Understanding Solar+Storage

Answers to Commonly Asked Questions About Solar PV and Battery Storage

Clean Energy Group

About this Report

Clean Energy Group produced *Understanding Solar+Storage* to provide information and guidance to address some of the most commonly asked questions about pairing solar photovoltaic systems with battery storage technologies (solar+storage). Topics in this guide include factors to consider when designing a solar+storage system, sizing a battery system, and safety and environmental considerations, as well as how to value and finance solar+storage. The guide is organized around 12 topic area questions. These questions and the issues discussed within each section were informed by and developed for community-based organizations. The guide was produced under Clean Energy Group's Resilient Power Project (www.resilient-power.org). The Resilient Power Project works to accelerate the equitable deployment of solar+storage technologies in historically marginalized and underserved communities through technical assistance, knowledge and capacity building, advancing enabling policies and programs, and amplifying community voices. This release is an updated and enhanced version of the original guide, which was prepared and published in October 2020.

ACKNOWLEDGEMENTS

The authors would like to thank Mayra Cruz at Catalyst Miami, Logan Atkinson Burke at Alliance for Affordable Energy, Shelley Robbins at Upstate Forever, Chelsea Barnes at Appalachian Voices, Timna Zemel and Chris Keast at Simpliphi Power, Will Heegaard at Footprint Project, Geoff Oxnam at American Microgrid Solutions, Laurie Mazur at Island Press, and Meghan Monahan, Samantha Donalds, Todd Olinsky-Paul, and Anna Adamsson at Clean Energy Group for their valuable input and review of this guide. Maria Blais Costello of Clean Energy Group was responsible for report production, working with David Gerratt of DG Communications on the report design. Much appreciation also for the generous support of the foundations, organizations, and individuals funding this work, including The Kresge Foundation, The JPB Foundation, Wells Fargo Foundation, JPMorganChase Foundation, the Center for Impact Finance at the University of New Hampshire's Carsey School of Public Policy, and Inclusiv. The views and opinions expressed in this guide are solely those of the authors.

This report can be found on the Clean Energy Group website at https://www.cleanegroup.org/ceg-resources/resource/understanding-solar-storage, and in Spanish at https://www.cleanegroup.org/publication/Lista-de-Verificación-del-Proyecto-Solar-Almacenamiento.

Understanding Solar+Storage

Answers to Commonly Asked Questions About Solar PV and Battery Storage

Marriele Mango | Seth Mullendore

CLEAN ENERGY GROUP

JULY 2024

CleanEnergyGroup

Table of Contents

Glossary of Terms

AVOIDED OUTAGE COSTS: Avoided outage costs represent the value of losses that would have been incurred if a facility were to experience a power outage without a backup power system. Losses could include decreased workforce productivity, interruption of services, and even loss of life due to a lack of medical care or disaster response services.

BATTERY STORAGE: Battery storage is a rechargeable battery that stores energy from other sources, such as solar arrays or the electric grid, to be discharged and used at a later time. The reserved energy can be used for many purposes, including shifting when solar energy is consumed onsite, powering homes or businesses in the event of an outage, and generating revenue for the system owner by providing grid services. Two of the most common types of battery storage paired with solar are lithium-ion batteries and lead acid batteries.

BEHIND-THE-METER: Behind-the-meter, also known as customer-sited, energy storage systems are located on the owner's property, literally behind the utility meter on the customer side, as opposed to front-of-the-meter systems, which are located on the utility side of the meter and directly connected to the utility distribution system.

COMBINED HEAT AND POWER (CHP): Combined heat and power systems are technologies that produce both electricity and thermal energy (heating and cooling), from a single or blended fuel source. Common combined heat and power technologies include fuel cells, reciprocating engines, and microturbines. Combined heat and power is also known as cogeneration.

COMMUNITY SOLAR: Community solar, also called shared solar, is a purchasing arrangement in which multiple customers share the electricity or the economic benefits of solar power from a single solar array. Community solar installations may be physically located at a property shared by the customers, such as a multifamily apartment building, or located at a remote location.

COST-BENEFIT ANALYSIS: A cost-benefit analysis compares the costs and benefits of a particular investment with other investment options, and/or maintaining the status quo (i.e., not making an investment).

CRITICAL LOADS: The electrical equipment and devices that are the most important to keep powered during a grid outage. Critical loads will vary depending on the type of facility and customer needs. Examples of common critical loads include emergency lighting, outlets for charging electric devices, and refrigeration.

CYCLING: Cycling is the process of a battery system charging (storing energy) and discharging (releasing energy). Essentially, one full charge and discharge represents one cycle.

DEGRADATION: Solar panels and battery storage systems become less efficient as they operate over time. For solar panels, the amount of energy produced slowly declines due to the effects of exposure to the elements. Battery storage energy capacity declines as batteries are charged and discharged due to chemical reactions that occur as part of the processes. The rate of these declines is the degradation rate.

DEMAND MANAGEMENT: The ability to reduce electricity consumption from the grid during times of high onsite demand or periods of high utility demand charges. The process of managing onsite demand to reduce demand charges billed by an electric utility is known as demand charge management.

DEMAND RESPONSE: Lowering consumption of grid electricity, either through discharging stored energy or reducing energy use, in response to utility signals. These demand response events typically occur at times when systemwide demand for grid electricity is high, such as hot days when air conditioning is consuming more energy than usual.

DEPTH OF DISCHARGE (DOD): The percentage of energy capacity that can be discharged from a battery before its performance is negatively impacted.

ENERGY ARBITRAGE: The storing of energy, either from the grid or onsite generation, during periods when electricity prices are low, to be discharged at a later time when electricity prices are higher.

ENERGY CAPACITY: The total amount of energy that can be stored by an energy storage system, usually measured in kilowatt-hours, or megawatt-hours for larger storage systems.

ENERGY DENSITY: A measure of how much energy (kilowatt-hours) can be stored in a battery per unit of weight, which typically corresponds to battery size. Usually, a more energy dense battery will require less physical space in an installation.

ENERGY SERVICES AGREEMENT (ESA): A type of third-party financing in which all project development and construction costs, as well as maintenance and operation of a system, are covered by the developer. Once the system is operational, the customer begins making service charge payments based on realized savings. The developer can benefit from any applicable Renewable Energy Certificates (RECs) and tax incentives associated with the project. Energy Services Agreements are similar to solar Power Purchase Agreements (defined below), but often include other types of energy technologies, such as energy storage and efficiency measures.

ENERGY THROUGHPUT: The total amount of energy that can be charged and discharged throughout the useful life of a battery system, typically represented in megawatt-hours.

FREQUENCY REGULATION: The balancing of electricity supply and demand to keep grid frequency within acceptable bounds for the electric power system to operate properly. Grid frequency is the number of oscillations of alternating current (AC) over a period of time (measured in hertz). In the United States, the grid operates at a frequency of 60 hertz.

GRID: A network that delivers electricity from producers to consumers. Utilities typically operate the electric grid and charge customers for the energy they use.

GRID SERVICES: Services, such as frequency regulation, voltage support, and demand response, that support the operation, balancing, and management of the power grid.

HYBRID SYSTEM: A system that includes both renewable energy and fossil-fuel components. For example, a solar+storage system with a diesel generator.

INTERCONNECTION: The process of connecting an energy resource, such as solar PV and battery storage, to the electric grid. Utilities will oftentimes mandate an interconnection review to ensure that the proposed system will have no negative impacts on the grid.

INVERTER: An inverter is used to convert DC power generated by solar and battery storage into AC power for use in homes and businesses and/or AC power from the grid to DC when charging a battery storage system.

KILOWATT: A kilowatt (kW) is a measure of power. One kilowatt is equal to 1,000 watts.

KILOWATT-HOUR: A kilowatt-hour (kWh) is a measure of how much energy is used or generated. A device requiring 1 kilowatt of power that is operated for two hours will use 2 kilowatt-hours of energy. On a utility bill, a kilowatt-hour indicates how much energy was delivered to a customer by an electric utility.

MICROGRID: A microgrid is a local energy system with onsite sources of generation that can disconnect from the utility grid and operate independently. A microgrid may be composed of a single building, sometimes referred to as a nanogrid, or multiple interconnected buildings.

NET ENERGY METERING (NEM): Net energy metering programs allow customers to earn utility bill credits for the electricity they generate from their solar array that is not directly consumed onsite. The bill credits can be applied to offset the cost of electricity consumed from the utility grid.

OFF-GRID: Local energy systems that operate completely separate and disconnected from the grid.

PEAK DEMAND: The highest level of power demand (kilowatts) during a given period.

PEAK SHAVING: The process of lowering peak demand by reducing energy consumption or by discharging stored energy during times of high energy usage.

POWER PURCHASE AGREEMENT (PPA): A type of third-party financing that establishes an agreement between a developer and a customer to install a solar (or solar+storage) system on a customer's property with little to no upfront out-of-pocket expenses. Through the agreement, the customer pays the third-party an agreed upon rate (dollars per kilowatt-hour) for the energy generated by the system.

POWER RATING: The maximum rate at which a battery can charge or discharge energy or a solar system can generate energy. The power rating of a battery or solar system is typically given in kilowatts, or megawatts for larger systems.

SELF-CONSUMPTION: When a battery or other type of energy management system is used to maximize the amount of solar energy directly consumed onsite and minimize the amount of solar generation sent to the grid or curtailed (lowering the output of the solar system).

SIMPLE PAYBACK PERIOD: The time it takes for a project's savings and revenue to equal or exceed the full installed cost of the system.

SOLAR+STORAGE: A solar photovoltaics array connected to a battery storage system, either directly or through one or more inverters.

STORAGE-READY SOLAR: A solar system that was installed anticipating that battery storage would be installed at a later date. Adding battery storage to a storage-ready solar system is an easier and oftentimes less expensive process than adding battery storage to a solar system that did not plan for the addition of storage.

RELIABILITY: The ability for a backup power system to maintain continuous power without relying on access to outside resources that may be experiencing disruptions. Grid reliability refers to the ability of the electric grid to withstand disruptions to service and avoid power outages.

RESILIENCE HUB: A community-serving facility that has been designed to support nearby community members during and after times of crisis, such as severe weather events and extended power outages, by maintaining access to essential services that may include electric device charging, temperature regulation, and resource distribution.

RESILIENT POWER: The ability to provide a facility with continuous, clean, and reliable power even when the electric grid goes down.

THERMAL RUNAWAY: A process where an increase in temperature alters conditions in a way that leads to further temperature increases. In some battery chemistries, thermal runaway can occur due to chemical reactions that can cause a battery cell to overheat and eventually catch fire.

TIME-OF-USE (TOU) RATES: An electric tariff structure used by some utilities that charges different pricing rates for electricity delivered at different times of day, with higher prices typically occurring during periods of high electricity demand (peak periods), and lower prices occurring during periods of low demand (off-peak periods).

USEFUL LIFE: The useful life of a device represents how long the device can operate before it has degraded to the point that it can no longer effectively serve its original intended purpose.

VIRTUAL POWER PLANT (VPP): The aggregation of many, hundreds or even thousands, smaller behind-the-meter distributed energy resources (e.g., solar PV, battery storage, controllable thermostats, and electric vehicle chargers) for the purposes of providing grid services that would normally be served by a utility-scale installation, such as a fossil-fuel power plant.

VALUE OF LOST LOAD (VOLL): VoLL is the approximate price that a customer is willing to pay to avoid a power outage. VoLL is helpful in monetizing the full value of battery storage for energy resilience.

WARRANTY: A guarantee of a product and/or its performance over a period of time.

INTRODUCTION

Understanding Solar+Storage

Answers to Commonly Asked Questions About Solar PV and Battery Storage

Every day, thousands of solar photovoltaic (PV) systems paired with battery storage (solar+storage) enable homes and businesses across the country to reduce energy costs, support the power grid, and deliver backup power during emergencies. While solar+storage deployment numbers are relatively small compared to solar-only systems, installation rates have grown significantly over the past few years and are expected to continue their rapid rise. Still, solar+storage remains a little understood technology solution for many property owners, energy managers, and community leaders.

> **This guide is designed to serve as a starting point to establish a foundation of understanding for individuals and organizations beginning to explore solar+storage options.**

By addressing commonly asked questions about solar+storage, this guide is designed to bridge some of the fundamental knowledge gaps regarding solar+storage technologies. It is meant to serve as a starting point to establish a foundation of understanding for individuals and organizations beginning to explore solar+storage options for their homes, businesses, or community facilities.

To determine what knowledge gaps exist, Clean Energy Group (CEG) conducted a survey to identify the most asked questions about solar+storage. The questions and topic areas addressed in this guide are based on feedback from nearly 100 stakeholders who submitted questions about solar+storage. The guide is organized into 12 common questions, each addressing multiple key topics. The answers are informed by more than ten years of experience through CEG's work with property owners, developers, nonprofits, and communities to advance solar+storage in historically marginalized and underserved communities.

The information presented in the guide focuses primarily on customer-sited, behind-the-meter solar+storage installations, though much of the information is relevant to other types of projects as well, including storage-only projects and front-of-the-meter solar+storage projects.

Solar+storage topics addressed include the following:

1. **What factors do I need to consider when designing a solar+storage system?**
   TOPICS COVERED: physical and structural considerations, permitting and interconnection, financial considerations, AC and DC coupling, additional factors for resilience projects and a few special cases

2. **Is solar+storage an effective backup power solution?**
   TOPICS COVERED: critical load considerations, comparison of solar+storage versus fossil-fuel generators, brief discussion of other backup power options (hybrid solutions, portable systems, storage-only)

3. **How do I determine the value of solar+storage (savings, revenue, resilience)?**
   TOPICS INCLUDE: utility bill savings, demand charge management, utility and grid services, avoided outage costs, health and environmental benefits, and methods to determine the cost effectiveness of solar+storage

4. **How much do batteries cost?**
   TOPICS INCLUDE: installed cost ranges for lithium-ion battery systems, projected battery storage cost declines, differences between per kilowatt and per kilowatt-hour pricing

5. **How can I pay for a solar+storage system (incentives, grants, financing)?**
   TOPICS INCLUDE: federal tax incentives, state and utility incentive programs, examples of programs targeted to support development in low-income communities, discussion of financing options

6. **Can storage be added to an existing solar system?**
   TOPICS COVERED: potential barriers to incorporating storage, approaches to retrofit an existing solar installation, installing a storage-ready solar system

7. **What different types of batteries are available (and which one is right for me)?**
   TOPICS COVERED: overview of lead acid and lithium-ion batteries, key differences between the technologies (energy density, depth of discharge, cycling, expected useful life), brief overview of other storage options

8. **What size battery do I need?**
   TOPICS COVERED: explanation of battery power rating, energy capacity, and duration sizing specifications; sizing considerations for backup power, demand management, and solar self-consumption applications; physical space requirements for battery systems

What is solar PV and battery storage and how do they work?

This guide answers questions about the design, installation, and economics of solar and battery storage for homes, businesses, and community facilities. It does not go into the basics of explaining what solar PV or batteries are and how they work.

For an introductory overview of solar basics, see “How do solar panels work? Solar power explained” by EnergySage, available online at https://news.energysage.com/solar-panels-work.

For a quick overview of the science behind batteries, see “How does a battery work?” by MIT’s School of Engineering at https://engineering.mit.edu/engage/ask-an-engineer/how-does-a-battery-work.

9. **Is battery storage safe?**
   TOPICS INCLUDE: overview of battery storage safety risks and siting considerations, thermal runaway, safety risks when a fire occurs, resources with more information about recommended fire safety codes, procedures, and best practices

10. **How long does a solar+storage system last?**
    TOPICS INCLUDE: expected lifespan and typical warranties for solar panels, inverters, and batteries

11. **Can solar+storage be developed to benefit low-income communities?**
    TOPICS INCLUDE: solar+storage economic, resilience, and environmental benefits for low-income communities; awareness and affordability barriers to solar+storage adoption; case studies of projects benefiting low-income communities

12. **What are the environmental impacts of battery storage?**
    TOPICS INCLUDE: societal and environmental impact of lead acid and lithium-ion battery mining and manufacturing processes; end-of-life considerations (recycling, reuse)

To help think through the initial stages of approaching a solar+storage installation, CEG published a complimentary "Storage+Storage Project Checklist" with seven simple steps to begin the process. The checklist is available at https://www.cleanegroup.org/publication/solar-storage-project-checklist. In addition to the information contained in this report and accompanying checklist, CEG has compiled dozens of resources to dig deeper into many of these topics. Some of those resource can be found in the end notes of each section, others can be accessed through CEG's Resilient Power Project, available at www.resilient-power.org.

Solar and battery storage installation at the Migrant Health Center in Maricao, Puerto Rico, a non-profit clinic committed to providing medical services to everyone regardless of insurance or ability to pay.

Courtesy of The Solar Foundation & GETCHARGEDUP

Why solar+storage?

Millions of solar projects have been installed in the US; and while most solar installations do not include any form of energy storage, pairing solar with battery storage has become increasingly common.

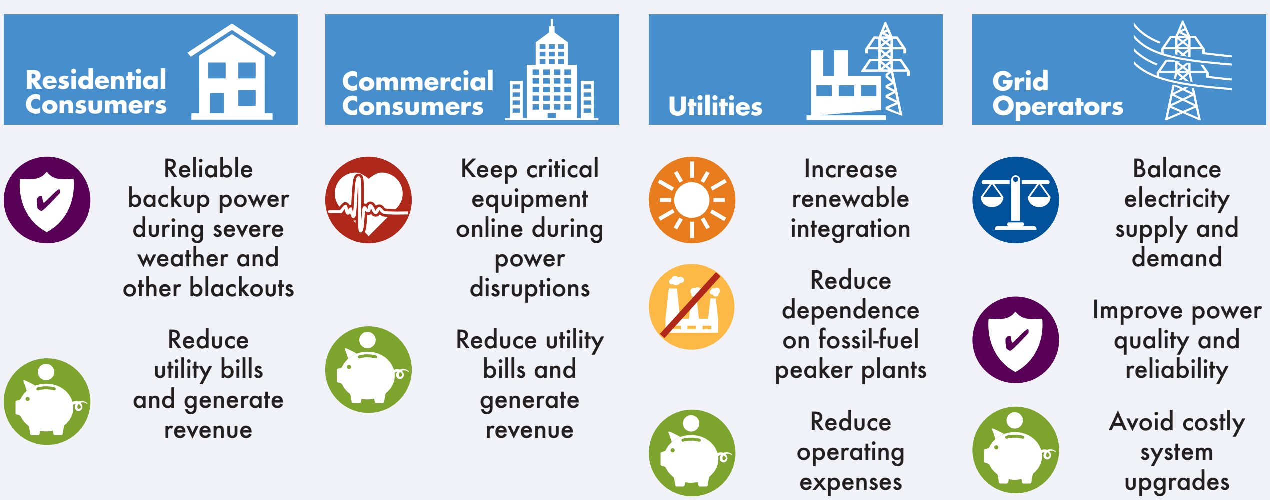
There are many reasons to include battery storage in a solar system installation. Energy resilience has been the primary driver for residential solar+storage projects, as nearly all solar systems shutdown when a grid outage occurs. Demand-related utility charges have been a driving force for storage adoption in commercial properties, and, as the frequency and severity of power outages has continued to rise, many commercial and community-serving facilities are adopting battery storage to boost energy resilience. Storage transforms solar into a flexible, controllable resource that can be strategically dispatched to maximize energy saving and deliver backup power.

Beyond these customer-specific needs for energy storage, the grid will require significant amounts of storage to achieve the critical goals of improving reliability and providing electricity with zero emissions. As more solar systems are connected to the grid, the energy produced will increasingly need to be stored and shifted to periods of the day when solar panels are not generating electricity. Utilities are adapting to this evolution of the energy system, with peak energy pricing periods moving to mornings and evenings in regions with high levels of solar penetration, by creating new programs for battery storage and other customer devices to target periods of peak electricity demand.

While solar and storage can each deliver valuable benefits to customers and the power grid, the combination of the two technologies can result in value above and beyond the sum of their individual benefits. Combined benefits include the ability to provide backup power throughout extended power outages and deliver clean energy when the grid needs it most, not just when the sun is shining. For these reasons, many energy experts and market analysts agree that solar and storage are integral to the future of the energy system.

The Value of Storage

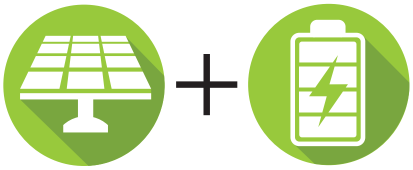
Energy storage technologies have the capacity to benefit each segment of the power system.



QUESTION 1

What factors do I need to consider when designing a solar+storage system?

TOPICS COVERED: Physical and structural considerations, permitting and interconnection, financial considerations, AC and DC coupling, additional factors for resilience projects and a few special cases



When approaching a new solar+storage project, the first step should be to clearly define the project's objectives. What is it you want the solar+storage system to do? Is utility bill savings the driving factor? Or is it resilience? Or emissions reduction? The answers to these questions will help guide and inform the rest of the development process.

When approaching a new solar+storage project, the first step should be to clearly define the project's objectives. What is it you want the solar+storage system to do?

The next step before going too far down the project development path is to assess the feasibility of installing a system. Key factors and potential barriers to consider fall into three general buckets: physical and structural, permitting and interconnection, and financial considerations. (See Q1 Figure 1, p.14.)

