A Case Study on Emergency Backup Power with Renewable Energy

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Executive Summary

The current standard in British Columbia is to provide diesel generators as the only acceptable form of emergency backup power available for contractors to use when designing multi-unit residential buildings (MURBs) that house vulnerable populations. As more of the population ages and begins to fall under the category of vulnerable, and with increases in MURB construction steadily increasing over the past 20 years, the number of generators installed in urban BC areas are set to consistently increase in the near and long term[1]. Standalone diesel generators have been the only economically viable option to provide near-instantaneous backup power to MURBs in the past, but with an increased focus on low carbon and resilient energy systems by local and federal governments, other technologies might better satisfy these requirements. With renewable energy dropping in price dramatically alongside the increase in availability of other energy storage technologies, the potential to use low carbon options is becoming more viable. With various power generation and energy storage options out there, the question becomes which technologies are optimal to implement for urban residential applications? Moreover, how would a proposed solution compare against existing diesel generator economics?

For power generation, solar is the ideal technology because of its low operating noise, relatively low-cost of installation, and 25-year expected project life. Installation costs of $1,830/kW and current average solar energy conversion efficiencies of 18% are driving the current cost and space constraints for solar implementation [2, 3]. With future efficiencies of solar panels expected to improve to 20-22%, the overall cost and space required to install the same amount of power production will decrease accordingly [2, 3].

Lithium-ion batteries are proving to be the optional form of energy storage now and in the near future. Although flow batteries offer promising resilience in the long term, the technology needs to mature and prices need to drop for this technology to be competitive with lithium-ion. Lead-acid batteries provide a low-cost option that has a very short lifetime due to low cycle counts, and are not recommended. Hydrogen batteries were also reviewed, but the research showed that their low efficiencies and overall cost make them prohibitive for such small scale, non-critical applications.

The most economical fuel option for systems above 150 kW is diesel as initial costs are lower and required storage tank size for fuel is much less. For systems under 150 kW, propane is the recommended fuel type, as it is competitive with diesel in price and provides significantly lower particulate matter (PM_{10}) emissions. Natural gas is preferred over propane in jurisdictions where it is allowed[1] as it does not require on-site storage.

A case study on the Arbutus Housing Co-op in the Kitsilano area of Vancouver, B.C. was performed to develop a cost-benefit analysis for various backup power system designs. Five separate systems were modelled to determine their ability to accommodate the required backup power of 80kW for the building over a 72-hour outage period. The systems compared included: standalone diesel; standalone propane; diesel + lithium-ion; diesel + lithium-ion + photo voltaic (PV); and propane + lithium-ion + PV.

Each system was evaluated based on 3 main criteria; economic feasibility compared to standalone diesel in net present value (NPV), resilience, and environmental impact.

A key factor in the economic feasibility of a project when considering storage or renewable energy is heavily dependent on the type of energy pricing the jurisdiction in question has. These prices define how

[1] Refer to CSA 282 code which requires fuel to be reliably available during initialy running of an emergency back up generator. Because natural gas may be shut-off during an emergency, this is deemed “not-reliable” based on the definitions provided.

a system might create revenue during charging and discharging and similarly during energy production. For this reason, three energy-pricing structures were considered for the case study to allow for a comparison across prices and to understand how they affect overall implementation economics.

Using a 25-year project-life, the net present values (NPVs) of each system were calculated using three different energy-pricing structures: (1) current B.C. electricity prices, (2) Ontario's Time of Use pricing, and (3) an aggressive peak energy pricing structure.

Each power system was evaluated for resilience based on five current urban energy resilience criteria; adaptability, diversity, redundancy, resourcefulness, and stability. Each system was ranked out of five to provide a quantitative lens through which to review each system.

Finally, an environmental impact was performed to assess the CO_2 and PM_{10} emissions of each system relative to a baseline diesel generator.

