Business & Technology Report

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# Battery Energy Storage Overview

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This Battery Energy Storage Overview is a joint publication by the National Rural Electric Cooperative Association, National Rural Utilities Cooperative Finance Corporation, CoBank, and NRTC.

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## Disclaimers

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# Executive Summary

Battery energy storage systems (BESS) can be used for a variety of applications, including frequency regulation, demand response, transmission and distribution infrastructure deferral, integration of renewable energy, and microgrids. Different battery technologies can enable different applications that can provide various benefits to utility services, Independent System Operator (ISO) services, Regional Transmission Organization (RTO) services, and consumer services. This report focuses on the two principal technologies being deployed: lithium-ion and flow batteries.

While each technology has its strengths and weaknesses, lithium-ion has seen the fastest growth and cost declines, thanks in part to the proliferation of electric vehicles. Both lithium-ion and flow battery technologies are projected to see significant cost declines in the coming years. These cost declines coupled with policy incentives will drive increased demand for battery storage from utilities, commercial and industrial (C&I) consumers, and residential consumers, leading to continued growth in the battery market in coming years. Higher penetration of variable renewable generation will drive the need to store the electricity generated during times it cannot be used. Wind energy generation, for instance, tends to be highest in the middle of the night when demand is typically low. The capability to store that energy for use during the daytime when demand is higher can allow for more wind energy to be generated. Similarly, excess solar generation during the middle of the day can be stored to be used later in the evening when demand is higher.

Several electric co-ops are currently deploying BESS, as highlighted by the case studies in this report. Interest among electric co-ops in deploying battery energy storage is growing, and will likely accelerate as more experience is gained, costs continue to fall, and technological advances improve the performance of batteries. Important challenges remain, including developing sustainable business and financing models, overcoming technology performance uncertainty, determining comprehensive and credible cost estimates, warranties and insurance, and integrating battery energy storage with existing utility systems. Some of these challenges will be addressed with the natural maturation of the technology, while others require a broader effort to develop focused programs, projects, tools, and resources.

# 1: Introduction

Because electricity supply and demand on the power system must always be in balance, real-time energy production across the grid must always match the ever-changing loads. The advent of economical battery energy storage systems (BESS) at scale can now be a major contributor to this balancing process. The BESS industry is also evolving to improve the performance and operational characteristics of new battery technologies.

Energy storage for utilities can take many forms, with pumped hydro-electric comprising roughly 95 percent of the existing storage capacity today.[1] In recent years, other technologies, such as batteries, flywheels, compressed air, and localized gravity-based systems, have seen a dramatic surge in research and development (R&D) and deployments. The focus of this report will be on stationary electro-chemical batteries. This covers BESS at the utility, C&I, and residential levels.

Policy support, increased demand from utilities and consumers, and the growth of electric vehicles (EVs) all contribute to falling battery costs and growth in overall BESS capacity. Lithium-ion (li-ion) batteries have become the dominant form for new BESS installations, thanks to the significant cost declines of battery modules, favorable performance characteristics, flexibility of application, and high energy density.

This document begins by providing an overview of stationary electrochemical BESS applications and technologies, with a specific focus on li-ion and flow batteries. It then presents recent cost trends of li-ion and flow batteries, followed by examining various adoption drivers and growth forecasts. It concludes by providing examples of electric cooperatives that have developed BESS for various applications.

[1] DOE Global Energy Storage Database: **https://www.energystorageexchange.org/projects/data_visualization**

# 2: Energy Storage Technology Environment

*This section provides an overview of the various grid applications of BESS. At the end of the document, several examples of these applications within the electric cooperative network are offered. This section also looks at the major technologies for electrochemical batteries intended for interactive use with or by utilities.*

## Grid Applications

Most BESS projects are developed with a primary application in mind. However, additional value can be extracted by optimizing the BESS for multiple applications and use cases.[2] This idea is known as *value stacking.* There are several additional applications that may become more important in the future, but the most common applications today include:

- **Demand Side Management/Peak Reduction:** Use energy storage to reduce electricity demand during peak demand periods, recharging during low demand periods. This may be implemented by the customer or the utility.
- **Electric Service Reliability/ Resilience:** Provide backup power during outages, including integration with distributed generation sources.
- **Energy Arbitrage:** Purchase off-peak electricity at low prices for charging the storage system, so that stored energy can be used or sold at a later time when the price of purchased electricity is high. This is sometimes referred to as *electric energy time–shift.*
- **Fast Response Frequency Regulation:** Manage the interchange flows between control areas to maintain frequency within the tolerance bands. FERC Order 755 promotes energy storage as an option for frequency regulation, allowing for a premium to be paid in markets for ancillary services for the rapid response of energy storage to maintain system frequency.
- **Micro-grids:** The use of dispatchable and non-dispatchable generators, often combined with energy storage, to produce energy for distribution to a local set of loads that can be intentionally islanded from the larger grid. This is usually done for energy resilience or economic optimization purposes.
- **Off-grid systems:** This applies to systems that are not connected to a utility grid. These range from solar-powered streetlights and mountaintop microwave repeaters to individual homes and even whole communities that are typically located in remote or isolated areas.
- **Renewables Firming:** Use energy storage in tandem with intermittent wind or solar to provide a more predictable power supply.
- **Transmission/Distribution System Deferral:** Defer and/or reduce the need to build new generation/distribution capacity or purchase generation capacity in the wholesale electricity marketplace. Distribution applications include deferral of transformer upgrades or line reconductoring.

[2] "Distributed Energy Resources Compensation and Cost Recovery Guide". February 23, 2018.

## Battery Technologies

Li-ion and flow batteries currently are the two most commercially viable technologies for stationary BESS. Their characteristics are summarized in Table 2.1 and a li-ion installation is shown in Figure 2.1.

**TABLE 2.1: Summary of Li-ion and Flow Battery Characteristics**

| Technology | Typical Duration | Size | Service Life | AC Round trip efficiency | Cycle Life | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|
| Lithium-Ion | 0-6 hour | Up to 100 MW+ | 10-15 years* | 85% | Annual degradation | Efficient power<br>Energy dense<br>Flexible | Flammable**<br>Cycle life limited |
| Flow | 2-8 hour | Up to 100 MW+ | 20 years | 65-75% | Theoretically unlimited and can be discharged 100% | High cycle life/service life<br>No degradation<br>Not flammable | Reduced efficiency |

* Warrantees are around 7 years with 1-2 year workmanship warranties

** Note: flammability is dependent on specific chemistry used to develop battery. When considering any type of battery, including li-ion, it is important to discuss flammability issues with the vendor.

Source: Lazard

**FIGURE 2.1 – Ocracoke Island li-on Battery System**
Courtesy of Carolina Country, NC

## LITHIUM-ION BATTERIES

The vast majority of utility-scale battery systems installed in the U.S. over the past few years have been li-ion, driven largely by cost reductions and power density achieved through electric vehicle manufacturing. Li-ion systems are also popular due to the expected versatility of applications and flexibility of performance (supplying both energy and power).

Multiple configurations of battery chemistries are available for li-ion batteries, making them attractive to electricity providers, especially for applications that require output duration of 4 hours or less. Lithium nickel manganese cobalt (NMC) batteries are the most widely utilized li-ion chemistry for stationary applications. NMC chemistries demonstrate balanced performance characteristics in terms of energy, power, cost, and cycle life. However, lithium-iron-phosphate (LFP) batteries have become increasingly prevalent. The move towards LFP is driven by higher cobalt prices. While LFI does not have the same energy density as NMC, LFI has reduced flammability risk.

Lithium technologies have a high DC round trip efficiency (typically > 85 percent), but experience annual degradation and have a service life of 10 to 15 years.[3] However, some battery vendors are currently quoting 20+ year lives for certain chemistries.[4]

Li-ion batteries are used at scales ranging from toys and cell phones to electric vehicles and utility-scale power systems up to 100 MW or larger. While this technology was originally only used for short-time applications, such as frequency regulation or renewables-firming, these batteries are increasingly used in longer duration (2- to 6-hour) applications.

## FLOW BATTERIES

Flow batteries are still mostly in the demonstration phase, but there are examples of deployments of sizable batteries. For instance, San Diego Gas & Electric and Sumitomo installed a 2 MW/8 MWh flow battery (vanadium redox chemistry) in California (see Figure 2.2). A 200 MW/400 MWh battery system is being built in Dalian, China, and the U.S. Department of Energy's national labs are also hosting large systems. Today, flow battery developers are moving away from custom systems to prepackaged systems to compete with lithium-ion systems. As with li-ion systems, flow batteries are designed using various chemistries, including vanadium redox, zinc-bromide and zinc-iron redox. These chemistries have similar characteristics and capabilities. Flow batteries use tanks of electrolyte and some sort of membrane to control the flow of electrons. These systems use pumps to control the flow of electrolyte. In many ways, flow batteries most resemble fuel cells that can be run in reverse. Flow batteries are generally only economically viable in large, stationary applications.

Flow systems are recognized for their long service life, the ability to provide a storage duration from 2 to 8 hours, and the flexibility to provide system sizing flexibility. Vanadium redox flow vendors,

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[3] While theoretical models show a service life of 10-15 years, there has not been sufficient data to validate this. Majority of projects are being built with 8-year service life.

[4] Long service life is due to vendors replacing cells thanks to continued cost decreases as opposed to li-ion cells lasting a long time.

for instance, offer 2- to 20-year warranties with performance guarantees and long-term service agreements. However, the systems tend to be uneconomic for storage durations less than 3 hours.**[6]**

Flow batteries have a significantly lower energy density[5] than solid state batteries such as li-ion, which means that they use up more physical space and are only suitable for stationary applications. While the battery itself is not inherently flammable, the electrolyte needs to be safely contained since leaking is a concern. Vanadium batteries (like other flow batteries) have a lower DC round trip efficiency (typically 70 to 80 percent) than lithium batteries. However, they have a theoretically unlimited cycle life[6] and a typical service life of 20 years. Although the batteries themselves have a lower energy density than lithium technologies, the containers can be stacked, potentially resulting in a smaller footprint for a given system.

