Facility Scale Energy Storage: Applications, Technologies, and Barriers

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ABSTRACT

Many large facilities in the U.S. are considering the deployment of energy storage technologies for electric demand response programs. Technologies developed for facility- and campus-scale energy storage show promise for managing short-term electrical demand peaks as well as longer-period demand response events.

This article's author has investigated facility and campus-scale energy storage for efficiency program administrators in the U.S. and recently completed a storage technology research report for an international consortium of utilities. This work has identified promising avenues for distributed storage. Facility-scale storage has three primary uses: 1) power quality—the monitoring and regulation of voltage fluctuations, frequency disruptions, and harmonic distortions; 2) bridging power—short-term power supply for critical demands, often used to cover time periods in which emergency generators are powering up; and 3) energy management—energy storage on a scale to support a facility or campus of buildings for extended periods of time. These systems can be responsive to utility demand programs and time-of-use rates to reduce electrical peak demand costs.

All three of these facility-scale applications incorporate the development of strategies to use distributed storage for electric power continuity and demand management strategies.

This article considers the technical properties of current storage systems, including flywheel, compressed air, and various battery technologies. The technical and market barriers associated with distributed storage, along with proposed paths for resolving these barriers, will also be discussed.

INTRODUCTION

Modern energy storage originated at the electrical grid scale in the mid-1920s. Pumped hydro storage provided an early 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. 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 article focuses on the practical considerations of customer energy storage applications, the energy storage technologies currently available, and the primary barriers to widespread behind-the-meter energy storage implementation.

Energy storage has become a proven solution for demand response events, peak demand reduction, power quality regulation, and emergency response power supplies. While there are several technologies that support facility-scale energy storage, batteries and flywheels are the most mature and readily available technologies. The advantages that batteries and flywheels offer over competing technologies, such as generators, include millisecond response times and highly accurate load-following capability. Their primary disadvantage is that these are emerging technologies. As such, costs are high and most city building codes accept only the most basic technologies for indoor installations.

There is increasing recognition of the important role energy storage will play in electric utility grids that rely on large percentages of renewable generation whether they are distributed or utility scale. The recognition of this imminent need, combined with the growing acceptance of hybrid and electric vehicles, is driving a research boom in battery technologies.

Despite the need for energy storage solutions, there remain barriers to the widespread implementation of energy storage. These include the high costs of energy storage systems, limited lifetimes of storage equipment, public perception of safety, material hazards and building code acceptance. It is estimated that once the costs of installed energy storage systems drop to $300 per kWh, they will begin to displace generation used for peak power requirements [2]. If energy storage providers, utilities and facilities work together to overcome these barriers, energy storage could 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 these 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 into one of three groups—power quality, bridging power, or energy management—each requiring increasing response times. Table 1 contains a list of key energy storage terms, their definitions and considerations.

Applications for energy storage can be categorized as either power (demand) applications or energy (consumption) applications. A power application refers to a system that is designed to provide power to the system over a short time period in order to reduce peak power demands and/or to improve facility power quality. Energy applications are designed to shift energy usage from one time period to another.

FACILITY APPLICATIONS FOR ENERGY STORAGE

Energy storage equipment is expensive and business facility owners will likely install the equipment if it is necessary or provides tangible value. An example is the installation of uninterruptible power supplies (UPS) that keep critical systems operating during brief power disruptions. Incentives through rate structures, or other mechanisms, create added value that outweighs the capital cost and risks associated with installing storage systems. The facility uses for energy storage that are considered in this article include:

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

These facility uses are discussed in the most recent version of the Department of Energy (DOE) Energy Storage Handbook and are support-

Table 1. Energy storage terms, definitions and considerations.

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 equipment's safely rated operating output in kilowatts (kW).	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 DOD limitations.
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.
Cycle life	The number of charge and discharge cycles that a battery can sustain within its expected useful lifetime (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 EUL when they reach 80% of their original energy capacity. 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.

ed 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 also protect facility equipment such as compressors and servers. Those that provide dependable power prevent business losses caused by equipment downtime. Examples of poor-quality power that can be corrected with an energy storage system include variations in voltage and harmonic distortions. Dependable power solutions are intended to prevent interruptions of service that can be unacceptable to equipment or business operations. Examples of dependable power solutions are systems that provide 15 minutes or less of power during service interruptions while generators are being started.

