# Solar Plus Storage Companion Measures For High-Value Community Solar

## A Guide For Utility Program Planners

### Community Solar Value Project

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## Summary

This guide to **Solar Plus Storage Companion Measures for High-Value Community Solar** is a companion to an earlier Community Solar Value Project (CSVP) publication, **Demand Response Measures for High-Value Community Solar Programs**. Both guides can help utility solar program planners in creating compatible distributed energy resource (DER) programs, and especially in bringing greater utility value into community-scale solar, by adding companion measures. The CSVP is focused on community solar as the likely solar program model, but, in fact, any solar resource or aggregation of solar resources may be matched with complementary storage and demand response (DR).

This guide also may be useful to utility strategic planners, resource procurement specialists, DR program managers, marketing program managers, non-utility vendors and others who wish to understand current and emerging storage opportunities and storage measures on both sides of the customer meter.

The authors assume an introductory understanding of issues related to rising distributed-solar market penetration. As a framework for early-stage program planning, this guide presents a five-step process:

1. Characterize Utility Solar Plus Storage Program Objectives
2. Review Storage Technology Options.
3. Assess Integration Value Streams.
4. Score Technologies and Configurations for Relevance to Program Objectives.
5. Design the Program to Deliver Solar Plus Storage and/or Demand Response.

The range of storage technologies covered include those suited for deployment on the utility side of the meter and on the customer side of the meter. The use of stationary batteries for energy storage has become the center of industry attention today, and this guide provides summary information and resources to help facilitate their practical use. However, this guide gives equal attention to thermal storage options, such as grid-interactive water heating (GIWH) and controlled ice storage systems, which are most likely to be aggregated through a customer-focused program. A number of other options are also discussed, including emerging controlled electric vehicle charging and bi-directional vehicle-to-grid (V2G) strategies. A sampling of utility programs and references for more information are included in each technology discussion.

Value streams are discussed from both the utility perspective and the customer perspective. Value is derived from using storage and DR to meet the utility system's integration needs along different time horizons, from addressing seasonal generation and load-curve characteristics to instantaneous needs for frequency response and voltage stability.

The market structures needed to explicitly monetize these values are just emerging, and for some utilities and customer groups this will be a limitation. Yet programs available to most distribution utilities can provide benefits today. These programs can solve some

integration problems close to home and minimize exposure to the eccentricities of external markets.

The CSVP has developed a simple scoring approach to help utility planners in assessing choices among storage technologies and deployment configurations. The approach presented here precedes more technically refined methods, which are currently under development by the U.S. DOE Grid Modernization Consortium and other advanced engineering groups. In working with utilities and stakeholders today, CSVP recognizes a pressing need for elementary understanding of renewables-integration problems and solutions, which could be implemented in the market today. The CSVP's recommended model is a community-solar program, co-marketed with storage companion measures. Several relevant demonstrations of this approach include the local community solar plus storage program at Steele Waseca Electric Cooperative, in Minnesota, implemented with the co-op's power supplier, Great River Energy. In other cases, solar thermal energy storage or customer-side batteries have been offered to address increasing integration needs, but without specific reference to a community solar offer. The CSVP's work with its primary utility partner, the Sacramento Municipal Utility District (SMUD) in California, also has contributed to that utility's understanding of solar plus storage program options, with new product offers anticipated in the next two to three years.

This guide concludes that there are many ready opportunities for utilities and their customers to benefit from solar plus storage program options. Solutions to relatively straightforward problems, such as the need to smooth the "duck curve," can and should be introduced today, so utilities, customers, and third-party innovators can gain experience working together to solve integration problems. Their timely efforts can prepare utilities on pace with the potentially skyrocketing growth of renewables and especially distributed energy resources (DERs). Because of their inherent flexibility, many storage solutions introduced for load-shifting today could be applied to more sophisticated integration problems as markets evolve and change.

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## About the Community Solar Value Project

The Community Solar Value Project is aimed at developing best practices for community solar at electric utilities, including guidelines on how to achieve lower costs and greater value in five areas: optimal siting and project design, procurement, pricing, target marketing, and matching the solar offer with companion measures that attack solar-integration challenges. The project is led by Extensible Energy, with support from Cliburn and Associates, LLC, Olivine, Inc., Millennium Energy and Navigant Consulting. Utility participants include the Sacramento (California) Municipal Utility District (SMUD), and other utilities nationwide. The project is powered by SunShot, under the Solar Market Pathways program of the U.S. Department of Energy. See http://www.communitysolarvalueproject.com

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## Disclaimer

# Contents

# 1 Introduction

The Community Solar Value Project (CSVP) aims to increase the value and reach of community solar programs and community-scale projects through improvements in five challenge areas: strategic project siting and design, procurement, pricing, target marketing and matching the solar offer with demand response (DR), and storage companion measures that add solar integration value.

Before turning to a detailed exploration of storage as a promising challenge area, some definitions can help to set boundaries for the discussion. First, the focus of this guide is on the role of the local utility, which is most likely to drive solar generation on its own distribution system. The term *distributed solar*, thus refers to that local, community-scale PV resource, as well as to customer-sited PV. We use the term as broadly inclusive for solar on the local grid.

The term *integration* is used in many different contexts when discussing renewable resources, and especially solar. For this guide, we consider integration primarily as a set of strategies that compensate for variable generation from solar projects, at intervals ranging from a few seconds to a few hours, as well as to the seasonally shifting characteristics of PV generation. Integration issues are relatively inconsequential at lower solar-resource penetrations, but as penetrations rise, diurnal and seasonal variability creates a mismatch between utility generation and load. Often, this is a first-line challenge, which storage or DR or both can readily address. But systems also experience imbalances of much shorter duration, and these are more challenging to address. This guide explores how storage, along with DR and control technologies, apply to the range of integration challenges: which configurations work best for utilities today, and how practical issues, from cost to market and policy pressures, affect the utility's decisions about what kind of storage to use, and where and how in the market today.

The term *energy storage* itself needs some definition, in the context of this guide. Obviously, the context is storage to support electric utility service. At that, the choices for product selection, scale, placement and operation are many. For the most part, we focus on options that complement community solar program design. As such, customer-side options are highlighted; thermal storage is especially highlighted for its relatively low cost and accessibility. Customer-side battery storage is also discussed. Utility-side battery options are discussed primarily for their value in strategic-use applications. For interested readers, we include references to the full range of storage approaches in another CSVP publication, *CSVP Resource Links for Solar Plus Storage* (Cliburn, Halberstadt, & Powers, 2017). We also provide references for the special case of local resiliency, which is a potentially great value stream, but which is not covered in depth here.

While storage is rarely used in community solar programs today, some storage programs complement community-scale solar portfolios or address the wholesale-market impacts of renewable-resource variability, through an approach of "solving the problem near the source." This approach has benefits that limit utility exposure to the risks and costs of responding only to wholesale market conditions.

One final note: When storage is deployed on the customer side of the meter, the storage measure may be implemented under the utility's DR or load management or broader energy services program, often in collaboration with solar and resource planning managers. This guide does not provide detail on implementation strategies. CSVP's earlier guide to *Demand Response Measures for High-Value Community Solar Programs* (Huffaker & Powers, 2016) goes into more detail and provides case studies. CSVP also has addressed important challenges of cross-departmental collaboration in its community solar design guide and other publications. This guide to *Solar Plus Storage Companion Measures* offers a five-step process for setting the course toward implementing a successful solar-plus strategy, but these are early steps along a path that utilities are beginning to walk, together with their partners in market innovation.

## 1.1 Market Trends for Distribution-Scale Solar

The U.S. solar market grew by nearly 14.8 GW of capacity in 2016, nearly doubling its 2015 growth, according to the Solar Energy Industries Association (SEIA, 2017). Most of this growth was in the utility sector (10 GW). The total 40.4-GW capacity of the U.S. solar market in early 2017 was dominated by large, centralized solar projects, owned by or under power-purchase agreements with utilities. This has pushed the solar fraction of total U.S. generation from near-invisibility to 3.2% of net summer capacity and 1.4% of annual generation nationwide—a 73x multiplication market scale since 2006. Of course, the impact of solar generation is much greater in some states than in others. But the rapid growth of the solar market is occurring far beyond California. Rising solar states, with strong market growth in 2016, included Utah, Georgia and North Carolina. Utilities nationwide recognize that a solar transition is underway.

The growth of solar on the local distribution grid is an important subset of overall solar-resource growth. Distributed solar includes the widely recognized residential market segment and a non-residential market, which may—due to shifting approaches to categorization—include a significant number of utility-driven projects, as well as a growing number of corporate projects that exceed typical non-residential scale. The total market that is generally classified as *distributed solar* has been growing by about 5-GW annually (Margolis, Feldman, & Boff, 2017).

Whether growth in the local solar sector dramatically accelerates depends in part upon whether integrated distributed energy resource (DER) strategies take hold. Local solar is the cornerstone of most DER strategies, including those supported by policies in California, New York, and other states. Beginning in 2016, growth in the non-residential solar sector picked up, due in part to interest in DERs. This includes utility-driven community solar projects and utilities working to meet specific key-account, corporate customer needs.

According to Rocky Mountain Institute (RMI), utilities could add significantly to overall distributed solar growth. According to RMI, "Community-scale solar represents a substantial untapped market that could powerfully complement existing utility-scale and behind-the-meter solar market segments" (Brehm et al., 2016). The majority of these new, utility-driven projects would be in the 0.5 to 5-MW range. RMI believes this market potential could total 30 GW by 2020.

While the terminology can be confusing, RMI's definition of community-scale solar includes distributed solar developed for community solar programs *and* for the utility's overall resource portfolio needs. According to many sources, community solar program development presents opportunities that are especially strong. The Smart Electric Power Alliance (SEPA) reports that the market for community solar took off in 2016, topping 300 MW installed, with more than 300 MW in the pipeline. Over 170 utilities reported that they had active community solar programs by late 2016 (SEPA, 2017a). GTM Research, an arm of GreenTech Media, concurs: 2017 is seeing dramatic growth in community solar. GTM has predicted 400 MW of community solar in 2017 alone. Further, it cites statements from the National Rural Electric Cooperative Association (NRECA) that co-ops alone could account for more than 480 MW of community solar in the near future, outpacing GTM's already bullish market estimate (Trabish, 2017b).

The reasons for the dramatic growth of local, community-scale solar are varied. One driver is the growing segment of businesses that want to express their commitment to clean energy in a visible way. Another driver is a growing interest in broader solar access—e.g., using community solar in particular to extend the benefits that early adopters of rooftop solar have enjoyed to a broader cross-section of customers. And there is also a growing understanding of the strategic value of DERs, including solar plus storage and DR, to add integration value. Some commercial customers already grasp the benefits of using solar plus storage and DR to minimize demand charges on their bills. Utilities are responding, introducing incentives that insure more upstream load management and integration value—a utility/customer win-win. There is no single reason behind local solar market growth, but the numbers show a significant shift.

## 1.2 Solar Variability

The output of any PV system is inherently variable: Generation varies by season and time of day, and over much shorter intervals due to passing clouds and other weather effects. In each of these time domains, the variability of a growing solar resource can introduce grid operations, stability, and planning problems that require mitigation. Yet it has only been in the past five years or so that a significant number of utilities have been working to deploy better solutions than the "15 percent rule." By that outdated rule, utilities would arbitrarily close any distribution circuit to further solar development, once it reached 15 percent solar penetration.

Experience in growing solar markets shows that PV variability is not a major challenge at low penetration. Even at moderate levels of penetration, PV often claims capacity credit for reducing a portion of peak demand. This is especially true in regions where the peak is driven by daytime commercial air conditioning. Even as solar penetration rises, there are basic, proven ways to mitigate variability impacts. For example, geographic diversity—encouraging a wide distribution of solar installations rather than a few large systems in one place—greatly reduces the cumulative short-term swings in production and their impacts on the utility system. Better solar forecasting has a strong impact, not on changing solar variability, but on reducing the cost of dealing with it. Advanced inverters also have integration capabilities that barely have been tapped (Perez, 2016).

The type of solar variability that has garnered the most attention is the daily variation in solar output. The fact that solar output drops as load typically rises in the early evening has led utility planners to worry about a mismatch between generation and load during the day, especially as it occurs in the spring and fall, when solar generation is great but air conditioning loads are small. This mismatch is called the *duck curve,* based on a graph (Figure 1) in an early analysis by the California Independent System Operator (CAISO). Even with best-practice strategic solar design, which may include single-axis tracking and advanced inverters, the challenge of a rapid late-day ramp in customer load affects utilities that have significant amounts of solar on the grid. A related problem is the possibility that solar generation may be over-abundant in midday—especially during shoulder seasons of the year, when daytime loads do not reach peak conditions. As solar market penetrations rise, the duck curve is becoming a real, though surmountable challenge.

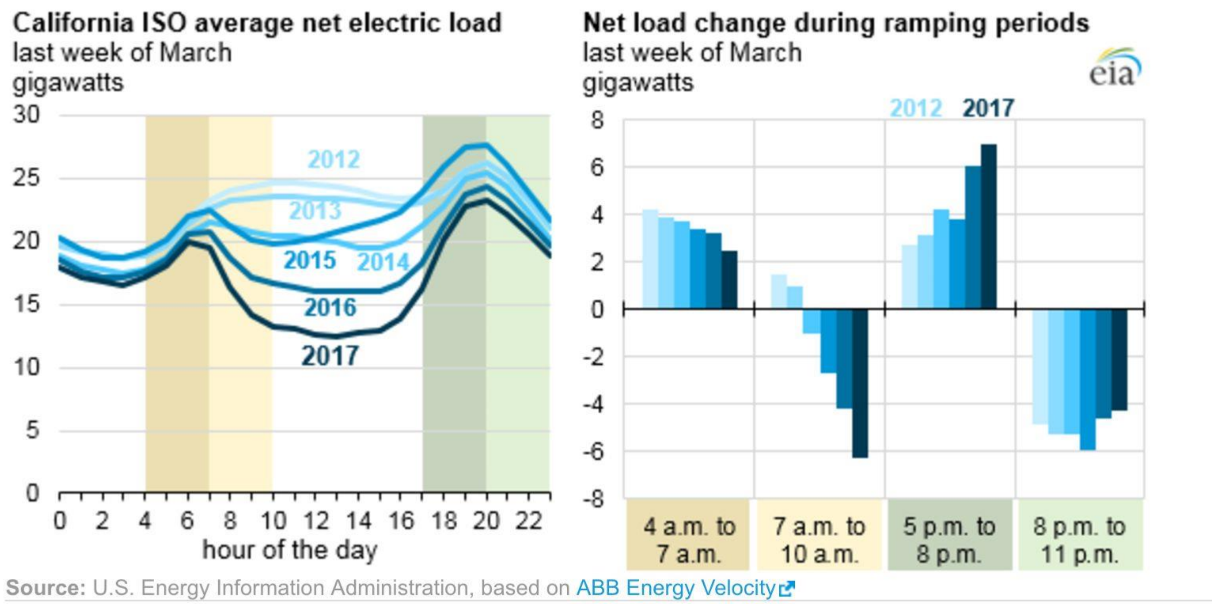


*Figure 1. California ISO "Duck Curve" Documented by U.S. EIA, Spring 2017. Source: U.S. EIA, 2017.*

As renewable energy penetration rises, the job of meeting customer loads—which are themselves variable—is becoming a complex series of trade-offs. Utilities wish to tap the value of solar and wind when available, while meeting the practical requirements of conventional generating systems and modulating loads through a growing range of technical, operational, policy, and customer-engagement tools.

Unless your utility is in a high solar-growth region—such as California, Hawaii, Massachusetts, New Jersey, North Carolina and Arizona—concerns about solar integration may not crystallize for some time. And even in these states, responsibilities are often shared with regional power markets. However, regional markets are already recognizing that the cheapest, surest way to avoid regional grid imbalances is to solve some integration problems *closer to the source*—at the distribution level. Solving integration problems locally is good for operations and risk management—and ultimately for improving customer satisfaction. The advice from utility planners who already have walked this path is clear: It is better to start early, to be ready when the inevitable need for integration solutions become urgent.

## 1.3 Storage in the Context of Community Solar

Community solar provides utilities with many benefits over typical customer-owned rooftop installations. Community solar projects are installed on the utility side of the meter. They are planned and built in close collaboration with utility resource planners, and their generation characteristics are fully visible to the utility. These facts alone offer the utility more flexibility in how to offset the variability of such installations. In addition, the utility can research the level of interest in community solar, long before construction and enrollment; hence, the utility can design the PV strategically and offer solar-plus companion measures, including storage, to add grid-integration value. Further, by promoting storage and DR along with a popular community solar offer, the utility can lower customer-acquisition costs for each offer and double or triple the value of each customer contact.

Community solar provides considerable economies of scale when compared to most rooftop-scale solar installations. With utility involvement, community solar planning also may be coordinated with the development and use of storage technology on the utility side of the meter, extending economies of scale to the storage proposition as well. Such solar-plus facilities may be planned to minimize interconnection expenses and delays and—sometimes—to add specific grid benefits such as enhanced reliability or upgrade deferral.