**FIGURE 2.2 – Sumitomo and SDG&E's Redox Flow Battery**
Credit Sumitom

## Battery System Recycling

Recycling battery systems is still in its infancy and many changes will likely occur over the next few years. For instance, recycling may become mandated in the U.S.

Companies will typically take back the systems at end of life for recycling, as long as it is requested by the utility. If not specifically requested during procurement, utilities may have to pay someone for the recycling service.
Some technology companies, such as vanadium redox flow companies, pay/credit customers for the value of the vanadium, since it is so valuable and can easily be reused. A large percentage of li-ion batteries can be recycled. Tesla, for instance, claims that they can take batteries back at end of life and that they can recycle over 60 percent of the materials.[7]

[5] Energy density is the amount of energy stored in a given system or region of space per unit volume.
[6] Note: there is currently no data to corroborate this since it is a relatively new technology.

[7] **https://www.tesla.com/blog/teslas-closed-loop-battery-recycling-program**

As battery systems become larger, transportation will become more of an issue. In addition, this discussion only covers the batteries themselves — inverters, transformers, electronics also need to be recycled. Co-ops may want to consider requiring the system supplier to pick up and dispose the entire energy storage system at end of life.[8]

### Technologies On the Horizon

- Zinc hybrid cathode battery developed by Eos Energy Storage claims impressive performance characteristics at a low cost.
- Aquion has developed a "saltwater battery" using very common materials along with slightly more complex cathodes. The battery is non-toxic, has good cycling characteristics, and came with an 8-year warranty (see case study on Vermont Electric Cooperative).

*Due to limited deployment there is a lack of technical information on these technologies.*

[8] PPA style structures are potentially another business model that addresses a way of eliminating the disposal concerns and can address the risks of new technology.

# 3: Cost Trends

The costs of batteries are projected to continue to fall over the medium to long term. However, the rate of decrease is likely to vary significantly by battery technology. Likewise, the various components of a BESS are likely to decrease at different rates based on such variables as level of standardization, economies of scale, and industry learning.

Costs of BESS are typically described in two ways:

- **Cost per kW (MW)** – the total installed cost of the system divided by the instantaneous output power rating of the system. Must specify as $/kW-AC (preferred) or $/kW-DC.

- **Cost per kWh (MWh)** – the cost of the system divided by its projected energy output. The appropriate unit of measure is $/kWh-AC (preferred) or $/kWh-DC. One must also specify whether this is based on the useable storage capacity versus the rated storage capacity, if different. In addition, for any given BESS, this cost metric can be expressed in the following ways:

  - **Installed cost** – the equipment cost of the battery, balance of system (BOS) costs plus any engineering, procurement, and construction (EPC) costs.

  - **Levelized cost** – the "all-in" cost to design, construct, and utilize the BESS over the course of its useful life. Notably, this includes maintenance costs, effects of battery degradation (i.e., decreased output), etc. When comparing a BESS against an alternative resource, the levelized cost of storage (LCOS)[9] is the preferred unit of measurement.

Figures 3.1 below illustrates the cost components of a BESS.

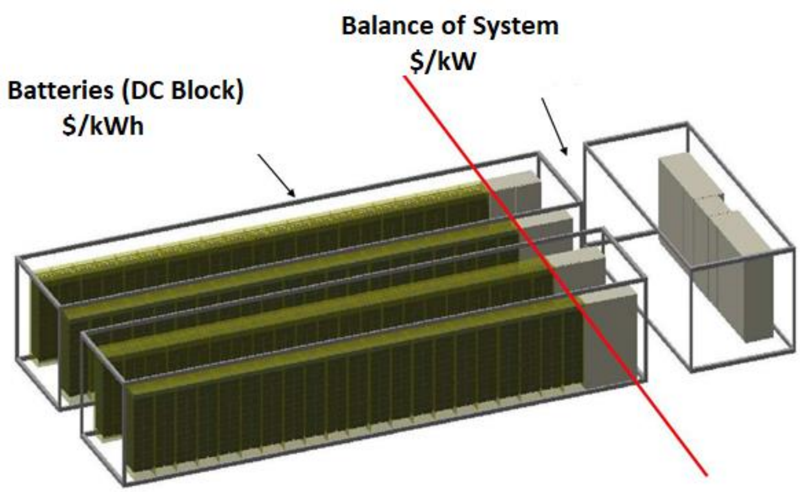


**FIGURE 3.1 – Cost Components of a BESS**

[9] LCOS is analogous to the LCOE calculation but uses charging cost as fuel cost and takes the discharged electricity instead of generated electricity. LCOS is discussed in detail later in the report.

Figure 3.2 illustrates the cost components of a BESS using a water tank as an analogy. The size of the tank (gallons) is analogous to the energy (kWh), while the flow rate (gallons/hour) is analogous to power (kW).

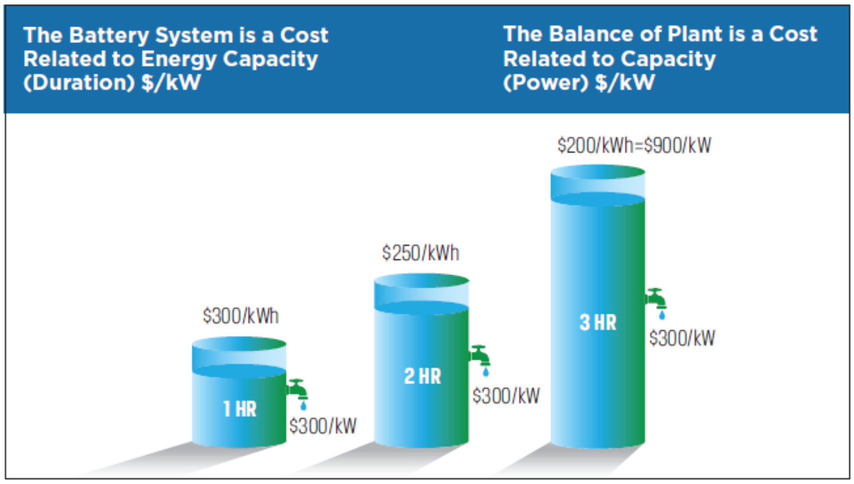


**FIGURE 3.2 – Cost Components of a BESS Using a Water Tank as an Analogy**

The total cost of a BESS is calculated by adding the costs of the battery, BOS, and EPC. As an example, consider a 3-hour $200/kWh battery with BOS costs totaling $300/kW. If you convert all costs to kW, the 3 hour $200/kWh battery would cost $600/kW. Adding the $300/kW BOS component would make the total cost of the BESS $900/kW.

## Lithium-Ion BESS Costs

Figure 3.3 below highlights the relationship between battery cells, modules, and panels. It also illustrates the additional components that are required for a complete li-ion BESS.

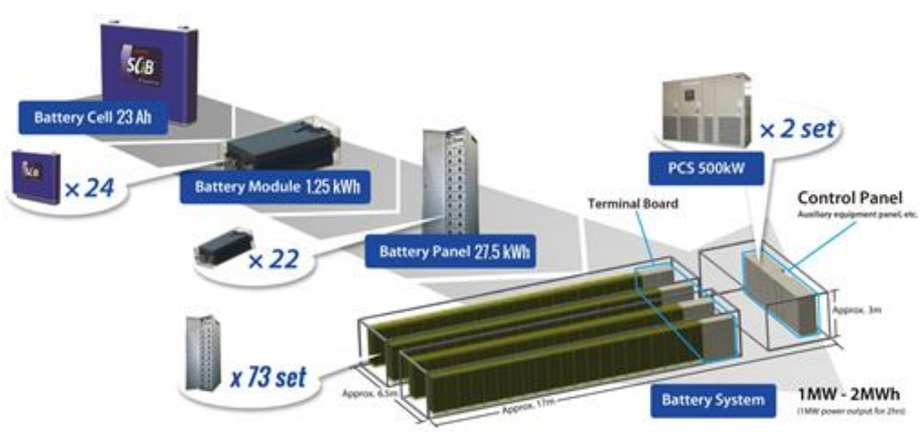


**FIGURE 3.3 – Relationship Between Battery Cells, Modules and Panels**

## BATTERY CELL COSTS

Increased activity across the manufacturing landscape has led to greater economies of scale for li-ion cells and battery modules. Innovation remains the most critical component of cost reductions for batteries, including the li-ion variety. In 2017 (the latest data available), battery-related patent activity proceeded at a breakneck pace, with over 30,400 new patent families published, nearly 40,000 patents granted, and over 6,400 patents expired.**[1]**

Companies in the power sector and automotive sector, such as Tesla, continue to invest heavily in module assembly. This is forcing battery makers, such as LG Chem, Panasonic, Samsung SDI, and others to compete to participate in the burgeoning stationary storage market.

## BATTERY MODULE COSTS

As depicted in Figure 3.3, battery modules combine hundreds of cells and include battery management systems and cooling systems. Strong research and development (R&D) within the electric vehicle (EV) industry and expanding global production capacity have historically placed downward pressure on the cost of battery modules. Per Bloomberg New Energy Finance's annual pricing survey, since 2010, volume-weighted li-ion battery module costs have fallen by 85 percent to an average of $176/kWh in 2018. The reduction is attributable to significant cost savings in both the battery cells and in the other components of the broader battery packs.

The supply of nickel-manganese-cobalt-oxide (NMC) batteries to the U.S. energy storage market temporarily slowed in Q2 2018 as shortages of cobalt arose. Korean battery vendors' prioritization of their domestic market further intensified the shortage. While these supply deficiencies slowed the decline in NMC battery module costs in the U.S. market, several top-tier battery manufacturers are in the process of increasing their battery cell production capacity.**[2]** This increased capacity is expected to include not only NMC batteries, but also lithium-iron-phosphate (LFP) batteries, which are also applicable in stationary energy storage use cases**.[3]** As shown in Figure 3.4, if the increased battery cell supply begins to put downward pressure on module prices beginning in Q3 2019 as projected, then module prices may reach $150/kWh in the 2020 to 2023 timeframe – a price considered critical to the acceleration of demand for stationary battery systems.

