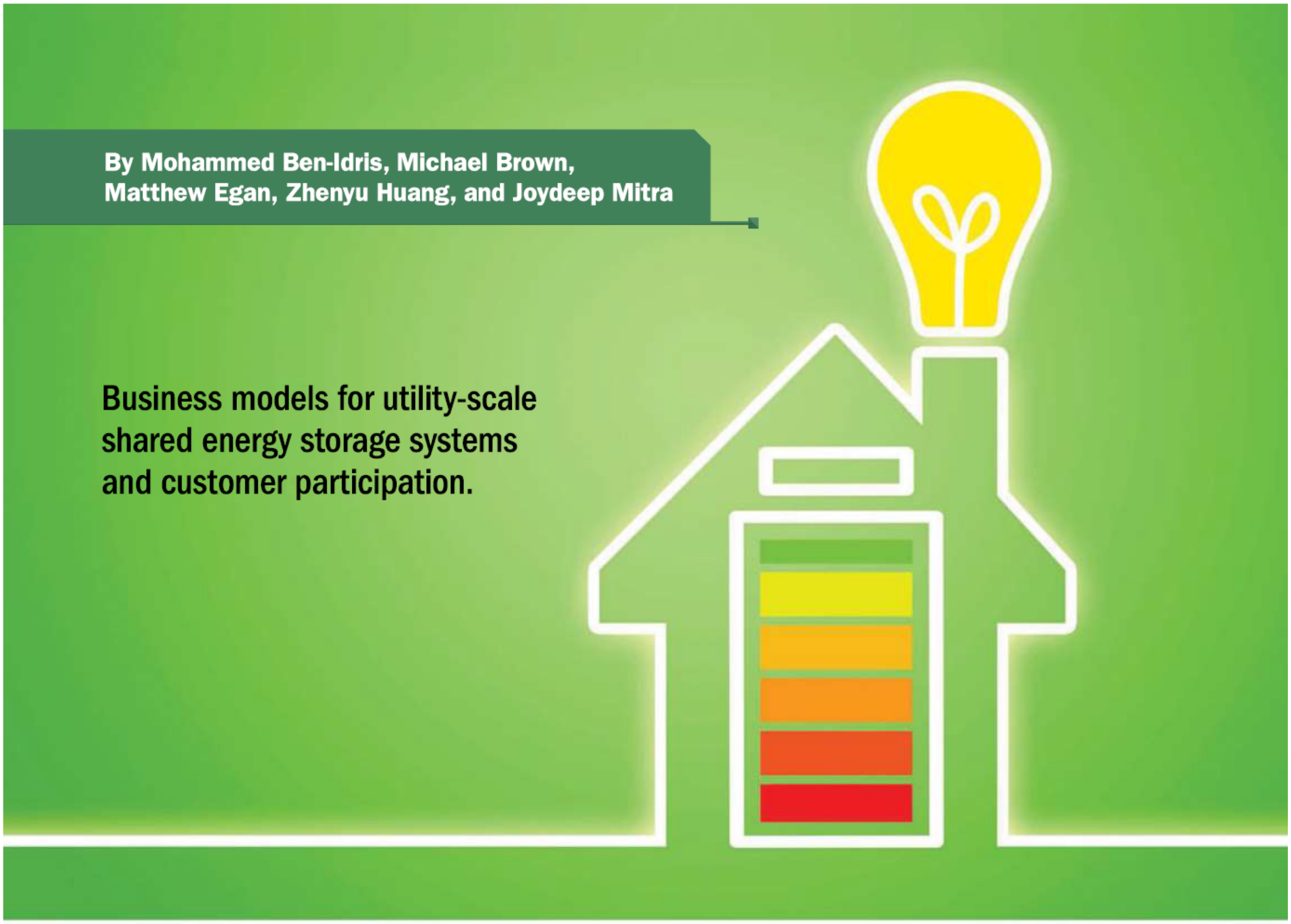

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Business models for utility-scale shared energy storage systems and customer participation.

Utility-Scale Shared Energy Storage

DUE TO CLIMATE CHANGE, SUPPLY SCARCITY, and society's desire to expand access to electricity and improve energy-system resilience, there has been an increasing demand to invest in and use renewable energy sources (RESs) that are environmentally friendly, efficient, sustainable, and affordable. This has diversified and decentralized energy sources and increased their penetration. However, the variability and intermittency of RESs has introduced new challenges to power system operators, such as the requirement for high ramping rates when solar energy declines in the afternoon, known colloquially as the *duck curve*, voltage and frequency fluctuations, and reduced overall system inertia. In response to these challenges, energy storage systems (ESSs) (devices such as batteries, energy management, and energy conditioning) have become crucial components to the reliable and stable operation of modern power systems. ESSs can tackle the aforementioned challenges to seamlessly integrate RESs into the power grid. They can help system operators to smooth the output power of RESs and provide grid services, such as voltage and frequency regulation, peak load shaving, phase balancing, energy arbitrage, expansion deferral, and so on.