The modelling analyses showed that:
Standalone diesel has a negative NPV of $84,000 for all three pricing structures. It also received a score of one out five for resilience due to the absence of a redundant fuel supply and limited ability for the emergency system adapt to changing conditions (longer blackouts, reduced loads required etc.). The system also performed the worst for environmental impact with 2.3 tons of CO_2 and 10.4 kg of PM_{10} released on an average yearly basis.
Standalone propane has a negative NPV of $64,000 for all three pricing structures. It received a score of two out of five for resilience because propane can be used interchangeably with natural gas, which allows for redundancy during a power outage. It also resulted in a reduction in yearly CO_2 and PM_{10} emissions of 1% (0.1 tons/year) and 92% (10.9 kg/year) respectively.
Diesel + lithium-ion proved not to be economically viable under any pricing structure and wouldn't be recommended unless subsidies could be provided to bring down the initial cost required for the battery system. The model showed an improved diversity of energy supply and therefore received a score of three out of five for resilience. It also showed a reduction in yearly CO_2 and PM_{10} emissions of 13% each.
Diesel + lithium-ion + PV has a negative NPV of $179,000 under the current B.C. pricing structure, which improved by 8% under Ontario's Time of Use structure, and by 40% under an aggressive peak pricing structure to negative $108,000. This system improved adaptability and resourcefulness and received a score of five out of five for resilience. Finally, it resulted in a reduction of yearly CO_2 emissions of 47% (1.1 tons/year) and PM_{10} emissions by 13% (1.6 kg/year).
Propane + lithium-ion + PV has a negative NPV of $159,000 under the current B.C. pricing structure, improves by 9% under Ontario's Time of Use structure, and by 45% under an aggressive peak pricing structure to negative $88,000. This NPV value is within 5% of the cost of the baseline diesel generator, and could be a viable option considering the many improvements to resilience this provides. This system improved adaptability and resourcefulness and received a score of five out of five for resilience. Finally, this system model showed a reduction of yearly CO_2 and PM_{10} emissions of 51% (1.2 tons/year) and 93% (11 kg/year), respectively.

The findings indicate that Implementing a hybrid system with solar PV and lithium-ion under the current B.C. energy-pricing structure is not cost effective. The analysis showed that if peak pricing incentives are high enough then the NPV of these projects can compete with standalone backup generators. The sensitivity analysis also confirmed this by demonstrating that an increase in pricing incentives (the value of peak energy over non-peak energy price) of 20% leads to an NPV improvement of 32%, making it the single largest contributing factor to the final NPV of a system. As such, hybrid systems will only become attractive to future developers if there are pricing incentives available and aggressive enough to create a demand.

System resilience increases when there are more energy supply options rather than only using a stand-alone generator. Systems that include solar power and batteries provide the most redundancy and become tools for building operations to use during a power outage, which in turn enables better adaptability. Although seemingly obvious, the addition of multiple energy production methods is a key factor in the ability of buildings to be more resilient to power outages in the long term.

Although emergency back-up power might be considered a rarely used system, the analysis demonstrates that nearly 88% of yearly CO_2 and PM_{10} emissions are due to maintenance activities designed to ensure generator reliability during outages. The remaining 12% is caused by the 5.56 hours/year that the generator would be used to actually produce backup power. With a standalone diesel generator producing 2.3 tons of CO_2 and 11.9 kg PM_{10} annually, the addition of solar PV and batteries to this system would save 1.1 tons of CO_2 and 1.6 kg of PM_{10} emissions per year. If new diesel standalone generators were simply replaced with propane fuel generators during the design stage, the reductions in CO_2 emissions would be 5% while PM_{10} annual emissions would reduce by 92%. These findings directly support the need for rapid change towards low carbon emergency backup power solutions for urban building energy systems.

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Introduction

The built environment is currently inextricably linked to its other half; energy, but with increasing threats to the stability of energy supply such as climate change, cyber threats, and increased technology dependencies, among others, the need for resilient backup systems to our energy grid are critical to the continued functioning of our built environment. Currently, emergency backup generation is used to ensure that buildings are able to function for hours to days after a power outage occurs. Emergency backup power has exclusively used fossil fuel based technologies but are no longer in-line with future climate and energy goals setup by local, federal and global governments. Therefore, the need to understand the potential to replace some of this demand with renewable power generation and energy storage needs to be understood.

With renewable energy sources, like solar, dropping in price by 85% in the last 8 years and energy storage seeing drastic cost reductions of more than 20% year over year since 2012 [4, 5]. With existing infrastructure currently built to handle fossil fuel backup power, the use of renewables in the area is slow and has certain economic and implementation barriers to overcome. Though because renewable energy does not satisfy the CSA definition of a "reliable and constant fuel source", a combination of carbon based fuel source must be used in conjunction with these technologies to make them feasible for the durations required. For these reasons, this report will focus on exploring how current renewable and storage technologies might combine with other fossil fuel based power generation to improve resiliency and overall environmental impact.

To begin, it's important to understand the current state of affairs and this report will briefly explore current definitions for resiliency, current building code requirements, fossil fuel options and their impact, renewable energy solutions, and finally energy storage. These topics will then inform a case study done on Arbutus Housing Co-op, a 6 story building in Vancouver British Columbia, to compare 5 various combinations of backup power systems in terms of initial costs, Net Present Value (NPV) of the investment based on 3 separate energy pricing schemes, their resiliency score, and finally their environmental impact. To conclude, a set of recommendations for further work to build on this report as well as other potential technologies to consider in the future.

