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2020_11_04 for recent diesel backup generation plant designs_Clean Energy Group's, Understanding Solar + Storage

2020_11_04 for recent diesel backup generation plant designs_Clean Energy Group's, Understanding Solar + Storage

Many Small Power Plant Exemptions, SPPEs, have been recently submitted to the California Energy Commission, CEC, with diesel backup generation - Sequoia 2019-SPPE-03, Mission College 2019-SPPE-05, Walsh 2019-SPPE-02, San Jose Data Center 2019-SPPE-04, Laurelwood 2019-SPPE-01, Lafayette 2019-SPPE-02, Great Oaks South 2020-SPPE-01. These new SPPEs, which may entirely be new data centers, are mostly concentrated in the Silicon Valley, Santa Clara County. This area had usually been considered a more innovative, high technology part of California. Parts of the Santa Clara county appear harsh and industrial.

Diesel backup generation also seems more prevalent in the utility system, i.e., Pacific Gas and Electric, and at customer properties, due to more frequent, somewhat planned, outage processes, e.g., Public Safety Power Shutoffs, 2019-2020.

To an outside stakeholder, i.e., myself, hardly involved in such construction designs or CEC work, the newly submitted SPPE designs seemed counter-productive to reduction of bad California emissions. The goal for more clean energy seemed well recognized and talked about in CEC business meetings since 2017, and probably long beforehand. Diesel generation also has been noisy. Diesel using people might want to be indoors more for quiet, better air and to avoid their own emissions. Cumulative emissions might be disastrous for public health, if many of these diesel backup generators operate during an â€œemergency,â€□ especially a wildfire emergency. I learned SPPE processes do not have easy ways of rejecting submissions due to design choice alone, including choices of older diesel Tier 1-3 engine types.

I worked as a designer for the Sacramento Municipal Utility District (SMUD). I know it is difficult to change design processes due to many reasons. Sometimes particular patterns are well established and new ways to design are hampered by lack of an obvious path. Because of this problem, it seems wise to share this recent resource, a â€œUnderstanding Solar + Storageâ€□ report by the Clean Energy Group. This report might lend advice and ideas to those who were no longer certain that reliable new backup generation with clean energy was available/ready, due to the many recent California SPPE submissions which primarily utilize diesel.

NOTE: This report has a significant disclaimer on page 2. I have had no affiliation with the authors until recently when signed up for Clean Energy Group social media, and sent â€œthank youâ€□ comments.

Understanding Solar+Storage

Answers to Commonly Asked Questions About Solar PV and Battery Storage

CleanEnergyGroup

About this Report

Understanding Solar+Storage provides information and guidance to address some of the most commonly asked questions about pairing solar photovoltaic systems with battery storage technologies (solar+storage). Topics included in the guide range from factors to consider when designing a solar+storage system, battery sizing, safety and environmental considerations, and how to value solar+storage. The guide is organized into 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 the Resilient Power Project (www.resilient-power.org), a joint project of Clean Energy Group and Meridian Institute. The Resilient Power Project works to accelerate market development of *resilient, clean energy solutions* in low-income and underserved communities to further clean energy equity by ensuring that all communities have access to the economic, health, and resiliency benefits that solar+storage can provide. The Resilient Power Project is supported by The JPB Foundation, The Kresge Foundation, Surdna Foundation, Nathan Cummings Foundation, The New York Community Trust, Barr Foundation, and Merck Family Fund.

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This report can be found on the Clean Energy Group website at https://www.cleanegroup.org/ceg-resources/resource/understanding-solar-storage.

Understanding Solar+Storage

Answers to Commonly Asked Questions About Solar PV and Battery Storage

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CLEAN ENERGY GROUP

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CleanEnergyGroup

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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.

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, utility-side systems, which are located directly on the utility distribution system.

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 most important to maintain power to during a grid outage. Critical loads will vary depending on facility types and customer needs. Examples of common critical loads include emergency lighting, outlets for charging 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 grid electricity usage during times of high onsite demand.

DEMAND RESPONSE: Lowering consumption of grid electricity, either through discharging stored energy or lowering the use of devices, 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.

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.

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: A network that delivers electricity from producers to consumers. Utilities typically operate the 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, balance 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 a distributed generation system, such as solar PV and battery storage, to the grid. Utilities will oftentimes mandate an interconnection review in order 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 is a measure of power. One kilowatt is equal to 1,000 watts.

KILOWATT-HOUR: A kilowatt-hour is a measure of how much energy is used. 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.

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 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 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. The power rating of a battery is typically given in kilowatts, or megawatts for larger battery 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.

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 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.

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 RATES: An electric tariff structure used by some utilities that charges different rates for electricity 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: The aggregation of many, hundreds or even thousands, smaller behind-the-meter distributed energy resources (e.g., solar PV and battery storage) for the purposes of providing grid scale energy services that would normally be served by a utility-scale installation.

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

Many of the definitions used here are from Clean Energy Group's 2015 report, *Energy Storage and Electricity Markets*, which can be found here: https://www.cleanegroup.org/wp-content/uploads/Energy-Storage-And-Electricity-Markets-August-2015.pdf. The definition of community solar is defined in a report by the Clean Energy States Alliance, found here: https://www.cesa.org/wp-content/uploads/Consumer-Protection-for-Community-Solar.pdf.

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) are operating in 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, despite being a decades-old technology combination and expanding adoption rates.

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

By addressing commonly asked questions about solar+storage technologies, 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 knowledge and 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 one hundred stakeholders who submitted questions they had about solar+storage. The guide is organized into 12 common questions, each addressing multiple key topics. The answers were informed by more than six years of experience through CEG's work with property owners, developers, nonprofits, and communities to advance solar+storage in 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. **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

3. **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

4. **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, solar-only, storage-only)

5. **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

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

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

8. **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

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

This paper answers questions about the design, installation, and economics of solar and battery storage for homes and businesses. 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?” 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. **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, project examples benefiting from grant support, discussion of financing options

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

11. **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

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)

In addition to the information contained in this report, 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 Toolkit, available at www.cleanegroup.org/ceg-projects/resilient-power-project/toolkit.

Solar and battery storage installation completed at a fire station in Humacao, Puerto Rico in early October 2020.

Courtesy of Solar Responders

Why solar+storage?

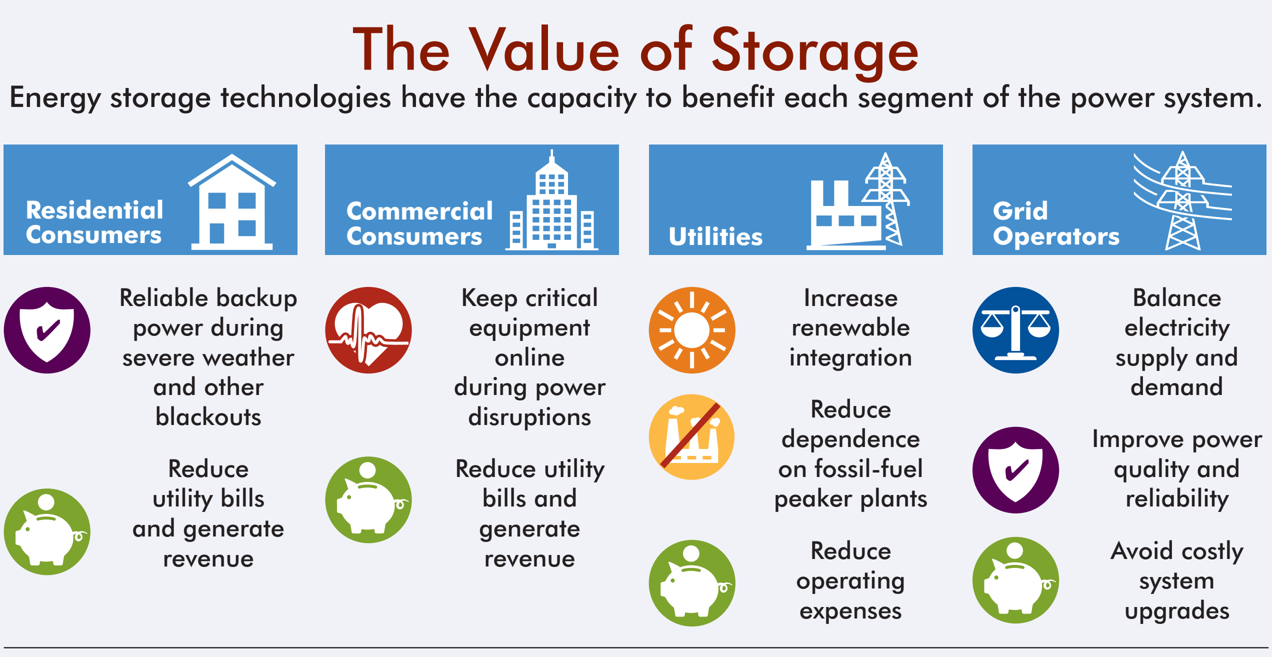
More than two million solar projects have been installed in the US, the vast majority of which do not include any form of energy storage. So why focus on solar+storage now?

There are many reasons why battery storage is increasingly being incorporated into solar PV systems. 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 among commercial properties; while solar can intermittently reduce demand for electricity from the power grid during the day, only storage can reliably provide electricity during specific periods of peak energy demand.

Beyond these customer-specific needs for energy storage, the grid will require significant amounts of storage to ultimately achieve the critical goal of providing electricity with zero emissions. As more and more solar systems are connected to the grid, essentially producing energy all at the same time, that energy will increasingly need to be stored and its use shifted to periods of the day when solar panels are not producing electricity. Utility rates and grid services programs are already shifting to recognize this evolution of the energy system, with peak energy pricing periods moving to mornings and evenings, and utilities creating new demand response programs to target periods of peak electricity demand.

Battery storage systems can also be installed without an accompanying solar system. Batteries can be charged from the grid to provide hours or even days of backup power, depending on the size of the battery system relative to the electrical loads being supported by it. The economic benefits of batteries are typically not dependent on being connected to a solar system either, though the two technologies are often paired to take advantage of federal investment tax credits, which are not currently available for storage-only projects.

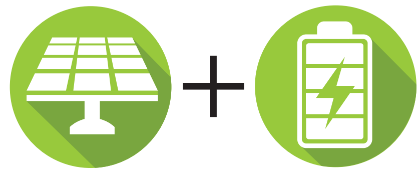
While solar and storage can each deliver valuable benefits to customers and the power grid, the combination of the two technologies can result in value above and beyond the sum of their individual benefits. Combined benefits include the ability to provide backup power throughout extended power outages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



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.12.)

