. However, these systems usually are not designed to operate the storage device in the execution of any particular use case. A battery management system (BMS) is required to interface with the load and/or generation resource to enable use case execution. Some batteries (typically residential, such as the Tesla Powerwall) are purchased and installed with a BMS as part of the product package, while others

require the purchase of a compatible management device. The BMS is in many ways the most important piece of an energy storage installation; without it, the device is unable to provide the desired services.

POWER INVERTER

In addition to a BMS, battery devices typically need to be connected through a power inverter to function. Load centers such as homes and businesses operate on AC power, while batteries use DC power to charge and discharge. An inverter converts between these two formats, allowing power to flow back and forth. Batteries typically do not include an inverter, and a compatible device must be purchased separately. Some systems, typically designed for small, residential installations, do come with built-in inverters. (Example: Tesla's Powerwall has a built-in inverter while the LG Chem RESU battery does not.)

If the energy storage battery is paired with a generation resource such as solar photovoltaic, the storage device can often be installed in one of two general ways: DC-coupled or AC-coupled. When AC-coupled, the battery storage device and the generation resource are each connected to an inverter to convert output to AC, before joining the two and connecting to the targeted source of load (Figure 12a). DC-coupled devices on the other hand, are connected while still in DC state, before passing through an inverter to the building load (Figure 12b). While AC-coupled systems allow more versatility in terms of placement of the storage and generation devices, DC coupled systems tend to be more efficient as they have less energy loss from electricity passing through inverters.

Getting Started

FIRE SUPPRESSION SYSTEM

Unfortunately, lithium-ion batteries can present fire hazards due to the flammability of the lithium material and the high concentration of energy stored in the cell. This combination has led to a range of outcomes from cell phone batteries burning up to utility-scale battery systems producing large explosions. However, these risks can be effectively mitigated using proper fire prevention strategies. These strategies typically entail four key aspects: failure prevention, fire detection, fire suppression, and compartmentation.

QUESTIONS TO ASK:

1. Is a separate battery management system (BMS) needed or will one come with the selected battery? Considering my use case, how should the BMS work with the battery (what controls and functions should it offer)?
2. What type of power inverter is needed: AC- or DC-coupled?
3. If purchasing a lithium-ion battery, what building environment will it be placed in and what type of fire prevention system is required?
4. What other technology might be needed to support battery energy storage at my site?

Fire prevention is simply the process of designing the battery cell to minimize the risk of thermal runaway events that are often the cause of overheating and fires. During the information gathering stage of purchasing a lithium-ion battery it is important to ask potential vendors about design and construction features that serve as fire prevention measures. Fire detection involves rapid recognition of conditions that could lead to fires or the early stages of a fire. The nature of thermal runaway events is that they escalate extremely rapidly as one exothermic reaction creates heat which accelerates

another exothermic reaction, which continues this cycle to disastrous effect. Early detection of these events is critical in minimizing risk of severe fires and explosions. Fire suppression systems receive signals from detection systems and respond quickly to cool the battery and suppress the fire if it exists. Water mist is a common way to achieve both of these aims. Finally, compartmentation is the design aspect of the battery that seals off each of the individual cells from each other so that if one cell catches fire, it will not spread rapidly to each of the other cells in the unit.

4. LEARN ABOUT WARRANTY OPTIONS AND CONSIDERATIONS

There are a number of different warranty and insurance options available from battery manufacturers to ensure battery storage devices operate properly for as long as possible. The simplest form is a product warranty, which guarantees repairs in the event of defects in the device. There are also performance warranties, which ensures that one or more of the four key attributes (energy and power capacity, availability, and round-trip efficiency) maintain certain levels of performance over time (i.e. 70 percent of the original capacity). Finally, there may also be an option of an energy throughput warranty, which guarantees that the storage device delivers or discharges a certain amount of energy over the product's lifespan.

Depending on the specifics of the storage system and the warranty options available, manufacturers may offer self-insurance, where the company itself bears the risks of the warranty they have offered. Manufacturers may also oversize the battery relative to the capacity specified in the sale. For example, a battery sold with 100 kilowatt-hours of nominal capacity may be built with 110 kilowatt-hours of actual capacity, so that as the battery experiences degradation over time, the apparent degradation relative to the nominal, purchased capacity appears less significant than the actual capacity degradation.

