Facility Scale Energy Storage: Applications, Technologies, and Barriers

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ABSTRACT

High demand charges and lucrative demand response programs have many large facilities considering the deployment of energy storage technologies. Technologies developed for facility- and campus-scale energy storage are now proven solutions for managing short-term demand peaks as well as longer-period demand response events.

The paper's authors have investigated facility/campus-scale energy storage for efficiency program administrators in the US and recently completed a storage technology research report for an international consortium of utilities. This work has identified promising avenues for distributed storage. Currently, facility-scale storage has three primary applications: power quality, bridging power, and energy management. All three of these uses inform the development of strategies for utilizing distributed storage for successful power continuity and demand management strategies.

This paper will present the technical properties of current energy storage technologies, and the technical and market barriers associated with distributed storage.

INTRODUCTION

Modern energy storage originated at the grid scale in the mid-1920s in the form of pumped hydro storage in order to provide a means of shifting electricity from periods of low demand to periods of high demand [1]. Little research was devoted to energy storage applications from that time until the 1990s, when the Sandia National Laboratory (SNL) identified and documented thirteen ways that utilities could use energy storage. Finally, during the summer of 2013, SNL released an updated electricity storage handbook detailing additional uses for energy storage–specifically, behind-the-meter, customer applications [1]. The focus of this paper is on the practical considerations of customer energy storage applications, the energy storage technologies currently available and emerging, and the primary barriers to widespread behind-the-meter energy storage implementation.

Energy storage has become a proven solution for a variety of commercial end uses, including demand response, peak demand reduction, power quality regulation, and emergency response. While there are several types of technologies that support facility-scale energy storage, batteries, and flywheels are the most mature and readily available for smaller applications. The advantages that batteries offer over competing technologies, such as generators, are response times on the order of milli-seconds and highly accurate load-following capability. Their primary disadvantages are routed in the fact that the market is still evolving such that costs are high, the best technologies are not widely available, and most city building codes accept only the most basic technologies for indoor installations.

There is ever-increasing recognition of the huge role energy storage will play in modern electrical utility grids that rely on large percentages of renewable or intermittent generation. This, combined with the growing acceptance of hybrid and electric vehicles, is driving a research boom in the area of batteries. There are many promising battery technologies suitable for facility-scale energy storage, ranging from research endeavors, such as iron-chromium chemistries, to mature commercial technologies such as lead-acid batteries.

Despite the need for energy storage solutions, there are still significant barriers to the widespread implementation of energy storage. These include the current high costs of battery systems, public perception of safety, material hazards, and building code acceptance. It is estimated that once batteries achieve installed costs of $300 per kWh they will be able to displace generation used for peak power requirements [12]. If energy storage providers, utilities, and facilities can work together to overcome these barriers, energy storage can provide solutions for grid stability, power quality, demand management, and renewables integration.

Key Terminology

In order to understand the functions that energy storage serves for utilities and their customers, certain key parameters need to be defined. The first of which is discharge time, which is defined as the amount of time that a battery can maintain its rated power output. Energy storage applications can generally be categorized in one of three groups – power quality, bridging power, or energy management – that describe a sliding scale of increasing discharge time illustrated in Figure 1.

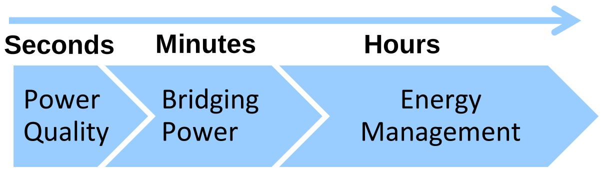

Figure 1. Use Categories on the Discharge Time Spectrum

Applications for energy storage can be categorized even more generally as either power (demand) applications or energy (consumption) applications. A power application refers to a system that is primarily designed to provide power to the system over a short time period in order to reduce momentary peak power levels and/or to improve facility power quality. Energy applications are designed primarily to shift energy usage from one time period to another. Like the sliding scale of discharge times, there is a sliding scale between power and energy applications with a broad grey area in between.

Table 1 contains key terminology and their definitions. Important implications are also provided for additional insight as considerations.