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.

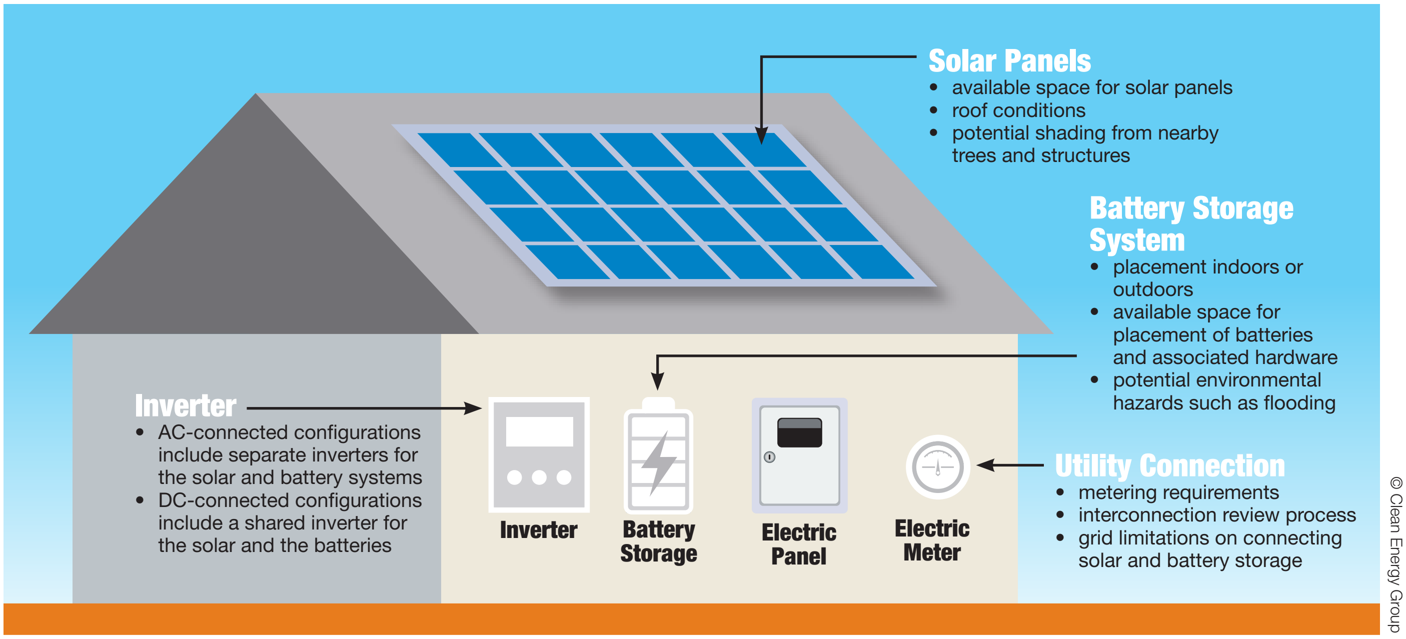
BATTERY PLACEMENT: Is the battery system going to be placed indoors or outdoors? How much suitable space is available to install a battery system and associated hardware? Can the system be insulated from any potential environmental hazards such as flooding?

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 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 addressing all types of battery system technologies, which could result in permitting delays.

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

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 these factors can impact the cost and feasibility of a planned installation.

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 that intend 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 metering may be required by the utility in order to track and verify that only solar energy is receiving 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 by increasing the amount of solar directly consumed onsite, thereby limiting or even eliminating solar exports to the grid.

INCENTIVES: Another important financial factor for solar+storage economics is the availability of incentives, particularly tax incentives such as the federal investment tax credit (ITC). Federal guidance has indicated that the ITC can be applied to the storage portion of a solar+storage system, but only if the batteries are predominately charged by onsite solar (or only charged by solar, in the case of residential solar+storage). If the ITC is key to making the economics of a project work, it may be worth considering a system configuration that ensures the battery is only charged with energy from onsite solar. For more on tax credits and financing, see *Question 9: 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 is often 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 directly passed 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 by onsite solar when the systems are DC coupled, which is important to qualify for the ITC and some net metering programs.

In AC coupling, the solar and storage systems are more independent from one another. Both systems will have a separate inverter, one to convert solar to AC and one to convert stored energy from the battery to AC when discharging energy, and to convert 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 to take advantage of the solar inverter already in place; this is a cheaper option than rewiring the system for a DC connection behind a shared inverter. There are some 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 from solar. 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. 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 5: Can storage be added to an existing solar system?*

Resilience

Designing a solar+storage system to provide energy resilience during a power outage adds a number of 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 devices are considered "non-critical."

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

Courtesy of Clean Energy Group

A key consideration is how difficult would it be to isolate those essential devices (or "loads") from non-critical loads, assuming the entire building won't need to be powered. If the site already has an existing 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 sense of the power and energy needs of critical devices can provide a sense of needed system sizing and help determine if the resilience goals of the project can be feasibly met by solar+storage alone, or if other forms of onsite generation, such as combined heat and power and traditional backup generators, should be considered.

Another factor in resilient systems is the need to withstand extreme weather conditions, whether in the form of hurricane 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 and have sufficient anchoring 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 4: 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.

For community solar projects paired with storage to realize additional revenue generation, a compensation structure must be developed 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 beginning to be paired with battery storage. For community solar projects paired with storage to realize additional revenue generation, a compensation structure must be developed to define how any storage-related revenues, such as payments for providing services to the grid, will be shared among subscribers.[3] 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.[4]

MULTIFAMILY HOUSING: Solar for multifamily housing is sometimes 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/or resilience or, less commonly, configured as multiple smaller battery systems providing benefits directly to individual units.[5]

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.

Q1 ENDNOTES

1 Federal Emergency Management Agency, "Rooftop Solar Panel Attachment: Design, Installation, and Maintenance," Recovery Advisory 5, April 2018, Revised August 2018, https://www.fema.gov/media-library-data/1535554011182-e061c2804fab7556ec848ffc091d6487/USVI-RA5RooftopSolarPanelAttachment_finalv3_508.pdf.

2 U.S. Department of Energy, "Distributed Energy Resources Disaster Matrix," DER Disaster Impacts Issue Brief, *Better Buildings Solution Center*, https://betterbuildingsinitiative.energy.gov/sites/default/files/attachments/DER_Disaster_Impacts_Issue%20Brief.pdf (accessed October 5, 2020). For more information about designing solar system to withstand hurricane weather conditions, see Laurie Stone, Christopher Burgess and Justin Locke, "Solar Under Storm for Policymakers," *Rocky Mountain Institute*, 2020, https://rmi.org/insight/solar-under-storm.

3 Kelsey Misbrener, "Clearway completes two community solar + storage projects in Massachusetts," *Solar Power World*, June 9, 2020, https://www.solarpowerworldonline.com/2020/06/clearway-completes-two-community-solar-storage-projects-massachusetts.

4 Clean Energy Group, "Featured Resilient Power Installations: Maycroft Apartments," *Clean Energy Group*, https://www.cleanegroup.org/ceg-projects/resilient-power-project/featured-installations/maycroft-apartments (accessed September 4, 2020).

5 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

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.

Currently, 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. 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

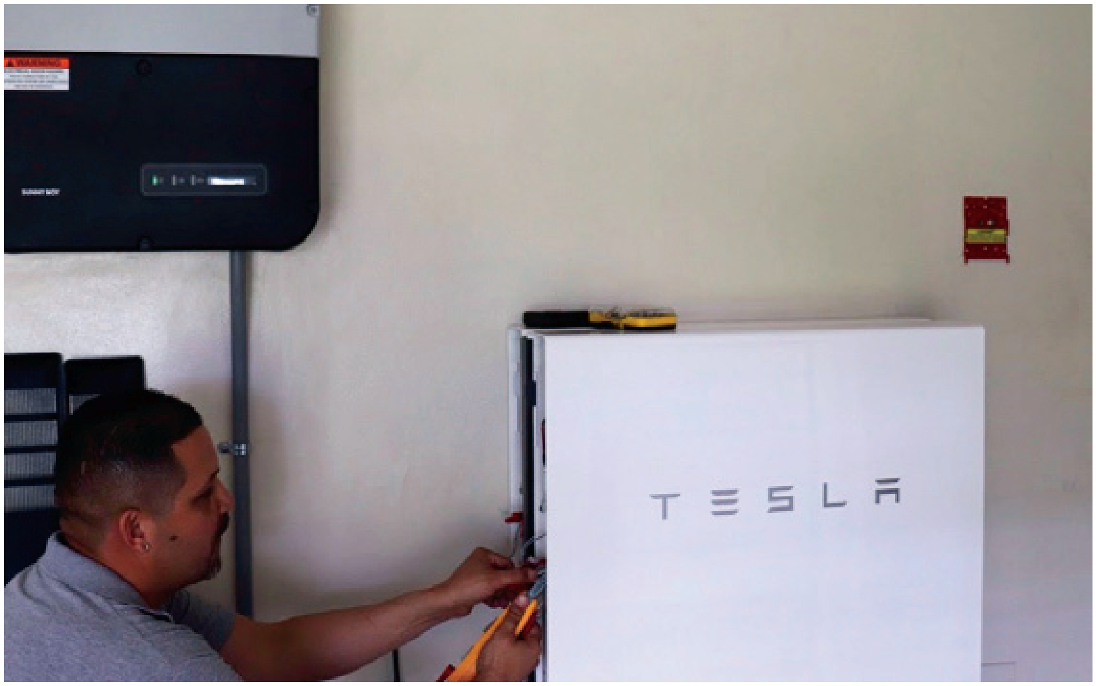
Lead acid batteries are largely a known commodity. They've been around for more than a century and have been the go-to technology choice for off-grid solar systems for decades. Unlike the lead acid batteries found in most cars, lead acid batteries best suited for use with solar systems are designed to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

Sealed lead acid batteries (also known as valve regulated lead acid batteries) are the most common type being installed with solar today, as opposed to flooded lead acid batteries that require regular monitoring and maintenance. Within sealed lead acid batteries, there are different technologies, such as absorbent glass mat (AGM) batteries, which some companies are marketing 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. In recent years, lithium-ion batteries have dominated the stationary storage industry, at times representing upwards of 99 percent of battery deployments in a given period.[1]



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

Courtesy of Hunter Johansson, Solar Responders

Several different battery chemistries fall under the umbrella term of lithium-ion. The two most common varieties are Lithium Nickel Manganese Cobalt Oxide (NMC) and Lithium Iron Phosphate (LFP). NMC batteries, found in Tesla and LG Chem battery systems, are more common and generally have lower upfront costs. However, NMC batteries may have greater safety concerns due to the threat of "thermal runaway," a chemical reaction that can cause a battery to overheat and catch fire. See *Question 11: Is battery storage safe?* To date, there have been no known cases of behind-the-meter batteries catching fire due to thermal runaway in the U.S., but the issue is still worth noting. LFP batteries, found in systems from battery manufacturers sonnen and SimpliPhi, currently have higher upfront costs but come with some advantages, such as greater cycling life (more charging and discharging) and increased safety, compared to 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 Q2 Figure 1, p. 20).

