Ensuring HFC Network Resiliency During Extended Utility Outages

A Technical Paper prepared for SCTE by

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1. Introduction

High-speed Internet is ingrained in our culture. From email and social media to videos and entertainment, the online experience is part of everyday society. One primary enabler of high-speed Internet is the cable broadband network, a collection of Hybrid Fiber Coax (HFC) networks connecting residential and business users to the Internet. In the US alone, the cable broadband industry has over 78 million high-speed Internet connections.

The Covid-19 pandemic made these broadband connections even more essential. As much of the workforce transitioned to work-from-home status, businesses became reliant on stable Internet connections to perform core functions. Parents depended on these connections to support remote learning for their children. The line between business services and residential customers blurred, transforming high-speed data connections into a universal requirement.

Because the traffic flowing across broadband connections are vital for business, school, and health in general, the need for dependable service has become even more critical. Yet, at the time when we seem to need it most, our utility grid was exposed as a potential weak link for network resiliency. Across the United States, there have been waves of multiple day power outages, with reasons stemming from tropical storms, snowstorms, fires and freezing temperatures. Due to the susceptibility of the grid to severe weather, natural disasters, and planned outages, customers are purchasing home generation solutions at record rates. However, electricity at the customer's premises exacerbates the broadband problem, since TVs and laptops are functional, but without a connection to the Internet.

As performance of the grid brings to question the reliability of the HFC network, government entities have begun to legislate network backup time. High-speed Internet connections are so important that Multiple-System Operators (MSOs) are being mandated to keep their networks online, regardless of the utility grid. These mandates present a fundamental question for network reliability: How can we ensure power availability for critical HFC services during extended outages?

There are several potential solutions that continue to be explored, however, in many situations the simplest and cost-effective answer is adding batteries to existing HFC network elements to extend run time. However straightforward the concept may be, these batteries require space, environmental protection, thermal management, ongoing maintenance, budget, and end-of-life management. Solutions are heavily dependent on run time requirements, battery selection and, in many cases space limitations at existing broadband power system locations. Which battery chemistry provides the best run time? Which meets the budget? Which can be maintained by MSO technicians?

This paper explores various extended run time solutions using both Lithium Ion (Li-ion) and Thin Plate Pure Lead (TPPL) batteries. For each battery chemistry, comparisons are presented for run time, space requirements, thermal management, relative cost, and perspective comparison to higher total cost of ownership (TCO) for on-site generation solutions.

2. Extended Run Time

For discussion purposes, this paper will consider an "extended outage" as a utility outage that lasts longer than the average run time of the installed backup batteries plus run time of an average portable generator. This is assumed to be approximately 12 hours. For the last two decades, a three to four hour backup run time was typical for many cable outside plant (OSP) sites. This amount was determined to be sufficient for the operator to roll a truck with technicians, replacement equipment, or a generator. But with severe weather and natural disasters causing longer grid outages across broad swaths of the network, standard run times have been questioned.

The California Public Utility Commission (CPUC) has been at the forefront of investigating these requirements. Since the state had experienced several instances of prolonged outages driven by utilities de-energizing sections of the grid to prevent possible wildfires, the CPUC created a new extended backup requirement. This was specifically developed for wireline carriers to enact "comprehensive resiliency strategies to prepare for catastrophic disasters and power outages." The new requirements adopted a 72-hour backup power requirement for the wireline providers' facilities in Tier 2 and Tier 3 High Fire Threat Districts[i]. This new requirement is far from the three to four-hour historic backup standard for which HFC sites were initially designed.

Not all regions will follow the CPUC's lead, but many areas are ideal candidates for extended run time. Texas was in the news for outages caused by freezing conditions, the Midwest and Southeast US are vulnerable to hurricanes, tornadoes or winter freezes and Northeastern US and Canada experience frequent extended outages due to annual winter storms. With the HFC network becoming increasingly important for society, it is likely some form of run time extension will be adopted in these regions as well.

While adding energy storage seems like a straightforward method of compliance, there are many challenges to overcome. Some reasons existing locations do not always lend themselves to easy upgrades include:

- 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 additional battery enclosures, re-permitting can cost $10K or more per site and could add up to 6 months to install
- 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.

These hurdles are not show-stoppers but do eliminate the opportunity for a one-size-fits-all solution. The result is to look at the application, the location, and the installation to determine the right fit. The analysis starts with diverse options for energy storage and backup. After establishing different backup alternatives, the paper looks at the key factors for determining the best fit per application.

Figure 1 - Example cable broadband powering sites. The variability in available space, loading, and local regulations makes a one-size-fits-all solution for extended run time nearly impossible.

3. Backup Power Methods

There are a variety of possibilities available when considering how to provide backup power to the outside plant broadband network, including batteries, generators, fuel cells, and flywheels. Solar power is also a consideration when combined with an energy storage solution. While solar power, fuel cells, or flywheels could fill a niche, they do not currently present a viable solution for the broad deployment required to meet the new governmental mandates. These options must continue to be explored as their technologies mature, however they currently present significant issues regarding deployment and scalability. For this reason, this paper focuses on more prevalent alternatives – generators and batteries.

3.1. Generator Overview

Generators convert fuel (diesel, propane, natural gas, etc.) via internal combustion engine into electricity. The output can be either alternating current (AC) or direct current (DC), depending on the type of generator. A major advantage for generators is the ability to deliver power and keep the network running as long as they have fuel. This becomes a key factor in the viability of generators as a solution for extended run time scenarios.