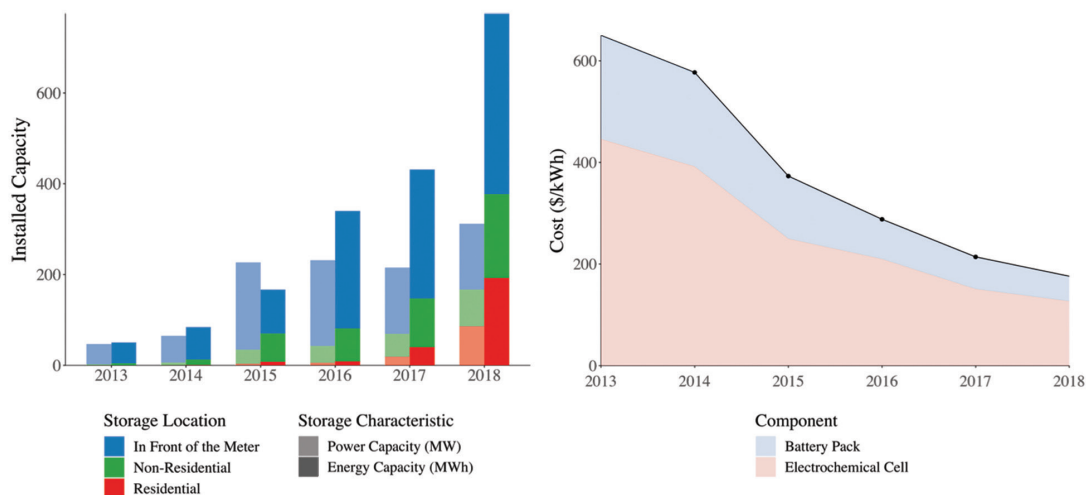
This practice reduces the level of risk for performance and throughput warranties. Warranties will often be contingent on certain battery use stipulations, such as use case(s) and/or cycle limits per day, month, or year. These conditions are often set because of the frequency and depth of cycling, which can vary significantly depending on the use case(s) employed, and can have a great impact on the degradation rate of battery capacities.

QUESTIONS TO ASK:

1. What warranty and insurance options do different battery manufacturers offer (product, performance, and energy throughput warranties)? Which best meets my needs?
2. What is *not* covered by the warranty? What is *not* covered by the insurance?
3. Is manufacturer self-insurance a good option for me?

FIGURE 13

Yearly (non-cumulative) installed capacity of energy storage batteries and their average cost per kilowatt-hour, from 2013 to 2018. Since 2013, there's been a rapid increase in the installation rate of energy storage batteries. Average costs have also fallen to roughly 30 percent of their previous values - both a cause and an effect of the increasing installation rate. ["Battery pack" refers to all parts of an energy storage system aside from the electrochemical cell that stores energy. It may include control systems, hardware, casing, and pump systems.] Image Source: Institute on the Environment, University of Minnesota.



5. RESEARCH STARTING COSTS, MAINTENANCE COSTS, AND FUNDING OPTIONS

Typically, energy storage batteries are financed either by upfront self-funding (money raised by the customer to cover the costs) or captive lending arrangements with manufacturers (loans provided by a subsidiary company to cover products and services provided by a particular manufacturer). Because the technology has yet to establish a consistent record of cost-recovery and profitability, it remains challenging for homeowners and smaller communities to secure energy-storage loans from banks and other lending institutions. That is slowly changing at a utility and large-commercial scale, thanks to advances in modeling capabilities and an expanding record of implementation. But because community-scale, small-commercial, and residential energy storage all have less extensive track records, purchasers can expect to face challenges to cost-recovery, such as market access, rate design, economies of scale, and volatile tariff structures. Luckily, as more consumers invest in battery energy storage, the costs of the technology continue to decline. From 2013 - 2018, the average costs for battery storage devices fell to roughly 30 percent of their previous values (Figure 13), both a cause and an effect of the rapidly increasing installation rate.

Getting Started

AVAILABLE TAX INCENTIVES

Under current law, there are generally two incentive mechanisms for energy storage installations. These include the federal Investment Tax Credit (ITC)⁸ and Modified Accelerated Cost Recovery System (MACRS).⁹

INVESTMENT TAX CREDIT (ITC)

The ITC is typically used for renewable generation resources, such as solar panels, and allows owners to deduct a portion of the cost from their taxes. Until 2019, this deduction was set at 30 percent but has since declined to 26 percent for 2020 through 2022, then to 22 percent in 2023. For non-residential installations, it will be set at 10 percent starting in 2024. If an energy storage battery is charged with renewable energy from a solar array or other renewable generation resource, it may be eligible for the same ITC rebate amount. Energy storage systems that are charged 75 percent or more from renewable resources are eligible for a portion of the full ITC equal to the fraction of renewable energy that they use.

While securing the ITC can represent significant savings, committing to charge from solar

generation has the potential to complicate the execution of certain use cases. For example, if a battery system is engaged in demand-charge management but experiences an extended period of dense cloud cover during key times, it may miss a peak and thereby miss out on cost savings. For this reason, some owners avoid the ITC altogether to focus on use-case execution.