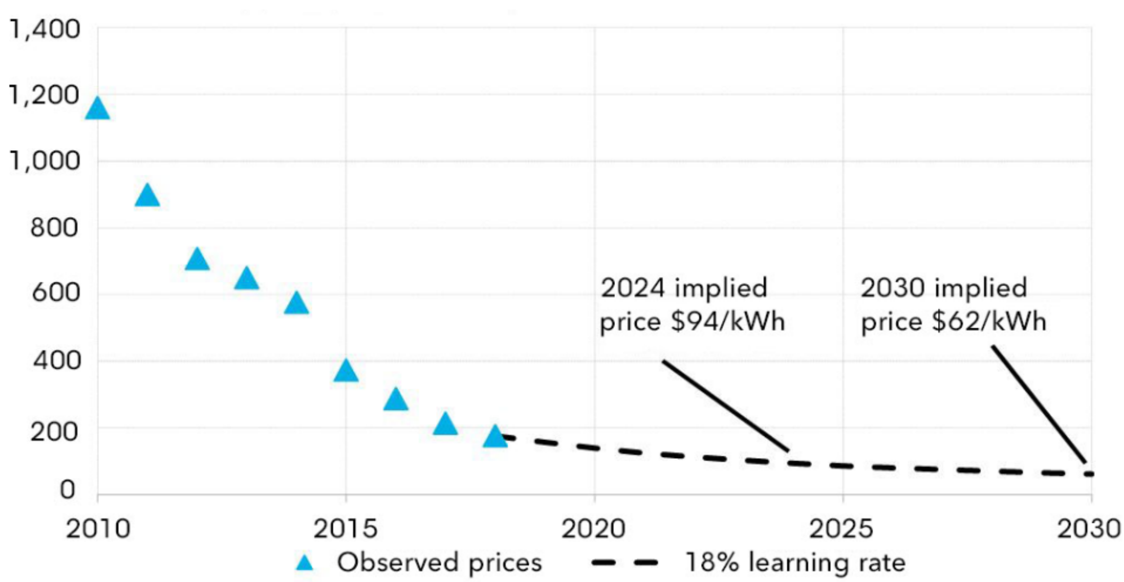


**FIGURE 3.4 – Li-ion Battery Module Costs Trend & Outlook (2018 $/kWh)**

Source: Bloomberg New Energy Finance, “A Behind the Scenes Take on Lithium-ion Battery Prices”, March 2019

## BOS AND EPC COSTS

Typical BOS components for stationary li-ion battery systems include the containers, climate control, container, power management system, fire suppression system, and related components. From 2012 to 2017, BOS costs for a 1 MWh BESS declined by 78 percent overall for a compound annual growth rate (CAGR) of -26 percent. This reduction reflects the increased availability of purpose-built componentry for use in utility-scale BESS, among other advancements.**[4]**

For a BESS of the same capacity, EPC costs have declined at a similar rate, from approximately $278/kWh in 2012 to $70/kWh.**[5]** This drop is attributable to learning by EPC firms, increasing standardization of design and installation techniques, and increased commercial competition as EPC firms proliferate, among other factors. See Figure 3.5.

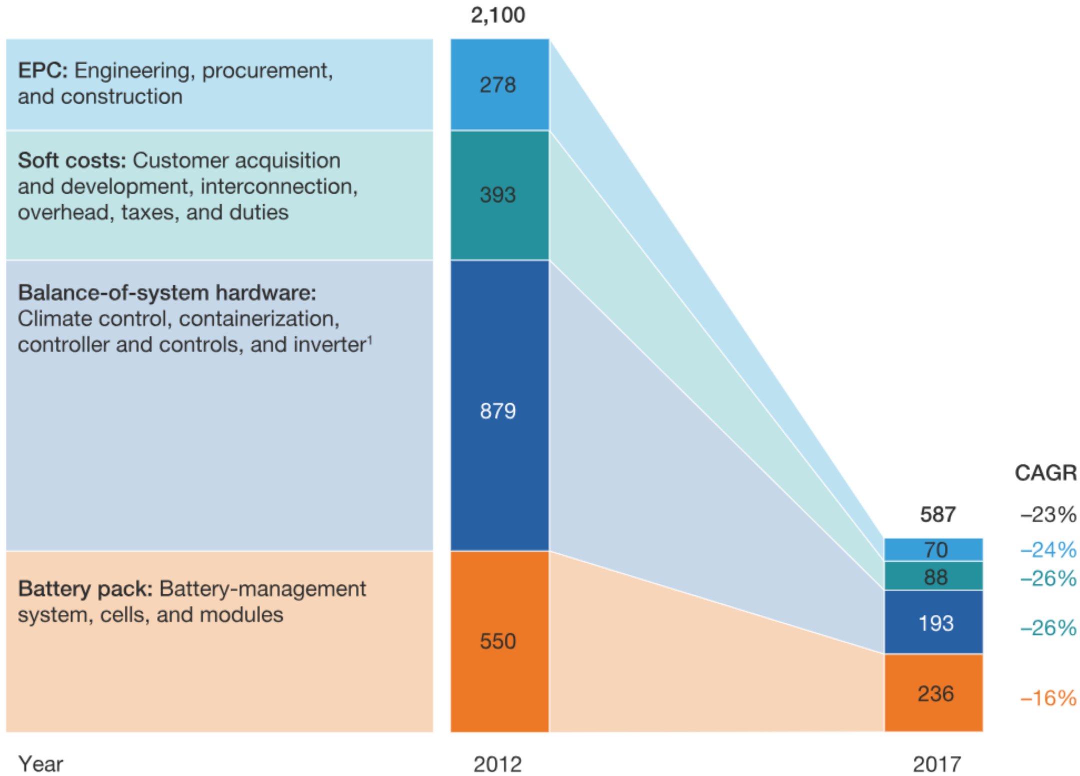


**FIGURE 3.5 – Cost Breakdown of a 1 MWh BESS (2017 $/kWh)**
Source: McKinsey & Company, GTM Research

By 2025, the BOS portion of a 1 MWh BESS is projected to decline to $85/kWh, or just 32 percent of the total system cost. Such a decline would equate to a -10 percent CAGR from the aforementioned cost as of 2017.

Through 2025, EPC costs are projected to decrease significantly, albeit not as rapidly as BOS costs. By 2025, the EPC portion of a 1 MWh BESS is projected to decline to $40/kWh, or just 15 percent of the total system cost. That decline would equate to a -7 percent CAGR from the aforementioned cost as of 2017. See Figure 3.6.

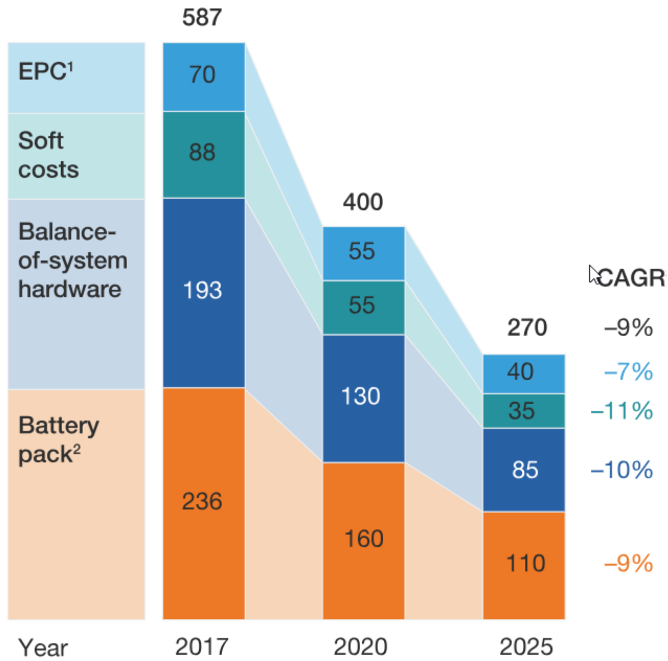


**FIGURE 3.6 – Projected Decline in Component Costs for a 1 MWh BESS (2017 $/kWh)**
Source: McKinsey & Company, GTM Research

## Levelized Cost of Storage

Levelized Cost of Storage (LCOS) reflects the total cost of the BESS divided by the energy it is projected to provide over the course of its useful life. When comparing a BESS against an alternative resource, the LCOS is the preferred unit of measurement. The LCOS includes all of the aforementioned installed costs, and adds the projected operational expenditures, such as maintenance costs and battery degradation over time. While batteries are certainly not the only technology to suffer from degradation, the industry has relatively little experience with its effect on battery life, especially with the newer li-ion battery chemistries. As such, estimates of the energy portion of LCOS (i.e., the divisor in the LCOS ratio) are likely to become more precise in the coming years as more BESS operational data becomes available for evaluation.

LCOS is analogous to the Levelized Cost of Energy (LCOE) calculation but uses charging cost as fuel cost and takes the discharged electricity instead of generated electricity.

$$LCOS = \frac{\sum(Capital_t + O\&M_t + Fuel_t) \cdot (1+r)^{-t}}{\sum MWh_t \cdot (1+r)^{-t}}$$

where $Capital_t$ = Total capital expenditures in year t, $O\&M_t$ = Fixed operation and maintenance costs in year t, $Fuel_t$ = Charging cost in year t, $MWh_t$ = The amount of electricity discharged in MWh in year t - measure for the capacity factor, and $(1+r)^{-t}$ = The discount factor for year t.

BESS with li-ion batteries can be utilized in front-of-the-meter (FTM) as well as behind-the-meter (BTM) applications, while BESS using flow batteries are generally found in FTM applications.

Typical FTM use cases include large-scale peaking capacity sold into a wholesale market (e.g., PJM, CAISO, ERCOT, etc.), transmission and distribution (T&D), and utility-scale solar PV + battery energy storage.