There are two broad categories of generators that can be used for extended run time scenarios in the cable broadband network: portable generators and curbside or stationary generators. Portable generators are designed for deployment during extended outages and provide flexible run time augmentation, then retrieved and stored until the next outage. Curbside generators are permanently stationed at the site to provide additional backup when needed. Most major operators have deployed both types of generators for extending run time in outage situations and have strategies for when and where to deploy based on unique site requirements.

3.2. Portable Generators

Portable generators have been broadly used in OSP for years as a flexible option to add backup time only when and where it is needed. Nearly all MSOs have an operational strategy for deploying portable generators to extend plant backup time during an outage. These strategies usually start by assuming a baseline backup time that is resident at each site based on the batteries installed. From there, remote status monitoring tracks the duration of the utility outage. Once an outage duration reaches a critical point set by the operator the site is at risk of dropping plant power and a network management system will trigger a technician to deploy a portable generator to the site to augment run time.

This strategy has proven effective over the years but has its limitations when dealing with outages of an extended nature. Portable generators are designed to be relatively small to be easily transported and deployed, and most suitcase style generators are optimized to completely enclose the engine to reduce noise. A standard 2 or 3kW suitcase style AC portable generator ranges from 50 to 100lbs. and will provide six to ten hours of backup per tank of gasoline for an average plant load of 600W. Due to this limitation, extended outages often require portable generators to be refueled multiple times, adding significant operational cost and environmental risk of technicians spilling gasoline in the field. Additionally, the flexibility and portability of generators make them an easy target for theft, often requiring additional cost and effort to secure. Another drawback to portable generators is that their output voltage quality is typically less stable than utility power. Variations in frequency and fluctuations in voltage can interact with the broadband UPS, causing the UPS to switch between utility line mode and battery backup mode. To avoid this undesirable behavior, modern UPS systems employ an AC input desensitizing feature to overcome poor input voltage quality typical of portable AC generators.

Portable generators can be staged from an operators' regional facilities to be within physical proximity of UPS locations that may require extended backup power. A typical portable generator staging approach utilizes trailers with multiple generators that are ready to deploy when needed. An example of a portable generator trailer is shown in Figure 2.