Table 1. Key Terminology

Term	**Definition**	**Considerations**
Depth of discharge (DOD)	The percentage of a battery's technical energy capacity that has been discharged	Batteries are rated for DOD, and cycling beyond this will significantly reduce cycle life for certain battery types.
Power capacity	The kilowatt (kW) output that the equipment is safely rated to operate at	Operating at higher power outputs, relative to the battery's rated power, can cause excessive wear and tear.
Energy capacity	The total amount of energy (kWh) that the storage can hold	The technical energy capacity of the battery will be greater than the rated energy capacity because of efficiency losses and depth of discharge limitations (see below)[1].
Discharge time	The maximum duration over which a battery can discharge at its rated power	Discharge time is derived from the ratio of the battery's energy capacity to its power capacity.[2]
Cycle life	The number of charge and discharge cycles that a battery can sustain within its EUL	Cycle life varies widely by technology, as well as within each technology, by manufacturing quality and operating conditions.
Degradation	The rate of reduction in a battery's technical energy capacity over time or use	Most batteries are considered at the end of their expected useful lifetime (EUL) when they reach 80% of their original energy capacity[3]. Degradation rates are impacted by battery design and operational factors including the DOD, operating temperature, and rate of discharge.
Self-discharge rate	The rate at which batteries lose energy while idle	Typically 2% to 5% of the total system capacity per month for lithium-ion (li-ion) and lead acid batteries; in part this rate defines the shelf life of the battery.
Round-trip efficiency	The ratio of usable energy to the energy required to charge the battery	Round-trip efficiency is a measure of the charging and inverter losses.
Power density	The battery's power output (kW) per unit of the device's physical volume	Power density defines how much space a battery will need for a given power rating.
Energy density	The battery's energy capacity per unit volume	Energy density defines how much space a battery will require for a given energy capacity.

[1]Technical energy capacity × Maximum DOD = Energy capacity

[2]It is useful to compare batteries to a car in order to understand these terms. If power capacity is the "top speed" of the battery, energy capacity is the "gas tank," and discharge time is the "miles" that the battery system can travel without refueling.

[3]Most batteries lose energy capacity in a linear fashion up until they reach a critical point, called rollover. At this point degradation gathers speed rapidly and the battery soon becomes inoperable. Not all batteries have a rollover point.

FACILITY APPLICATIONS FOR ENERGY STORAGE

Energy storage equipment is expensive and business facility owners are only likely to install the equipment if it is necessary or provides tangible value. An example is the installation of uninterruptible power supplies (UPS) to keep critical systems operating during brief power disruptions. Also, incentives through rate structures, or other mechanisms, can create value streams that outweigh the capital cost and risks associated with installing the storage system. The facility uses for energy storage that will be covered in this paper are:

1. Power quality and dependability
2. Demand charge reduction
3. Demand response
4. Retail energy time shift
5. Renewables integration

These end uses are covered by the most recent version of the DOE Energy Storage Handbook and are supported by multiple interviews with energy storage system providers. Their comparative parameters are summarized in Table 2.

Table 2. Facility Use Characteristics [1] [3] [4]

Facility Use	**Power Capacity**	**Discharge Time**	**Frequency of Use**
Power quality and dependability	100 kW to 1 MW	15 minutes or less	Variable; as needed
Demand charge reduction	50 kW to 1 MW	1 to 4 hours	Daily
Demand response	50 kW to 1 MW	4 to 6 hours	Infrequent
Energy cost savings	100 kW to 1 MW	> 1 hour	Daily
Renewables integration (power quality and dependability)	100 kW to 500 MW	up to several hours	Daily
Renewables integration (energy shifting)	100 kW to 500 MW	> 1 hour	Daily

Power Quality and Dependability

Energy storage systems that correct poor-quality power protect facility equipment such as compressors and servers, and those that provide dependable power prevent loss of business from equipment downtime. Some examples of poor-quality power that can be corrected with an energy storage system are variations in voltage and harmonic distortions. Dependability power solutions are installed when even short interruptions of service are unacceptable to equipment or business operations and are typically used as transition power while generators start up.

These types of systems are commonly known as UPSs. Because they are necessary for certain types of equipment and commerce, they have become the second-most installed type of energy storage, measured in total installed kW of capacity, after utility scale bulk storage [5]. Although data centers are the primary businesses purchasing UPS systems, other building types also utilize UPSs, such as:

- Telecommunications – Telecommunications companies utilize equipment that is very similar to data centers and is also vulnerable to low-quality power.
- Industrial – Certain industrial processes may result in costly loss of product if there are power interruptions, even if on a very short time scale.
- Emergency response – 911 call centers are often required by law to have a UPS system.
- Medical – Hospitals may have certain types of equipment that cannot have power interruptions.