Physical and Structural

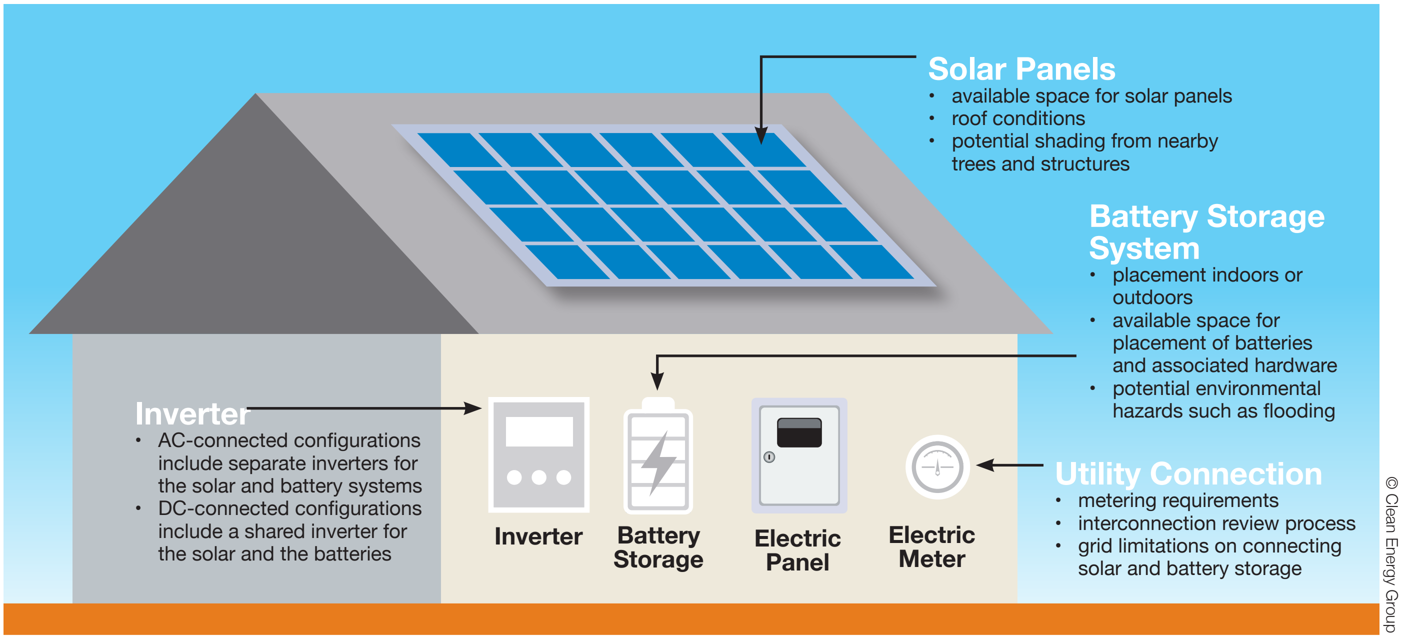
SOLAR AVAILABILITY: It is important to assess and identify any potential solar system sizing limitations, including roof conditions (available space, age, structural integrity, pitch, orientation, and necessary offsets), potential shading from trees and nearby structures, and alternative placement options such as on carports and ground-mount systems.

BATTERY PLACEMENT: Will the battery system be placed indoors or outdoors? How much suitable space is available to install a battery system and associated hardware? Can the system be insulated from any potential environmental hazards such as flooding?

Permitting and Interconnection

PERMITTING REQUIREMENTS: Check with local permitting offices to get a clear understanding of the regulations and requirements governing the installation of both solar and battery storage systems. An experienced consultant or installer can be helpful in this process and should take the lead on determining compliance with local requirements and obtaining necessary permits. Because battery storage systems are still fairly new technologies, some permitting authorities may not have code requirements in place that address all types of battery system technologies, which could result in permitting delays.

Q1 FIGURE 1: **Factors to consider when planning a solar+storage system**



There are several important factors to consider when approaching a new solar+storage project: physical and structural barriers that may limit system siting and configuration, local permitting and safety requirements, and utility interconnection procedures. All of these factors can impact the cost and feasibility of a planned installation.

UTILITY INTERCONNECTION: Depending on the utility, an interconnection review may be required before a solar+storage system is approved for interconnection with the grid, particularly for larger systems. There may also be limitations to how much solar and storage may be connected to certain sections of the grid before an infrastructure upgrade is necessary, which could add delays and expenses that might make a project unfeasible. Under certain conditions, utilities may not allow any solar or storage to be connected to specific portions of the grid, though battery systems designed to minimize or eliminate the amount of energy that is exported to the grid may be exempt from these restrictions.

METERING REQUIREMENTS: For solar+storage systems designed to participate in net energy metering or other programs where utility bill credits are earned for solar energy produced or exported to the grid, additional meters may be required by the utility to track and verify that only solar energy is receiving bill credits. In some cases, metering requirements can add significant costs to a project.

Financial

NET ENERGY METERING: Net metering, or some similar form of compensation for energy produced by a solar system and exported to the grid, is often critical to the economics of solar. In addition to understanding any utility metering requirements, it's important to verify that batteries are allowed under state and utility solar net energy metering policies. Some solar+storage system configurations, such as DC coupling (discussed more below) may be more acceptable under net metering policies. In cases where solar net metering is not available or compensation rates are very low for exported energy, storage may be beneficial to increase solar self-consumption, the amount of solar directly consumed onsite, thereby limiting or even eliminating solar exports to the grid.

INCENTIVES: An important financial factor for solar+storage economics is the availability of incentives, particularly tax incentives such as the federal investment tax credit (ITC). The ITC provides a 30 percent tax credit baseline, as well as six additional bonus credits, to incentivize equitable solar+storage development. These tax incentives are available for solar and battery storage systems, whether installed separately or as a combined system. Through an option called Direct Pay or Elective Pay, tax-exempt entities, including nonprofit organizations and government entities, can directly apply for and receive ITC credits. For more on tax credits and financing, see *Question 5: How can I pay for a solar+storage system (incentives, grants, financing)*?

An experienced solar+storage installer, developer, or consultant should be able to assist you in working through each of these considerations and help you make informed decisions as you continue through the development process.

Most things that run on electricity are powered by alternating current (AC). Solar and batteries, on the other hand, both work in direct current (DC). That's why solar and storage systems need inverters to convert DC power into AC power for use in homes and businesses.

AC or DC?

Most things that run on electricity are powered by alternating current (AC). Solar and batteries, on the other hand, both work in direct current (DC). That's why solar and storage systems need inverters to convert DC power into AC power for use in homes and businesses. Solar and storage can be coupled together through either an AC configuration or a DC configuration.

DC coupling may be the preferred configuration when solar and storage are installed at the same time, though that's not always the case. DC coupling basically means that generation from the solar system is passed directly along to the battery storage system, without going through an inverter. DC coupling allows the solar and storage systems to share a single inverter, which can reduce equipment costs. It can be easier to verify that a battery is only charged with electricity generated by onsite solar when the systems are DC coupled, which is important for some net metering programs.

In AC coupling, the solar and storage systems are more independent from one another. Each system will have a its own inverter, one converts solar to AC; another converts stored energy from the battery to AC when discharging energy and converts AC energy from the grid or solar inverter to DC when charging. AC coupling is common when adding a battery to an existing solar system. The configuration takes advantage of the solar inverter already in place, which is often less expensive than rewiring the system as DC-coupled behind a single shared inverter. There are some small efficiency losses in AC coupling due to the added power conversion from DC to AC, and then back to DC again to charge the battery. But AC-coupled systems are sometimes preferred, even when solar and storage are installed at the same time due to the flexibility of AC coupling, or in cases where the solar system and batteries are located a great distance from each other. And some battery systems include built-in inverters that may make DC coupling impossible. AC- and DC-coupled solar+storage systems are addressed more fully in *Question 6: Can storage be added to an existing solar system*?

A residential battery is paired with solar in affordable housing at the McKnight Lane Redevelopment in Waltham, VT.

Courtesy of Clean Energy Group

Resilience

Designing a solar+storage system to provide energy resilience during a power outage involves additional factors to consider. The most important factor is determining what's going to be powered by the batteries during an outage and for how long—in other words, identifying which appliances and devices are considered "critical loads" that must run during a grid outage, and which are considered "non-critical."

A key consideration is how difficult it would be to isolate critical from non-critical loads, assuming the entire building won't need to be powered. If the site already has a critical load panel, or all loads need to be backed up, then no additional wiring should be needed. If that's not the case, a preliminary evaluation of which critical loads can and cannot be reasonably isolated together is worth exploring. Getting an early idea of the power and energy needs of critical devices can provide a sense of needed system sizing and help determine if the project's resilience goals can be feasibly met by solar+storage alone, or if other forms of onsite generation, such as combined heat and power systems and traditional backup generators, should be considered.

Another factor when designing resilient power systems is the need to withstand extreme weather conditions, whether in the form of hurricane-force winds, flooding, heat waves, snow, or fire. For hurricane-prone areas, the Federal Emergency Management Agency (FEMA) recommends that rooftop solar panels are installed on mechanically anchored rails or racks to avoid damage due to uplift.[1] Flexible racking devices can enable solar systems to survive hurricane-force winds.[2] Battery systems should be installed well above the floodplain or housed in waterproof enclosures. In areas where outages are frequently a result of snowy conditions, solar generation may not be available during extended periods, which should be factored into sizing considerations. Areas exposed to extreme heat or cold may need to consider temperature regulation equipment to ensure optimal battery system performance and to avoid damage. For more on resilience projects, see *Question 2: Is solar+storage an effective backup power solution?*

Additional Factors

The considerations detailed here represent just a handful of factors that commonly come up when considering a solar+storage project. Many more will need to be addressed depending on the type of project being pursued. A few examples of more complex scenarios include the following.

Community solar+storage projects must develop a compensation structure to define how any storage-related revenues, such as payments for providing services to the grid, will be shared among subscribers.

COMMUNITY SOLAR: Some community solar projects are now paired with battery storage. Community solar+storage projects must develop a compensation structure to define how any storage-related revenues, such as payments for providing services to the grid, will be shared among subscribers. For resilience projects, community solar installations configured to send energy only to the grid may need additional components to interact with a behind-the-meter battery system during outages.[3]

MULTIFAMILY HOUSING: Solar+storage aimed at providing resilience in multifamily housing is, most commonly, utilized to power a resilience hub within the housing complex (for instance, in a common area or community space). During regular grid operations, solar+storage is used to offset utility bills for the property owner and, depending on the utility, generate revenue through grid services. Solar for multifamily housing can also be configured like community solar, where some of the electricity from the solar system is allocated to offset the electric bills of individual units. In this scenario, storage can either be configured as a single larger system providing community-wide savings and resilience or, less commonly, configured as multiple smaller battery systems providing economic and resilience benefits directly to individual units.[4]

OFF-GRID: Solar+storage systems that operate completely off-grid all the time involve a whole new set of considerations, namely, how to get through long stretches of time with only minimal solar production, such as during shorter periods of sunlight on winter days or during rainy seasons. These systems often include traditional backup power generators.

Q1 ENDNOTES

1 Federal Emergency Management Agency, "Rooftop Solar Panel Attachment: Design, Installation, and Maintenance," *Recovery Advisory 5*, April 2018, Revised August 2018, https://vitema.vi.gov/docs/default-source/response-recovery-documents/(7)-usvi-ra5--rooftop-solar-panel-attachment.pdf?sfvrsn=4c0b82ea_2.

2 U.S. Department of Energy, "Distributed Energy Resources Disaster Matrix," DER Disaster Impacts Issue Brief, *Better Buildings Solution Center,* https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/DER_Disaster_Impacts_Issue%20Brief.pdf (accessed March 25, 2024). For more information about designing solar system to withstand hurricane weather conditions, see Laurie Stone, Christopher Burgess and Justin Locke, "Solar Under Storm for Policy-makers," *Rocky Mountain Institute*, 2020, https://rmi.org/insight/solar-under-storm.

3 Clean Energy Group, "Featured Resilient Power Installations: Maycroft Apartments," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/maycroft-apartments (accessed March 25, 2024).

4 Julian Spector, "'Transformative': Sonnen to Deliver Community Battery Network with Grid Services Contract," *GTM,* August 27, 2019, https://www.greentechmedia.com/articles/read/sonnen-delivers-long-promised-goal.

QUESTION 2

Is solar+storage an effective backup power solution?

TOPICS COVERED: Critical load considerations, comparison of solar+storage versus fossil-fuel generators, brief discussion of other backup power options (hybrid solutions, portable systems, storage-only)

In many cases, a solar+storage system may be well suited to meeting a building's backup power needs; in other cases, not so much, or only as one piece of a broader backup power strategy. Whether or not solar+storage represents a viable, cost-effective solution for your backup power needs depends on several factors—but most importantly, what needs to be backed up and for how long.

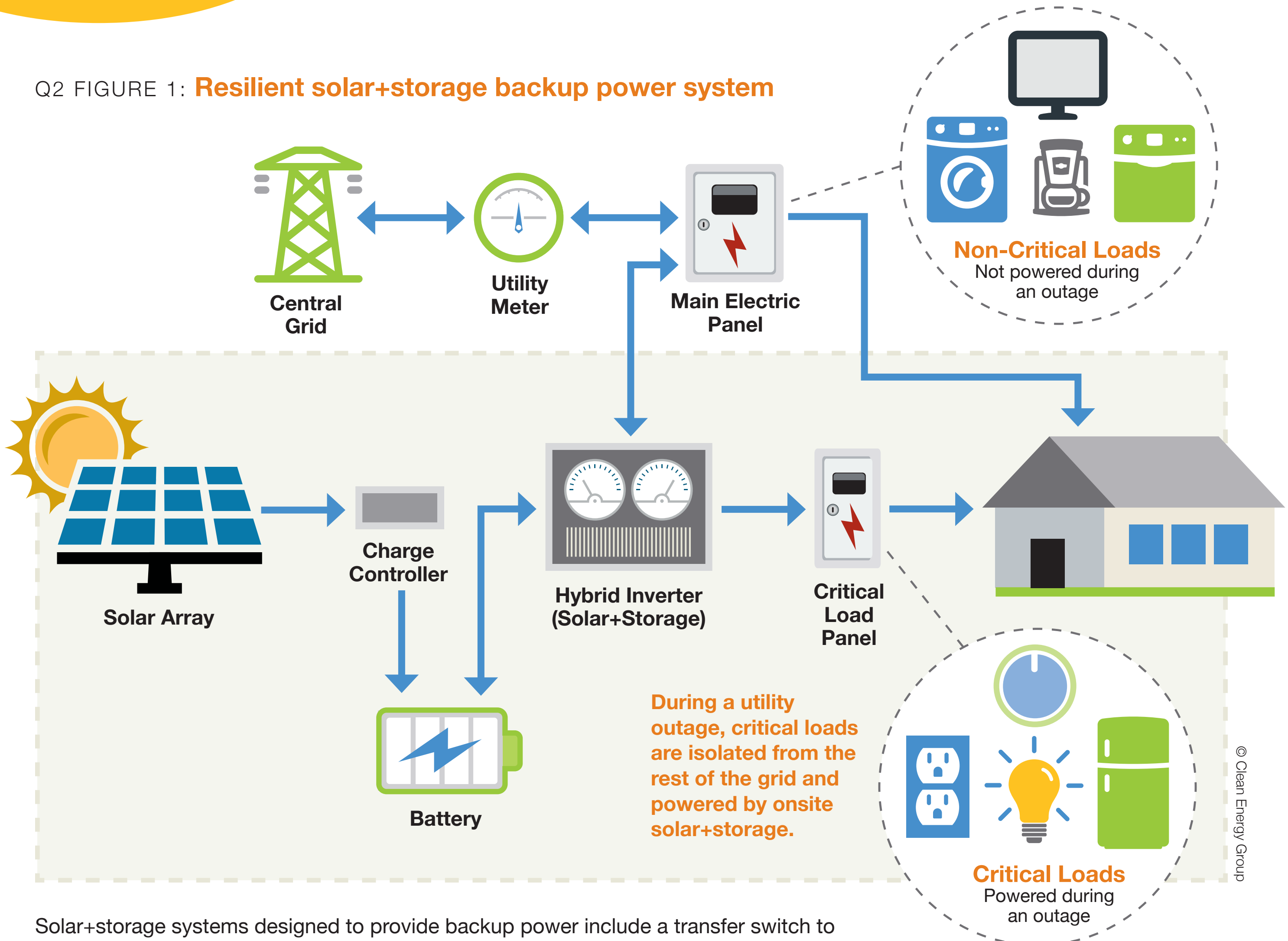
> **It may not always be practical to design a solar+storage backup system with the goal of powering all of a building's electrical loads during a grid outage. The barrier is more of an economic issue than a technical one.**

Solar+storage can be sized to power an entire facility or support only designated critical loads, ensuring backup power to the most vital services for a longer duration (see Q2 Figure 1, p. 19). Depending on the size and power requirements of a facility, it may not always be practical to design a solar+storage backup system with the goal of powering all of a building's electrical loads during a grid outage. The barrier is more of an economic issue than a technical one. Though batteries continue to decline in price, they are still expensive technologies. When a full-facility system is not economically viable, solar+storage can be tied into a critical load panel, which includes only loads that need to be powered during an outage.

In the event of an outage, most solar+storage systems are designed to switch from grid power to backup power automatically, a nearly instantaneous process. Loads can also be manually switched on and off, and there are even new advanced load panels that allow circuits to be managed remotely through an online interface, allowing critical loads to be turned on and off through an app on your phone.

Loads commonly designated as critical include lighting, fans, well pumps, and outlets to power plug-in loads such as refrigerators, heating and cooling devices, computers, modems and routers, phone chargers, and medical devices. For larger buildings, loads such as elevators and HVAC systems may also need to be designated as critical during an outage, though these high-power loads may be cost-prohibitive for solar+storage to support alone.

Q2 FIGURE 1: **Resilient solar+storage backup power system**



Solar+storage systems designed to provide backup power include a transfer switch to disconnect from the utility grid and often incorporate a critical load panel. The transfer switch is typically incorporated as a component of the system's hybrid inverter, shown here in a DC-coupled configuration. When an outage occurs, the transfer switch isolates the solar+storage system from the grid along with the critical load panel. Any devices served by the critical load panel will continue to be powered by solar+storage, while those served by the main electric panel will not be powered during an outage.

Solar+Storage versus Fossil-fuel Generators

Is solar+storage cheaper than a traditional gas or diesel generator? The answer is no, if only upfront system costs are considered. However, that answer can change when solar+storage is able to deliver economic benefits along with backup power. Solar+storage has also been found to be less expensive than fossil-fuel generators in cases where outages occur frequently or last for an extended period.

COSTS VERSUS BENEFITS: Gas and diesel generators pretty much sit there waiting to do one thing—deliver power during an outage. They also tend to fail at alarming rates when called upon or are required to operate over long periods of time. Solar+storage, on the other hand, can deliver benefits throughout the year, outage or no outage. Solar delivers electric bill savings by offsetting grid electricity consumption, and storage can cut utility demand charges or shift grid consumption from periods of high-cost electricity to times when electricity prices are lower. Some utilities are even paying to tap into small solar+storage systems to reduce their operating costs or to replace fossil-fuel power plants.[1] See *Question 3: How do I determine the value of solar+storage (savings, revenue, resilience)*?

UPFRONT VERSUS LIFETIME COSTS: Unlike fossil-fuel generators, solar+storage has no fuel costs and requires minimal maintenance. Even though solar+storage systems typically cost more upfront, fuel and maintenance savings can make solar+storage a more cost-effective backup power choice than generators over time. In one study, solar+storage had lower failure rates when compared to similarly sized emergency diesel generator systems and paid for themselves over time, whereas their diesel counterpart did not.[2] Researchers at the University of Washington found that small solar+storage systems deployed in Puerto Rico after Hurricane Maria were more cost effective to operate than diesel generators after about 60 days of operation, which could occur during one major long-duration event like a hurricane, or with multiple, shorter outage events over the life of the systems.[3]

Though batteries have a limited supply of stored electricity, onsite solar offers a ready supply of reliable, renewable energy to continually recharge batteries and power loads.

RELIABILITY AND RESILIENCE: While still the default solution for backup power, traditional fossil-fuel generators have an unfortunate history of failure when major disasters strike. During extended outages, fuel supplies are often constrained, leading to difficulties in refueling when onsite supplies run low. Generators are also prone to mechanical failure due to lack of adequate testing and maintenance, or when strained to operate over longer durations. In contrast, solar+storage systems typically operate every day, decreasing the chance of unexpected failures when called upon in an emergency.

Though batteries have a limited supply of stored electricity, onsite solar offers a ready supply of reliable, renewable energy to continually recharge batteries and power loads. The intermittency of solar resources may result in some gaps in energy availability and there may be times when an outage occurs and the battery system is not fully charged, but a well-designed solar+storage system should be able to power critical loads for days, weeks, or even months, without relying on access to outside resources that may be experiencing their own disruptions.

SAFETY: It is an unfortunate reality that carbon monoxide poisoning spikes when natural disasters occur due to the improper operation of diesel generators.[4] Along with greenhouse gases, generators release toxic emissions that can result in negative health impacts for nearby populations, particularly those with existing respiratory conditions. Batteries certainly come with their own safety concerns, but solar+storage offers a clean, quiet alternative to noisy, polluting generators (see *Question 9: Is battery storage safe?*).

SITING: Solar+storage may be the only viable backup power solution in some cases where permitting or space constraints make it challenging or impossible to install a generator. Solar panels can be placed on existing structures, and storage can be sited indoors, on rooftops, or outside of buildings. Solar+storage systems may be the only option in locations where regulatory limits on noise and/or emissions make the placement and operation of generators challenging.

HYBRID SOLAR+STORAGE: Despite the many benefits that solar+storage can offer over fossil-fuel generators, there may be some cases where generators continue to be a necessary part of a backup power solution. Some high-power loads may not be economical to support with solar+storage alone; in snowy regions solar generation may not always be readily available; and, in some cases, regulatory requirements may dictate that certain critical loads must be

Mobile solar+storage trailer designed by Footprint Project with funding from Empowered by Light and assembled in Puerto Rico by Sail Relief Team and Humacao Fire Station.

Courtesy of Footprint Project

backed up by traditional generators. In these cases, a hybrid solution combining solar, battery storage, and a fossil-fuel powered generator may offer the most resilient and cost-effective solution. Incorporating solar and storage with a traditional generator can extend the operating life of a generator, reduce fuel consumption and emissions, and provide an additional layer of reliability for a subset of critical loads.

Portable Systems

Like traditional generators, solar+storage backup systems also come in smaller, portable varieties. Instead of directly supporting building circuits during an outage, portable solar+storage systems offer outlets and charging ports to keep individual devices powered and charged up. These systems can range anywhere from a couple of hundred watts for small devices up to a few kilowatts in size, with larger systems able to support loads as large as a refrigerator. Increasingly, portable solar+storage is being utilized in emergency response and recovery efforts. Footprint Project, a nonprofit organization that helps emergency responders deploy clean technologies during and after a disaster, supports community organizations and disaster management departments through portable solar+storage.[5] In some cases, their trailer-sized systems can be attached to stationary facilities, such as a school or church, to provide temporary emergency power.

Solar system supporting a community resilience hub at the California Indian Museum and Cultural Center in Santa Rosa, CA.

Courtesy of California Indian Museum and Cultural Center.