All dollar amounts in this paper are reported in $USD.

BC Housing

BC Housing is the largest landlord in British Columbia and with 65,000 seniors currently relying on BC housing for their low-income housing requirements, and 2,500 new units on the way, there is a large population that relies on back-up generators for stability and comfort during an outage. With an ever changing climate, and an increase of power outages by a factor of 3 over the past 5 years in British Columbia, the need to assess and design back-up power generation for the vulnerable populations that rely on BC housing are imperative [6].

As the global community moves to more sustainable and resilient practices, certain design features such as back-up power are sometimes left unchanged from the status quo, but if modified can present a significant opportunity. The potential to allocate funds at the design stage to understand if alternative, low carbon technologies can be used to compliment backup power to vulnerable communities should be considered and understood.

Designing for Resiliency

Cities are inextricably linked to the energy grid and are dependent on its electricity to continue normal operation, the consequences of this dependence become evident when looking at power outage situations such as the Northeast blackout of 2003, which left nearly 50 million people without power, costing nearly $6 Billion in damages and leaving 11 people dead [7]. With cities continually expanding upwards leading to a rise in construction of multi-unit residential buildings (MURB) which has surpassed the rate of single home construction since 2011, the refocus onto these segments of the energy grid are crucial in the long term viability of our built environment [8]. In order to mitigate the risks of more potential large blackout situations caused by expanding global threats as well as local environmental changes, the concept of energy resiliency is gaining importance. This section of the report will focus on defining urban energy resilience as defined in various technical literatures to be applied to the broader picture of backup power systems.

Resilience is a broad topic that covers all areas of design, implementation, and building use but for the purposes of this report, a simplified view of resilience will be used in order create an actionable set of rules and definitions that industry can use to better define resilience. This report will rely on a paper written by Ayyoob Sharifi and Yoshiki Yamagata, which combined the findings of various papers in order to unify a common definition of urban energy system resilience [9]. From this report, five main criteria are chosen and are used to score each proposed system in the analysis section of the report. These five criteria can also be used to better understand the potential for system improvement or modification in other energy resilience contexts. This provides not only a general definition of energy resilience, but also provides a reference of each backup power system's resilience. The five criteria are listed and defined in Table 1.

Table 1: Urban energy resilience criteria as adapted from Sharifi & Yamagata.

Criteria	Definition
Adaptability	Reduction of pre-disturbance vulnerabilities and **enhance its capacity to adapt** to changing conditions.
Diversity	The degree to which **multiple distinct options** can be used simultaneously, are included in the system.
Redundancy	Having **overlapping resources** to pull from.
Resourcefulness	**Availability of tools** for planners to adapt to conditions.
Stability	Ability to **endure long term** disruptions by maintaining operability and return to order quickly.

The general findings of their report define four main factors that most heavily influence the resilience of an energy system; efficiency, diversity, adaptability, and stability. For the purposes of this report, efficiency was not used as a criterion because of its larger implications to the building as a whole, and is out of the scope of this report. Two other main criteria were identified as important with respect to backup power; redundancy and resourcefulness. These criteria were chosen based on their direct correlation with backup power, and their strong association with urban energy resilience as outlined in the report findings [9].

Backup Load Requirements by Code

Building codes are the main contributing factor to the size and scope of an emergency backup power system, and before looking at system sizing and design options these codes must be referenced and understood. In order to understand the differences between building codes/requirements, five prominent local codes are compared; The minimum standard codes required by British Columbia building code, International Building Code Level 1, 2 and 3, and finally BC housing's Design Guidelines [10, 11, 12]. Table 2 summarizes the direct comparison of building code requirements, and highlights key differences in their methodology. An important note here is that Level 1 and BC's standard minimum codes are very similar and for ease of understanding have been lumped together.

Backup power in the case of BC Housing shall apply in our case to "[Buildings] for seniors or persons with disabilities where prolonged power outages could present a safety or major mobility issue" [10]. This is to allow for these vulnerable populations to stay in their dwellings over the course of an outage.

Table 2: A general comparison of building guidelines aimed at pointing out the differences in load inclusions for sizing generators for emergency power [11, 10, 12].