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. So, a battery with a higher energy density—able to store more energy per weight—will tend to take up less space than a battery with a lower energy density. Lead acid batteries have a lower energy density than lithium-ion batteries, so to achieve the same energy capacity, a lead acid battery system will be heavier and take up more space than a lithium-ion system.

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, and many lead acid battery owners maintain their batteries at 20 percent to 30 percent of capacity to increase battery cycle life and maintain battery health. Discharging a lead acid battery below

50 percent capacity 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 10 kilowatt-hours. For lithium-ion batteries, DOD is often in the 80 to 100 percent range. Because lithium-ion batteries have a much higher DOD rating, a lithium-ion battery's usable energy storage capacity could be two times 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 the chemistry. Lithium-ion batteries will last from 2,000 to 10,000 cycles (e.g., Tesla NMC guarantees 3,000 cycles, sonnen LFP 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 and calendar years. Lithium-ion warranties are typically 10 years, while lead acid battery warranties often range from two to five years. See *Question 6: 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.

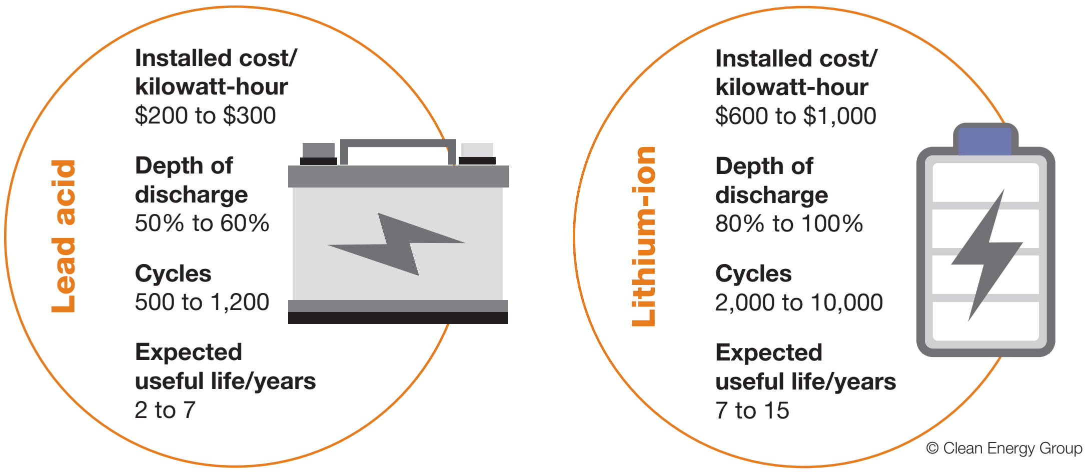
Other Options

Lithium-ion and lead acid very much dominate the solar+storage market today, but there are other storage options. Some of the top alternative contenders include flow batteries (longer duration,

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

Courtesy of SimpliPhi Power

Q2 FIGURE 1: **Lead acid versus lithium-ion battery systems**



few safety issues, no performance degradation); sodium-sulfur batteries (viable alternative for large-scale projects); and zinc-air (high energy density, abundant materials). Then there are more novel large-scale alternatives, like compressed air storage and gravity energy storage, where trains or giant bricks are hoisted up to store energy and lowered down to generate energy.

However, none of these technologies have been able to achieve the same economies of scale and price declines as the success of 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

Q2 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) define the battery's end of life at 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 consider the battery's useful life as when the system has reached 70 percent or even 60 percent of its original rated capacity.

QUESTION 3

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, it's important to understand that batteries have two key characteristics to consider: **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. The power rating of a battery is typically given in kilowatts, or megawatts for larger battery 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 x 15 watts = 3,000 watts), or 3 kilowatts.

A battery system's *energy capacity* represents the total amount of energy the battery can store or discharge over time. 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). Sometimes the energy capacity of a battery is represented by the amount of time the battery can 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.

The process of figuring out the most suitable battery storage system size for a project is dependent on how the system will be used over time.

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 are lower than the maximum power rating of the system, it will last longer. If only 2 kilowatts of power are needed to keep the lights on, a 12-kilowatt-hour system could keep the lights powered for six hours. If it only took 1 kilowatt to keep the lights on, the battery system could keep the lights powered for 12 hours.

How to Size a Battery System?

The process of figuring out the most suitable battery storage system size for a project is dependent on how the system will be used over time. This is because sizing a system for managing energy demand or maximizing solar self-consumption is a very different process from sizing a battery system to provide backup power.

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**.

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

Courtesy of sonnen

BACKUP POWER: Energy resilience is the primary goal of most residential battery storage projects, and an increasing number of commercial projects as well. 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 selected 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. That will ensure the battery is sized with a high enough power rating to handle a worst-case scenario when all loads are running at maximum power at the same time.

The duration/energy capacity of the battery system can be determined by multiplying the average power needs of critical loads over a specified time. For example, if the maximum power draw for a set of loads is 60 kilowatts and the average power draw is 20 kilowatts, a battery sized to keep loads running for six hours would be a 60-kilowatt/120-kilowatt-hour battery. The availability of solar power to offset some of the critical loads or recharge the battery system can increase 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 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 4: Is solar+storage an effective backup power solution?*

DEMAND MANAGEMENT: Demand charge management continues to be one of the main drivers for commercial customers installing battery storage. Customers with a demand charge component on their electric bills—common for commercial customers and rare for residential customers—

are charged based on the maximum rate at which they are consuming 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 (during times of high demand for electricity), or during times when demand charge prices are highest (during times of peak demand for the utility). This process of using storage for lowering 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 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 power to energy capacity can effectively reduce demand spikes.

SOLAR SELF-CONSUMPTION: There are a variety of reasons why it may be in the best economic interest of a property owner to maximize the amount of solar energy directly consumed onsite and minimize the amount of solar generation that is sent to the grid. Under certain solar policies, solar credits for exported energy may be worth significantly less than the bill savings achieved through directly offsetting grid electricity consumption. In other cases, solar exports to the grid may not be allowed at all, so any generation greater than the amount of electricity being used directly by the property 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 then be used later when solar generation is lower or nonexistent.

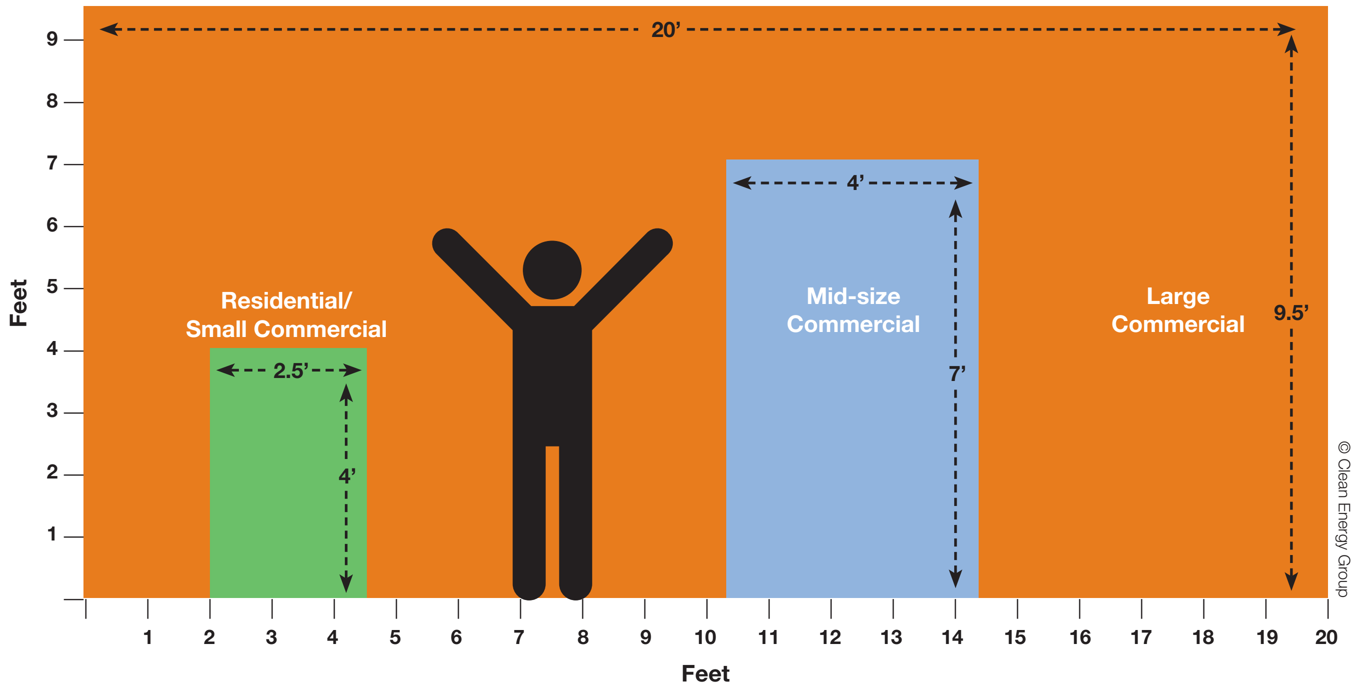
To maximize solar self-consumption, a battery system should be sized to capture as much excess solar generation as possible. This stored energy can then be used later when solar generation is lower or nonexistent. The power rating of the storage system should be enough to cost-effectively capture solar 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 to store solar that would otherwise be exported or curtailed. Storage system sizing would be a similar process for *solar time-shifting*, 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. System sizing 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 for a project is how much space is physically available to install a battery. This is particularly important when possible battery siting locations will be limited within the footprint of an existing property where available space may be constrained, whether indoors or outdoors.

Q3 FIGURE 1: **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).