Storage without Solar

Battery storage without solar is another viable option for backup power, particularly for locations where it can be difficult to install solar, such as apartments and dense urban environments. The main drawback of this approach is that batteries have a limited capacity to provide energy before needing to be recharged. Without solar or some other form of onsite generation, there's nothing available to recharge the batteries until grid power is restored. However, when properly sized, batteries alone can still power electrical loads for an extended period, hours or even days, which can be lifesaving for those dependent on electricity for critical needs like medical devices or refrigeration for medicines.[6]

Q2 ENDNOTES

1 Julian Spector, "Batteries vs. Blackouts: 1,100 Homes Powered Through Vermont Outage With Storage," *GTM²*, November 7, 2019, https://www.greentechmedia.com/articles/read/green-mountain-power-kept-1100-homes-lit-up-during-storm-outage and Julian Spector, "Sunrun Wins Another Capacity Contract for Aggregated Home Storage," *GTM²*, July 18, 2019, https://www.greentechmedia.com/articles/read/east-bay-power-purchaser-signs-distributed-capacity-contract-with-sunrun.

2 John Fitzgerald Weaver, "Solar-plus-storage outperforms diesel in US military survival analysis," *PV magazine*, November 9, 2023. https://www.pv-magazine.com/2023/11/09/solar-plus-storage-outperforms-diesel-in-us-military-survival-analysis/.

3 Chanaka Keerthisinghe, et al., "PV-Battery Systems for Critical Loads During Emergencies: A Case Study from Puerto Rico After Hurricane Maria," *IEEE Power and Energy Magazine*, Volume 17, Issue: 1, January 9, 2019, https://ieeexplore.ieee.org/document/8606510.

4 Shahed Iqbal, et al., "A Review of Disaster-Related Carbon Monoxide Poisoning: Surveillance, Epidemiology, and Opportunities for Prevention," *American Journal of Public Health* 102(10): October 2012; p. 1957–1963, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3490658.

5 "Vieques Emergency Management Trailer," *Clean Energy Group*, 2020, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/vieques-emergency-management-trailer.

6 Annie Shapiro and Marriele Mango, "Home Health Care in the Dark: Why Climate, Wildfires and Other Risks Call for New Resilient Energy Storage Solutions to Protect Medically Vulnerable Households from Power Outages," *Clean Energy Group*, June 2019, https://www.cleanegroup.org/ceg-resources/resource/battery-storage-home-healthcare.

QUESTION 3

How do I determine the value of solar+storage (savings, revenue, resilience)?

TOPICS COVERED: Utility bill savings, demand charge management, utility and grid services, avoided outage costs, health and environmental benefits, and methods to determine the cost-effectiveness of solar+storage

Various metrics and considerations can help determine if a solar+storage system is a cost-effective, economically-beneficial investment. Evaluating value streams is important when calculating the economic viability of a project. This section focuses on metrics that help to determine financial feasibility, including utility savings, payback period, and cost-benefit analysis. However, other metrics, such as Return on Investment (ROI), Internal Rate of Return (IRR), Net Present Value (NPV), and discount rates are also important to consider.[1] This section also explores the potential economic benefits of solar and battery storage, including an introduction to existing utility-led battery storage programs, and an overview of how to calculate whether a solar+storage project is economically viable.

> **The full value of solar+storage (including losses avoided by having backup power during an outage, and environmental and health benefits) can be hard to quantify.**

Beyond straightforward financial benefits (like utility bill savings), the full value of solar+storage (including losses avoided by having backup power during an outage, and environmental and health benefits) can be hard to quantify. Nonetheless, those other benefits should be taken into consideration when determining if a battery storage system is a worthwhile investment.

Solar

The economic value of solar is relatively simple. Solar panels generate energy that can offset electricity from the grid, lowering electric utility bills.

COMMON SOLAR VALUE STREAMS

- Lower utility bills. Onsite solar power generation offsets electricity consumption from the grid. Instead of purchasing all of their energy from a utility, some of a customer's electricity needs will be met by a solar array. Using less electricity from the utility translates into lower monthly utility bills throughout the year.
- Net energy metering (NEM). Net energy metering programs allow customers to earn bill credits for the electricity they generate from their solar array that is not directly consumed onsite. Any excess solar generation flows onto the grid. Customers participating in NEM will see a credit on their electric bill indicating how much energy their solar system exported to

the grid and how much that electricity earned in bill credits. NEM programs and the value of credits for excess generation vary widely depending on the state and utility program.[2]

- Solar Renewable Energy Certificates (SRECs). SRECs are credits for the energy a solar system generates, whether consumed onsite or exported to the grid. A solar system earns one SREC for every 1,000 kilowatt-hours of electricity produced. Once an SREC is earned, the system owner can sell it to their electric utility.[3] SREC values vary widely by state; SREC prices in Washington, DC are over $400 per 1,000 kilowatt-hours, while in Ohio they're around $4 per 1,000 kilowatt-hours.[4] SRECs are offered in most states that have Renewable Portfolio Standards or Goals.

Battery Storage

The value of battery storage can be a bit more complex. Batteries allow users to store electricity for later use. For customers with utilities that have time-of-use rates, batteries can be managed to charge when electricity prices are low and discharge later when rates are higher. For commercial utility customers with high demand charges, battery storage can be used to lower these charges through demand management.[5] Batteries can also generate revenue by providing valuable services to the local utility or regional grid operator.

For customers with utilities that have time-of-use rates, batteries can be managed to charge when electricity prices are low and discharge later when rates are higher. For utility customers with high demand charges, battery storage can be used to lower these charges through demand management.

COMMON BATTERY STORAGE VALUE STREAMS

- Lower utility bills. Batteries typically lower utility bills in three ways:
  - Demand charge management reduces a customer's demand-related utility charges by deploying stored energy when electricity usage spikes, such as when high-power devices like heaters or water pumps kick on. In some areas, demand charges can account for well over half of a commercial customer's electricity bill.[6]
  - Energy arbitrage lowers utility bills by charging and discharging the batteries depending on pricing periods throughout the day. Batteries charge when electricity prices are low (off-peak), then discharge stored energy when electricity prices are highest (peak), so there is less need to buy energy from the grid during peak pricing. When there is a large difference between the price of peak and off-peak electricity rates, batteries used for energy arbitrage can be a worthwhile investment.
  - Through solar self-consumption a customer can prioritize directly offsetting their utility bill through solar. Solar self-consumption aims to maximize onsite use of the electricity generated through solar panels and minimize the amount of solar generation sent to the grid. Electricity is either used for facility loads in real time or stored in a battery for use later.[7] Some states allow battery storage to participate in net metering. In California, for example, battery storage can be used to export net-metered energy to the grid. Recent changes to California's net metering program lowered the value of bill credits for energy exported to the grid during times when solar production is at its peak, effectively incentivizing greater battery storage adoption and making solar-only systems less cost effective.[8]

Blue Lake Rancheria Microgrid

In Humboldt County, California the **Blue Lake Rancheria Microgrid** is a prime example of how solar+storage can provide economic benefits from a variety of grid services.[9] Owned by Blue Lake Rancheria, a federally recognized Native American tribe in northwestern California, the microgrid project provides electricity to tribal government offices, electric vehicle charging stations, and a hotel and casino. In addition to providing at least seven days of backup power, the Blue Lake Rancheria Microgrid provides energy arbitrage and frequency regulation services and is equipped to participate in utility demand response programs. These grid services, combined with bill savings from solar, result in an anticipated annual return of $200,000.

To learn more about sizing storage for utility bill savings, see *Question 8: What size battery do I need?*

- Generate revenue by providing utility services:
  - Demand response programs reduce electricity usage by utility customers during times of peak systemwide demand. Batteries can participate in demand response by discharging stored electricity to meet onsite demand or export energy to the grid during peak demand periods, alleviating the energy demand burden on the power system. Demand response programs help utilities reduce costs by avoiding the use of expensive, inefficient power plants, or even avoiding outages at times when electricity demand is close to exceeding available grid supply.[10]
  - Battery storage can be managed to charge and discharge in response to fluctuations in the grid, known as frequency regulation.[11] Frequency regulation supports grid reliability by balancing supply and demand. Utilities and grid operators can deploy the energy stored in battery systems instantaneously, when necessary, to help balance the grid.
  - Increasingly, utilities are instituting programs that allow them to harness the hundreds or thousands of behind-the-meter battery storage systems operating in their territory. The aggregation of these systems, along with other controllable devices like smart thermostats, water heaters, and electric vehicle chargers, act as a virtual power plant, allowing the utility to provide grid-scale energy services that would normally be served by a utility-scale installation.

A battery storage system may participate in all, some, or none of these services (much depends on the utility serving the area).

Battery storage and solar each provide separate and unique economic advantages; but combined solar+storage systems could result in additional benefits, such as greater utility bill savings and increased energy resilience. Furthermore, by installing solar and battery storage at the same time, equipment cost savings and system optimization can reduce the cost of a battery system installation by more than 25 percent when compared to installing a stand-alone battery.[12]

How to Value Solar+Storage Benefits

CASE STUDY: Boulder Housing Partners
LOCATION: Boulder, Colorado

SUMMARY: In addition to being a leading affordable housing developer and the housing authority for the City of Boulder, Boulder Housing Partners (BHP) also provides command-post services to over 3,000 low-income residents during emergencies. BHP explored solar+storage as an option for its North Boulder headquarters, with the goal of remaining open and operational through a power outage.

The total cost of the solar+storage installation was $143,476. After factoring in various value streams, the estimated payback was approximately 19 years.

The items listed below highlight the value streams BHP considered when evaluating the benefits of solar+storage. Some benefits had a monetizable value, while others did not.

More information and resources related to the BHP solar+storage project are contained in an extensive case study, found at https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/boulder-housing-partners.

Monetizable Benefits

Utility bill savings from solar
$1,145 in electric bill savings annually

Utility bill savings from battery storage and smart control system
Demand charge electric utility savings of $456 for a single month

Avoided cost of outages
Estimated $6,295 saved each year by maintaining services, rather than having to cease operations during an outage

Nonmonetizable Benefits

Emissions reduction
Solar+storage offset 40,000 pounds of CO_2 emissions over the life of the system

Resilience
Reliable and automatic backup power in the event of an outage

Avoided emissions
BHP was able to install a smaller gas generator that runs less often by prioritizing solar+storage

Harder to Monetize Benefits

Not all benefits are simple to put a price on. (See Box: *How to Value Solar+Storage Benefits,* p. 26.) Solar+storage has numerous benefits that don't have an obvious or easy-to-calculate value, including the following.

For medically vulnerable households, residential systems (or systems installed in community spaces of multifamily properties) can provide backup power to support electricity-dependent medical equipment, like oxygen concentrators, when grid electricity becomes unavailable.

AVOIDED OUTAGE COSTS: Avoided outage costs represent the value of losses that would be incurred if a facility experienced a power outage without a backup power system.[13] Similarly, Value of Lost Load (VoLL) is a calculation of the approximate price a customer is willing to pay to avoid an outage/ensure reliable electricity.[14] Losses could include workforce productivity, interruption of services, and even loss of life due to a lack of medical care or disaster response services. Avoided outage costs are not typically included when assessing the economic value of solar+storage because it's difficult to calculate and monetize losses related to something like negative health impacts, for example. However, some critical facilities have been able to include avoided outage costs in their solar+storage value calculations. A leading affordable housing provider in Boulder, Colorado found that solar+storage would save their facility approximately $2,500 in avoided downtime costs per every hour of a power outage. With an average of 2.5 hours of outages per year, that equated to an estimated savings of over $6,000 each year.[15] A survey of community health centers in Florida found that power outages cost the health centers an average of $41,000 per day in lost revenue.[16]

HEALTH: Solar+storage can improve public health outcomes during an outage by providing reliable backup power to critical community facilities and medical institutions, allowing service providers to remain open and operational. In addition to maintaining operations, solar+storage can also support a facility's cooling and heating systems, a critical service when temperatures are dangerously high or low. For medically vulnerable households, residential systems (or systems installed in community spaces of multifamily properties) can provide backup power to support electricity-dependent medical equipment, like oxygen concentrators, when grid electricity becomes unavailable. And battery storage is a zero-emission alternative to diesel generators, which emit pollutants that negatively impact public health (especially respiratory conditions). To learn more about the health impacts of diesel generators, see the "solar+storage versus fossil-fuel generators" section of *Question 2: Is solar+storage an effective backup power solution?*

ENVIRONMENT: Replacing a diesel generator with a solar+storage system reduces toxic emissions that contribute to poor air quality and climate change. Solar+storage also offsets the amount of energy required from the grid, which is likely to be partially generated by fossil-fuel power plants. For example, solar+storage at the Boulder Housing Partners headquarters in Colorado offset 40,000 pounds of carbon dioxide that would have otherwise been emitted as a product of grid-supplied electricity.[17]

Utility Distributed Battery Storage Programs

Tesla residential battery system.

Courtesy of NREL/ Dennis Schroeder

Increasingly, utilities are recognizing the value distributed energy storage systems bring to both customers and the grid. The result has been innovative programs across the country that incentivize behind-the-meter battery storage in an effort to aggregate thousands of smaller batteries throughout a region to use for grid-scale services, such as capacity and peak demand reduction. These aggregations are sometimes referred to as virtual power plants. The following programs are examples of battery storage programs offered by utilities.

CONNECTED SOLUTIONS (CT, NH, MA, AND RI).[18] ConnectedSolutions is a utility-run battery storage program that has been offered in four states in the Northeast—Connecticut, New Hampshire, Massachusetts, and Rhode Island—and emulated by other states.[19] ConnectedSolutions is unique in that it is funded through state energy efficiency budgets as an active demand reduction measure, rather than as a separate clean energy initiative or utility demand response program. Through a multi-year contract between the customer and their utility, ConnectedSolutions compensates battery storage owners who discharge their systems to reduce regional peak electricity demand when called upon to do so by the utility. This saves the utility money by reducing its peak demand costs. When not called upon, customers can use the battery system as they wish—to lower utility bills, participate in other programs, and provide backup power during outages. During the first year of program operation in Massachusetts, one utility, National Grid, reported that average residential customer participating in the program would have earned $1,375 for the year.[20] Massachusetts customers can also access incentives through the Solar Massachusetts Renewable Target (SMART) program, which provides incentives for solar PV systems as well as additional incentives for systems that include battery storage.[21] Battery owners can also participate in the Massachusetts Clean Peak Energy Standard, a program that requires utilities to procure renewable energy for periods of peak demand.[22]

ENERGY STORAGE SOLUTIONS (CT).[23] The ConnectedSolutions program in Connecticut was discontinued in favor of an expanded program called Energy Storage Solutions, which is co-administered by the electric utilities, Eversource and UI, and the Connecticut Green Bank. This program offers customers a combination of upfront incentives (from the Green Bank) and performance incentives (from the utility). It also has a robust equity component, offering low-income residential customers a higher upfront incentive, as well as low-cost financing and on-bill payment options. Energy Storage Solutions maintains a commitment to the Biden administration's Justice40 goal, meaning that 40 percent of enrolled systems must be located in and serve low- to moderate-income communities.

— CONTINUED —

— CONTINUED —

GREEN MOUNTAIN POWER HOME ENERGY STORAGE (VT).[24] The utility Green Mountain Power (GMP) in Vermont has created a Home Energy Storage battery program that offers residential customers two leased Tesla Powerwall battery systems for $55 per month, over 10 years (or one upfront payment of $5,500).[25] GMP retains ownership of the leased batteries. GMP also offers a Bring-Your-Own-Device (BYOD) program, which provides upfront payments to battery-owning customers of up to $950 per kilowatt of storage, in exchange for enrolling their batteries in GMP's program.[26] These programs have been very successful, with some 4,800 batteries currently enrolled. Both programs give GMP the ability to remotely dispatch the residential batteries to reduce utility operating costs, and the batteries are available to households for backup power during grid outages. After a severe winter storm in 2019, more than 400 Tesla Powerwalls maintained backup power for an average of 13 hours for residential customers experiencing grid outages throughout GMP's service territory.[27] In 2020, the utility reported saving $3 million in utility costs for all GMP customers by calling upon battery systems in its service territory during times of high regional demand for electricity.[28] Utilities in New Hampshire, New York, and Oregon, have launched similar battery storage programs and pilot programs are underway in Maryland and North Carolina.

Determining the Value of Solar+Storage

There are multiple methods to determine if solar+storage is a cost-effective solution. Two of the more straightforward calculations are simple payback period and cost-benefit analysis.

SIMPLE PAYBACK PERIOD: Simple payback period is the time it takes for a solar+storage project's savings and revenue to equal or exceed the initial cost of the system. A quick way to calculate simple payback period in years is to divide your total system costs (hardware and installation minus any incentives, tax credits, and/or rebates) by the system's projected average annual savings and revenue streams (such as bill savings, utility program revenue, and avoided outage costs). The shorter the simple payback period, the better—a payback period should be less than the useful life of the system to make it a cost-effective solution.

For a solar+storage system, payback varies greatly depending, primarily, on utility rate structures and the availability of programs or incentives for solar and storage installations. For example, California's updated net-metering rules negatively impacted the economics of solar-only systems, but greatly improved the payback of battery storage. Some of those solar losses have been offset by utility rate increases that have helped maintain the value of solar. Currently, Californians can expect a payback period of 7 to 8 years for solar+storage systems, or 9 to 10 years for a comparable solar-only system.[29] Alternatively, in New Orleans, where electric rates are very low and demand charges are challenging to reduce, the payback for a solar+storage system at a commercial facility could be more than 30 years—well past the useful life and warranty period of a typical system.[30]

Solar+storage microgrid at a field hospital at the Matamoros migrant camp in Mexico on the U.S. border, powering the camp's first mobile medical ICU to treat COVID-19 patients operated by Global Response Management.

Courtesy of Footprint Project

State and utility programs can greatly improve the payback of a battery storage system by reducing upfront costs or providing revenue generating opportunities. For more information about utility programs, see the box on *Utility Distributed Battery Storage Programs* (p. 28). More information regarding state incentives can be found in *Question 9: How do I pay for solar+storage (incentives, grants, financing)?*

COST-BENEFIT ANALYSIS: A cost-benefit analysis compares the costs and benefits of a particular investment with other investment options, and/or maintaining the status quo. Standalone storage can be compared to a combined solar+storage system, or to a solar-only system. Gas or diesel generators, along with their annual maintenance and fuel costs, may be used in a cost-benefit analysis for backup power projects. Each option should be evaluated based on lifetime costs (installation, maintenance, and operations) and payback—and non-monetary or harder-to-monetize benefits, such as reliability, environmental impacts, and avoided outage costs.

Q3 ENDNOTES

1 To learn more about Return on Investment, Internal Rate of Return, and discount rates, see "Finance 101 for Solar Professionals," *CED Greentech*, February 2018, https://www.cedgreentech.com/article/finance-101-solar-professionals (accessed March 27, 2024).

2 To see which states offer net metering programs, visit "Net Metering," *Solar Energy Industries Association*, https://www.seia.org/initiatives/net-metering (accessed March 22, 2024).

3 To learn more about SRECs, see "SRECs: Understanding solar renewable energy credits," *EnergySage*, updated October 23, 2024, https://www.energysage.com/solar/cost-benefit/srecs-solar-renewable-energy-certificates (accessed March 27, 2024).

4 “District of Columbia SREC Market Prices,” *SRECTrade*, https://www.srectrade.com/markets/rps/srec/district_of_columbia and “Spot data for the Ohio SREC market,” Flett Exchange, https://www.flettexchange.com/markets/srec/ohio/market-prices (accessed March 20, 2024).

5 “Energy Storage for Demand Charge Management Webinar,” *Clean Energy Group*, June 24, 2015, https://www.cleanegroup.org/webinar/resilient-power-project-webinar-energy-storage-for-demand-charge-management.

6 “An Introduction to Demand Charges,” Clean Energy Group, August 24, 2017, https://www.cleanegroup.org/publication/demand-charge-fact-sheet.

7 Jacob Marsh, “Self-consumption: What you need to know,” *EnergySage*, February 27, 2024, https://www.energysage.com/energy-storage/self-consumption.

8 Robert Senior, “NEM 3.0: Why is Battery Storage so Important?” *Fortress Power*, June 5, 2023, https://www.fortresspower.com/nem3-why-is-battery-storage-so-important.

9 “Demonstrating a Secure, Reliable, Low-Carbon Community Microgrid at the Blue Lake Rancheria,” *California Energy Commission*, January 2019, https://www.energy.ca.gov/publications/2019/demonstrating-secure-reliable-low-carbon-community-microgrid-blue-lake-rancheria and Blue Lake Rancheria Home Page, https://bluelakerancheria-nsn.gov (accessed March 27, 2024).

10 Seth Mullendore, “Energy Storage and Electricity Markets,” *Clean Energy Group*, August 2015, https://www.cleanegroup.org/publication/energy-storage-and-electricity-markets-the-value-of-storage-to-the-power-system-and-the-importance-of-electricity-markets-in-energy-storage-economics.

11 Ibid.

12 Jason Finkelstein, Sean Kane, and Matt Rogers, “How residential energy storage could help support the power grid,” *McKinsey & Company*, March 20, 2019, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-residential-energy-storage-could-help-support-the-power-grid.

13 To learn more about avoided outage costs and how these costs can impact the economics of a solar+storage system, see Marriele Mango and Seth Mullendore, “Resilient Southeast: Exploring Opportunities for Solar+Storage in Five Cities,” *Clean Energy Group*, April 25, 2019, https://www.cleanegroup.org/publication/resilient-southeast/; and “Valuing the Resilience Provided by Solar and Battery Energy Storage Systems,” *National Renewable Energy Laboratory*, https://www.nrel.gov/docs/fy18osti/70679.pdf (accessed March 27, 2024).

14 To learn more about Value of Lost Load, visit “Valuing Resilience in Electricity Systems,” *NREL*, September 2022, https://www.nrel.gov/docs/fy19osti/74673.pdf.

15 Marriele Robinson, “Boulder Housing Partners Resilience Upgrades,” *Clean Energy Group*, November 2018, https://www.cleanegroup.org/publication/boulder-housing-partners.

16 Marriele Mango and Gianna Van Winkle, “Supporting Access to Health Care: Resilient Emergency Power for Florida Community Health Centers,” *Clean Energy Group*, May 24, 2023, https://www.cleanegroup.org/publication/resilient-emergency-power-for-florida-community-health-centers.

17 Marriele Robinson, “Boulder Housing Partners Resilience Upgrades,” *Clean Energy Group*, November 2018, https://www.cleanegroup.org/publication/boulder-housing-partners.

18 “ConnectedSolutions Resource Page,” *Clean Energy Group*, https://www.cleanegroup.org/initiatives/energy-storage-policy-and-regulation/connectedsolutions (accessed March 27, 2024).

19 The program is called ConnectedSolutions in MA, where it originated, but may have other names in other states. For example, in NH is it called “Storage Performance.” However, the structure of the plan is the same.