Behind-the-meter, customer-side storage may be supported by community solar. Opportunities for customers, working alone, to install storage and recoup their investment are limited. By contrast, a full-scale, utility-run behind-the-meter storage program can combine customer benefits (e.g., avoiding high time-of-use rates) with utility benefits (e.g., storage for emergencies or for more frequent load-control) and change the economic proposition from red to black. Customer-side storage technologies include options from thermal storage to small battery banks, which can be readily economic.

In these ways, local community solar programs represent a market-based laboratory for advanced solar integration strategies. Customer participation is voluntary, attracting the same customers who are interested in the range of technologies needed for the 21$^{st}$-century clean-energy grid (Smart Grid Consumer Collaborative, 2015). A well planned community solar program can provide relatively low-risk benefits to customers, while reserving the likelihood that there will be lessons learned before storage and specific solar-plus options are rolled out at full market scale. In the context of a community-solar program, technical and program improvements are relatively easy to make. Well-reported news of progress only builds customer loyalty and interest in doing more. Community solar offers opportunities for meaningful customer engagement, technical and operational learning, and dialog with policy-makers about just where the path to the future should go. This guide will support utilities in any type of local solar-plus-storage planning, but the authors generally assume a community solar program context.

# 2 Solar Plus Storage and the Solar Triple Play

Energy storage and solar-plus have grown into a complex and promising industry in recent years, with technologies and investors ready to address a range of problems. According to GTM Research (GTM Research and Energy Storage Association, 2017), the conventional energy storage market, defined primarily by batteries, is set to grow 11 times over between 2016 and 2022—to about 2.5 GW. Leading states in the storage market include California, Arizona, Hawaii, Massachusetts, New York, and Texas, but this may change with shifts in policy emphasis, corporate leadership, and regional market demand for resilience. Dramatic price drops, characterized by a drop of more than 60% in lithium-ion battery costs since 2012 (SEPA, 2017b) continue to impact the market. Behind-the-meter storage is seeing a sharp rise, and may represent at least half of the storage market in coming years. Utilities are more likely to seek win-win solutions—working with customer-side storage—than they are to fight the trend.

Further, utilities realize that even with dramatic market growth, battery solutions alone may not may not be the answer. A DER approach—including generation and storage options that include batteries and more, with advanced control technologies and price signals for DR, plus energy efficiency and infrastructure improvements—holds the greatest promise for utilities that face high-renewables penetration in the foreseeable future. CSVP's market-based laboratory approach presents practical first steps for utilities to approach this complex and fast-changing market.

Beyond the option of working toward an integrated community solar plus storage program roll-out, utilities may see the entire distribution system or any operational subset (e.g., circuit) as their test bed for solar-plus-storage and triple play solutions.

Readers of CSVP's 2016 publication, the guide to *Demand Response Measures for High-Value Community Solar Programs* (Huffaker & Powers, 2016), will recognize that there is an overlap between strategies for energy storage and DR. Indeed, many DR programs have made use of some type of energy storage for many years, and many storage technologies rely on the same control options as DR. In practical terms, it is beneficial that some storage measures that use DR controls have already passed regulatory review, allowing their costs to be monetized. Notably, some storage resources are distinct from those typically used in DR programs, and there are intriguing approaches for combining such resources into a solar-plus-storage-plus-DR configuration. CSVP has called this the *solar triple play*.

CSVP favors a triple play strategy because combining solar, storage, and DR allows each of these resources to be put to its best and most economic use. In addition, new synergies emerge.

This guide gives relatively little attention to the most obvious solar-plus configuration: a large bank of batteries sited at or near a solar installation, which together serve a community solar-plus program. Field experience suggests that batteries are best used for purposes beyond smoothing the output from a single PV installation, so the benefits of taking a micro-grid or "virtual micro-grid" approach would be limited. Utilities that have co-located battery storage with solar so far have operated the storage components separately from any community solar offer that might exist.

One utility-led alternative: The solar-plus-battery installation could be operated to ease the peak-load burden on an entire circuit, taking into account supply and demand characteristics beyond those specifically tied to a particular solar plant. A circuit-scale design and operating protocol would be especially smart if the feeder were slated for a relatively near-term upgrade. In that case, the solar triple play also could provide grid benefits and possibly defer the upgrade. Moreover, if front-end cost were a consideration, program planners could eliminate the utility-side battery altogether, relying instead on customer-side batteries or other customer-side options.

A study recently completed by PNM Resources for CSVP (Hawkins & Sena, 2017) modeled a solar triple play scenario on a PNM feeder that needed voltage support. As modeled, the triple play strategy would not only resolve voltage problems, but it would also drive more cost-effective load-management, support local solar development, and open the way for the utility to promote clean electrification.

CSVP anticipates other program-design innovations, too, around this dedicated solar-plus-storage configuration. Yet these would most likely emerge from a customer-driven or third-party-driven effort to tap unique value streams—resilience benefits, near-zero energy development benefits, etc.

# 3 Utility Planning Process for Solar Plus Storage or a Solar Triple Play

The focus of this guide is a five-step process for designing a solar plus storage program. As noted above, this process applies whether or not the solar resource is presented to customers as a community solar program offer.

Figure 2 summarizes the steps recommended in planning a utility-driven solar plus program. They are comparable to steps in any utility program-design process, in which the early steps involve defining needs and opportunities, and the later steps involve ranking and then customizing viable solutions.

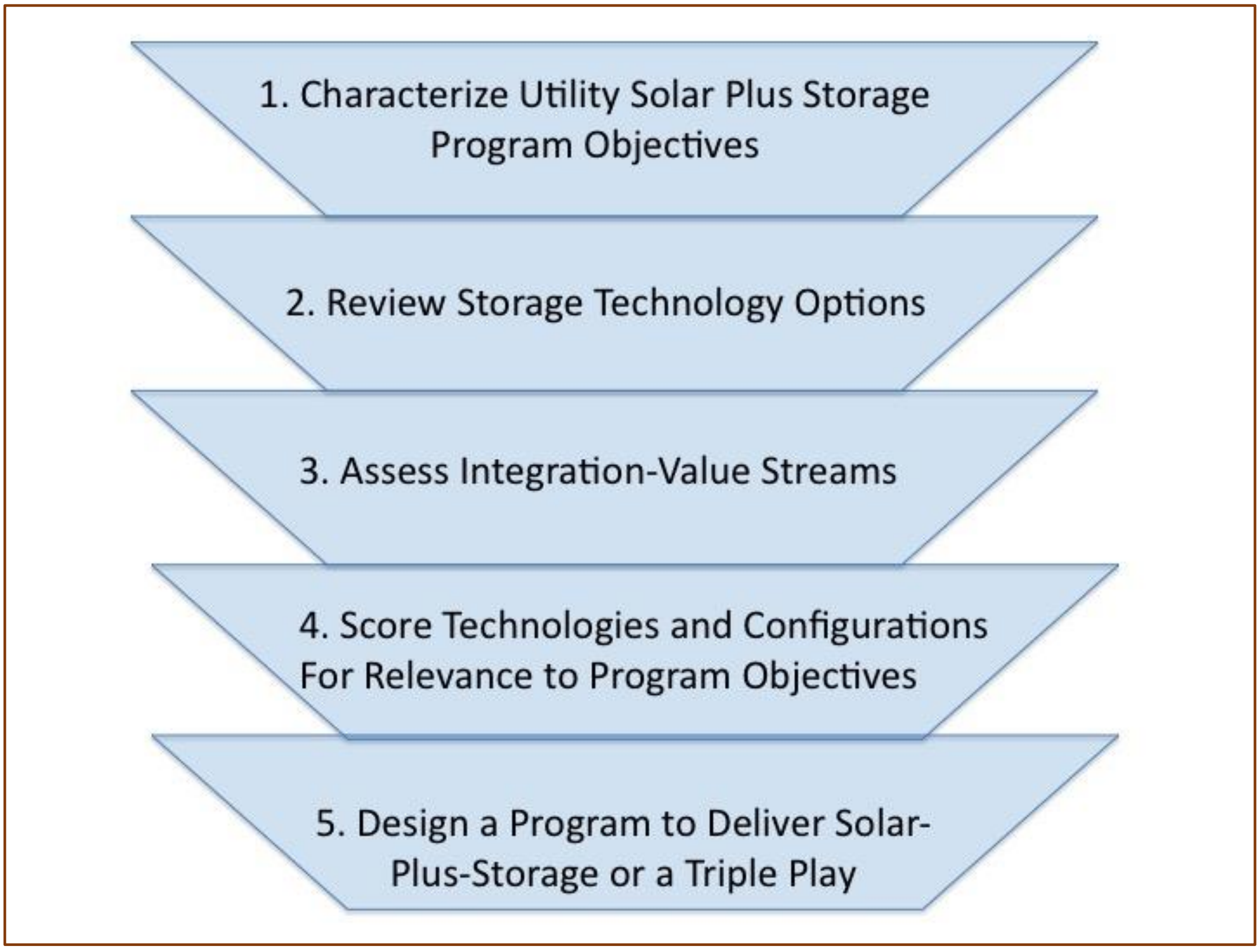


*Figure 2. Utility Planning Steps for a Solar Plus Storage Program or Triple Play*

Here, we briefly introduce each step in this process. Later, will return to the process in Section 8, where the information presented on different storage technologies, value streams, targeted configurations and program elements will come into focus for the utility's final consideration of program design and delivery.

**1. Characterize Utility Solar Plus Storage Program Objectives.** The list of possible program objectives is long, and it is divided by perspective, whether from the utility view or from the customer view. Within the utility category, these include needs to address system wide renewable energy penetration; to address renewables penetration on a particular circuit; to address local power quality problems; to respond to customer interest; to test storage configurations for technical and market-based applicability; to manage market risks from so-called grid defection, and to respond to emerging policies and regional markets (e.g., an ISO that will monetize some integration values). On the customer side, there may be specific reliability or power quality needs. More often, the need to deploy integration technologies arises from a desire to cut electricity bills, to take advantage of special incentives, to promote emergency service resilience, or to decarbonize energy used. Such needs may be important to the customer and to the utility, too, in light customer-satisfaction goals. Using CSVP program design process as a reference, check both utility-side and market-side perspectives. The utility planner should be able to answer the all-important question: *Why* pursue solar-plus at this utility today? With the answer in hand, the planner is more likely to gain all-important top-level support.

**2. Review Storage Technology Options.** Section 4 of this guide describes currently useful storage technologies, which are deployed on either side of the meter. Familiarity with the range of technical options and applications (e.g., the types of batteries and their merits; types of thermal storage and their merits) will give the planner a better understanding of which technologies belong in this utility's solar plus plan.

**3. Assess Integration Value Streams.** Section 5 of this guide describes integration value streams that drive interest in solar plus storage. These are divided between integration values that the utility can realize directly and those that are primarily realized by the customer. Examples include ancillary/grid services, delivered by the strategic use of storage technologies. Planners can assess which technologies tap which value streams, and under what market conditions. In this way, they can prioritize technologies for further consideration. Then, Section 6 is geared to help planners envision suitable deployment configurations. The five generic configurations discussed are differentiated by the location of solar and storage on the utility-side or customer-side of the meter and whether these technologies are operated independently or as one.

**4. Score Technologies and Configurations for Relevance to Program Objectives.** This step helps define which technologies would be most desirable for a given utility program. It offers two matrices for scoring value: one from the utility's perspective and one from the customer's perspective. If the utility plans to promote customer-side storage, then both utility and customer value streams are relevant. A supporting discussion focuses on understanding how utility assumptions might change outcomes. CSVP offers a sample assessment, using defined assumptions, but it also invites planners to make their own, customized assumptions, for their own program scoring.

**5. Design the Program to Deliver Solar Plus Storage or a Triple Play.** At this step, the planner may refer to the overall program-design process, which takes input from both the utility side and marketing side. Here, generic configurations become program *companion measures*. This section poses program-design questions that are especially important or unique to working with solar plus storage and/or DR. (CVSP refers to the latter, three-part combination as the *Triple Play*.) This guide does not provide detailed program design advice, but it will help planners to set the stage for program design success.

# 4 Storage Technologies for Community Solar Program Design

If deploying or evaluating storage as a remedy for renewables-related integration challenges is among top program objectives, then it is important to begin with an understanding of current utility system design and operations. Planners can achieve this best by working cross-departmentally and developing a collaborative understanding of solar plus storage project objectives. While cautious, distribution system engineers are interested in finding the most reliable and cost-effective ways to maintain and upgrade service, as local and regional energy markets continue to change.

This guide is written primarily for the non-engineer, but it can provide a common foundation of knowledge for cross-departmental and decision-level discussions related to solar plus storage planning. The focus is on readily accessible storage technology options, including options on either side of the meter:

- Utility-side energy storage options
    - Pumped hydro-power
    - Compressed air
    - Thermal storage
    - Flywheels
    - Stationary batteries

- Customer-side energy storage options: batteries
    - Stationary batteries
    - Smart electric vehicle charging

- Customer-side energy storage options: thermal storage
    - Electric water heaters, with storage and controls
    - Storage in thermal mass for space heating
    - Building pre-cooling
    - Ice storage for air conditioning
    - Cold water storage for commercial air conditioning
    - Ice storage for grocery refrigeration

Most utility-side storage and battery storage options convert electricity into various forms of potential energy (e.g., chemical energy in batteries) and convert it back to electricity at a later time. Thermal storage options store energy in either warm or cold mass, but generally cannot convert that stored energy back into electricity. (An exception might be high-temperature molten salts, being tested for centralized solar generation.) In addition, advanced chemical storage processes, including hydrogen storage, may become important in coming years, but these are not detailed in this guide. Each storage option discussed here includes a definition, brief review of technology variations, advantages or limitations and applications.

## 4.1 Storage in the Context of Strategic Solar

Some solar-design measures are aimed at achieving the same renewables-integration objectives as are achieved by stand-alone storage technologies, and projects can take advantage of solar-plus synergies by looking at options together. Note that some PV system-design options are suited for particular solar-resource conditions. In many cases, strategic solar orientation or the use of single-axis tracking systems can improve on-peak system performance. And most importantly, solar forecasting and smart inverters or advanced inverter design can add integration value—expanding the capabilities of a solar-plus configuration more cost-effectively than relying on batteries or other storage options alone.

Smart inverters have reactive power and real power functions. Their ability to address reactive power needs, in terms of VARs and power-factor correction, is among their most valuable attributes. Solar projects that use advanced inverters can provide very fast autonomous real power (e.g. virtual inertial response) or reactive power (e.g. voltage regulation) services, as fast as 50 to 100 milliseconds. These inverters, which are commonplace for new PV systems, have been under-utilized to address voltage and frequency issues and grid synchronization needs. This problem is more common for customer-side solar projects than for utility-side projects. In order to optimize inverter potential, customers would need to participate in a control strategy and be compensated for operations beyond simple kWh production. By contrast, the utility has easy access to inverter controls and a big-picture view of solar economics.

Smart/advanced inverter control in combination with advanced solar forecasting can change the economics for storage. Program planners are advised to work closely with utility engineering staff and qualified solar engineers in order to make sure that each technology in a solar-plus configuration is utilized to its best, most economic, advantage (Chakraborty, 2017).

## 4.2 Utility-side Storage Options

A sampling of technologies for utility-side storage are defined here, in order to familiarize planners with available options and for a local project or program. The majority of utility-side storage projects today tap battery options, for their widespread applicability and availability. However, it is important to recognize that many storage technologies are market-proven or in various stages of research and development today, as the field of energy storage gains global importance. Refer to *CSVP Resource Links for Solar Plus Storage* (Cliburn et al., 2017) for detailed research, after pre-screening storage options.