Q3 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 SAGM 12 105[a]	0.5	1.3	0.8	0.6	1.1	0.5
Residential lead acid	Trojan SAGM 12 105 (12)	6	15	3.8	2.2	1.1	9
Residential lithium-ion	SimphliPhi AmpliPHI[b]	1.9	3.8	1.2	1.1	0.7	0.9
Residential lithium-ion	sonnen eco 8.2/16[c]	2	16	6	2	0.7	8
Residential lithium-ion	Tesla Powerwall 2.0[d]	5	14	4	2.5	0.5	5
Residential lithium-ion	Blue Ion[e]	8	16	3.5	2	2	14
Commercial lithium-ion	Samsung SDI E3-R256[f]	128	256	9	3	2.5	68
Commercial lithium-ion	Tesla Powerpack[g]	130	232	7	4	3	84
Large-scale lithium-ion	GE Reservoir Storage Unit 4000[h]	1,300	4,184	9.5	8	20	1,520

a "SOLAR SAGM 12 105 Data Sheet." *Trojan Battery Company.* 2019. *https://www.trojanbattery.com/pdf/SAGM_12_105_AGM_DS.pdf*.

b "AmpliPHI 3.8™ BATTERY Data Sheet." *SimpliPhi Power, Inc. https://simpliphipower.com/wp-content/uploads/documentation/ampliphi-series/simpliphi-power-ampliphi-3-8-kwh-100-amp-specification-sheet.pdf*. Accessed September 9, 2020.

c "Technical Data SonnenBatterie Data Sheet." *Sonnen. https://sonnenbatterie.de/sites/default/files/161018_datasheet_sonnenbatterie.pdf*. Accessed September 3, 2020.

d "PowerWall Data Sheet." *Tesla.* June 11, 2019. *https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall%202_AC_Datasheet_en_northamerica.pdf*.

e "Blue Ion 2.0 Energy Storage System Data Sheet." *Blue Planet Energy. https://blueplanetenergy.com/pdfs/Blue_Ion_2.0_datasheet_Nov2019_DIGITAL.pdf*. Accessed September 3, 2020.

f "ESS Batteries by Samsung SDI." *Samsung SDI. https://www.samsungsdi.com/upload/ess_brochure/201902_Samsung%20SDI%20ESS_EN.pdf*. Accessed September 9, 2020.

g "Powerpack: Utility and Business Energy Storage." *Tesla. https://www.tesla.com/powerpack*. Accessed September 3, 2020.

h "GE Energy Storage Unit RSU-4000." *GE Renewable Energy. https://www.ge.com/renewableenergy/sites/default/files/related_documents/RSU-4000_Data%20sheet_0.pdf*. Accessed September 9, 2020.

Different battery storage products have varying space requirements. In general, residential and small commercial lithium-ion battery systems have a similar footprint as a dormitory refrigerator or very thin full-sized refrigerator. Larger commercial lithium-ion battery systems tend to be around the size of a large refrigerator, depending on their energy capacity. Larger, megawatt-scale battery systems, and their associated components, are often housed in 20-foot or 40-foot shipping containers. (See Q3 Figure 1.) Lead acid systems tend to take up more space—with a typical lead acid battery of around one kilowatt-hour taking up about the same space as a shoebox—resulting in a full battery system requiring 20 percent to 50 percent or more space than a comparable lithium-ion battery system. (See Q3 Table 1.)

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.

Q3 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 covert 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 4

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, solar-only, storage-only)**

In many cases, a solar+storage system may be very well suited for 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?

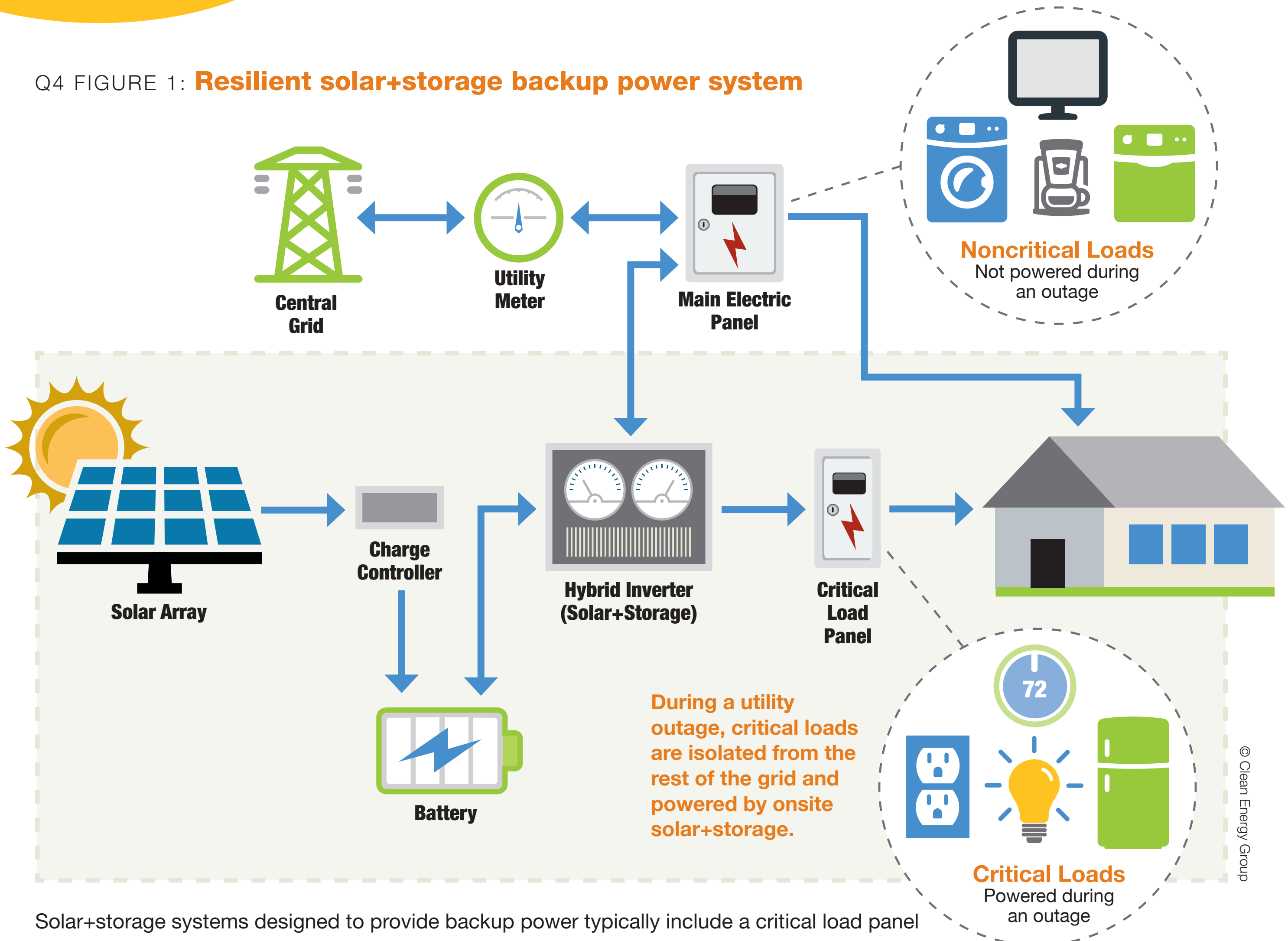
It is often not practical to design a solar+storage backup system with the goal of powering all of a building's electrical loads during a grid outage, though it is possible to do so. The barrier is more of an economic issue than a technical one. Though batteries continue to decline in price, they are still expensive technologies. Because of this, solar+storage systems installed for backup power are typically tied into a critical load panel, which includes only loads that need to be powered during an outage.

It is often not practical to design a solar+storage backup system with the goal of powering all of a building's electrical loads during a grid outage, though it is possible to do so. The barrier is more of an economic issue than a technical one.

While a solar+storage system can help to power all electrical loads when the grid is running normally, systems are typically designed to power only designated critical loads when the grid is down. (See Q4 Figure 1.) In most cases, the system can switch between grid power and backup power automatically, a nearly instantaneous process. Loads can also be manually switched on and off, and there are even new generations of 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 the following devices: lighting, fans, well pumps, and outlets to power plug-in loads such as refrigerators, heating and cooling devices, computers, modems and routers, phone charging, 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 types of high-power loads may be more cost-prohibitive for solar+storage to support alone.

Q4 FIGURE 1: **Resilient solar+storage backup power system**



Solar+storage systems designed to provide backup power typically include a critical load panel and a transfer switch to disconnect from the utility grid. The transfer switch is often 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 being 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 of time.

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 tapping into small solar+storage systems designed for backup power to reduce their operating costs or to replace fossil fuel power plants.[1] See *Question 8: 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 over time. 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. 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. This could occur during one major long-duration event like a hurricane, or with multiple, shorter outage events over the life of the systems.[2]

Though batteries do 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 do 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.[3] 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 11: 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, and regulatory requirements may dictate that certain critical loads must be backed up by traditional generators. In these cases, a hybrid solution combining solar, battery storage, and a 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,

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

reduce fuel consumption and emissions, and provide an additional layer of reliability for a subset of essential 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 USB 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. A few companies have even developed mobile solar+storage trailers, that can be deployed during emergencies to power large, building-scale loads.[4]

Solar without Storage

Some solar inverters allow you to continue powering a few devices when the grid goes down even without battery storage. Unlike the majority of inverters that will automatically shut off during an outage, these inverters offer one or two outlets to plug in devices. Of course, the devices will only be powered when there's enough solar available to support the load.

Multi-unit apartment building with solar panels in Vermont.

Courtesy of Clean Energy States Alliance

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 when depending on batteries without solar 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 critical for populations dependent on electricity for critical needs like medical devices or refrigeration for medicines.[5]

Q4 ENDNOTES

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QUESTION 5

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

The short answer is yes, 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 adding storage, depend on a few factors. The challenges and costs associated with adding storage to an existing solar array vary depending 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 potential barriers to retrofitting an existing solar system with battery storage have to do with 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 may prohibit the addition of storage or violate some portion of the financing agreement. 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: Another potential barrier may be warranty restrictions on existing solar equipment that could prevent the addition of storage. This is primarily a concern for older inverters that specify 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), projects looking to add storage should consult with developers and equipment vendors to ensure warranties will remain intact. For older equipment approaching the end of its useful life, 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 energy 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 New York, for example, battery storage is allowed under net metering if the system meets one of the following criteria: 1) the storage system shuts down when energy is being exported to the grid, 2) the storage system is only charged by solar (no grid charging), or 3) the storage system is only used as a source of backup power during grid outages.[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

Once it has been determined that 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. When a solar system is storage-ready, 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 Q5 Figure 1). 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 batteries, like the Tesla Powerwall 2, even 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, another important consideration is verifying that the existing solar inverters can communicate with the new battery-based inverter. Failure to communicate properly could create issues that prevent the

Residential LG Chem battery storage system.