20 “Battery Storage,” Mass Save, https://www.masssave.com/saving/residential-rebates/connectedsolutions-batteries (accessed March 27, 2024).

21 “Solar Massachusetts Renewable Target (SMART),” *Commonwealth of Massachusetts*, https://www.mass.gov/solar-massachusetts-renewable-target-smart (accessed March 27, 2024).

22 “Clean Peak Energy Standard),” *Commonwealth of Massachusetts*, https://www.mass.gov/clean-peak-energy-standard.

23 “Energy Storage Solutions,” *Connecticut Department of Energy and Environmental Protection Public Utilities Regulatory Authority*, https://portal.ct.gov/pura/electric/office-of-technical-and-regulatory-analysis/clean-energy-programs/energy-storage-solutions-program (accessed March 27, 2024).

24 “Home Energy Storage,“ *Green Mountain Power*, https://greenmountainpower.com/rebates-programs/home-energy-storage (accessed March 27, 2024).

25 “Tesla Powerwall,” *Green Mountain Power*, https://greenmountainpower.com/rebates-programs/home-energy-storage/powerwall (accessed March 27, 2024).

26 “Bring Your Own Device,” *Green Mountain Power*, https://greenmountainpower.com/rebates-programs/home-energy-storage/bring-your-own-device (accessed March 27, 2024).

27 “GMP Customers Keep Lights on With Stored Low Carbon Energy During Storm Outages,” *Green Mountain Power*, December 13, 2018, https://greenmountainpower.com/news/gmp-customers-keep-lights-on-with-stored-low-carbon-energy-during-storm-outages.

28 “GMP’s Energy Storage Programs Deliver $3 Million In Savings for All Customers During 2020 Energy Peaks,” *Green Mountain Power*, September 29, 2020, https://greenmountainpower.com/news/gmps-energy-storage-programs-deliver-3-million-in-savings.

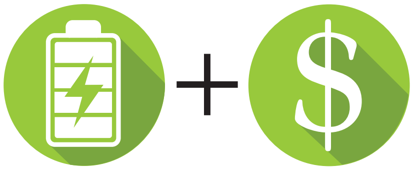
29 “NEM 3.0 in California: What you need to know,” *EnergySage*, August 25, 2023, https://www.energysage.com/blog/net-metering-3-0. (accessed March 24, 2024).

30 Seth Mullendore, Marriele Robinson, and Logan Burke, “Resilient Southeast: Exploring Opportunities for Solar+Storage in New Orleans, LA”, *Clean Energy Group*, April 2019, https://www.cleanegroup.org/wp-content/uploads/Resilient-Southeast-New-Orleans.pdf.

QUESTION 4

How much do batteries cost?

TOPICS COVERED: Installed cost ranges for lithium-ion battery systems, projected battery storage cost declines, differences between per kilowatt and per kilowatt-hour pricing



The cost of battery storage is a common, seemingly straightforward question. Unfortunately, trying to pin down an answer is not always easy.

To simplify, this section will focus on lithium-based battery chemistries. For some projects, advanced lead acid batteries may be a viable, cost-effective option to explore, particularly if the batteries will only be providing backup power. Other battery chemistries could also be an option, but for most projects, they may not be as practical or widely available as lithium-ion batteries at this time. For more on battery types, see *Question 7: What different types of batteries are available (and which one is right for me)?*

> **Public information comparing battery storage system costs across technology types, manufacturers, system sizes, and locations can still be challenging to find.**

While information about the cost of battery storage systems has become more available as the market has expanded over the past several years, public information comparing battery storage system costs across technology types, manufacturers, system sizes, and locations can still be challenging to find. In part, this is because much of the installed price depends on how the battery system is configured for different uses; for example, a short-duration, high-power battery system for onsite demand reduction versus a longer-duration battery system used for backup power. Because of this, it can be difficult to describe battery pricing in general terms.

The greatest level of price transparency can be found in the residential battery storage market. Home storage systems are typically priced as standard product offerings, and thousands of batteries are installed in homes across the US every year.

According to EnergySage, which tracks residential solar and energy storage installation pricing trends, the average cost of a typical home battery installation installed with solar is about $9,000 after federal tax incentives. (For more on tax incentives, see *Question 5: How can I pay for a solar+storage system (incentives, grants, financing)?*) However, storage system costs can vary significantly depending on the battery manufacturer and location of the installation. EnergySage found that average costs can range from just under $1,000 per kilowatt-hour to almost $2,000 per kilowatt-hour before incentives.[1] Most systems fall in the range of $1,000 to $1,400 per kilowatt-hour. Based on market analysis by the National Renewable Energy Laboratory (NREL), adding a 12.5-kilowatt-hour lithium-ion battery to a home solar system adds roughly $16,000 to the total installed cost when no federal or other incentives are factored in.[2] This represents a battery installed cost of $1,280 per kilowatt-hour. Lead acid batteries typically cost less than lithium-ion batteries, more in the $300-$400 per kilowatt-hour range, but lead acid batteries don't last as long as lithium-ion systems, particularly when frequently charged and discharged.

It's important to note that equipment prices quoted by battery storage vendors typically do not include the cost of installing the system. Additional hardware, electrical upgrades, taxes, permitting fees, and other costs associated with installing a battery system will often add $2,000 to $4,000 to the base cost of a residential battery.

For commercial systems, the general rule is the larger the system, the lower the relative installed cost. Small commercial systems between 10 to 100 kilowatt-hours in size tend to fall in a similar range as residential storage systems, around $1,000 to $1,400 per kilowatt-hour, sometimes less for batteries on the larger end of this range. Systems between 100 kilowatt-hours to 1,000 kilowatt-hours should cost a bit less, in the range of $600 to $800 per kilowatt-hour. Large-scale battery systems over a megawatt-hour can cost below $600 per kilowatt-hour installed. NREL estimates that a 1.2-megawatt-hour (1,200-kilowatt-hour) system will cost an average of $672 per kilowatt-hour and a community-scale, 7.2-megawatt-hour battery will cost in the range of $490 per kilowatt-hour.[3]

Residential and small commercial battery systems, like this 14-kilowatt-hour sonnen eco 14 battery at a remote school in Orcovis, Puerto Rico, tend to have an average installed cost between $1,000 to $1,400 per kilowatt-hour.

Courtesy of sonnen

Battery systems in the 100 kilowatt-hour to 500 kilowatt-hour range, such as this system at a Safeway supermarket in San Jose, CA, typically cost less than smaller systems, around the $600 to $800 per kilowatt-hour range.

Courtesy of ENGIE

Of course, these ranges should only be used as a starting point. Battery equipment prices can be fairly consistent across similar projects within a given region and timeframe, but installed costs can vary widely depending on the complexity of an installation and local requirements on permitting and interconnection. Battery system prices tend to be a constantly moving target.

This gets to another difficulty in pinning down the cost of batteries: they tend to keep getting lower every year. The price of lithium-ion battery packs (not the full system cost) has fallen nearly 90 percent since 2010, from an average of $1,100 per kilowatt-hour in 2010 to $139 per kilowatt-hour in 2023. Analysts expect significant cost declines to continue over the next few years, approaching $80 per kilowatt-hour by 2030.[4]

Installed costs can vary widely depending on the complexity of an installation and local requirements on permitting and interconnection. Battery system prices tend to be a constantly moving target.

Clearly, $139 per kilowatt-hour is a lot lower than the system prices listed above. That's because battery packs are only one piece of a full battery storage system. A full system may include an inverter, a container, climate control systems, and a battery management system, to name just a few. As battery pack prices have dropped, these additional components have become larger portions of the total cost, often representing the majority of the full system cost. With these additional components included, battery system prices range from a few hundred dollars per kilowatt-hour to more than a thousand.

The good news is that price declines are expected to be realized for the rest of a battery system as well, with some analysts expecting non-battery-pack costs to represent the largest portion of system price declines in the coming years.[5] This path is similar to the evolution of solar cost declines; the price of solar cells dropped rapidly over time, while total solar system costs fell more slowly.

Though price is certainly important, it's not the only factor to consider when buying a battery storage system. The length of warranty, both in calendar years and number of cycles (charges and discharges), is extremely important and can greatly impact pricing. The warranty terms give

Larger-scale battery systems, like this 2.9-megawatt-hour system at the Atrisco Heritage Academy High School in Albuquerque, NM, can have installed costs below $600 per kilowatt-hour.
Courtesy of OE Solar

an indication of when a battery might need to be replaced, which is critical for determining the true cost of batteries over an extended period. (See *Question 10: How long does a solar+storage system last?*) Battery chemistry type, which impacts battery operation, safety considerations, and management system options (flexibility in what the system can do), must also be considered when selecting a storage system.

Another complexity in battery system pricing is understanding the difference between kilowatts and kilowatt-hours. The kilowatt rating of a battery system represents the maximum power the system can deliver, while the kilowatt-hour rating represents the total amount of energy that can be delivered over time. (See *Question 8: What size battery do I need?*) Pricing per kilowatt-hour has largely become the standard, but battery prices can sometimes be represented dollars per kilowatt. The difference can be confusing, sometimes leading to misleading cost comparisons. For instance, a 10-kilowatt/40-kilowatt-hour battery system priced at $40,000 would cost $4,000 per kilowatt and $1,000 per kilowatt-hour; whereas, a 10-kilowatt/10-kilowatt-hour battery (same power with less capacity) priced at $20,000 would equate to $2,000 per kilowatt and $2,000 per kilowatt-hour. If all you care about is power, the $20,000 system may be the better option, but based on energy capacity, the $40,000 system is the lower-cost option.

Q4 ENDNOTES

1 Spencer Fields and Emily Walker, "Solar battery cost: Why they're not always worth it," *EnergySage*, https://www.energysage.com/energy-storage/how-much-do-batteries-cost (accessed March 11, 2024).

2 Vignesh Ramasamy et al., "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023," *National Renewable Energy Laboratory*, September 2023, https://www.nrel.gov/docs/fy23osti/87303.pdf.

3 "Commercial Battery Storage—Annual Technology Baseline, 2023," *National Renewable Energy Laboratory,* https://atb.nrel.gov/electricity/2023/commercial_battery_storage (accessed March 11, 2024).

4 "Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh," *BloombergNEF,* November 26, 2023, https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh.

5 Mitalee Gupta, "Balance-of-System Costs Falling for Non-Residential Storage," *GTM²,* October 25, 2019, https://www.greentechmedia.com/articles/read/balance-of-systems-costs-falling-for-non-residential-storage.

QUESTION 5

How can I pay for a solar+storage system (incentives, grants, financing)?

TOPICS COVERED: Federal tax incentives, state and utility incentive programs, examples of programs targeted to support development in low-income communities, project examples benefiting from grant support, discussion of financing options

While the prices of solar and battery storage have dropped dramatically over the past several years, they can still be too costly for many customers. The upfront cost of a solar+storage system can be a significant barrier to many projects, particularly when securing financing is a challenge. In regions where savings and revenue opportunities are not strong enough to easily secure financing, incentives and grant opportunities play an important role in accelerating the deployment of solar+storage. Depending on the location of the project, multiple sources of funding and financing may be available to help pay for a solar+storage installation.

Incentive programs that carve out funding for low-income and environmental justice communities go a step further by ensuring that the technologies are accessible to more communities.

Solar and Battery Storage Incentives

State, federal, and utility incentives help drive solar+storage market development by lowering upfront costs and improving system economics.[1] Incentive programs that carve out funding for low-income and environmental justice communities go a step further by ensuring that the technologies are accessible to more communities. In some instances, it's possible to combine battery storage and solar incentives, offsetting significant out-of-pocket project costs.

FEDERAL INCENTIVES: Solar and battery storage are each eligible for a federal Investment Tax Credit (ITC). Projects up to one megawatt in capacity qualify for an ITC of at least 30 percent, as do larger projects that meet prevailing wage and apprenticeship requirements.

In addition to the 30 percent baseline credit, projects may also be eligible for up to six bonus credits that could raise the value of the ITC to up to 70 percent of the project cost.[2] Four of these credits are not stackable, meaning a project can only select one. These non-stackable credits include 10 percent bonus credits that are available for projects located in a low-income community or on Tribal Land, and 20 percent bonus credits that are available for projects where the facility is part of a qualified low-income residential project or low-income economic benefit project. In addition to these four credits, the ITC offers two stackable 10 percent bonus credits for projects located in an "energy community" and/or that meet domestic manufacturing requirements.[3]

Technical assistance engineering partners with Navajo Nation residents receiving a solar PV and battery storage system to deliver reliable power to their remote family home.

Courtesy of JPHB

Importantly, through a Direct Pay option, also known as Elective Pay, tax-exempt organizations can now directly benefit from the ITC.[4] Nonprofits and other tax-exempt entities—like municipalities and Tribal governments—receive the ITC in the form of a direct pay reimbursement after a clean energy project has been placed in service. The ITC is not an upfront incentive, so organizations will need to pay for and/or finance the entire cost of the system prior to applying for the payment, which may be difficult for institutions with limited operating budgets.

STATE INCENTIVES: More states are beginning to offer battery storage incentives. Maryland, for example, is the first state to offer a tax credit to incentivize battery systems. Those credits equal 30 percent of total system costs or $5,000 for a residential property and $150,000 for a commercial property, whichever is lower. Tax credit certificates are issued on a first-come, first-served basis with separate funding allocated for residential and commercial projects.[5] Other states offer solar tax incentives. South Carolina and New York, for example, offer solar energy credits of up to 25 percent of the system costs.[6]

A few states have gone a step further by structuring incentives to allocate additional funding for projects in low-income communities. The following state incentive programs are notable for prioritizing funds to battery storage development in low-income communities.

- **California Self-Generation Incentive Program (SGIP)**. SGIP provides different rebate compensation levels for battery storage based on certain criteria, including income and proximity to high wildfire risk areas. The program is split into three main incentive categories: Base, Equity, and Equity Resiliency. The Equity and Equity Resiliency incentives are specifically tailored for low-income and high-risk communities. Critical facilities and residences in low-income communities and state-defined disadvantaged communities throughout California are eligible for the Equity incentive, which covers approximately 80 percent of the cost to install a battery storage system. The Equity Resiliency incentive offers the highest compensation rate ($1,000/kWh), enough to offset nearly the entire installed cost of a battery storage system. This incentive is specifically for low-income, disadvantaged, and medically vulnerable customers living in high wildfire threat zones or in areas that have experienced multiple outages due to wildfire-related Public Safety Power Shutoffs (PSPS). Both critical facilities and residences are eligible.[7]

- **Solar Massachusetts Renewable Target (SMART)**. SMART is structured as a production-based incentive program, guaranteeing a certain compensation rate for each kilowatt-hour of solar energy generated by a system. Although the SMART program was primarily launched to incentivize solar, the program includes an "adder" (additional funds) for systems that include battery storage. SMART also offers compensation rate adders for projects in low-income communities. A customer's SMART incentive rate is dependent on the utility, system size, and project location.[8]

Utility programs provide customers with the benefit low- or reduced-cost battery storage systems that can provide resilient backup power in the event of an outage.

UTILITY INCENTIVES: Utilities increasingly offer incentives and program opportunities for customers to install battery storage systems. Utility programs provide customers with low- or reduced-cost battery storage systems that can provide resilient backup power in the event of an outage. These programs also benefit the utilities, which can tap the batteries to meet system peak demand and provide other valuable grid services. Multi-year utility programs can greatly improve the financeability of a solar+storage project. For more information about utility battery storage programs, see the box on *Utility Distributed Battery Storage Programs* (p. 28).

DISASTER RESPONSE AND RECOVERY FUNDS: The Federal Emergency Management Agency's (FEMA) Hazard Mitigation Assistance programs now consider solar and battery storage technologies eligible secondary power sources for grant support.[9] Furthermore, FEMA's largest grant program, Public Assistance, will now allow states to include renewable energy technologies in the rebuilding of damaged critical facilities after a natural disaster.[10] After a major disaster, Public Assistance funds can be used to reimburse state, local, tribal or territorial governments for 75 percent of the cost of rebuilding or repairing critical community facilities, including "net-zero energy projects" such as the addition of solar and storage technologies.

Grants

Grants—from federal, state, utility, and foundation sources—can provide needed funding for many solar+storage projects. Depending on the source, these grants may be offered in support of energy innovation initiatives, demonstration projects, or to benefit specific communities or populations. Grants may not cover all project costs but can help reduce upfront costs or bridge financial gaps.

Grants can be especially helpful in offsetting costs associated with a preliminary step in the project development process: conducting a solar+storage feasibility assessment. Technical assistance grants allow organizations to engage third-party expertise to analyze a facility and create a report on what a potential solar+storage project would look like, including cost, system sizing, economic benefits, and backup power duration for critical loads.[11] Washington State's "Solar plus Storage for Resilient Communities" program provides grants for technical assistance as well as installation costs.[12]

Other grant programs support project implementation, or a combination of project implementation and technical assistance. Southface Institute, a nonprofit organization based in Atlanta, offers the GoodUse program that provides technical assistance and project implementation grants to nonprofit organizations in the Southeast. The GoodUse program greatly offsets the costs associated with energy improvements, including solar and battery storage, by providing a funding match. For organizations with an operating budget below $1 million, Southface provides a 2:1 match up to $40,000.[13] In Maryland, the Maryland Energy Administration (MEA) Resiliency Hub program provides nonprofits, local governments, and businesses with grants that support installing solar+storage in underserved communities.[14]

The following are examples of solar+storage projects that benefitted from various forms of grant assistance.

Solar+storage projects for affordable housing and nonprofit community facilities may require different structures of financing and ownership.

- **Sterling Municipal Light Department** in Massachusetts used state and federal grants to install battery storage tied to an existing solar farm, powering critical facilities that provide first responder services. Over 75 percent of Sterling's project costs were covered by grants. The Massachusetts Department of Energy Resources provided a $1.465 million grant, and the US Department of Energy Office of Electricity awarded an additional $250,000 grant through the Energy Storage Technology Advancement Partnership, along with free technical assistance.[15]
- **The Maycroft Apartments** solar+storage project in Washington, DC was the first affordable housing development in the city to fully power a resiliency center through solar+storage. Jubilee Housing received a technical assistance grant from Clean Energy Group to conduct the initial solar+storage feasibility assessment, as well as a $65,000 grant from the local utility's foundation, The PEPCO Foundation, which partially funded the battery storage system.[16]
- **POWER House Community Center**, located in the largest public housing community in Baltimore, is equipped with solar+storage to provide emergency services in the event of an outage. During regular operations, the center offers community programming, including education and career development services. POWER House benefitted from a $250,000 grant through the MEA Resiliency Hub program.[17]

Financing

Several financing tools are available for solar and storage projects. Mainstream and low-income markets require different financing models to address their unique needs. Conventional loans, tax equity investments, and traditional lease financing may be a good fit for credit enabled mainstream commercial customers. Affordable housing and nonprofit community facilities may require different structures of financing and ownership.[18]

Third-party financing, a popular option to finance solar systems, is now often used to finance battery storage. One type of third-party financing is a power purchase agreement (PPA), in which a developer installs a solar (or solar+storage) system on a customer's property with little to no upfront out-of-pocket expenses.[19] The developer owns the power generated by the system and sells that electricity back to the customer at an agreed upon rate. This rate is typically lower than the rate charged by the utility, resulting in savings for the customer and a monthly payment to the developer. Adding battery storage to a solar PPA increases the amount a customer pays per kilowatt-hour but, depending on the project, this increase can be very low.[20] Another type of third-party financing is an Energy Services Agreement (ESA), where all project development and construction costs, as well as maintenance and operation of a system, are covered by the developer. Once the system is operational, the customer begins making ESA payments based on realized savings. In some cases, the solar and battery storage portions of a project may be financed through separate mechanisms, such as a PPA for solar generation, and an ESA or monthly lease fee for the storage system.

Q5 ENDNOTES

1 The North Carolina Clean Energy Technology Center offers the "Database of State Incentives for Renewables and Efficiency," which provides a comprehensive overview of incentives by state and is available at https://www.dsireusa.org.

2 To learn more about Investment Tax Credit Bonus Credits, visit "Investment Tax Credit Fact Sheets: Bonus Credit Program," *Clean Energy Group*, https://www.cleanegroup.org/publication/investment-tax-credit-fact-sheets-bonus-credit-program (accessed March 14, 2024).

3 Three types of areas can qualify as an energy community: 1) a census tract, or directly adjoining census tract, where a coal mine closed after 1999 or a coal-fired electric generating unit was retired after 2009; 2) an area with significant employment or local tax revenue from fossil fuels and higher-than-average unemployment rates; 3) brownfield sites.

4 To learn more about Direct Pay for Nonprofits, visit "Investment Tax Credit (ITC) Direct Pay Fact Sheet for Nonprofits," *Clean Energy Group*, https://www.cleanegroup.org/publication/direct-pay-fact-sheet (accessed March 14, 2024).

5 To learn more about the Maryland Energy Storage Income Tax Credit for 2024, visit https://energy.maryland.gov/business/Pages/EnergyStorage.aspx. (accessed March 14, 2024).

6 To learn more about state solar energy incentives, visit "Solar Incentives by State," *Sunrun*, https://www.sunrun.com/solar-lease/cost-of-solar/state-rebates (accessed March 15, 2024).

7 To learn more about California's SGIP program, visit "SGIP Incentive Step Tracker," *Self-Generation Incentive Program*, https://www.selfgenca.com/home/program_metrics (accessed March 26, 2024).

8 To learn more about Massachusetts' SMART program, see "Solar Massachusetts Renewable Target (SMART) Program," *Massachusetts Department of Energy Resources*, https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program (accessed March 26, 2024).

9 "B.11. Secondary Power Source," *Federal Emergency Management Agency*, https://www.fema.gov/grants/mitigation/guide/part-12/b/11 (accessed March 15, 2024).

10 Justine Calma, "FEMA will pay states to install solar panels and heat pumps," *The Verge*, January 30, 2024, https://www.theverge.com/2024/1/30/24055546/fema-solar-panel-pay-costs-disaster-reimbursement.

11 Through its Resilient Power Project, Clean Energy Group established a national technical assistance program that awards small grants to nonprofit entities for solar+storage feasibility assessments. The program is focused on supporting projects in low-income communities and historically marginalized communities, providing one-on-one technical guidance and grants to support solar+storage feasible assessments for hundreds of facilities, including affordable housing, community centers, and critical service providers. To learn more about Clean Energy Group's Technical Assistance Fund, see https://www.cleanegroup.org/initiatives/technical-assistance-fund.