ESS sizes range from large-scale storage systems, such as pumped-storage hydropower (PSH), to small batteries

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installed in home appliances. Each type and size of ESS has specific uses, operation requirements, and challenges. In this article, we discuss the utility-scale shared energy storage (USES) battery systems that are operated by a distribution utility and available for use by customers under various business models—not to be confused with community energy storage systems (CESs). USES systems provide fractional storage to customers under various metering, pricing, and billing approaches. Generally, there are three levels of battery-type ESSs that have been used at the distribution-system level: at-home, CES, and USES. ESSs at home can be either directly behind the meter (BTM) or at the point of connection for home appliances. CESs are usually installed at the secondary side of distribution transformers and used by groups of customers (e.g., homes on a residential feeder and commercial buildings). USES systems are much larger than CESs and installed at the substation. They are usually owned by utilities or investors. Figure 1 shows the applications of battery ESSs at different levels of an example distribution system.

USES systems provide many advantages over CES and BTM storage systems: USES systems are more flexible and less expensive than other types of ESSs for comparable sizes, can offer grid service at scale, improve grid reliability and resilience at scale, and reduce fire and other hazards in homes. Photovoltaic (PV) owners and other community members can purchase a fractional portion of a USES system to help manage their premise load and electricity bill. This fractional portion operates as a virtual storage block allocated for customer use. However, there are many challenges in the development of USES systems. These challenges include developing technology and business processes that effectively manage energy flows for both customer use and grid services use cases. The principle among the challenges is to determine the optimal charging/discharging schedules for the virtual storage blocks and the battery as a whole while considering both the customer rate structure and the economic value derived from grid services.

History

As mentioned previously, a variety of ESSs have been used at different levels. The choice of a given energy storage device depends on the needed application, although here we are mostly interested in the grid applications that provide grid services, and at the customer side, for demand flexibility. Large storage systems, including pumped hydrostorage and compressed-air energy storage, have been developed and deployed for decades. However, until