Courtesy of Cinnamon Energy Systems

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.

DC-COUPLED RETROFIT: DC-coupling solar and storage results in better overall system efficiencies because of fewer AC/DC power conversions, but it can result in a more expensive retrofit to 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 costing more, a DC-coupled retrofit may also be more limiting in placement of the new inverter and battery system than AC-coupling 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. It's a good idea to check with your utility to understand the interconnection process for retrofitting your solar system with storage.

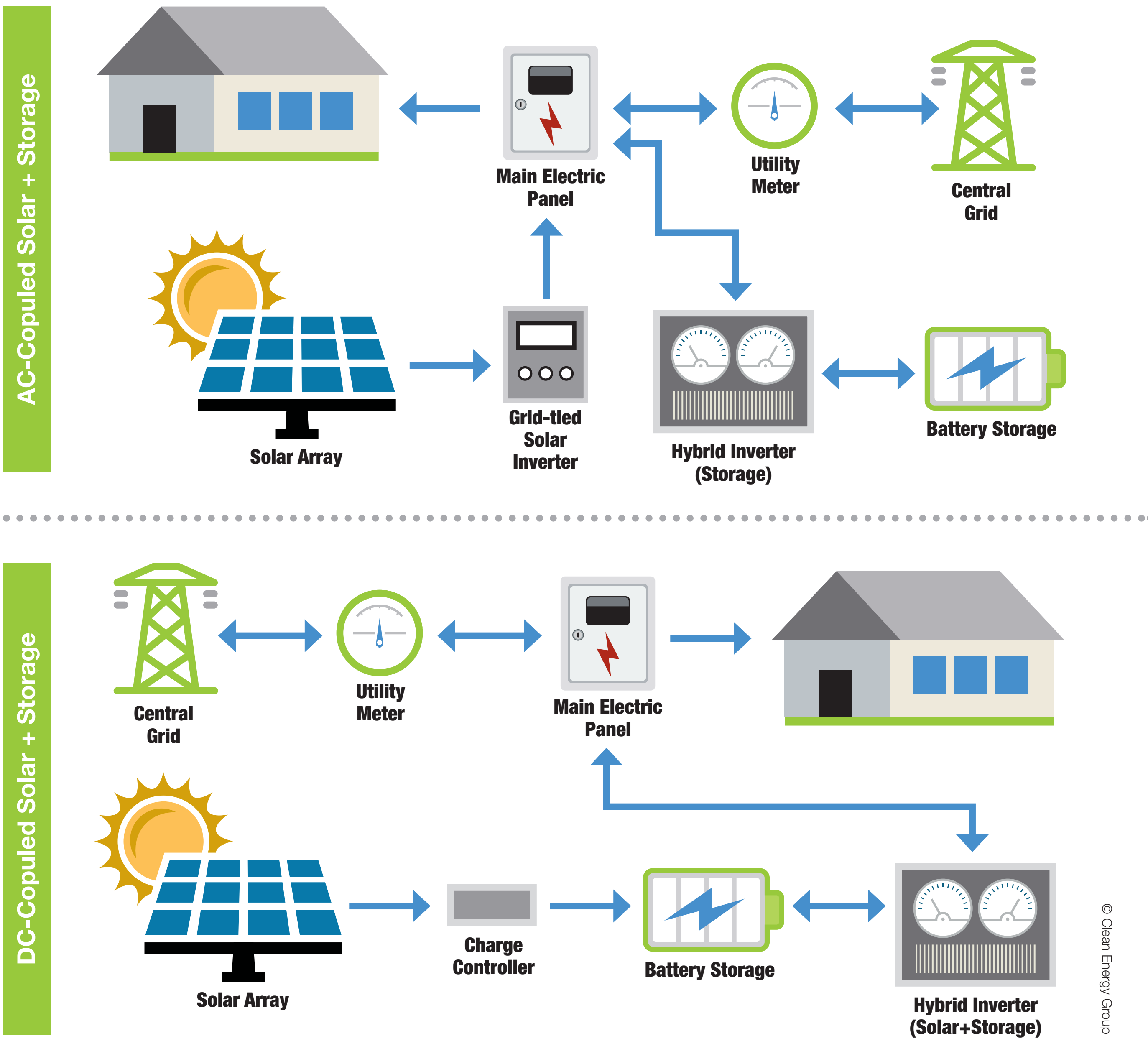
Making Solar "Storage Ready"

If you're installing a solar system now but aren't quite ready to add battery storage, it may be worth considering making your solar 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 designed as 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 hybrid 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's 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 4: Is solar+storage an effective backup power solution?*).[2]

Q5 FIGURE 1: **AC- and DC-coupled solar+storage**



Solar and energy storage systems can be integrated together through either AC- or DC-coupled configurations. The main difference between AC and DC coupling 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.

Q5 ENDNOTES

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2 Many hybrid, battery-based inverters include a built-in transfer switch.

QUESTION 6

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 Q6 Figure 1, p. 37.)

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

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Solar Panels

LIFESPAN: Solar panels degrade over time and produce less electricity. The annual rate of degradation is very small, with the industry average below 1 percent; some manufacturers have degradation rates under 0.5 percent per year.[1] Due to this degradation, most warranties guarantee product 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 in the following section.

WARRANTY: Solar panels have two different types of warranties: product and performance. The *product warranty* covers equipment (the solar panels) in the event there is a defect or equipment failure, such as a faulty panel. Most product warranties are 10 to 12 years, with only a few manufacturers providing up to 25 years of coverage.[2] However, even after the product warranty expires, panels may continue to operate. For instance, using a 1 percent degradation rate, a panel would still be able to produce 70 percent rated power after 30 years.

Luckily, solar panels are very durable, and most are tested to withstand harsh weather conditions like hail.[3] Solar panels can also withstand high windspeeds. After Hurricane Irma landed in North

Carolina in 2017, the local utility reported that two solar+storage systems installed at critical facilities (a fire station and communications tower) remained operational through the hurricane, despite widespread outages in neighboring communities.[4]

Whereas a product warranty focuses on equipment, a *performance warranty* guarantees solar panel electricity production, ensuring that solar panels maintain a level of electricity production for a certain amount of time. Most manufacturers guarantee solar panels at 90 percent production for the first 10 years, and 80 percent for up to 25 years; therefore, after 25 years of operation, the solar PV system will still produce at least 80 percent as much energy as when it was first installed.[5]

After 25 years of operation, most solar PV systems will still produce at least 80 percent as much energy as when they 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 section *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 up to 20 years. Microinverters have a longer lifespan between 20 to 25 years, similar to solar panels.[6]

WARRANTY: Inverter warrantees align with the anticipated lifespan of the inverter. String inverters have, on average, a 10-year warranty, and microinverters typically warranty up to 25 years. It's worth noting that a system that utilizes microinverters can be significantly more expensive than one that uses string inverters. For example, opting for microinverters on a 5-kilowatt residential system can increase the total system price by upwards of $1,000 when compared to the same system with a standard string inverter.[7]

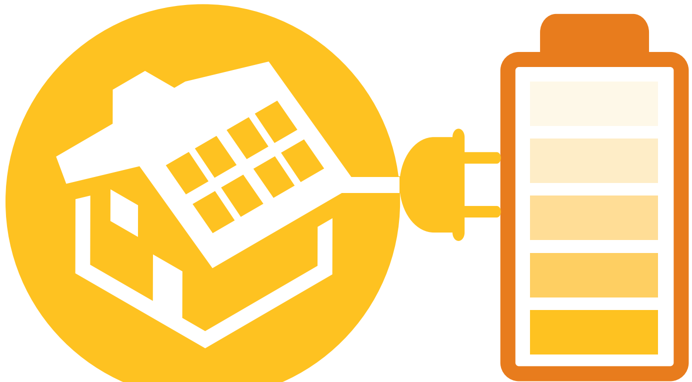
Battery Storage

While there are many types of battery storage, for the purposes of this guide we'll be reviewing two of the most common types: lithium-ion and lead acid.

LIFESPAN: The average useful life of a battery is five to 15 years.[8] This wide range is due to a multitude of factors, primarily battery chemistry, use, and maintenance. Lithium-ion batteries typically have a longer useful life because lithium-ion cycles more efficiently than lead acid batteries, averaging up to 10,000 lifetime cycles.[9] Comparatively, lead-acid batteries have a shorter lifespan with 500 to 1,200 lifetime cycles.[10] To learn more about the different types of batteries, see *Question 2: What different types of batteries are available (and which one is right for me)?*

For example, a lithium-ion battery used four 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 a lithium-ion battery that is used to maximize solar self-consumption, and therefore requires daily cycling. Batteries that are cycled frequently will degrade more quickly than batteries that are only used rarely, such as in the event of an outage.

Q6 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

© Clean Energy Group

WARRANTY: Similar to solar panel warranties, battery manufacturers provide two types of warranties: guaranteed operational years and guaranteed cycles (or warrantied energy throughput). As outlined in the lifespan sections of this guide, the useful life of a battery and how many times a battery can cycle in its lifetime depends on the battery chemistry. For lithium-ion, a warranty is typically for 10 operational years or up to 10,000 cycles. A warranty for a lead acid battery is usually between two to five operational years.[11]

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. Additionally, the battery installer will likely also provide some type of warranty for the work associated with the installation (such as electrical wiring).

Q6 ENDNOTES

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QUESTION 7

How much do batteries cost?

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

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

To make things a little bit simpler, this section is going to 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, more novel battery chemistries could also be an option, but they may not be practical at this time for many projects. For more on battery types, see *Question 2: What different types of batteries are available (and which one is right for me)?*

One of the reasons that questions about battery costs are not easy to answer is due to a lack of market transparency about how much batteries really do cost. Unlike solar, there's little public information available comparing battery storage system costs across technology types, manufacturers, system sizes, and locations. This is largely because the lithium-ion battery market for home and business applications is still relatively new, which means there's a lot of industry angling going on to gain market position as well as a lot of fluctuation in the price of systems. Also, a lot depends on how the system is configured for different uses; for example a short-duration, high-power battery system for 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.

Unlike solar, there's little public information available comparing battery storage system costs across technology types, manufacturers, system sizes, and locations.