MODIFIED ACCELERATED COST RECOVERY SYSTEM (MACRS)

Energy storage devices both paired with and in the absence of renewable generation resources are eligible for Modified Accelerated Cost Recovery System (MACRS) unless they are owned by a public institution or other non-profit organization. This accounting mechanism allows owners to recover some of the capital cost of the device over time. Systems eligible for the ITC may employ a 5-year MACRS schedule, equivalent to savings of approximately 21 percent of the cost of the system. Those which are ineligible for the ITC, such as government and non-profit organizations, can qualify for a 7-year MACRS timeframe, corresponding to 20 percent savings over those seven years

HOT TIPS

KNOW YOUR USE CASE(S)

When researching funding opportunities, pay attention to the use case(s) that will be employed by the device as it (they) affect a lending institution's ability to approve a loan. Because demand-charge management is currently the primary means for cost-recovery among commercial installations, for example, it's more likely to be approved for financing

GET MULTIPLE BIDS

Because it's currently a startup market for energy-storage technologies, costs can vary significantly from manufacturer to manufacturer. Make sure to request bids for the same technology from different companies to ensure you find the best fit for your budget and timeline.

ONGOING COSTS: OPERATIONS AND MAINTENANCE

As with modeling and use-case selection, operation and maintenance is much more complex for energy storage systems than it is for solar photovoltaic (PV) arrays, which also means that energy storage systems currently require more maintenance to ensure performance than solar PV. There are several reasons that contribute to this trend. First, storage devices are very complex systems. Some, such as redox-flow batteries, also have many moving parts. Maintenance involves the management of electrical, electromechanical, electrochemical, and thermal systems. Depending on battery chemistry and scale, maintenance may involve monitoring fluid levels, chemical concentrations, hosing and pump manifolds, and/or fire suppression systems. Additionally, control systems, firmware, and software are more complex because storage systems have

more complex operational needs than solar arrays, which are designed primarily to convert light into electrical energy in the most efficient way possible.

Furthermore, the repercussions of maintenance practices vary between the two technologies. Poor maintenance may cause solar PV systems to lose efficiency or generation capacity. Often, any damage or detriment incurred from poor maintenance practices can be fixed by subsequent repairs or the replacement of a panel. On the other hand, poor maintenance of battery systems, especially lithium-ion batteries, can lead to chemical leaks and contamination or thermal runaway events, which can either destroy the battery altogether or render it unable to function.

VENDOR-PERFORMED MAINTENANCE AND SELF-MAINTENANCE OPTIONS

Most vendors offer service contracts along with their battery systems in which they will send an employee or authorized representative to perform periodic maintenance of the battery system. This typically includes routine maintenance such as monitoring key systems like those described above, replacing equipment such as pumps when they reach the end of their service lifespan, and checking for malfunctioning equipment. Depending on the location of the battery and the capabilities of the vendor, service contracts may cost around 1 to 3 percent of the total capital cost on a yearly basis. If the routine service uncovers a problem with the battery that is covered by warranty, the vendor will fix it at their expense; if the problem is not covered by the warranty or if the warranty has expired, the vendor will fix it and bill the device's owner.

Currently, many vendors are relatively small organizations with limited capacity for on-site maintenance, particularly for small- to medium-scale installations. (This can vary for different battery technologies.) For this reason, vendors may offer training on basic, routine maintenance for host-site employees and/or members. (Incidental maintenance

for larger issues that require specialized knowledge would still be performed by the vendor.) This also creates an opportunity for sites to further serve their communities by incorporating energy storage system maintenance into training programs and curriculums.

QUESTIONS TO ASK:

FUNDING

1. What options do I have for raising money to cover upfront technology and installation costs? Are there investors willing to support the project or available grant opportunities?
2. How might reduced long-term operating costs compensate for the high upfront costs (10 year forecasting)?
3. **Loans:** Do the battery companies I'm looking into offer captive lending agreements? Do local lending companies offer loans for community-scale battery energy storage? If so, what is my use case? Is it supported by a track record required by banks to give loans (ex: demand-charge management)?
4. **Tax Incentives:** Are investment tax credits (ITC) available to me? What do I need to do to qualify for them? Likewise, which modified accelerated cost recovery system (MACRS) incentives are available to me? What do I need to do to qualify for them?

MAINTENANCE AND OPERATING COSTS

1. What ongoing maintenance is required by the battery I'm considering?
2. Which on- and off-site maintenance options are performed by the vendor? Which *aren't* covered?
3. What resources are required to operate the battery on a daily basis? What are their costs?
4. What training, expertise, and/or staffing is required to run the energy storage battery at my site?
5. What training does the vendor provide?