These types of systems are commonly known as uninterruptable power systems (UPS). Since they are necessary for certain types of equipment, they are the second-most installed category of energy storage systems, measured in total installed kW of capacity, after utility-scale bulk storage [5]. Although businesses that own data centers are the primary purchasers of UPS systems, they are used for other applications, such as:

- Telecommunications—Telecommunications companies use 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 for very short time periods.
- Emergency response—Call centers are often required by law to have a UPS system.
- Medical—Hospitals may have certain types of equipment that cannot tolerate power interruptions.

Demand Charge Reduction (Peak Clipping)

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

The interviews ERS conducted revealed that businesses that design and provide energy storage systems report simple paybacks of five to seven years when demand charges are greater than 50% of total electric costs. By targeting facilities with intermittent and large demand spikes, energy storage systems can yield substantial cost savings with low-energy, and thus low-cost, solutions. 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.

Key components of electric demand charge reduction systems include the controls used to predict when peak demand periods will occur and to deploy the stored energy within the batteries to offset demand during those periods. Being able to predict the peak demand periods is crucial since most demand charges are typically set by a 15-minute average peak demand for the month regardless of the time of occurrence.

Demand Response

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

While the economic feasibility of demand response varies, it may be worthwhile for a facility to consider expanding a relatively low-energy battery system to accommodate local demand response requirements. Systems designed for demand response have the same approximate discharge capacity as demand charge reduction systems and can be used for either purpose. There is a tradeoff for systems intended for both purposes. The storage system may be unable to provide both demand charge reduction and demand response duties unless it is sized to accommodate both requirements or there is sufficient time between peak demand and the demand response periods for the system to recharge.

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 when the local utilities apply time-of-use pricing.

Energy systems providers report that retail energy time shift is not a particularly lucrative value proposition for businesses and thus does not drive projects except in places where there is a large peak to off-peak spread in energy prices (e.g., Hawaii). Although it is not a primary driver of projects, retail energy time shift cost benefits are usually an additional benefit of peak clipping and demand response solutions.

Renewables Integration

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

While energy storage will support renewables integration with the utility grid, usually the grid itself supports the renewable generation installed at customer locations. With increasing distributed renewable

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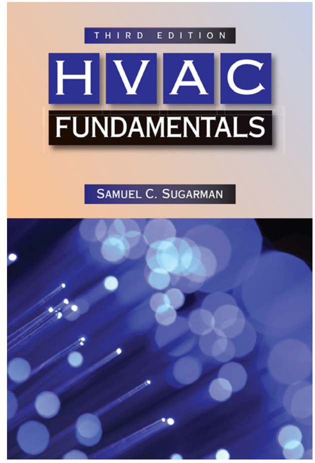