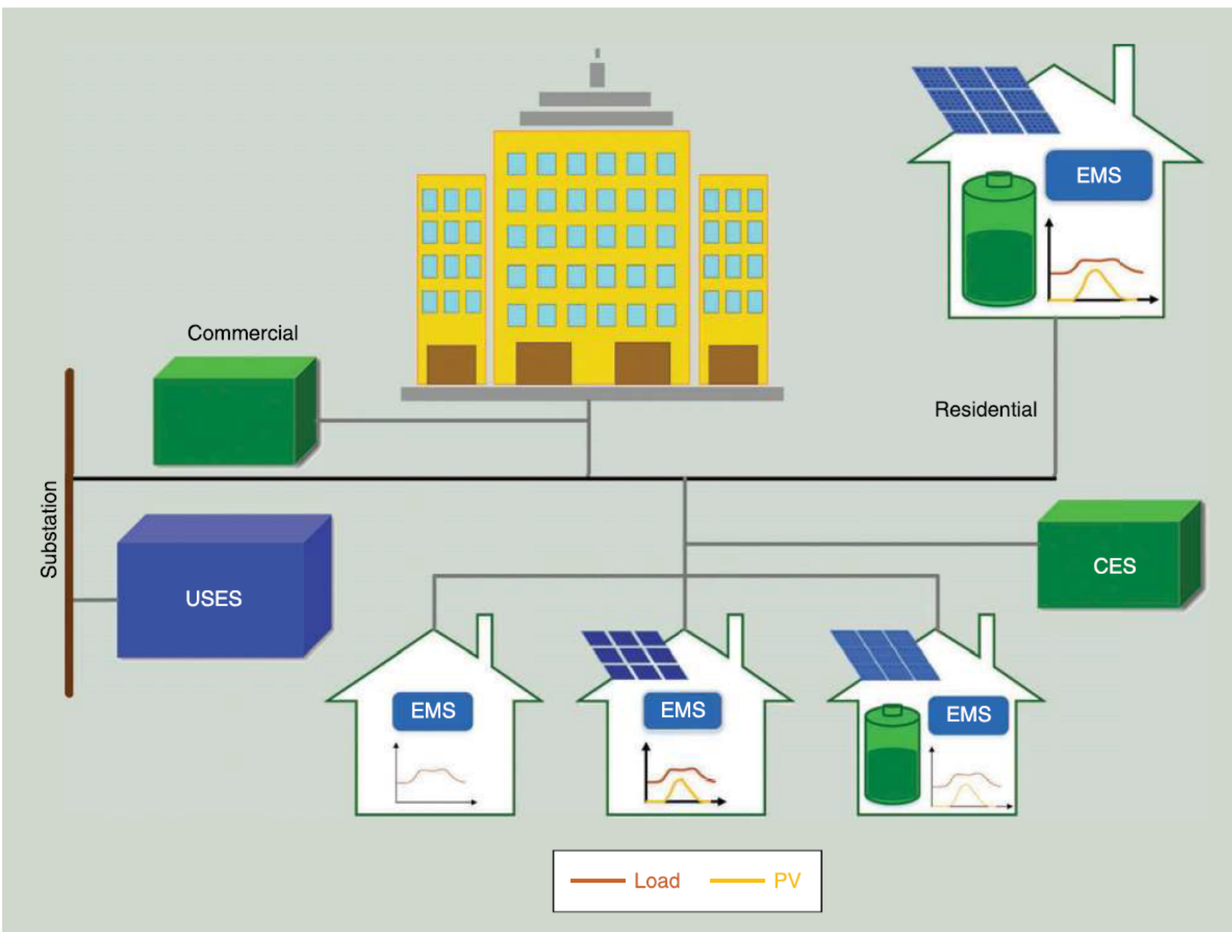

Figure 1. The applications of (battery) ESSs at different levels: USES, CES, and local residential and commercial ESSs.

recently, battery applications have been limited to small-scale usages such as uninterruptible power supplies, back-up in some applications, bridging with backup generators, at-home applications, auxiliary services at power plants, and so forth. Large-scale applications, such as grid- and utility-scale batteries, have been mostly in lab development up until the past decade.

The last 10 years have yielded an exponential increase in the manufacturing and installation of large-scale batteries. The main technologies in use have been sodium-sulfur, vanadium-redox, lithium-ion (Li-ion), and lead-acid batteries. For example, a 200-MW/800-MWh, vanadium-redox flow battery-storage project is under construction in Dalian, China, and will be the world's largest battery-storage facility when completed. Li-ion batteries are widely used and applied in a significant majority of grid-scale, battery-storage projects. The world's largest solar (850 MW) and battery system (531 MW/2,125 MWh) has been approved for construction in the desert north of Las Vegas, Nevada—there is some opposition due to its environmental impact as well as it being an eyesore to local residents. In large-scale energy storage deployment, the state of California was the first to reach gigawatt-scale deployment and achieved its 2020 1,325-MW energy-storage goal ahead of schedule. California further projected 55,000 MW of new storage by 2045. Arizona Public Service is planning to install 850 MW of storage by 2025. Southern California Edition (195 MW) and Pacific Gas and Electric (567.5 MW) have received approvals from the California Public Utilities Commission to build storage facilities.

Publicly available data from the U.S. Energy Information Administration regarding battery storage only go as far back as 2003, when the largest—and only—battery facility in the United States had a nameplate rating of 27 MW in the battery ESSs in Alaska. Within the past 10 years, large-scale batteries have been installed at an exponential rate, as depicted in Figure 2. They went from being installed in only two facilities with nameplate capacities under 30 MW in 2010, to having more than 1.5 GW of nameplate capacity at more than 230 locations in only 10 years. This was driven largely by the falling costs of batteries, which went from prohibitively expensive at more than US$1,000 per kWh, to under US$200 over the same decade. Therefore, from an economic perspective, it only makes more sense to install storage systems in a fashion similar to the precipitous decline in price for PV solar panels.

Financial and Operational Challenges

Although USES systems offer control and management flexibility for system operators and equity and affordability for customers, many challenges remain for the widespread application and utilization of USES systems. The biggest challenges relate to the management of energy storage, distribution, degradation, and ownership, which can result in greater financial benefits or in burdens for the utility and customers. One of the biggest hurdles in executing USES systems is developing and employing business models that not only manage bills and agreements between utilities and users but also allow utilities and communities to benefit from energy charging/discharging to provide a stable and resilient power supply and necessary grid services. Although seemingly complex by design, only a few studies have made efforts to design a business model for shared battery storage.

