Focusing (Stored) Energy Where It Matters Most

Optimizing the Impact of Energy Storage in the Access Network

A Technical Paper prepared for SCTE by

Toby Peck
Senior Director, Product Management
EnerSys

Creighton Brown
Engineering Manager, Energy Storage
EnerSys

Mark Vodopest
Broadband &Renewables Market Manager, Energy Storage
EnerSys

Greg Laughlin
Strategic Marketing Manager
EnerSys

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1. Introduction

We have become increasingly reliant on the hybrid fiber-coax (HFC) network for high-speed data, as much of the workforce has transitioned to a hybrid work environment between office and home. The line between business services and residential customers has been blurred – and the need for this ultra-reliable data source has become universal. We have charted a course to meet future bandwidth needs with the 10G initiative, and new mobility offerings are leveraging the HFC network to ensure connectivity while on the go. With all of this, it has never been more important to have reliable power to keep the network up and running.

Energy storage is fundamental to reliable powering; without it, every blip on the grid can cause a business transaction to fail or an important Zoom call to drop. There is an estimated 3.2 GWh of energy storage in the access network today that guards against outages for millions of customers. So how can we use this available energy most effectively? Is it being deployed and maintained efficiently to minimize operational costs? Can it be leveraged to lower utility impact? Is there intelligence that can be embedded to increase operational efficiency and plant reliability?

This paper will explore:

- Various energy storage technologies being reviewed in for use in the outside plant (OSP)
- Key considerations for deployment of OSP energy storage solutions
- A methodology for determining the best energy storage technology for any plant scenario

2. Evaluation Process

Choosing the best energy storage system (ESS) for a specific application can be challenging, but if you assess the right information during the design phase of a project, this task can be much less daunting. There are many key system requirements that need to be considered as part of the ESS such as required backup time, load profile, cycling frequency, environmental factors, cost, site limitations, local code requirements and safety. Making the final decision should be based on all these factors and not just one or two key characteristics. Purchasing the best value solution will ensure that the ESS will perform safely and optimize the operational benefits of the system. Below is a description of some of these key factors for choosing the right ESS and the role that they play in determining which solution is best for any unique application.

2.1. Load

2.1.1. General Considerations

The load is the amount of power that will be required from the ESS for a specified period. A load profile is given either as a constant current (constant amperage), constant power (constant watts), or a multi-step load, where loads turn on and off throughout the backup period. Understanding the unique charge/discharge characteristics of each battery will help you to make the best ESS selection.

2.1.2. Cable Broadband Applications

The traditional application for outdoor cable broadband backup power is for HFC nodes and amplifiers, which through distributed access architecture (DAA) are migrating to remote-phy devices (RPDs) and passive optical network (PON) optical line terminals (OLTs). The traditional load profile is a constant power load that only requires battery support during infrequent utility power outages. Figure **1** below illustrates typical loads at an HFC power supply; while most HFC power supplies support 15A to 18A of power, many operators tend to load the supplies close to 50% capacity to allow for future additions.

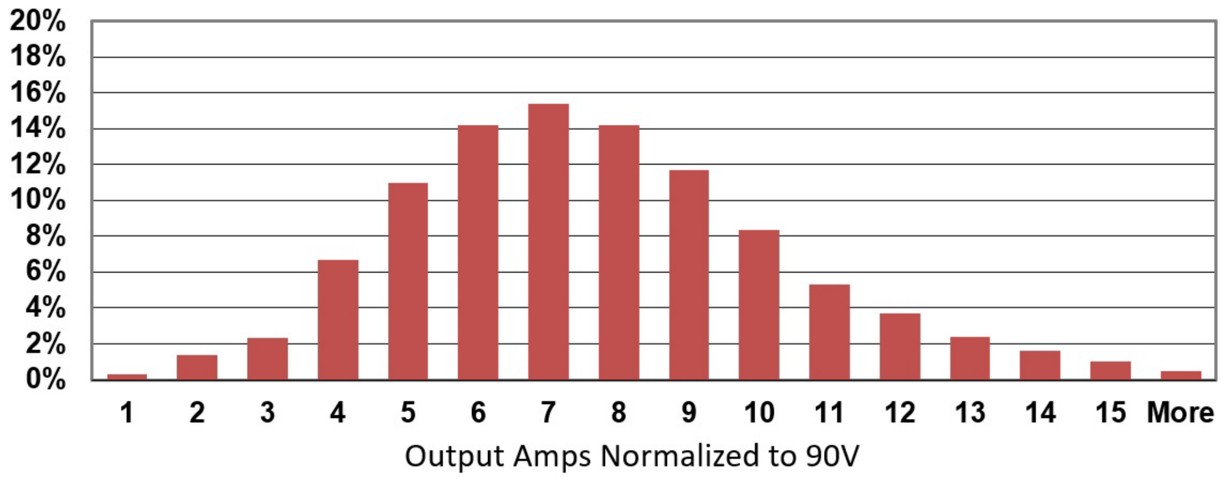


Figure 1 - Estimated distribution of North American power supply loads

2.2. Backup Runtime

2.2.1. General Considerations

Required backup time is an important attribute of the load profile and needs to be fully understood upfront. Batteries are often engineered with specific charge and discharge characteristics in mind. Certain chemistries perform better at different discharge rates and even within the same chemistry batteries can be designed for high instant power for short durations or high energy (capacity) low power for longer durations. For the purposes of this paper, the term battery can be defined by the Oxfor dictionary definition - a container consisting of one or more cells, in which chemical energy is converted into electricity and used as a source of power.

2.2.2. Cable Broadband Applications

Entire white papers can be written on strategies for determining required runtime at any unique OSP powering location, but to provide context for understanding the best ESS solution it is important to have a high-level understanding of what might drive runtime requirements.