<table>
<tr><th colspan="5">A General Comparison of Building Guidelines</th></tr>
<tr><td rowspan="7">BC Building Code (Level 1 – IBC)</td><td rowspan="14">BC Housing - Design Guidelines</td><td rowspan="20">Level 2 - International Building Code (IBC)</td><td rowspan="21">Level 3 - International Building Code (IBC)</td><td>Exit Signs</td></tr>
<tr><td>Egress Lighting</td></tr>
<tr><td>Elevator Car Lighting and Communication</td></tr>
<tr><td>Emergency Alarm System</td></tr>
<tr><td>Emergency Communications System</td></tr>
<tr><td>Fire Pumps and Jockey pump</td></tr>
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<tr><td>Water System Booster Pumps</td></tr>
<tr><td>Domestic Hot Water Circulator Pumps</td></tr>
<tr><td>Duplex Receptacles for Common Room*</td></tr>
<tr><td>IT Systems (provide UPS Power)</td></tr>
<tr><td rowspan="7"></td><td>Ventilation in Operational Areas</td></tr>
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<tr><td>Building Heating Systems</td></tr>
<tr><td></td><td>Air Conditioning Systems</td></tr>
</table>

BCBC Minimum requirements are designed simply to provide egress of the building in a safe and controlled manner, this requirement typically requires buildings to have these systems powered for 90 minutes to a few hours. BC Housing guidelines, level 2 and level 3 are designed to ensure occupants of a building can remain in the building for a predefined duration in the event of a power outage. BC Housing specifies in section 4.8.3 that they require 72 hours of backup power for specialty and recreation centers, but does not specify any other lengths of time for non-specialty buildings, and therefore 72 hours of operability will be assumed for the case study in this report. The International Building Code leaves the length of time open for jurisdictional decisions.

A main area of interest for this section are the differences between IBC level 2 and BC Housing guidelines, namely food preservation and preparation loads. IBC Level 2 specifies preparation and preservation loads for extended outages (Cooking and refrigeration), while BC Housing includes only “common area” receptacles to cover refrigeration and charging loads, but makes no mention of preparation loads. This could become a larger issue if outages are extended due to the inability to cook food.

BC Housing does not included requirements for heating, and during cold snaps, if an outage were to occur, lack of heating could be an issue if solar gains are not enough to support livability. Further discussions on potential areas of improvement will be explored briefly in future considerations section of this report.

Finally, IBC Level 3 indicates the need for air conditioning, while Level 2 and BC Housing guidelines do not.

Backup Fuel Requirements by Code

According to CSA standard 282 section 7.3, there must be a minimum of two hours’ worth of fuel available to operate the engine under maximum design load [13]. If the authority having jurisdiction deems that off-site fuel supply (piped in fuel) can be relied on for the two-hour rule, than off-site fuels such as Natural Gas are allowed. If this fuel is not deemed reliable, then on-site storage is required. In the case of BC, utility supplied fuel, such as Natural Gas is not deemed reliable due to seismic activity and therefore requires on-site storage.

In section 4.8.4 of BC Housing Design guidelines, it states explicitly that the fuel supply must be Diesel. This is of course because of CSA standards stated above, but does not factor in other fuel options such as Propane that can also be stored on-site [10].

General Terms

In this section the general terminology and meanings of general climate change items and acronyms will be explained for clarity to the reader.

Greenhouse Gas (GHG) – These are gases that are defined to trap heat within our atmosphere by allowing shortwave radiation through but reflecting long wave radiation back, ultimately leading to higher global temperatures. Greenhouse Gases include gases such as CO_2, CH4 (methane), Nitrous Oxide (NOx), and others.

CO_2 equivalent (CO_2e) – This refers to the standard measurement of global warming potential. It is most often convenient to express the effect of other gases such as CH_4 and NOx to warm the environment in terms of a standard unit of global warming potential in CO_2e.

PM_{10} – This is a measure of particulate matter created and released to the atmosphere during combustion. The number 10 denotes the size of the particles being measured, being 10µm in diameter or less. This type of emission is considered to adversely affect human health and has larger environmental effects such as acid rain, and soil contamination [14].

Peaking – This term denotes a time during the day where utilities see a peak demand in energy use. Typically, this energy is either bought from external provinces or states, or generated using high cost “peaking plants” that provide instant extra power to supplement the energy demand spike.

Value Stacking – This is the process of adding up various benefits of a system that are not directly related to its primary function. Taking utility scale batteries as an example, the primary function is to supply on demand power, but there are secondary benefits that are not accounted for initially such as maximizing renewable energy use, reducing peak power demand, and increasing resilience of an energy grid. Value stacking is the process of adding all these secondary benefits to come up with an aggregated value for the system.

Normalized Emissions – This term relates to a technique used often in Life Cycle Assessments, where the emissions generated (or saved) by a system or process is converted to a percentage of the average yearly emissions for a single person from the jurisdiction in question.