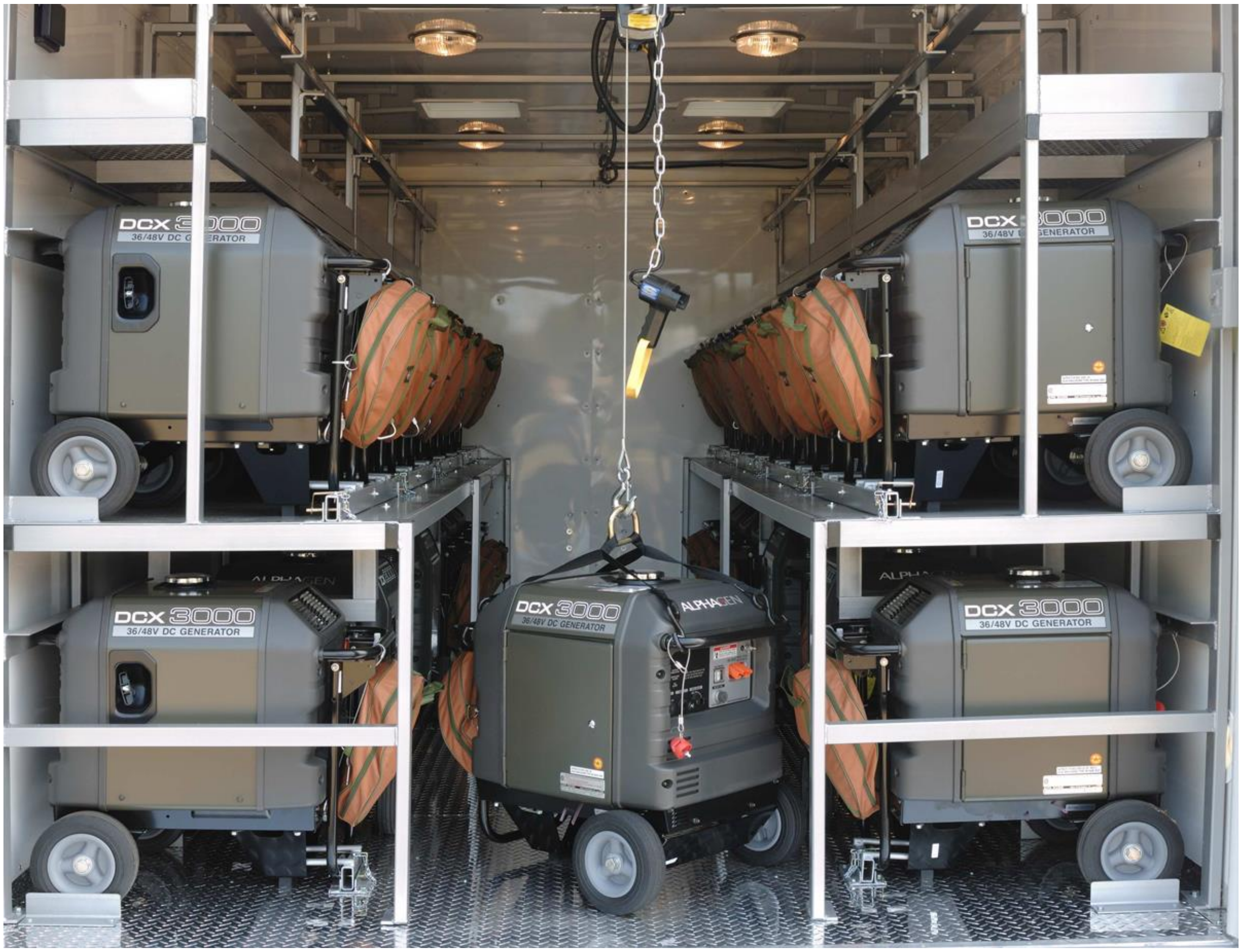

Figure 2- Portable Generators Staged for Rapid Deployment During an Outage

Run time limitation and theft risk of small portable generators can also be mitigated by using larger, tow-behind portable generators designed for construction sites. These larger generators can be capable of storing more than 50 gallons of gasoline allowing them to provide significantly more backup time, and due to their size, there is a reduced risk of theft. Larger generators do, however, have some drawbacks. Once again, due to their size and design, they can only be deployed one-at-a-time, meaning activation in a widespread outage can take a small army of technicians or making dozens of trips to and from the operator’s warehouse. In addition, the amount of space required to store a fleet of large generators can be prohibitive and carry higher costs to maintain. In conclusion, larger portable generators are sized for larger loads than what’s typically needed for cable, making them highly inefficient in this application.

3.3. Curbside (Stationary) Generators

Curbside or stationary generators are permanently stationed next to an existing cable powering site with critical loads to provide consistent support for extended outages. Historically, curbside generators were deployed in centralized powering architectures, where multiple power supplies were installed in a single location which fed power to the plant in multiple directions like the hub of a wheel. This allowed the significant cost to purchase and install the generator, and connect fuel to the site, to be distributed across multiple power supplies, making the cost per supply more reasonable. Stationary generators used in OSP powering applications provide DC voltage and connect directly to the system’s DC bus with the battery string and power supply inverter. This allows the generator to avoid frequent stops and starts from momentary outages by only starting when DC voltage drops below a certain level. A typical curbside generator installation included multiple enclosures: one enclosure houses the power supplies and limited battery backup. A second enclosure houses the generator. Some installations include a third enclosure to house propane fuel tanks for locations where natural gas is not available. A typical curbside generator installation is shown in Figure 3.

Figure 3 - Typical Curbside Generator Installation Using Natural Gas

Stationary generators are likely fueled with plumbed natural gas or with liquid propane cannisters. Of these two, generators that operate on natural gas are better candidates for delivering extended run time. When generators are fed natural gas via a pipeline it is less likely to be affected by a power outage. The drawback is many sites are not in locations with access to natural gas, and most sites that could have access are not currently equipped with natural gas due to upfront costs of digging a trench, running a new gas line to a site, installing and certifying a metered service, and permitting. Combined this process can add months of delays and thousands of dollars to site turnup and eliminate financial viability to add natural gas connection to meet the extended run time requirements. Liquid propane is used when natural gas is not available and the inherent limit to the amount of fuel that can generally be stored on-site for backup makes propane a less desirable fuel for extended outages of more than 24 hours.

Another factor to consider when looking at curbside generators as an option is the amount of maintenance required for proper functionality during extended outages. Since generators run on an internal combustion engine, which is a complex system of moving parts, it is necessary to perform maintenance at least twice annually. An increased number of extended outages may also necessitate more frequent maintenance visits. Because of this additional maintenance requirement, TCO models should always bear this in mind.

One other key factor that cannot be overlooked when deploying portable or curbside generators is the noise level of the engine and its impact on overall customer satisfaction. As shown in Figure 1, many OSP powering sites are adjacent to customer residences or within utility easements on customer property. This alone can be a point of frustration, but when generator noise is added, it can often lead to customer complaints and, in some cases, customers lobbying local governments for restrictive ordinances to be placed on cable installations. For this reason, potential impact to customers is a primary factor when considering generator-based solutions.

4. Battery Overview

Batteries, the most common source of backup power, provide DC power to a standby power supply to be converted to AC plant power in times of utility outage. Batteries come in many shapes, sizes, capacities, and chemistries. Lead-acid chemistry has been a fundamental stalwart of energy storage for many decades. Traditionally, indoor applications were supported with flooded lead-acid batteries. These batteries have a liquid electrolyte, generate oxygen at their positive electrodes and hydrogen at their negative electrodes. Over time, water loss occurs, which requires the electrolyte to be topped off with water on a regular basis. A byproduct is the production of hydrogen and oxygen gas which must be ventilated to avoid hydrogen accumulation and the potential of combustion.

Both outdoor and indoor applications use valve regulated lead-acid (VRLA) batteries. The electrolyte is not liquid, but instead is immobilized with either a gel or absorbent glass mat (AGM). The result is less water loss, eliminating the need for topping off with water. Gas emissions are much lower in this solution, therefore ventilation requirements are far less than flooded lead acid batteries. Additionally, VRLA AGM batteries are generally rated non-spillable per UN 2800, which reduces regulations required for safe shipping.