The first question to be answered is how much downtime can you tolerate? The answer to this question may be dictated by competition, service agreements or mandates. Our societal reliance on network connectivity for work, life management and entertainment has made the cable network essential to the point where any downtime is unacceptable. Competitive pressure from other wireline, wireless and satellite options place power reliability as a differentiator for customer retention.

Government mandates for emergency services (911) – or in the case of California Public Utility Commission's (CPUC) 72-hour mandate for wildfire mitigation[i] – may also affect your backup power requirements.

The next consideration for estimating required backup time is understanding how long it will take to dispatch technicians to augment power with curbside generators until utility service is restored. It is important to factor not only the distance to reach a site, but also the quantity of sites and ability to serve during widespread outages in a given service area.

2.3. Cycling Frequency

2.3.1. General Considerations

Once a clear understanding of the load profile has been established, it needs to be determined how often this load will be applied to the ESS. Depending on the application, an ESS may be utilized daily, or in the case of standby backup power, may only be used a few times per year. It may not make financial sense to pay significantly more for a technology that offers thousands of cycles if those cycles will never be realized. In contrast, if the system is going to be cycled on a regular basis it may make sense to pay more up front for a battery system that cycles better to reduce the number of required battery changes over the life of the system.

2.3.2. Cable Broadband Applications

Decision factors with respect to cycling requirements have been traditionally placed around the stability of the utility grid serving each site. In areas where the utility grid is stable and reliable, the batteries spend most of their time in float mode waiting to be used, in which case battery cycling is not a concern. Alternately, areas prone to frequent (daily) outages may benefit from a storage solution designed for high cycles.

Energy mitigation may have some future application as well as any potential renewable applications, where battery power is intentionally invoked. A high-cycle energy storage solution would be more applicable for these energy strategies.

2.4. Site Limitations

2.4.1. General Considerations

As the two drivers connected to runtime, load demands and required backup times, continue to increase, designers are often challenged with meeting these requirements within a fixed space available for both the batteries and corresponding electronics. Some installations may have weight limitations, such as pole mounted systems or systems that are not installed on the base floor of a structure.

As an example, the California Public Utilities Commission [CPUC] increased the required backup time of critical communications infrastructure from 24 hours to 72 hours in fire prone areas. In many cases this extended runtime had to be met without expanding the existing available space for energy storage. In these scenarios, volumetric and gravimetric energy density of the ESS becomes a critical attribute that needs to be considered closely and may outweigh other attributes.

2.4.2. Cable Broadband Applications

When considering the best energy storage for any OSP ESS, a key detail to understand is the physical space limitations of the specific site being built.

- Currently most sites have been designed specifically around the form-factor of three or six batteries in case size 27 (306 x 173 x 225mm) or case size 31 (330 x 173 x 240mm)
- Sites are often in easements in front of residences or on utility poles, so there is usually little or no space for additional battery cabinets to extend run times
- Many areas have height restrictions for cabinets making it impractical to add battery extensions to existing locations
- In locations where space does exist for larger installations, permitting can still be restrictive, and requirements vary between national, regional and local Authorities Having Jurisdiction (AHJs).
- When upgrading existing sites with established utility service connections, it is often a requirement to maintain that connection to reduce costs and minimize logistical issues with local electrical utilities.

2.4.2.1. Cabinet Space limitations (Typical)

There are numerous exceptions to these and thus there is no one-size-fits-all ESS solution for every site.

Figure 2 - Example cable broadband powering sites. The variability in available space, loading, and local regulations makes a one-size-fits-all solution for ESS solutions nearly impossible.

2.4.2.2. Other Physical Restrictions

The access network has often been weaved in amidst its surroundings to stand out as little as possible. Network power systems in a particular location often existed prior to suburban development that now restricts their expansion or adaptation. Ground space around existing sites often has limited clearance to expand, especially in scenarios like the CPUC's 72-hour mandated backup time, which required immense increases in runtime with limited room for expansion. Pole attachments can be heavily regulated by the utilities that own them, and many local regulations exist around the space that an enclosure can occupy on a pole as well as the total weight of the system attached to a pole. It is important to understand these requirements as they can factor heavily in the process of deciding an energy storage solution for any given site.

2.5. Environmental Resiliance

2.5.1. General Considerations

Outdoor ESS can be exposed to a wide array of environmental challenges including excessive heat, cold, heavy rains, wind, humidity, earthquake and more. Each battery chemistry handles these environmental concerns differently.

2.5.2. Cable Broadband Applications

The OSP broadband network is generally powered and backed up by energy storage systems in enclosures that have only passive thermal management. This means that in many geographies these systems will be subjected to a wide range of temperatures ranging from -40°C to + 60°C. Additionally, the majority of OSP enclosures are NEMA 3R rated, which provides a degree of protection against falling objects and precipitation but allows open airflow through the cabinet as a measure of passive cooling. This means that these systems are often subjected to moisture from humidity. Finally, as most of these systems are close to roads, they can be impacted by roadside vibration caused by larger vehicles.

2.6. Safety

2.6.1. General Considerations

Safety is perhaps the most important consideration when discussing energy storage technology. The harsh nature of outdoor installations, especially within proximity to the public, creates inherent risk. Any energy storage technology should be proven and certified safe to the highest possible standards before being deployed.

2.6.2. Cable Broadband Considerations

2.6.2.1. Standards and Codes

A key factor in deploying the best ESS for any application is the understanding of relevant safety standards. There are two main organizations who produce recommended fire codes, International Fire Code (IFC) and National Fire Protection Association (NFPA). Each of these organizations release recommended codes related to fire safety which are often adopted as requirements, either in part or in full, by fire marshals and AHJ's in their local building codes. Contained within chapters related to energy storage systems, IFC and NFPA855 documents often require adherence and certification to UL Solutions (UL – formerly Underwriters Laboratory) test standards and certifications to dictate fundamental system safety.