The greatest level of transparency can be found in the residential battery storage market. Home storage systems are typically priced as standard product offerings, and some companies make it easy to access pricing information. For instance on Tesla's website, the company quotes a price of $6,500 for one 13.5-kilowatt-hour Tesla Powerwall, plus an additional $1,100 for supporting hardware, for a total equipment price of $7,600.[1] However, the equipment cost does not include any electrical upgrades, taxes, permitting fees, or other costs that are involved in installing a system, which could cost an additional $1,000 or so. All in all, the Tesla system should have a total installed cost of between $8,500 to $9,500, or about $650 per kilowatt-hour. (It is important to note that the per kilowatt-hour pricing of a battery system does not represent the cost of electricity discharged from the battery, known as the levelized cost of energy.)

Tesla tends to come in at the lower side of the cost spectrum for residential battery systems: a BrightBox home battery system from Sunrun reportedly costs in the range of $6,500 to $8,000 for 9.3 kilowatt-hours of storage, around $750 per kilowatt-hour.[2] A Pika Energy Harbor Smart Battery starts around $12,000 installed for 11.4 kilowatt-hours, or $1,050 per kilowatt-hour.[3] Lead acid batteries typically cost less, more in the $200-$300 per kilowatt-hour range for the battery and installation costs, but lead acid batteries don't last as long as lithium-ion systems, particularly when frequently charged and discharged.

While 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 gives 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; for example, when batteries are paired with solar panels, which typically have a much longer lifespan. (See *Question 6: How long does a solar+storage system last?*) Battery chemistry type, which could impact battery operation, safety considerations, and management system options (flexibility in what the system can do), is also significant to take into account when selecting a storage system.

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 $800 to $1,000 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

Another complexity in battery system pricing is understanding the difference between kilowatts and kilowatt-hours. Battery prices can be represented in either of these values. Expressing pricing in kilowatt-hours (energy capacity) instead of kilowatts (power rating) seems to have become more of a standard practice, but it's still common to see both used. The difference can be confusing, sometimes leading to misleading cost comparisons. For instance, a 10-kilowatt/40-kilowatt-hour battery priced at $2,000 per kilowatt may appear more expensive than a 10-kilowatt/10-kilowatt-hour battery that costs $1,000 per kilowatt, but the higher capacity 40-kilowatt-hour battery is a much better deal on a per kilowatt-hour basis—$500 per kilowatt-hour versus $1,000 per kilowatt-hour.

There can be major variations in installed costs depending on the complexity of an installation and local variations in permitting and interconnection processes. Battery system prices tend to be a constantly moving target.

So, what about the cost of larger battery systems? In general, the larger the system, the lower the relative per kilowatt-hour installed cost. Small commercial systems, between 10 to 50 kilowatt-hours in size, tend to fall in a similar range as residential storage systems, around $800 to $1,000 per kilowatt-hour. Larger-scale systems, between 100 kilowatt-hours to 500 kilowatt-hours, should cost a bit less, in the range of $600 to $800 per kilowatt-hour. Large-scale battery systems, getting into a megawatt-hour or more, can start to see installed costs of $600 per kilowatt-hour or less.

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 timeframe, but there can be major variations in installed costs depending on the complexity of an installation and local variations in permitting and interconnection processes. Battery system prices tend to be a constantly moving target.

This gets to another difficulty in pinning down the cost of batteries: they keep getting lower every year. The price of lithium-ion battery packs (not the full system cost) fell nearly 90 percent over the past decade, dropping from an average of $1,100 per kilowatt-hour in 2010 to $156 per kilowatt-hour in 2019. Analysts expect significant cost declines to continue over the next few years, approaching $100 per kilowatt-hour by 2023.[4]

Large-scale battery systems, like this 1.2-megawatt-hour system at the Marcus Garvey Apartments in Brooklyn, NY, often have installed costs of $600 per kilowatt-hour or less.

Courtesy of Demand Energy

Clearly, $156 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 battery storage system includes many additional components such as 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 increasingly larger portions of the total cost, often representing half to three-quarters of the full system cost. That's why battery system prices range from a few hundred dollars per kilowatt-hour to more than a thousand, instead of $156 per kilowatt-hour.

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 reductions in non-battery pack costs to represent the majority of system price declines in the coming years.[5] This path is similar to the evolution of solar cost declines, where the price of solar cells dropped rapidly over time, while total solar system costs fell more slowly, with solar cells representing a smaller and smaller fraction of the total installed cost.

Q7 ENDNOTES

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QUESTION 8

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

There are various metrics and considerations that can help to determine if a solar+storage system is a cost-effective, economically beneficial investment. Evaluating various value streams are important when calculating the economic viability of a project. This section focuses on understanding 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]

> **The other positive benefits of a solar+storage system can be harder to monetize (such as losses avoided by having backup power, and environmental and health benefits).**

In addition to straightforward financial benefits (like utility bill savings), the other positive benefits of a solar+storage system can be harder to monetize (such as losses avoided by having backup power during an outage, and environmental and health benefits). Other benefits should be taken into consideration when determining if a battery storage system is a worthwhile investment. This section explores the potential economic benefits of solar and battery storage, including an introduction to existing utility-led battery storage programs, and overviews of how to calculate whether a solar+storage project is economically viable.

Solar

The 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.** 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 net metering programs will see a credit on their electric bill indicating how much energy generated by their solar array was exported onto the grid and how much that electricity earned in bill credits. Net metering programs and the value of credits for excess generation vary widely depending on the state and utility program.[2]

- **Solar Renewable Energy Certificates (SRECs).** An SREC is basically a solar renewable energy credit. A solar system earns one SREC for every 1,000 killowatt-hours of electricity produced. Once a SREC is earned, the system owner can then 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 $7.50 per 1,000 kilowatt-hours. 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.[4] For utility customers with high demand charges (commercial customers are more likely to be subject to 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 can typically lower utility bills in two ways: 1) reducing demand-related charges and 2) energy arbitrage.
  - ***Demand charge management*** with batteries reduces a customer's demand-related utility charges by deploying stored energy during times when a lot of electricity is being used over a short time, 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]
  - Batteries can also lower utility bills through ***energy arbitrage*** by charging and discharging the batteries depending on pricing periods throughout the day. Energy arbitrage is the process of charging a battery during periods of low electricity pricing (off-peak) and then discharging (using energy stored in the battery) 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 on-peak and off-peak electricity rates, batteries used for energy arbitrage can be a worthwhile investment.
- **Generate revenue by providing utility services.** Batteries can provide useful services to the electricity grid. The most common types of utility programs available to compensate battery storage for grid services are demand response programs. The goal of a demand response program is to reduce electricity usage by utility customers during times of high ("peak") system-wide 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. Battery storage 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.[7]

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.

- **Generate revenue through providing grid services.** Batteries have the potential to provide many different valuable services to support operation of the power grid, however many of these values are currently not easy to monetize. One of the more common value streams available to battery storage is through charging and discharging in response to fluctuations in the grid, known as *frequency regulation.*[8]

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 provide separate and unique economic advantages on their own; but combined solar+storage systems could result in additional benefits, such as greater utility bill savings and access to tax incentives for both solar and battery storage. Furthermore, by installing solar PV 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).[10]

Harder to Monetize Benefits

Not all services are simple to put a price on. (See Box: *How to Value Solar+Storage Benefits,* p. 45.) Solar+storage has numerous benefits that don't have an obvious or easy-to-calculate value, including the following.

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.[11] 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.[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 their North Boulder headquarters. Their primary goal was to remain 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 that BHP considered when evaluating the benefits that solar+storage could add to their headquarter offices. 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/ceg-projects/resilient-power-project/featured-installations/boulder-housing-partners.

Montetizable 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.

Nonmontetizable 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

HEALTH: Solar+storage can improve public health outcomes in the event of an outage by providing critical community facilities and medical institutions with reliable emergency backup power, allowing service providers to remain open and operational to support communities through an outage. In addition to maintaining business operations, solar+storage at facilities 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. Furthermore, 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 generator" section of *Question 4: Is solar+storage an effective backup power solution?*

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.

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 energy 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.[13]

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) 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 instance, a commercial solar+storage system installed in a facility in Piqua, Ohio—where commercial demand charges are very high–was estimated to have a payback of less than eight years. In the Piqua case, including battery storage with the solar system reduced the entire system's payback period from 14 years (for a stand-alone solar system) to eight years.[14] 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.[15]

State and utility programs can provide monetary incentives to 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 Battery Storage Programs.*

Utility 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 hundreds, in some cases thousands, of smaller batteries throughout a region to use for grid-scale services, 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).[16] ConnectedSolutions is a utility-run battery storage program currently available in four states in the Northeast—Connecticut, New Hampshire, Massachusetts, and Rhode Island—and being considered by others.[17] ConnectedSolutions is unique in that it is funded through state energy efficiency budgets as a demand reduction measure, rather than as a separate clean energy initiative or utility demand response program. Through a five-year contract between the customer and their utility, ConnectedSolutions compensates battery storage owners that discharge their systems to reduce energy demand when called upon to do so by the utility. This saves the utility money by reducing its peak demand expenses. 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 National Grid territory in Massachusetts, the average residential customer participating in the program would have earned $1,375 for the year.[18] Massachusetts customers can also access incentives through the Solar Massachusetts Renewable Target (SMART) program, a program that both provides incentives for solar systems as well as additional incentives for systems that include battery storage. And they may be able to participate in the new Clean Peak Standard, a program that requires utilities to procure renewable energy for peak demand periods.

GREEN MOUNTAIN POWER (VT).[19] The utility Green Mountain Power (GMP) in Vermont has created a residential battery program that leases customers two Tesla Powerwalls for $55 per month, over 10 years (or one upfront payment of $5,500).[20] GMP also offers a Bring-Your-Own-Device (BYOD) program, which provides upfront payments to customers of $850 per kilowatt of storage.[21] The programs give GMP control over the batteries to reduce their operating costs, and the batteries are available to households for backup power during grid outages. After a 2019 winter storm, more than 400 Tesla Powerwalls maintained backup power for an average of 13 hours for customers experiencing outages throughout GMP's service territory.[22] In 2020, GMP reported saving $3 million in utility costs for all GMP customers by utilizing battery systems in its service territory during times of high regional demand for electricity.[23] Other utilities have launched similar battery storage programs, including utilities in New Hampshire, New York, and Oregon.

Solar+storage micro-grid 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

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 (i.e., not making an investment). Stand-alone storage can be compared to a combined solar+storage system, or to only solar PV. Gas or diesel generators, along with annual maintenance and fuel costs, would likely be factored in for projects considering alternative backup power technologies. Each option should be evaluated based on economic factors, such as installation costs, maintenance and operational costs, and payback, as well as non-monetary (or harder to monetize) benefits, such as reliability, environmental impacts, and avoided outage costs.