The arrival of TPPL technology, a type of AGM VRLA battery, transformed lead-acid battery performance. TPPL batteries have thinner, high purity grids meaning more of them can be stacked into the battery. The result is increased surface area contact between the grid and active material boosting power densities. Therefore, TPPL batteries can deal with much higher current peaks and have faster charging capability. Standard TPPL batteries in case sizes designed to fit in most standard OSP cable enclosures, generally have higher capacities than other equivalent AGM VRLA batteries. For Extended Run Time applications where space is available for additional ground-mount cabinets, larger, high capacity TPPL batteries can be an additional high-value option.

Positive attributes for VRLA batteries include ease of transport, ease of installation, reduced maintenance, and higher energy densities compared to their flooded counterparts. A 98% recycling rate at end of life is also beneficial to the environment. Technicians in general like working with VRLA batteries, as they are typically non-spillable, include handles for improved installation and handling, and require limited maintenance. TPPL versions include greater temperature tolerance, higher energy density and longer life.

Two key downsides of VRLA batteries are slightly higher costs measured against flooded batteries and heavier weights associated with increased energy density. The high purity of TPPL models also increase initial cost, but the TCO is favorable due to the improvements in energy density and battery life.

4.1. Lithium Ion Batteries

Lithium Ion (Li-ion) batteries were originally conceived in the early 1970's and first commercialized by Sony 30 years ago[ii], but even as a result of continued research, development, and investment, they are still in infancy. Although there is still a positive and negative electrode, separator, and electrolyte similar to traditional lead-acid batteries, the key method of operation is the shuttling of Lithium Ions between electrodes. Temperature, charge voltage, end of discharge voltage and impurities limit the shuttling ability over time resulting in the loss of battery capacity.

The positive and negative electrodes of Lithium Ion batteries vary by technology and application, with this variance defining cell voltage and energy density. More research has been conducted on the positive electrode with Nickel-Manganese-Cobalt (NMC) and Iron Phosphate (LFP) being the most common, however research to improve the negative electrode is equally promising for the future.

Since multiple Lithium Ion chemistries exist, selecting the right one for an application is important. In Figure 4, the selection of chemistry will determine the voltage operating window and can impact the system cell count. LFP for instance operates at a lower voltage, therefore, to meet a higher system voltage, more LFP cells will be needed over other chemistries, such as NCM or NCA to meet the same system voltage window.

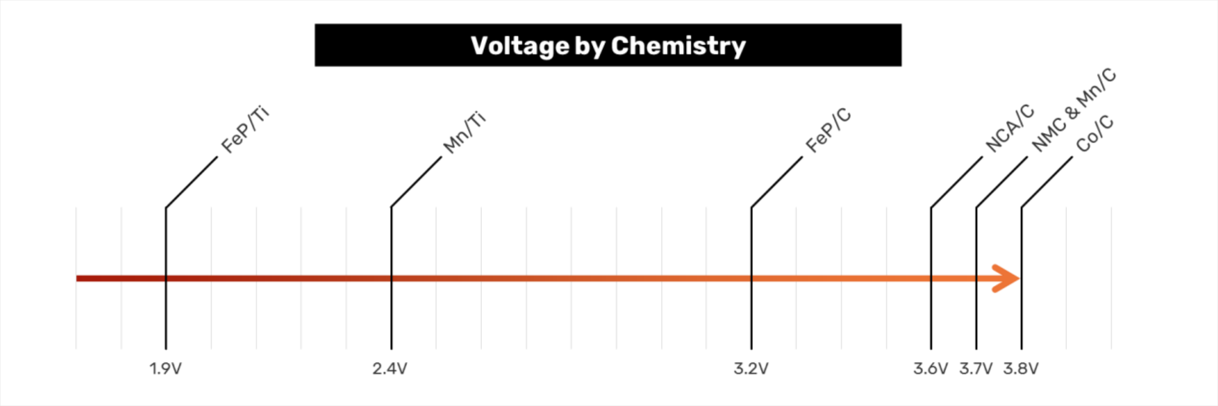

Figure 4- Standard Voltages of Lithium Ion Battery Cells based on Chemistry

Some key attributes for LFP and NMC chemistry batteries are depicted in the spider chart shown below. Since the CPUC project requires the providers to maximize run time and local jurisdictions would prefer as little physical presence as possible, NMC is a desirable choice to meet these goals. It also offers both cold and warm temperature tolerance and suggests long life in this type of application.