Learn by Example: Energy Storage Pilot Projects

In order to demonstrate the efficacy of community-scale energy storage in Minnesota, the University of Minnesota's Institute on the Environment coordinated the installation of three energy storage systems at sites across Minnesota in 2021: the Government Center for the Red Lake Band of Ojibwe Indians, the Green Prairie Community residence hall at the University of Minnesota Morris, and Renewable Energy Partners' (REP) Regional Apprenticeship Training Center (RATC)

in North Minneapolis. Funding for the installation of batteries was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) to provide mid-scale battery storage demonstration projects. Below, we outline the priorities, use cases, and site requirements that were weighted in order to determine the most optimal energy storage systems for each site.



FIGURE 14

Three host sites have been selected across the state of Minnesota to host energy storage batteries as part of this community-scale energy storage pilot. Image Source: Institute on the Environment, University of Minnesota.



North Minneapolis, Minnesota. Renewable Energy Partners solar installation site.



RENEWABLE ENERGY PARTNERS

PRIORITIES FOR ENERGY STORAGE INSTALLATION:

- A) Demonstrate novel energy technology
- B) Maximize consumption of rooftop solar
- C) Transparency and visibility of battery systems

PRIMARY USE CASE: Solar PV integration

BACKGROUND

Leadership at Renewable Energy Partners (REP) indicated that the demonstration of a novel energy technology was high on their priority list, along with fulfilling their primary use case of integrating a rooftop solar array. Early in the process, this involved exploring opportunities for flow battery technologies, which offer high energy capacities and long duration times. When that option fell through, REP expressed interest in employing conventional lithium-ion technology in novel and cutting-edge applications instead.

BATTERY SELECTION

Because the rooftop solar array was installed concurrently with energy storage system planning, REP was able to design the solar installation to optimize synergy between the two systems. This resulted in four individual Sonnen lithium-ion batteries installed so as to imitate a “transactive energy” grid system.

Transactive energy is a grid setup with economic, communication, and control systems in place to allow more flexible market-based transactions of electricity between distributed energy resources. In contrast to traditional grid design, where energy is generated at a handful of large, centralized power plants and flows in one direction to consumers, transactive energy allows people with generation assets such as wind turbines or solar panels to sell the electricity they generate through a market.

At REP, each of the four batteries are set up as “virtual customers” to be connected to different sized portions of the rooftop solar array. One battery is connected to a portion of the solar array with a larger generation capacity and is therefore likely to export energy after fully charging. Other batteries are either connected to a small portion of solar or not connected to solar at all, facilitating a need to import electricity to charge. Complex electronic communication and electric control systems monitor the generation and flow of electricity and the charge level of each battery to control the “transactions,” or flow of energy, between each virtual customer. Since this installation is very complex, the REP team worked extensively with engineers from their electricity utility provider, Xcel Energy, to develop wiring diagrams and complete their interconnection application.

Pilot Projects



Red Lake, Minnesota. Red Lake Nation Government Center rooftop solar installation.

RED LAKE NATION GOVERNMENT CENTER

PRIORITIES FOR ENERGY STORAGE INSTALLATION:

- A) Resiliency and data security in response to frequent power outages
- B) Preparation for larger storage installations on Oshkiimaajitahdah, schools, casinos, etc.
- C) Learning tool for Workforce Training Center
- D) Eventual energy sovereignty

PRIMARY USE CASE: Resiliency / backup power

BACKGROUND

Because Red Lake Nation experiences frequent power outages, the Tribal Council identified their primary use cases as the need to withstand outages without losing critical data and maintaining power to critical loads. They selected the Government Center building as the future site for the energy storage battery as it is located at the center of their community and provides many critical services to residents living on the reservation and visiting Tribal members.

The Tribe's data servers, which are housed in the Government Center, have previously had backup power through an uninterruptible power supply (UPS) made up of a few small lead-acid batteries. The Tribal Chairman expressed concern that the UPS was not adequate for the protection of data during

extended outages. He also expressed interest in using battery storage to cover other critical loads in the building. The government center is already equipped with a small rooftop solar array that offsets 25 percent of its energy use, but seldom generates more power than the building consumes.

Additional aims for this future installation involve gaining experience with energy storage and preparing for larger installations across the reservation. At the Oshkiimaajitahdah (a workforce training center), a battery identical to the one at the Government Center will help avoid curtailment of surplus energy during times of peak solar generation, allowing for self-consumption of that energy later in the day. The battery and controls will also serve as learning tools for successive training classes.



Dissatisfaction with their electric utility and a strong interest in being self-sufficient has also driven Red Lake leadership to pursue energy sovereignty. To serve their residents, they will install large amounts of solar generation on the reservation, and want adequate energy storage capacity to use the energy they generate without having to sell it back to their utility. Ultimately, they plan to purchase the distribution infrastructure from their utility and form a municipal utility to provide renewable, locally-generated energy to their residents.