Technology – Fossil Fuel Backup Power

This section will focus on the existing technologies available for fossil fuel based backup power generation, namely the fuel types. A summary of the various fuel type options with a focus on potential benefits and downsides with respect to resilience, cost, implementation and environmental impact. Some technologies will not apply to certain BC Housing projects and particularly to the west coast of North America due to seismic risks (i.e. piped Natural Gas for backup fuel supply), but will still be presented and reported on with the intention to provide information for a broader audience.

Diesel

Diesel is currently the fuel type that BC Housing is able to implement in their buildings, and are most often used in larger backup power application above 150 kW due to their high power density. Diesel backup generators have grown in popularity and become the industry standard because of its reliable technology, high power output and simple system design.

Figure 1 demonstrates the high energy density of diesel compared with any other fuel or storage devices. Of all energy storage systems, diesel requires the least amount of space to store the same amount of energy. The benefits of which are most often realized in larger power applications requiring 150 kW or more, which require a large amount of energy stored on-site to keep buildings running during longer outage times. At these higher power outputs, the cost of diesel generators is also the lowest among generator options and is a major consideration during the design phase.

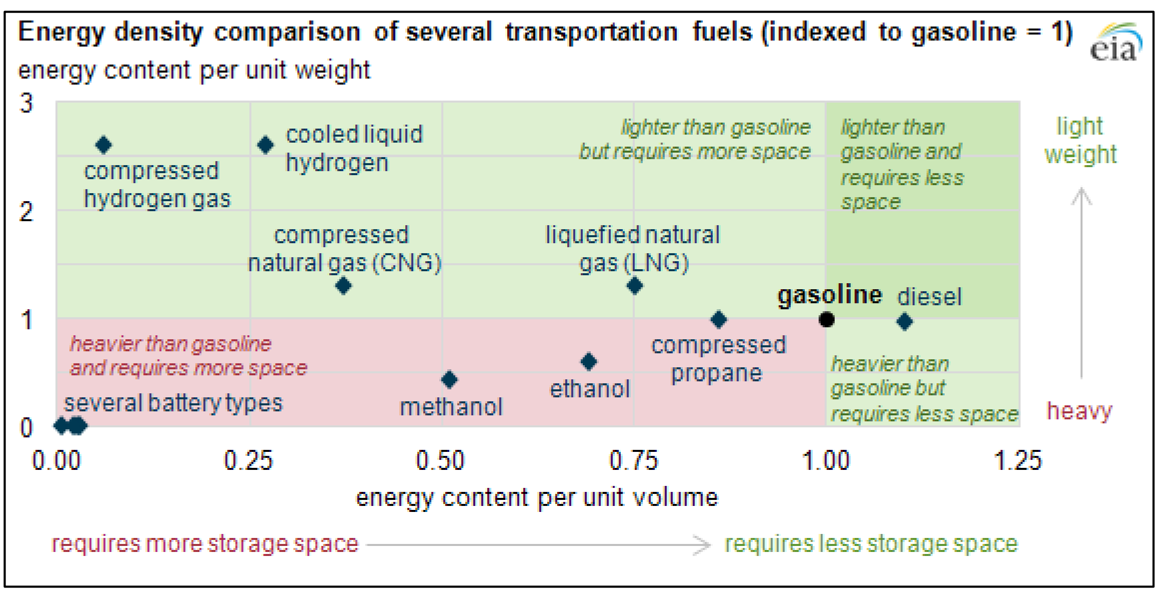

Figure 1: A General volume and energy density plot showing the various fuel options with respect to gasoline as a standard. Figure provided by the EIA and the National Defense University [15].

There are downsides to diesel, namely that it has the highest CO_2 emission factor of all fuel types at 73.96 kgCO2/MMBTU, releases the most amount of PM_{10} into the air during combustion at a rate of

0.392 kg/MMBTU [14, 16]. In the European Union there are calls to remove Diesel as a fuel option for transportation in cities due to poor air quality, and have placed large taxes on people who drive their Diesel vehicles in city centers [17]. Considering the amount of fuel burned yearly for maintenance, this type of action in Europe leaves the impression that Diesel backup generation might well soon start to experience similar pushback.

Stored Diesel fuel is typically only good for 6-12 months; if not used or maintained, it will start to react with oxygen to create sediment and gum that will render the engine useless by plugging up filters. Maintenance requires regular water removal procedures and cleaning of gum and particulates which are done on monthly schedules. There are additives that can help aid the process by slowing the degradation of the fuel but it is typically recommended that the fuel is used in 1-5 years in order to avoid the risk of a fuel malfunction during operation [15]. All this to say that diesel has a relatively high maintenance cost over the life of the generator itself.

Diesel is the most economic and easy to implement for larger power applications but remains cost competitive relative to other fuels for systems less than 150 kW [18].