While limited in impact to most current broadband OSP applications, NFPA 855 2023 edition also dictates ground clearances and site protection required, which can have a drastic impact on the area required for deployment. Required compliance to NFPA 855 is defined by the ESS technology and the aggregate energy capacity. Table **1** below from NFPA defines where ESS must comply to this standard.

Table 1 – NFPA 855 Application[ii]

NFPA 855 – Application

ESS TECHNOLOGY	Aggregate CAPACITY[a]
BATTERY ESS	
Lead acid	70 KWh
Nickel cadmium	70 KWh
Lithium-Ion	20 KWh
Sodium	20 KWh
Flow batteries	20 KWh
Other battery technologies	10 KWh
Batteries in residential occupancies	1 KWh
CAPACITOR ESS	
Capacitors, all types	3 KWh
OTHER ESS	
All other ESS	70 KWh

2.6.2.2. UL Standards for Energy Storage Systems

In Energy storage markets, UL provides standards that are either pass/fail and carry a certification or listing or are merely to gather data to make educated decisions on installation parameters. The following sections summarize standards that most often impact energy storage.

2.6.2.2.1. UL1973

UL1973 is a series of tests that subject batteries (specifically at battery level) to abusive test situations (such as overcharge, drop test, crush test etc.) to ensure that the battery design is robust enough to safely handle challenging environmental and operational hazards. This standard was originally written with lithium chemistries in mind, but Annex H of the standard – with tests more applicable to lead acid batteries – has recently been released.[iii]

2.6.2.2.2. UL9540

UL9540 is a system level test that includes a UL1973 listed battery, along with other UL listed electronics and controls (inverters, breakers etc.). This is a safety standard to ensure that all system components interact correctly with each other to maximize safe operation of the system and is not a test of any individual component. It should be noted that per the scope of UL9540 Section 1.5: "systems using lead acid or Ni-Cad batteries that fall within the scope of UL 1778 and only serve an uninterruptible power system (UPS) application are outside the scope of this standard."[iv]

2.6.2.2.3. UL9540A

UL9540A is a "Test Method for evaluating thermal runaway and fire propagation in battery energy storage systems". The goal of this set of tests is to determine if a battery is capable of entering thermal runaway, and how it responds at a cell, module, unit, and installation-level once in thermal runaway.

Temperature, deflagration, propagation, and quantities of released gases are measured and recorded at each phase of the test. This data is then used to determine spacing requirements, fire protection and suppression requirements as well as other aspects of the installation.[v]

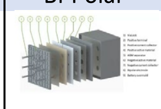
2.7. Recyclability

As our industry leads the way toward a more sustainable future, it is paramount to consider the impact of end-of-life disposal of any energy storage technology, as well as the assumed life cycle. While many technologies can be recycled at some level, market value of the recyclable material will determine whether recycling becomes an added cost.

3. Energy Storage System Technologies

Although there is continual research and development in potential ESS technologies and battery chemistries, we will only highlight technologies that are currently available or expected within the next 24 months, and applicable for use in the cable broadband market. This includes lead acid, lithium, hybrid supercapacitor, nickel-zinc and sodium-ion. Each battery chemistry has its own benefits which make it ideal for various applications. In Table 2 below, is a comparison of important characteristics to assess as you are considering available ESS options.

Table 2 – Chemistry Comparison[vi][vii]

	Lead Acid	Bi-Polar	LFP	NMC	NCA	Nickel Zinc	Sodium Ion	Hyb SuperCap
								
Full Chemistry Name	Lead Acid	Bi-Polar Lead Acid	Lithium Iron Phosphate	Nickel Manganese Cobalt	Nickel Cobalt Aluminum Oxide	Nickel Zinc	Sodium Ion	Lithium SuperCap
Applications	ESS/Telecom/ Datacenter UPS / Transportation/ Engine start	Under development	ESS/EV/Consumer Storage	EV, Ebike, Medical Devices, Industrial	EV, Consumer Electronics	UPS-High power discharge	EV, ESS	Telecom/Broadband, 36V, 48V
Nominal Voltage	2	2	3.2	3.6	3.6	1.7	3	3.6
Operational Voltage	1.67 to 2.27	1.67 to 2.27	2.5 to 3.65	3.0 to 4.2	3.0 to 4.2	1.2 -1.9	1.5 to 4.3	3.0 To 4.2
Cycle Life	200 to 2050 (50% DOD Carbon)	500+	3000-5000	1500-3000	500	500	3000	10000
Design Life	5-7 Years	5-7 Years	10 to 15 years	10 to 15 years	10 to 15 years	10 to 15 years	10 to 15 year Estimate	20+ years
Charge Current	.1C to Unlimited	.1C to Unlimited	1C	.7 to 1C	.7C	.45C		.5C
Discharge current	4C	4C	1C	1 - 2C	1C	.45C		1C
Energy Wh/KG	35 - 50	50-60	90 - 120	150 to 220	200 -260	62.5	160	126
Energy Wh/L	20 - 50	50-60	250	338-545	569	280	~200	~150
Main Benfits	Low cost, Low risk Thermal runaway	Increased power density, 15% lighter than trad. Lead Acid, lower cost	High Cycle life, Perceived safer	High Energy Density	High Energy Density	No Thermal Runaway	No Thermal runaway, Cheap BOM, Sodium cheap and plentiful	Very High Cycle life, No Thermal runaway
Challenges	High Weight, lower cycles @ high DOD	Under development	Lower Energy Density	Lower cycle life	Lower cycle life	Limited Application, limited charge/Discharge profile	New Tech, Manufacturing Challenges	High cost
Thermal Runaway Temp	NA	NA	270C	210C	150C	NA	NA	NA
Form Factor	Primarily prismatic	Prismatic	18650, 32650, Prismatic	18650, Prismatic	18650, Prismatic	Cylindrical	Prismatic, Cylindrical	Pouch
Cost/KWH	$75	~$50	$100	$150	$150	$150	$137	$500
Operat. Temp	-40C to 65C	-40C to 65C	-20 to 60 C (0C min for charging)	-20 to 55 C (0C min for charging)	-20 to 60 C (0C min for charging)	-20 to 50 c	-20 to 60c	-20 to 60 C (0C min for charging)