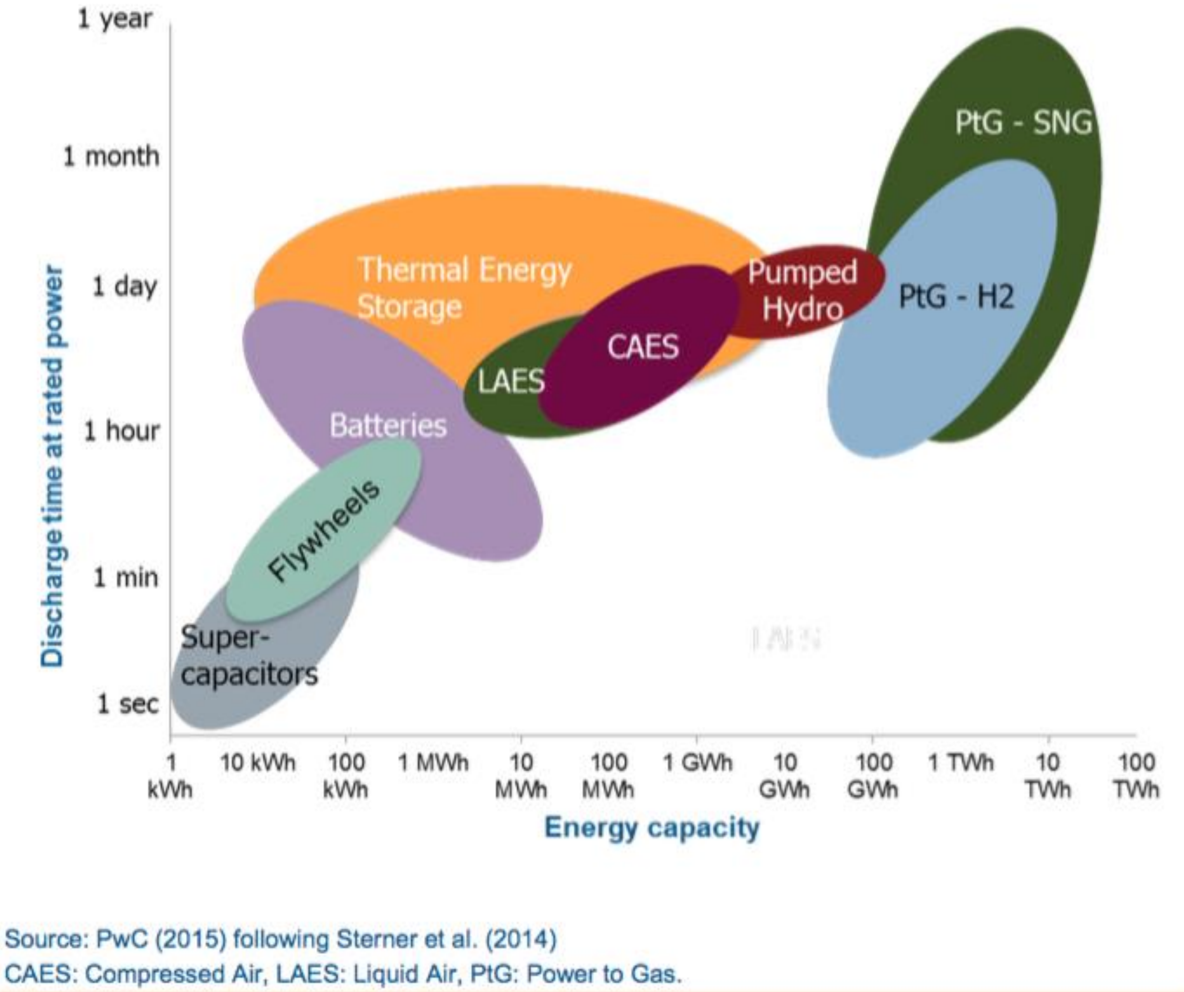


*Figure 3. Utility-side Storage Options (World Energy Council, 2016)*

## Pumped Hydro-power

Pumped hydro-power (pumped hydro) stores energy by moving water uphill to a higher elevation. Pumped hydro installations include an upper and lower storage reservoir, a water turbine and piping and a control system. To charge the system, water is pumped from the lower to the upper reservoir, using the on-site turbine generators. To discharge the system and generate electricity, water is run downhill through the turbines, which are then run to generate electricity. The typical round-trip efficiency is 75 percent, although theoretical efficiency can be as high as 85 percent.

Pumped hydro has been popular because of its relative simplicity, low cost and use of well-established technologies. However, its potential for future development is limited. It relies on the presence of two large reservoirs, separated by suitable height. There are potential environmental issues with disrupting natural ecosystems to construct new pumped hydro installations. In some cases, modifications to existing reservoirs would be relatively simple.

Pumped hydro is currently the largest source of utility energy storage. In 2013 pumped hydro accounted for 97 percent of utility-scale energy storage in the US, totaling 21.6 GW of installed capacity (U.S. DOE, 2015). Examples of distribution-system pumped hydro projects are rare, but some exist in California, led by irrigation districts that have both water and energy needs (California Municipal Utilities Association, 2017). The concept of distributed solar plus pumped hydro was tested by the South San Joaquin Irrigation District nearly a decade ago. Traditionally, pumped hydro plants have been utilized to take advantage of seasonal or daily electricity price differentials, e.g., pumping to store energy at night and releasing water during peak hours to generate electricity.

### Compressed Air

Compressed air storage involves using electricity to run air through a compressor and store it either underground or in pipes or storage tanks. Underground storage systems that use abandoned mines or caves are cheaper, but are dependent on suitable geology. To generate electricity, the air is expanded and heated and run through a turbine. The heat source is typically natural gas, although the waste heat from the compression process may be used. A significant weakness of compressed air storage is low efficiency, with current systems operating at 42-54%. German companies are demonstrating a high-efficiency, wind-powered compressed air storage system (Luo, Wang, Dooner, & Clarke, 2015), but commercial applications are not yet available in the U.S.

### Flywheels

Flywheel systems store kinetic energy by using a spinning rotor of high mass, attached to a motor/generator. They draw power from the grid to increase rotational speed. Then the system is run in reverse to generate electricity, which slows down the rotor. Flywheels have fast response times and high power density. They also have long cycle life and good performance through the full charge cycle. They are attractive for short-term frequency regulation, and they are already in use by some industrial energy customers. However, they can lose up to 20 percent of stored energy in an hour and are not well suited for longer-duration energy storage, backup power, or residential applications (Luo et al., 2015).

### Battery Storage

An electrochemical battery storage system typically includes the battery cells, a control system, and a power conversion system. The conversion system is needed to convert AC power from the electrical grid to DC power for storage in the batteries and back again. Solar-plus-battery applications can use direct DC to DC energy storage, but most are designed for the added flexibility of advanced inverters, which allow both grid-tied and islanded (off-grid) operations.

Several battery chemistries are used for grid storage. Table 1 provides a summary of these, plus their relative advantages and disadvantages for grid storage applications. Additional details on these battery options are provided below.

## Table 1. Comparison of Battery Storage Options

| Technology | Advantages | Disadvantages |
|---|---|---|
| **Lead Acid** | • Low cost<br>• Mature technology | • Short cycle life(1)<br>• Low energy density(2)<br>• Poor operation at low temperatures |
| **Lithium Ion (Li-Ion)** | • High energy density<br>• Long cycle life<br>• Dominates utility-scale and behind-the-meter markets | • Require advanced control<br>• High, though rapidly declining cost |
| **Sodium Sulfur (NaS)** | • High energy density | • Relatively high operating costs<br>• Not easily moveable |
| **Flow Battery** | • High efficiency<br>• Long usable life | • Relatively high cost<br>• High complexity |

1. Cycle life is a measure of the number of complete charge/discharge cycles the battery can handle before its capacity falls below 80% of its original capacity.

2. Energy density is a measure of the amount of energy a battery can store for a given volume, usually measured in kWh/L.

(Source: Hirtenstein, 2015)

**Lead Acid** batteries, commonly recognized as standard car batteries, are a very mature technology, advantageous for grid-scale storage due to their low cost. However, they have short cycle life and can have poor performance at low temperatures.

**Lithium Ion (Li-Ion)** batteries have gained favor in recent years due to their presence in consumer electronics and electric vehicles (EVs). They have demonstrated rapidly declining costs. They have high energy density and high efficiency compared to other battery technologies, but they need computer control systems to ensure safe operation. The high energy density of Li-Ion batteries make them ideal for mobile storage applications, to defer transmission and distribution system upgrades.

**Sodium Sulfur (NaS)** batteries use molten sodium and sulfur as electrodes. As a result, they have a high operating cost and are not easily moveable. NaS batteries have relatively high energy densities, making them attractive for space-constrained large-scale operations. NaS were an early battery-market leader, though their growth rate is significantly lower compared to Li-Ion (International Renewable Energy Agency [IRENA], 2015).

**Flow Batteries** are made of two electrolyte liquid tanks and operate based on reduction-oxidation reactions between the tanks. Unlike traditional batteries, these require no tradeoffs between energy density and power density; they are relatively easy to size optimally. Like electrochemical batteries, flow batteries can provide voltage support and peak shaving, and they can help with renewables integration. However, they are relatively high-cost and complicated, especially for smaller-scale, distributed energy storage purposes. The most common and mature flow battery is the vanadium redox battery (VRB). Luo et al. (2015) offers examples of their use for utility-scale renewables integration.

**Emerging Technologies** include high-temperature molten salt storage, which holds at more than 1000 degrees F. This technology is currently associated with very high-temperature concentrating solar collectors. Power to Gas (PtG or P2G) uses electricity—including solar generation where it is available—to create hydrogen by electrolysis. Stored energy in hydrogen has been the focus of a fuel-cell development push in recent decades.

Other emerging storage methods are similar to pumped hydro storage, as they use gravity to run electric generating turbines. Examples, ranging from electric storage trains that are run up a mountain when energy is cheap and released when it is needed, to elaborate lifts for rocks or other objects, have site-specific uses. Yet these remain out of reach for most distribution utilities that are interested in solar-plus strategies.

One very important consideration for planners who are working with storage options is that both technology assessments and market-based data are subject to change. This is especially true in the battery industry, where Li-Ion battery costs have fallen by more than 60 percent in 2012-16 and improved systems are constantly emerging.

In 2015, CSVP published a white paper intended to shake old notions that storage would remain technically and economically out of reach; two years later, that paper is out of date. GTM Research (Lacey, 2017) recently began to track this problem, which dramatically came into focus after the California Energy Commission (CEC) used data that were several years old for a current market assessment. Based on the past trajectory, it predicted *future* battery costs that are already available today. The future for batteries cannot be predicted based only on a straight-line projection of any one factor, such as increasing manufacturing output, but only on a detailed understanding of industry forces. This does not mean that investing in a battery-storage program or pilot today is a bad bet. Utility experience in solar and other rapidly developing markets suggests that early experience can be invaluable, providing a much-needed edge when the market suddenly takes off.

This same thinking applies to non-battery storage technologies. It is unrealistic and unnecessary to expect all future storage needs to be met with batteries. The cost and environmental risk to any utility of a batteries-only storage strategy would be very high. A combination of utility-side and customer side options, including battery storage plus thermal storage and other options, plus DR appears most promising for a renewable-energy future.

It is worth noting that, with the exception of pumped hydro, the majority of U.S. energy storage projects by capacity today are on the utility side of the meter, and the majority of those are battery storage projects. SEPA (2017b) reports that total energy storage capacity in 2016 was about 620 MW—about 500 of which were located on the utility side of the meter. Batteries accounted for more than 95 percent of utility-side storage projects at that time.

States that have been most active in promoting utility-side storage include California, Massachusetts, Nevada, and Oregon. Indiana, Ohio, Hawaii, and other states and territories also have provided recent, utility-led initiatives.

One project that has gained attention for its relationship to community solar is Austin Energy's distributed-solar plus storage pilot. For one aspect of the project, the utility received $1 million from the Texas Commission on Environmental Quality to help fund a 1.5-MW (3.0 MWh) Tesla battery system, co-located with a 2 MW community solar project. While community solar program participants do not directly support the storage project, the co-location of solar plus storage offers the utility a prime opportunity to explore solar-plus synergies. The project is aimed at achieving a full-system levelized cost of $0.14/kWh for distributed solar and storage.

In addition, Austin Energy received U.S. DOE SunShot funding to integrate a grid-scale battery with rooftop commercial and residential solar in a mixed-use development. The project is in early stage development (Spector, 2017a).

## 4.3 Customer-sited Storage Options: Thermal

Customer-sited storage options include primarily thermal storage and battery storage. Thermal storage itself is a broad category. These technologies typically transform electricity into heat energy (or, in turn, heat-to-cold) and store it at relatively moderate temperatures, which are ideal for customer-sited storage configurations. They typically involve hot water storage, storage of heat in rocks, bricks, and other thermal mass or some kind of chilled water or ice storage.

While this section is aimed at reviewing thermal storage technologies by themselves, these technologies require program infrastructure for delivery. Therefore, this section also previews program-delivery options.

### Hot Water and Thermal Storage Units

Hot water energy storage is typically straightforward, using highly insulated electric resistance water heaters or boilers. A 105-gallon water heater can store the energy equivalent of 13 kWh of electricity at a fraction of the cost of any battery currently offered in the residential or commercial market (Little, 2016). With electric units holding an estimated 40 percent of the U.S. water heater market, the potential for hot water energy storage is vast. There are obvious limitations in transforming from electricity to thermal energy, but an aggregation of grid-interactive water heaters can provide services to energy, capacity, and ancillary/grid services markets. These units may tap different value streams; they are most often used for peak load shifting and easing a steep load-ramp, or for fine-tuned load shifting (arbitrage), frequency regulation or grid stabilization.

Some water heater units are manufactured expressly for storage functions. In addition to bi-directional controls, these systems feature mixing valves to ensure that the water temperature remains consistent at the point of use. Market leaders include Steffes Corporation, which has worked extensively in the electric cooperative market, and Vaughn Thermal Corporation.

This segment of the water heater industry touts *community storage* as a natural corollary to community solar. Some providers have innovated finer, faster DR controls, which capture grid-integration value beyond simple load-shifting. The technology may be applied to new GIWH units and to existing units, as a retrofit with bi-directional control technology. Most use secure internet protocol (IP) communications, some replacing a previous generation of radio-controlled units. For example, Mosaic Power has been controlling water heaters in homes and low-income housing to participate in PJM's frequency regulation market. Other manufacturers in the field include Carina, Power Over Time, and Sequentric (Podorson, 2016).

Case studies to review include the PowerShift Atlantic project in eastern Canada, recent deployments by Hawaiian Electric in West Oahu and the various initiatives the Bonneville Power Administration and Great River Energy, a cooperative G&T. For example, Great River Energy aggregates 65,000 water heater storage units to store a gigawatt-hour of energy, on average, every night (Grant, Keegan, & Wheeless, 2016). While the majority of the energy stored is generated by wind, at least two GRE distribution co-ops have launched programs that incorporate community solar plus water heater storage.

One challenge to this strategy is simply that electric resistance water heating has been more expensive to operate than fossil-fueled alternatives. If natural gas is available, net costs must be compared. Environmental impacts depend on the source of the electricity generation that is being stored. In a growing number of cases, night-time wind generation is stored and environmental results are favorable (Hart, Miller, & Robbins, 2016). Controlled electric water heating is considered a promising clean electrification option as renewable energy penetration continues to rise.

Notably, in regions where radiant floor heating or ground-source heat pumps are popular, boilers and heat-exchange systems may be adapted for whole-house heat-storage applications. In addition to using water, other types of thermal mass may be used. Electric Thermal Storage (ETS) units have a footprint similar to large space heaters and have been marketed for decades as an off-peak heat storage option. Electric cooperatives have been at the forefront in promoting these systems for load management; new grid-interactive control systems may spur a resurgence in these markets.

## Pre-cooling and HVAC Control in Buildings

A simple example of thermal storage is using air conditioners to pre-cool buildings. Buildings can be programmed to turn on air conditioners before the peak hours of the day, so that air conditioners do not have to run as much later, during steep ramping or peak hours. A number of utilities, including CoServ, a Texas-based cooperative G&T,

have paired smart-thermostat controls with the concept of solar load management. CoServe simply encourages rooftop solar customers to use off-the-shelf thermostats, controlled with the help of their DR services provider, Enernoc. The strategy is aimed at easing the steep ramp in afternoon load, when the solar resource begins to subside (Cliburn, 2017).

More refined pre-cooling strategies are integrated with high-efficiency building architecture. For example, the addition of thermal mass in walls, floors, etc., supports thermal storage while easing temperature swings. Depending on building characteristics, pre-cooling may reduce total energy consumption, because it reduces the air conditioner run time at higher temperatures and lower efficiency. New systems, including both building elements and equipment innovations, are still in development to achieve both maximum peak load shaving and energy conservation (German, Hoeshele, & Springer, 2014). Because HVAC-related energy storage has typically been addressed as a DR strategy, CSVP refers readers to its guide to *Demand Response Measures for High-Value Community Solar Programs* (Huffaker & Powers, 2016) for more details.

### Cold Water or Ice Storage

Similar to heat storage, water- or ice-based storage systems work by using electricity to chill or freeze water during off-peak hours. Like GIWH, these units may tap different value streams, including peak load shifting and easing steep ramping, fine-tuned load shifting (through a fleet strategy), and frequency regulation. Cold water and ice technologies are limited by their capacity to store "coolth." Once the water reaches a freezing point, there are significant energy storage benefits in phase change, but to increase storage capacity beyond that, the logical option is to store yet more ice. Residential units in particular are limited by size. The impacts of frequent control operations on system compressors present some limitations, too, but at least one manufacturer addresses this issue by delivering aggregated fleet services, instead of controlling each unit separately.

New ice storage technologies, including residential-scale systems designed to work with low-profile heat pumps, are coming on the market today. After many years of slow growth and incremental technology improvements, markets for residential and commercial ice storage and chilled water storage systems in commercial buildings are expanding. Market leaders include CALMAC and Ice Energy (Trabish, 2015). For example, in early 2017, Ice Energy announced a program with Southern California Public Power Authority (SCPPA) to provide ice storage at 100 homes, with the same impact as a 1-MW battery storage unit (Hutchins, 2017).