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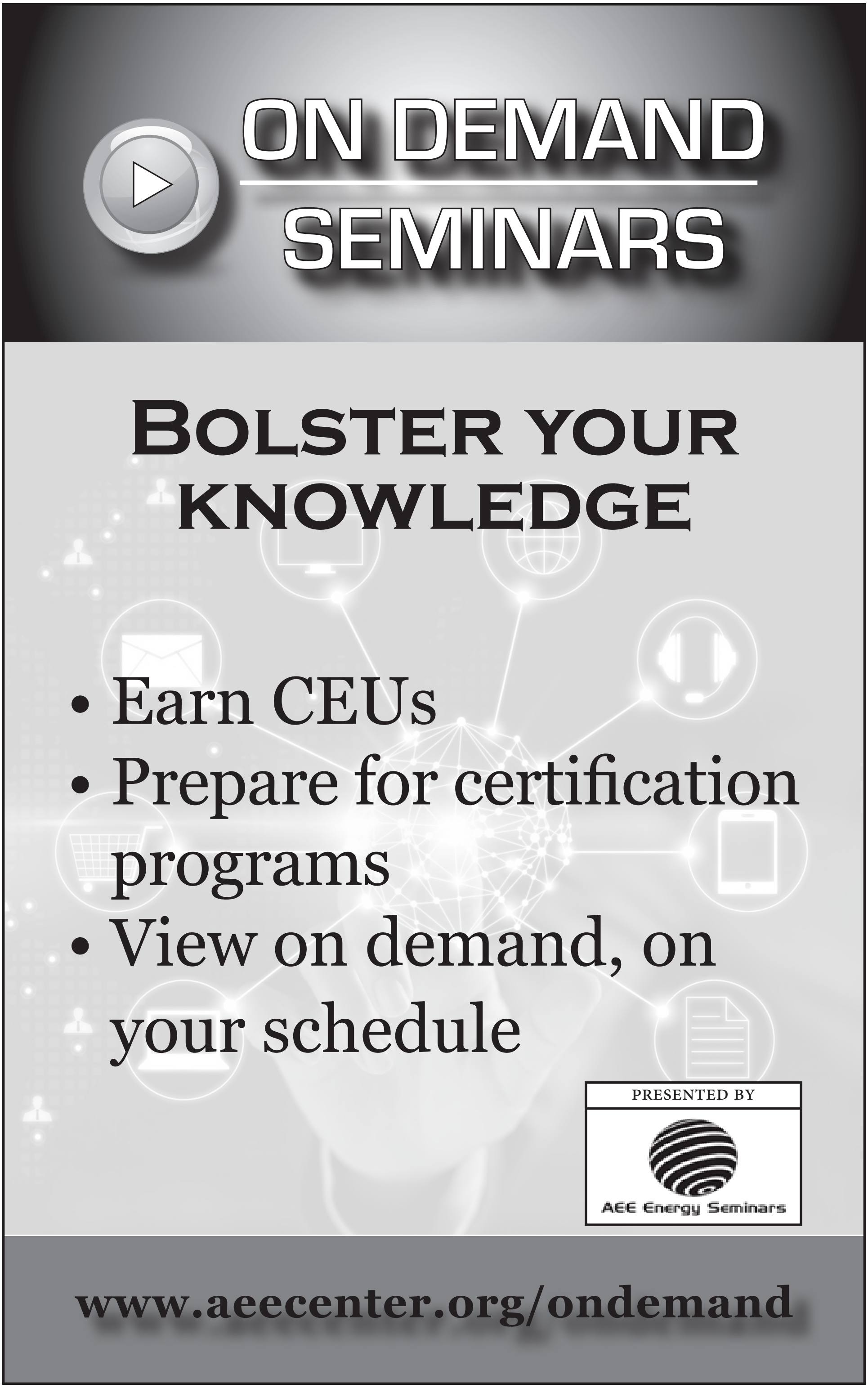
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generation, electrical energy storage will be important to support the grid regardless of installation at facilities or utilities. It is recognized that energy storage will become a necessity in order to mitigate the intermittent nature of electrical generation from certain types of renewables. What is not clear is the point it will be reached. This will vary depending on the nature of the loads and other variables associated with the electric grid to which they are connected.

Energy storage plays a larger role in distributed renewable generation in Germany, where retail electricity prices are relatively high and wholesale energy prices are relatively low. This gap in pricing makes it particularly advantageous for renewable systems that can store extra energy until it is required [6].

DUAL PURPOSE SYSYEMS

It is common for facilities to install multiple use systems because of the added value they offer. 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 power outages that occur during natural disasters. The Barclay Tower in New York City (NYC) used its demand charge reduction system to power service elevators and emergency lighting during Hurricane Sandy [7].