12 "Solar plus Storage for Resilient Communities," *Washington State Department of Commerce*, https://www.commerce.wa.gov/growing-the-economy/energy/solar-plus-storage (accessed March 14, 2024).

13 To learn more about the GoodUse program offered by Southface, visit "GoodUse," *Southface*, https://www.southface.org/our-work/programs/gooduse/gooduse-faqs (accessed March 20, 2024).

14 "FY24 Resilient Maryland Program," *Maryland Energy Administration*, https://energy.maryland.gov/business/pages/Resilient-Maryland.aspx (accessed March 20, 2024).

15 To learn more about the Sterling Municipal Light Department project, visit "Featured Resilient Power Installations: Sterling Municipal Light Dept. Energy Storage System," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/sterling-energy-storage (accessed March 26, 2024).

16 To learn more about the Maycroft Apartment project, visit "Featured Resilient Power Installations: Maycroft Apartments," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/maycroft-apartments (accessed March 26, 2024).

17 To learn more about the POWER House project, visit "Maryland Resiliency Hubs: Open Invitation to Help Neighborhoods," *Maryland Energy Administration*, November 8, 2018, https://news.maryland.gov/mea/2018/11/08/resiliency-hubs-are-an-open-invitation-to-help-neighborhoods and "Our Programs," Living Classrooms Foundation, https://livingclassrooms.org/programs/power-house-community-center (accessed March 26, 2024).

18 For more information on these financing tools, see Robert Sanders and Lewis Milford, "Owning the Benefits of Solar+Storage," *Clean Energy Group*, February 2018, https://www.cleanegroup.org/publication/owning-the-benefits-of-solar-storage.

19 "Solar Power Purchase Agreements," *Solar Energy Industries Association*, https://www.seia.org/research-resources/solar-power-purchase-agreements (accessed September 9, 2020).

20 To see an example of how battery storage can be added to a solar PPA, see Florian Mayr, "Battery storage at US$20/MWh? Breaking down low-cost solar-plus-storage PPAs in the USA," *Energy Storage News*, March 23, 2020, https://www.energy-storage.news/blogs/battery-storage-at-us20-mwh-breaking-down-low-cost-solar-plus-storage-ppas.

QUESTION 6

Can storage be added to an existing solar system?

TOPICS COVERED: Potential barriers to incorporating storage, approaches to retrofit an existing solar installation, installing a storage-ready solar system

In most cases, battery storage can be added to an existing solar system. How difficult it is to add storage, and the best way to go about it, depend on a few key factors including 1) the ownership structure of the existing solar array, 2) how storage is addressed in net metering policies, and 3) whether the solar system was installed as "storage ready."

For new projects, it is important to be clear on contract terms when installing a solar system that may later incorporate storage.

Possible Barriers

The most common barriers to retrofitting an existing solar system with battery storage involve the solar ownership structure, equipment warranties, and net metering policies.

SOLAR OWNERSHIP STRUCTURE: The first question to address is who owns the existing solar system? If the solar system is owned by the resident or property owner, there should be little problem in incorporating battery storage. Systems owned by a third party, either through a lease or power purchase agreement, could complicate a storage retrofit. The terms of a third-party ownership arrangement or financing agreement may prohibit the addition of storage. For third party-owned systems, it's important to discuss adding battery storage with all parties involved in ownership of the solar system before proceeding. For new projects, it is important to be clear on contract terms when installing a solar system that may later incorporate storage.

EQUIPMENT WARRANTIES: Warranty restrictions on existing solar equipment could also prevent the addition of storage. This is primarily a concern for older inverters that specify that adding storage would void the equipment warranty. If the rules regarding battery storage are unclear based on equipment manuals and warranty documents (many of which are available online), consult with developers and equipment vendors to ensure warranties will remain intact. For older equipment approaching the end of its useful life, equipment replacement may make sense as part of the storage retrofit, in which case existing warranties are no longer an issue.

NET ENERGY METERING: Most existing solar systems participate in some sort of net metering program where credits are earned for any solar energy exported to the grid. Different states have different policies for how storage is handled under a net metering arrangement. In Massachusetts, for example, only energy storage that charges from its host facility (such as through rooftop solar panels) can participate in net energy metering.[1] It's important to check with your utility to verify if and how storage can be added to a solar system that is net metered.

Adding Storage

If battery storage can be added to a solar system without jeopardizing existing ownership agreements, equipment warranties, or net metering contracts, the next step is to decide on the best approach to integrate a battery storage system.

The best-case scenario is when a solar system is already designed with storage in mind, known as a *storage-ready* solar system. In these systems, it should be an easy, almost plug-and-play process to add storage (more on making a solar system storage-ready below). Unfortunately, most existing solar systems did not envision adding batteries when first installed, so the process of adding storage may be more complex and costly.

There are two basic ways to add storage, through AC coupling or DC coupling (see Q6 Figure 1, p. 43). For existing solar systems, AC coupling is often the preferred option.

AC-COUPLED RETROFIT: For an AC-coupled retrofit, the existing grid-tied solar inverters remain in place, and a new battery-based or hybrid inverter is added for the storage system. Choosing AC-coupling allows existing solar equipment and wiring to be reused and offers flexibility for where the new battery system and associated equipment can be installed. Some battery systems, like the Tesla Powerwall 2, include a built-in inverter, making AC-coupling a simple approach. AC-coupling is often a lower cost retrofit option than DC-coupling.

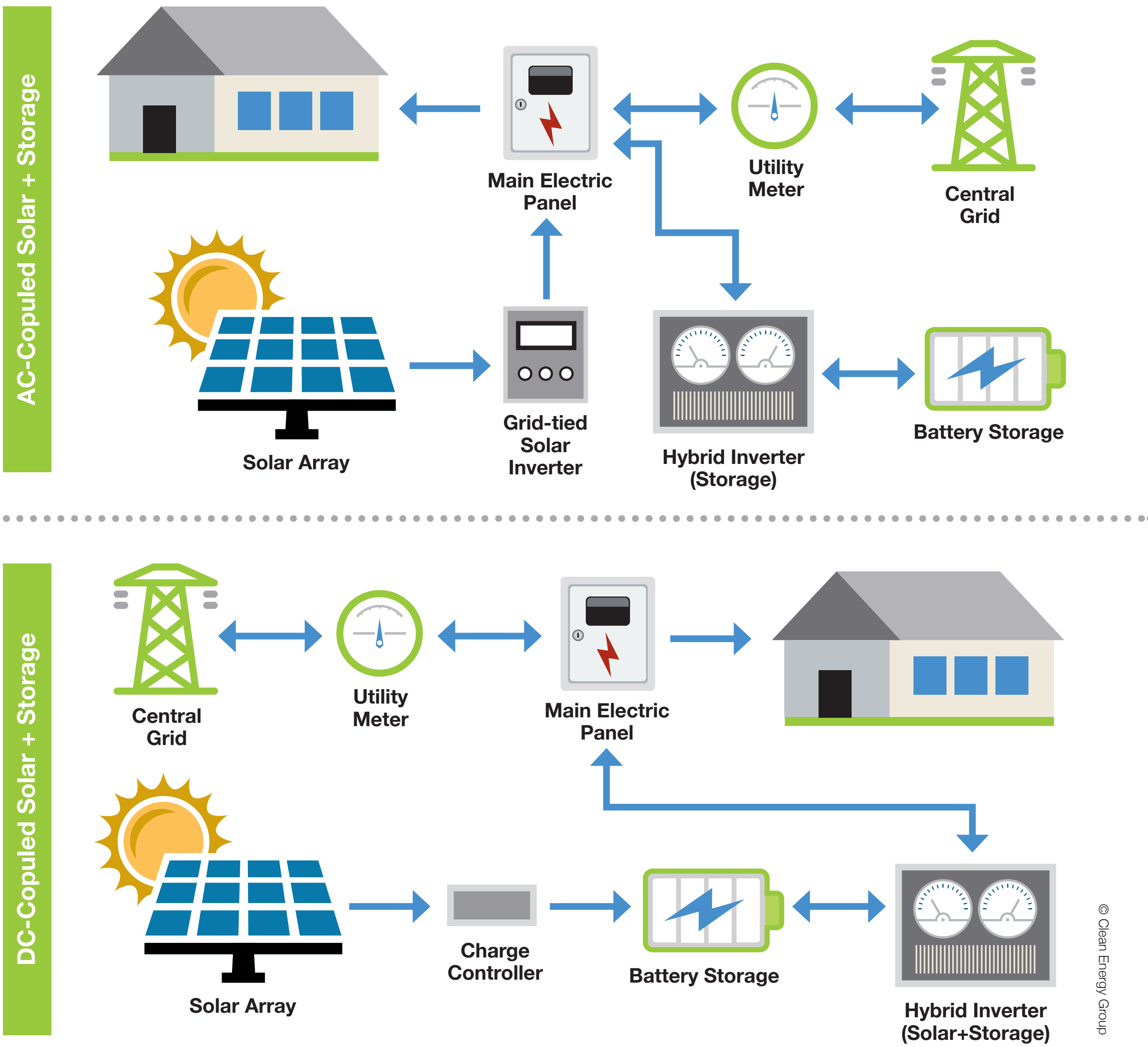
If the battery system is being added to provide backup power during grid outages, it is important to verify that the existing solar inverters can communicate with the new battery-based inverter. Failure to communicate properly could create issues that prevent the system from working properly during an outage and possibly cause harm to the battery system. Potential compatibility issues should be explored by an experienced project developer prior to beginning a retrofit.

Because AC coupling doesn't involve swapping out existing equipment, adding storage is less likely to conflict with third-party ownership arrangements or warranties.

Residential LG Chem battery storage system.

Courtesy of Cinnamon Energy Systems

Q6 FIGURE 1: **AC- and DC-coupled solar+storage**



Solar and energy storage systems can be integrated through either AC- or DC-coupled configurations. The main difference is that in a DC-coupled system, solar and storage components share a hybrid inverter, whereas in AC coupling, solar and storage components each have their own separate inverters.

DC-COUPLED RETROFIT: DC coupling solar and storage may result in better overall system efficiencies because of fewer AC/DC power conversions, but it can be a more expensive retrofit option for an existing solar system. However, for solar systems with aging equipment, such as inverters that are nearing the end of their expected useful life, a DC-coupled retrofit may be a viable option.

In a DC-coupled retrofit, the existing inverters are replaced with a charge controller and hybrid inverter that interacts with both the battery system and solar system. The retrofit may include significant redesign and rewiring of the existing system, though that is not always the case. Along with higher costs, a DC-coupled retrofit may also limit placement options for the new inverter and battery system compared to AC-coupling, in order to avoid long distances between the battery and solar systems.

Interconnection

One last consideration when adding battery storage to an existing solar system is the utility interconnection process. In some cases, a new interconnection agreement may need to be filed and approved by the utility when incorporating storage to an existing solar system. Storage systems that will not interact with the grid, such as those designed to only deliver backup power, may not have to go through a new interconnection process. Interconnection delays have become an increasingly common challenge as both solar and battery storage have grown in popularity. In some utility territories, these delays can be significant.[2] It's a good idea to check with your utility to understand the interconnection process, and any associated delays, for retrofitting your solar system with storage.

Making Solar "Storage Ready"

If you're installing a solar system now but aren't quite ready to add battery storage, it may be worth considering making your system storage ready. Even if it may not make sense today, changing electrical loads, evolving utility rate structures, and falling storage costs could make battery storage a cost-effective choice in the future. While installing a storage-ready solar system costs more upfront, the cost savings realized when incorporating battery storage later on can more than offset the initial investment.

Like any solar+storage system, a storage-ready system can be either AC- or DC-coupled. To prepare a DC-coupled storage-ready solar system, a hybrid inverter is substituted for the usual grid-tied solar inverter. However, many hybrid inverters require a battery as their power source, so make sure to check with the inverter manufacturer that their product can be used both as a grid-tied inverter (no battery required) and as a hybrid inverter. For AC coupling, a grid-tied inverter is still used for the solar system, but additional wiring can be installed and run to the eventual location of the battery-based inverter and additional storage equipment.

Regardless of the configuration, adequate space for the battery system and associated equipment should be identified and reserved during the solar system design process. Systems that intend to incorporate storage for backup power should identify and isolate essential loads in a critical load panel and install a transfer switch if needed (see *Question 2: Is solar+storage an effective backup power solution?*).

Q6 ENDNOTES

1 "Energy Storage and Net Metering," *Commonwealth of Massachusetts*, https://www.mass.gov/info-details/energy-storage-and-net-metering (accessed March 22, 2024).

2 "The Interconnection Bottleneck: Why Most Energy Storage Projects Never Get Built," *Applied Economics Clinic* and *Clean Energy Group*, May 11, 2023, https://www.cleanegroup.org/publication/the-interconnection-bottleneck-why-most-energy-storage-projects-never-get-built.

QUESTION 7

What different types of batteries are available (and which one is right for me)?

TOPICS COVERED: Overview of lead acid and lithium-ion batteries, key differences between the technologies (energy density, depth of discharge, cycling, expected useful life), brief overview of other storage options

Selecting the right battery storage system for a project can be a daunting task. There are many different products available, and new, sometimes exotic, systems seem to be entering the market all the time.

The vast majority of solar+storage projects being installed today incorporate one of two types of battery systems: lead acid or lithium-ion, with lithium-ion increasingly dominating the space. There are significant differences between the two technology types; and within each broad category, there is an array of battery chemistries, configurations, and individual products.

> **The vast majority of solar+ storage projects incorporate one of two types of battery systems: lead acid or lithium-ion, with lithium-ion increasingly dominating the space.**

Lead Acid Batteries

Lead acid batteries are largely a known commodity. They've been around for more than a century and have been the go-to technology choice for off-grid solar systems for decades. Unlike the lead acid batteries found in most cars, those best suited for use with solar systems are designed to handle frequent, deep discharges of energy; they are known as deep-cycle lead acid batteries.

Sealed lead acid (SLA) batteries, also known as valve regulated lead acid (VRLA) batteries, are the type most commonly installed with solar today, as opposed to flooded lead acid batteries, which require regular monitoring and maintenance. Within sealed lead acid batteries, there are different technologies, such as absorbent glass mat (AGM) batteries that can be more deeply discharged than other types of lead acid batteries. Some companies market AGM batteries specifically for integration with solar systems.

Lead acid batteries tend to be cheaper on an upfront, dollar-per-kilowatt-hour basis than lithium-ion, but they have some drawbacks, including shorter lifespans, less ability to discharge full capacity without degradation, and lower energy densities, as discussed below.

Lithium-ion Batteries

Lithium-ion batteries have also been around for a while, first in small electronics, then in larger devices like cordless tools, and now in cars, buildings, and large-scale power systems.

Tesla Powerwall 2 being installed at a fire station in Puerto Rico.

Courtesy of Hunter Johansson, Solar Responders

In recent years, lithium-ion batteries have dominated the stationary storage market, at times representing upwards of 99 percent of battery deployments.[1]

Several different battery chemistries fall under the umbrella term of lithium-ion. The two most common varieties are Lithium Nickel Manganese Cobalt (NMC) and Lithium Iron Phosphate (LFP). NMC batteries, found in the popular Tesla Powerwall 2, were the most common chemistry used in stationary storage systems for several years. However, largely due to dropping costs, many manufacturers have transitioned to LFP battery packs, which are used in Tesla's Powerwall 3. In addition to lower costs, LFP batteries present fewer fire safety concerns than NMC batteries as they are less likely to experience "thermal runaway," a chemical reaction that can cause a battery to overheat and catch fire. See *Question 9: Is battery storage safe?* LFP batteries also tend to have a higher cycling life (more charging and discharging with less degradation) than NMC batteries.

Lead Acid versus Lithium-ion

While lead acid batteries are typically the cheaper battery option based on upfront costs, over the lifetime of a system, lithium-ion batteries win in other important categories, namely energy density, depth of discharge, cycling life, and expected useful life (see Q7 Figure 1, p.48).

ENERGY DENSITY: Energy density is a measure of how much energy (measured in kilowatt-hours) can be packed into a battery per unit of weight, which typically corresponds to battery size. In other words, a battery with a higher energy density is able to store more energy pound for pound (and usually has a smaller physical footprint) than a battery with a lower energy density. Because lead acid batteries have a lower energy density than lithium-ion batteries, they are heavier and take up more space.

DEPTH OF DISCHARGE: Depth of discharge (DOD) is a measure of how much energy capacity can be discharged from a battery before the performance of the system is negatively impacted. The maximum DOD for lead acid batteries is typically around 50 percent of capacity, though some AGM batteries can achieve a DOD of up to 80 percent. Discharging a lead acid battery below rated DOD severely impacts battery performance and accelerates battery degradation, shortening its useful life. For a 20-kilowatt-hour battery system, a 50 percent DOD would represent a usable capacity of 10 kilowatt-hours. For lithium-ion batteries, DOD is often in the 80–100 percent range. Because lithium-ion batteries have a much higher DOD rating, a lithium-ion battery could have two to five times as much usable energy as a lead acid system with the same total rated energy capacity, which can make lithium-ion systems much more cost-competitive.

CYCLING: Cycle life represents how often a battery system can be charged and discharged before significant degradation occurs. Essentially, one full charge and discharge (up to the recommended DOD) represents one cycle. Each cycle tends to reduce battery performance a little bit, until the battery reaches the end of its useful life. The cycle life of a battery varies depending on its chemistry. A lithium-ion storage system will typically last from 2,000 to 10,000 cycles (e.g., Enphase IQ battery guarantees 6,000 cycles, sonnen eco battery guarantees 10,000 cycles). Lead acid batteries, on the other hand, tend to last between 500 and 1,200 cycles.

EXPECTED USEFUL LIFE: The useful life of a battery system represents how long the batteries can last before they are degraded to the point that the system can no longer effectively serve its intended purpose.[2] How long a battery lasts largely depends on how it is operated; for instance, if a battery is cycled once a day, a lead acid battery may last no more than two years, whereas, a lithium-ion battery could last more than 15 years before needing to be replaced. A battery warranty is often indicative of how long the system might last. Warranties typically specify number of cycles (or energy throughput) and calendar years. Lithium-ion warranties are typically 10 to 15 years (in some cases, longer) while lead acid battery warranties often range from two to five years. *See Question 10: How long does a solar+storage system last*?

In general, lead acid batteries can serve as a cost-effective option for systems that won't experience a lot of charging and discharging, such as systems designed primarily for backup power. Applications that involve more frequent cycling may be better suited for lithium-ion batteries.

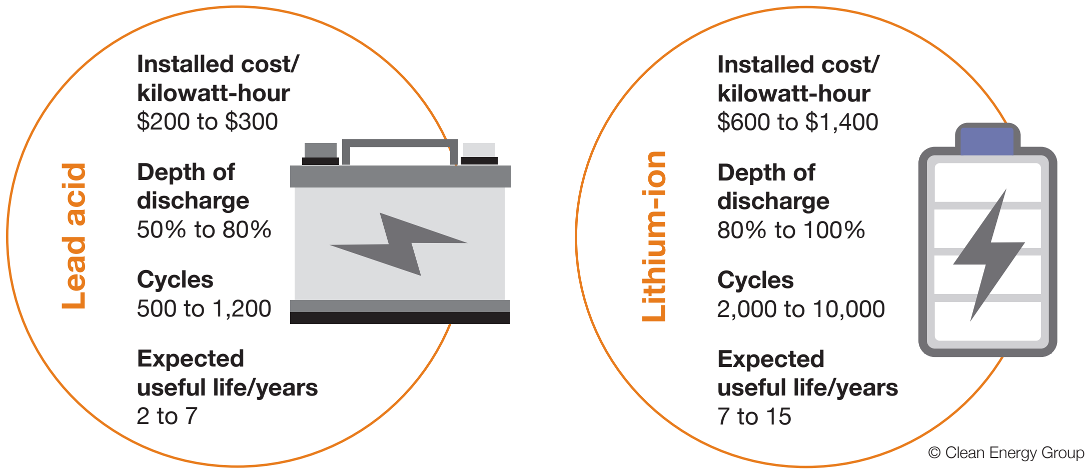
Other Options

Lithium-ion and lead acid very much dominate the solar+storage market today, but there are certainly other types of storage options available. Some of the top energy storage contenders include sodium-based batteries (potentially less expensive than lithium-ion), metal-air batteries (abundant source materials), solid-state batteries (high energy density), and flow batteries

56 kilowatt-hour SimpliPhi battery system at Maycroft Apartments in Washington, DC.

Courtesy of SimpliPhi Power

Q7 FIGURE 1: **Lead acid versus lithium-ion battery systems**



(longer duration, few safety issues, no performance degradation). Then there are more novel large-scale alternatives, like thermal storage, compressed air storage, and gravity energy storage, where trains or giant bricks are hoisted up to store energy and lowered down to generate energy.[3]

While many types of batteries are being deployed in real-world applications, none of these alternative technologies have been able to achieve the same economies of scale and price declines as lithium-ion technologies over the past decade. That could certainly change, but it will likely take time for the next “big breakthrough” to become a trusted and widely available storage option.

16 kilowatt-hour lead acid battery system at the Cimarron Forestry Office in New Mexico.

Courtesy of M. Gaiser,
New Mexico State Energy Office

Q7 ENDNOTES

1 Julian Spector, “What Would It Take for the US to Become an Energy Storage Manufacturing Powerhouse?” *GTM*^{2}, January 13, 2020, https://www.greentechmedia.com/articles/read/can-the-us-claim-dominance-in-energy-storage-manufacturing.

2 The Institute of Electrical and Electronics Engineers (IEEE) defines a battery’s end of life as 80 percent of its original rated capacity (for example, a 10-kilowatt-hour battery will have reached the end of its useful life once it degrades to an 8-kilowatt-hour capacity), although many lithium-ion battery manufacturers define end of life as 70 percent or even 60 percent of the battery’s original rated capacity. It is important to read through a battery’s warranty information to determine how end of life is being defined.

3 Claudia Lee, “We rely heavily on lithium batteries—but there’s a growing array of alternatives?” *BBC*, March 19, 2024, https://www.bbc.com/future/article/20240319-the-most-sustainable-alternatives-to-lithium-batteries and Susan Taylor, “Can anything topple lithium-ion?” *PV Magazine*, March 18, 2024, https://pv-magazine-usa.com/2024/03/18/can-anything-topple-lithium-ion.

QUESTION 8

What size battery do I need?

TOPICS COVERED: Explanation of battery power rating, energy capacity, and duration sizing specifications; sizing considerations for backup power, demand management, and solar self-consumption applications; physical space requirements for battery systems

Before sizing a battery system, consider that batteries have two key characteristics: power rating and energy capacity.