Ice storage for grocery refrigeration is a particularly promising application, forming the basis for potential commercial-sector solar plus programs. Refrigeration can account for up to 60 percent of the total electricity usage of a supermarket (Wesoff, 2017). A relatively new company, Axiom Exergy, has developed an ice storage system that can provide more than 1,000 kWh of storage. Each installation can shift six hours of refrigeration load from one period of the day to another. When scaled to a major grocery chain in a large service territory, this can add up quickly. This approach holds promise for load-shifting, including relatively long-term storage and hourly shifting, though it has not been marketed as a source of ancillary grid services.

## 4.4 Customer-sited Storage Options: Batteries

Behind-the-meter battery storage was almost non-existent a decade ago, but is fast emerging for residential, commercial, and industrial customers today. Vendors, including STEM, Tesla, Sonnen and dozens of others now offer systems to capture value streams including renewables integration, demand-charge management, DR and resiliency. Most of these systems are geared to commercial customers that pay high demand charges and can access other incentives. Commercial solar markets are especially poised to benefit. Affordable battery storage systems (possibly in combination with DR) attack the barriers presented by commercial rate structures, which feature relatively lower energy rates and high demand charges.

While the promise of batteries has long been discussed, the market was largely transformed in 2015, with the introduction of the Tesla Powerwall—a 6.4-kWh lithium-ion battery system that was within reach of many residential and small business users. The Powerwall Model 2 was released in 2017, with twice the capacity. In 2016, Tesla introduced a similar product, called the Powerpack, for C&I customer markets.

The majority of customer-side battery systems rely upon lithium-ion technologies. There are differences among brands, including the convenience of mounting and controls and use of organic versus inorganic cells that affect the level of battery toxicity. Of other battery technologies, lead-acid products are losing market share, while flow batteries are on the rise. The vanadium redox flow battery (VRFB) is often cited as the most promising of these. As its costs decline, its operational advantages, including cycling flexibility, will be better demonstrated in the market.

According to SEPA's 2017 Utility Energy Storage Market Snapshot, eight percent of utilities currently have some kind of behind-the-meter battery storage program for residential customers, and slightly more have programs for non-residential customers (SEPA, 2017b).

While this section is primarily focused on reviewing viable storage technologies, it is helpful to preview how each technology, and especially battery technologies, performs in a program context. Relevant integration value streams are discussed in Section 5 of this report, but it is worth noting that batteries are often considered the standard by which other storage devices are measured for their load-shifting and ancillary/grid services value.

For example, Green Mountain Power (GMP) in Vermont led the customer-side battery market, when it first offered Tesla Powerwalls to its customers through a one-time purchase option or a low-cost financing plan. In 2017, that program was updated, with price cuts derived from improved battery capacity and energy output, along with the use of control software developed by SolarCity to help provide grid benefits. The cost is now $15 per month per unit. GMP allows customer control for backup energy in case of an outage, but controls the units at other times and aggregates their integration value. Grid services include dynamic capacity, meaning energy reserves that can be dispatched when they are needed most, plus arbitrage sales into the New England electricity market (Walton, 2017).

A solar-plus battery storage project is under development in Prescott, Arizona, using Sonnen battery technology. Homes in this near-zero energy (NZE) community are super-efficient and fitted with appropriately sized solar arrays. Batteries allow homeowners to take advantage of a new pilot rate from Arizona Public Service designed to incentivize peak demand reductions and to promote DER integration. The rate includes a per-day service charge, plus a high demand charge, matched with very low per-kWh pricing. Customers that have solar plus storage and EVs are well-positioned to benefit. In addition, control systems draw this subdivision into what Sonnen calls a virtual power plant model. However, the solar-plus developer and the utility have not yet come to agreement on how to monetize available, aggregated grid services (Spector, 2017b).

Other storage companies offer similar services in the international DER arena, including Sunverge, a U.S.-based company that recently struck a deal to provide large-scale customer-side battery deployment in Australia. Sunverge has a commercial battery system of its own, but also has begun to provide control services across battery platforms.

California has been the site of several customer-side storage programs, administered in whole or part by the state's leading utilities. For example PG&E's Supply Side Pilot (SSP) has tested integration and participation in the market for load reduction and shifting. In particular, stationary and EV battery storage have been tested with customers who are on solar net energy metering (NEM) rates. A related Excess Supply Pilot (XSP) is predicated on the notion that when excess generation from solar and wind drives prices lower, storage devices can capture value by charging during low and even negative price periods. This pilot uses actual price signals, but the resources are not bid into the CAISO market, inasmuch as market mechanisms are still being developed (Anderson & Burrows, 2017).

The California Self-Generation Incentive Program (SGIP) was established in 2001 primarily to incentivize commercial-scale, non-utility renewable energy projects, but in recent years the focus has shifted to energy storage. In 2017, several rounds of SGIP funding, totaling almost $600 million, were approved through 2019, with 80 percent allocated to funding energy storage. The focus is on commercial-scale storage greater than 10 kW, but 13 percent of total funding is allocated for residential-scale projects of less than 10 kW (Center for Sustainable Energy, 2017). Applying the investment tax credit and the SGIP rebate can cover nearly the full cost for a typical residential system.

Because the battery storage program is being implemented in tandem with new time-of-use rates—a strategy out of the DR playbook—these new California programs may be considered the first market-scale implementation of a storage plus DR strategy. In the presence of customer-side solar, it represents what CSVP has called solar-plus triple play.

The CSVP's primary utility partner, the Sacramento Municipal Utility District, has committed to a new community solar development plan, which pairs TOU rates with community-solar participation. That utility also has plans to encourage use of battery-powered EVs for at least one targeted community solar program option.

Hawaii is also pairing TOU rates with community solar through its Community Based Renewable Energy (CBRE) plan (Trabish, 2017a). Hawaiian Electric is also promoting customer-side energy storage options, through its customer self-supply program. That program incentivizes customers that do not export electricity to the grid. Other states that have developed incentive programs for customer-side storage (not necessarily paired with renewables) include Massachusetts, Nevada, and New Jersey. Readers are advised to check the current status of these state-funded programs.

While lithium-ion batteries receive most of the attention, developers of other chemistries and technologies are also developing innovative solutions. Utility planners may familiarize themselves with different battery technologies and how they address different capacity and cycling needs.

### Electric Vehicle Battery Storage

In October, 2017, General Motors (GM) announced an accelerated transition to an all-electric fleet. It will begin with at least 18 new all-electric models, introduced by 2023. This puts the U.S. auto industry leader on track with car-makers in other countries, like France and the U.K. (and more recently, China), in aiming to get gasoline and diesel engines off the road by mid-century. The trend may have political undertones, but the overtone is purely business. According to *Forbes*, "Sales of EVs in China are forecasted to grow 30% to 680,000 units in 2017, with a 46% increase projected for 2019" (Perkowski, 2017). Driven by the need for standardization in the global market, the auto industry worldwide is expected to turn out 14 million EVs annually by 2025. When it comes to electric vehicles, China's market power is turning the globe.

The development of EVs could be a huge problem for U.S. utilities, or—if managed well—could be a game-changing benefit. For example, SMUD recently commissioned a grid study that assumed little control over its burgeoning EV fleet. It estimated that the impact of unmanaged EV charging, just in terms of the need to upgrade distribution transformers, could cost the utility some $90 million. However, SMUD and other utilities nationwide are pursuing research and planning, so they will not be caught off-guard by the EV boom. A 2017 SEPA survey indicated that about 70 percent of utilities already engaged in some type of planning or preparations to manage EVs (SEPA, 2017b).

The national energy labs also have provided in-depth collaborative research and strategic innovations. The National Renewable Energy Laboratory (NREL) has developed a portal for utilities seeking cutting-edge information on vehicle-to-grid technology solutions (https://www.nrel.gov/transportation/project-ev-grid-integration.html).

Currently, most EVs do not allow for discharging their batteries back to the grid. But over the long term, properly integrated EVs can provide substantial grid benefits. For example, a recent U.S. DOE inter-lab collaboration, called INTEGRATE, illustrated the potential for V2G performance, modeled on a utility that generates half its electricity from renewables (NREL, 2017a) One modeled scenario, calling on three million EVs, with 50 percent optimized charging, indicated the following potential benefits:

- Over $300 million in grid savings
- Reduced electricity costs by as much as 3%
- Reduced peak demand by 1.5%
- Reduced grid-related $CO_2$ emissions by 1–4%
- Reduced renewables curtailment by 25%

Efforts to capture integration value from EVs on this massive scale are in the earliest stages. In the meantime, many utilities have found that it is not too soon to learn how to manage EV batteries. They are promoting smart-charging, using TOU rates and deeply discounted real-time pricing and testing convenience measures, such as midday park-and-charge discounts at solar-shaded locations, in order to engage with customers on the challenge of creating an electric vehicle win-win.

# 5 Integration Value Streams

The previous section referred to the grid-value of various storage technologies; here we define some of the specific value streams that utility- or customer-driven solar plus storage projects can tap. A *value stream*, if monetized internally or through a grid-integration market, is a benefit that can drive technology investments and use. In some markets, such as California, the idea that the availability of a value stream can help build a case for technology use has spawned yet another term, *use cases* (Fortune, Williams, & Edgette, 2014). Terminology choices aside, integration value streams are typically derived from load shifting, distribution upgrade deferral, ancillary/grid services, customer demand-charge management, back-up power, and so on.

A subsequent section of this guide discusses how these value streams are realized in various solar plus *configurations*. A configuration includes a technical layout and also a depiction of the flow of benefits, including utility and/or customer benefits.

As the discussion is geared primarily for program planners, it takes an introductory tone. The CSVP anticipates that this guide will facilitate better cross-departmental discussions, as local utilities strive to solve renewables-integration problems near the source, on their own distribution grids. Planners also may gain a baseline understanding for working with market-level (e.g., ISO) engineers, storage product providers, and third-party grid-service aggregators. The documents and websites recommended in *CSVP Resource Links for Solar Plus Storage* (Cliburn et al., 2017), as well as the sources referenced here, will be useful to those requiring more detail about integration challenges and solutions.

Storage projects today generally fall into two categories: those driven primarily by utility value, and those driven primarily by customer value. There is overlap—especially for customer-side storage that is utility-controlled. For the sake of discussion, we treat the utility-side and the customer-side perspectives separately.

## 5.1 Value Streams from the Utility Perspective

This section reviews value streams that support grid integration. Engaging these value streams typically lowers the cost to operate the grid and to provide consistent service, even as market penetration of variable renewable resources increases. Figure 4 offers one perspective on the defining characteristics of common grid-integration strategies. In general, ancillary service responses are quicker and more frequent; load shifting to address daily or seasonal peaks, ramping and emerging duck curve issues are fairly long-duration events. They may be somewhat frequent (e.g., daily load shifting) or infrequent (e.g., shifting to correct a forecast error). In each case, deploying grid-integration strategies taps a corresponding value-stream.

While storage is a promising grid-integration tool, utility system engineers are developing multiple possible solutions for some grid-integration issues. In coming years, these may reduce the need to use storage for some ancillary/grid services. Yet, other storage applications are likely to increase in value, as utilities integrate more and more variable renewable resources to the grid.

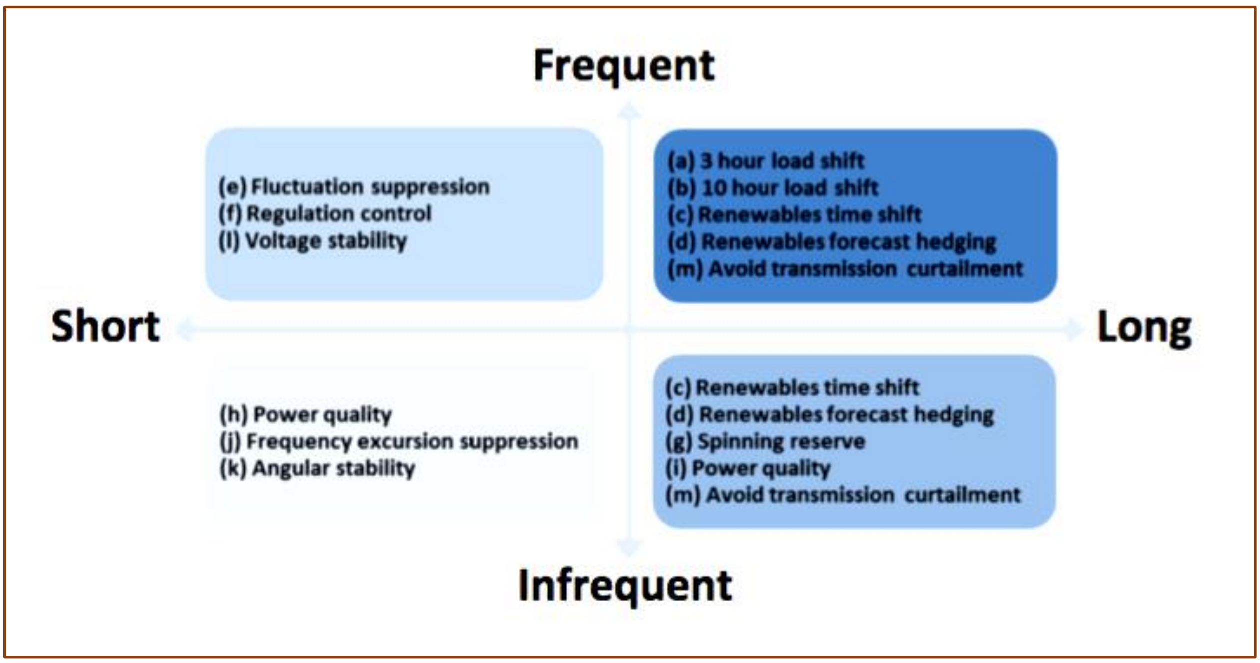


*Figure 4. Examples of Utility Storage Capabilities, Considering Response Time and Frequency (Source: Carnegie, Gotham, Nderitu, & Preckel, 2013)*

### Load Shifting and Arbitrage

As the penetration of distributed solar increases, utilities anticipate challenges in actively balancing supply and demand. A utility can use solar-plus technologies to store energy produced during periods of low demand, and then use that energy during periods of high demand. Generally, prices track demand, so the technical benefits of smoothing the load curve are accompanied by economic benefits. When utilities or third-party aggregators gear the use of different generation and DR or storage strategies primarily to market price signals, the practice is called *arbitrage*—the simultaneous purchase and sale of an asset to profit from a difference in the price.

When storage has been used in the past, it has typically been to charge a battery or other storage device at night, when the predominant generation (nuclear and coal) would have low marginal cost, and then to release that energy in the afternoon, when prices peak. This approach is used in regions with high wind penetrations, where wind generation is usually greatest—and cheapest—at night. The approach could be adapted to store energy at any time when it is abundant and relatively cheap, so it could be discharged when supplies are short and prices are high.

It is important to note that load shifting has valuable indirect benefits to the utility, too. By balancing the system, storage technologies can help reduce the utility's allocated obligations for spinning, supplemental, and replacement reserves. According to one report by R.W. Beck, "Such reductions may permit the utility to avoid or defer the installation of reserve capacity to be provided by future generating resources, or may permit the utility to sell its surplus reserve capacity, or reduce its transmission service reservation and associated reserves if it is purchasing these reserves through a transmission tariff" (Beck, 2011). In general, a utility with well-managed, relatively level loads on a daily and seasonal basis would experience fewer and less costly operational challenges. This includes conventional load shifting during rare, but critical events, when utility system reliability is at stake.

Yet, increasing renewable-energy generation complicates grid operations. Rising solar penetration has already begun to impact California, Hawaii, pockets of the Southwest, and other regions in the U.S. and Europe. In these regions, solar production in the middle of the day can exceed demand. The result is depressed midday wholesale energy prices and increased the need for flexibility. This problem can be severe in so-called shoulder months, such as March and April, when solar generation is strong, but air conditioning loads are small. Indeed, the California Independent System Operator (CAISO) reported wind and solar curtailment of over 80 GWH per month in March and April, 2017 (CAISO, 2017). Storage may be used to absorb excess solar production midday and release it in the early evening, as loads increase and prices rise.

## Ancillary Services or Grid Services

The Federal Energy Regulatory Commission (FERC) defines ancillary services as *services necessary to support the transmission of electric power from seller to purchaser, given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system*. The term *grid services* is a bit broader, referring collectively to services that a regional grid operator or a local utility operator can provide, as it orchestrates the use of generators and DERs and flexible loads (including DR) to keep the power grid stable, reliable and economically efficient.

Ancillary/grid services have traditionally been provided by fast-acting generation resources, such as hydroelectric plants or gas turbines. While all utilities must provide these services, a few regional markets, led by PJM in the Northeast and the CAISO in the West, allow DERs and DR to monetize ancillary services. A Grid Modernization

Consortium, led by the U.S. DOE and the national energy labs, is currently establishing methods and metrics for valuing grid-service DERs and flexible load strategies. The task is challenging because of differences in scale, operation, and especially synergistic impacts when working with solar-plus configurations. Yet market experience has been instructive, too. Utilities that never set a precise value on frequency or voltage regulation or other grid services have been quick to recognize that there is value in balancing their systems, even before they look to a regional market for solutions.