Peak Demand Reduction and Demand Response

While systems designed for peak demand reduction may not be configured to simultaneously deploy during demand response events, owners can choose strategies that provide the most value. Glenwood, the company that owns the Barclay Tower, announced that it plans to install 1 MW of energy storage across its portfolio. The company plans to use its energy storage capacity 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

While UPS systems are necessary for certain facilities they are not used the vast majority of the time. The Pennsylvania, Jersey, Maryland (PJM) Interconnection took advantage of these standby resources by offering an incentive of $40/MWh for energy supplied to the grid from energy storage for frequency regulation [9]. This resulted from the Federal Energy Regulatory Commission (FERC) Order 745, which allowed utilities to pay for performance for frequency regulation services from fast-responding energy storage technologies such as batteries [10]. Regrettably, Order 745 was vacated due to a case brought by the Electric Power Supply Association, which determined that the FERC lacked jurisdiction over demand response. FERC has appealed this decision and oral arguments were made for both sides to the Supreme Court on October 14, 2015 [11]. The implications of this decision will have far reaching impacts regarding the availability of demand response incentives offered by utilities.

Peak Demand Reduction and Retail Energy Time Shift

Taking advantage of differences in peak and off-peak energy prices is a benefit of peak demand reduction or demand response systems since battery systems are typically charging during the off-peak hours and discharging during peak hours.

FACILITY SCALE ENERGY STORAGE TECHNOLOGIES

A variety of technologies are being developed for energy storage applications at all scales. Mature technologies are those that are widely available and are generally accepted by building codes for installation. Currently, the mature energy storage 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, facility owners are less likely to install such systems because of the risks associated with emerging technologies that are less available and not widely accepted by building authorities. 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)

There are multiple companies working on emerging storage technologies that are poised to enter the commercial market. Companies that have received funding for demonstration projects include Ambri (liquid metal), EOS (zinc air) and Aquion (magnesium salt). Each has its own proprietary technology and seeks to provide systems at groundbreaking costs and lifetimes competitive with customary peak generation sources [12,13,14]. Table 3 presents a summary of technical parameters for each of the technologies reviewed by the author using published literature and battery manufacturer interviews.

Lead Acid

Lead acid batteries are the most mature battery technology available and they are used in motorized vehicles worldwide [15]. They are typically the standard by which other batteries are compared due to their reliability and low cost, but they offer only mediocre energy/power density and short expected lifetimes. Importantly, they are capable of only a limited DOD; full discharges will damage the battery and shorten its life.

Due to their prevalence and cost advantages, lead acid batteries will continue to be a staple of energy storage projects worldwide until the costs of other technologies are reduced.

Advantages

- They are the least expensive option per installed kW and kWh.
- They are highly modular.
- They are easily recyclable.
- They are accepted by building codes.

Disadvantages

- Their cycle life is short even under optimal conditions (<2,000 cycles). Under high temperatures or especially deep DODs (>50%) their cycle life is reduced to as few as 500 cycles.

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	$400 – $700	$600 – $1,000	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

- Lead acid batteries are comparatively heavy, restricting their usage due to practical and building code considerations.

Lithium Ion

Lithium-Ion (LI) 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 specific manufacturers. The market for LI batteries continues to grow due to their excellent energy and power densities. They weigh less and more compact than other commercial battery technologies. Unlike lead acid batteries, they can be fully discharged and recharged without reducing the battery's cycle life. LI batteries typically last about twice as long as lead acid batteries when operated under optimal conditions. However, LI batteries currently cost about twice as much as lead acid batteries on a power capacity basis. These characteristics give them an edge in situations where space or weight is more highly valued than cost, such as small businesses with space limitations.

The costs of LI batteries are expected to decrease more than any other commercial technology in upcoming years, which makes them a likely candidate to become the dominant battery technology in the next 5-10 years.

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 batteries.
- 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. 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 [15].

Sodium sulfur batteries are primarily installed in controlled outdoor locations because of their high operating temperatures. They are often used in energy arbitrage or other uses that require long discharge times. They have been looked upon unfavorably by building- and fire-code enforcement agencies, limiting their deployment potential in urban areas. For certain niche applications requiring lengthy discharge duration and with ample outdoor space, this technology offers competitive solutions.

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

Advancements in flywheel technologies during the last 15 years have enabled them to compete with batteries in the power quality and dependability markets. There are many grid scale flywheel demonstration projects. Companies that offer flywheels include Active Power, Beacon Power, Vycon Energy and PowerThru [16,17,18,19,20].

