Energy Resiliency Identification Report

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1. Introduction

Electricity supply and energy resilience are important considerations for transportation authorities transitioning from fossil fuel to a zero-emission fleet. These factors are especially important when considering battery electric technology. As a growing portion of the fleet is electrified, the ability of the authority to provide service is dependent on access to reliable power. For hydrogen fuel cell technology, a backup power supply is required for electrolysis (if the hydrogen is produced on site), for refuelling operations, and for keeping the stored hydrogen in a cryogenic temperature range to maintain its liquid state. As Cape Cod Regional Transit Authority (CCRTA) begins transitioning fleet vehicles to zero emission technology, these considerations will be critical to ensure uninterrupted service and operations.

Some regions have already witnessed climate change effects, such as more frequent, extreme weather, coupled with increased electric grid demand and impacts to service reliability. These are motivating factors for CCRTA to consider backup power. There are two main options to consider for local backup power:

- Conventional Generation
- Microgrid

Both options have advantages and disadvantages, however, either one can be an ideal solution for specific application. A system requirement analysis specific to CCRTA's operation will be conducted to determine the best solution for CCRTA.

A secondary option for energy resiliency is redundant utility feeds on-site. A redundant feed can be requested from the local utility to serve as backup when there is an outage on the primary feed.

Lastly, CCRTA may consider operational resiliency rather than backup power as a feasible option for the Authority. In this case, spare vehicles with conventional propulsion technologies are retained from the retired fleet and kept on standby. Diesel or hybrid vehicles that do not rely on electricity can substitute the zero emissions fleet during an outage.

The following report will highlight these options and speak to the opportunities and challenges associated with each.

2. Conventional Generation

On-site generation is a trusted option for prolonged outages as it can provide backup power for virtually unlimited duration. Compressed natural gas (CNG) and Diesel generators are most common for this kind of application. They are widely used for reliable backup power at industrial sites, factories, hospitals, hotels, airports, and many other sites where lifesaving and mission-critical operations take place.

2.1 Diesel Generator

Diesel generators are the most traditional form of backup power used at industrial and transit facilities. Diesel generators use mature technology with well understood maintenance and servicing requirements. As such, Diesel generators are typically cheaper to purchase and maintain compared to other types of conventional on-site generation options like CNG generators. Diesel generators also present the benefit that they can be "hot" refueled during operation, which means that the system can be refueled while it is running to enable continuous operation and to extend duration. Both permanent and temporary (mobile) diesel generators, discussed in the following section, can be used for backup power.

2.1.1 Permanent

An on-site, permanent diesel generator offers the benefits of immediate availability in the event of an outage but requires allocated space and clearance around the generator. A permanent generator also requires the necessary structural supports and several auxiliary loads to ensure that the generator is ready to start. Figure 1 shows a typical permanent diesel generator installation.

The power and energy ratings of the permanent unit is fully decoupled. This means that the fuel system is commissioned separately to match the duration of the power application needed and that diesel tanks can be custom designed and welded to customer specifications. Decoupling guarantees that diesel generators are specified to provide support during prolonged outages. The generator's power output is specified based on the minimum electrical load needed to support operations during an outage.

Figure 1 - Cummins Permanent Diesel Generator

2.1.2 Mobile

Mobile diesel generators are typically installed on a trailer or other form of mobile platform that is transported to the required site when needed. Hence, mobile generators have a design constraint in that they are generally smaller in power output. However, a major advantage of a mobile generator is its flexibility. The unit does not require a designated space in a facility and can be parked in unused bus rows or temporarily repurposed areas of the facility. This can be especially advantageous in a space-constrained facility. Several mobile generators can also be connected to the same electrical panel to increase the overall output of the backup power system.