3.1. Lead Acid

3.1.1. Description

Lead acid battery technology was first developed in 1859 and has been a commercially available battery for over 150 years. Although there are many different designs of lead acid batteries, the primary characteristics of positive and negative plates sandwiched around a separator material, which are stacked in parallel to provide a 2-volt cell are common amongst the different designs. These plates are either submerged in electrolyte or in the case of absorbent glass mat (AGM) design, the electrolyte is held close to the plates in a super absorbent fiber glass mat that also acts as the separator. Gel batteries use a silica-based gel to suspend the electrolyte. The most common forms of lead acid batteries include Vented Lead Acid (VLA or flooded lead acid), Valve Regulated Lead Acid (VRLA), Thin Plate Pure Lead (TPPL), Absorbent Glass Mat (AGM), and gel. Although many lead acid batteries today are made of 6 cells in series which provide a 12 V nominal rating, they can also be found in 2 V single cells, 4 V, 6 V, and 8v configurations.

3.1.2. Benefits

Advances in carbon infused AGM and pure lead technologies have improved the potential cycle life of lead acid batteries to reach as high as 2050 cycles at 50% depth of discharge in products that are already commercially available. These batteries also perform much better at a partial state of charge and thus are well suited for renewable or unstable grid scenarios where there is no guarantee that the batteries will be fully charged immediately after a discharge. The added carbon optimizes sulphate crystal size allowing the sulphate crystals to convert back into the electrolyte during the charging process, thus extending the life and kWh throughput of the battery.

Lead acid batteries in the USA are 99% recycled with over 95% of the components being recyclable. [viii] This has a staggering effect on the overall environmental impact of producing new batteries as a vast circular economy has been created. In addition, lead is a domestically available resource which is often mined as a byproduct of other mineral mining such as silver and zinc. Also, lead acid batteries do not require any rare minerals that may bring additional environmental impact from mining.

If properly maintained and protected lead acid batteries can perform well in a wide variety of environmental conditions. Although lead acid batteries lose some capacity at lower temperatures and have a shortened life at high temperatures, they perform safely at temperatures as low as -40C and as high as 65C. The ideal operational temperature, which is where most batteries are rated at, is between 20C and 25C.

With recent battery incidents in the news, regulators are revisiting the safety of ESS installations. Because lead acid batteries use an aqueous non-flammable electrolyte, they cannot enter a thermal runaway event in the same way that other technologies may. Under normal operation lead acid batteries function reliably and safely.

As batteries approach the end of their design life or if they sustain damage due to abuse, the internal resistance of the battery can increase, which in turn raises the required float current. As the float current increases, more heat is generated and much of the excess energy breaks the electrolyte into hydrogen and oxygen. The increase of hydrogen and oxygen exceeds the battery's ability to recombine the gases, which build in pressure until they are vented. This process is known as thermal walk away and in contrast to a lithium-ion battery in thermal runaway, this process is not self-sustaining and can be stopped at any time by disconnecting the incoming current to the battery. Proper ventilation and hydrogen alarms should be considered when the project is being planned to ensure the system. Some battery manufacturers add a catalyst to lead acid batteries to aid in the hydrogen/oxygen recombination process. This helps to reduce electrolyte loss, vented gases, and prolongs the life of the battery.

3.1.3. Limitations

As a lead acid battery is discharged, the acid is absorbed from the electrolyte and sulphation of the lead plates begins to occur. The deeper the discharge, the more acid is absorbed allowing for increased sulphation throughout the plates. This sulphation process slowly degrades the capacity of the battery over each cycle. Due to the effects of sulphation in deep cycling applications over time, lead acid batteries perform best in constant float applications with in-frequent discharges. This makes lead acid batteries a great fit for standby reserve applications such as telecom, datacenter, broadband and switch gear where systems spend the majority of their working life on float.

3.2. Lithium-ion

3.2.1. Description

Although a much newer technology than lead acid, over the past 30 years lithium-ion batteries have taken over many markets due to their high volumetric and gravimetric energy density as well as excellent performance in cycling applications. This is especially true of portable and mobility devices such as cell phones, laptops, cordless hand tools, electric vehicles, and in more recent years ESS. Lithium-ion refers to a battery where lithium-ions are exchanged across a micro permeable separator. Many chemistry variations can be found within the category of lithium-ion batteries such as Lithium Iron Phosphate (LFP), Nickel Manganese Cobalt (NMC), Nickel Cobalt Aluminum Oxide (NCA). Each of these chemistries brings its own set of positive and negative attributes to the market, but there are some key elements that are common to all lithium-based chemistries. Some of the key differences between various lithium chemistries include cycle life, volatility, risk of thermal runaway, energy density, and cost of critical minerals used in the design of the battery. The scope of this paper will focus on the common attributes of lithium-based batteries and will refer to them as one chemistry.