### Advanced Inverters and Engineering Solutions Also in Play

A study of resilient and self-healing grid design and operation is beyond the scope of this guide, but storage planners must work with their engineering departments to be sure that predicted grid issues are being addressed in the most cost-effective and strategic manner possible. For example, the use of solar forecasting and smart inverters can address some solar integration issues and ease the way to more cost-effective solar fleet management. Solar program managers can insure that engineering staff are aware of these options. Conversely, solar and storage planners will sometimes find that a standard grid solution is best. In one case, the CSVP worked with PNM, in New Mexico, in modeling the use of solar plus customer-side storage, as it would address a circuit-level voltage issue. Staff engineers knew that relatively low-cost capacitors were the immediate solution, but modeling also indicated that a solar plus strategy could resolve the issue (Hawkins & Sena, 2017). Cross-departmental planning might weigh the merits of looking for a similar opportunity to engage customers in a solar plus solution, where the wires solution could still be held for later use. Today, grid planning and operations is exceedingly dynamic, and utilities need to be prepared for all kinds of supply- and demand-side shifts, over numerous time horizons.

Ancillary services that storage generally addresses include

- **Voltage Regulation.** Storage can be used by utilities to provide extra power to the grid to reduce voltage sags and spikes. Voltage management includes fast response (typically less than 1 second) with reactive and real power, as well as preparing grid systems to minimize voltage problems and respond.
- **Frequency Regulation/Response.** Storage can provide automated power output to help maintain grid frequency, until dispatchable loads that perform this service routinely can come online. Many generators are set to automatically control for real-time balancing of supply and demand. However, this reduces system efficiency and increases equipment wear and tear. Further, generators alone may not respond fast enough to the signal. Regulation response typically must be fast, in a matter of seconds. Several types of storage can provide fast response as needed. While this market is not yet mature, there is potential for the regulation/response market to grow, to compensate for increasingly variable generation.
- **Spinning and Non-spinning Reserves.** Storage can supplement or replace spinning reserves that are operating at partial load, ready for a fast ramp-up as needed. Further, non-spinning reserves typically turn on and respond within 10

minutes. This reduces the wear-and tear on thermal generators, and it can reduce the need for little-used and often inefficient generators to be kept as reserves.

- **Black Start Support.** Storage—and especially utility-side batteries—can provide the initial power needed to get generators online, in the case of an outage that cuts off all power.

Strategic utilization of storage includes planning for which value streams to address, given that each technology and each configuration has limitations. Yet solar plus DER strategies tend to be flexible, so they may be designed on the basis of one application or value stream, and then be repurposed if a different one is more compelling.

**Distribution Upgrade Deferral**

This value stream derives from the ability to eliminate or delay upgrades of the utility's transmission or distribution (T&D) infrastructure. Currently, there is increasing strain on T&D systems due to aging infrastructure, pockets of increasing demand, increasing distributed generation, increasing needs for reliability, and other factors.

In addition, in areas of high distributed solar penetration, the distribution grid must accommodate large power flows from distributed solar during the afternoons and then reverse that flow as evening approaches, when solar output drops and demand increases. Supporting large bidirectional power flows could require costly infrastructure upgrades. Localized storage can reduce grid congestion and correct related power quality problems *near the source*, meaning nearer to the customer load. Even delaying the need for an expensive upgrade by one year can be sufficient economic justification for integrated DER solutions—especially solar plus storage.

Utilities are still gaining experience with distribution upgrade deferral, leading some utilities to take a conservative view of deferral value. As one solution, members of the CSVP team have suggested a discounted deferral strategy, assuming that for any set of proposed solar plus deferral projects, some percentage will be successful (Bourg, Cliburn, & Powers, 2017). As utilities gain experience with solar plus storage and DR strategies, they will get better at selecting and implementing deferral projects, so the percentage of successful projects will increase, along with accepted deferral value.

An emerging value, which may be considerable, is related to portability. Some battery storage systems are mobile, meaning they can be relocated to strained parts of the distribution system to provide the greatest value in upgrade deferral. Some distributed-solar products and installation methods have been tested for portability value as well, with limited success to date.

## 5.2 Value Streams From the Customer Perspective

Here, we address value streams for energy storage that primarily benefit the customer. These value streams typically lower customer electricity bills, provide backup power or additional revenue streams for better project return on investment. Some apply well to solar plus storage configurations. Some address needs of residential customers, while others address commercial and industrial customers.

### Demand Charge Management

Most large commercial and industrial utility rates include a demand charge, usually based on the greatest load requirement the customer imposes during any one 15-minute interval per month. Behind-the-meter storage systems can be used to reduce these demand charges. For example, batteries may be controlled to store energy at low-cost times and to discharge them during peak hours. Today, most residential customers do not pay demand charges, but TOU rates and load management incentives are common. Some utilities also foresee introducing residential demand charges as rate structures evolve. Note that demand charge management also benefits the utility. Achieving a more predictable load curve, where large customers contribute less to system peaks can ease wholesale capacity requirements and reduce utility system operating costs.

### Managing Costs under TOU Rates

For customers on a TOU rate schedule, storage can be used behind-the-meter to manage costs. This practice of customer-driven arbitrage has been available for decades; Consistent benefits for utilities and customers have been documented across more than 30 TOU pilot projects in the U.S. and abroad (Faruqui, Serguci, & Schultz, 2013). With appropriate automation, solar plus storage or solar plus DR can capture this value stream. Notably, community solar pairs well with TOU rate arbitrage, as illustrated by new programs in Hawaii and California.

### Power Quality

Customer-side storage may be used by commercial and industrial customers to improve power quality, through power factor correction and by eliminating voltage sag. This can be important in avoiding power factor charges and maintaining operation of critical equipment, which requires performance in a tight range of voltage to operate smoothly. The utility may provide incentives for additional customer-side power quality measures, in order to increase its value streams for ancillary services, distribution upgrade deferral, etc.

### Back-up Power and Resilience

Local storage can provide backup power during grid outages. This could be at the individual customer level, if each has its own storage system, or at a community level using a shared storage system. When back-up batteries or solar plus battery systems are used, they often provide power only to critical loads (e.g., refrigeration, communications, emergency lighting), in order to maintain cost-effectiveness. A solar plus project might be designed primarily for resilience, but also to allow the project to regularly tap grid-integration value streams—or vice versa (Simpkins, Anderson, Cutler, & Olis, 2016). The utility may incentivize participation with a larger aggregation of customers, in order to tap ancillary/grid services markets, as well as reliability-related value streams.

### Micro-grid Service

When solar is paired with storage in a local or stand-alone micro-grid configuration, it can serve some or all facility loads without regular utility service. Alternatively, a micro-grid could be grid-tied, in order to provide services to the grid or to rely upon the grid, using special pricing that reflects its burden or benefit. A solar micro-grid could charge storage batteries or other devices during the day and discharge at night. Grid islanding could be achieved for critical loads, or household-, facility- or community-level service.

### Zero Net Energy (ZNE)

Houses or communities with solar could achieve zero net energy (ZNE) status or certification if the total amount of energy they consume is less than that which is produced by integrated solar PV. In some cases, ZNE guidelines allow the customer to use net metering on the grid as a virtual storage strategy. In most cases, customer-side battery or thermal storage are the preferred options, with storage located on site at the household or community level. ZNE certification is strictly voluntary in most states. However, California has a goal for full compliance with ZNE in residential new developments by 2020. All commercial development and half of existing commercial buildings in California must achieve ZNE by 2030.

### Ancillary- or Grid-Service Markets

In some regions, customers with storage systems or solar plus storage configurations can tap markets for grid services, usually with the support of a utility or third-party aggregator. This is true for customers in certain wholesale markets, if the DER assets are properly monitored and controlled. For example, in the PJM region, customer-side storage with fast-response control technology can participate in the ancillary/grid services market for regulation.

Storage may also be compensated in some wholesale markets for its capacity contribution towards meeting peak demand, as well for meeting expected flexible resource adequacy. The latter use case is currently in play in California, with other regions assessing CAISO market outcomes. Utilities that are interested in learning more about these opportunities may wish to review the services provided by third-party aggregators, as these utility partners currently hold the most market experience.

# 6 Solar Plus Storage and Triple Play Configurations

A planning step closely related to the choice of storage technologies is the choice of a configuration that puts solar plus storage in play. A configuration typically includes a technical layout and also a depiction of the flow of benefits, including utility and/or customer benefits. For example, in a configuration that features customer-side thermal storage, the customer might enjoy special rates or incentive payments. There may be utility benefits as well. Those might include customer satisfaction, customer retention and (depending on the market structure) lower wholesale costs, greater reliability, grid integration benefits, and so on. When a value stream is monetized by the wholesale energy market (e.g., the CAISO), benefits are accrued by the customer, and also by the third-party aggregator and, in most cases, the utility.

Utility-side storage configurations include those where the storage is provided by the utility and directly integrated into the grid. Only one utility-side configuration is described here, because it is most applicable to a community solar plus strategy. Subsequently, we review configurations where one or more technical components are located on the customer side of the meter.

## 6.1 Utility-Side Solar Plus Storage

Here, both the solar array and energy storage (typically batteries) are directly integrated into the grid, as shown in *Figure* 5. If this were a community solar project, participants could hold a share of the output from the solar plus project, or the project could track benefits of the solar and storage aspects separately. The configuration in Figure 5 shows the option for customer-side electric vehicle charging, but that is not a core element for this model.

In another variation on this configuration, similar to a community solar plus model currently piloted in Austin, Texas, the utility offers customer participation only in the community solar portion of the project. It owns and operates the storage portion of the project separately, to benefit all customers.

This configuration is typically developed so the utility can capture value streams, such as intra-day load shifting for daily peak reduction or shoulder-season management of the duck curve. If located on a stressed circuit and properly sized, this configuration can help to provide voltage support and, if properly controlled, could provide other integration services to the utility.

From the customer perspective, this configuration is well suited to a ZNE community. CSVP has worked with SMUD to develop this a version of this model for possible implementation as an alternative for ZNE community development, where siting individual homes for solar access could be a problem. Note that customers may also benefit from utility incentives to increase the utility-side benefits—for example, responding to TOU rates or DR load controls.

One variation on this model could offer rooftop leasing for utility-owned solar plus storage. The CPS Energy program in San Antonio has demonstrated rooftop leasing, and the model could be expanded to include grid-connected, utility controlled storage as well. This alternative model would promote direct, widespread customer engagement in helping to manifest the 21$^{st}$ Century grid.

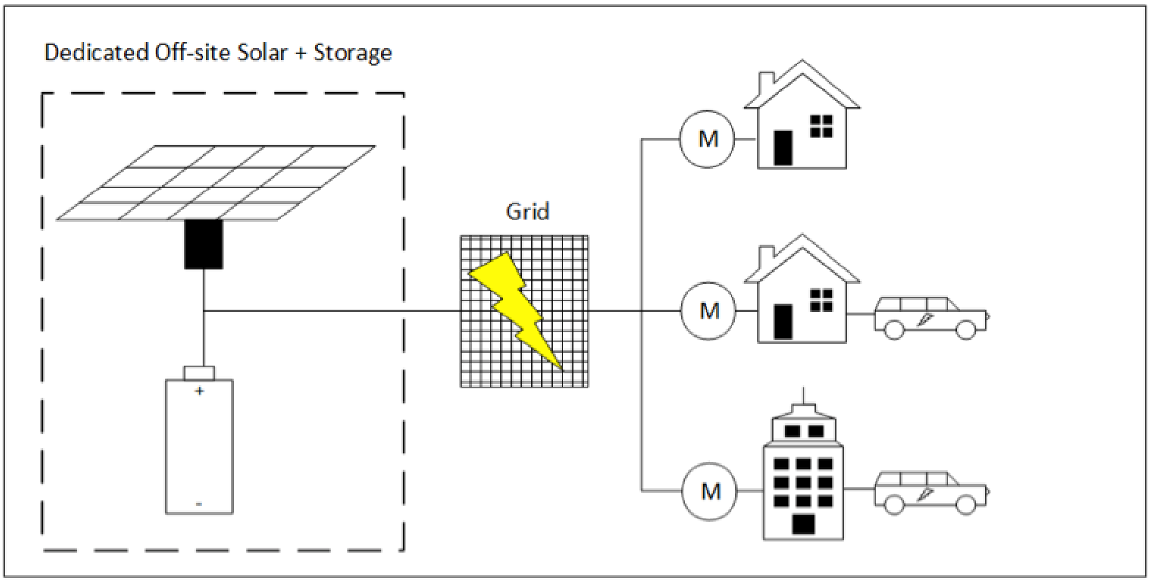

*Figure 5. Utility-side Solar Plus Storage Configuration*

## 6.2 Customer-side Storage Configurations

Here, the storage is provided on the customer side of the meter. These configurations include solar and storage that are integrated with each customer premise, or where a community solar array and storage system are integrated. There are many possible behind-the-meter storage configurations; here we consider a few of the most promising. Note that the opportunity to monetize different value streams does not mean that the project would be economical. In most cases today, solar plus battery storage still requires subsidy, either from a government program or from a business partner that sees value in being early to market. Further, there is always a customer segment of early adopters for batteries and EVs, but utilities are cautioned to perform market research before moving ahead. As noted earlier in this guide, thermal storage and DR options are relatively more mature and far more cost effective; they may be good choices for a first-generation solar plus storage or triple play project.

**Utility-side Solar Plus With Customer-side Storage**

In this configuration, shown in Figure 6, there is still a dedicated off-site community solar array, but each customer participating in the community solar program has a grid-tied, customer-side storage system. This could be in the form of batteries, such as a Tesla Powerwall, or thermal storage technologies, such as grid-interactive electric water heating, pre-cooling or ice cooling. The utility might serve as the aggregator of customer-side value streams, or it could work with a third-party aggregator. This configuration might also include controlled charging for electric vehicles or even a pilot bi-directional V2G system. It is a versatile configuration—the likely choice for many community solar plus programs.

The utility may select which value streams to tap, depending on its own interests and access to grid-services markets. Since the storage is on the customer side of the meter, the customer incentive to participate must be successful in order for grid-services value streams to flow.

From the customer perspective, there may be ready opportunities for demand-charge management, TOU rate arbitrage, power-quality enhancement, and back-up emergency power. Depending on the exact location of the solar array, this configuration is also well suited to ZNE community development.

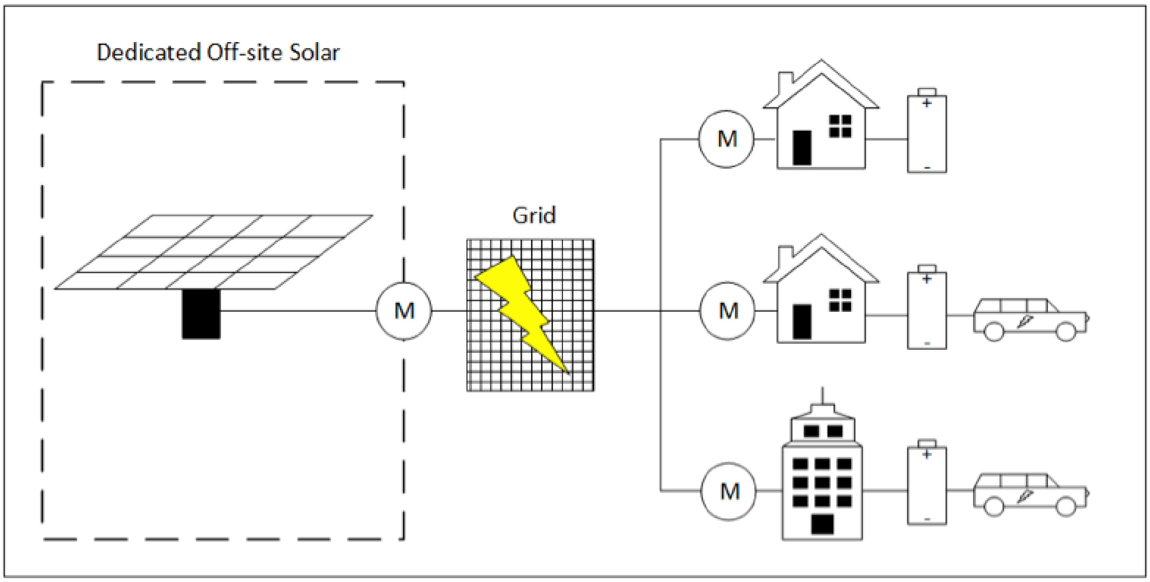


*Figure 6. Utility-side Solar Plus Customer-side Storage*

## Customer-side Integrated Solar Plus Storage

This model is not suited for a conventional community solar project, but it may support rooftop leasing options or group-buy solar programs. In this configuration, shown in Figure 7, both a solar array and storage system are integrated separately with each household or commercial customer. With this configuration, there is an added capability that each household could potentially island itself and operate completely off grid.