The power rating (or rated output) of a battery represents the maximum rate that the battery can charge or discharge energy. Thinking about energy storage in terms of water storage, the power rating represents how quickly a bathtub can be filled or drained. The power rating of a battery is typically given in kilowatts (1,000 watts), or megawatts (1,000 kilowatts) for larger systems. If you wanted to power 200 lightbulbs that each required 15 watts of electricity, you would need a battery with a power rating of at least 3,000 watts (200 lightbulbs x 15 watts = 3,000 watts), or 3 kilowatts.

To figure out the most suitable battery storage system size for a project, determine how the system will be used over time.

A battery system's energy capacity represents the total amount of energy the battery can store or discharge over time. In the water storage example, energy capacity represents how much water the bathtub can hold. Energy capacity is typically given in kilowatt-hours.[1] So, to keep those 200 lights on for four hours, you would need a battery with an energy capacity of at least 12 kilowatt-hours (3 kilowatts x 4 hours = 12 kilowatt-hours). Energy capacity can also be represented by the amount of time it would take for the battery to discharge at its maximum power rating. In this case, the 3-kilowatt/12-kilowatt-hour battery system could also be described as a 3-kilowatt/4-hour duration battery system.

It's important to note that a four-hour duration battery can power devices for longer than four hours depending on the loads it is supporting. If the power needed to support the loads is lower than the maximum power rating of the system, the battery will last longer. If only 2 kilowatts of power are needed to keep the lights on instead of 3 kilowatts, a 12-kilowatt-hour battery system could keep the lights powered for six hours. If it only takes 1 kilowatt to keep the lights on, the same battery could keep the lights powered for 12 hours.

How to Size a Battery System?

To figure out the most suitable battery storage system size for a project, determine how the system will be used over time. This is because sizing a system to manage energy demand or maximize solar self-consumption is very different from sizing to provide backup power.

Sonnen battery storage system in an apartment at Soleil Lofts in Utah.

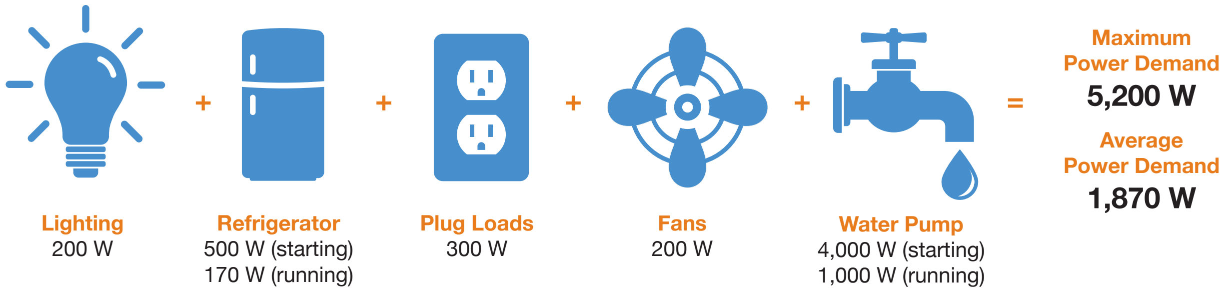
Courtesy of sonnen

Storage systems can be designed to do many different things. In this section, we'll focus on sizing considerations for three common applications: backup power, demand management, and solar self-consumption.

BACKUP POWER: Energy resilience is the primary goal of most residential and community-based battery storage projects (such as community centers, institutions of faith, and first responders), as well as an increasing number of commercial projects. Sizing systems for backup power depends on two primary factors: critical loads and outage durations. Critical loads represent all the electrical loads that must be supported by the backup system, which could be an entire home or facility but is more commonly a subset of loads to minimize the cost of the backup power system. To determine the power rating of a backup battery system, the maximum power rating for all critical loads should be added together, as shown in Q8 Figure 1 (p. 51). This calculation will ensure the battery is sized with enough available kilowatts to handle a worst-case scenario when all loads are running at maximum power at the same time. One important consideration is that the starting power rating for some devices, such as refrigerators and water pumps, can be significantly higher than the average power needed to keep the devices running. Ideally, a backup system should be sized to meet the combined starting power requirements for all critical loads unless a strategy is put into place to avoid this high-demand scenario, such as implementing a staggered startup of critical devices.

The energy capacity (duration) sizing of the battery system can be determined by multiplying the average power demand of critical loads (running power rating for all devices) over a specified time. As Q8 Figure 1 (p. 51) shows, if the maximum power demand for the critical loads is 5,200 watts (5.2 kilowatts) and the average power demand is 1,870 watts (1.87 kilowatts), an 11-kilowatt-hour battery system (1.87 kilowatts x 6 hours = 11.2 kilowatt-hours) with a power rating of at least 5.2 kilowatts could keep loads running for six hours. For reference, a Tesla Powerwall 2 has a maximum power rating of 7 kilowatts, a continuous power rating of 5 kilowatts, and an energy capacity of 13.5 kilowatt-hours.

Q8 FIGURE 1: **Examples of Critical Loads to Calculate Power Rating**



Solar power can offset some critical loads or recharge the battery system, increasing the length of time a battery can power loads during an outage, though solar will not always be available. For a solar+storage system, even if the battery system gets fully discharged during an outage, the system will again be able to deliver backup power when enough solar energy is available to recharge the batteries. The incorporation of other sources of generation, such as combined-heat-and-power systems, fuel cells, or traditional generators, would also increase the length of time critical loads could be supported and should be factored into any backup power sizing considerations. See *Question 2: Is solar+storage an effective backup power solution*?

DEMAND MANAGEMENT: Demand management has been one of the main drivers of commercial battery storage installations. Utility customers that pay demand charges—common for commercial customers and rare for residential customers—are partially charged based on the maximum rate at which they consume electricity (measured in kilowatts), along with typical energy consumption charges (measured in kilowatt-hours).[2] With battery storage, a customer can discharge stored energy during times when a facility is consuming electricity at its highest rate, or when utility demand charge prices are highest. This process of using storage to lower onsite demand is often referred to as *peak shaving*. To optimize demand management, a battery should be sized to reduce the maximum kilowatts of demand (power rating) over the shortest period of time (duration/energy capacity) to maximize savings while minimizing the cost of the battery system. Facilities with spikes in energy demand over short periods of time, such as those operating devices with a high starting power requirement, will have the best economic case for reducing bills with battery storage. The ideal situation occurs when a battery system with a high ratio of rated power to energy capacity can effectively reduce demand spikes.

SOLAR SELF-CONSUMPTION: There are many reasons why it may be in the economic interest of a property owner to maximize the solar energy directly consumed onsite and minimize the amount of solar generation that is sent to the grid. Under certain solar net metering policies, the value of solar credits earned for exported energy may be worth significantly less than the bill savings achieved through directly offsetting grid electricity consumption. In some cases, solar exports to the grid may not be allowed at all, so any generation not used onsite would have no economic value.

To maximize solar self-consumption, a battery system should be sized to capture as much excess solar generation as possible. This stored energy can be used later when solar generation is lower or nonexistent. The power rating of the storage system should be enough to

To maximize solar self-consumption, a battery system should be sized to capture as much excess solar generation as possible. This stored energy can be used later when solar generation is lower or nonexistent.

Q8 TABLE 1: Comparison of battery space requirements across various chemistries and system power/capacity ratings

System type	Brand	Power rating (kilowatts)	Energy Capacity (kilowatt-hours)	Height (feet)	Width (feet)	Depth (feet)	Total space (cubic feet)
Single lead acid battery	Trojan Solar SAES 12 105 12V AES AGM[a]	0.5	1.3	0.8	0.6	1.1	0.5
Residential lead acid	Trojan Solaress 9.84[b]	8	9.5	2	3	1.8	10.8
Residential lithium-ion	Enphase IQ Battery 5P[c]	3.8	5	3.2	0.6	1.8	3.6
Residential lithium-ion	Franklin Home Power[d]	5	13.6	2.6	1.8	0.5	2.5
Residential lithium-ion	Tesla Powerwall 2.0[e]	5	13.5	3.8	2.5	0.5	4.5
Residential lithium-ion	SunPower SunVault 26[f]	6.8	24	5.4	2.2	1.2	14.4
Commercial lithium-ion	Samsung SDI E3-R256[g]	128	256	9	3	2.5	68
Commercial lithium-ion	LG TR1300[h]	92	328	5.7	3.4	3.9	77
Large-scale lithium-ion	Tesla Megapack[i]	979	3,854	9.2	28.9	5.4	1,436

a Trojan Battery Company, "Solar SAES 12 105 Data Sheet," *trojcanbatterysales.com*, July 10, 2023, https://assets.ctfassets.net/nh2mdhlonj7m/2v6mQ58e3SPBXJtCMEVPs1/1f05f49741c417c717e4e3ba59c77ee7/202307-SAES-12-105-Datasheet-WEB.pdf.

b Trojan Battery Company, "Solaress 9.84 Residential Energy Storage Solution," *trojanbatterysales.com*, October 24, 2019, https://www.trojanbatterysales.com/pdf/TBS_Solaress_9.84.pdf.

c Enphase Energy, "IQ Battery 5P Datasheet," *enphase.com*, November 7, 2023, https://enphase.com/download/iq-battery-5p-data-sheet.

d FranklinWH. "Franklin Home Power—Data Sheet," *franklinwh.com*, May 25, 2023, https://www.franklinwh.com/document/franklin-home-power-v11-datasheet.

e Telsa, "Powerwall Datasheet," *tesla.com,* June 11, 2019, https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall%202_AC_Datasheet_en_northamerica.pdf.

f SunPower, "SunPower SunVault Energy Storage System (ESS): SunVault 13 and SunVault 26 Datasheet," *sunpower.com,* https://es-media-prod.s3.amazonaws.com/media/components/panels/spec-sheets/SunVault_ESS_datasheet_536812__RevC_orkjjBI.pdf (accessed March 15, 2024).

g Samsung, "ESS Batteries by Samsung SDI," *samsung SDI.com,* https://www.samsungsdi.com/upload/ess_brochure/201902_Samsung%20SDI%20ESS_EN.pdf (accessed March 15, 2024).

h LG Energy Solution, "Rack ERT5422CN201 Specifications," *lgessbattery.com*, https://www.lgessbattery.com/ImageServlet?imgPath=20210427141654562[20210427141654563].pdf&imageType=PRODUCT (accessed March 15, 2024).

i Tesla, "Select Megapack," *tesla.com,* https://www.tesla.com/megapack/design (accessed March 15, 2024).

cost-effectively capture solar power coming into the battery, which may be the full kilowatt power rating of the solar system. Energy capacity should be sized based on the economics of storing energy versus the cost of additional storage capacity, i.e., the value of additional solar kilowatt-hours directly consumed over the life of the storage system versus the upfront cost of purchasing additional battery system kilowatt-hours. Storage system sizing would follow a similar process for solar time-shifting applications, also known as energy arbitrage—where solar generated during periods of low electricity pricing is stored to be used at a time when electricity prices are higher.

When it comes to developing solar+storage projects, the ideal size of a battery system often depends on balancing multiple factors such as system costs, economic returns, and resilience benefits. It may also depend on what size systems are readily available and most cost-effective for each project. One free tool that can be useful as a first step in sizing a battery system is REopt Lite (https://reopt.nrel.gov/tool) developed by the National Renewable Energy Laboratory.

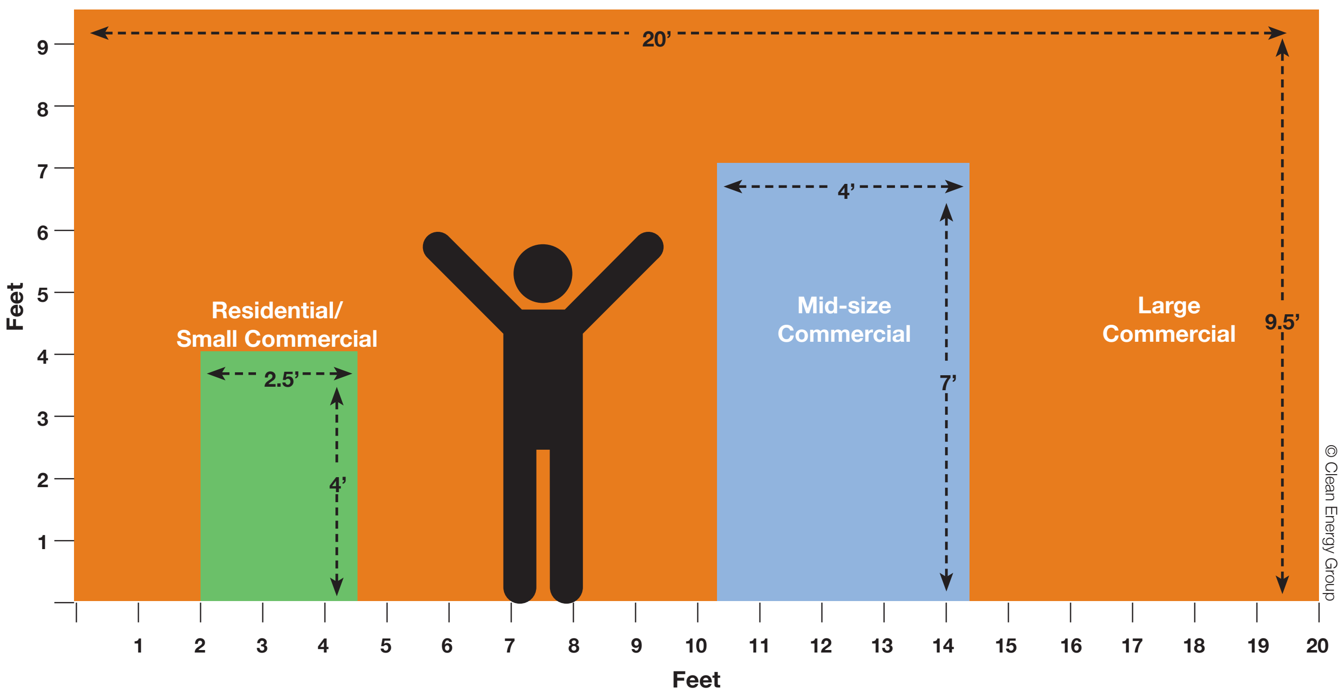
How Much Space Do I Need for a Battery?

Another key consideration in determining the right size battery system is how much space is physically available. This is particularly important when battery siting locations are limited to the footprint of an existing property, whether indoors or outdoors.

Battery storage products have varying space requirements. In general, residential and small commercial lithium-ion battery systems are about the same size as a dormitory refrigerator or very thin full-sized refrigerator. Larger commercial lithium-ion battery systems are roughly the size of a large refrigerator, depending on their energy capacity. Larger megawatt-hour-scale battery systems and their associated components are often housed in 20-foot or 40-foot shipping containers (see Q8 Figure 2). Lead acid systems tend to take up more space; a typical lead acid battery of around one kilowatt-hour is about the size of a shoebox; a full battery system requires 20 to 50 percent or more space than a comparable lithium-ion battery system (see Q8 Table 1, p. 52).

In addition to the physical size of the battery system, building and permitting space requirements such as clearance distances and safety measures must be considered when determining minimum space requirements for a battery system.

Q8 FIGURE 2: **How big is a lithium-ion battery storage system?**



Battery storage systems come in a variety of shapes and sizes depending on the battery system chemistry and manufacturer. In general, residential and small commercial storage systems take up about the same space as a dormitory refrigerator or very thin household refrigerator (green rectangle). Mid-size commercial systems have a footprint similar to a commercial refrigerator (blue rectangle). Large, megawatt-scale systems are often housed in a 20-foot or 40-foot shipping container (orange rectangle).

Q8 ENDNOTES

1 Battery energy capacity ratings are sometimes given in amp-hours instead of kilowatt-hours. Lead acid battery systems are commonly rated in amp-hours. Amp-hours must be multiplied by the battery's voltage rating in order to convert the rating to kilowatt-hours, so a 100-amp-hour, 12-volt battery would have an energy capacity of 1,200 watt-hours, or 1.2 kilowatt-hours.

2 For more information about demand charges and energy storage, see: "An Introduction to Demand Charges," by Clean Energy Group and National Renewable Energy Laboratory at https://www.cleanegroup.org/wp-content/uploads/Demand-Charge-Fact-Sheet.pdf (accessed September 3, 2020).

QUESTION 9

Is battery storage safe?

TOPICS COVERED: Overview of battery storage safety risks and siting considerations; thermal runaway; safety risks when a fire occurs; resources with more information about recommended fire safety codes, procedures, and best practices

As with any energy technology, there are certain safety concerns that should be addressed when considering a battery storage system. However, based on numerous studies and hundreds of thousands of real-world deployments, battery technologies from trusted manufacturers have widely proven to be safe for onsite energy storage when installed by experienced professionals following recommended procedures. The types of battery technologies commonly used in energy storage installations do not emit any harmful gases during operation and pose few serious risks if properly installed, operated, and maintained.

Battery technologies from trusted manufacturers have widely proven to be safe for onsite energy storage applications when installed by experienced professionals following recommended procedures.

Battery storage safety begins with proper siting of the system based on an assessment of potential hazards, such as extreme climate conditions or weather events. Batteries sited in hotter climates may require extra cooling measures. When sited in areas subject to flooding, batteries should be installed at elevations well above the floodplain or in waterproof enclosures. Siting considerations should also ensure adequate and clearly marked access to the battery system and related hardware in the event of a fire or other emergencies when the system may need to be deactivated to protect the safety of first responders.

Fire Safety

Most safety concerns associated with battery storage systems are related to fire risks. While battery storage system fires are exceedingly rare, they do periodically occur. Globally, the International Association of Fire Fighters has cataloged 141 energy storage system fire events over the past decade, with most events occurring in Europe and Asia.[1] About 40 percent of these fires have involved residential battery systems.

Battery storage fire risk can be broken down into two categories: 1) the risk of a storage system igniting and starting a fire, and 2) the risk to individuals onsite and those responding when a fire occurs at a facility with battery storage. The severity of both risks often has less to do with the specific energy storage chemistry being used (though that can be a factor) and more to do with fire containment, suppression, and safety measures that have been implemented. Codes and standards have been designed for batteries to minimize any safety risks by providing guidance for best practices when siting, installing, operating, and maintaining a storage system.

STARTING A FIRE: Most fires caused by batteries are due to design, manufacturing, or installation errors. Flawed battery production or damaged battery packs can cause energy storage systems to overheat, resulting in a system failure known as "thermal runaway." Thermal runaway basically means that the battery cannot remove heat as quickly as it is being generated. Under these conditions, temperature may rise to the point where the battery cell combusts. If not properly contained, thermal runaway can propagate to nearby cells, resulting in a cascading system failure and increased fire severity.

Certain battery technologies carry a higher risk of thermal runaway due to the underlying chemistry of their cells. For example, lithium-ion battery systems using Nickel Manganese Cobalt (NMC) cells carry a higher risk of thermal runaway than the other leading lithium-ion chemistry, Lithium Iron Phosphate (LFP) (see *Question 7: What different types of batteries are available (and which one is right for me)?).* Many non-lithium battery chemistries carry little to no risk of thermal runaway. Even in chemistries that do carry a higher risk of thermal runaway, the risk can be minimized by proper system design and the implementation of early detection and battery shutdown systems. It's important to research any battery product under consideration for a project to make sure the manufacturer has a proven track record of deployments, to verify that the battery technology has been fully tested and certified, and to make sure that battery is backed by a reliable warranty. One way to do so is by verifying that a battery technology has received UL certification.[2] Equally important is working with an experienced developer to install the system. Before engaging a developer, be sure to discuss any fire safety concerns and what measures will be taken to minimize risks and ensure safety if an event does occur.

The best way to minimize and prevent injuries from fires at sites with battery storage systems is to incorporate monitoring devices that will detect fire risks and alert onsite personnel.

WHEN A FIRE OCCURS: In 2019, a fire occurred at a large battery storage facility in Arizona.[3] This was the first documented instance of a serious fire at a lithium-ion battery facility in the United States. Multiple firefighters were injured by an explosion at the site when responding to the incident. An extensive investigation into the event found that though the fire began due to a faulty battery cell, injuries could have been avoided by implementing a few additional safety measures, including sensors to detect battery system failure, venting to eliminate the buildup of explosive gases released during combustion, and more extensive training of first responders.[4]

Most safety and industry experts agree that the best way to minimize and prevent injuries from fires at sites with battery storage systems is to incorporate monitoring devices that will detect fire risks and alert onsite personnel. Fire suppression and ventilation systems minimize the risk when first responders arrive. In response to battery fire incidents at utility-scale installations in New York, a state fire safety working group recommended multiple actions to minimize risk, including increased monitoring, more frequent safety inspections, and extended signage to indicate the presence of an energy storage system onsite.[5] Depending on the size, location, and type of battery system, specialized ventilation systems may be recommended—or in some cases required—as part of an energy storage installation. Smaller systems and those installed outdoors may not necessarily require additional ventilation. (See Q9 Figure 1, p. 56.)

In 2016, The National Fire Protection Association (NFPA) began developing a standard (NFPA 855) for the installation of energy storage technologies.[6] The goal of the guidance document is to establish a standard for fire safety measures and set minimum requirements for mitigating hazards associated with energy storage installations. Among the topics addressed by NFPA

855 are safe methods for cooling and extinguishing energy storage system fires. According to the standard, water has been found to be an "effective extinguishing agent" for most energy storage fires, including lithium-ion battery chemistries.[7]

Q9 FIGURE 1: **Battery Storage Safety Measures**

Environmental Hazards

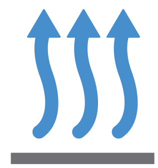
Battery storage safety begins with proper siting to ensure the battery system is insulated from potential environmental hazards, such as extreme weather and flooding.

Temperature Controls

Some storage systems may require dedicated heating and/or cooling systems to regulate temperatures and operate properly.

Codes and Standards

Follow the most up-to-date codes and standards and implement safety best practices when installing a storage system.



Venting

Battery systems contained in enclosed areas may require venting to avoid the buildup of explosive gases during a system failure.

Awareness

Areas containing battery storage systems should be clearly marked and onsite staff should be made aware of any potential safety hazards. Warning systems should immediately alert staff and first responders of system failures.

Fire Suppression

Effective fire suppression equipment should be installed in case a fire does occur. Local and regional first responders should be informed of potential hazards and receive relevant training.