Propane or LPG

Propane, sometimes referred to as Liquefied Petroleum Gas (LPG), as a fuel source for on-site generation has started to increase in popularity due to the lower cost per kW in smaller system sizes (150kW), reduced maintenance cost and improved emissions [18]. Propane is combusted in an internal combustion engine using a standard spark plug ignition technology. To store Propane, it is first compressed to 850 kPa, which converts the normally gaseous fuel into a liquid, and is then stored in a large compressed tank to satisfy the required operation time.

Although the use of Propane backup generators is relatively new compared with Diesel, it does have a few desirable advantages in that it releases 17% less CO_2e when running, burns with minimal particulate matter, and has the potential to be used interchangeably with Natural Gas (NG). The ability to interchange fuels has a large upside for building scale backup power in that, if refueling options are not possible and NG is still accessible, it would allow a generator to run indefinitely. Further, the Propane fuel is compressed and sealed without oxygen present, therefore there is no chance of fuel spoilage and maintenance costs are much lower [19].

The main downside of Propane is that it has a lower energy density than diesel, and therefore will require a larger fuel tank to provide the same generator running time. On top of that, the installation is much more complex because the system is under pressure and the storage tank must be stored outside the building as per code requirements.

Natural Gas

Due to its abundance in Canada and low-cost, Natural Gas (NG) is currently being used in six million Canadian homes, with one million in BC alone, making it one of, if not the easiest fuel to access in urban centers [20]. Similar to Propane, NG uses an internal combustion engine to generate backup power. NG is almost never used for on-site storage because of the very large space required and high pressures involved (see Figure 1), and would instead be connected directly to utility fuel supply systems. NG also burns very clean compared to diesel, emitting no particulates, and also releases 24% less CO_2 per unit of energy burned [19].

According to CSA 282, the supply of fuel must be reliable and constant to be used as stand-by fuel, and it is this distinction that makes NG not suitable as a fuel for backup power in British Columbia [13]. In a region with high risks for seismic activity, Natural Gas pipelines have the potential to rupture rendering Natural Gas backup power systems useless, and are therefore not considered reliable. In locations with minimal risk for seismic activity like Saskatchewan, NG generators are much more widely used [21]. The main benefit of mentioning Natural Gas in this context is in the event where gas lines are not shut down, Natural Gas can be used as an endless source of backup power, significantly improving resilience as a secondary/redundant fuel option.

Dual Fuel Systems

Dual fuel systems use a mixture of fuels, most commonly, Diesel and Natural Gas to run a generator. By taking advantage of the high torque diesel fuel and combining it with a cleaner burning fuel like Natural Gas or Hydrogen, a dual fuel system improves the overall environmental impact, reduces running costs and increases running time [22, 18].

It is therefore useful to consider a system that could use exclusively Diesel if Natural Gas lines are shut down to ensure CSA 282 compliance, but when not shut down could use NG to extend the running time, reduce running cost, and improve the environmental impact of running the generator.

There are also companies currently developing and launching dual fuel engines with hydrogen as the secondary fuel[2]. The ability to use Hydrogen will be covered later on in this report, but would be used in the context of storing excess electrical energy in the form of Hydrogen (the storage medium) and using this during a dual fuel combustion process reducing environmental impact and increasing running time of the generator during outage conditions.

Technology – Renewable Energy

Solar Power

Solar power from Photovoltaics (PV), are the most likely candidate to be used for long term projects for building integrated power generation. This is in part due to the age of the technology, which has been in development for over 60 years, and most importantly because of the current price of the technology. The technology has seen a significant price drop in the past 8 years, dropping more than 85% since 2010 to $1,830/kW of installed capacity based on US solar installations between 10-100kW [5, 3]. Currently markets and manufacturers provide warrantees for 25 years that ensure power production does not drop below their regulated levels in that same time frame, though many panels have been known to last much longer.

In recent years' solar panel efficiency has improved to numbers averaging around 18% for the higher efficiency monocrystalline solar panels [23]. These increases are mostly due to various improvements to manufacturing processes, materials being used in the panels themselves and to cell technology and production. It can be expected that these efficiencies will improve, with high-end panels currently reaching commercial efficiencies of 21-22% [2].

Unlike other technologies, solar power production requires no moving parts and is typically kept out of the way of higher value spaces that residents are likely to use. A major barrier to implementation is the amount of space required to produce a significant fraction of the building energy, but as efficiency increases the required space will inevitably decrease along with it.

[2] See Hydra Energy, https://hydraenergy.com/

Wind Power

Due to a current lack of technology that can reliably produce power in an urban setting wind is not a viable option for a MURB. Vertical wind turbines show promise in future years to reduce noise, and function more consistently at low and turbulent wind speeds. Until technology and price become viable, wind energy should not be considered for urban installations.