BATTERY SELECTION

The most appropriate battery system for the Government Center has been determined to be a relatively small battery whose extended

duration is large relative to most common batteries. The power capacity needs to be sized to accommodate the critical loads, as designated by a critical load survey, and the energy capacity must meet backup power needs (i.e. adequate duration to outlast most outages). Due to their high energy capacity and long durations, vanadium-flow batteries were considered as prime candidates for this application. A 10-kW vanadium-flow battery with a 4-hour duration was eventually selected due to its capacity to provide outage resiliency and its ability to be installed inside the Government Center building without the need for supplemental heating or construction of an external structure. [At the time of publication, the project partners are still working on installing the battery system.]

Pilot Projects



Morris, Minnesota. UMN Morris solar array on campus. Inset photo: Green Prairie Community residence hall.

UNIVERSITY OF MINNESOTA MORRIS

PRIORITIES FOR ENERGY STORAGE INSTALLATION:

- A) Demonstrate use cases and value stacking
 - i. Peak-shaving / holding building load constant
 - ii. Optimization of solar generation and consumption
 - iii. Time-shifting / Time-of-use management
- B) Preparation for megawatt-scale battery

PRIMARY USE CASE: Peak shaving / stabilizing load

BACKGROUND

The team at the University of Minnesota Morris chose to install energy storage at the Green Prairie Community residence hall, a relatively new residence hall built to high sustainability standards and designed to support students' sustainable lifestyles. The Green Prairie Community is also served by a 20-kW solar photovoltaic (PV) array located just outside the building. The typical building load is about 20 - 30 kW. The UMN Morris team's primary interest is to use energy storage installation as an educational instrument and to demonstrate various energy storage use cases, including optimizing the use of solar energy in the building and holding building load constant throughout the day. Additionally, they expressed interest in using this storage installation to research the process and capacity of increasing the value created by a storage device by stacking multiple use cases, performed concurrently.

The Morris campus features multiple renewable energy generation assets - including two wind

turbines, multiple solar PV arrays, and a biomass gasification facility - and generates more electricity through these renewable resources than it consumes. However, because the energy generated does not match the energy consumed throughout the day and year, the campus must sell a considerable portion of this energy back to their utility. The long-term goals of the campus are to be able to store the energy it generates in a battery so it can be used directly rather than sold back to the utility and to maximize its usage of renewable energy. The campus also seeks to demonstrate a novel battery installation, which it can run several tests on over the next two decades, in order to help move forward the burgeoning industry for battery energy storage.

BATTERY SELECTION

In order to stack multiple use cases and enable use-case experimentation, the Green Prairie Community residence hall requires a battery with a large energy and power capacity. Due to its placement in a densely populated residential building, the campus was interested in vanadium-flow batteries, which are flame resistant, rather than lithium-ion batteries. Advanced lead-acid batteries were also considered due to safety concerns. Ultimately, two 7.5-kW, 4-hour vanadium-flow batteries were selected due to their ability to meet the goals of the project and address safety concerns. [At the time of publication, the project partners are still working on installing the battery system.]



CHALLENGES TO BENEFITING FINANCIALLY FROM ENERGY STORAGE AT A COMMUNITY-SCALE

Two of the most important factors in facilitating the adoption of community-scale and other behind-the-meter (BTM) energy storage technologies are the cost of the batteries and the ability to benefit financially from the services provided in order to offset the cost of the battery and benefit the owner/investor. Many markets for grid services are not available to customer-sited batteries or those smaller than a certain capacity threshold, or utilities employ rate designs that do not monetize the value that they

provide. As a result, while BTM storage is able to provide more services to the grid than in-front-of-the-meter (FTM) installations, the typical value returned to the battery owner is lower relative to capacity (Figure 14). In many cases, as demonstrated by the Rocky Mountain Institute’s “Economics of Battery Storage” report, behind-the-meter storage devices generate enough value to offset the cost of the battery, but typically encounter market inefficiencies, whereby the theoretical value is not fully compensated, and the typical delivered value does not make storage installation cost effective.¹⁰ Incentives and rate designs for behind-the-meter battery energy storage do not adequately compensate storage owners for the services they provide so as to incentivize more widespread use of storage batteries.

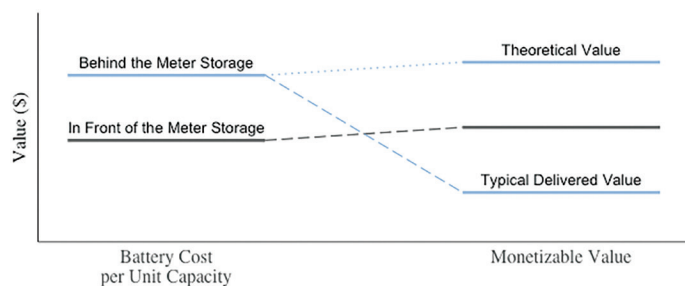


FIGURE 14
Inaccessible or uncompensated value streams of several grid services for behind-the-meter residential batteries lower the average deliverable monetized value relative to its theoretical value and decrease the likelihood of a return on investment. Image Source: Institute on the Environment, University of Minnesota.