Q8 ENDNOTES

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QUESTION 9

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 price of solar and battery storage technologies has 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, there may be multiple sources of funding and financing to help pay for a solar+storage installation.

Incentive programs that carve-out funding for low-income populations ensure that the technologies are accessible to more communities.

Solar and Battery Storage Incentives

State, federal, and utility incentives help to drive solar+storage market development by lowering upfront costs and improving the system economics.[1] Incentive programs that carve-out funding for low-income populations go a step further in 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: When paired together, both solar PV and battery storage are eligible for the federal investment tax credit (ITC). Households and organizations that have enough taxable income are eligible for a 26 percent investment tax credit (otherwise referred to as the federal solar tax credit) to offset solar costs.[2] The tax incentive level was set at 30 percent for systems that began construction prior to the end of 2019, reduced to 26 percent in 2020, and it will reduce to 22 percent in 2021, before phasing out entirely for residential customers and reducing to 10 percent for commercial customers in 2022.

For storage to be eligible for the ITC, commercial battery systems must be primarily charged by onsite solar (at least 75 percent of the time). Residential battery systems must be entirely charged by solar to be eligible for the federal tax credit. There is currently no federal tax incentive for stand-alone storage projects or batteries not charged by onsite renewables.

STATE INCENTIVES: More states are beginning to offer battery storage incentives. New York's battery storage incentive provides customers (residential, industrial, and commercial) with a single up-front payment towards an energy storage project. Depending on the location of the proposed

The Sterling Municipal Light Department's battery storage system provides backup power to the town's police station.

Courtesy of Clean Energy States Alliance

project, incentives can vary between $125 and $350 per kilowatt-hour.[3] Over the two years that the program has been available, incentives have covered, on average, approximately 18 percent of project costs.[4]

In Maryland, the battery storage incentive is structured as a state tax credit. The Maryland Storage Tax Credit was the first of its kind in the country. The tax credit is for 30 percent of total system costs with a maximum award of $5,000. Tax credit certificates are issued on a first come, first served basis with separate funding allocated for residential and commercial projects. Some states also offer solar tax incentives. South Carolina and New York, for example, offer solar energy credits up to 25 percent of the system costs.[5]

LOW-INCOME INCENTIVES: Some 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, primarily 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 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).[6]

- **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.[7]

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

UTILITY INCENTIVES: Utilities are increasingly offering customers incentives and program opportunities to install battery storage systems. Utility programs typically provide customers with the benefit of low or reduced cost battery storage systems that can provide resilient backup power in the event of an outage, while the utility benefits from tapping into the batteries for valuable grid services, such as to meet system peak demand needs. The availability of multi-year utility programs as a source of battery storage revenue can greatly improve the financeability of a solar+storage project. For more information about utility battery storage programs, see the box on *Utility Battery Storage Programs.*

Grants

Although battery costs are dropping and financing and utility programs are expanding, solar+storage remains uneconomical for many individuals and organizations. Grants—including 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, calls for demonstration projects, or to advance goals to benefit specific communities or populations. Oftentimes, grants don't cover all project costs, but instead help to reduce upfront costs.

Grants can be especially helpful in offsetting costs associated with some of the preliminary steps in the project development process: conducting solar+storage feasibility assessments. 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.[8]

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 non-profit organizations in the Southeast. The GoodUse program greatly offsets the costs associated with energy improvements, including solar and battery storage.[9] In Maryland, the Maryland Energy Administration (MEA) Resiliency Hub program provides nonprofits, local governments, and businesses with grants that support installing solar+storage in low-to-moderate income, high density communities.[10]

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

- **Sterling Municipal Light Department** in Massachusetts benefited from state and federal grants to support a battery storage project tied to an existing solar farm to power critical facilities providing first responder services.[11] 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 U.S. Department of Energy Office of Electricity awarded an additional $250,000 grant through the Energy Storage Technology Advancement Partnership, along with free technical assistance.

- **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.[12]
- **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.[13]

Financing

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

There are several financing tools 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 are examples of better-fit options for various segments of credit enabled mainstream commercial customers. Solar+storage projects for affordable housing and nonprofit community facilities require different structures of financing and ownership models.[14]

Third-party financing, which has been a popular option to finance solar systems in the past, is becoming more popular as a tool to finance battery storage. One type of third-party financing is a power purchase agreement (PPA), which is 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.[15] 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 made 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.[16] 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 a monthly lease for the storage system.

Foundations are also stepping in to create financing models that support low-income solar+storage project development. In January 2020, The Kresge Foundation, Clean Energy Group, and New York City Energy Efficiency Corporation (NYCEEC) announced the "Financing Resilient Power initiative," a multi-million dollar effort to accelerate the market development of solar+storage in historically underserved communities through a payment loan guarantee.[17] As part of this initiative, eligible organizations are able to access technical assistance grants to cover the costs of hiring a third-party engineer to conduct a solar+storage feasibility assessment at a specific property or portfolio of properties.

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QUESTION 10

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

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

For many reasons, solar+storage deployment should be prioritized in low-income communities first, 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 ways: **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 higher energy burdens and community facilities must oftentimes contend with shoestring budgets and capacity issues. Residential systems installed in utility service areas that have storage-friendly programs, such as the programs offered by Green Mountain Power in Vermont (see the box on *Utility Battery Storage Programs*), can receive subsidized batteries and/or payment for allowing the utility to use their battery for grid services. Some state incentive programs also offer higher incentives specifically 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.

For community facilities serving low-income populations, solar+storage can often reduce utility costs through managing onsite demand. Critical facilities have the added economic benefit of potentially avoiding significant negative financial impacts during power outages, which could otherwise equate to thousands of dollars lost in the event of an outage. One California health clinic, for instance, lost hundreds of thousands of dollars' worth of temperature-regulated medications/vaccines when a power outage left the clinic without refrigeration.[2]

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. 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.[3] Without power, lost food due to a lack of refrigeration can result in food security issues. For medically vulnerable residents, battery storage could support critical medical equipment, such as oxygen concentrators or 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.[4] 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 disaster response and disaster recovery efforts, allowing those facilities to continue to serve as a local, trusted institution that is available to provide emergency power when needed.

Environmental Benefits

Solar+storage offsets greenhouse gas emissions by reducing a building's reliance on the grid and can reduce the need for fossil-fuel power plants during times of high energy demand. Energy during these peak demand periods is often met by inefficient power plants known as peakers that are typically located in low-income and minority communities.[5] 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 and are harmful to public health. In fact, one study found that 83 percent of fatal disaster-related carbon monoxide poisonings in the United States were attributed to improper generator use.[6] 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.

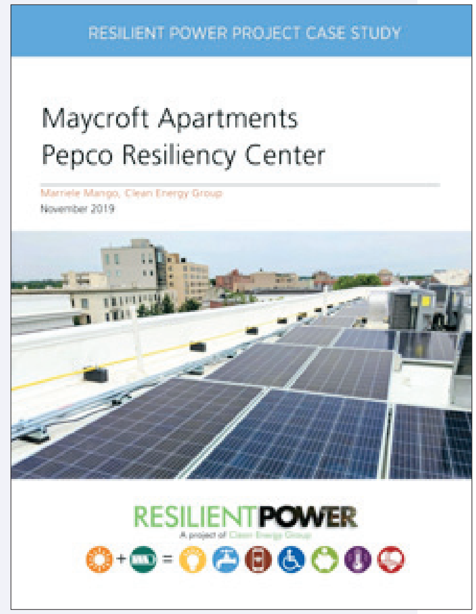
Programs designed to improve education and adoption need to be implemented for battery storage to reach low-income and disadvantaged communities.

AWARENESS: The majority of residents and service providers in low-income communities have limited or no knowledge of battery storage technologies; in many cases, even solar may be little understood. Education is a major issue; for instance, few states offer battery storage programs that educate and/or incentivize battery storage for low-income communities, unlike the low-income solar market which has benefited from years of dedicated federal and state incentive programs.[7] 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.[8] Even in states that have developed incentives to boost storage uptake among low-income communities, there has tended to be little uptake due to limited program visibility, poor program design, and inadequate community engagement.

Programs designed to improve education and adoption need to be implemented for battery storage to reach low-income and disadvantaged communities. Building resilient power awareness 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, such as carbon monoxide poisoning and toxic gas emissions, and operational challenges (for example, diesel generators require 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 largely 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 to take on. Without economic incentives and financing opportunities, solar+storage will remain uneconomical for most low-income community members.

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.

MAYCROFT APARTMENTS, DC: 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 will save each household approximately $40 every month on utility bills.[10]

SUNSMART EMERGENCY SHELTERS, FL: The Florida Office of Energy and state partners created the Florida SunSmart E-Shelter Program to equip 112 public schools with small solar+storage systems (typically 10 kilowatts of solar paired with a 40-kilowatt-hour battery system). The systems deliver enough backup power to maintain lighting, electrical outlets and communications equipment, allowing the schools to act as emergency resource centers in the event of a power outage. Each shelter can provide services to 100–500 people. During Hurricane Irma in 2017, 41 schools opened as shelters using their solar+storage systems. During regular operations, the solar system reduces electric utility costs. Each school is anticipated to save between $1,500 and $1,600 on energy costs each year.[11]

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. 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. The system operated as expected, providing automatic power to critical loads through the outage.[12]

TISH NON COMMUNITY CENTER, CA:[13] The Bear River Band of the Rohnerville Rancheria, a federally-recognized Native American tribe in Northern California, installed a hybrid solar+storage and wind system at their Tish Non Community Center, which consists of a ground-mounted 100-kilowatt solar array, 30-kilowatt/60-kilowatt-hour battery storage system, and 20 wind micro-turbines. The Tish Non Community Center provides vital community services, including educational programs and a daycare, and hosts an array of important community programs. The hybrid system will support critical loads through an outage. Furthermore, the system payback period is estimated to be only 10 years—primarily due to utility bill savings—the system provides 40 percent of annual energy usage and reduces demand charges through peak shaving.

Programs that allocate designated funds and higher incentive levels to support solar+storage development in low-income communities reduce risks associated with financing and lower out-of-pocket investments. California's Self Generation Incentive Program (SGIP), for example, offers much larger battery storage incentives for customers in low-income communities, 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. To read a more detailed review of incentive programs, see *Question 9: How can I pay for a solar+storage system (incentives, grants, financing)?*

Programs that allocate designated funds and higher incentive levels to support solar+storage development in low-income communities reduce risks associated with financing and lower out-of-pocket investments.