It should be noted that if communities are located outside of urban areas, and have access to larger, undisturbed land off-site wind energy would be a viable option.

Technology – Energy Storage

Energy storage plays a large part in the future of our energy grid, and must be adopted in the near future in order to improve overall resiliency of local building infrastructure as well as the energy grid as a whole [24]. As intermittent power generation, such as wind and solar come online, the need for further energy storage will only increase. With so much future demand for energy storage, there are countless new technologies emerging out of research and development to consider when thinking about integrating energy storage in buildings. This section aims to introduce various battery technologies that are most likely to be deployed in a Multi-Unit Residential Building (MURB) backup power application. The most common battery types were chosen because of their level of development, existing uses and potential benefits. The technologies explored are Lithium-ion, lead acid, redox flow batteries, and hydrogen to supplement a fossil fuel based emergency backup power system.

Lithium-ion

Lithium-ion Batteries (LIBs) which use a liquid or polymer based electrolytic solution have taken over the market and seen drastic improvements to power and pricing in the past decade. With electric vehicles set to take over 26.4% of the new vehicle market by 2030, the pressure on companies to produce and manufacture high density, low-cost batteries is very high [25]. Lithium-ion technology uses an electrochemical storage system to gather and store electrons in the electrolyte solution held between the Cathode and Anode. When a load is applied to the system, the electrons are allowed to flow from anode to cathode to satisfy the load demands. This type of storage provides direct electricity to electricity storage, requiring no further conversion of energy using mechanical or magnetic methods, simplifying the maintenance and reliability of the system.

Lithium-ion is a developed technology that is set to further decrease in cost and increase in reliability and lifetime in the next 10 -15 years as the technology matures in EV and storage applications [25]. Currently, the number of cycles (charge and discharge) the battery is able to efficiently complete, as of 2017 is 3,000 to 5,000 cycles at which point they need replacement, providing a reasonable lifetime of about 10 years in a daily charge and discharge situation [26]. With efficiencies of up to 97% and depth of discharge of 85%, the technology is still maturing but is currently a frontrunner in almost all categories [27]. Due to the interest in other industries in this technology, it is expected that cost will be harder to improve through to 2030, but with increased investment in research and development, it is expected that number of cycles will see major improvements (doubling or greater) in the next 10 years [28].

Lead Acid

Lead Acid batteries are the oldest of all the stationary battery technologies being considered, with history dating back to the 1800s. They're currently the most deployed storage medium for small scale applications for off-grid and PV systems [29]. This has been attributed to their low-cost and well understood technology, allowing them to be deployed easily in various applications. Lead acid has also matured in recent years providing gel batteries that are very low maintenance, compared with their flooded battery brethren. They do however have some downsides; having efficiencies around 70-90% with a depth of discharge (DoD) of 50%, very low comparative lifetime cycle counts lasting sometimes as little as 5 years, and a low energy density compared to some other chemistries [27]. In terms of resilience, because these systems are well understood and easy to replace and repair they would be considered robust and simple to implement in the short term but are likely soon to be considered an outdated technology.

As cost and space are the main constraints for a typical BC Housing project, the density and efficiency values will no doubt affect both of these criteria. With other batteries poised to quickly overtake this technology in price, the downsides of short life span, high maintenance and low depth of discharge make it a technology quickly losing its foothold in the storage world.

Flow Battery

This is the newest type of stationary energy storage system being considered for solar storage and emergency backup power. These batteries function in a fundamentally different way than lead acid or Lithium-ion chemistries. There is a central membrane with two storage tanks designed to hold charged and uncharged electrolyte. During power production, the charged electrolyte is pumped across the membrane, releasing electrical energy. During charging, the uncharged electrolyte is pumped across the membrane to pick up electrons. The size of the battery is dependent on the size of the storage tanks available, making this technology extremely flexible in its implementation capabilities.

Although flow batteries are still considered in development, there are a select few companies currently providing full solutions, as they've recognized the potential for them to supply large amounts of storage. Vanadium Redox Batteries (VRB) are the most developed of the flow battery chemistries which have been measured to have very good efficiencies between 65% - 85%, cycle counts of at least 5,000, and the added benefit that without access to a power source the charged electrolyte can be trucked in to effectively "recharge" the battery without the need for a charging cycle [30]. The technology does have some downsides; the system requires pumps and mechanical pieces that will require maintenance and have the potential to breakdown. More importantly, this battery is still currently in the R&D and early development stages and is considered too immature to consider for backup power as of writing this report. Though within a few years it would be wise to begin considering this as an option alongside Lithium-ion technology once technical and deployment details are settled and the cost structure is well understood for the lifetime of a project.