Residential customers in many states and utility service territories do not have options available to them to create monetizable value from battery storage. These customers often receive retail-rate net metering compensation and usually do not have options for time-of-use or demand-metered

Appendix

rate designs. This denies them access to some of the most crucial value streams available to behind-the-meter storage. While energy storage is a relatively nascent market, and the residential storage market is particularly underdeveloped, key analogies can be drawn to behind-the-meter residential solar installations. Between 2009 and 2016, many of the same states were among those with the greatest installed solar capacity year after year (Figure 15).

While a few of the states with high solar-generation rates have large populations (i.e. California, New York), or an abundance of solar capacity (i.e. Arizona, New Mexico, Texas), several of the states have neither. Notable among the top ten in 2016 are Massachusetts, New Jersey, Connecticut, and Delaware, which have modest populations and solar capacity. The more indicative factor with regard to adoption of residential solar in these states appears to be policy levers which incentivize its use.¹¹

Likewise, policy measures have significant impact on the installation rate of behind-the-meter battery storage. BTM residential energy storage installations are led primarily by California and Hawaii, making up 72 percent of total energy capacity, with Massachusetts and Arizona the next two highest.¹² Each of these states has incentive programs, tariff structures, and/or favorable rate designs which add value and incentivize storage installation.¹³ Minnesota, on the other hand, does not have any state-wide initiatives to encourage behind-the-meter energy storage,¹⁴ and many of the utilities in the state do not offer rate designs to residential customers that monetize the value contributed by storage batteries.

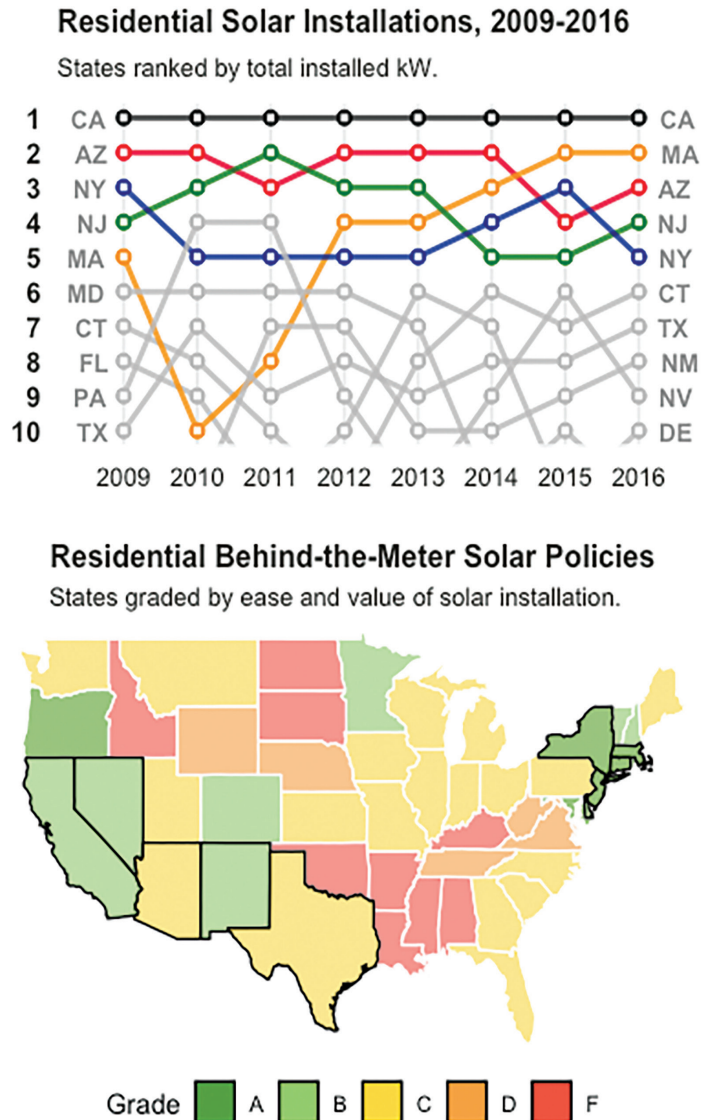


FIGURE 15

Leading states with regard to residential solar capacity installed by year, 2009 - 2016; assessment of state residential solar policies. Outlined states are among top ten for installed capacity in 2016. Image Source: Institute on the Environment, University of Minnesota.