Demand Charge Reduction (Peak Clipping)

Utilities assess demand charges ($/kW) to commercial and industrial facilities based typically on their highest monthly demand. If periods of peak demands can be predicted, then battery systems can be discharged to offset the peak demands and lower demand charges for the facility.

The interviews ERS conducted revealed that businesses that design and provide energy storage system services report simple paybacks of 5 to 7 years for facilities that have more than 50% of their electric bill from demand charges. By targeting facilities with intermittent and large demand spikes, energy storage systems can yield large cost savings with a low-energy, and thus low-cost, solution. Energy storage system suppliers unanimously indicated in interviews that demand-charge savings are the primary driving force of nearly all non-UPS facility-scale storage projects.

A key component of a demand charge reduction system are the controls used to predict when peak demand periods will happen, and to deploy the stored energy within the battery to offset demand during that period. Being able to predict the peak demands is critical for this to happen since most demand charges are set by a 15-minute average peak demand for the month regardless of the time of occurrence.

Demand Response

Demand response (DR) programs offer to pay for reliable demand reduction during certain peak demand windows. These peak demand "events" typically occur during summer peak usage hours with each event lasting 4 hours or longer. Utilities sponsor DR programs to alleviate loads on the electricity distribution system during periods of anticipated heavy use.

The lucrativeness of demand response events varies by region, but in some cases it may be worthwhile for a facility to expand a relatively low-energy battery system to accommodate local demand response requirements. Systems designed for demand response will have the same approximate discharge capacity as demand charge reduction systems, and could potentially be used for either purpose during any given month. There is a tradeoff for systems intended for both demand response and demand charge reduction, which is during any given month, the system will only be able to provide either demand charge reduction or demand response duties unless it is sized to meet both requirements or there is sufficient time between peak demand and the demand response periods for the system to charge.

Retail Energy Time Shift

Retail energy time shift refers to storing energy during periods when the retail electric price ($/kWh) is low and using the stored energy when prices are high. Businesses can employ this strategy to reduce their electricity bills where the local utilities apply time-of-use pricing.

Energy systems providers report that retail energy time shift is not a particularly lucrative value stream for businesses and thus does not drive projects except in places where there is a large peak to off-peak spread for energy prices (e.g., Hawaii). However, it is usually included in the cost benefits of any system.

Renewables Integration

The integration of battery storage capacity with renewable energy generation projects, primarily for wind and solar, is an increasingly common practice that provides important benefits to the grid. The fast response time of batteries presents an attractive pairing with renewables; batteries can provide frequency regulation services and can bridge gaps in generation due to the intermittency of renewables, while also time shifting the load to periods of high demand.

While energy storage provides critical support for utility-scale renewables integration with the grid, usually the grid itself supports renewable generation installed at customer locations. As distributed renewable generation increases, electrical energy storage will play a critical role in supporting the grid regardless of installation at facilities or utilities. It is recognized that at a certain percentage of renewable generation on the grid, energy storage will become a necessity in order to mitigate the intermittent nature of renewables. What is not clear is what that percentage is, or when it will be reached.

Energy storage is playing a bigger role in distributed renewable generation in Germany, where retail electricity prices are very high and wholesale energy prices are very low. This makes it particularly advantageous for renewable systems that can store extra energy until it is needed [6].

Dual-Purpose Systems

As mentioned, it is common for facilities to install systems with multiple uses in mind because of the added value this can bring. Some examples of potential combinations and case studies are discussed in the following subsections.

Peak demand reduction and emergency backup.

Systems designed to reduce peak demand or allow participation in demand response programs typically have the capability to provide ancillary power during critical events such as power outages during natural disasters. The Barclay Tower in New York City used its demand reduction system to power service elevators and emergency lighting during Hurricane Sandy [7].

Peak demand reduction and demand response.

Although systems designed for peak demand reduction would not also be able to participate in demand response events simultaneously, they can choose which strategy provides the most value over a given period. Glenwood, the company that owns the Barclay Tower, announced that it plans to install 1 MW of energy storage across its portfolio, and plans to use the energy storage to participate in the NYC Indian Point Demand Management program during the summer and for daily demand reduction during the winter [8].

Power quality and grid support.