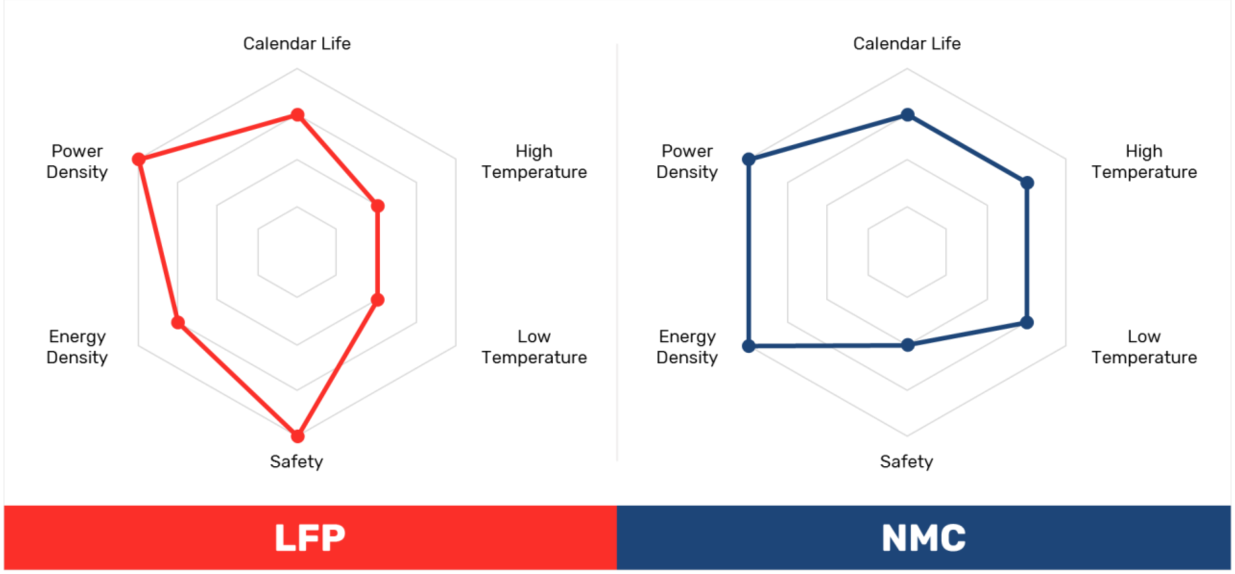

Figure 5- Spider Chart Showing Key Attributes of LFP & NMC Lithium Ion Batteries

4.2. Safe Lithium Ion Battery Design

When building Lithium Ion battery modules and systems, product developers must incorporate varied and numerous safety layers into the design as the battery needs to have optimize life, performance, and most importantly, safety. A graphic representation of these safety layers is shown in Figure 6. The Western Automotive-Grade Cell is the high-quality center of the layered approach. This is the optimal starting point for any designer as they develop an integrated system. Mechanical Safety System layers are designed to fit the battery housing, while providing physical protection for the critical internal elements. Operating the system in a safe way, while monitoring the key diagnostic parameters adds the Application-Level Software and Functional Safety Layers to the design.

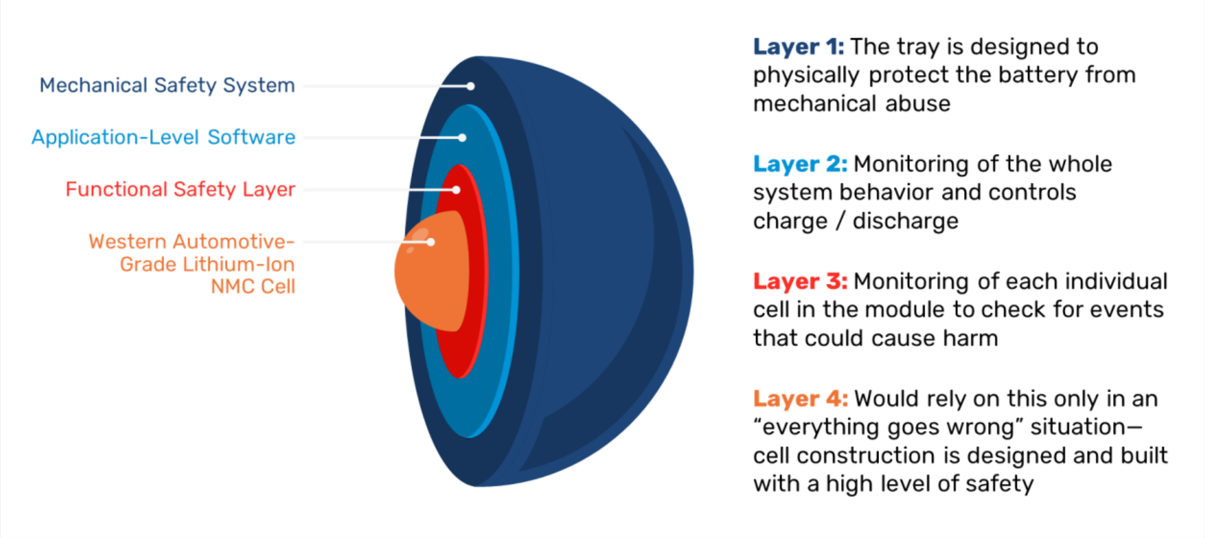

Figure 6- Graphic Representation of Layered Safety Design for Lithium Ion Batteries

Lithium Ion batteries require a Battery Management System (BMS) since, unlike lead-acid batteries, individual cells in a Lithium Ion system do not inherently work with each other to maintain system harmony and balance. The BMS can be active or passive, but it is critical to safe operation and application of the battery for successful system design. As a BMS gathers data, it raises alarms and makes critical decisions. With the proper communication protocols and interaction, the BMS can input information to the network operation center to allow assessment of battery health and overall system readiness prior to, during, or after an outage.

4.3. System Design for Lithium Ion Batteries

When designing any power system that integrates energy storage, it is always recommended to consider how battery performance, life and safety can be maximized by the broader system. This concept becomes significantly more important when considering lithium battery deployment in the OSP, where there is limited environmental control and most power supplies have been designed to manage unintelligent lead-acid batteries with brute force charging methods. Elements such as the system enclosure, power supply charger, internal infrastructure, and remote monitoring systems should all be optimized for integration with Lithium Ion batteries. Simplicity and safety for Lithium Ion products comes through a fully-integrated, engineered system.