3.2.2. Benefits

In general, lithium-ion batteries perform very well in cyclical applications with very minimal degradation or loss of capacity over time. At 80% depth of discharge, lithium-ion batteries are capable of between 2000 and 7000 cycles depending on chemistry and operating conditions.[ix]

One of the key differences between lithium-ion and many other chemistries is the requirement of a Battery Management System (BMS). The functionality of each BMS varies significantly from each application and each manufacturer, but at a minimum they monitor temperature, voltage and current. The main function of the BMS is to protect the battery from entering an unsafe state by disconnecting incoming and outgoing current if one of these monitored parameters goes beyond the specification limits. Some BMS also actively balance cells in a module to ensure the voltage remains consistent. A BMS used in a typical ESS will have additional functionality such as using past and present data to establish a state of health for the battery, recording or broadcasting data through Wi-Fi or wired connections, and alerting the user of an unsafe state. They also provide valuable data to the end user that can help understand usage and performance characteristics of the battery over time.

Applications that require a significant amount of energy in a limited space or have strict weight restrictions are perfect candidates for the use of lithium-ion batteries as the energy density is 2 to 3 times higher than other chemistries. The data that is available thanks to the BMS also makes lithium-ion batteries a good solution for applications that require detailed data and remote monitoring.

3.2.3. Limitations

Although the BMS is a valuable tool in keeping lithium-ion batteries safe and providing data, it also presents more failure points to the system and adds cost to the overall ESS. BMS is a complex circuit board with many components and relies heavily on accurate data from temperature, voltage, and current sensors. If one of these sensors or components on the board fail or give a false reading, the BMS can disconnect the battery from the load, rendering it unusable. In addition, due to current limitations of the circuitry of the BMS, the BMS can become the limiting factor of how much instantaneous power can be provided by a battery.

Increasing public awareness of safety challenges associated with lithium-ion technologies has come to light over the past several years as issues have been reported. This includes issue with EV's, cell phones, grid-scale energy storage, E-bikes and more. Most currently available lithium-ion chemistries use an organic electrolyte and if a cell is damaged or abused it can enter into what is known as thermal runaway. UL9540A defines thermal runaway as: "The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cells generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution."[x] A thermal runaway event can be initiated from many sources including but not limited to: short circuit, puncture of cell, manufacturing defect, external heating, over charging, and discharging outside of specified parameters.

It is important to note that although lithium-ion batteries are capable of entering thermal runaway, modern design and manufacturing has significantly reduced this risk and that the number of issues as a percentage of batteries sold is very low. In addition, UL has created standards and test procedures to help ensure that batteries are as safe as possible. In choosing any lithium-based product, it is critical that all cells, modules, or batteries are sourced from a reliable manufacturer who adheres to strict quality and traceability guidelines and has undergone UL listing and testing as recommended in NFPA855.

Very cold climates can be particularly challenging for lithium-ion batteries, as they cannot be charged if the temperature drops below freezing without causing permanent damage at the cellular level. When the temperature drops below freezing the BMS will prevent the battery from charging until the temperature has returned to a safe level. One solution to overcome this challenge in cold climates is to add heat sources to maintain safe operating temperatures. Although this approach can be effective, depending on the severity of the climate, significant power could be required to maintain the temperature and it may take several hours to heat the batteries to a safe charging temperature after an extended outage.

Due to the difference in cell voltages and charge parameters between lithium-ion batteries and previously installed chemistries there may be some compatibility challenges between existing equipment and the requirements of the lithium-ion battery. In a retrofit scenario when swapping out lead-acid batteries for lithium, attention to detail should be given when considering voltage ranges, charge requirements, and BMS limitations of various chemistries under consideration.

3.3. Hybrid Supercapacitor

3.3.1. Description

Hybrid supercapacitors are relatively new. They are considered electrostatic energy storage and combine the high cycling capability and high-power output of super capacitors with the power density of lithium-ion as illustrated in Figure **3**. Hybrid supercapacitors have primarily been targeted at 36V broadband and 48V telecom markets but have also seen some penetration into backup generator starting applications.

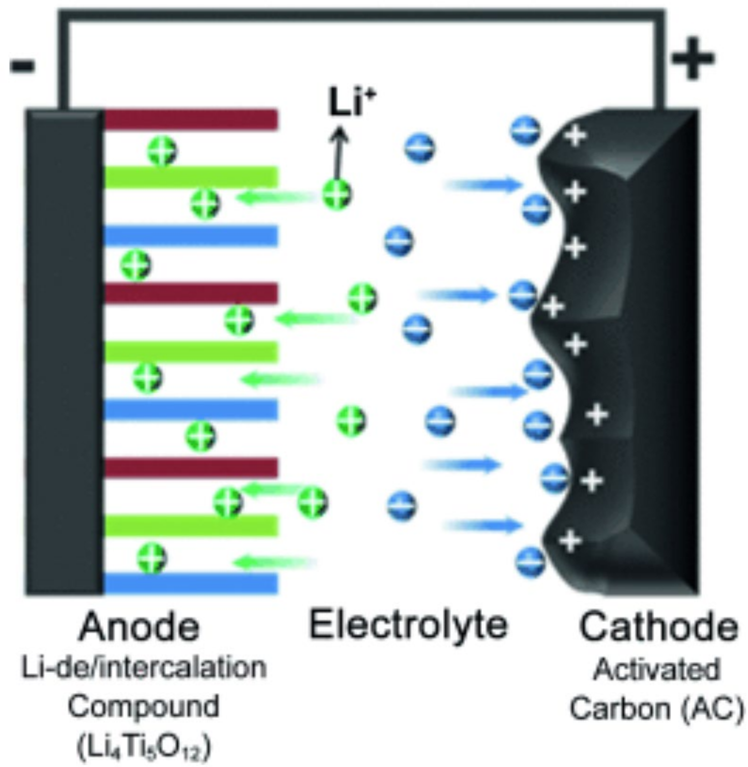


Figure 3 – Hybrid supercapacitor[xi]

3.3.2. Benefits

With a cycle life rating of up to 10,000 cycles, and up to a 20-year calendar life with minimal degradation, hybrid supercapacitors are ideal for use with unreliable grids or in off-grid applications. They can be recharged quickly (under 2 hours) and are capable of 1C continuous discharge – meaning the discharge current will discharge the entire battery in 1 hour. Although their energy density is lower than most lithium-ion chemistries, hybrid supercapacitors currently achieve a 100-150 Wh/kg, which is an improvement to most nickel-based and lead-based chemistries.[xii]

In a typical lithium-ion battery, during a thermal runaway event lithium-ion cathodes release oxygen which enhances or sustains the flames and makes it very difficult to extinguish a fire once it has started.