Besides the economic considerations, challenges with USES also arise from an operational perspective. USES offers multiple potential applications, including firming renewable generation, supporting frequency and voltage profiles, mitigating transient stability, providing local black-start capabilities, enabling energy arbitrage, and enhancing demand response. These applications are achieved at various time frames and need to be carefully managed so that the state-of-charge (SoC) of the battery system is maintained at an optimal level to enable these applications when needed. These can often create a conflict for the stored energy among the intended applications. For example, the battery should have an adequate SoC level when an outage occurs and black start is called for, charging and discharging rooms should be reserved so that the battery can absorb or release energy in the range of renewable variations the battery intends to mitigate, and the inverter control should be designed to manage multiple functions and coordinate competing objectives. Although none of these needs are mutually exclusive, they can be close to zero sum as prioritizing one need may come at the cost of another. Ultimately, all of these applications translate into financial terms, as either gained benefits or incurred costs in the pursuit of an optimal solution. These costs and benefits should be properly assessed and represented in the business model for optimal financial performance and, more importantly, provide incentives for USES to offer these applications for any and all interested customers.

Environmental Challenges

Operational challenges are relatively well understood within the industry, but there is no product without its

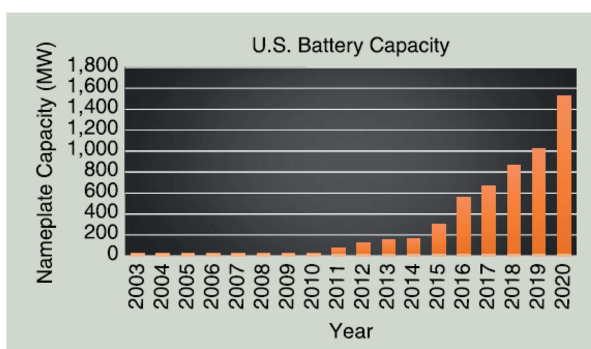

Figure 2. The reported battery USES growth in the United States in the past 20 years. The information was gathered from publicly available U.S. Energy Information Administration data obtained from utility companies.

externalities. USES systems do have them, and they are worth noting. The two main forms of battery storage are Li-ion and lead acid. Lead-acid batteries have very clear disadvantages as they are from one of the most hazardous metals known to humanity. Li-ion batteries, on the other hand, do not have the same health drawbacks that come from lead-acid batteries, or from their disposal. Their difficulties lie on the other end of the supply chain.

An ESS can be utilized to store energy during off-peak hours and then discharges at peak demand periods for peak shaving or load following.

Li-ion batteries, the main form of battery storage for USES, can create significant environmental damage during the procurement and extraction of lithium. Current lithium mining techniques involve both strip and brine mining. Strip mining involves the stripping of a mountain or landscape to find the minerals underneath. This can be very difficult for plants and animals, especially the endangered species that may rely on elements in the area. Brine mining can have just as significant an impact as strip mining, although not in the same way. It is a system wherein aquifers are deliberately drained and allowed to evaporate so that the minerals within it can be extracted. Brine mining can be damaging to water-scarce areas, such as the American Southwest, which may need that water for agriculture, conservation, or domestic uses.

This is seen especially in the Thacker Pass project, which has faced heavy backlash from environmentalists over concerns for local species, which live on top of what is one of the largest proven reserves of lithium in the United States. This can cause cognitive dissonance for environmentally minded utilities, which may rightly see the benefits that USES can give to improving the viability of renewables, but also do not wish to see more immediate harm come to ecologically significant areas or to endangered species.

None of this is to say that large-scale batteries would do more harm than good. There are clear and observable benefits to using more storage, which has helped make things such as solar and wind generation far more viable components of the grid. It is only to say that policy should be directed in a considered manner for the pros and cons of each energy storage method.

Services From USES Systems and Value Proposition

USES systems can provide grid services and various forms of support at the distribution level. These include energy services (energy time shift and supply capacity), ancillary services (regulation, voltage support, and so on), transmission and distribution (T&D) infrastructure services (T&D upgrade deferral, transmission congestion relief, and so forth), and customer energy-management services (power quality, demand charge management, and so on). We discuss some of these services in the following sections.

Reliability Services: Outage Mitigation

Service interruptions can be caused by many events, such as failures of generating units, or T&D components such as transformers, lines, and feeders. In such situations, a USES can effectively support customer loads when a partial or complete loss of power from the source utility takes place. Sometimes, due to the capacity constraint, it might not be possible for a USES to mitigate the outage completely. However, for such an event, it can shorten the interruption duration or reduce the number of interrupted customers. Blocks can also be appropriately allocated to customers based on load criticality to provide a framework that supports reliability-differentiated services. USES also creates a better opportunity to recover from said outages, as unlike traditional turbine systems, they are able to come back online very rapidly, allowing for local microgrid creation, which can supply critical loads while the grid at-large comes back online.