First, it is vital to see if there is ample space for proper airflow between lithium batteries, and any necessary passive or active heating and cooling to maximize battery life and performance for outdoor systems. Next, the intelligence inherent in the BMS, required for safe deployment of a Lithium Ion battery, presents an opportunity to use the power supply charger as an additional safety layer. By creating a coordinated communication path between the Lithium Ion BMS and power supply, charge currents can be safely managed and optimized for the battery modules. Additionally, a Lithium Ion BMS should have the ability to provide valuable information that can be leveraged by remote status monitoring such as state of charge and state of health of the battery modules. Conversely, adding lithium batteries to an OSP power supply that has not been designed and tested for interoperability and communication can be potentially dangerous as the potential exists for the power supply charger to provide improper charge current to the BMS and harm Lithium Ion batteries. For these reasons, it is of the utmost importance that Lithium Ion batteries be designed into, and thoroughly tested with their intended OSP power system before being deployed in the field.

4.4. Comparison of TPPL and Lithium Ion Batteries

TPPL and Lithium Ion batteries have unique attributes, yet many applications will see the combination of both chemistries drive value for the application:

Physical Attributes:

Chemistry	Energy Density	Form Factors	Weight	Physical Orientations	Include BMS Electronics
TPPL	High	Many	Heavier	Most	Not required
Lithium Ion	Higher	Limited	Lighter	All	Yes, required

Operational Attributes:

Chemistry	Ventilation	Cut Off Voltage	Cycling Capable	Partial SoC Operation	Recycling
TPPL	Limited	Variable	Limited	Limited	98%
Lithium Ion	None	Fixed	Significant	Excellent	Limited

Figure 7- Comparison of the benefits of TPPL Lead-Acid and Lithium Ion Batteries

With noted differences above, each chemistry has physical and operational advantages depending on the application. Every day more applications arise where a Lithium Ion solution is the most viable solution because of energy density, longer life and greater cycling capability. However, in many situations TPPL remains the most cost effective and flexible solution available.

5. Requirements for Extended Run time Solutions

Generators and/or batteries (TPPL or Lithium Ion) can be used to meet extended run time requirements, but the right selection depends on analysis of several factors:

1. **Required backup time**: *The CPUC requires 72 hrs., however this may vary as other states develop backup recommendations around their unique needs.*
2. **Real estate:** *How much space is available at the site for additional enclosures or generators. Many sites have limited space and would require significant redesigns to create additional space.*
3. **Existing cabinet space:** *Using the existing cabinet where utility connection has been established is often paramount to avoid significant costs for running a new service. Maximizing energy density within an existing cabinet is the best strategy in these situations.*
4. **Location of the existing plant (aerial/underground)**: *Generally, this determines the location of the established cabinet.*
5. **Power system load**: *OSP power system loads can vary substantially where two sites with virtually identical systems can require drastically different upgrades for extended run time capability.*
6. **Fuel availability**: *Primarily, is natural gas readily available at or near the site? This is one of the biggest questions when determining curbside generator viability.*
7. **Local regulations**: *Local laws can restrict everything from the height, width, or weight of an enclosure to the type of fuel you are allowed to use and the permits required to do so.*
8. **Security concerns**: *Sites at risk for theft can have unique challenges securing batteries, portable generators, or propane tanks. Additional security measures can drastically change TCO.*

9. **Total initial system cost**: *Upfront spend for the system cabinet, equipment and turn-up. This is often the biggest limiting factor for traditional extended run time solutions like curbside generators.*

5.1. Scenario Solution Comparisons

There are many different scenarios to consider when defining solutions. For brevity, this paper addresses several popular scenarios using common loads and varying available space, fuel, and security needed at each system location. Some assumptions were made for scenario comparisons:

- All loads are critical for support as driven by customer agreement or government regulation, therefore allowing the network to go down has significant financial consequence
- At least one extended outage greater than 12 hours occurs annually
- Costs for all equipment are based on currently deployed products plus known installation expenses
- Cost per truck-roll for generator maintenance or refueling is around $200 USD
- Impact of security concerns will be higher for lead batteries and portable generators having greater potential for reuse or value from recycling
- Lead-acid battery weight and energy density calculated from known TPPL configurations
- Lithium Ion battery weight and energy density is based on known NMC cell configurations
- Lithium Ion battery useful life assumed to be approximately two times that of TPPL

Scenario 1:

First, let's look at the run time capabilities for lead-acid batteries, lithium-ion batteries, and portable generators when the load is 4 Amps and there is only enough space for one pole mounted cabinet with a weight limit of approximately 600 lbs.