Q9 ENDNOTES

1 Alex Schraiber, et al., "Considerations for Fire Service Response to Residential Battery Energy Storage System Incidents," *International Association of Fire Fighters*, December 4, 2023, https://www.iaff.org/wp-content/uploads/IAFF_DOE_ResidentialESSConsiderations_Final.pdf.

2 UL certifications, such as UL 9540: Standard for Energy Storage Systems and Equipment and UL 9540A: Test Method for Evaluating Thermal Runaway Fire Propagation, include testing requirements to verify an energy storage product meets certain minimum safety standard thresholds. See "UL 9540A Test Method," *UL Solutions,* https://www.ul.com/services/ul-9540a-test-method (accessed March 18, 2024).

3 Julian Spector, "The Arizona Battery Explosion Is Changing Conventional Wisdom on Safety," *GTM*, October 10, 2019, https://www.greentechmedia.com/articles/read/arizona-battery-explosion-conventional-wisdom-safety.

4 DNV GL Energy Insights USA, Inc., "McMicken Battery Energy Storage System Event Technical Analysis and Recommendations," *Arizona Public Service*, July 18, 2020, https://www.aps.com/-/media/APS/APSCOM-PDFs/About/Our-Company/Newsroom/McMickenFinalTechnicalReport.ashx?la=en&hash=50335FB5098D9858BFD276C40FA54FCE.

5 "New York's Inter-Agency Fire Safety Working Group," *New York State Energy Research and Development Authority*, https://www.nyserda.ny.gov/All-Programs/Energy-Storage-Program/New-York-Inter-Agency-Fire-Safety-Working-Group (accessed March 18, 2024).

6 "NFPA 855: Standard for the Installation of Stationary Energy Storage Systems," *National Fire Protection Association*, https://www.nfpa.org/codes-and-standards/nfpa-855-standard-development/855 (accessed March 18, 2024).

7 To learn more about fire safety training for first responders, see "Solar+Storage Fire Safety Training: Single and Multifamily Residential," *Clean Energy Group*, January 12, 2021, https://www.cleanegroup.org/webinar/solarstorage-fire-safety-training.

QUESTION 10

How long does a solar+storage system last?

TOPICS COVERED: Expected lifespan and typical warranties for solar panels, inverters, and batteries

A solar+storage system consists of three primary pieces of equipment: solar panels, inverters, and batteries. The lifespan of the whole system depends on the durability of each of these three main components. Throughout the useful life of a solar+storage system, certain pieces of equipment will likely need to be replaced at different times. For instance, solar panels may function properly for 25 years or more, but the inverter might need to be replaced after 10 years and the battery replaced at year 15. (See Q10 Figure 1, p. 58.)

Understanding the different lifespans and warranties for each type of equipment will provide owners with the information necessary to make a sound decision on the type of system they want installed and plan financially for future system upgrades.

Understanding the different lifespans and warranties for each type of equipment will provide owners with the information necessary to make a sound decision on the type of system they want installed and plan financially for future system upgrades.

Solar Panels

LIFESPAN: Solar panel performance degrades over time, producing less electricity as the panels age. The annual rate of degradation is very small, with the industry average below 1 percent. Many manufacturers now offer solar panels with degradation rates under 0.5 percent per year.[1] Due to this decrease in solar panel efficiency, most warranties guarantee equipment and performance for a set number of a years; however, even after the warranty expires, the panels may continue to operate.

The useful lifespan of solar panels is measured by the length of the performance warranty, which is described in more detail below.

WARRANTY: Solar panels have two types of warranties: product and performance. The *product warranty*, also known as an equipment warranty or materials warranty, covers the equipment (the solar panels and related hardware) in the event there is a defect, such as a faulty panel. Most product warranties are 10 to 12 years, though some manufacturers will provide 25 years or more of coverage.[2] Barring any physical damage, most solar equipment will continue operate for decades, well after the product warranty expires.

Solar panels are very durable, and most are tested to withstand harsh weather conditions like hail and strong winds. However, areas that are highly prone to specific severe weather events should evaluate the benefit of implementing additional design measures that could help ensure the long-term health of solar investments.

Whereas a product warranty focuses on equipment, a *performance warranty*, or power warranty, guarantees solar panel electricity production, ensuring that solar panels maintain a level of power output for a certain amount of time. Most manufacturers guarantee that their solar panels will produce at least 80 percent as much energy after 25 years as when the panels were first installed. For example, a solar panel with an average degradation rate of 0.75 percent per year will still be producing 83.5 percent of its original rated power in year 25.

Most manufacturers guarantee that their solar panels will produce at least 80 percent as much energy after 25 years as when the panels were first installed.

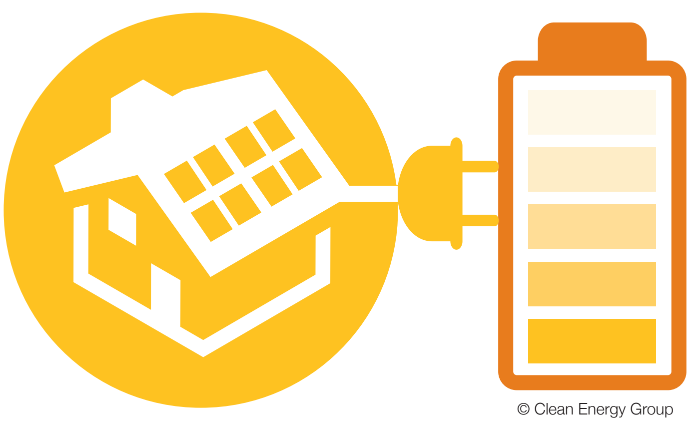
Solar Inverter

Solar systems rely on either string inverters or microinverters. A string inverter is a single unit, installed inside or outside a building, that serves multiple panels in the system. For many smaller systems, only one string inverter may be required. Alternatively, a microinverter system consists of a small inverter installed under each solar panel. (To read more about how inverters work, see *Question 1: What factors do I need to consider when designing a solar+storage system?*)

LIFESPAN: Environmental conditions (such as heat and humidity) and the system's maintenance schedule can impact the lifespan of an inverter. The average lifespan of most string inverters is typically between 10 to 15 years, although some can last 20 years or longer. Microinverters have a lifespan of 20 to 25 years, similar to solar panels.

WARRANTY: Inverter warrantees align with the anticipated lifespan of the inverter. String inverters are often backed by a 10- to 12-year warranty, and microinverters are typically warrantied for up to 25 years.[3] It's worth noting that a system that utilizes microinverters can be significantly more expensive than one that uses string inverters.

Q10 FIGURE 1: **How long does a solar+storage system last?**



Years	Replacement
25+	Entire system replacement
20–25	Microinverter replacement
10–15	Standard inverter replacement Lithium-ion battery replacement
2–7	Lead acid battery replacement
0	Solar+storage system installed

Battery Storage

LIFESPAN: The average useful life of a battery storage system paired with solar is 5–15 years. This wide range is due to a multitude of factors, primarily battery chemistry, use, and maintenance. Batteries that are frequently charged and discharged will degrade more quickly than batteries that are rarely used. For instance, a battery only used a few times a year for resilience (i.e., to provide backup power when electricity from the grid is unavailable) will likely have a longer lifespan than one that is used daily to maximize solar self-consumption or participate in a utility program.

Lithium-ion batteries typically have a longer useful life (7–15 years) than lead acid batteries (2–7 years) because lithium-ion cycles more efficiently and, thus, degrade more slowly over time. See *Question 7: What different types of batteries are available (and which one is right for me*)?

WARRANTY: Battery manufacturers provide multiple types of warranties: guaranteed operational years, guaranteed cycles (or energy throughput), and guaranteed end-of-warranty capacity. For lithium-ion batteries, a warranty is typically for 10 operational years (though some batteries offer longer warranties of 12–15 years). A warranty for a lead acid battery is usually between two to five operational years. For lithium-ion battery systems that include built-in inverters, the same warranty usually covers both the battery and the inverter.

The lithium-ion battery cycle warranties typically range between 4,000 and 15,000 cycles, with an industry average of around 6,000 cycles.[4] Lead acid batteries have a much shorter expected cycle life of 1,200 cycles or less. Energy throughput can be thought of as the total amount of energy a battery is expected to deliver over the course of its useful life. Many battery manufacturers are now including energy throughput as part of their warranty, with common residential lithium-ion battery models having an average throughput warranty between 30–50 megawatt-hours.

An end-of-warranty capacity guarantee ensures that a battery's capacity to store energy will not degrade too quickly as the battery charges and discharges over time. Many lithium-ion batteries come with a 70 percent end-of-warranty capacity guarantee, though the guarantee can range from 60 percent to 85 percent depending on the product. A 10-kilowatt-hour battery storage system with a 70 percent end-of-warranty capacity guarantee would be expected to retain at least 7 kilowatt-hours of usable energy capacity at the end of its warranty.

Note that the warrantied lifespan of a battery system ends when any defined warranty limit is reached. The warranty for Tesla's Powerwall 2 covers the battery system for 10 years or 37 megawatt-hours of throughput, whichever comes first. So, a Powerwall that is frequently discharged may reach its throughput limit, thus ending the warranty period, in fewer than 10 years.[5]

Q10 ENDNOTES

1 To learn more about solar panel degradation, see "How long do solar panels last? Solar panel lifespan 101," *EnergySage*, https://www.energysage.com/solar/how-long-do-solar-panels-last (accessed March 18, 2024).

2 "Solar panel warranties: What to know," *EnergySage*, https://www.energysage.com/solar/solar-panel-warranties/ (accessed March 18, 2024).

3 "Solar inverter warranties: What's covered?" *EnergySage,* https://www.energysage.com/solar/solar-inverter-warranties/ (accessed March 18, 2024).

4 "Everything You Need to Know About Your Solar Battery's Warranty." *CNET*, https://www.cnet.com/home/energy-and-utilities/everything-you-need-to-know-about-your-solar-batterys-warranty/ (accessed March 20, 2024).

5 "Battery warranties: What you need to know." *EnergySage*, https://www.energysage.com/energy-storage/battery-warranties-overview/ (accessed March 20, 2024).

QUESTION 11

Can solar+storage be developed to benefit low-income communities?

TOPICS COVERED: Solar+storage economic, resilience, and environmental benefits for low-income communities; awareness and affordability barriers to solar+storage adoption; case studies of projects benefiting low-income communities

For many reasons, solar+storage should be deployed in low-income communities first and not as an afterthought, as has been the case for other clean energy solutions and efficiency measures. Low-income populations face greater energy burdens than other communities, meaning residents pay a higher proportion of their income on utility costs compared to residents in middle-income or high-income areas.[1] Low-income communities are also more vulnerable to adverse climate impacts and more likely to be subject to greater environmental burdens, such as pollutants from the fossil fuel industry. There are, however, barriers to solar+storage development in low-income communities that can make projects more challenging. These barriers must be addressed to ensure a more equitable distribution of resources.

Low-income populations face greater energy burdens than other communities, meaning residents pay a higher proportion of their income on utility costs compared to residents in middle-income or high-income areas.

Solar+storage can benefit low-income communities in three important areas: economic, resilience, and environmental.

Economic Benefits

Solar+storage can deliver economic benefits throughout the year. The savings and revenue generated by solar+storage is especially critical in low-income communities, where households suffer heavy energy burdens and community facilities often contend with shoestring budgets and capacity issues. Residential systems installed in utility service areas with storage-friendly programs can receive subsidized batteries and/or payment for allowing the utility to use their battery for grid services (see the box on *Utility Distributed Battery Storage Programs*, p. 28). Some state incentive programs also offer higher incentives for low-income or medically vulnerable populations (both residential and commercial customers). These incentives and value streams can make solar+storage more accessible, in some cases offsetting most or even all of the cost of a battery system. Connecticut's Energy Storage Solutions program provides upfront incentives as well as performance payments for battery storage installations. The Connecticut program provides tiered rebates, with higher incentive amounts for projects that support low-income households, critical community facilities, and affordable housing.[2] For community facilities serving low-income populations, solar+storage can often reduce utility costs by managing onsite demand.

New solar system installed at a fire station in Yauco, Puerto Rico as part of a resilient solar+storage system.
Courtesy of Solar Responders

Resilience Benefits

Batteries can provide hours, or even days, of power in the event of an outage, depending on the loads the system is supporting and whether it's paired with onsite solar. With solar+storage, critical facilities can potentially avoid significant negative financial impacts during power outages. One California health clinic lost hundreds of thousands of dollars' worth of temperature-regulated medications and vaccines when a power outage left the clinic without refrigeration.[3] In Florida, community health centers reported losses of up to $300,000 per outage.[4] Low-income residents face disproportionate impacts when outages occur. Planned power outages in California in October 2019 left the most vulnerable without power, including 300,000 people on Medi-Cal (a low-income health insurance program in California) and 51,000 households that rely on food assistance.[5] Without refrigeration, spoiled food can result in food security issues. For medically vulnerable residents, battery storage can support critical medical equipment, such as oxygen concentrators and refrigeration for temperature-sensitive medication.

Combined with solar, battery storage can power critical loads even longer. One resident in Vermont reported that their solar+storage system powered their home for 82 hours throughout a power outage.[6] Community facilities equipped with solar+storage can provide emergency services to surrounding neighborhoods during an outage. Solar+storage can also power community spaces in affordable housing, independent living facilities, and senior housing, allowing residents to access local and reliable power in the event of an outage to charge medical devices, access heating/cooling, and store perishables in a community refrigerator. By equipping these facilities with reliable solar+storage systems, community members have an invaluable backup-power resource during disasters.

Environmental Benefits

Solar+storage offsets greenhouse gas emissions by reducing a building's reliance on the grid. It can also reduce the need for fossil-fuel power plants, known as "peakers," during times of peak demand. Peakers are typically located in low-income communities and communities of color.[7] Battery storage can also reduce or replace the need for diesel or natural gas backup generators. Currently, critical facilities with a backup power system likely rely on traditional diesel or gas generators, which emit toxic pollutants that contribute to air pollution that is harmful to public health. One study found that 83 percent of fatal disaster-related carbon monoxide poisonings in the United States were attributed to improper generator use.[8] Battery storage can serve as a reliable backup power resource that doesn't emit any harmful pollutants.

Barriers to Solar+Storage Adoption

Solar+storage adoption is growing rapidly, but most low-income communities remain unable to fully access solar and battery storage technologies. The primary obstacles to solar+storage development in low-income communities relate to awareness and affordability.

Programs designed to improve education and adoption must be implemented for battery storage to reach low-income and disadvantaged communities.

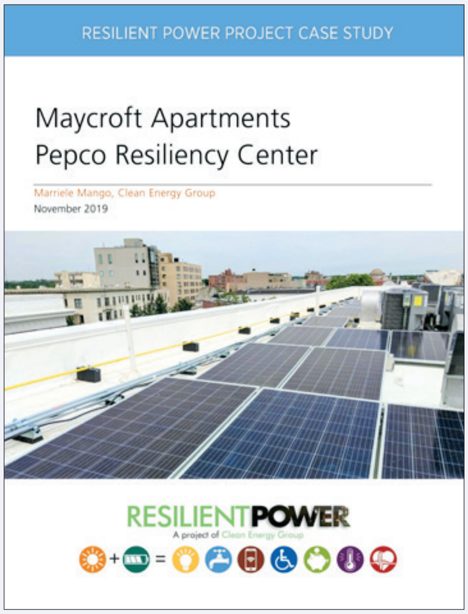
AWARENESS: Lack of energy storage education and awareness is a major issue; few states offer battery storage programs that educate and/or incentivize battery storage for low-income communities, unlike the low-income solar market that has benefited from years of dedicated federal and state incentive programs.[9] These programs not only improved the economics of solar, but they also promoted market expansion by incentivizing developers to expand their markets to low-income communities. Some states partnered with community-based organizations for outreach to maximize solar education.[10] Even in states that have developed incentives to boost storage deployment in low-income communities, there has been little uptake due to limited program visibility, poor program design, and inadequate community engagement.

Programs designed to improve education and adoption must be implemented for battery storage to reach low-income and disadvantaged communities. Building awareness of resilient power is especially difficult because, unlike solar PV, battery storage often competes with another distributed technology that benefits from decades of market dominance: diesel generators. Despite the health risks and operational challenges (including the need for frequent refueling), diesel generators (and, increasingly, natural gas generators) are the go-to, more easily accessible option during an outage. Programs that incorporate battery storage education are necessary in order to build battery storage awareness, especially in low-income communities.

AFFORDABILITY: With a few exceptions, battery storage remains unaffordable for individuals and organizations lacking significant financial resources. Service providers operating in low-income communities oftentimes deal with capacity issues and limited budget resources, making battery storage development an especially difficult endeavor. Without economic incentives and financing opportunities, solar+storage may remain uneconomical for most low-income community members.

Programs that allocate designated funds and higher incentive levels to support solar+storage development in low-income communities can lower out-of-pocket investments and reduce risks associated with financing. California's Self Generation Incentive Program (SGIP), for example, offers much larger battery storage incentives for customers in low-income communities,

Solar+Storage Case Studies



Early adopters of solar+storage provide real-world case studies of how solar and battery storage systems operate in community settings. Solar+storage projects at critical facilities serving low-income communities, especially, provide valuable insight into how these systems can serve the broader community, both through economic and resilience benefits. Here we'll explore four case studies: affordable housing, schools, nonprofit service providers, and community centers. All of the case studies featured received support from Clean Energy Group and/or were an awardee of Clean Energy Group's Technical Assistance Fund.[11]

MAYCROFT APARTMENTS, DC: Jubilee Housing provides affordable homes and supportive services to low-income and very low-income residents in Washington, DC.[12] Solar+storage at Jubilee Housing's Maycroft Apartments provides emergency backup power to a community space. In the event of an outage, residents, many of whom rely on electricity for medical purposes, can use the community space to access heating/cooling, a television, refrigeration for perishables and temperature-sensitive medication, and outlets to charge cell phones and electricity-dependent medical equipment. The 46-kilowatt/56-kilowatt-hour battery system, connected to a 62.4-kilowatt rooftop solar array, also powers lighting for stairwells and hallways throughout the complex. In addition to resilience, the community solar array saves each household approximately $40 every month on utility bills.[13]

VIEQUES MICROGRID NETWORK, PR: Community Through Colors (CTC), a nonprofit bringing disaster relief and preparedness to remote, isolated, and underserved coastal communities, developed a solar+storage microgrid for residents living in single-family homes on the island of Vieques in Puerto Rico.[14] CTC prioritized installing resilient power systems at the homes of vulnerable residents who rely on electricity to power their medical equipment, including those who utilize nebulizers and refrigeration for medication. As of Spring 2023, CTC has installed solar+storage at six single-family homes. An additional ten critical community facilities have received solar+storage, including the only fire department on the island and an elderly care facility that also serves as a food bank. Some residents and facility owners have reported upwards of 80 percent utility savings.[15]

VIA MOBILITY SERVICES, CO: Via Mobility Services (Via), Boulder's leading nonprofit mobility services provider, worked with the City of Boulder to develop a solar+storage system for their transportation hub.[16] Via operates a variety of transportation programs for seniors, people with disabilities, and others living with mobility limitations in Colorado. The solar+storage system consists of a 10.7-kilowatt solar array and a 57.2-kilowatt lithium-titanium oxide battery. Solar+storage powers critical IT loads (such as phones and computers) at all times. In the event of an outage, the system also supports lighting, HVAC, and electric bus charging. In summer 2018, after the system was installed, Via experienced an outage.

— CONTINUED —

— CONTINUED —

The system operated as expected, providing automatic power to critical loads through the outage.[17]

FLORIDA COMMUNITY HEALTH CENTERS, FL Florida Association of Community Health Centers (FACHC) is the federally designated primary care association for the state of Florida. FACHC is the primary provider of training and technical assistance to Florida's Federally Qualified Health Centers (FQHCs), which serve low-income and other underserved communities. To help ensure continuity of operations at FQHCs during emergencies and disasters, FACHC launched an effort to understand the backup power capabilities of health centers across the state. FACHC worked with Clean Energy Group and Direct Relief to assess 15 FQHCs for solar+storage, with nine of these facilities, thus far, moving forward with solar+storage installations. The systems will provide backup power in the event of an outage as well as economic benefits including utility savings and avoided losses due to outages.[18]

particularly those at risk of power outages due to wildfires. Similarly, the Solar Massachusetts Renewable Target (SMART) Program provides an "adder" (increased incentives) for projects in low-income communities and for projects that include battery storage with solar. For a more detailed review of incentive programs, see *Question 5: How can I pay for a solar+storage system (incentives, grants, financing)?*

Additionally, technical assistance funding to offset pre-development costs and innovative financing opportunities tailored to the needs of low-income communities can help critical community facilities overcome the financial hurdles associated with understanding and paying for solar+storage.[19]

Technical assistance funding to offset pre-development costs and innovative financing opportunities tailored to the needs of low-income communities can help critical community facilities overcome the financial hurdles associated with understanding and paying for solar+storage.

Q11 ENDNOTES

1 To learn more about the term "energy burden" and how low-income households are disproportionately impacted, visit "Energy Burden: What It Is and How Renewables Can Help," *Climate Reality Project*, March 10,2020, https://climaterealityproject.org/blog/energy-burden-what-it-and-how-renewables-can-help.

2 To learn more about the Connecticut Energy Storage Solutions program, visit "Introducing Energy Storage Solutions," *Energy Storage Solutions Administrators*, https://energystoragect.com/ (accessed March 26, 2024).

3 Maya Earls, "Clinics thrown into crisis during intentional blackouts," *Climate Wire*, November 13, 2019, https://subscriber.politicopro.com/article/eenews/1061524971.

4 Marriele Mango and Gianna Van Winkle, "Supporting Access to Health Care: Resilient Emergency Power for Florida Community Health Centers," *Clean Energy Group*, May 24, 2023, https://www.cleanegroup.org/publication/resilient-emergency-power-for-florida-community-health-centers.

5 Joaquin Palomino and Cynthia Dizikes, "Power outages hit some of state's poorest communities hard," *San Francisco Chronicle*, November 3, 2019, https://www.sfchronicle.com/california-wildfires/article/Power-outages-hit-some-of-state-s-poorest-14804853.php.

6 Julian Spector, "Batteries vs. Blackouts: 1,100 Homes Powered Through Vermont Outage with Storage," *GTM*, November 7, 2019, https://www.greentechmedia.com/articles/read/green-mountain-power-kept-1100-homes-lit-up-during-storm-outage.

7 To learn more about replacing peaker power plants with clean alternatives, see "Phase Out Peakers," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/phase-out-peakers (accessed March 28, 2024).