Flywheels are marketed for high-cycle, low-energy applications such as frequency regulation, and offer distinct advantages over battery systems. 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 future capital costs are unlikely to 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 is increasing with the widespread emergence of hybrid vehicles and renewable electricity generation. These applications are causing an explosion of interest in supporting these markets with the development of new storage technologies. While many of these emerging technologies are promising in regard to cost-effectiveness and performance, they often lack established manufacturing practices and safety protocols. It is likely that these barriers will fall in response to the need for lower costs and improved performance. Some of the emerging technologies that may be prominent in future storage applications are discussed next.

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 currently making their batteries. 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 [15].

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 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 manufacturer of zinc bromine batteries. Both have package options available for purchase although the number of deployments is limited [21]. Another variation of flow batteries, using iron-chromium chemistry, is being demonstrated in California with support from the DOE, which could prove to be quite inexpensive due to the use of abundant, low-cost materials [22].

Recently, a startup company named Imergy Power Systems has made 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 (<250 kW) 4-hour discharge solutions and claim to have more than two hundred residential, commercial, and utility grid-scale systems installed [23,24].

The pumps, storage, and piping required by flow batteries reduce their overall energy density (thus requiring expanded footprints for the equipment) and entails operations and maintenance responsibilities that exceed those of other technologies. Although these systems are not yet readily obtainable, they may become more cost-effective in the future than conventional batteries. Vanadium batteries have the potential for very long shelf life (>10 years) and cycle life (>10,000 cycles) [25,26].

TECHNICAL AND MARKET BARRIERS

There are a number of market barriers preventing energy storage systems from reaching their full distribution potential. There is a consensus among energy storage system designers that one of the biggest issues is a negative public perception toward energy storage technologies. Building owners often lack an understanding of how energy storage systems operate and the value they can offer. Improved marketing and better education of building owners can help overcome these market barriers.

Performance

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

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

It is essential for battery systems to have longer lifetimes and better warranties in order to gain greater acceptance. A lead acid battery's lifetime of three to five years is very short compared to most commercial equipment's Estimated Useful Life (EUL). Progress is being made, primarily with flow batteries and LI chemistries, which boast lifetimes of seven to ten years but suffer from high cost and lack of technological maturity.

Longer cycle and shelf live increases the value of batteries but the primary barrier to their widespread use remains capital costs. Increasing demand charges and demand management programs (e.g., those available in NYC that provide incentives of $2,100/kW for battery storage) improve the economics of projects. Facilities require high electrical demand charges to provide a revenue stream that supports the installation costs for energy storage systems.

Material Hazards and Siting Barriers

All battery technologies have inherent risks to human and environmental health and safety. They often 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. Risks can largely be mitigated through appropriate installation and fire protection, rendering batteries safe in urban environments. Many energy storage systems are packaged in containers. These are durable, weatherproof and adequately secure to allow for outdoor installations.

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

1. Size—The facility needs to find suitable unoccupied, dry space designated to permanently site these systems.
2. Weight—Due to the nature of the materials used in their manufacture, most batteries are quite heavy. For instance, sodium sulfur batteries weigh upwards of 500 lbs/ft^2 (21kg/m^2) or 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 in a sheltered enclosure. Because of this, many companies sell their equipment packaged in shipping containers.

Permitting and Codes

Local building fire codes and construction permitting hinder the adoption of specific technologies. Permitting is the largest barrier to adoption of storage technologies excluding costs. 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. Barriers are falling. NYC recently incorporated lead acid battery storage systems and LI batteries in its fire code [27].

SUMMARY

No single battery technology has proven superior to all others. Specific battery technologies are designed to be suitable for varying requirements and applications. Today's competitive markets support a broad range of developmental storage solutions and it is unclear if the marketplace will remain highly competitive or yield to a dominant brand or chemistry.

Energy storage technologies address specific needs for both facility owners and electrical generation and distribution managers. Facility owners can utilize storage to provide resiliency for critical operations, thereby protecting profitability. Utility companies and electric system operators increasingly need storage capability to effectively use renewable and other variable generation resources. By offering electric customers educational opportunities in power management and financial incentives, the value of electrical energy storage systems for both campus and facility scale applications will increase in the future.

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