BTM applications generally pertain to commercial and industrial (C&I) and residential facilities, with or without solar PV. Given that each of these use cases calls for a distinct battery capacity (MWh) and cycling schedule, their respective LCOS differ somewhat.

As shown in Figure 3.7, li-ion batteries used in FTM applications have a projected 2018 LCOS ranging from $108/MWh to $471/MWh depending on the specific use case. When combined with a solar PV power generator, a li-ion BESS has a LCOS of just $108/MWh to $140/MWh. The LCOS for li-ion BESS rises for other FTM applications, with the highest range of $263/MWh to $471/MWh estimated for T&D applications. The LCOS in BTM use cases rises significantly, reaching $829/MWh to $1,152/MWh, reflecting the decreased BESS capacity and the resulting lesser economy of scale.

While li-ion is clearly the market leading battery technology in 2019, flow batteries using vanadium or zinc may offer an economic alternative in some use cases. Flow batteries are a newer technology. Early systems were complex, custom engineered systems, resulting in relatively high upfront costs. Despite manufacturers adopting pre-packaged designs to reduce costs, global commercialization of flow battery technology remains muted. This will likely limit the growth in market share for flow batteries over the next decade. However, BESS developers indicate cost improvements for flow batteries will be realized through improved design of the electrode, flow, and membrane systems.

As shown in Figure 3.7, flow batteries used in FTM applications have a projected 2018 LCOS ranging from $133/MWh to $467/MWh depending on the specific use case. When combined with a solar PV power generator, a flow BESS has a LCOS of $115/MWh to $222/MWh depending on the technology used. As with systems comprised of li-ion batteries, the LCOS for flow BESS increases significantly for other FTM applications, with the highest range of $406/MWh to $464/MWh for T&D applications.

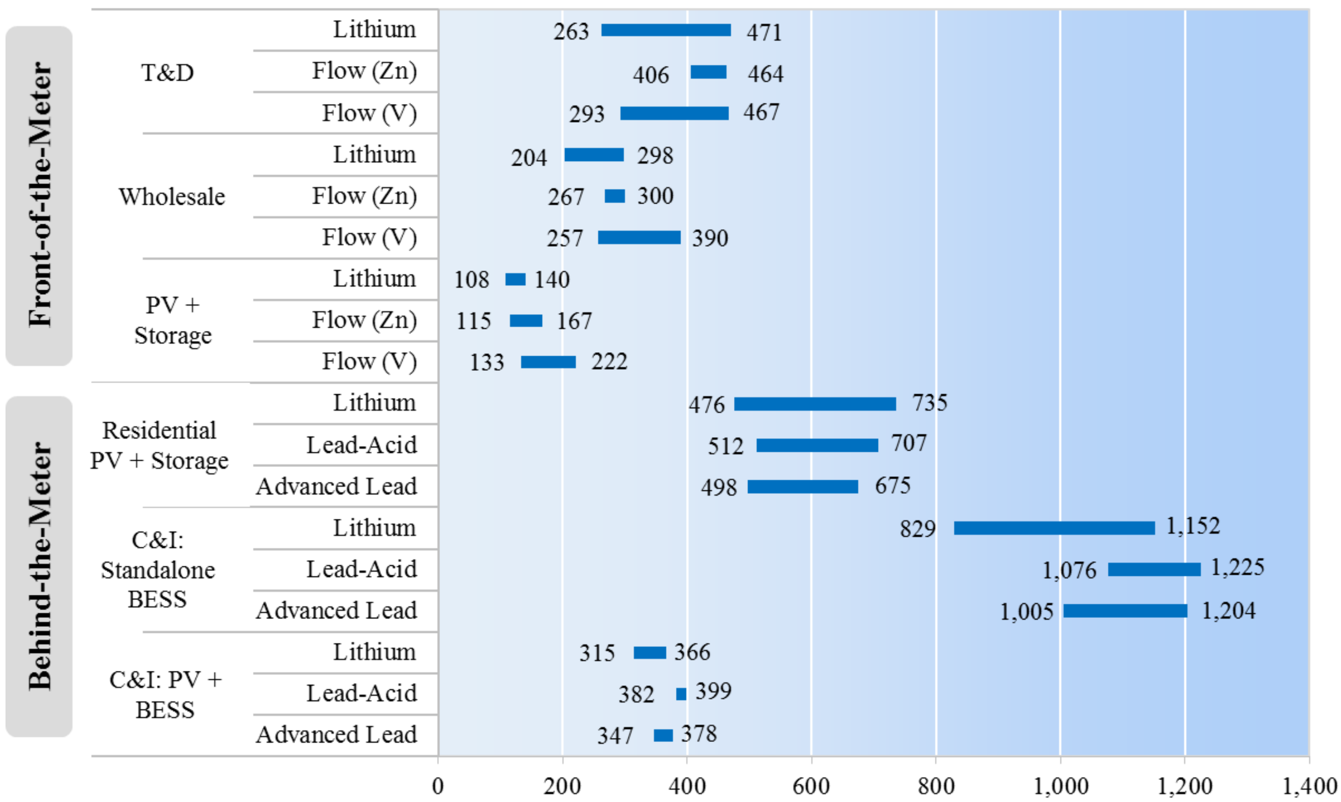


**FIGURE 3.7 – Comparison of Unsubsidized LCOS ($/MWh)**

As LCOS of various battery technologies varies, defining the application (often referred to as “use case”) becomes critical to ensure the best benefit cost analysis. Batteries can have various use cases and that can lead to selecting one technology over another. As shown in Figure 3.8, the application tends to define the duration, which then defines the technology that is best for that use case.

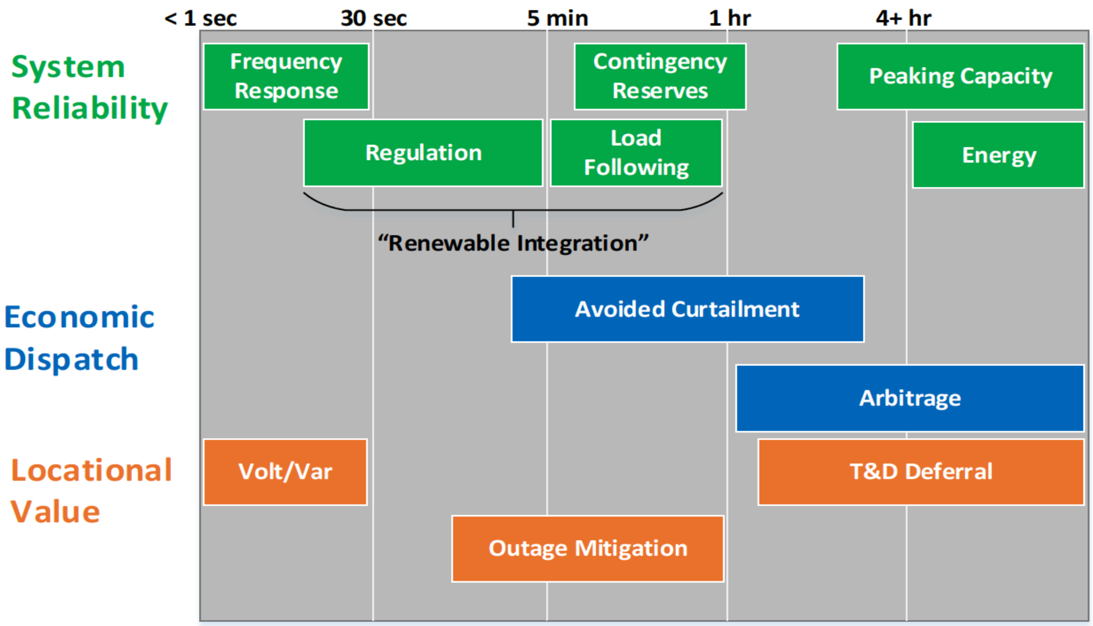


**FIGURE 3.8 – Use Case Applications for Batteries**

Consider the need for reducing demand charges. An ideal technology would be li-ion as you need longer duration. Assuming demand charges of about $12/kW-month, power costs of about $22/MWh, a 4 MW / 16 MWh battery with a total installed cost of $400/kWh would yield about a 8-year payback. Depending on the warranty, such a battery can provide relief of demand charges, but could also be located somewhere to help with a few other factors such as T&D asset deferral or outage mitigation.

# 4: Electricity Sector Drivers

*Demand for battery systems is driven by a variety of factors, including Federal and State policy incentives, and economic and system efficiency drivers at the utility and C&I levels.*

## Policy Incentives

At the Federal level, taxable co-ops can take advantage of the 30 percent Investment Tax Credit (ITC) when pairing a BESS with solar and some wind projects. Much like solar projects, co-ops can also utilize a lease-to-buy structure with a third-party financier, such as NRUCFC or CoBank, to take advantage of the ITC. Power Purchase Agreements (PPA) are another option, whereby a third party can take advantage of the ITC and pass those savings along to the co-op. While the IRS rulings are lacking in some specifics, if the BESS is installed at the same time as the solar facility and 100 percent of the energy used to charge the BESS comes from solar, then 100 percent of the ITC can be claimed. Private letter rulings from the IRS imply that a BESS installed at the solar facility within the same tax year should also qualify, as long as 75 percent of the energy used to charge the batteries is derived from the renewable resource, though the IRS may only allow a proportional amount of the BESS ITC. Co-ops should work with their tax advisors to check the applicability of their installation.

In April 2019, in the House and Senate chambers, bills were introduced that would allow stand-alone energy storage to qualify for the ITC. If approved, energy storage economic viability would increase in a variety of applications, from utility-scale systems down to residential systems.