Energy Arbitrage

An ESS can be utilized to store energy during off-peak hours and then discharges at peak demand periods for peak shaving or load following. This helps to reduce the generation cost and postpone the need for peaking units. It is also profitable for the energy storage owners as they can take advantage of the energy price difference. In competitive markets, locational marginal prices (LMPs) indicate the value of energy at different locations and points of time. To benefit from this application, the USES can be charged at off-peak hours or with less-expensive energy, and discharged during peak hours or when LMPs are high. The locations with large variability in LMPs will generally provide higher margins.

Frequency Regulation

Energy storage is also well suited for frequency regulation. Frequency regulation helps to maintain grid frequency within specified limits and comply with the Real Power Balancing Control Performance (BAL001) and Disturbance Control Performance (BAL002) Standards of the North American Electric Reliability Corporation (NERC) or any other relevant governing agency. The system's frequency tends to deviate from the specified value as generation and load imbalances occur during normal operation. Traditionally, several generator actions are taken to restore and maintain frequency within the normal operating range. These include primary, secondary, and tertiary frequency control and response times, which range from a few seconds to several minutes. A USES can help in such a situation, either by acting as an extra load to lower the frequency when supply exceeds demand, or to discharge when demand exceeds supply. Suitably interfaced, it can be twice as effective in regulation compared to conventional fossil fuel generators such as coal units and combustion turbines.

The aforementioned services have often been used to quantify the "payback" of USES installations, although in many cases, the payback has been lower than the investment cost. Perhaps the most lucrative service has been that of frequency regulation. PJM Interconnect has been a leading driver in this space, initially remunerating generous amounts in capacity and performance payments. However, other markets have been slow to follow, and the payouts have declined as the proliferation has increased. Yet it is perhaps unfair to judge the value of USES installations based on payback alone. There are several other services that are very beneficial to the system, but the impact on payback is hard to determine.

Other Services and Benefits

USES can also be used for various other applications that are crucial to the power grid in several ways, but they might be difficult to demonstrate in terms of monetary benefits. These applications can be classified according to the customers being served, e.g., residential, commercial, or industrial customers. The following are a few of these applications:

- *Voltage-flicker mitigation*: Voltage flicker is often a problem that needs to be addressed in power distribution systems. It is harmful for customers of all load profiles. Voltage flicker might damage electrical devices ranging from the most common household appliances household to industrial-scale equipment. It might also lead to spoilage from semifinished industrial products. Thankfully, USES can help stabilize the voltage by charging or discharging within a very short time, thus protecting the customer's equipment.
- *Power-factor improvement*: This problem is mostly applicable to industrial customers that use a significant amount of reactive power for their daily operation. In most of the cases, they are charged with a penalty from the utility serving them if the power factor goes below a prespecified limit. These customers can greatly benefit from the presence of USES, which can act similarly to supercapacitors by providing reactive power while also providing more general uses.
- *T&D upgrade deferral*: USES can also be used for the deferral of T&D system upgrades. It can help in delaying investments that would otherwise be necessary to maintain the T&D capacity in accordance with the load demand. For example, the purchase of a new transformer with a high capacity may be avoided by using a USES instead.
- *Voltage-regulator lifetime extension*: The addition of distributed generation, e.g., PV or wind power to a feeder in the distribution system, might decrease the lifetime of a voltage regulator due to a rise in the number of tap changes with an increase in voltage fluctuation. If USES is suitably used to smooth variability, then it can reduce the number of tap changes of the regulator by reducing the voltage fluctuation, thus extending its lifetime.
- *Emission reduction*: Climate change and global warming are matters of concern, especially with regards to emissions from fossil fuel plants. Thermal power plants across the world are among the largest consumers of fossil fuels. The generation of renewable resources and their integration into the grid reduces emissions and the burning of conventional fuels. USES can accumulate clean energy at off-peak hours, e.g., when wind power generation is high at night, while load demand is low, and then discharges it at peak hours, thus improving its effectiveness at reducing emissions.

Business Models

USES systems have gained significant momentum to provide opportunities for owners of RESs to lease portions of their storage instead of buying individual ESSs. In this context, new multiuse business models, which utilize battery storage for different grid services and improve power supply reliability and resilience for local communities, are needed to increase economic benefits for USES owners (e.g., utilities) and customers with BTM distributed energy resources (DERs). In theory, USES can provide many benefits for individual households and the community. For example, blackouts and shortages due to extreme weather conditions can be mitigated with an ESS. However, before this scheme can be implemented, utilities, investors, and community members need to know how to assess its costs and benefits. As mentioned previously, developing and employing business models for USES systems can be a challenge due to complicated interactions between utilities, system operators, and BTM participants. Also, USES can provide several benefits to both utilities and investors (e.g., BTM participants) with different perspectives, which can introduce conflicting objectives. For utilities, the benefits can include increasing the hosting capacities of distribution systems to electric vehicles and high penetration of RESs, deferral of distribution system expansion, and fewer communication requirements as communicating with one point at the substation level requires less communication than communicating with many ESSs at homes or BTM devices.