For space-constrained facilities, mobile generators can either be purchased and stored off-site or rented from a supplier. A rental agreement shifts the cost of ownership to an external entity. A mobile generator fleet also offers the benefit of being redeployed to other locations. For example, a generator could be moved to an on-route charging location if maintenance was being completed on the normal power supply. In addition, the mobile generator is easier to scale up as fleet electrification grows and increases the vehicle charging power needs. However, one disadvantage of mobile generation is its relatively longer restoration time compared to a standby permanent unit. The start-up and synchronization times for diesel generators can range from 10 seconds to two minutes depending on technology. Since a

Figure 2 - CAT XQ2000 Mobile Diesel Generator

mobile unit must be transported to the site and connected to the system before power can be restored, the overall process may take a few hours.

Should CCRTA decide to pursue diesel generation there are additional factors that would need to be considered like vibrations, noise levels, and spill mitigation plans.

2.2 Compressed Natural Gas Generator

CNG generators offer many of the same benefits of diesel generators but run on cleaner natural gas. Compared to diesel generators, CNG generators typically have higher capital costs for an equivalent generation capacity. The operational costs are higher and maintenance tasks are more intensive, which are largely related to the safe management of the highly flammable gas fuel. The major benefit of CNG generators over diesel generators is the lower fuel cost and lower emissions.

The fuel supply system for these generators can either be a direct connection to a nearby natural gas pipeline or on-site storage using compressed tanks. The on-site fuel storage option requires additional capital investment for storage and handling equipment, staff training, and on-going oversight. Direct connection with a local gas utility would shift the maintenance and handling requirements to an external party. However, this option requires a carefully crafted supply agreement that guarantees the availability of the fuel when required.

An additional consideration for CNG generators is that there are several makes and models that have been adapted to accept a hybrid fuel consisting of natural gas and hydrogen. These dual-fuel generators have been developed by making modifications to the ignition and fuel system on a CNG generator, allowing for adjustment for hydrogen properties. This option allows for a flexible choice when tailpipe emissions are a major consideration and can be quickly activated to run on CNG as a secondary back-up fuel.

3. Microgrid

A Microgrid – the integration of onsite renewable energy production and an energy storage system – can be an effective resiliency alternative to fossil fuel-based generation. The largest advantage of renewable power generation is its zero emissions, thus clean energy. Solar generation is the most prevalent option for clean energy generation currently. This is because the application of other forms of clean power generation, like hydrogen fuel cell, is relatively new and costly for backup power application. As such the upfront costs for implementation, maintenance, and operations for these options are high.

3.1 Solar

On-site solar generation can add resiliency, offset energy costs, and further reduce greenhouse gas (GHG) impact by utilizing clean energy produced on-site. In most cases, however, solar does not reliably provide enough instantaneous power to provide full operational resilience. On-site solar production can provide backup power in specific scenarios, but a battery storage system is necessary for solar to be considered part of a resiliency system. The primary function of a solar array would be to offset energy from the grid and reduce utility costs.

The following factors require evaluation when considering solar power:

- Available space/area for solar panels
- Sunny days per year

An on-site battery storage system can complement solar generation to provide limited resiliency. On-site battery storage systems store energy produced when sunlight is available and use that energy during outages when no sunlight is available. The size of the battery storage system is determined based on the site's solar production, average outage duration, and the power requirements during an outage.

A microgrid system also has additional advantages like cost savings from the grid energy offset and a smaller utility feed requirement due to a lower local peak load.

Often a major catalyst for fleet electrification is the potential for GHG emissions reduction. If charging energy is provided through connection to the local electrical grid, the GHG emissions reduction will be dependent on the carbon intensity of the energy mix feeding the grid. On-site renewable energy production supported by a local microgrid can help to offset these associated carbon emissions. This is an added opportunity worth considering.

3.2 Energy Storage Systems (ESS)

Section 3.1 describes how energy storage systems can complement on-site renewable generation. However, on-site storage such as a battery energy storage system (BESS) can also be deployed as a stand-alone unit to provide backup in a situation where grid power is lost. In this case the energy storage system would store grid energy instead of energy from a local renewable source.