Perhaps the most consequential policy driver is the Federal Energy Regulatory Commission's (FERC) 2018 Order No. 841,[10] which is intended to allow market access to energy storage participation for all services it can provide in RTO and ISO wholesale markets.[11] The order requires RTOs and ISOs to develop tarrifs for various electricity market services. It has the potential to make energy storage more valuable because it opens up new revenue streams. In theory, the Order could allow multiple entities, including aggregators of services, to sell those services into the organized market. This could include not only a utility, but DER aggregators and individual C&I and residential customers. The order is expected to be finalized by the end of 2019.

At the state policy level, an increasing number of states are pursuing policies supporting increased BESS adoption. Renewable Portfolio Standards (RPS), which have been in place for several years, are now expanding to include specific energy storage targets in California, Massachusetts, New Jersey, and New York. Other states considering such a target include Arizona, Nevada, and Oregon. States are also looking at incentivizing energy storage in other ways. Maryland, for instance, is the first state to offer tax credits.

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[10] **FERC Issues Final Rule on Electric Storage Participation in Regional Markets**. February 15, 2018.
[11] Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, 83 Fed. Reg. 9580 (Mar. 6, 2018), **www.federalregister.gov**. Order No. 841 is the subject of several requests for rehearing, which remain pending at this date

## Utility Drivers

At the utility level, battery energy storage can be an ideal complementary resource in locations where there is increasing penetration of renewable power generation.[12] Energy storage allows for more efficient use of renewables, because of its ability to smooth out intermittent generation that is often-times characterized by large fluctuations. The power supply profile of solar power is sometimes in opposition to the demand profile, with production at its highest during daytime off-peak hours and production at its lowest during on-peak hours in the late afternoon.

Battery energy storage allows production from intermittent renewable resources to be optimized, storing renewable energy when demand is low and discharging the energy when production ramps down and demand ramps up.

Utilities have a growing interest in managing peak demand to increase operational efficiency, as well as to lower costs. Battery energy storage is well suited to leveling out spikes in load. When load and prices are low, utilities can store this power and then discharge it when load and prices are high.

Battery storage has a lot of potential as a peaking capacity resource. These systems can be installed much faster than traditional combustion turbine (CT) gas peaking plants. In addition, CT peaking plants generally have very low utilization factors and cannot provide any other services to the market during downtimes. Conversely, battery storage can provide a variety of services to the market and capture additional revenue streams when peaking capacity is not needed. Battery storage systems can also provide a significantly faster response time than conventional CT plants.

Building and investing in new transmission and distribution (T&D) infrastructure has been the primary solution for utilities to address load growth, rising peak demand, congestion on the network, and reliability issues. With costs increasing for upgrading transmission and distribution lines, energy storage systems are conducive for utilities that want to save money with "non-wires" solutions to T&D upgrade needs. Energy storage systems allow utilities to optimize their T&D assets, as well as defer more costly infrastructure upgrades like investing in new feeder lines and substations. This is because battery storage installed at an optimal location can reduce the demand on transmission lines, substations, and transformers, relieving congestion on the system. As battery storage costs decline, utility storage systems are becoming an increasingly economical alternative to traditional T&D upgrade projects. Furthermore, the utility is afforded more time to better understand exactly what upgrades are needed, as opposed to under- or over-building systems due to uncertainty over future load growth and demand patterns. This would redefine how utilities do their long-range planning and construction work plans.

## C&I Drivers

Battery storage systems at C&I locations allow for reduced grid consumption during coincident peak demand and could result in lower demand charge costs.

[12] ***When It Comes to Battery Storage, Co-ops Should Focus on a Primary Application***. February 8, 2017.

In conjunction with lowering peak demand, battery storage at the C&I level is conducive to the ongoing promotion and expansion of distributed energy resources (DER). On-site solar PV production, for example, can dramatically lower the amount of power a building or location consumes. Combining solar and a BESS can decrease net building load. Solar production can also be more efficiently used, particularly if the amount of solar production exceeds the gross load. That power can be stored and discharged as solar production ramps down later in the day without having to rely on the grid when prices are generally rising.

## Residential Drivers

Battery storage at residential locations is also expanding for a variety of reasons, including the need for resiliency, the ability to take advantage of new rate structures and DER compensation mechanisms, and the ability to aggregate residential batteries into a "virtual power plant" to provide various grid services. An increasing number of utilities are implementing advanced rate designs, such as time-of-use rates and demand charges for residential customers. Certain rate designs will incentivize storage adoption in the same way as for C&I customers who have had demand charges for decades. Batteries can be used to reduce demand charges or to shift energy usage to lower priced periods. Demand shifting can be especially incentived for those residential locations with solar PV already installed. The solar PV could charge the battery during the day and discharge at night when prices are higher and the sun is down.

Utilities are starting to roll out pilot programs that seek to aggregate residential batteries to manage overall system peak demand. Much like other demand response programs that utilize water heaters or smart thermostats, these programs offer enrollment incentives to the consumer. In addition, as wholesale market rules are finalized for battery storage participation, residential customers may be able to work with an aggregator, such as a utility or other entity, to sell services into the wholesale market and earn additional revenue.

In areas without utility aggregation programs or advanced rates such as TOU and demand charges, resiliency is the primary driver. Battery systems that allow the consumer to completely disconnect from the utility system are currently cost-prohibitive given the size of the battery needed. It is unlikely that off-grid systems will ever constitute a significant market share.

## Projected Growth of Battery Systems

As a result of cost declines, policy drivers, and increased demand from the utility, C&I and residential levels, BESS are expected to grow substantially in the coming years. Of note, total deployments in MW and MWh in the U.S. is forecast to be split evenly between front-of-the-meter (FOM) and behind-the-meter (BTM).

Figure 4.1 shows the deployments projected within the U.S. through 2023, and Figure 4.2 indicates the breakdown of energy storage deployment internationally.

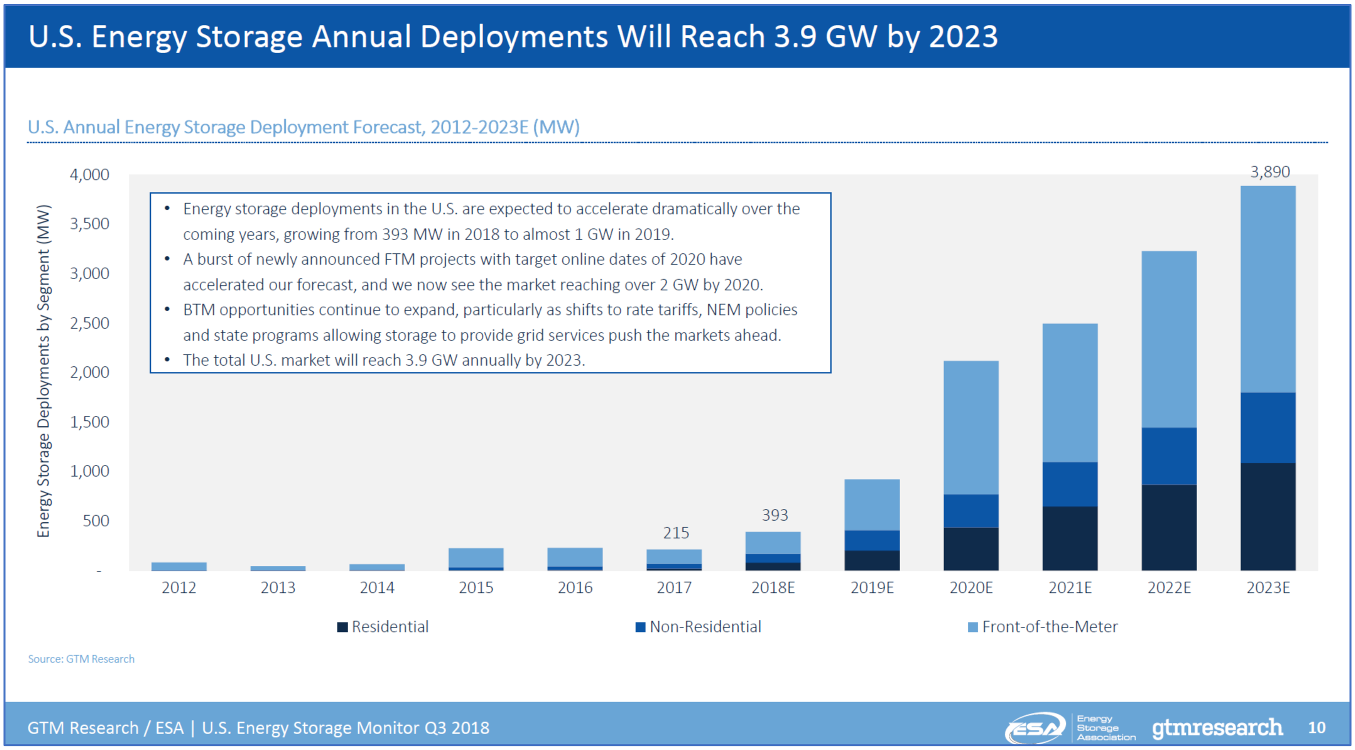


**FIGURE 4.1 – Projected Energy Storage Deployment within the United States**

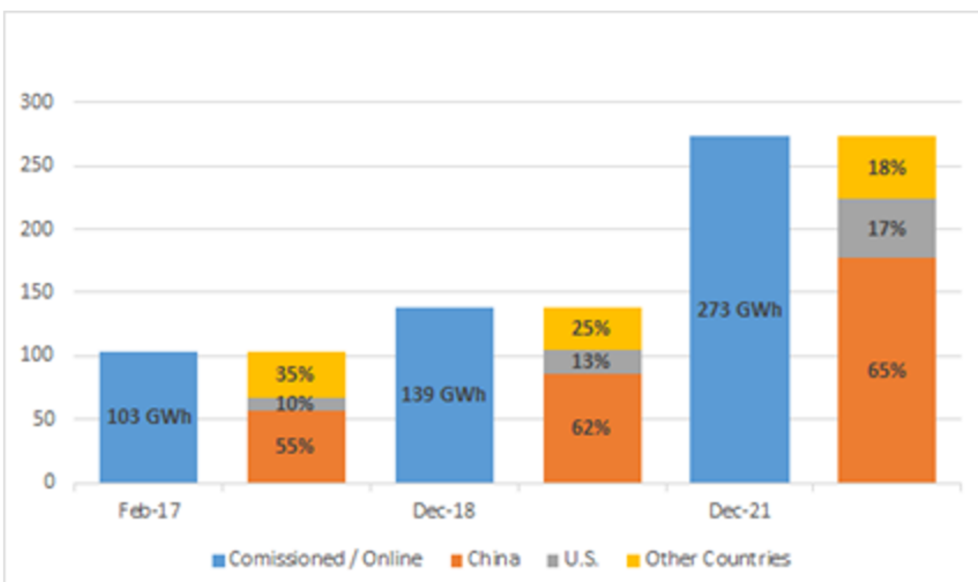


**FIGURE 4.2 – Global Li-Ion Battery Output Capacity (GWh)**

While power sector applications utilize li-ion batteries with somewhat different chemistries than those used in EVs, the utility battery energy storage market will benefit from the scaling up of manufacturing and the associated strengthening of the supply chain to meet expected EV demand. As capital costs come down, demand should ramp up as battery energy storage becomes more economically viable, allowing batteries to challenge a myriad of incumbent technologies on value proposition alone (see Figure 4.3).