UPS systems are a necessity for certain facilities, but for the vast majority of the time, they are not utilized. The regional transmission organization PJM has found a way to take advantage of these resources by offering an incentive of $40/MWh for energy supplied to the grid from energy storage for frequency regulation [9]. This is a result of the Federal Energy Regulatory Commission (FERC) Order 755 and Order 784, which allow utilities to pay for performance for frequency regulation services from fast-responding energy storage technologies such as batteries [10] [11].

Peak demand reduction and retail energy time shift. Taking advantage of differences in peak/off-peak energy prices is a natural benefit to most peak demand reduction or demand response systems since they would typically be charging during the off-peak hours and discharging during peak hours.

FACILITY SCALE ENERGY STORAGE TECHNOLOGIES

A broad variety of technologies are being developed for energy storage uses at all scales, but currently the only mature technologies that suit the commercial needs for businesses are the following:

- Lead acid (Pb)
- Lithium ion (li-ion)
- Sodium sulfur (Na-S)
- Flywheels

While other technologies may be available, facilities are not likely to install such systems because of the risks of investing in an immature technology. Several other technologies that are poised to enter the energy storage market in the near future include:

- Sodium nickel chloride (ZEBRA)
- Flow (vanadium redox or zinc bromine)

Note, that this is not a comprehensive list of emerging technologies and there are multiple other companies that have received significant investment funding and are also poised to enter the commercial market. Several other companies that have received significant private and/or government funding for demonstration projects are Ambri (liquid metal), EOS (zinc air), and Aquion (magnesium salt); each has its own proprietary technology and seeks to provide systems at ground-breaking costs and lifetimes competitive with customary peak generation sources [13] [14] [15].

Table 3 presents compiled summary technical parameters for each of the technologies reviewed as compiled by the author from published literature and battery manufacturer interviews.

Mature

Mature technologies are those that are widely available and are generally accepted by building codes for installation in indoor settings.

Lead Acid.

Lead acid batteries are the most mature battery technology available and they are used in vehicles worldwide [2]. They are typically the standard by which other batteries are measured due to their reliability and low cost, but they offer only mediocre energy density or power density and lifetime. Importantly, they are capable of only a limited DOD; full discharges will damage the battery and shorten its life.

Table 3. Comparison of Battery Technical Parameters

Market	Battery Type	Installed Energy Cost ($/kWh)		Roundtrip Efficiency (%)	Useful Life	
		Suburban (Outdoors)	Urban (Indoors)		Cycle Life	Expected Lifetime (Years)
Commercial Technologies	Lead acid	$700 – $1,000	$800 – $1,200	70% – 80%	500 – 1,500	3 – 5
	Lithium ion	$1,000 – $2,000	$1,500 – $2,500	85% – 98%	2,000 – 5,000	10 – 15
	Sodium sulfur (salt)	$750 – $900	$1,000 – $2,000	70% – 80%	2,500 – 4,500	10 – 15
	Flywheels	N/A	N/A	90% – 98%	10,000+	15 – 20
Near Commercial	Advanced lead acid	$900 – $1,500	$1,200 – $1,800	80% – 90%	1,000 – 2,000	5 – 7
	Vanadium redox (flow)	$1,000 – $1,500	$1,500 – $2,000	60% – 70%	10,000+	10 – 20
	Zinc bromine (flow)	$750 – $1,250	$1,250 – $1,750	60% – 70%	10,000+	5 – 10
	Sodium nickel chloride	$1,000 – $1,500	$1,300 – $1,800	80% – 90%	2,500 – 4,500	10 – 15

Due to their prevalence and capital cost advantage, lead acid batteries will continue to be a staple of energy storage projects worldwide until the capital costs of other technologies can overcome those offered by lead acid.

Advantages:

- They are the cheapest option per installed kW and kWh.
- They are highly modular.
- They are easily recyclable.
- Accepted by building codes

Disadvantages:

- Their cycle life is low under even optimal conditions (<2,000), and under high temperatures or especially deep DODs (>50%) their cycle life is greatly reduced down to as few as 500 cycles.
- Lead acid batteries are comparatively heavy, restricting their usage due to practical and building code considerations.

Lithium Ion.

Lithium ion batteries are typically constructed of carbon and metallic electrodes with a lithium-based electrolyte. There are a variety of subtly different cell chemistries that can be used to construct these batteries that are often proprietary to a specific manufacturer.