Grid operators can utilize USES systems to provide grid services at scale, including frequency regulation, voltage control, and demand-side management. For investors, USES systems can provide an affordable and safe energy storage through leasing blocks of the shared energy storage; this is extremely important for the occupants of multifamily buildings and tenants. Such an offering would also benefit property owners through a reduced maintenance burden. This fee may be similar in nature to already-existing renewable energy fees, wherein ratepayers who wish to ensure that they are funding reliable technologies will pay a premium. For this case, it may be necessary to have a certain amount of power reserved to shorten an outage or to allow for a flatter rate overall. This may appeal to risk-averse ratepayers who would rather not have to worry about how costs vary with the time of day or how temporary faults may affect the grid around them.

USES systems can provide revenue for both the utility and customers through energy arbitrage, which can be managed through business models and agreements. Under the existing cost structure, ESSs have been deployed to only provide grid services that utilize less than 50% of the total battery lifetime capacity, which cannot justify economic benefits to owners and investors. To fully utilize USES systems, their use and benefits can be managed through storage-leasing agreements.

Building and implementing business models for USES requires the consideration of stakeholder perspectives, including customer, regulatory, and utility perspectives.

Utilities need to adapt business, financial, and process models for a mass-market, energy-storage-as-a-service (ESaaS) business model for utility-owned USES systems. One ESaaS model candidate that is under investigation by NV Energy—a vertically integrated utility in Nevada—includes a fixed fee for a managed services offering in which customers pay the utility a calculated monthly fee per virtual storage block on a subscription basis. This particular model uses ESaaS as one component in an overall Integrated Services Bundle (ISB) in which the customer takes service under a particular rate, and the utility uses targeted demand management to achieve both customer bill savings and the provision of grid services. The EsaaS customer payments contribute to recovering the installed equipment cost plus the allowed return on capital, and ongoing maintenance. This approach reduces the utility rate-base requirement and minimizes or eliminates cross subsidization from other customers.

There may also be a justification, both in public relations and in the aforementioned savings to upgrading systems, to simply include energy storage in the general cost of electricity. This may be best implemented in remote areas that suffer from low voltages at peak loads. This would help to lower the stress or sag on transmission lines. This can be done in a way similar to how utilities may already require customers to install capacitors as methods of power-factor correction. This would, of course, require a significant amount of analysis on the cost of power line upgrades versus the cost of battery installation, especially if it would require hiring outside firms for the management of said batteries, but it is only likely to become more viable as the cost of batteries drops.

The utilities would need to work with local government and regulatory stakeholders to reach a consensus on the business models that are compatible with the utility's regulatory compact, and identify the changes (if necessary) to existing franchise agreements. Working with local governments, business models for USES systems can be designed to accelerate the clean energy transition and carbon-reduction goals among the mass-market customers that do not have access to the financial or technical resources required to dramatically expand energy efficiency, load flexibility, and site-renewable energy.

Customer Willingness to Participate in USES

Building and implementing business models for USES requires the consideration of stakeholder perspectives, including customer, regulatory, and utility perspectives. The following sections further review the ESaaS and ISB approach under development at NV Energy with partners at University of Nevada, Reno (UNR), University of Nevada, Las Vegas (UNLV), and Evolution Networks under contract to the U.S. Department of Energy. It includes a discussion of product development criteria as well as survey data collected from customers of NV Energy in Nevada to determine their willingness to participate in grid services and lease blocks of USES.

Integrated Service Bundle

One of the approaches to consider when developing ESaaS products is to include them in a tailored ISB that provides positive perceived use value to customers through a bundle of financial and environmental benefits.

NV Energy started research into an ISB developed for single family residential customers with rooftop solar tailored to its regulatory environment that includes:

- *Dynamic rate*: a dispatchable, time-varying rate treatment with a demand component that provides pricing signals intended to align consumption patterns with electric grid costs and support nonwire solutions.
- *ESaaS*: a low-cost, virtual storage offering to further enhance the customer's ability to derive savings from the rate treatment.
- *Grid service payments*: the opportunity to earn money by allowing their DER devices to participate in the grid service set.
- *Home-automation gateway*: a premise hardware gateway that integrates into the customer's DERs to enable the aforementioned offerings via intelligent agent software while also providing added convenience features in the form of a home-automation gateway, which the customer can use for a wide variety of both energy and nonenergy-related automation functions.