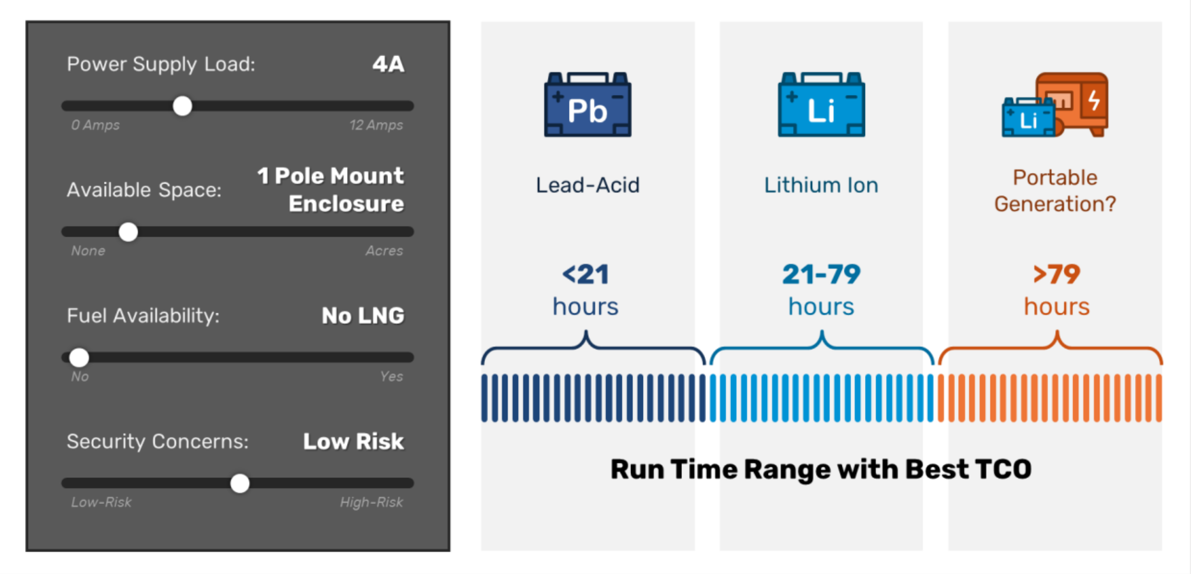

Figure 8- Run Time Ranges for Solutions in Extended Run Time Scenario 1

Due to space and weight restrictions of many pole mount installations, Lithium Ion batteries can play a key role in meeting extended run time requirements in this application and avoid the significant operational costs of portable generator deployment and refueling. However, as with any situation where space is limited, after a certain run time threshold, the ability to continually bring new fuel on site to keep a portable generator running will be the only available tactic.

Scenario 2:

The next hypothetical scenario involves a ground mount site with an 8A load allowing space for one additional cabinet and an available natural gas hookup for a curbside generator. It is assumed this is a roadside deployment with little potential for noise to impact customer perception.

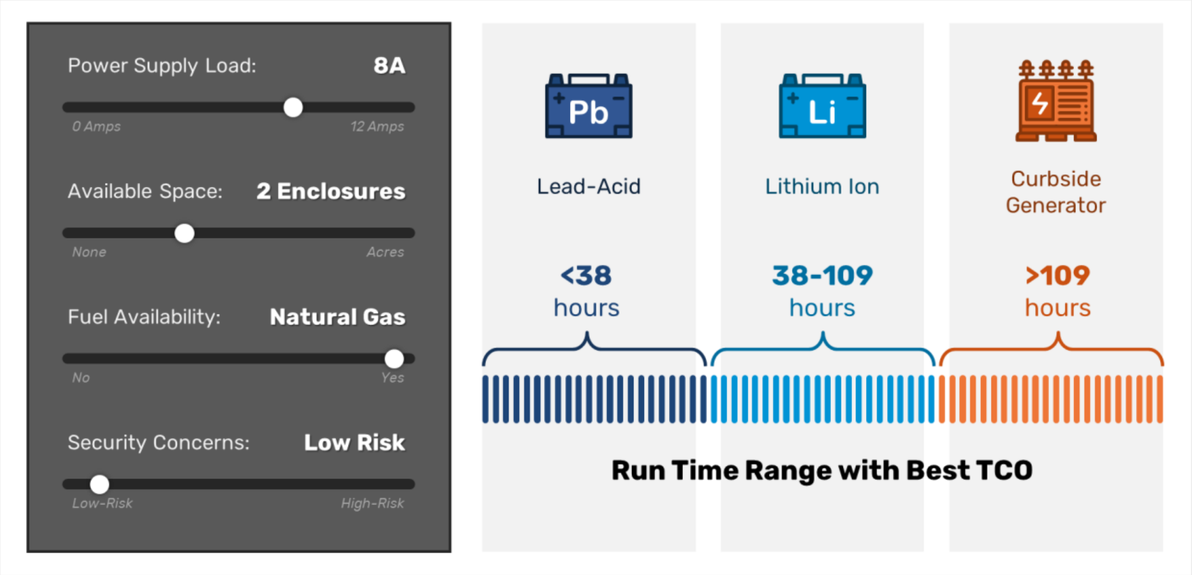

Figure 9- Run Time Ranges for Solutions in Extended Run Time Scenario 2

In this scenario, additional space afforded has an impact on useful range of battery solutions, as the amount of energy that can be stored on site is significantly increased. All three solutions can now be considered with using a second ground-mount enclosure on site. The TPPL solution no longer needs to be limited to case size 31 batteries and can now leverage an additional enclosure with High-Capacity TPPL batteries that may have been too heavy or taken up too much space for a pole mount application. The availability of a natural gas connection supports an on-site generator solution for extreme outages and does not require an army of technicians to refuel portable generators. Once again, Lithium Ion batteries show great promise as an alternative to a curbside generators in this extended run time scenario.

Scenario 3:

The first two scenarios considered common loads on the lower end and middle end of the load spectrum. This scenario has a higher site load of 12A, there is some restriction in available real estate, and an available natural gas line near the site. For this scenario we will assume this site has a history of frequent battery theft.