8 Shahed Iqbal, PhD et al., "A Review of Disaster-Related Carbon Monoxide Poisoning: Surveillance, Epidemiology, and Opportunities for Prevention," *American Journal of Public Health*, 102(10): 1957–1963, October 2012, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3490658.

9 Bentham Paulos, "Bringing the Benefits of Solar Energy to Low-Income Consumers: A Guide for States & Municipalities," *Clean Energy States Alliance*, 2017, https://www.cesa.org/resource-library/resource/bringing-the-benefits-of-solar-energy-to-low-income-consumers.

10 "SOMAH Our Partners: Community-Based Organizations," *Solar on Multifamily Affordable Housing* (SOMAH), https://calsomah.org/somah-and-community-based-partners (accessed March 28, 2024).

11 To learn more about Clean Energy Group's Technical Assistance Fund, visit "Technical Assistance Fund," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund (accessed March 24, 2024).

12 To learn more about Jubilee Housing, visit "Jubilee Housing," *Jubilee Housing*, https://jubileehousing.org (accessed March 24, 2024).

13 "Featured Installations: Maycroft Apartments," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/maycroft-apartments (accessed March 28, 2020).

14 To learn more about Community Through Colors, visit "Community Through Colors," *Community Through Colors*, https://communitythroughcolors.org (accessed March 28, 2024).

15 "Featured Installations: Vieques Microgrid Network," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/vieques-microgrid-network (accessed March 24, 2024).

16 To learn more about Via Mobility Services, visit "Via Mobility Services," *Via Mobility Services*, https://viacolorado.org (accessed March 24, 2024).

17 "Featured Installations: Via Mobility Services," *Clean Energy Group*, https://www.cleanegroup.org/initiatives/technical-assistance-fund/featured-installations/via-mobility-services (accessed March 28, 2024).

18 Marriele Mango and Gianna Van Winkle, "Supporting Access to Health Care: Resilient Emergency Power for Florida Community Health Centers," *Clean Energy Group*, May 24, 2023, https://www.cleanegroup.org/publication/resilient-emergency-power-for-florida-community-health-centers.

19 To learn more about Financing Resilient Power, a $3.3 million initiative of The Kresge Foundation, in partnership with the Clean Energy Group, to accelerate the market development of solar PV plus battery storage technologies in historically underserved communities, see "Financing Resilient Power Fact Sheet," *Clean Energy Group*, updated September 24, 2020, https://www.cleanegroup.org/publication/financing-resilient-power-fact-sheet.

QUESTION 12

What are the environmental impacts of battery storage?

TOPICS COVERED: Societal and environmental impacts of lead acid and lithium-ion battery mining and manufacturing processes; end-of-life considerations (recycling, reuse)

The development of lead acid and lithium-ion batteries comes with both societal and environmental concerns. Here we'll focus on three stages of the battery lifecycle to examine environmental and human impacts: extraction, production, and end-of-life.

There are social and environmental concerns associated with mining and manufacturing lithium-ion and lead acid batteries. Both are composed of finite resources that impact the environment through mining and manufacturing processes.

Extraction and Production

There are social and environmental concerns associated with mining and manufacturing lithium-ion and lead acid batteries. Both are composed of finite resources that impact the environment through mining and manufacturing processes and can be associated with exploitive practices due to lax (or nonexistent) regulations. (See Q12 Table 1, p. 67.)

The major manufacturing and mining concern associated with lead acid batteries is related to the toxicity of lead. There is no safe level of lead exposure for humans and even modest exposure over a period of time can result in major health complications, such as organ failure. Contaminated soil or dust can, and has, caused lead poisoning and deaths, especially in developing countries where mining is common and regulations are lax.[1] For the environment, mining-related lead exposure can contaminate water, soil, and crops. One study found widespread health impacts on communities in China surrounding lead mines.[2] Lead acid batteries also require energy intensive processing practices, resulting in higher rates of pollution than lithium-ion batteries.

Lithium-ion batteries require significantly less raw materials than lead acid batteries, and therefore have a lower impact on the surrounding environment when being mined.[3] Furthermore, the materials that go into a lithium-ion battery are less hazardous than lead, which is a toxic heavy metal, making contamination concerns less of an issue. However, mining lithium-ion materials comes with its own environmental issues. Current lithium mining practices can include invasive extraction processes and require a significant amount of water. In fact, entire communities in Chile (which has one of the largest lithium reserves in the world) have been depleted of water or are dealing with water pollution due to lithium mining.[4]

In addition to the environmental issues, cobalt, a necessary component of a common lithium-ion battery chemistry, Nickel Manganese Cobalt (NMC), is tied to exploitative labor practices. Human rights abuses, in addition to numerous other environmental and labor violations, have

Q12 TABLE 1: **Pros and cons of lithium-ion and lead acid batteries**

Lithium-ion Batteries	
Pros	**Cons**
Mining: Less environmental impact Lithium-ion batteries require significantly less raw materials than lead acid. **Mining and Manufacturing: Less health and environmental contamination risk** Lithium-ion battery components are less hazardous than lead; contamination concerns are less of an issue. **Mining and Manufacturing: Alternative options** Some battery vendors use lithium-ion chemistries that do not contain cobalt. **Recycling: Battery life** Lithium-ion batteries last longer than other battery chemistries; systems therefore require fewer battery replacements. **Reuse: EV batteries** EV batteries can be recycled, remanufactured, and reused in stationary battery storage systems.	**Mining: Exploitative labor practices** Cobalt, a necessary component of some common lithium-ion battery chemistries, is tied to exploitative labor practices and human rights abuses internationally. **Mining: Environmentally invasive practices** Invasive extraction processes that require a significant amount of water. **Recycling: Limited recycling industry** Less than 5% of lithium-ion batteries are recycled. The number of battery compounds makes recycling challenging. Recycling also requires expensive, energy intensive facilities, which makes the process less cost effective. **Recycling: Polluting facilities** Recycling typically requires expensive facilities that operate with energy intensive, polluting processes. This process is also wasteful, so less of the battery is recycled.

Lead Acid Batteries	
Pro	**Cons**
Recycling: Easily recycled Almost 100% of lead acid batteries are recycled. Lead acid benefits from a developed industry and a simpler battery chemistry, which makes recycling easier, less energy intensive, and more cost effective.	**Mining, Manufacturing, and Recycling: Health risks** There is no safe level of lead exposure for humans and even modest exposure over a period of time can result in major health complications. **Mining: Environmental contamination** Mining-related lead exposure can contaminate water, soil, and crops. **Manufacturing: Energy intensive** Requires more energy to process than lithium-ion, resulting in comparatively higher rates of pollution

been documented in cobalt mines in the Democratic Republic of Congo, which produces 50 percent of the world's cobalt supply.[5] The demand for NMC batteries, and therefore cobalt, has steadily decreased in recent years in favor of the leading alterative lithium-ion option, Lithium Iron Phosphate (LFP), which does not require cobalt.

End-of-Life

RECYCLING: Almost 100 percent of lead acid batteries are recycled today, compared to less than five percent of lithium-ion batteries. Lead acid is an older technology (lead acid batteries have been an integral component of the transportation industry for more than a century) and benefits from an established manufacturing and recycling industry that has developed over the last 100 years.[6] Lead acid is also a simpler battery chemistry than lithium-ion, which makes the recycling process easier and more efficient.[7]

Despite a well-developed industry, lead recycling remains problematic due to the health consequences of lead exposure. Although the lead recycling industry in the United States is one of the most regulated in the world, lead poisoning from recycling plants is still being reported. Until it was closed in 2015, a lead recycling plant in California released 3,500 tons of lead into the air over its lifetime. Exposure to lead could result in chronic health complications for the plant's 250,000 nearby residents.[8]

While a lead acid battery is mostly composed of lead, lithium-ion batteries can include a mixture of cobalt, manganese, iron phosphate, or nickel compounds, as well as aluminum, copper, and graphite. This makes recycling more challenging.[9] Furthermore, the lithium-ion industry has only started to take off in the past couple of decades and developing a recycling industry has taken a backseat to building a cost and technology competitive industry.

Though new, more efficient processes are being developed, established lithium-ion recycling practices typically rely on expensive facilities that use energy intensive, polluting processes to break down batteries. Furthermore, these processes fail to fully recover all the valuable materials that makeup a lithium-ion battery.[10] Alternatively, 100 percent of lead from lead acid batteries can be extracted and recycled over multiple battery lifetimes without degrading.[11]

Despite a bleak recycling landscape today, there is hope for an improved lithium-ion recycling industry in the future. Many of the primary components of lithium-ion batteries can be used to manufacture new lithium-ion batteries. If the recycling process can be made more efficient and cost-effective, the industry and environment would benefit; as expensive metals are recycled into new batteries, less mining for new resources is required. More research is being dedicated to understanding the potential of lithium-ion recycling, and companies are forming to demonstrate new and improved recycling methodologies. In 2023, the Department of Energy invested $2 million in "rejuvenation, recycling, and reuse of lithium-ion battery programs."[12] Leading battery manufacturers, like LG Energy Solution, are partnering with recycling partners to streamline battery recycling systems.[13]

REUSE: Batteries in electric vehicles (EVs) typically have a useful life of 10 years. However, recycling and remanufacturing processes can prepare EV batteries for a second life in stationary battery storage systems, which can utilize the significant battery life remaining in EV batteries without being limited by the same performance, space, and weight limitations as transportation.[14]

Redwood Materials, a battery recycling company, is working with the Kaua'i Island Utility Cooperative to decommission and recycle the 4.6-megawatt-hour battery storage system at the Anahola substation, which was commissioned in 2015 as one of the first large scale battery storage systems in the United States. The battery is being recycled at a facility in Nevada to use in a next generation fleet of energy storage.[15] Redwood Materials also operated an electric vehicle battery recycling initiative in California that resulted in over 1,000 recycled batteries in its first year. The recycled components of the batteries, over 80 of percent which were lithium-ion, will be used by US battery cell manufacturers.[16]

Entire companies are emerging with the mission of recycling and reusing EV batteries for stationary energy storage. B2U, a battery recycling company based in California, led a project in which a 1.5-megawatt solar farm charges 600 repurposed EV batteries during the day and deploys/sells the energy back to the grid at night, when demand and electricity prices are higher.[17] Another B2U site in Lancaster, California has 25 megawatt-hours of battery storage capacity across 1,300 recycled EV batteries—the largest operational energy storage system using second-life EV batteries.[18]

Q12 ENDNOTES

1 "Lead poisoning and health," *World Health Organization*, August 23, 2019, https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health.

2 Xiuwu Zhang, et al., "Impacts of lead/zinc mining and smelting on the environment and human health in China," Environmental Monitoring and Assessment, *National Center for Biotechnology Information*, 2012, https://www.ncbi.nlm.nih.gov/pubmed/21573711 (accessed March 26, 2024).

3 AllCell Technologies, LLC, "A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications, *Battery Power Online*, March 2012, https://www.batterypoweronline.com/wp-content/uploads/2012/07/Lead-acid-white-paper.pdf (accessed March 26, 2024).

4 Nicole Karlis, "Electric cars are still better for the environment. But lithium mining has some problems" *Salon*, June 17, 2019. https://www.salon.com/2019/06/17/lithium-mining-for-green-electric-cars-is-leaving-a-stain-on-the-planet.

5 Mitch Jacoby, "It's time to get serious about recycling lithium-ion batteries," *Chemical & Engineering News*, Volume 97, Issue 28, July 14, 2019, https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28 (accessed March 26, 2024).

6 "Lead Vs. Lithium Battery Recycling," *Waste Advantage Magazine*, July 18, 2018, https://wasteadvantagemag.com/lead-vs-lithium-battery-recycling.

7 Mitch Jacoby, "It's time to get serious about recycling lithium-ion batteries," *Chemical & Engineering News*, Volume 97, Issue 28, July 14, 2019, https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28.

8 Leigh Hopper, "Lead contamination found in baby teeth of children living near Exide battery plant," *USC News*, May 6, 2019, https://news.usc.edu/156523/lead-in-baby-teeth-exide-battery-plant.

9 "Lead Vs. Lithium Battery Recycling," *Waste Advantage Magazine*, July 18, 2018, https://wasteadvantagemag.com/lead-vs-lithium-battery-recycling.

10 Mitch Jacoby, "It's time to get serious about recycling lithium-ion batteries," *Chemical & Engineering News*, Volume 97, Issue 28, July 14, 2019, https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28.

11 Kelly Pickerel, "The importance of recycling batteries on solar projects," *Solar Power World*, October 24, 2019, https://www.solarpowerworldonline.com/2019/10/a-qa-on-battery-recycling.

12 DOE Invests $2 Million to Advance Li-Ion Battery Recycling and Remanufacturing Technologies", *Advanced Materials & Manufacturing Technologies Office*, June 7, 2023, https://www.energy.gov/eere/ammto/articles/doe-invests-2-million-advance-li-ion-battery-recycling-and-remanufacturing.

13 Mitch Jacoby, "LG Energy Solution partners with battery recycling branch in Australia," *TESLARATI*, March 22, 2024, https://www.teslarati.com/lg-energy-solution-battery-recycling-australia.

14 To learn more about recycling and reusing EV batteries for stationary applications see Hauke Engel, Patrick Hertzke and Giulia Siccardo, "Second-life EV batteries: The newest value pool in energy storage," *McKinsey & Company*, April 30, 2019, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage.

15 "KIUC and Redwood Materials Sustainably Recycle Lithium-Ion Batteries," *Kaua'i Island Utility Cooperative*, November 7, 2023, https://www.kiuc.coop/kiuc-and-redwood-materials-sustainably-recycle-lithium-ion-batteries.

16 "One year update: Redwood's California EV Battery Recycling Program," *Redwood Materials*, March 2, 2023, https://www.redwoodmaterials.com/news/update-california-ev-battery-recycling-program.

17 Kavya Balaraman, "California project is second in US to employ used EV batteries to sell power to the grid: B2U," *Utility Dive*, November 14, 2023, https://www.utilitydive.com/news/b2u-california-project-used-honda-ev-batteries-energy-storage/699749.

18 Stephen Singer, "B2U reaches 25 MWh storage capacity at California facility with 1,300 used Honda and Nissan EV batteries," *Utility Dive*, Febuary 7, 2023, https://www.utilitydive.com/news/B2U-storage-solutions-ev-batteries-second-life/642107.

Conclusion

The economic, market, and regulatory landscape for solar+storage is constantly evolving. Since this guide was originally published in 2020, there have been significant shifts in the battery industry, changes to federal incentives, and rapid growth in solar+storage deployments. The answers presented in this release reflect these changes in the solar+storage landscape, which will continue to evolve in the coming years as solar+storage becomes an increasingly important piece of the clean energy transition. New opportunities and new challenges will inevitably prompt new questions in the future.

As the solar+storage landscape changes, Clean Energy Group will continue to provide updated information, through publications, webinars, tutorials, and periodic updates to this guide. New resources, along with numerous existing resources, will be made available through our website, at www.cleanegroup.org and www.resilient-power.org. We encourage organizations and individuals to reach out to us with any questions they may have about solar+storage.

2014–2023

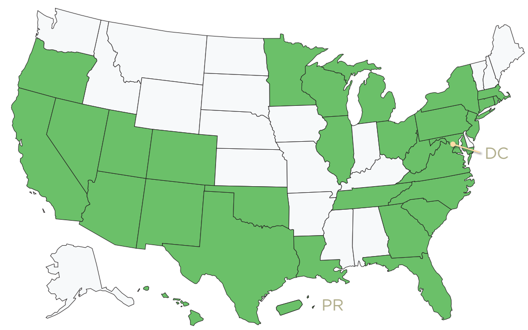
Resilient Power Funding Program Impacts

Clean Energy Group (CEG) established two small-grant programs, the Technical Assistance Fund (TAF) and the Resilient Power Leadership Initiative (RPLI), to improve a community's capacity to provide energy assurance, public safety, and better public health outcomes by advancing resilient power technologies—solar paired with battery storage (solar+storage). CEG's Resilient Power Funding Programs seek to expand local knowledge about clean energy and resilient power technologies and build expertise within community-based organizations on the benefits of solar+storage solutions. To date, the TAF and the RPLI have assisted over 150 communities across 32 states and territories in the US to learn more about resilient power and how solar+storage can serve their communities.

309 Community Facilities

Clean Energy Group's **Resilient Power Funding Programs** have advanced the exploration of resilient solar+storage for **309** community facilities in low-income and underserved communities across **32** states and US territories.

32 States and Territories

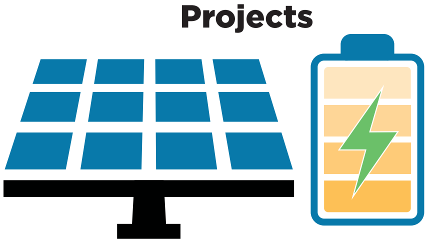


$1.7 million in Grant Awards

Awarded **167** technical assistance and capacity-building grants totaling **$1.7 million** to over **150** community-based organizations, municipalities, Native Nations, affordable housing, and community service providers working to advance resilient solar+storage in their communities.

Over 150 Community Service Partners

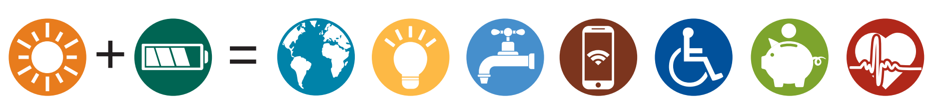
60 Completed Projects



These collaborations have resulted in **60** completed projects, including fire stations, health clinics, institutions of faith, resilience hubs, municipal facilities, and over **3,000** units of affordable housing.

3,000 Affordable Housing Units

CleanEnergyGroup



www.cleanegroup.org | TAF@cleanegroup.org

About the Authors

Marriele Robinson Mango

PROJECT DIRECTOR
marriele@cleanegroup.org

Marriele Mango is a project director for Clean Energy Group (CEG), where she leads CEG's efforts advocating for resilient power as essential to public health and emergency response. She also manages technical assistance and capacity building programs to support critical service providers and community-based organizations in their efforts to develop resilient power projects that benefit historically marginalized communities. Marriele has experience in disaster management with the Marion County Emergency Management Office in Salem, OR, where she focused on developing clean energy strategies for mitigation and emergency response initiatives. Prior to her work in Oregon, she served as Project Coordinator for a nonprofit energy efficiency program aimed at assisting low-wealth communities and faith-based institutions on Long Island. She has over 15 years' experience in clean energy advocacy, policy, and program implementation and holds a M.S. in Environmental Policy and Sustainability Management from The New School.

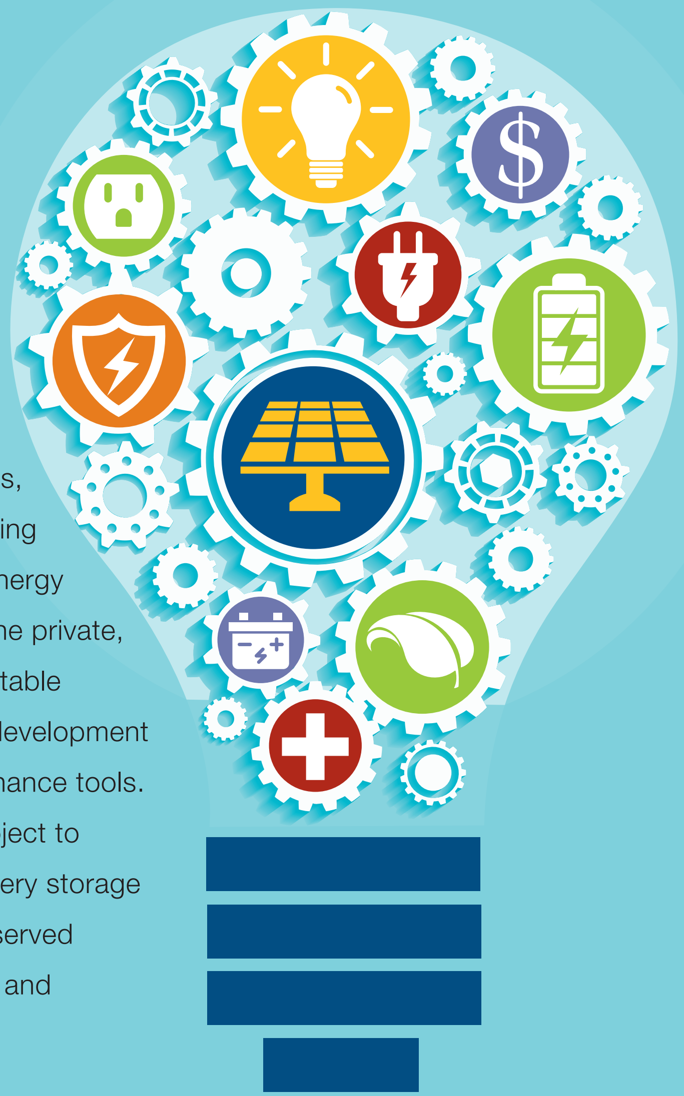
Seth Mullendore

PRESIDENT AND EXECUTIVE DIRECTOR, CLEAN ENERGY GROUP
seth@cleanegroup.org

Seth Mullendore is president and executive director of CEG, where he oversees the organization's mission to advance energy justice and catalyze innovative energy strategies to address the climate crisis. He previously served as vice president and a project director for CEG. In those roles, he led efforts to expand access to the benefits of solar PV and battery storage technologies for low-income communities and communities of color and worked with community-based partners to replace polluting power plants with clean alternatives. Prior to joining CEG, Seth served as a Sustainable Energy Fellow with Union of Concerned Scientists and worked with Maine Clean Communities to advance clean transportation initiatives. Seth holds a M.S. in Civil & Environmental Engineering from Stanford University and a B.S. in Geosciences from the University of Southern Maine.

About Clean Energy Group

Clean Energy Group (CEG) is a national nonprofit that works to accelerate an equitable and inclusive transition to a resilient, sustainable, clean energy future. CEG fills a critical resource gap by advancing new energy initiatives and serving as a trusted source of technical expertise and independent analysis in support of communities, nonprofit advocates, and government leaders working on the frontlines of climate change and the clean energy transition. CEG collaborates with partners across the private, public, and nonprofit sectors to accelerate the equitable deployment of clean energy technologies and the development of inclusive clean energy programs, policies, and finance tools. CEG created and manages the Resilient Power Project to accelerate access to the benefits solar PV and battery storage technologies in historically marginalized and underserved communities. Learn more at *www.cleanegroup.org* and *www.resilient-power.org*.



CleanEnergyGroup

50 State Street, Suite 1, Montpelier, VT 05602

802.223.2554 | info@cleanegroup.org | www.cleanegroup.org