Conversely, hybrid supercapacitors use a lithium-doped carbon cathode which contains no oxygen, thus eliminating the risk of a self-sustained thermal runaway event.

3.3.3. Limitations

Currently, these batteries have an initial cost of up to 2 times that of lithium-ion. However, under certain use case scenarios where high throughput of kWh's or extreme cycling is important these batteries may offer an overall total cost of ownership (TCO) benefit over some of the other chemistries discussed, especially where longer-term TCO models of 20 years or more are used.

As with other batteries using lithium, hybrid supercapacitors have a limited operating and charging temperature range. They are unable to be charged in temperatures below 0°C and would require a heat source to recharge in colder climates.

3.4. Nickel-Zinc

3.4.1. Description

In recent years, nickel-zinc batteries have reemerged and have begun to gain ESS market share primarily in the datacenter industry. According to Zinc 5, Thomas Edison was awarded a US patent for a nickel-zinc battery in 1901, but he was never able to produce a commercially viable battery due to a very limited cycle life (Five, n.d.). The cycle life hurdle has been overcome in recent years allowing the technology to push forward. As a chemistry, nickel-zinc has many similarities with other nickel-based batteries such as nickel cadmium and nickel metal hydride which have been used for many years in various ESS applications. Nickel zinc batteries are valve-regulated, non-spillable batteries like many VRLA batteries.[xiii]

3.4.2. Benefits

Nickel-Zinc batteries use an alkaline, non-flammable liquid electrolyte and they have no propensity to enter thermal runaway. Depending on the manufacturer some nickel-zinc batteries offer a simplified BMS that can provide overcharge and overcurrent protection but are typically not as sophisticated as a BMS you would find on a lithium-ion module. This lack of a sophisticated BMS is primarily due to the inherently safe nature of the battery during operation.

Nickel-zinc batteries fall between lead acid and lithium-ion solutions on the energy density scale and is similar with other nickel-based chemistries as shown in Figure **4**. These batteries can provide significant power in a small footprint.

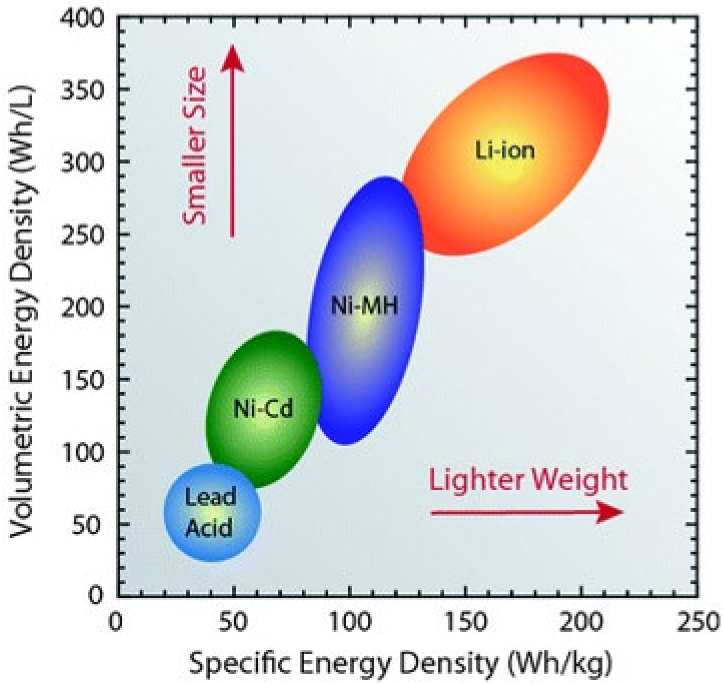


Figure 4 – Volumetric energy density of common energy storage chemistries[xiv]

3.4.3. Limitations

One important characteristic that is relatively unique to nickel-zinc chemistries that should be noted is the minimum charge and discharge profiles. In order to maintain optimal health and performance, nickel-zinc batteries can require 4-hour minimum charge and discharge rate. Lower charge and discharge rates may cause unwanted damage or premature aging of the cell, making it challenging to use this chemistry in applications requiring a multiple day discharge. However, the lower discharge rate makes it ideal for high-power short duration needs. In addition, this chemistry would not work well in applications with unreliable grids or when using intermittent sources of power such as renewables to charge the batteries.[xv]

3.5. Sodium-Ion

3.5.1. Description

Although this technology has been under development for many years, commercially viable sodium-ion batteries are very new to the market and have primarily been focused on the EV market. As the price and availability of lithium-ion has risen over the past few years, more focus has been put into working through the challenges with commercially producing a battery. At a chemistry level, sodium-ion batteries function much in the same way as lithium-based batteries but do not use lithium, cobalt, manganese or other rare minerals.

3.5.2. Benefits

Although slightly lower in energy density than current lithium-ion solutions, sodium-ion batteries use the low cost and abundantly available element of sodium as the as a key component. This has the potential to significantly reduce costs and provide the ability to domestically source the raw materials instead of relying on delicate, and often unreliable, international supply chains. Safety is another key benefit when comparing sodium-ion to lithium-ion batteries. Sodium-ion batteries do not have any risk of entering thermal runaway.