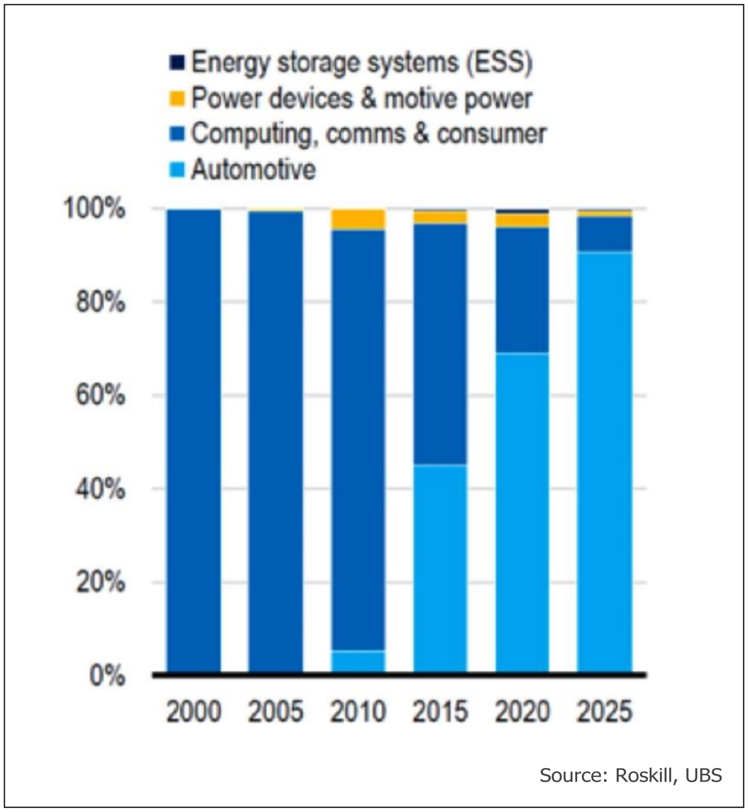


**FIGURE 4.3 – Rechargeable Battery Demand by Application Share**

# 5: Co-op Case Studies

*Stationary battery energy storage is a flexible resource that can be used for a variety of purposes. Electric cooperatives are beginning to implement battery systems for the following applications: infrastructure deferral, frequency regulation, resilience, demand management, renewables integration, and microgrids. The following section provides a selected group of projects that illustrate the various grid applications of BESS.*

## Case Study #1
## Anza Electric Cooperative (California)

**Application:** T&D deferral, resilience

**Narrative:** Anza Electric Cooperative's service area covers nearly 550 square miles of high desert in southeastern California. It is a member of Arizona G&T Cooperatives and operates within the California Independent System Operator (ISO). Anza experienced increased load growth in 2015 and 2016 that required infrastructure upgrades. Anza's system is also connected to the grid through a single transmission line, exposing the system to outages throughout the year. Its goal was to defer an upgrade to their substation, utilize batteries for a micro-grid project, reduce peak demand, and increase resilience. After weighing the options, Anza is studying the installation of a battery system which would postpone any traditional infrastructure upgrades until 2024.

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 500 kW |
| Capacity: | 1-4 MWh |
| Duration: | TBD |
| Technology: | Li-ion |
| Supplier: | TBD |

## Case Study #2
## Kotzebue Electric Association (Alaska)

KOTZEBUE ELECTRIC ASSOCIATION
*Energizing our community today and tomorrow*

**Application:** Grid stability (frequency regulation, renewables firming, spinning reserve)

**Narrative:** Kotzebue Electric Association is a co-op serving a remote Alaskan community approximately 24 miles north of the Arctic Circle. Power is delivered primarily from multiple diesel generators supplemented by a wind farm with approximately 2.7 MW of capacity. Kotzebue is not connected to any transmission system or any road system. In November 2015, the co-op installed a li-ion battery system to help mitigate wind turbine fluctuations, as well as to provide peaking power to reduce diesel generator operation.

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 1.225 MW |
| Capacity: | 0. 95 MWh |
| Duration: | 0.75 hours |
| Technology: | Li-ion |
| Supplier: | SAFT |
| Date installed: | November 2015 |

## Case Study #3
## Kauai Island Utility Cooperative (KIUC, Hawaii)

**Application:** Replacement of old peaking generators with solar+storage

**Narrative:** KIUC on Kauai Island, Hawaii has a service area that abounds in solar energy. KIUC has taken full advantage of that resource in order to reduce the consumption of fossil fuels otherwise required to run the diesel engines that supply the island's electricity. Distributed and utility-scale solar resources supply up to 80 percent of the KIUC system load during the day, with other renewable resources (hydro and biomass) enabling close to 100 percent. With such a high percentage of variable renewable resources on the system, stability is a concern during the day. In order to mitigate the intermittency of the solar generation, KIUC and SolarCity (now Tesla) pioneered the nation's first utility scale solar and battery storage system. The project included a 13 MW solar array with a 52 MWh battery, and achieved commercial operation in May 2017. Since then, KIUC has partnered with AES on two more solar plus storage systems. By the end of 2019, KIUC will be able to supply roughly 65 percent of nighttime peak load with renewable energy. KIUC's Board of Directors originally set a goal of reaching 70 percent renewables by 2030. By 2020, KIUC will likely reach that goal a decade early.

Kaua'i Island Utility Cooperative
Your Touchstone Energy® Cooperative

**Battery Technical Specifications:**

**Project 1**

| | |
|---|---|
| Power: | 13 MWac + 13 MWac solar |
| Capacity: | 52 MWh |
| Duration: | 4 hours |
| Technology: | Li-ion |
| Supplier: | Solar City (Tesla) |
| Date Installed: | May 2017 |

**Lawa'i Solar & Energy Storage Project**

| | |
|---|---|
| Power: | 20 MWac + 20 MWac solar |
| Capacity: | 100 MWh |
| Duration: | 5 hours |
| Technology: | Li-ion |
| Supplier: | Samsung SDI |
| Developer: | AES |
| Date Installed: | December 2018 |

**Kekaha Solar & Energy Storage Project**

| | |
|---|---|
| Power: | 14 MWac + 14 MWdc solar |
| Capacity: | 70 MWh |
| Duration: | 5 hours |
| Technology: | Li-ion |
| Supplier: | Samsung SDI |
| Developer: | AES |
| Expected COD: | Q1 2020 |

## Case Study #4
## Brunswick Electric Membership Corporation (BEMC, North Carolina)

**Application:** Microgrid

**Narrative:** In late 2016, Brunswick Electric Membership Cooperative in North Carolina installed a 1.2 MW PV array at the Army's "Military Ocean Terminal Sunny Point" (MOTSU). In 2017, it added 840 kWh of batteries to the system. BEMC has a long-term operations contract for the MOTSU grid. More solar and batteries are planned for the future, with the eventual goal of being able to island the entire facility and run it as a microgrid.

BRUNSWICK ELECTRIC Membership Corporation
A Touchstone Energy® Cooperative

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 0.25 MW |
| Capacity: | 840 kWh |
| Duration: | 4 hours |
| Technology: | LG Chem Li-ion |
| Supplier: | Solar City (Tesla) |
| Date Installed: | Siemens/LG Chem |

Apart from their contract with MOTSU, in late 2017 Cypress Creek Renewables installed 12 solar+battery systems under a power purchase agreement (PPA) with Brunswick Electric Membership Cooperative. Each system consists of a 499 kW- AC PV array, and two containerized 250 kW / 500 kWh capacity batteries. The batteries have a total capacity of 6 MW / 12 MWh and are connected to 6 MW of solar.

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 6 MW |
| Capacity: | 12 MWh |
| Duration: | 2 hours |
| Technology: | Li-ion |
| Supplier: | Cypress Creek (Lockheed batteries) |
| Date Installed: | 2018 |

## Case Study #5
## North Carolina Electric Membership Corporation (NCEMC)

North Carolina Electric Membership Corporation
A Touchstone Energy Cooperative

**Application:** Microgrid

**Narrative:** In 2017, NCEMC and one of its member distribution co-ops, Tideland EMC, developed North Carolina's first microgrid on Ocracoke Island. The Ocracoke Island microgrid integrates generation and storage assets, including a 3 MW diesel generator, 15 kW roof-mounted solar panels and a 500 kW/1 MWh Tesla Powerpack battery, with the demand response components of 200 Wi-Fi thermostats and 50 water heater control devices. These assets and components are dispatched to reduce peak demand, provide localized sources of power, and can allow for smoothing the integration of renewables.

NCEMC and its distribution co-op, South River EMC, recently completed a second microgrid at Butler Farms, a sustainability-focused hog farm in Lillington, NC. During an outage, the microgrid can provide power to itself and surrounding homes using a combination of a biogas digester, ground mounted solar, a diesel generator, and a battery storage system.