Glossary of Key Terms & Abbreviations

ANODE

The negative electrode in the electrochemical cell of a battery. The anode accumulates negative charge (electrons) when the battery is charged. During discharge, electrons flow out of the anode toward the cathode.

AVAILABILITY

The state of a storage device being ready and capable of performing a service or use case. If a battery only charges from an attached solar array, then its availability depends on the array's ability to charge the device.

BATTERY MANAGEMENT SYSTEMS (BMS)

Basic control systems for maintaining key measurements and processes of the device within a safe operating range, preventing it from inflicting damage on itself through overcharging, overheating, or some other detrimental behavior; however, these systems usually are not designed to operate the storage device in the execution of any particular use case. A BMS is required to interface with the load and/or generation resource to enable use case execution. Some batteries (typically residential, such as the Tesla Powerwall) are purchased and installed with a BMS as part of the product package, while others require the purchase of a compatible management device. The BMS is in many ways the most important piece of an energy storage installation because without it, the device is unable to provide the desired services.

BUILDING ENVELOPE

The physical separation between a building's interior and exterior, which is essential to climate control. Includes doors, windows, masonry, insulation, roof, foundation, floor, and siding.

CATHODE

The positive electrode in the electrochemical cell of a battery. The cathode loses negative charge (electrons) when the battery is charged, giving it a positive charge. During discharge, electrons flow back towards the cathode from the anode.

CYCLE LIFE

Over time, a battery's ability to charge and discharge will slowly diminish. Cycle life refers to the rate at which this occurs with respect to the number of times the device is able to charge and discharge. A battery with a long cycle life can undergo many charge-discharge cycles with low degradation of its capacity. Storage devices often include a warranty from

the manufacturer which specifies a time period and a capacity threshold. [See "warranty" description below.]

DENDRITE

Growths of lithium (or other material in a battery) that builds up on an electrode and protrudes towards or into the membrane separating the electrodes. In lithium-ion batteries, dendrites are caused by uneven deposition of lithium ions when they return to the cathode from the anode during discharge. Dendrites contribute to the deterioration of many battery types and in extreme cases can cause fires and/or explosions.

DEPTH OF DISCHARGE

Most batteries have to maintain some minimum level of charge to avoid long-term damage or decreased capacity. The depth of discharge refers to the amount of the battery's energy capacity that has been utilized. Each battery typically has a maximum depth of discharge, which is the fraction of energy that can be drawn from the battery without depleting its minimum charge.

DISPATCHABLE GENERATION

Generation resources that can be deployed (or ramped up) as needed to meet demand. Non-dispatchable resources are those which cannot be controlled such as wind and solar, which generate power according to weather conditions. Renewable dispatchable energy sources are, for example, hydroelectric and geothermal because they can be deployed by operators when there is additional energy demand.

DURATION

The length of time a storage device can provide 100 percent power delivery, typically measured in hours. A device with one kilowatt of rated power and two kilowatt-hours of energy capacity has a duration of two hours.

ELECTROCHEMICAL CELL

An electrochemical cell is the basic unit of any battery. It is typically described by two "half reactions," one that releases electrons and one that accepts electrons. These two half reactions each have a voltage rating which describes the amount of energy that is either created or used up in the reaction. The total voltage of an electrochemical cell is the sum of the voltage of the two half reactions.

ELECTRODE

A conductor used to establish electrical contact with a nonmetallic part of a circuit.

ELECTROLYTE

The electrolyte in a battery is the medium that facilitates ion flow within the battery, between the anode and the cathode. This material varies depending on the battery chemistry and can be an acidic or alkaline solution, a gel or polymer, or a solid such as ceramic or aluminum.

ENERGY RATING / ENERGY CAPACITY

The total amount of energy that an energy storage battery is capable of storing. Measured in kilowatt-hours (kWh).

ENERGY/POWER DENSITY

Energy and power density are measurements of energy capacity and power rating per unit of mass of the storage device. Typically measured in watt-hours per kilogram (Wh/kg) and watts per kilogram (W/kg) respectively.

FREQUENCY

Refers to the frequency of the oscillations of alternating current (AC) electricity. In the United States the standard frequency is 60 Hertz (Hz). Significant deviation away from this value can result in damage to electrical equipment or interruptions to electrical service.

GRID FLEXIBILITY

The ability to maintain the proper balance between generation and load, typically by leveraging control over both the generation and load sides of the equation. This can be achieved through energy storage, demand side management, and dispatchable generation resources.

IN FRONT OF / BEHIND THE METER

Location on the electrical system with respect to a customer's electric meter. Equipment in front of the meter is owned and controlled by an electric utility or other energy company, while equipment behind the meter is owned and controlled by the customer.