The market for lithium ion batteries continues to grow due to their excellent energy and power densities, which makes them lighter and more compact than any other commercial battery technology. They are also capable of full discharge/charge cycles without reducing the battery's cycle life, unlike lead acid batteries. They will also typically last about twice as long as lead acid batteries, when operated under optimal conditions. However, the lithium ion batteries currently cost about two times more than lead acid batteries on a power capacity basis. These characteristics give them an edge in situations where space or weight might be valued over capital cost such as small businesses without much space to spare.

The costs of lithium ion batteries are expected to reduce more than any other commercial technology in upcoming years, which makes them a likely candidate to become the dominant battery technology in the medium term.

Advantages:

- They have a long cycle life that is not affected by DOD.
- They can be arranged to provide the same voltages as lead acid for easy retrofits.
- They have a high energy/power density.

Disadvantages:

- They are costly.
- They have the potential to cause runaway fires if not properly maintained and operated.

Sodium Sulfur

Sodium sulfur (NaS) batteries were developed in the 1980s by NGK Insulators, LTD., the primary manufacturer of the technology, and Tokyo Electric Power Co. Except for requiring very high operating temperatures, NaS batteries have favorable characteristics for larger-scale energy storage, such as low cost and high energy capacity. They are often referred to as molten salt batteries because during operation they are composed of molten sulfur and liquid sodium separated by a ceramic electrolyte [2].

Sodium sulfur batteries are primarily installed in controlled outdoor locations because of their high operating temperatures and are used typically in energy arbitrage or other uses that require long discharge times (Poullikkas 2013). They have not been looked upon favorably by building- and fire-code departments, limiting their urban-scale deployment potential. For certain niche applications requiring lengthy discharge duration and with ample outdoor space, this technology may offer a competitive solution.

Advantages

- They have a long shelf life.
- They are well-suited to energy applications.

Disadvantages:

- They require high operating temperatures (>300°F).
- There are very few manufacturers of this technology.
- They are heavy and require a lot of space.

Flywheels

Although the focus of this paper is on batteries because of the research investments being made into these technologies, flywheels have made significant advancements in the last 15 years. This has enabled them to compete in the power quality and dependability market with batteries and there are now multiple flywheel demonstrations at the grid scale for this purpose. Several companies offering flywheels in the USA including Active Power, Beacon Power, Vycon Energy, and PowerThru [16] [17] [18] [19] [20].

Flywheels are marketed to high-cycle, low-energy applications such as frequency regulation, and offer a few distinct advantages over current battery offerings. These include a very high cycle life (greater than 10,000 cycles), low maintenance, and high energy density. Unfortunately, flywheels have struggled in the commercial market because they lack flexibility for energy applications and their capital costs are not forecasted to ever be competitive with battery systems.

Advantages:

- They have long lifetimes.
- They are well suited to applications requiring frequent cycling.

Disadvantages

- Comparatively higher capital costs
- They are not suited to energy applications.
- There are very few manufacturers of this technology.

Emerging and Competitive

The potential value of energy storage has only truly emerged in recent years with the widespread emergence of hybrid vehicles and renewable generation. The combination of these end uses has caused an explosion of research into this yet undeveloped market, resulting in many new and emerging technologies. Many of these emerging technologies are very promising in respect to cost-effectiveness and performance, but they do not yet have established manufacturing practices or safety protocols. It is likely that these barriers will fall in response to the need for improved costs and performance. Some of the leading contenders looking to take a prominent place in the market are listed below.

Sodium Nickel Chloride.

Sodium nickel chloride – also called ZEBRA – batteries are high temperature (300+°C) batteries that are similar to sodium sulfur technologies, but with improved safety characteristics. Only two manufacturers are making these batteries currently, but they have long lifetimes and generally better performance characteristics than traditional lead acid batteries without some of the safety concerns associated with sodium sulfur batteries [2].

Flow Batteries – Vanadium Redox (VRB) and Zinc Bromine (ZnBr)

Flow batteries rely on a liquid electrolyte that flows through the battery. This means that the energy storage capacity of the battery can be increased or decreased just by adding or removing electrolyte. This allows the energy storage capacity to be decoupled from the number of cells. Sumitomo Electric Industries is the main investor in vanadium flow batteries and ZBB Energy Corporation is the primary manufacturers of zinc bromine batteries. Both have package options available for purchase, although the number of deployments is limited [21]. Another variation of flow batteries, with iron-chromium chemistry, is also being demonstrated in California with support from the Department of Energy (DOE), which could prove to be quite inexpensive due to the use of abundant, low-cost materials [22].