3.5.3. Limitations

Sodium-ion batteries share many of the positive performance attributes of lithium-ion batteries while eliminating many of the concerns. As this is a new technology, initial deployments have yet to fully prove the validity of research-based claims of cycle life, safety, and overall performance of this chemistry. Sodium-ion will likely not completely displace lithium-ion batteries but the inherent safety of this chemistry along with the other key performance specifications make it a great candidate in the future of energy storage.

3.6. Comparing Technologies

Before discussing a decision process, it is useful to summarize how these technologies compare relative to each of our key considerations. As product cost and expected life are key considerations for analysis, we have added those into Table **3** below. As you can see, lead acid, lithium-ion and hybrid supercapacitor systems have distinct areas where they excel, while sodium-ion tends to be strong in all categories. Nickel-zinc does not seem to have any distinct advantages over other technologies.

Table 3 – Battery chemistry analysis (5=Best)

ESS Technology	Cost	Expected Life	Runtime		Temperature Resilience	Cycling
			By Volume	By Weight		
Lead Acid	5	2	2	1	5	1
Lithium-Ion	2	4	5	5	3	4
Hybrid Supercapacitor	1	5	2	3	3	5
Nickel-Zinc	2	2	3	2	2	2
Sodium-Ion	4	4	4	4	4	4

Notably missing from this chart are the safety and recyclability considerations discussed previously. These are vital inputs to the decision-making process, but they can be somewhat technology agnostic. While there is a proportional risk increase with any technology as the available energy increases, it is the management of that energy and thorough vetting via agency certification that determines how safe an ESS is. Second, within each technology there are significant variations in design and chemistry that impact their ability to be recycled. Both will still play a significant part in the decision-making process.

4. Determing the Best ESS Technology for any Given Site

Now that we have defined the key considerations for ESS deployment in the OSP and the benefits and limitations of common energy storage technologies, we can layout a process for deciding the best technology for any given site. By weighting the importance of each of the key considerations at a particular site and comparing those weightings to the relative strengths and weaknesses of deployable ESS technologies operators can be assured the best ESS is being deployed. While simple conceptually, the nuances in this process can drive significant gains in plant reliability. As we discuss this process, we will do so with an understanding that every operator has their own methods of defining value for any decision and discuss valuation in general terms as this paper is not a study of valuation methods.

4.1. Aligning Application Needs to Technology

A basic initial method to align application needs to the best ESS technology is to create profile of the needs of a given site through the lens of the key ESS considerations. By ranking the importance of each key consideration one can quickly align site demands with technology advantages of a given ESS.

As an example: Figure **5** below evaluates a ground-mounted site in a location that generally sees very cold winters, is close to a service location, rarely has outages and has no additional value drivers for above standard backup time. As such, its profile might look something like the upper table in Figure 5.

			Runtime			
ESS Technology	Cost	Expected Life	By Volume	By Weight	Temperature Resilience	Cycling
Example Site #1	5	4	3	2	5	1

			Runtime			
ESS Technology	Cost	Expected Life	By Volume	By Weight	Temperature Resilience	Cycling
Lead Acid	5	2	2	1	5	1
Lithium-Ion	2	4	5	5	3	4
Hybrid Supercapacitor	1	5	2	3	3	5
Nickel-Zinc	2	2	3	2	2	2
Sodium-Ion	4	4	4	4	4	4

Figure 5 – Example Site Evaluation

By evaluating the site profile against the ESS Technology comparison, one would quickly see the best technology to align with site needs in this example is lead acid. The alignment of a need for cold temperature resilience with the wider functional operating range of lead-acid is the most critical synergy here. Cost is always a factor in any decision, however, with no other value drivers such as additional runtime regulations or critical loads being backed up, cost becomes more important relative to other considerations. This is a very targeted example of how to use a very simplistic approach, but often times there is no clear answer and it becomes necessary to use a more complex method.

4.2. Valuation of key considerations and costs

When alignments between technology and site needs are not as clear, leveraging a valuation method to determine the best path can be helpful. As with any operational decision, the ability to understand all key considerations and use data to assign them a value is paramount. A simple equation can be used to determine value added to the plant of any ESS technologies which is essentially a cost benefit analysis which determines which technology can add the greatest value.

$$\text{Value added} = \text{Benefits} - \text{Costs}$$

Within this “simple” equation are numerous complex nuances that any operator must determine for their own plant. First, what time period (T) should be used to determine my value added? This brings into play the life cycle of a product, its resiliency, plant impacts to customer churn rates, and, for public companies, the market expectation of return on capital investment. Recent sustainability initiatives have driven models with more long-term thinking, but each operator should use their own desired time period. Second, which of the key considerations should be considered a cost versus a benefit? For example, the safety of a system could be considered a cost or a benefit. Below we will lay out how key considerations can be thought of and even some scenarios where key considerations might eliminate an ESS from the decision process by default. Finally, what metrics does one use to value each of the potential benefits. This is something that should be decided by each operator, but we will discuss some finer points in determining value of each key consideration.

4.2.1. Key considerations: Costs

- **Product Costs –** This is probably the most intuitive part of the calculation. This includes the actual capital cost of the ESS hardware, the cost to install and permit and any assumed annual maintenance costs over the assumed life of the product. Assumed maintenance costs should be based on truck rolls required over the assumed time period following the manufacturer's recommended guidelines.

- **Safety –** While fundamentally a benefit, safety is more appropriately calculated as a cost. ESS's with well-developed safety systems that have been certified to high safety standards will have inherent cost built into their hardware, thus the potential long-term costs for safety should be close to zero. Energy Storage Systems that are not appropriately certified may have long term risks to employees or public safety which must be understood and quantified. Additionally, in many instances, certification to certain safety standards is required by Authorities Having Jurisdiction (AHJ) in order to deploy a technology in the plant.