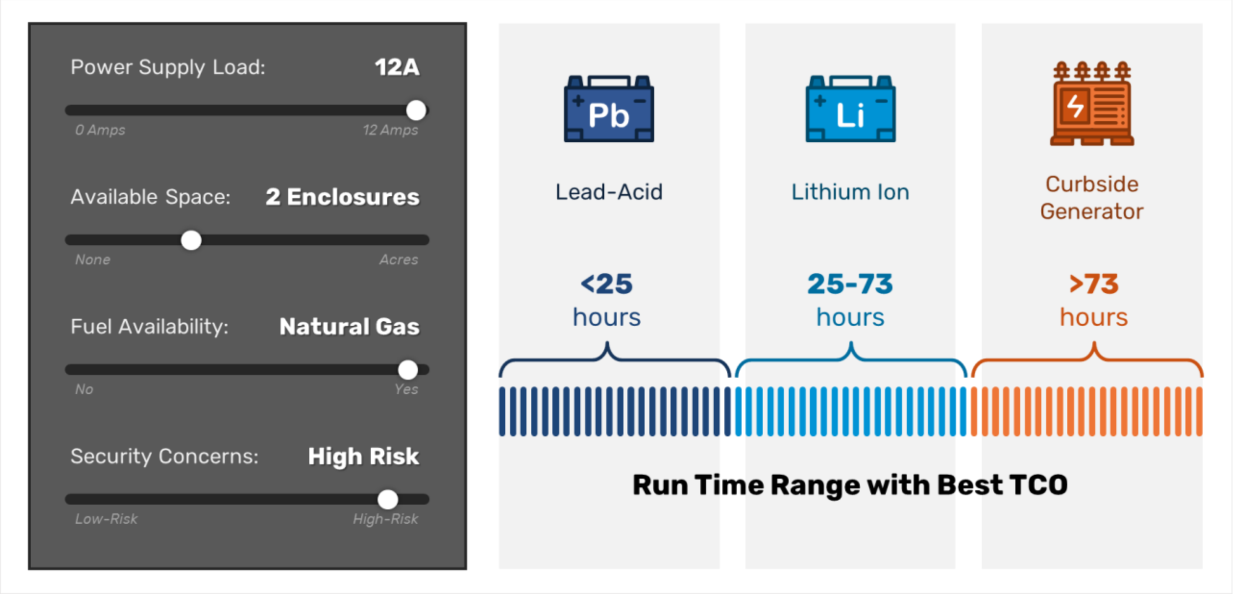

Figure 10 – Run Time Ranges for Solutions in Extended Run Time Scenario 3

The increased load on the power supply has an obvious effect on the available run time from battery-based options where Lithium Ion continues to show promise as the best TCO option to protect against extended outages. A subtle point to be understood here is the higher threat of theft could change the viability of lead acid, by building significant cost into the model for site security options. It could also mean planning multiple replacement cycles for the TPPL option, which also brings risk of the site being without backup during a critical outage.

5.2. Scenario summary

The number of variables in the explored scenarios further emphasizes the fact that there is no one-size-fits all solution for extended run time outages. Each variable needs to be carefully considered in order determine the best solution at each site. The key to having a solution for every site is to have a variety of tools to adjust for variability in site dynamics and run time requirements.

6. Conclusion

Power availability for critical HFC service during extended outages has become increasingly vital for operators because of new government regulations and greater global reliance on the broadband network. Simultaneously, the problem of extended outages does not seem to be going away any time soon. Data from the U.S. Energy Information Administration shows from 2018-2020 there were 164 extended outages in the U.S. alone that impacted more than 50,000 customers at a time, the largest of which impacted more than 1.4 million homes. [iii]These outages have begun to garner the attention of state and federal lawmakers and, in the case of California have driven strict wireline resiliency regulations.

Current available solutions addressing the challenge of extended outages have their own unique set of benefits and limitations, so having a suite of solutions to address the nuances of varied existing HFC powering deployments is imperative. High capacity TPPL lead-acid batteries will allow for adequate run time extension in a number of scenarios. And, while portable and stationary generators will continue to be useful in limited situations, advancements in Lithium Ion battery technology, and economies of scale driven by electric vehicles, have broadened the applications where lithium has a better TCO. Due to its extreme energy density, light weight, cycling capability and advanced intelligent diagnostics, Lithium Ion technology as a part of an integrated, engineered system will become the keystone of many operators extended run time network resiliency programs.

Abbreviations

AC	Alternating Current
AGM	Absorbent Glass Mat
BMS	Battery Management System
CPUC	California Public Utility Commission
DC	Direct Current
HFC	Hybrid Fiber Coax
LFP	Iron Phosphate
Li-Ion	Lithium Ion
MSO	Multiple-System Operator
NMC	Nickel-Manganese-Cobalt
OSP	Outside Plant
TCO	Total Cost of Ownership
TPPL	Thin Plate Pure Lead
UPS	Uninterruptible Power Supply
VRLA	Valve Regulated Lead Acid

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[i] *"Decision Adopting Wireline Provider Resiliency Strategies," Public Utilities Commission of California, February 11, 2021.*

[ii] *https://www.energy.gov/science/articles/charging-development-lithium-ion-batteries*

[iii] *Data analyzed for 2018-2020 from the US Energy Information Administration website: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_b_2*