Energy storage systems are quiet and do not require a separate fuel source. However, these systems can become expensive if the storage requirement is high, specifically if the intent for the backup power is to support full service for a prolonged period. In most cases energy storage systems provide the best value through "value stacking." Value stacking occurs when the system provides added benefit by providing a buffer for intermittent supply from a renewable power source such as solar or wind; smoothing out the load profile (peak shaving) to avoid peak demand charges, and the responsible party takes advantage of time-of-use billing. These benefits result in significant operational cost savings. Energy storage systems can also help the Authority avoid penalties which are imposed by utilities when the voltage or frequency fluctuates outside the allowed limits due to the customers' electrical load.

3.2.1 Stationary Lithium-ion Energy Storage

Lithium-ion energy storage systems are quickly becoming ubiquitous as the dominant grid-scale storage medium. Stationary lithium-ion systems have also benefited from the economies of scale associated with the growth of the electric vehicle industry. Lithium-ion systems are commonly found in the footprint of a typical 40-foot shipping container, however other outdoor-rated configurations exist. Figure 3 shows an outdoor energy storage system installation.

Figure 3 Energy Storage System

Lithium-ion systems can have very fast response times based on the AC/DC power conversion system used, making for a near-seamless transfer to backup power in the event of a grid outage.

One of the disadvantages of Lithium-ion batteries is that they suffer from both calendar and throughput degradation. Throughput degradation applies to the number of annual cumulative charge/discharge cycles and calendar aging occurs even when the battery is on standby. The aging effect is accelerated when a battery sits on standby at a high state of charge, typically above 80%. This degradation results in available backup power reduction as the system ages. Therefore, it is recommended to put the battery on stand-by at a low state of charge and to cycle the battery periodically.

The Lithium-ion cells are also sensitive to temperature changes. Cold temperature can temporarily reduce the systems power output and charging speed. High temperatures are cause for serious concern because heat can cause irreparable damage to the battery cells. Therefore, when installed outdoors, the lithium-ion battery storage systems are typically equipped with thermal management systems which impose additional operations and maintenance requirements.

One of the biggest concerns with Lithium-ion batteries is the risk of thermal runaway in the battery cells. A battery pack is a dense assembly of chemical energy. If this large supply of energy begins reacting outside of its intended circuitry, for example due to faulty wiring or defective or damaged components, the battery can start rapidly expelling heat and flammable gas, causing a “thermal runaway” fire. Given their abundant fuel supply, battery fires are notoriously difficult to put out and can even reignite after they are extinguished. Furthermore, without prompt fire mitigation the dispersed heat and gas will likely spread to adjacent structure or objects.

3.3 Hydrogen Fuel Cell

Hydrogen fuel cells have operated reliably in commercial back-up power operations and in vehicle applications for almost 20 years. Common applications for fuel cell backup power are found in the telecommunications industry where they have been used to power communication towers in the event of an outage. Multi-megawatt fuel cell applications are less common than the smaller scale systems, however major companies such as Ballard, Cummins, and Hydrotec have concepts or pilot deployments for higher power application. Hydrogen fuel cell is an ideal option for scenarios in which there are strict emissions requirements and long outage durations.

The system operates on the same principle as a fuel cell electric vehicle. Air is pushed through the fuel cell stack to react with compressed hydrogen which produces electricity and water vapor. The operation is much quieter than any combustion engine and can provide full rated power until hydrogen pressure drops below the minimum level required by the fuel cells (typically 8 bar). Startup is fast and full power is available in less than 30 seconds.