Customer Criteria

The overall value proposition (of the ISB), considering the tradeoffs associated with making and receiving payments and receiving enabling technology (e.g., automation devices), must generate positive, customer-perceived value that includes financial savings. Each element of the service bundle should be designed such that the service 1) is easily understood by customers, 2) has demonstrable perceived use value, 3) has sufficient customer demand, 4) is congruent with customer willingness to pay, 5) does not present an unacceptable level of risk, and 6) is fair and transparent.

Building USES projects includes customer market research to determine whether there is sufficient market demand among customers for ESaaS and grid services. The service elements must also meet a series of regulatory requirements.

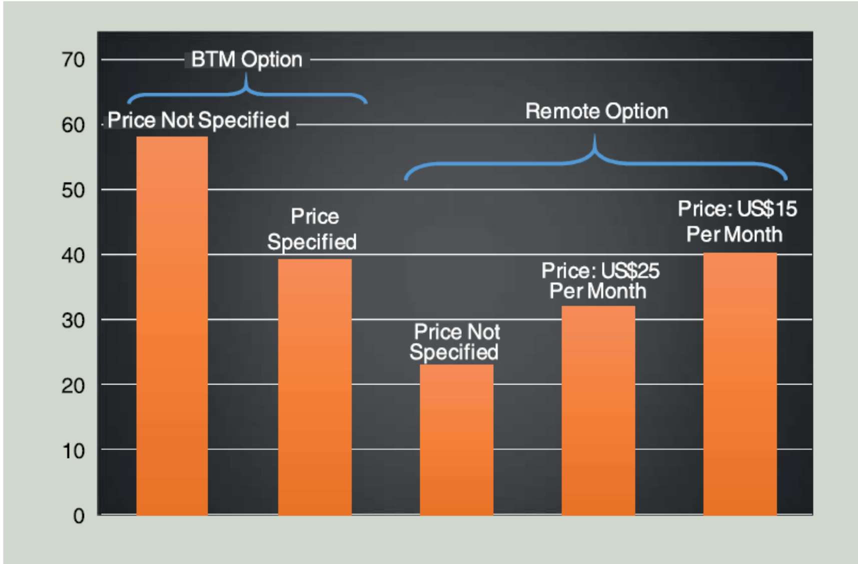

Figure 3. Customer willingness to participate in ESaaS for BTM and remote options (i.e., shared energy storage option).

Regulatory Criteria

From a regulatory perspective, service elements must satisfy a series of requirements, which include 1) compliance with existing regulations; 2) responsiveness to local government policy directions; 3) no returns that exceed an allowed rate of return; 4) no unreasonable costs for ratepayers, yet comprising a positive benefit-to-cost ratio; 5) no unreasonable risks for ratepayers; 6) usefulness and helpfulness to fulfill resource adequacy and operational needs; and 6) consistency with the overall resource plan. Electric utilities must prove that these requirements are met via a series of regulatory assessments and filings.

Utility Criteria

Utility criteria focus on operational and economic considerations. At a minimum, the introduced system must not generate unacceptable physical, cyber, or information security risks. It is also important that they comply with NERC's Critical Infrastructure Protection reliability standards and do not generate unacceptable levels of project cost recovery risk. It is essential that they provide a clear and observable benefit to grid management and/or quality and integrate effectively with both existing and future enterprise systems.

Customer Market Research

As mentioned previously, executing USES projects should include customer market research, which can be done through conducting surveys and analyzing customers' responses. A survey conducted by NV Energy to determine whether customer and owners of BTM PV systems and other DERs are willing to participate in and utilize USES systems has revealed the following.

Across a range of adoption and program scenarios that included options for utility-owned and managed BTM storage and remote "virtual" storage, the survey validates that monthly energy bill reduction is the top driver of DER adoption. For the BTM configuration, when price and savings were not specified, 58% of survey respondents said they "definitely" or "probably" would participate in an ESaaS offering. That level dropped to 39% when price and savings were specified and there was no statistically significant difference across either the price or savings levels tested.