**Battery Technical Specifications:**

| Ocracoke Island | | Butler Farms | |
|---|---|---|---|
| Power: | 500 kW | Power: | 250 kW |
| Capacity: | 1 MWh | Capacity: | 735 kWh |
| Duration: | 2 hours | Duration: | 3 hours |
| Technology: | Li-ion | Technology: | Li-ion |
| Supplier: | Tesla | Supplier: | PowerSecure |
| Date Installed: | 2017 | Date Installed: | 2018 |

## Case Study #6
## Central Electric Cooperative (Oklahoma)

**Application:** Microgrid

**Narrative:** Central Electric Cooperative is the first tenant of the Innovation Pointe Campus, a 650+ acre "innovation ecosphere" with renewable energy, energy storage, smart grid and building automation technologies. The campus currently contains a 500 kW solar array, a 250 kW/475 kWh battery system and a geothermal heat pump loop — engineered by Innovation Pointe to grow with the campus. Smart grid technologies tie the technology together and enable the microgrid. Central's headquarters building is a LEED Gold Certified building. The cooperative is currently engineering progression models to shed building load when solar production is not optimal, reducing the building's reliance on grid power and allowing Central to be a net-zero energy facility.

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 250 kW |
| Capacity: | 475 kWh |
| Duration: | 1-2 hours |
| Technology: | Li-ion |
| Supplier: | Tesla |
| Date Installed: | 2016 |

## Case Study #7
## United Power Cooperative (Colorado)

**Application:** Demand management, community storage

**Narrative:** United Power Cooperative and Engie Energy commissioned (2) battery storage projects in Dec 2018. One currently represents the largest storage system in the state of Colorado at 4 MW / 16 MWh, and the second project is located at the Brighton Headquarters building and is a .5 MW / 2 MWh system. Both systems are connected to the grid and will be charged during the night and made available for peak shaving every afternoon. In addition, United Power hopes to layer a unique "Community Battery" program on top of these storage projects. This new program would work much like community solar, but instead of offsetting the kWh energy portion of a member's bill, this Community Battery project would offset the capacity portion of a commercial and industrial utility rate. The concept is that a C&I member would buy into this remote co-op owned and managed storage device. Instead of managing an individual member's load profile, United Power would manage its system's overall utility load profile (which is much easier to manage) and share the savings off their wholesale power bill with the participating C&I member. Community Battery storage is a win-win for the co-op and the member, because the co-op transfers the up-front cost of the battery to the member and the member receives a capacity credit on its monthly bill.

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 4 MW |
| Capacity: | 16 MWh |
| Duration: | 4 hours |
| Technology: | Li-ion |
| Supplier: | SoCore (acquired by ENGIE in April 2018), using Tesla batteries |
| Date Installed: | 12/17/18 |

## Case Study #8
## Bandera Electric Cooperative (Texas)

**Application:** Residential-scale solution

**Narrative:** Bandera Electric Cooperative (BEC) in Texas has developed solar and energy storage options for their members through a for-profit subsidiary, BEC Solar. BEC Solar is one of the few utility companies authorized to re-sell and install the Tesla Powerwall in Texas and is a leading re-seller of the product statewide. Selling battery products adds another platform to bring value to BEC's membership. While Bandera promotes the storage option for load shifting and back-up power, it is exploring the idea of controlling the batteries to achieve increased system efficiencies and cost savings.

**Battery Technical Specifications:**

| | |
|---|---|
| Power: | 7 kW |
| Capacity: | 13.8 kWh |
| Duration: | 8 hours (varies by usage) |
| Technology: | Li-ion |
| Supplier: | Tesla |

**FUTURE GROWTH**

**Residential Applications**

Energy storage at the residential level can include applications such as solar self-consumption and demand response. While distributed batteries are unlikely to be a net financial gain for consumers in the short to medium term, some residential consumers will likely adopt solar and storage systems to achieve energy independence and disconnect from the grid. The value of energy storage to residential consumers increases if they are charged a demand charge of time-of-use (TOU) rate.

From the co-op's perspective, much like thermal storage, residential systems offer the ability for the co-op to aggregate the resources to improve system efficiency and reduce overall system demand.

## Case Study #9
## Dairyland Power, Jo-Carroll Energy, Richland Electric, Oakdale Electric and MiEnergy Cooperative

**Application:** Aggregated Residential Energy Storage

**Narrative:** Four distribution cooperatives within the Dairyland Power service area (Jo-Carroll Energy, Richland Electric, Oakdale Electric and MiEnergy Cooperative) determined that there was a need to better understand the capabilities of residential scale energy storage and, more importantly, to get some hands-on experience. On paper, combining multiple residential storage systems into a peak demand charge solution should be easy. But, the reality is often more complex. Terms such as "fully integrated" are often over-used. The four co-ops selected eco-16 batteries from Sonnen, a well-established German manufacturer recently acquired by Shell. The co-ops want insight into multiple areas. How do actual installation times compare with the manufacturer's projections? How difficult is the installation training and certification? What are the actual in-field capacities, discharge rates, and roundtrip efficiencies? How difficult is it to simultaneously discharge multiple batteries in residential locations? How seamless are the interfaces to other systems? What is the potential impact to rates, especially where net-metering is part of the rate structure? The four distribution co-ops and Dairyland Power plan to analyze and quantify the results later this year.

NRTC was able to negotiate a volume discount for the members.

**Battery Technical Specifications**

Power: 8 kW
Capacity: 16 kWh
Duration: 2 hours
Technology: Lithium-ion iron phosphate ($LiFePo_4$)
Supplier: Sonnen
Date Installed: Each co-op is on a different schedule.
Installations started in 4Q 2018
Expected completion in 2Q 2019

## Case Study #10
## Connexus Energy

CONNEXUS® ENERGY

**Application:** Solar plus Storage – Distribution Grid Interconnected

**Narrative:** In 2016, Connexus began exploring the potential of installing a megawatt class solar system integrated with battery storage. It took two years to go through the process of getting independent proposals for solar and battery storage. Given the size of the project, 10 MW of solar and 15 MW of battery storage, the project was split between 2 sites and 3 substations. The primary use for the solar plus storage case is to align the delivery of solar energy with Connexus' system peaks via battery storage. This project came online in phases during 4Q18. By December 23, 2018, both sites were fully operational.

**Battery Technical Specifications:**

| Anoka Site | | Athens Site | |
|---|---|---|---|
| Power: | 6 MW | Power: | 9 MW |
| Capacity: | 12 MWh | Capacity: | 18 MWh |
| Duration: | 2 hours | Duration: | 2 hours |
| Technology: | Lithium Iron Phosphate | Technology: | Lithium Iron Phosphate |
| Supplier: | Lishen | Supplier: | Lishen |
| Date Installed: | 2018 | Date Installed: | 2018 |

## Case Study #11
## Vermont Electric Cooperative

**Application:** Peak shaving/system optimization

**Narrative:** Vermont Electric Cooperative (VEC), located within the New England ISO territory, has developed two innovative battery storage projects to reduce peak electricity market costs and pass those savings along to their consumer-members. The first is a utility scale, 1 MW 4 MWh battery system located next to a substation. VEC signed a 10-year Energy Storage Services Agreement with Viridity Energy Solutions to lease up to 400 MWh of storage per year. VEC will be able to utilize the battery to reduce demand during the 13 hours of peak energy costs per year that it experiences, thereby saving its consumer-members tens of thousands of dollars per year.

VEC's other battery project is located behind-the-meter at a C&I member. The C&I member was concerned about its energy costs and was looking for a specific solution to shave peak demand. The C&I member has an unpredictable and long peak, making it difficult to anticipate its monthly peak and, thus, battery utilization and operation. However, VEC proactively engaged in discussions with the C&I member, and they were able to find a win-win solution. Under the agreement, the battery is located behind-the-meter, and VEC controls the battery to reduce its monthly peak demand and shares with the customer the savings it realizes from the dispatch of the battery.

**Battery Technical Specifications:**

Hinesburg Substation Site

| | |
|---|---|
| Power: | 1 MW |
| Capacity: | 4 MWh |
| Duration: | 4 hours |
| Technology: | Lithium Ion |
| Supplier: | Viridity Energy Solutions |
| Date Installed: | June 2019 |

C&I Member Site

| | |
|---|---|
| Power: | 5 kW |
| Capacity: | 30 kWh |
| Duration: | 6 hours |
| Technology: | Aqueous Hybrid Ion (AHI) |
| Supplier: | Aquion |
| Date Installed: | 2018 |

# 6: Conclusion

BESS has successfully matured from a research project to a potentially viable solution for multiple applications within the electric utility sector. Thanks to performance improvements and cost declines, battery storage is now a force to be reckoned with. In the future, performance is expected to continue to improve, and costs for both li-ion and flow battery systems are expected to continue to fall. As a result, the industry should expect substantial growth in the coming years. However, growth in BESS will likely not occur uniformly throughout the country. Growth will vary based on policy support, local system characteristics, and consumer demand. Supply chain as well as access to raw materials could also have some impact on the growth of BESS, especially when electric vehicles reach a 25 to 30 percent penetration in the automobile market.

BESS presents co-ops with an opportunity to improve system efficiency, reduce costs, improve reliability and resilience, and provide members with new services. Important challenges remain, including developing sustainable business and financing models, warranties, integrating battery energy storage, and other challenges. In addition, the challenges of econmic competitiveness with alternative technologies will need to be addressed. Some of these challenges will be overcome through the natural maturity of the technology, while others require a broader effort to develop focused programs, projects, tools, and resources. As BESS continues to evolve and improve, co-ops will be in a strong position to take advantage of the technology, given co-ops' strong ties to the community, flexible business model, and innovative spirit.

# A: Definitions

### Balance of System (BOS) Costs

BOS components for stationary battery systems include the containers, monitors and controls, thermal management, fire suppression, and the power conversion system.