Utility benefits depend on strategic choices of which value streams to tap. With storage and solar on the customer side of the meter, the utility may be challenged to capture added value. However, utilities like Hawaiian Electric, which have severe grid constraints, may find that this configuration suits their needs. Depending on regulatory rules, the utility may aggregate customer grid services (from storage or DR), or it might work with a third party.

Typical customer-side value streams for this configuration include demand charge management, TOU rate arbitrage, power quality, and back-up emergency power. Individual customers may opt to island during emergencies or over a longer term.

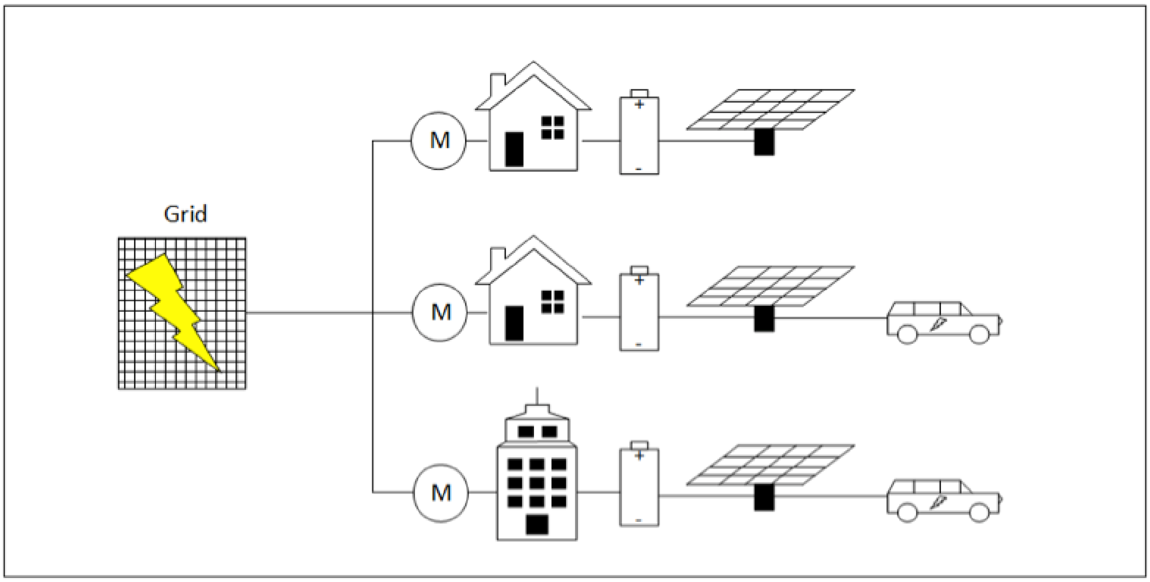


*Figure 7. Customer-Side Solar Plus Storage*

### Customer-side Integrated Solar Plus Storage as a Micro-grid

This configuration, shown in Figure 8, is very similar to the customer-side solar plus storage configuration, except that the entire community is metered in aggregate as a micro grid. It is assumed that battery storage is the primary storage technology choice, though other storage and DR technologies could be used. This configuration allows buildings within the community to share solar and storage resources, and therefore to provide islanding or backup power at a community level. This also could simplify aggregation for ancillary/grid services, increasing value to customers.

The local utility could benefit from ancillary services, but the extent depends in part on rules around working with the regional grid operator and third-party service aggregators. This configuration brings to the fore the question of why to solve integration problems locally. What is the benefit to the local utility of promoting a micro-grid project? It may provide distribution upgrade deferral and improve power quality and reliability on a particular circuit. More likely, the utility would support this configuration in order to serve customers that play a key role in a community resilience plan. Especially in the case of a regional emergency, the ability to serve critical loads in the community  could be highly valuable.

On a regular basis, customers could realize any of the full range of customer-side value streams: demand charge management, TOU rate arbitrage, power quality, backup power by household or community, micro-grid by household or community, ZNE household or community, or working with a third party aggregator, if available to monetize grid service value.

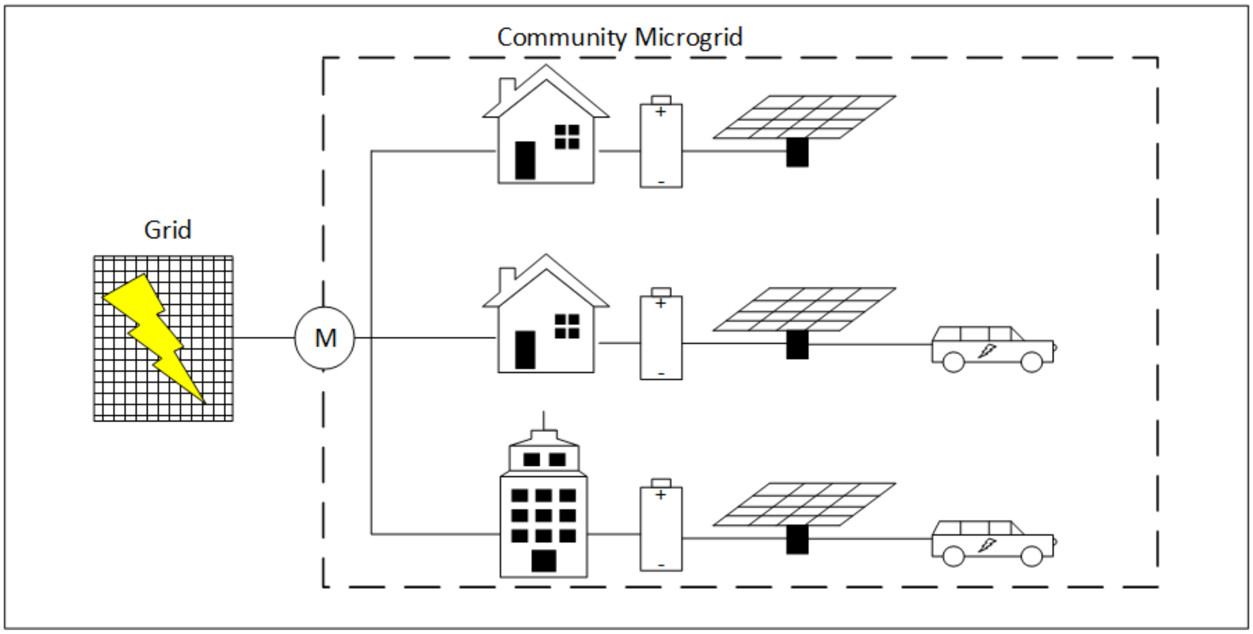


*Figure 8. Multi-Customer Integrated Solar Plus Storage, Operated as a Micro-grid*

## Community Micro-grid with Shared Solar Plus Storage

This configuration, shown in Figure 9, is very similar to the integrated solar plus storage configuration, above, except that the entire community is metered in aggregate as a micro-grid. It is assumed that battery storage is the primary storage technology choice, though other storage and DR technologies may be used. For example, this model could be adapted to a large-scale ground-source heat pump system with storage. The storage is operated for the advantage of all participants within the defined community.

This micro-grid configuration is similar to configuration with individual customer micro-grids, but having shared solar plus storage configured as a community micro-grid lowers costs and add community resilience benefits. At the same time, this means losing the potential for individual customer back-up power, islanding, or ZNE at the individual customer level.

Again, utility considerations would be similar to those for any micro-grid project. The shared solar configuration offers certain advantages in terms of solar siting, economy of scale, and O&M monitoring. If the utility is involved directly, it might prefer to work with this larger-scale solar option.

Customer benefits are also similar to those for the configurations above. These include demand charge management, TOU rate arbitrage, power quality, backup power by community, islanding by community, ZNE community, and marketing of grid services, if available.

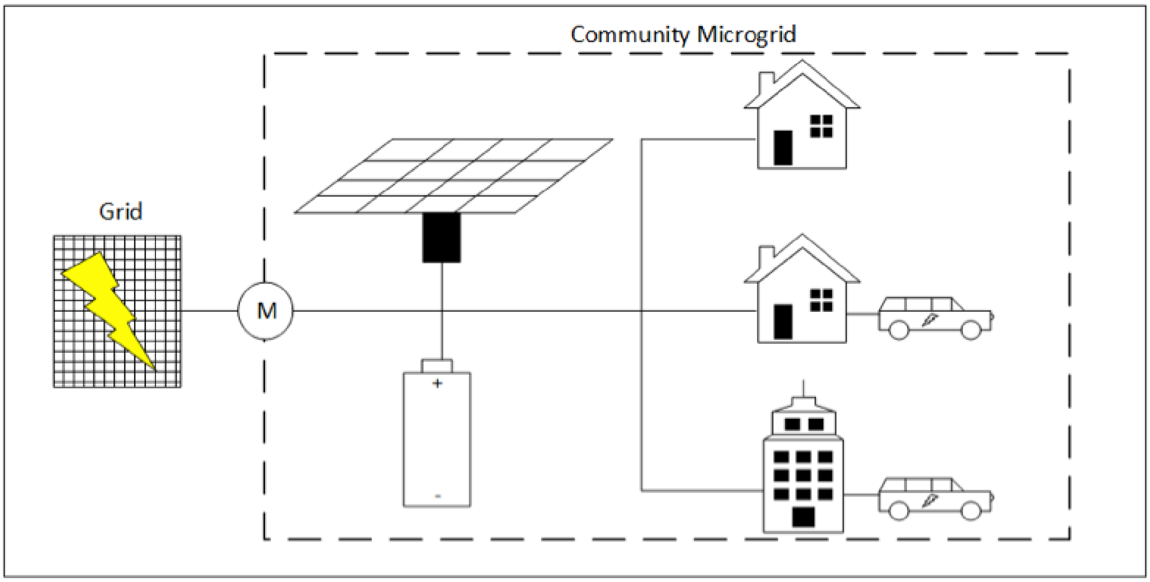


*Figure 9. Community Micro-grid with Shared Solar Plus Storage Configuration*

## 6.3 Summary: Matching Solar Plus Storage Configurations to Relevant Value Streams

The summary of solar plus storage configurations, matched against typically relevant value streams—shown in Table 2 below—indicates relatively few configurations where it would be impossible to tap any given value stream. One take-away is that these configurations are quite flexible, and that strategic program design is as important as the technical plan.

Section 7 will suggest how different technology choices—and different assumptions about how those technologies are used—would impact the full value available from a given solar plus configuration. In practice, some value streams are mutually limiting: For example, if a storage technology were used primarily for load shifting it might not be able to get a full charge in time to simultaneously participated in frequency regulation.

After fitting specific storage technologies into a given configuration, the choices that are most practical, customer-focused, and economical become clearer. For example, community solar plus customer-side batteries would not yield customer-side grid-service benefits *unless* the utility could incentivize customer participation and aggregate the desired grid services, directly or through a third-party that could monetize that value.

Utilities and third-party market players are still gaining early experience with solar plus configurations, so it is safe to assume that they will be looking for program designs that can scale up as they are tested and perfected. The benefit of using community solar plus storage as a market-based laboratory is that it is ideal for gaining real market experience on a limited, but scalable basis. Beyond load shifting, integration benefits could be estimated during the planning and approval stage, and then evaluated based on actual program performance. Whether or not the relevant regional balancing authority has a functioning market for grid services, the utility could gain experience with voluntary, community solar plus participants and assess the value of solving integration problems close to the source, on the distribution grid. Evolving programs could begin with a general, early-adopter market or they might target preparing for community emergencies, where resilient solar plus systems would have local value far beyond what markets typically would pay.

Of course, utilities and customers can access integration markets in some regions today. There, the appropriate test case might be for the utility to participate in the market on a limited scale, while planning for full, market-scale replication.

**Table 2. Summary of Solar Plus Configurations and Value Streams.**

| **Solar-Plus Configuration** | Utility-side Solar Plus Storage | Utility-Side Solar Plus Integrated Storage | Customer-side Integrated or Shared Solar Plus Storage | Micro-grid with Integrated Solar Plus Storage | Micro-grid with Shared Solar Plus Storage |
|---|---|---|---|---|---|
| **Utility-side Value Streams** | | | | | |
| Load shifting for eased ramp/peak, or arbitrage | √ | √ | √ | √ | √ |
| Transmission or distribution upgrade deferral | √ | √ | √ | √ | √ |
| Ancillary/grid services (Market dependent; may require aggregation) | √ | √ | √ | √ | √ |
| Demand charge management | N/A | √ | √ | √ | √ |
| **Customer-side Value Streams** | | | | | |
| TOU rate arbitrage | N/A | √ | √ | √ | √ |
| Power quality | N/A | √ | √ | √ | √ |
| Backup power | N/A | √ | √ | √ | √ |
| Micro-grid (Islanding) | N/A | N/A | √ | √ | √ |
| ZNE | √ | √ | √ | √ | √ |
| Grid-service aggregation | √ | √ | √ | √ | √ |

***(See Section 7, below for assumption that would apply to a generic utility- or customer-focused storage application. Different assumptions would impact how well a given solar-plus configuration would address different applications and value streams.)***

# 7 Scoring Technology Options

Given that several storage technologies could work within most of the configurations discussed above, Tables 3 and 5 are matrices, designed to help utility planners to focus on which options best match their specific integration needs. Table 3 matches storage options to utility-focused value streams and Table 5 matches storage options to customer-focused value streams. For each, scoring is based on assumptions that are described in Tables 4 and 6, respectively.

Looking first at Table 3, the value streams are ordered along the top horizontal axis, based on the approximate speed of response needed to realize the integration-value goal. On the vertical axis, technologies are listed in order, based on their ability to provide reliable capacity. For example, flywheels lose capacity quickly; EVs may, in aggregate, have considerable capacity, but bi-directional strategies are still emerging. Further, there are variations among the listed technologies. These include a range of stationary battery technologies and controlled thermal storage. Alternative assumptions about the technologies listed could change their integration-response characteristics. For example, the response times for thermal storage may be slower or faster, depending on the control technologies used.

As long as these storage options are grid-connected, the utility (and possibly the ISO) will reap benefits, but in working with highly distributed storage technologies, the customer will reap benefits, too. Table 5 takes the customer's viewpoint. Again, the value streams are ordered along the top horizontal axis, based on the approximate speed of response needed to achieve the integration goal. On the vertical axis, technologies are listed in order, based on their estimated ability to provide reliable capacity. Note that for a number of these technologies, individual systems must be aggregated in order to monetize their value. Grid-interactive storage water heaters, for example, may not bid resources into a regional market on a per-unit basis; they must be aggregated. Customer-side storage technologies represent a first line of cost-effective measures today, not only for the customer, but also for the utility/aggregator. Incentives provided by the utility to achieve utility-centric goals become an additional value stream for the customer.

After studying these sample matrices, we recommend customizing them, using utility-specific assumptions and prioritizing attainable value streams. This is important because (1) there are more variations in storage technologies than any one summary table can show, and (2) even if a given technology could tap several value streams in theory, in practice it would probably be directed to achieve at most a few integration goals. For example, if a battery is discharged to meet late afternoon peaks, it would not be available to provide ancillary/grid services during the same time frame.

This scoring process can give planners who do not customarily work on integration issues an introductory understanding. That would be useful for working with system engineers, who in turn may be fairly new to DER strategies. Many utility planners find that a scoring process like this helps them to build a case for promoting relatively low-cost customer-side storage, in cases where it might be just as effective as battery systems. The CSVP's utility-based engineering advisors have embraced the benefits of using thermal storage and DR, in order to assure that batteries could be available for challenges that specifically require electricity storage and dispatch.

However, not all utilities and not all customers can monetize all storage-technology value streams. First, the chosen technologies must fit into a viable solar plus configuration, as discussed above. Even then, planners must complete the program design, bringing targeted customers, technologies, configurations, and stakeholders together to actually develop and implement high-value strategies. Additional guidance on program design is included in Section 8.