A challenge with hydrogen fuel cell backup power systems is fuel storage. Hydrogen storage is difficult due to its low volumetric energy density and its low boiling point. There are two commercially available storage options for hydrogen: pressurized gas and liquid. Gaseous storage is perhaps the simplest because hydrogen is naturally a gas at room temperature. However, because of hydrogen's very low density, pressurization is used to keep storage tank sizes reasonable. Typical storage tanks use a pressure of 5,000-10,000 pounds per square inch (psi), which requires specialized tanks, pumping procedures, and safety regulations. Liquid storage avoids these challenges, but instead requires extensive cooling to keep the hydrogen below its boiling point of negative 423 degrees Fahrenheit. This cooling is highly energy intensive, reducing storage efficiency. However, because of the smaller tank size required compared to gaseous storage, liquid storage is the most common option.

Moreover, the cost of hydrogen storage systems is the biggest barrier to current, widespread implementation. Installation costs for these systems is typically an order of magnitude higher when considering the generation unit, hydrogen storage and hydrogen handling equipment.

4. Back-up Fleet

Another option for energy resiliency is naturally built into an authority's existing operations – existing fossil fueled fleets. In the case of power outages, these vehicles can be used to provide either full or reduced service if the authority is unable to operate zero emission vehicles. Hybrid vehicles may also be used in the same way.

Zero emission transition planning is typically performed using a phased approach. This strategy takes into consideration vehicle retirement year and necessary replacement dates. Not only is this fiscally responsible but it also serves as a fleet-based resiliency option. With authorities operating and maintaining mixed fleets comprised of new, zero-emission or hybrid vehicles and fossil fueled vehicles, it offers the potential to reduce pollution and noise, gain required skillsets and operating experience for future electrification, and is a fallback resiliency option should the authority face operational challenges with zero emission vehicles. For a few years following full transition to zero emission technologies, authorities can retain a certain number of fossil fueled vehicles to provide operational backup.

This option requires maintenance and upkeep of additional spare vehicles. Additional spare vehicle would also need additional storage space which can be particularly challenging for space constrained facilities.

5. Conclusions

It is important to consider the operational resiliency of a zero-emission fleet during the transition planning process, ensuring it is incorporated in the transition plan and capital budget planning. Unlike fossil fuel-based vehicles that are not reliant on the power supply for their operation, zero emission vehicles need reliable power supply to operate. In the event of a power outage, the Authority would lose its ability to provide service to its riders in the absence of backup.

Authorities have multiple fleet resiliency options to choose from. Each option has advantages and disadvantages. Conventional on-site generation options like diesel and CNG generators are relatively matured technologies that can theoretically provide backup power for an unlimited duration. Diesel generators are relatively cheaper, but they have higher GHG emissions. CNG generators are much more efficient and produce minimal GHG. Regardless of the fuel type, however, an on-site generation system's advantage is its ability to provide continuous power for a prolonged period.

Microgrid solutions like solar power and energy storage systems have low environmental impact but have other disadvantages. Solar production is heavily dependent on external conditions and cannot be relied upon for energy needs during outages. On the other hand, energy storage systems – specifically Lithium-ion batteries – are expensive alternates with diminishing storage capacity over their lifecycle. Energy storage systems are typically a cost prohibitive solution for prolonged outages and/or large electrical loads.

Table 1 summarizes the advantages and disadvantages of on-site generation and on-site storage systems.

Table 1: Comparison of Power Resiliency Options

	Pros	Cons
Conventional Generation	• Ability to provide power for prolonged periods • Lower upfront cost	• GHG emitter • Maintenance and upkeep are required and can be costly
Solar	• Reduced utility costs • Offsets carbon emissions associated with electrical grid	• Inability to provide instantaneous power sufficient to support all operations • Constraints related to real-estate space and support structures • Requires battery storage for resiliency usage.
Energy Storage	• Serves as intermittent buffer for renewables • Reduces utility costs through peak-shaving	• Short power supply in case of outages • Batteries degrades over time resulting in less available storage as the system ages • Increased costs for high storage capacity
Back-up Fleet	• Reliable proven technology	• Requires upkeep and maintenance of the standby conventional fuel fleet • Requires additional vehicle storage space

Deciding which option is right for CCRTA may seem daunting. There are multiple factors to consider when choosing from these options. To make it manageable, the decision-making process can be broken down into steps. First, CCRTA will need to define its operational goals during power outages (core service); determining the extent to which service needs to operate. This can be determined during the transition planning stage. Second, the duration for which the core service needs to be maintained must be determined by analyzing the power outage data for each sites' utility feed. Additionally, decisions should be made on whether "value stacking" in the form of utility cost offset, GHG off-set from local solar production and peak shaving using energy storage system is desired.