### Battery

An electrochemical energy storage device which is usually DC. This is one part of a battery energy storage system.

### Battery Cell

This is the smallest individual electrical component of a battery. It may be a separate physical device (such as an "18650" cell commonly used with lithium batteries), or it may be part of a larger package, yet electrically isolated (a 12V lead acid car battery actually has six two-volt cells connected via bus bars).

### Battery Energy Storage System (BESS)

BESS is a term used to describe the entire system, including the battery energy storage device along with any motor/generators, power electronics, control electronics, and packaging. Since all electrochemical batteries produce DC current, a BESS typically consists of the following components:

- DC battery system (batteries, racks, etc.)
- Enclosure(s) with thermal management
- Bi-directional DC/AC inverter
- EMS/system level software controller
- Switchgear/metering/MV step-up transformer, etc.

### Battery Management System

This is a system which manages and monitors the battery to ensure even charging and discharging. This may be part of a system controller or may be a separate subsystem controller.

### Electro-chemical flow battery

Battery that uses pumped electrolyte to transfer energy, typically involving a membrane. There are two primary types of flow batteries generally available — the "redox" battery, where the electrolyte is pumped through a membrane, and the Zinc Bromide battery, where zinc is plated from the electrolyte onto a membrane. Theoretically, the energy capacity is determined by the volume of electrolyte and the "power rating" is determined by the size of the membrane and some other factors. These batteries have moving parts (pumps) and "plumbing" which introduces failure mechanisms which are not present in solid state batteries. Redox batteries are very similar in concept to hydrogen fuel cells.

### Electro-chemical solid-state battery

Category includes lead acid, lead-carbon, nickel-metal-hydride, various lithium technologies, sodium nickel chloride, and "liquid metal" batteries, among others. Typically, there is an electrolyte that interacts with an "electrode" with no moving parts or pumps. (The liquid metal battery uses layers of molten metals and complex salts, but there are still no moving parts.)

There are two main types of electrochemical batteries — **standard (non- flow)** and **flow**. A **standard battery** consists of pairs of plates immersed in electrolyte and separated by non-conducting materials. They have no pumps or other moving parts. Examples include lead-acid, lithium-ion, nickel cadmium, nickel metal hydride, sodium-nickel chloride, zinc-air and, most recently, liquid metal batteries.

### Flow Batteries

Flow Batteries use tanks of electrolyte and some sort of membrane to control the flow of electrons. These systems use pumps to control the flow of electrolyte. In many ways, flow batteries most resemble fuel cells that can be run in reverse. Examples include vanadium redox, iron redox, and zinc bromide batteries.

### Islanding

Islanding occurs when a system continues to generate power and export it, even after the failure of the main electric grid.

There are two types of islanding — unintentional and intentional.

- **Unintentional Islanding.** This would happen if a system were to somehow continue to export power into the grid after the main grid had failed. This is a serious safety problem and would be dangerous both to the crews working to repair the lines and to other consumers sharing that line. Fortunately, all interconnected energy storage systems are subject to IEEE 1547, which requires that distributed generation systems (including energy storage systems which can act as generators) disconnect from the grid in the event of grid failure. Assuming that the equipment is listed to UL-1741 (which incorporates IEEE 1547) or other-wise certified to IEEE 1547 standards, this should prevent unintentional islanding.
- **Intentional Islanding.** This is a special case where the system disconnects from the electric grid as per UL-1741, but still continues to power a set of loads behind the system disconnect. To do this, the inverter has to switch from "grid interactive mode" to "load following mode." The system would continue to monitor the grid and reconnect when the grid is available and stable per IEEE 1547.

### Lithium-Ion Batteries

Most Li-ion batteries used in electric vehicles and utility energy storage are configured using "18650" cells originally developed for laptop batteries. For example, the 100-kWh battery module in a Tesla Model S contains 8,256 individual cells. (Note — this would mean a 10 MWh battery has nearly a million individual cells.) Some Lithium batteries are manufactured in "prismatic" form factor which offers fewer parts, but also larger form factors which can lead to cooling issues. Tesla recently introduced the "2170" cylindrical cell, which has almost 150 percent of the volume of the 18650 and is claimed to be 10-15 percent more energy efficient. LG Chem are also currently offering "pouch" type cells. Lithium batteries can store a great deal of energy in a small space, but are notoriously flammable, as noted in a number of high profile incidents involving cell phones, “hoverboards,” airplanes and electric cars. Some chemistries are inherently more flammable than others, but designers can also influence flammability through different choices of electrolyte, separators, physical packaging, and cooling systems. Grid-scale stationary storage systems are designed to be safer than Li-ion applications in products such as cell phones.

### Vanadium Redox Flow Battery

Vanadium redox flow systems use electrodes to generate currents through flowing Vanadium electrolytes. The size and shape of the electrodes govern power density, whereas the amount of electrolyte governs the energy capacity of the system. The cell stacks are comprised of two compartments separated by an ion exchange membrane. Two separate streams of electrolyte flow in and out of each cell with ion or proton exchange through the membrane and electron exchange through the external circuit.

Redox flow batteries consist of two tanks of electrolyte which are pumped past a proton exchange membrane. Power capacity is determined by membrane area, while energy capacity is determined by the volume of the tanks.

### Zinc Bromide Flow Battery

Zinc-bromine flow batteries use a significantly different process than redox flow batteries. During charge, zinc is drawn from the electrolyte and plated onto a microporous membrane at the negative electrode and bromine is created at the positive electrode. The zinc is dissolved back into the electro- lyte during discharge and the bromine is converted to bromide ions. Similar to other flow batteries, power is determined by the size and number of “membrane stacks” and energy capacity is a function of both the electrolyte volume and the number of membranes (because they have a limited plating thickness). These batteries can be thought of as a sort of reversible electro-plating machine.

### Zinc Iron Redox Flow Battery

Zinc Iron Redox flow batteries share many characteristics with vanadium technologies, except that they use iron and iron/zinc based chemistries and non-acid electrolytes.

## THE MAJOR FACTORS IN DESCRIBING A BATTERY SYSTEM INCLUDE:

### Cycle Life (#)/Throughput (kWh/MWH)

Cycle life is the number of times the battery can be discharged and recharged during its useful life. Cycle life is often specified as “number of cycles to XX percent DOD” since many batteries will have longer lives if discharges are kept shallow. There is an increasing trend to provide warranties based on “throughput,” specified as the number of kWh delivered by the battery/system. This assumes that cycle life is directionally proportional to DOD and is equivalent to saying something like “5,000 cycles to 50 percent DOD or 2,500 cycles to 100 percent DOD.” This may not be the case for many battery chemistries.

### Degradation (% per year)

With some technologies (especially lead-acid and Li-Ion), the battery capacity will degrade over time / number of cycles and “end-of-life” is often specified as minimum available capacity. System operators may deal with this my replacing battery modules over the life of the system to keep capacity above a specified level. Other technologies (flow batteries) may experience little or no degradation over the life of a system.

### Rated Energy (kWh / MWh)

The amount of energy stored in the battery. This quantity is generally specified in AC for complete systems or in DC when only the battery itself is being described. However, vendors will sometimes show a “rating” for kWh in DC before considering AC conversion. It is important to note that some manufacturers specify a “rated power,” but then list a “maximum depth-of-discharge (DOD)” which limits the actual energy available. Note that for some technologies, the energy available may be proportional to the discharge rate (higher discharge rates typically allow less energy to be removed from the battery). It is important to note that the AC rating of a battery system may be significantly smaller than the DC rating of the battery component itself, both due to inverter efficiencies and derating of maximum DOD to increase cycle life. Energy is sometimes rated in “hours,” which is simply the energy capacity divided by the discharge capacity. Typical utility batteries range from 15 minutes to about 8 hours, with a distinct trend towards batteries with 2-4 hours of capacity.

### Rated Power (kW / MW)

The maximum power that a battery system can provide at a given time. This is limited by the rating of the inverter, but some technologies are more suited to rapid discharge than others so they could have a higher discharge rate if the proper inverter is installed. The rated power is specified in AC Watts for complete systems, but may be specified as DC if only the battery side of the system is discussed.

### Round Trip Efficiency/RTE (%)

This is the ration of the amount of energy which has been discharged from the battery divided by the amount of energy needed to recharge the battery. It is always less than 100 percent. This is specified as DC RTE when discussing the battery alone, and as ACRTE when discussing complete systems. AC RTE is calculated as the DCRTE times the square of the inverter efficiency. Round trip efficiency may also be affected by the need to “top-balance (equalize)” or “bottom-balance (run to full discharge and balance cell voltages there)” battery cells or modules.

**System Life (years)**

This is the expected calendar life of a battery or system and may be a factor of corrosion, capacity degradation, life of seals/membranes, or other factors.

# B: References

[1] MarketWatch, "Status of the Battery Patents: 2017 Patenting Activity - 30,400 New Patent Families, 30,900+ Patents Granted & 6,400+ Patents Expired", April 2018.

[2] Bloomberg, "For Now, at Least, the World Isn't Making Enough Batteries", October, 2018.

[3] Utility Dive, "Battery material shortage pushes developers to shift li-ion chemistries", September 2018.

[4] McKinsey & Company, "The new rules of competition in energy storage", June, 2018.

[5] The units for installation costs are $/kWh, calculated as the total investment in equipment divided by the rated output of the system, which is 60,000 kWh in this case. See Lazard's LCOE studies 1.0, 2.0, 3.0 and 4.0. This is based on survey results reported in Lazard's Levelized Cost of Storage studies from 2015-2018. The numbers reported are average values for a 10 MW, 60 MWh Li-ion battery installed at the distribution level of the grid. Installation costs only include the upfront capital investment in racking equipment, battery modules, the battery management system, the BOS costs, the power conversion system, and engineering, procurement, and construction costs.

[6] Schmidt, O. Hawkes, A., Gambhir, A. & Staffell, I. The future cost of electrical energy storage based on experience rates. *Nat. Energy 2,* 17110 (2017).

## Other Resources:

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