**Table 3. Sample Scoring for Storage Options Focused on Utility Value Streams**

Fast Acting ⟵⟶ Slow Acting

| | | Frequency Regulation and Response | Voltage Support | Spinning and Non-spinning Reserves | Intra-Day Load Shifting | Black-start Support | Seasonal Load Shifting | Transmission and Distribution Upgrade Deferral |
|---|---|---|---|---|---|---|---|---|
| High Capacity | Pumped Hydro | ◔ | ◑ | ● | ● | ● | ◑ | ◔ |
| | Compressed Air | ◔ | ◑ | ● | ◕ | ○ | ○ | ◔ |
| | Thermal Storage | ◑ | ◑ | ◕ | ◕ | ○ | ○ | ◑ |
| | Batteries | ● | ● | ◕ | ◑ | ◔ | ◔ | ◕ |
| | Electric Vehicles | ◔ | ◔ | ◑ | ◕ | ○ | ○ | ◔ |
| Low Capacity | Flywheels | ◕ | ◕ | ◕ | ◔ | ◔ | ○ | ○ |

## Table 4. Definitions and Assumptions for Sample Scoring in Table 3, Storage Options Focused on Utility Value Streams

| Storage Technology | Definition and Assumptions Used in Table 7-1, Sample Scoring for Storage Options Focused on Utility Value Streams |
|---|---|
| Pumped Hydro | Most pumped hydro facilities are considered too large to be matched with community solar programs. Here, we assume a pumped hydro facility that would be shared between community solar and other uses. |
| Compressed Air | Compressed air technologies include industrial-scale devices using indoor tank storage and relatively rare, utility-scale facilities using underground caverns with appropriate geology. Similar scoring would apply to either approach. |
| Thermal Storage | Utilities can utilize large-scale thermal storage, such as molten salt; however, most utilities would opt for widely available and economic customer-side storage systems. Utilities can reap a range of benefits from these systems, depending on their market penetration. Scoring here is conservative due to the challenges of reaching full market penetration; however on a per-unit basis, value streams, especially including load shifting, are great. |
| Batteries | Utilities can reap integration benefits, whether deploying batteries on the utility side of the meter or on the customer side of the meter. On the utility side, we assume lithium ion battery systems with at least 500-kW capacity, located strategically on the distribution grid. On the customer-side of the meter, lithium ion battery systems comparable to the Tesla Powerwall are aggregated and controlled by the utility. Customers also would reap value from customer-sited systems, as indicated in the Table below. We urge program planner to investigate multiple vendors and technologies, as the market is changing rapidly. |
| Electric Vehicles | Smart charging of electric vehicles enables the utility to time charging to match grid conditions, including periods of high solar generation. Various controls and incentives may be used, with customers benefitting as well. Current EV technology provides an opportunity for most utilities; similarly, uncontrolled charging would be a significant risk. As this market is still evolving, we assume a relatively small, aggregated fleet, deployed in a market-based test. Bi-directional EVs, which can supply power to the grid, are not considered in this sample case, as market-based testing programs are still rare. |
| Flywheels | We assume behind-the-meter flywheels in industrial facilities, controlled by the utility to reap integration benefits. Participating customers can tap value streams from demand management and other incentives. |

**Table 5. Sample Scoring for Storage Options Focused on Customer Value Streams**

Short Duration ⟵⟶ Long Duration

| | | Power Quality | Grid Services | Demand Charge Managem | TOU Rate Arbitrage | Backup Power | Micro-grid | Zero Net Energy |
|---|---|---|---|---|---|---|---|---|
| High Capacity | Thermal Storage—Refrigeration Ice Storage | ○ | ◔ | ◑ | ● | ○ | ◔ | ◑ |
| | Thermal Storage—Ice for Cool/AC Storage | ◑ | ◑ | ◕ | ● | ○ | ◔ | ◑ |
| | Thermal Storage—Water Heating | ◑ | ◕ | ◑ | ● | ○ | ◔ | ◑ |
| | Thermal Storage—Chilled Water | ◔ | ◔ | ◕ | ● | ○ | ◔ | ◑ |
| | Batteries | ◕ | ● | ● | ◕ | ◕ | ◕ | ◑ |
| | Electric Vehicles | ○ | ◑ | ◑ | ◕ | ◔ | ◔ | ◔ |
| | Building Pre-Cooling/AC Control | ○ | ○ | ◕ | ◑ | ○ | ◔ | ◔ |
| Low Capacity | Flywheels | ◕ | ● | ◔ | ◔ | ◑ | ◑ | ◔ |

## Table 6. Definitions and Assumptions for Sample Scoring in Table 5, Storage Options Focused on Customer Value Streams

| Storage Technology | Definitions and Assumptions Used in Table 7-3, Sample Scoring for Storage Options Focused on Customer Value Streams |
|---|---|
| Electric Water Heater – Grid Interactive (GIWH) | Assume use of new residential GIWHs of 55 gallons or more, or smaller, older units that are retrofitted. Most early-market evaluations support use of broadband/wi-fi, bi-directional control signals. For demand charge management, other load profiles also must be considered. In addition to load-shifting, frequency regulation and grid stabilization are achieved. |
| Thermal Storage – Refrigeration Ice Storage | We assume use of ice storage units large enough to meet all commercial refrigeration needs of a supermarket for at least six hours on a summer day. Axiom is a market leader. Grocery store loads are relatively stable, but capabilities for demand-charge management should be evaluated. While ice systems can provide ancillary/grid services, that use could limit the systems primary, load-shifting capabilities. |
| Thermal Storage – Ice Storage for Air Conditioning | This sample case assumes commercial-building cool storage, using readily available package units; ice is typically made in off-peak times, and it is melted to meet cooling load when power is costly. Residential ice storage is also available. Assumes AC is a likely driver of demand charges; load profiles of other loads also must be considered. The technology has frequency regulation capability, and fleet-wide control may allow aggregated load following. However, use for ancillary/grid services could limit load-shifting capabilities, which are likely to be most valuable. Ice Energy is a market leader. |
| Thermal Storage – Cold Water Storage for Air Conditioning | The most common form of cool storage in commercial buildings with central chillers stores extra mass of cold water in large tanks. Water is chilled when power is inexpensive, and used to meet cooling load when power is expensive. Assumes AC is a likely driver of demand charges; load profiles of other loads also must be considered. When storage space is scarce, these systems can be complemented with ice making equipment. CALMAC is a market leader. |
| Batteries | Stationary batteries are often considered the standard against which other technologies' integration value is measured. There are multiple chemistries, configurations, and sizing options for customer-side batteries. We assume lithium ion batteries similar to those used by market leading vendors. Planners should explore multiple vendors, as the market is changing rapidly. |
| Electric Vehicles | Assume smart charging of electric vehicles enables the customer to time vehicle charging in response to TOU rates or other incentives. Opportunities to provide additional grid services with bi-directional controls are considered to be just emerging. Scores are likely to improve as the market develops. |
| Pre-cooling of buildings/AC control | Assume buildings with good insulation and significant thermal mass; poorly insulated buildings are unsuitable for pre-cooling. Note an overlap with advanced AC demand response controls. |
| Flywheels | Assume behind-the-meter flywheels in industrial facilities (the most common use case). New market entrant Amber Kinetics has introduced more general purpose flywheel applications. |

# 8 Program Design Considerations

Recalling the planning steps introduced in Section 3, number of non-technical, strategic considerations come in—both at the beginning and the end of the process (Figure 15, below). At the front end, the utility must have answered the questions, why storage, and why now? The answers should help the planner envision a program that begins on a relatively limited scale, such as a community solar program that builds out a fleet and takes on more solar plus customers over time. Given the way storage and DER markets are fast-evolving, it is wise to consider a program design that will grow in stages. It is also wise to consider a program design that is not shackled to a pilot, but rather grows seamlessly into market-scale deployment. One thing that is known about the fast-evolving storage market is that it is here—in some form—to stay.

Program design comes to the forefront after the technologies are selected and configurations are prioritized. In fact, program-related market research should be part of the earlier process, as well. What is the anticipated customer-acceptance for a given technology or configuration? Does the utility have a tentative site for the solar project? Will the utility be installing one or more large-scale utility-side storage projects, or is the utility planning to offer customer-side storage measures? What is the likely customer response to different alternatives? What terms and pricing are most likely to support program success? CSVP has proposed a complete program-design process, which can encompass the steps for solar-plus technology selection and project configuration. This process is illustrated in Figure 15.

If the utility is drawn to the utility-side solar-plus-storage configuration, then program design for the community solar program will need a solar-plus narrative that passes along “virtual storage benefits,” rather than hands-on customer-side storage experience. This is entirely plausible. Austin Energy currently has co-located a community solar project with battery storage, though storage benefits are not explicitly part of its community solar offer. Arguably, the utility could extend the community solar offer and attract participants in return for a share of solar *and* storage benefits. This seems most workable around the concept of solar plus storage for community resilience; such projects are under discussion in several states.

However, the thrust of this guide is planning for solar plus storage programs that include some element of customer-side storage, whether that is a solar plus grid-integrated water heater program or a solar plus electric vehicles program, or a program that incorporates customer-side batteries, under at least partial utility control. These options are readily characterized as “companion measures,” which has been the focus of the CSVP.

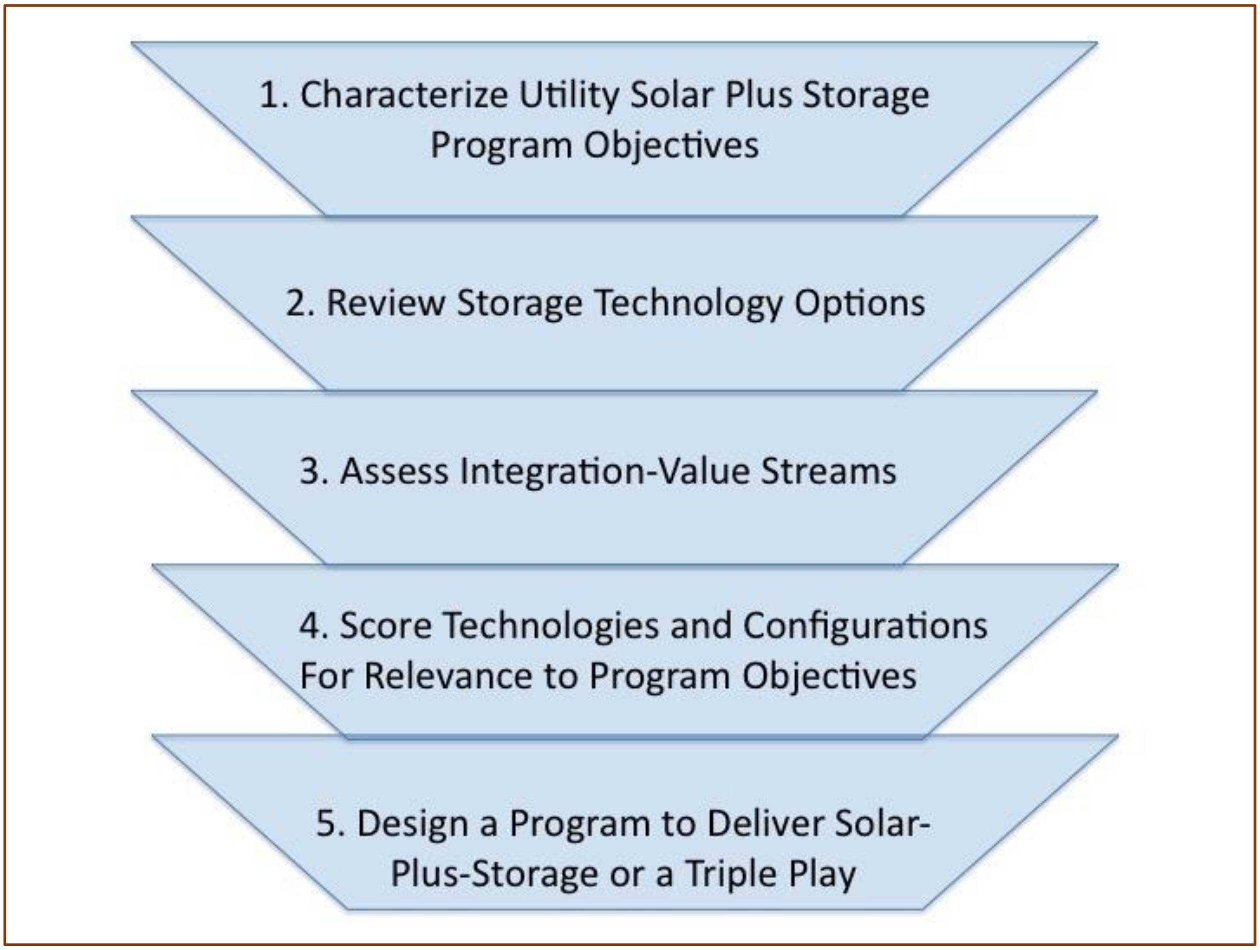


*Figure 15. CSVP Steps in the Solar-Plus Storage Planning Process*

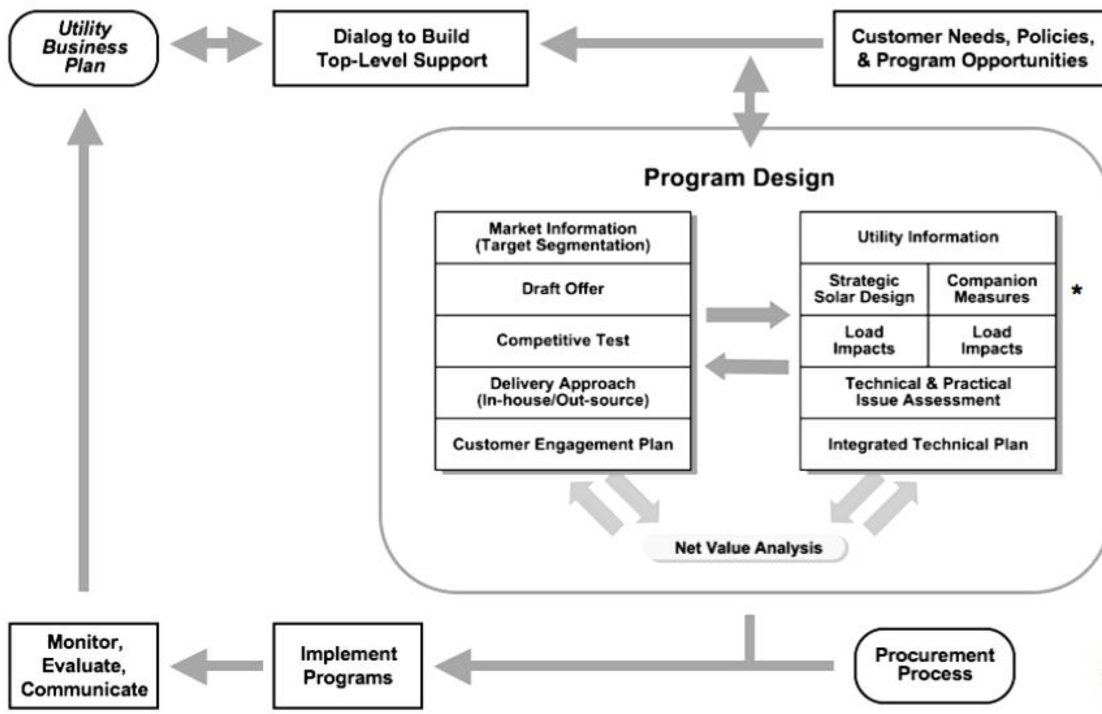


*Figure 16. CSVP Planning Process for Community Solar Plus Storage Companion Measures*

In Figure 16, the balance between customer-side program-design elements and utility-side considerations is clearly illustrated. As a process focused on community solar, the program design steps related to companion measures could be ignored, but this guide is focused *on just those steps*, diving deeper into the technical storage options, assessment of load impacts, technical and practical issue assessment and development of a solar-plus net value analysis. The result is what CSVP has called *high-value community solar*, with the inclusion of companion measures.

While this guide does not focus on the program-design process itself, a few observations should be evident:

1. Development of a technical plan that includes DERs will only be successful when customer-side issues and opportunities are also considered.

2. The program-design process is iterative and collaborative: The program designer must work cross-departmentally and respect the importance of each utility stakeholder perspective.

3. The steps in strategic program design are consistent and proven. A review of all program-design resources on the CSVP website is recommended.

4. Here, the utility-side options might include a customer-engaged community solar program. Or that choice could be simplified by focusing on storage and DR measures that are used to balance the utility's *community-scale solar*, not necessarily offered

for direct customer participation as a community-solar offer. In other words, utility planners must decide, early on, where their priorities lie. Community solar plus efforts, such as demonstrated by the Steele Waseca Electric Cooperative in Minnesota, show that model as fully market-ready and attractive. Still, utilities have options in how they design their specific program.

## 8.1 Program-Design Considerations Specific to Storage

Some program-design questions are specific to programs with storage measures. These questions vary regionally and can be regulatory- or market-related. Below, we summarize some of these questions, with comments on how they might be addressed.

**The Case for Integrated Solar Plus Storage**

Implied in the short list of observations above is a question: How integrated will the solar and storage measures be? If, for example, the utility decides it will market test storage measures separately from a community solar program offer, then that decision has strong implications for target market segmentation, incentive development and delivery, economics, and monitoring and evaluation. The case for packaging community solar together with storage and/or DR measures is worth considering. For one thing, market research data from the Smart Grid Consumer Collaborative (SGCC) and other sources suggests that several of the same customer target groups are interested in both smart-grid technologies and PV (SGCC, 2015). Considering that the cost of customer-acquisition is one of the biggest soft costs for either community solar or storage program implementation, it makes sense to potentially double the value of each customer contact and capitalize on the excitement and accessibility that is already associated with community solar.

Still, this observation comes with the caveat that some micro-market segments are more interested in personal control or savings, and other micro-market segments are more interested in the environmental and community-oriented aspects of an offer. This is true whether the offer is for community solar alone, storage alone, or solar-plus storage. Market research is key to any program's success.

**Using an Iterative Program-Design Process**

As indicated above, the CSVP program-design process requires cross-departmental collaboration, in which participants with customer-focused expertise and utility-operations expertise regularly meet and come to agreement on strategies that work for both sides. It is helpful to review the CSVP Program Design summary guide (a presentation-format report, available from CSVP), which provides touch-points for that process.