Once the operational goals are determined, a technical and financial feasibility study should be conducted. This step would include a cost benefit analysis for each system to determine the ideal solution for CCRTA's unique needs.

Finally, a conceptual level system design can be developed along with a planning level cost estimate study that would serve as basis for an in-depth engineering design. Additional considerations like fuel supply options; potential solar partnerships with the adjacent airport; equipment size and specifications; and existing equipment assessment would be conducted at this stage.

The following Figure 4 outlines these steps in the system resiliency planning process to determine the best alternative for CCRTA needs.

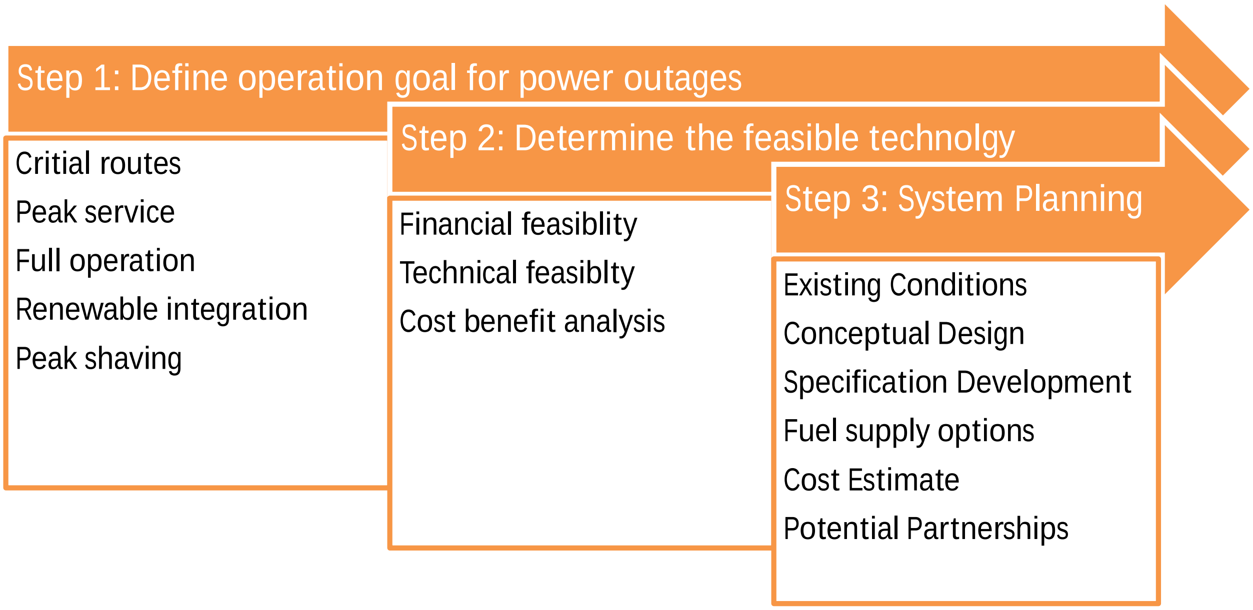

Figure 4 System Resiliency Planning Process

Resiliency planning takes a different shape with zero emission fleet transitions. The backup for ensuring reliable service switches from maintenance of spare vehicles, in the case of vehicle breakdowns, to ensuring a reliable supply of electricity and power for current and future needs. The first step in developing a robust, resilient system is to determine the requirements based on operational needs. Once the requirements are defined, CCRTA can make informed decisions as to which option(s) will meet the Authority's backup power needs.