For the remote configuration, when price and savings were not specified, 23% of survey respondents said they "definitely" or "probably" would participate. That level increased to 32% when price was specified at US$25 per month and further increased to 40% when price was specified at US$15 per month. There was no statistically

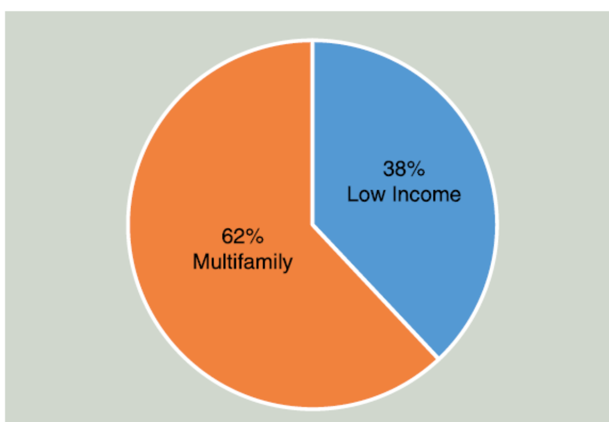

Figure 4. The willingness of multifamily and low-income customers to participate in ESaaS.

significant difference across the saving levels tested. The results of customer willingness to participate in ESaaS for both BTM and remote (virtual) options are summarized in Figure 3.

An examination of the demographic data revealed large differences in the percentage of customers who "definitely" or "probably" would participate in a shared energy storage offering (see Figure 4). Low-income and multifamily customers (38 and 62%, respectively) expressed the highest levels of interest; however, the sample size of the solar-adopting multifamily group was low (n=8) and merits further research to validate statistically significant differences from the single-family group. The research suggests that remote virtual storage, although quite attractive for single-family customers with high-energy bills, is probably more attractive for low-income and multifamily customers; hence, NV Energy expanded their initial development efforts to include an ISB approach for multi-family and low-income customers without existing rooftop solar or storage, which is less technologically complex and provides a simplified billing based approach for the ESaaS component in the form of a storage share, similar to a program developed at Sacramento Municipal Utility District.

Among storage adopters, 74% of respondents said they "definitely" or "probably" would participate in a grid service offering. The respondents expressed that a performance-based compensation methodology was the top choice, along with a discounted electricity rate. The performance-based methodology was explained as a "payment per unit of energy drawn from the battery."

Conclusion

The development and deployment of grid- and utility-scale battery ESSs have been exponentially increasing over the last decade as a result of several factors, including advancements in fabrication materials for batteries and the need to smooth the variability of RESs. Specifically, the applications of USES systems have been on the rise because they provide flexibility and controllability for both grid operators and customers. Power grid operators can use USES systems in several grid services (e.g., frequency and voltage regulation, resource adequacy, energy arbitrage, and the deferral of system upgrades) with less communication and control requirements than CESs and BTM storage. Also, customers can lease blocks of USES systems instead of installing local batteries that can be costly, inflexible, and introduce hazard concerns. In addition to these benefits, USES systems provide equity, reliability, and resiliency to local communities. However, USES systems still face several challenges, including building business models that can accurately capture charging/discharging costs and benefits, designing control systems capable of optimizing and prioritizing specific grid services with customer needs, and developing tools to improve the round-trip efficiency of USES systems and reduce losses in the grid due to charging/discharging actions initiated by customers.

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For Further Reading

"Form EIA-860 detailed data with previous form data (EIA-860A/860B)," The U.S. Energy Information Administration, Washington, D.C. Accessed: Sept. 15, 2021. [Online]. Available: https://www.eia.gov/electricity/data/eia860/

Y. Tian, A. Bera, M. Benidris, and J. Mitra, "Stacked revenue and technical benefits of a grid-connected energy storage system," *IEEE Trans. Ind. Appl.*, vol. 54, no. 4, pp. 3034–3043, July/Aug. 2018. doi: 10.1109/TIA.2018.2825303.

P. Denholm et al., "The value of energy storage for grid applications," National Renewable Energy Laboratory, Golden, CO, Tech. Rep. NREL/TP-6A20-58465, May 2013. [Online]. Available: https://www.nrel.gov/docs/fy13osti/58465.pdf

"Community batteries: A cost/benefit analysis," Australian National University, Canberra. Accessed: Aug. 15, 2021. [Online]. Available: https://arena.gov.au/assets/2020/08/community-batteries-cost-benefit-analysis.pdf

California Public Utilities Commission. https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-orders-clean-energy-procurement-to-ensure-electric-grid-reliability (accessed Oct. 10, 2021).

P. Pettingill, "Ensuring RA in future high VG scenarios – A view from CA," in *Proc. ESIG Spring Workshop*, Apr. 10, 2020. Accessed Oct. 10, 2021. [Online]. Available: https://www.esig.energy/event/2020-spring-technical-workshop/

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