**Planning for Existing and Emerging Markets**

Another key question pertains to the ability to monetize integration value streams in existing and emerging markets. Upon a full review of value streams that are available to utilities and customers today, CSVP has concluded that the most widely available and readily monetized applications have to do with load shifting, TOU rate arbitrage, demand-charge management, and other energy-related functions. This is especially true for using relatively low-cost measures, such as GIWH and ice storage and DR strategies. Such strategies represent a first-line actions to manage loads cost-effectively and to ensure that battery storage and other costlier or more environmentally concerning approaches are put the their best use. Further, by balancing system loads—lowering peaks and easing ramp rates—storage technologies can help reduce the utility's exposure to grid-service issues. These eliminate the need to go to markets for some grid services and, in effect, "solve problems closer to the source." The results include reducing the technical and economic risks inherent in relying on regional markets.

Market readiness is still an important consideration. Early in the planning process, utilities must consider their regional and state regulatory regimes, including relationships that may exist between consumer-owned utilities and their power suppliers and any changes they might anticipate. Many of the grid services derived from storage require automated control from the local utility, power supplier, regional ISO, or a DR aggregator. In many cases, state law and regulation dictate which options are available. Even if choices are available, participating in one control strategy may limit the program from using another control strategy. For example, a storage resource being used for a utility-run DR program likely will not be able to bid other services into the wholesale market.

This does not mean that strategies aimed at market values are ill-advised. One take-away from the discussion of technology choices and alternative solar plus configurations is that most of these are flexible. By incorporating solar plus storage measures into a DER plan, a utility has options to capture values both today and in the future, even if this means running a different control strategy as customer use patterns and markets change.

Some issues related to monetizing solar-plus storage or DR value have to do with the siloing of utility programs by regulators or by the utility itself. For example, if a utility is required to meet targets for DR and can rate base certain DR costs, then the accounting for such programs is likely going to be kept separate. The challenges of running an integrated DER program, including how to identify and categorize synergistic effects, can be resolved. But they will challenge utility planners and other stakeholders for years to come.

CSVP underscores the viability of a market-laboratory approach—e.g., focusing on an almost universal value stream, like load shifting, while evaluating how the storage configuration also could yield grid service value. Chances are that markets will be developing everywhere in coming years, whether they will monetize values locally or regionally, or both. The utility that knows how to approach customers with a storage option will be ahead of the game and ready to grow its program to an impactful (and economic) scale.

### Economics of Different Storage Options

Storage project economics depend greatly upon the configurations applied and value streams available. Thus, the tools for assessing storage projects are still evolving. CSVP points readers to some of these tools in *CSVP Resource Links for Solar Plus Storage* (Cliburn et al., 2017). In particular, one tool, the ReOpt model from NREL, is roughly compatible with the popular System Advisor Model (SAM) for solar, and it is emerging as a leading tool for solar plus storage assessment. (National Renewable Energy Laboratory, 2017b) The Clean Energy States Alliance (http://www.cesa.org), which is a center for the Energy Storage Technology Advancement Partnership, also offers up to date information for planners who need to assess storage system economics.

In particular, stationery battery storage projects to date have been supported with research and development funding assistance. In 2009, the U.S. DOE put $185 million from the American Recovery and Reinvestment Act (ARRA) into funding for energy storage projects. This triggered some 500 MW in various technical pilots, including utility-side battery demonstrations.

Besides applying the investment tax credit (ITC) on qualifying projects, most sponsors for battery projects today look to state funding incentives to help close a steadily narrowing, yet persistent cost-effectiveness gap. This includes a $10 million round, recently announced for the Massachusetts Energy Storage Initiative or latest round of California's massive Self-Generation Incentive Program (SGIP). That program will put nearly $400 million into storage incentives for commercial and residential customers through 2019. Utilities that are interested in battery storage programs on any scale would be wise to look into whatever incentives and special financing are available.

By comparison, customer-side thermal storage projects remain at the forefront for cost-effectiveness for both the utility and its customer participants. Many economic analysts anticipate increasing cost-competition among battery and non-battery options, but there should be reasons to justify either in suitable settings for decades to come.

To get a feel for the relationship between value streams and net storage benefits, we refer to an overview of results from the 2016 LCOE study of specific storage use cases from Lazard, shown in Figures 12 and 13 below (Lazard, 2016).

While other studies have estimated the cost of each storage technology at a given point in time, few have provided specific assumptions that produce reasonably comparable LCOE results (See Appendix A for Lazard assumptions; data used by permission). The authors of the Lazard study use somewhat unique terminology for each storage application, but the presentation is compatible with that presented in this guide. Note that storage costs have been changing rapidly; utility planners are cautioned to check current prices before estimating actual project economics.

## 8.2 Conclusion

There are inevitable challenges to high-penetration renewables integration, which utilities can only address through experience in an actual market setting, working with customers and collaborative partners under real-world supply and demand conditions. Yet markets for integration value *per se* are still forming today. The situation is anything but hopeless; the fact is that high-value solutions to relatively straightforward problems—such as the need to smooth the "duck curve"—are ready today. Because of their inherent flexibility, many of these solutions could be applied to more advanced integration problems as markets evolve and change.

A primary objective for solar plus storage programs should be to learn to solve more integration problems close to home. This would minimize the local utility's exposure to regional reliability risks and risks related inevitable price and supply swings in regional ISO markets. For some utilities, there are also benefits in strengthening relationships with customers. As utility planners get started, they will see ways to unlock untapped value streams, improving storage economics for the utility and its customers.

Lessons about assessing storage technologies and configurations, and about fitting these into a successful utility program design, will be useful to utility planners whether or not they choose to match community solar directly with storage and/or DR companion measures. Yet the case for deploying *local community solar* together with storage and/or DR measures is worth considering.

Utilities realize that no single resource or technology can meet the multifaceted needs of tomorrow's utility customers. Centralized energy resources are increasingly likely to be complemented by a local, DER approach. This would include integrated generation and storage options, with advanced controls and price signals for DR, plus energy efficiency and infrastructure improvements. Introducing community solar with companion measures can engage customers directly with this emerging 21$^{st}$ Century utility model. The community solar plus storage model can be a scalable, market-based laboratory for utilities working in partnership with customers and third-party innovators as they all learn to succeed in a fast-changing market.

This guide is an introduction for utility planners to lead one aspect of a far-reaching and profound transformation in the way we generate, distribute, and use electricity. The authors fully anticipate that planners will take exception to some of the best practices cultivated from industry progress on solar-plus strategies so far, in order to implement new solutions. Over the course of our work with a dozen members in the CSVP Utility Forum and our broader experience working in this industry, we have learned to expect unexpected innovations from all corners of the field. We welcome reader comments and suggestions for future updates of this guide.

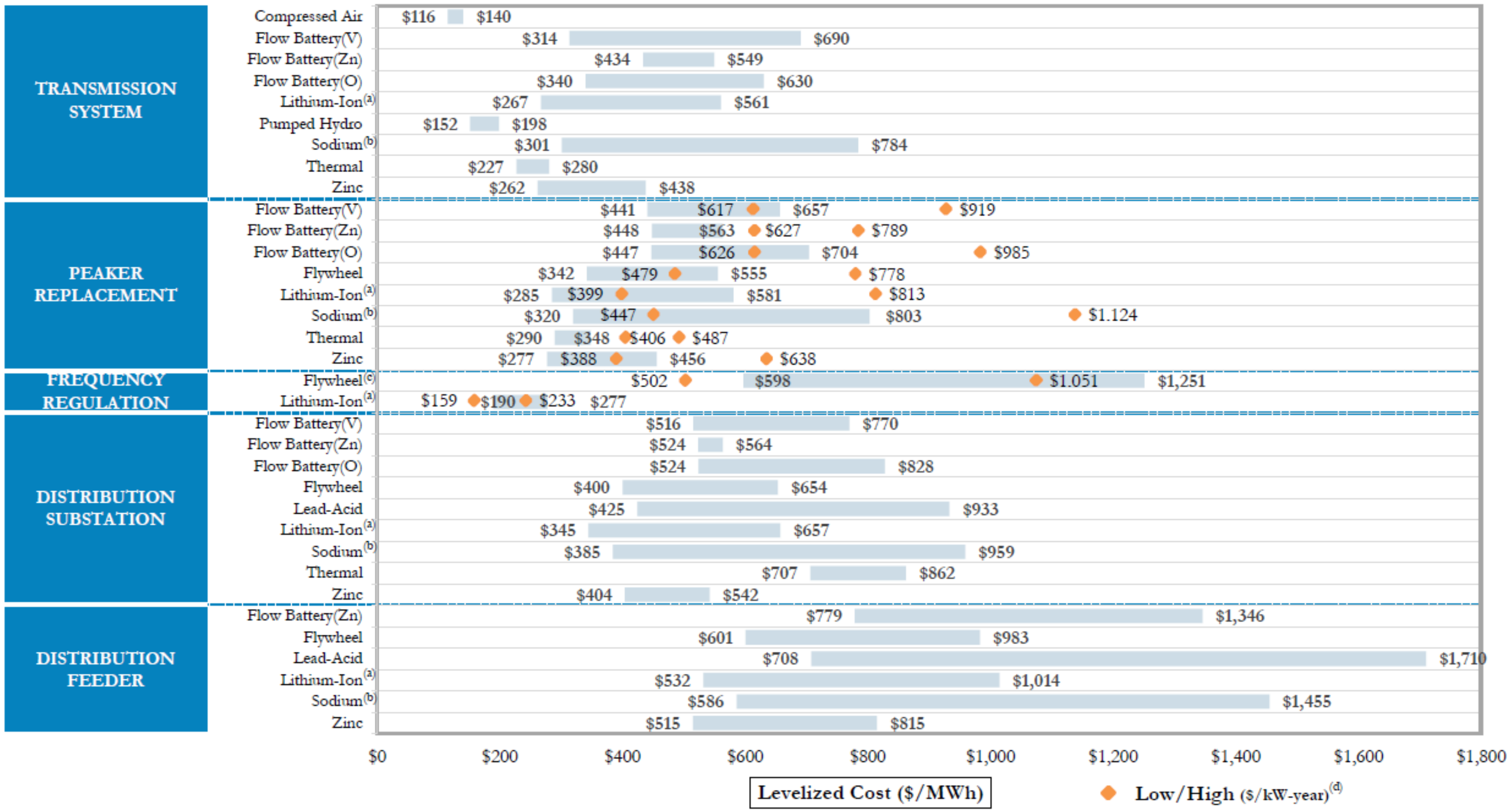


*Figure 12. LCOE of Storage Technologies in Different Siting Regimes on the Utility Side of the Meter (Source: Lazard, 2016, by permission)*

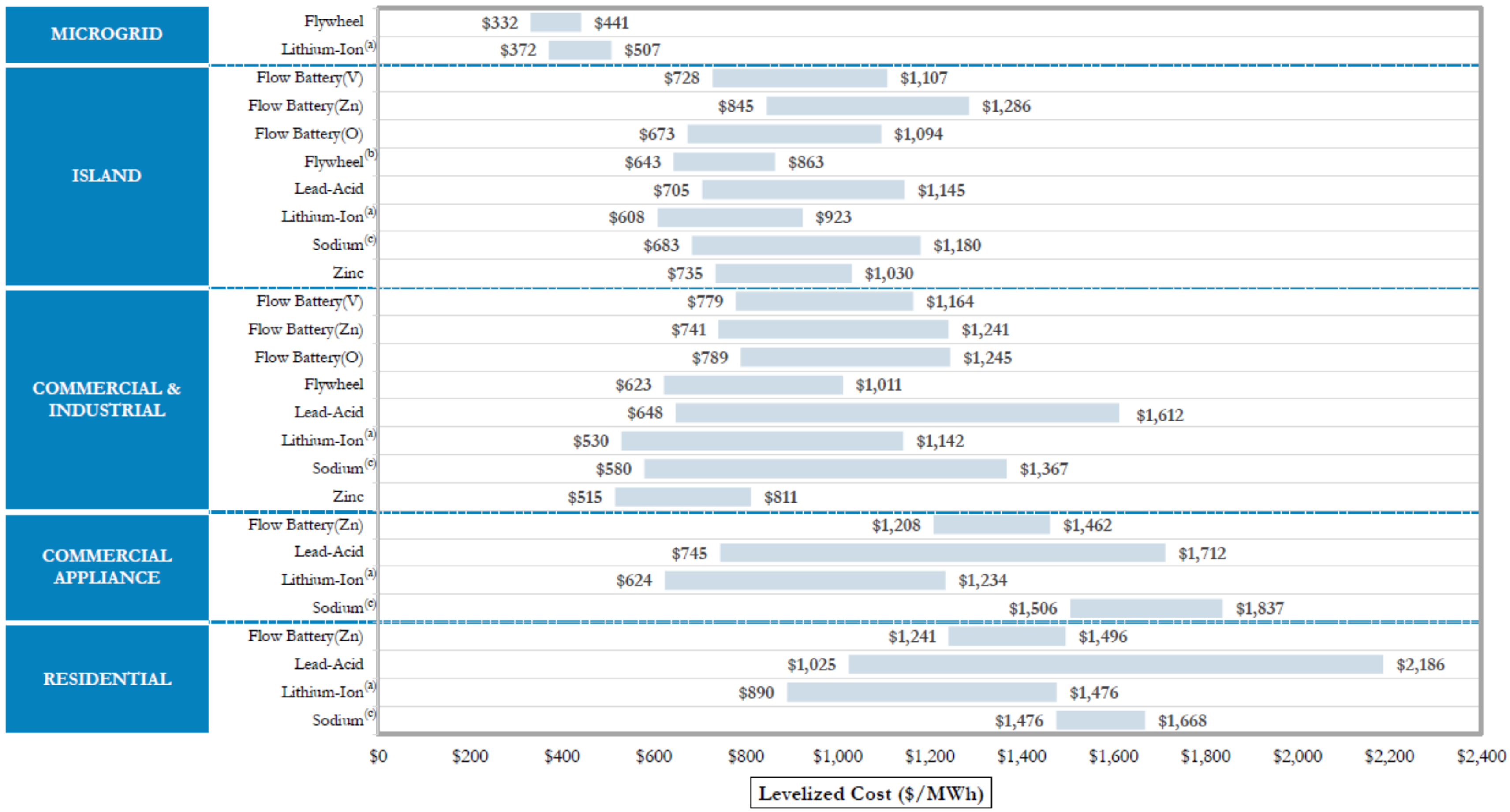


*Figure 13. LCOE of Storage Technologies in Different Siting Regimes on the Customer-side of the Meter (Source: Lazard, 2016, by permission)*

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# Appendix A

| | PROJECT LIFE (YEARS) | MW[a] | MWh OF CAPACITY[b] | 100% DOD CYCLES/ DAY[c] | DAYS / YEAR[d] | ANNUAL MWh | PROJECT MWh |
|---|---|---|---|---|---|---|---|
| TRANSMISSION SYSTEM | 20 | 100 | 800 | 1 | 350 | 280,000 | 5,600,000 |
| PEAKER REPLACEMENT | 20 | 100 | 400 | 1 | 350 | 140,000 | 2,800,000 |
| FREQUENCY REGULATION | 10 | 10 | 5 | 4.8 | 350 | 8,400 | 84,000 |
| DISTRIBUTION SUBSTATION | 20 | 4 | 16 | 1 | 300 | 4,800 | 96,000 |
| DISTRIBUTION FEEDER | 20 | 0.5 | 1.5 | 1 | 200 | 300 | 6,000 |
| MICROGRID | 20 | 2 | 2 | 2 | 350 | 1,400 | 28,000 |
| ISLAND GRID | 20 | 1 | 8 | 1 | 350 | 2,800 | 56,000 |
| COMMERCIAL & INDUSTRIAL | 10 | 0.5 | 2 | 1 | 250 | 500 | 5,000 |
| COMMERCIAL APPLIANCE | 10 | 0.1 | 0.2 | 1 | 250 | 50 | 500 |
| RESIDENTIAL | 10 | 0.005 | 0.01 | 1 | 250 | 2.5 | 25 |

[dashed box] = "Usable Energy"[e]

(a) Indicates power rating of system (i.e., system size).
(b) Indicates total battery energy content on a single, 100% charge, or "usable energy." Usable energy divided by power rating (in MW) reflects hourly duration of system.
(c) "DOD" denotes depth of battery discharge (i.e., the percent of the battery's energy content that is discharged). Depth of discharge of 100% indicates that a fully charged battery discharges all of its energy. For example, a battery that cycles 48 times per day with a 10% depth of discharge would be rated at 4.8 100% DOD Cycles per Day.
(d) Indicates number of days of system operation per calendar year.
(e) Usable energy indicates energy stored and able to be dispatched from system.

*Figure 14. Assumptions. (Source: Lazard, 2016)*

Figure 14 shows the most important assumptions employed in the study (Lazard, 2016) discussed in Section 8. Without such information, it is impossible to interpret the headline numbers often used in common references to the cost of storage technologies. A cost for batteries at $x/kWh, should always be viewed skeptically until assumptions are checked, regarding how a specific battery technology would be operated.