Recently, a startup, Imergy Power Systems has made significant progress on a cost-effective energy storage solution with their vanadium flow batteries utilizing a proprietary electrolyte developed in collaboration with the Pacific Northwest National Laboratory. They offer several packaged low power (<250kW) 4-hour discharge solutions and claim to have more than 200 systems installed from residential users to commercial and grid-scale systems [23] [24].

The pumps, storage, and piping required by a flow battery reduces its overall energy density (as they require expanded footprints for the equipment) and entails operations and maintenance responsibilities that exceed those of other technologies. On the other hand, although systems are not easily obtainable yet, predictions look more cost-effective than conventional batteries, and may soon be available at a cost very close to the believed breakthrough cost of $300 per kWh. Vanadium batteries in particular, also have the potential for very long shelf life (>10 years) and cycle life (>10,000 cycles) (Rastler 2010) (Chen, et al. 2008).

TECHNICAL AND MARKET BARRIERS

There are a number of technical and market barriers preventing energy storage systems from reaching their full distribution potential. Over and above specific technical barriers, there is general consensus among energy storage system designers that one of the biggest issues is a negative public perception toward energy storage technologies. Generally, there is poor understanding of energy storage systems among building owners, how they operate, and the value streams they can provide.

Performance

The two primary technical barriers for batteries at this time are:

1. Limited cycle life and shelf lives
2. High costs of systems

It is essential for battery systems to improve their lifetimes and provide better warranties in order to gain general acceptance for their uses. A lead acid battery's lifetime of 3 to 5 years is very short compared to most commercial equipment's expected useful life (EULs). Progress is being made on this front primarily in the form of flow batteries and lithium ion chemistries, which boast lifetimes of 7 to 10 years and up but suffer from high cost and lack of maturity.

Longer cycle and shelf lives will increase the value of batteries but the primary barrier to their widespread use is still capital costs. Increasing demand charges and demand management programs, such as New York City's, that provide incentives of $2,100/kW for battery storage, improve the simple paybacks of projects. But, facilities must still have high demand charges to provide a revenue stream that supports the current costs of installation for any energy storage system.

Material Hazards and Siting Barriers

All battery technologies come with some inherent risks to human and environmental health and safety. They typically contain toxic chemicals in their electrolytes and have the potential to overheat, catch fire, and explode.

For commercially available storage technologies the risks are generally well understood and can largely be mitigated through appropriate installation and fire protection, rendering batteries safe even in the urban environment. Many energy storage systems come packaged in 20- or 40-foot containers. These are durable, weatherproof, and secure enough to allow for outdoor installations.

There are two primary construction complexities when installing with facility-scale battery storage systems:

1. Size – The facility needs to find suitable unoccupied, dry space – which, depending on the technology, may need to be large – to designate to these systems for permanent siting.
2. Weight – Most batteries are quite heavy due to the nature of the materials they are constructed from. For instance, sodium sulfur batteries weigh upwards of 500 pounds per square foot, which is about five times the design standard of a normal commercial floor.

Often the best location for these systems is outside on a poured concrete slab and sheltered by a shipping container. This is why many companies package their energy storage systems in this way.

Permitting and Codes

Local building fire codes and construction permitting are significant hindrances to the adoption of specific technologies such as in New York City, which currently has incorporated in its fire code only lead acid, and very recently, lithium ion batteries [25]. Other than overcoming economic hurdles, this presents the largest barrier. Code requirements for battery storage are designed to ensure safe installation and operation of battery systems. Their focus is on safety precautions to mitigate impacts of spills, fires, natural disasters, and unauthorized access.

SUMMARY

No one battery has proven superior at this point and different battery systems continue to be most suitable for different applications. This competitive market supports a broad range of technologies in development and it is unclear if the environment will stay competitive or yield to a dominant brand or chemistry.

Energy storage technologies address specific needs for both facility owners and electrical generation/distribution managers. Facility owners can utilize storage to provide resiliency for critical operations, thereby protecting profitability. Utilities and electric system operators increasingly need storage capability to efficiently incorporate renewable and other variable generation sources. By offering electric customers the right mix of financial incentives and power management education, the combined value streams will support the growth of both campus and facility scale storage systems.

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