- **Resilience** – A system's level of resilience to the harsh environmental conditions in the outside plant will impact its overall expected life and potentially its performance and runtime during its functional life. It is necessary to understand how resilience impacts these benefits and include this in the value-added calculations. In some cases, lack of resilience may preclude an ESS from being deployed in certain areas. For example, many ESSs functional temperature ranges only go to -20°C, so in colder areas where these temperatures occur regularly during winter these should be eliminated from consideration without a safe method of warming them. There are various environmentally controlled enclosures that can make deployment of these a possibility in extreme conditions, however, the incremental cost and maintenance for those enclosures must be considered as part of the valuation.

4.2.2. Key considerations: Benefits

- **Expected Life –** The benefit of long life is its ability to increase the duration of product replacement cycles and reduce Total Cost of Ownership (TCO.) Total capital cost of hardware used to calculate added value should be equal to the ESS hardware cost times the analyzed time period over the expected life. For example, if an ESS has a hardware cost of C_h, the analyzed time period is ten years, and the expected life is five years, the total hardware cost of the period is 10/5 x C_h or $2C_h$. While this should be based on the manufacturer's stated expected life, warranted life should be factored into this calculation as well, as large gaps between warranted life and expected life for TCO calculations can leave operators with significant liability.

- **Runtime –** This is the primary benefit that can be quantified for an ESS. The amount of time that the system can run without needing to roll a truck to provide additional backup can greatly reduce operational costs and increase resiliency of the plant. In most cases having a plant that is adequately backed up provides value by reducing operational expense and improving customer satisfaction. Additionally, in some cases, being able to add greater runtime could open up new business opportunities with customers with higher reliability demand or could have significant cost reduction in sites that are more challenging to roll a truck to. While many times space is more of a premium and runtime by volume is more important, there are instances where runtime by weight can be key. A good example of this is where the best location for a site has no space to set a system on the ground and the pole owner has stringent weight restrictions to allow a cabinet to be mounted on a pole.

- **Cycling –** While many HFC powering sites rarely experience outages, in some cases where the grid is less reliable, frequent outages can mean increased operational costs from truck rolls or dissatisfied customers. In these instances, the ability for an ESS to handle more frequent outages without significant degradation to life or performance can have significant benefit. In addition to this, with the advent of time-of-use utility rate structures, there may be locations where ESS can be slightly oversized to provide significant reduction of utility expense, by cycling during peak rate periods.

- **Recyclability** – With many operators implementing sustainability initiatives to reduce their carbon footprint, the importance of using products with longer life which are composed of fully recyclable content cannot be overstated. Products which are recyclable at the end of their useful life have a significantly lower average emission factor and drastically reduce overall carbon footprint and hence impact to carbon neutral goals. Many energy storage products can be recycled, and while the return from recycling of products is rarely significant compared to the original capital investment, some require operators to pay to have them recycled creating additional liability at the end of their useful life. Additionally, paying to recycle spent products has a risk of motivating unsustainable behavior if thorough processes are not in place to ensure products are dealt with properly. When exploring an ESS solution, it is good to quantify any gain or liability from recycling at the end of the product's useful life.

By analyzing the value of each of these factors over time, one can determine the ESS technology that provides the most value in any scenario and determine which solution best meets the needs of any site.

While the valuation method is thorough, it involves a fair amount of characterization and calculation against each key consideration, for each technology. As more technologies become available this decision-making task can become increasingly daunting. One way to be more effective is to use the weighting and alignment method to reduce the decision to the two best aligned choices and use the valuation method to determine the best of the two ESS technologies for the application.

5. Conclusions

A fundamental element of the HFC network is the highly reliable power used to drive delivery of data and services to customers. Enabling this steadfast HFC power grid are the Energy Storage Systems that provide backup power when the utility grid fails to do so. As the network continues to evolve and becomes an increasingly more critical pipeline to connect us socially and economically, the make-up of the ESS holding that network up needs to evolve to meet ever-increasing demands for availability.

Because of this need for ESS to advance, innovative new solutions for storing energy in the plant are regularly being explored. These new solutions have continued to improve the reliability of the plant as it evolves around new challenges and regulations, validating the need for continued exploration and implementation of new solutions. The evolution of Lead-Acid, lithium-ion, Hybrid Supercapacitor, and in the near future Sodium Ion ESS technologies, have provided an array of solutions with various benefits and limitations which make available options to solve many of the challenges facing us today.

By continuing to build a library comparing the relative benefits and limitations of ESS technologies, we can use a simple weighting method to visualize how these technologies stack up with regard to cost, runtime, safety and other key considerations in the OSP. By using the weighting and alignment method to filter ESS choices for an application down to the best options, then using the valuation method to analyze those options in light of key considerations for OSP deployment, operators can make data-driven decisions on the most value-added energy storage solution possible. These methods can be expanded easily as new technologies and additional key considerations come to light, they provide a decision framework that allow our industry to continue to build the most reliable network possible.

Abbreviations

AGM	Absorbent glass mat
AHJ	Authority Having Jurisdiction
CI	Critical infrastructure
CMTS	Cable modem termination system
CPUC	California Public Utility Commission
ESS	Energy storage system
HFC	Hybrid fiber-coax
IFC	International Fire Code
kWh	Kilowatt hour
NFPA	National Fire Protection Association
OSP	Outside plant
TCO	Total cost of ownership
TPPL	Thin plate pure lead
UL	UL Solutions (formerly Underwriters Laboratories)
UPS	Uninterruptable power supply
VLA	Vented lead acid
VRLA	Valve regulated lead acid

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