INVESTOR-OWNED UTILITY (IOU)

A publicly-owned, corporate, for-profit utility company. In vertically-integrated states such as Minnesota, IOUs are granted monopolies over their respective service territories, but they are required to provide service to all customers in that territory and are regulated by state regulatory agencies (i.e. Minnesota Public Utilities Commission).

INVESTMENT TAX CREDIT (ITC)

The Investment Tax Credit is a federal tax incentive available to owners of wind and solar assets. Energy storage is eligible for the ITC if it is solar-paired and charges from that solar array at least 70 percent of the time. The ITC was set at 30 percent until 2019, when it began to be phased out. In 2020, the ITC decreased to 26 percent. In 2021 it will be 22 percent, while in 2022, the ITC will be 10 for commercial and utility-scale installations and will not be available to residential customers.

MARGINAL COST OF ELECTRICITY

The sum of all costs related to bringing one more unit of electricity to the grid. For example, if a solar installation is needed to increase electricity by one kilowatt (kW), then those costs (equipment, installation, staffing) are included in the marginal costs.

MODIFIED ACCELERATED COST RECOVERY SYSTEM (MACRS)

The Modified Accelerated Cost Recovery System (MACRS) depreciation deduction is a tax incentive available to non-public owners of energy storage batteries. The type of MACRS available depends on whether the storage device is paired with a solar photovoltaic array. Installations that are solar-paired and charge from that solar more than 70 percent of the time are eligible for a 5-year MACRS schedule, which is roughly equivalent to a 21 percent reduction of capital costs. All other privately-owned storage systems qualify for 7-year MACRS schedules, roughly equivalent to a 20 percent reduction in capital costs.

OPERATING RESERVE

The energy capacity (generation or storage) available to a utility or system operator to meet demand if a generation asset is taken offline or there is some other interruption in power supply. Two categories of operating reserve are spinning reserve and non-spinning or supplemental reserve. "Spinning reserve" refers to generation assets that are operating at less than full capacity that can be increased to full capacity. Supplemental reserve refers to generation assets that are not currently operational but can be activated. Spinning reserve can typically respond more rapidly than non-spinning reserve.

POWER RATING / POWER CAPACITY

The amount of energy that a storage device is capable of delivering at any given moment, measured in kilowatts (kW). Many batteries often can pulse a higher power for a short period of time (~30 minutes) above their general power rating.

PV

Photovoltaic, the most common method for solar panels to convert solar energy into electricity.

RAMPING/RAMP RATE

The process or rate of increasing power supply to the grid in order to match increasing demand. One of the most common examples is the rapid increase in demand on hot summer evenings when distributed solar generation wanes and home energy use increases, creating a rapid rise in demand.

ROUND-TRIP EFFICIENCY

A perfectly efficient storage device would be able to discharge one kilowatt-hour for each kilowatt-hour with which it is charged. However, each device experiences energy losses in the charge-discharge cycle. The round-trip efficiency is a measure of the fraction of energy that can be drawn out of a battery as a portion of the energy that has been put into it. For example, a battery which is charged with five kilowatt-hours, but can only discharge four kilowatt-hours has a round-trip efficiency of 80 percent.

SELF-DISCHARGE

Self-discharge occurs when the amount of energy stored in a device is reduced without discharging externally through any external circuit.

SPECIFIC ENERGY/POWER

Similar to energy and power density, but measures battery capacity relative to the volume of the storage device.

THERMAL ENERGY STORAGE

Storing energy in the form of a temperature difference between a storage medium and its surroundings. This can include storing warm or cool air within a building, hot water heaters, cold water or ice, or hot molten salt. Thermal energy storage is often not converted back to electricity, but rather is used for its heating or cooling abilities. Thermal storage allows for time-shifting, by heating or cooling the medium when energy demand or rates are low and using it when rates are high.

THERMAL RUNAWAY

Some types of lithium-ion batteries, especially lithium polymer chemistries, are prone to uncontrolled superheating events that can result in violent explosions of the batteries if improperly manufactured or operated. Thermal runaway is an uncontrolled positive feedback loop wherein an exothermic reaction in the battery, which releases heat, is then accelerated by the same heat that it releases. This cycle results in the rapid buildup of heat and extreme acceleration of the reaction in the battery.

WARRANTY/CYCLE LIFE

Over time, a battery's ability to charge and discharge will slowly diminish. Cycle life refers to the rate at which this occurs with respect to the number of times the device is able to charge and discharge. A battery with a long cycle life can undergo many charge-discharge cycles with low degradation of its capacity. Storage devices often include a warranty from the manufacturer which specifies a time period and a capacity threshold. The warranty guarantees that the device will maintain at least the stated capacity (often around 70 percent of the original value) for the designated time.

Endnotes

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