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.[9]

Q10 ENDNOTES

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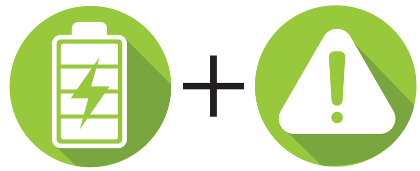
QUESTION 11

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 tens of thousands of real-world deployments, battery technologies from trusted manufacturers have been widely found to be safe for onsite energy storage applications when installed by experienced professionals following recommended procedures. The types of battery technologies commonly deployed in today's energy storage installations do not emit any harmful gases during operation and pose few serious risks if proper safety measures are implemented during the installation process.

Battery technologies from trusted manufacturers have been widely found 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. Batteries sited in areas subject to flooding should be installed at higher 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 where 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. This can be broken down into two buckets: 1) the risk of a storage system potentially 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 and installing a storage system.

STARTING A FIRE: There have been a few high-profile cases of lithium-ion batteries in consumer electronics igniting, such as the Samsung Galaxy Note 7 that was banned from commercial flights due to safety concerns. It was later found that the Galaxy Note 7 suffered from irregularly sized batteries and other manufacturing issues.[1]

As with the faulty Samsung phones, most fires caused by lithium-ion batteries are due to some type of design or manufacturing error. Flawed battery production can lead to energy storage systems that 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 makeup of their cells. For example, lithium-ion battery systems using nickel-manganese-cobalt (NMC) cells carry a higher risk of thermal runaway; whereas, lithium-iron-phosphate (LFP) battery cells do not (see *Question 2: What different types of batteries are available (and which one is right for me)?).* Even in chemistries that do carry some 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 being considered 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 example of this is checking to verifying that a battery technology being considered has received UL certification.[2]

The best way to minimize and prevent injuries when fires do occur at sites with battery storage systems is to incorporate monitoring devices that will detect fire risks and alert onsite personnel, along with suppression and ventilation systems.

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 when fires do occur at sites with battery storage systems is to incorporate monitoring devices that will detect fire risks and alert onsite personnel, along with suppression and ventilation systems to minimize the risk when first responders arrive. Depending on the size, location, and type of battery system being installed, 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 Q11 Figure 1, p. 62.)

The National Fire Protection Association (NFPA) began developing a standard for the installation of energy storage technologies in 2016, NFPA 855.[5] 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 the majority of energy storage fires, including lithium-ion battery chemistries.

The Energy Storage Association (ESA), an industry group, has also created energy storage safety guidance documents. Through the organization's Corporate Responsibility Initiative, ESA released an energy storage operational safety guidelines document and model energy storage emergency response plan.[6] The ESA documents include practical safety recommendations, such as ensuring that energy storage systems are clearly marked, informing the local fire department of appropriate fire suppression methods, safety training for onsite personnel, and installing sprinklers and ventilation systems as appropriate.

Q11 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.

Codes and Standards

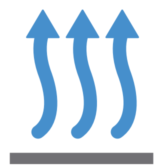
Follow the most up-to-date codes and standards and implement safety best practices when installing a storage system

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.

Temperature Controls

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



Venting

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

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 trainng.

Q11 ENDNOTES

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2 UL certifications, such as UL 9540: Standard for Energy Storage Systems and Equipment, include testing requirements to verify an energy storage product meets certain minimum safety standard thresholds. See "ANSI/CAN/UL Standard for Energy Storage Systems and Equipment, *UL Standards Sales Site*, https://standardscatalog.ul.com/standards/en/standard_9540, (accessed September 8, 2020).

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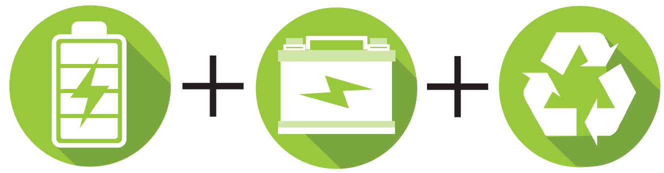
QUESTION 12

What are the environmental impacts of battery storage?

TOPICS COVERED: **Societal and environmental impact 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 impacts. Here we'll focus on three stages of the battery lifecycle to measure environmental and human impact: **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.)

The major manufacturing and mining concern associated with lead acid batteries is related to 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.

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 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 some common lithium-ion battery chemistries, is tied to exploitative labor practices. Human rights abuses, in addition to numerous other environmental and labor violations, have been tied to cobalt mining in the

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 (although these options typically cost more than others). **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

Democratic Republic of Congo, which produces 50 percent of the world's cobalt supply.[5] Some battery developers, such as Tesla, are pursuing strategies to reduce the level of cobalt required in their battery products. Researchers are also looking into improved battery development manufacturing practices that would reduce the amount of cobalt required.[6] Both efforts signal an industry shift away from cobalt mining. Other battery vendors, like sonnen, use lithium-ion chemistries that do not contain any cobalt but tend to cost more upfront.

End-of-Life

RECYCLING: Almost 100 percent of lead acid batteries are recycled today, compared to less than 5 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.[7] Lead acid is also a simpler battery chemistry (60 percent of a lead acid battery's weight is lead) than lithium-ion, which makes the recycling process easier and more efficient.[8]

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.[9]

The chemistry of lithium-ion batteries and number of compounds, which can include a mixture of cobalt, manganese, iron phosphate, or nickel compounds, as well as aluminum, copper, and graphite. This makes recycling more challenging.[10] 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.

Current lithium-ion recycling practices typically rely on expensive facilities that operate with energy intensive, polluting processes that require high-temperature smelting techniques to breakdown batteries. Furthermore, these processes can't capture a portion of lithium-ion compounds that could be repurposed (such as lithium and aluminum).[11] Alternatively, 100 percent of lead from lead acid batteries can be extracted and recycled over multiple battery lifetimes and not degrade.[12]

Despite a bleak recycling landscape today, there is hope for an improved lithium-ion recycling industry in the future. More research is being dedicated to understanding the potential of lithium-ion recycling, and companies are forming to tackle new and improved recycling methodologies. Chemical recycling plants are coming online, which utilize chemicals instead of high temperatures in the recycling process. These plants are less energy intensive and less expensive than their smelting counterparts and can recycle more components of the battery.[13] Lithium-ion batteries also last longer than other battery chemistries and therefore require fewer battery replacements. Furthermore, 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.

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 and are not limited by the same space and weight limitations as transportation.[14]

The Massachusetts Institute of Technology (MIT) recently published a study identifying how EV batteries could be used in stationary applications, and if the systems would be economical.[15] In one hypothetical scenario of a grid-scale solar farm in California, researchers found that a system of used EV batteries could be a profitable investment compared to a new battery installation of the same size, which was not economically feasible.[16]

Demonstration projects have begun to prove the viability of reusing EV batteries in solar+storage systems. One project in California is developing a solar+storage system with used EV batteries to provide energy resilience to a food cooperative in a low-income community.[17] Another is using refurbished EV batteries to provide resilience for a bookstore that requires constant temperature and moisture control.[18]

Q12 ENDNOTES

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Conclusion

The economic, market, and regulatory landscape for solar+storage is constantly evolving. The answers presented here represent the state of solar+storage for a specific snapshot in time, which will likely change dramatically in the coming years, particularly with anticipated advancements in battery storage technologies and the introduction of new value streams as utilities and grid operators become more comfortable with energy storage and regions pursue increasingly aggressive clean energy goals. 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, and tutorials. 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.

2013–2020

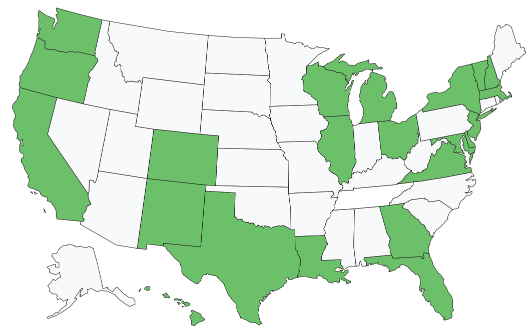
About the Resilient Power Project

The Resilient Power Project, a joint initiative of Clean Energy Group and Meridian Institute, is focused on accelerating market development of resilient, clean energy solutions for affordable housing and critical community facilities in low-income and disadvantaged communities. The Project is targeted to the deployment of solar PV combined with energy storage (solar+storage)—to power essential services during extended power outages and to reduce the economic burden of energy costs in vulnerable communities. The goal is to further clean energy equity by ensuring that all communities have access to the economic, health, and resiliency benefits that solar and energy storage technologies can provide. Learn more at www.resilient-power.org.

200-plus Community Facilities

The **Resilient Power Project** has advanced the exploration of resilient solar+storage for **247** community facilities in **89** low-income and underserved communities across **25** states and U.S. territories.

25 States and Territories

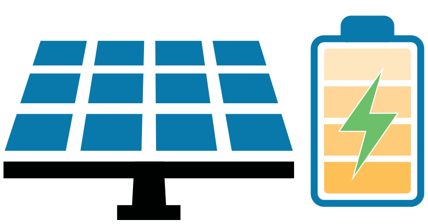


$850,000 in Grant Awards

Clean Energy Group has awarded **80** technical assistance and capacity-building grants totaling **$850,000** to **48** local nonprofit organizations working to advance resilient solar+storage in their communities.

48 Local Nonprofits

6.5 MW Solar + 10.6 MWh Storage



These collaborations have resultsed in **25** completed projects, delivering **6.5** megawatts of solar and **10.6** megawatt-hours of battery storage energy resilience to **22** communities, including **2,500** units of affordable housing.

2,500 Affordable Housing Units

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About Clean Energy Group

Clean Energy Group (CEG), a leading national, nonprofit advocacy organization, advances innovative policy, technology and finance programs in the areas of clean energy and climate change. CEG promotes effective clean energy policies, develops low-carbon technology innovation strategies, and works on new financial tools to advance clean energy markets and an equitable clean energy transition. CEG's projects concentrate on climate and clean energy issues at the local, state, national, and international levels as we work with stakeholders from communities, governments, and the private and nonprofit sectors. CEG created and manages The Resilient Power Project (*www.resilient-power.org*) to support new public policies and funding tools, facilitate community project development, and work with state, municipal, and community leaders to support greater investment in energy resilience, with a focus of bringing the benefits of solar PV plus battery storage to underserved communities. Clean Energy Group is headquartered in Montpelier, VT and funded by major foundations, as well as state and federal energy agencies. Learn more at *www.cleanegroup.org*.

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