Hydrogen

The hydrogen economy is a concept that sees the production and use of hydrogen eventually replacing the need for fossil fuels. Though this might be far off, the potential to use hydrogen to store energy in the form of a fuel, effectively acting as a potential storage medium for renewable power is a serious consideration for energy storage.

There are a couple useful ways hydrogen can be used in this type of configuration, either as a dual fuel compliment to diesel, Propane, or Natural Gas or for use with a Proton Exchange Membrane (PEM) Fuel Cell. Both of these options are discussed in more detail below.

Hydrogen – Dual Fuel

In a hydrogen dual fuel scenario, solar power would be used to convert water to hydrogen using an electrolyzer. This hydrogen would then be compressed to high pressure, and then used to as a Dual Fuel option for Diesel, Propane or Natural Gas generators, thus bringing down the CO_2

emissions released during combustion and also offsetting some of the carbon by producing it via renewable power. This type of technology already exists, but has not found commercial success outside of critical facility implementation.

This type of technology could be interesting should hydrogen begin to take on a larger market share of energy storage in the future. Because of the low efficiency of electrolyzers and energy intensity of the compression process, the current round trip efficiencies of this type of system would be around 20-50% conversion rate, which affects the feasibility of the overall system [27].

Hydrogen – PEM Fuel Cell

Much like a dual fuel system, hydrogen can be produced by using electrolyzer running on renewable power such as solar, and instead of burning it off in a combustion process the hydrogen would be used in a Proton Exchange Membrane (PEM) Fuel Cell. A Fuel Cell is designed to take a fuel, such as hydrogen, and combine it with Oxygen across a membrane, which releases a charge that can be harvested as electrical energy. The output of a PEM Fuel Cell is water, and creates only electricity with no side effects. This technology has been in development for decades but without major improvements in efficiency and cost, have typically remained cost prohibitive for large scale, non-critical application. Due to low electrolyzer efficiency and Fuel Cell conversion typical round trip efficiencies would be 30-40% [31].

Both technologies are currently viable to implement in their current state, but because costs are high for low power applications, and due to their low efficiencies the payback on the systems would be much longer than other technologies. Though it is an energy storage method, the resilience of this system is considered worse than other storage technologies because of the expert knowledge that would have to be available to maintain and repair the system if failures occur. If increased adoption occurs, this could provide an intriguing option for future building energy systems. Current prices for three main parts of a hydrogen system are provided in Table 1 below.

Table 3: Hydrogen system costs. Based on 2020 target prices made by the DOE.

	Electrolyzer ($/kW)	Stationary H_2 Fuel Cell ($/kW)	Storage Costs ($/kg)
Hydrogen Energy Storage System	430 [32]	1,500 [32]	623 [33]

Summary

Lithium-ion

- Good energy density, mature technology, and resilience of batteries makes this technology at the for front of battery uses for building applications.
- Cost is still dropping, but the 5 to 10-year life span can make this technology expensive.

Flow Battery

- The Vanadium Redox Battery (VRB) is currently the best developed flow battery available and due to chemistry potential, has the highest efficiency. This is definitely a very good option for energy storage because of the expandable size of the system based on tank size, has very good depth of discharge, and relatively high efficiency.
- Due to immaturity in technology and understanding of running cost, there is still research to be done to fully understand the value but in 2-5 years should be a contender with other main stream technologies.

Lead Acid

- Low-cost, and fully mature technology make this another highly viable option to implement with building scale energy storage.

- Replacement costs due to low lifespan, and efficiency make this system obsolete in the next decade, and should be considered to be replaced with another battery type with more cycles.

Hydrogen

- Multiple uses that makes a building much more resilient and self-sufficient.
- Technology is currently still developing, and requires improvements to efficiency or significant reduction in costs to make it competitive with other technology.

Table 4: Summary of Battery technology Information [26, 27, 34]

Technology	Max Capacity (kW)	Discharge Depth	Efficiency[1]	Cycles[2]	Energy Cost ($/kWh)	Technical Maturity	Timeline to Consider
Flow Battery (VRB)	100,000	>90%	65% - 85%	3,000-5,000	150-1,000	Developed	5 years
Lithium-ion Battery	100,000	85%	75% – 97%	3,000-5,000	350-700	Developed	Ready
Lead Acid	40,000	50%	70% - 90%	500-1,000	150-500	Mature	Ready
Hydrogen ES	50,000	100%	20% - 50%	1,000+	*	Developing	10 years

Mature = Currently being deployed and technology is mostly refined with no major changes to occur,
Developed = Ready for commercialization but have not been refined, improvements expected.
Developing = Still in R&D and not yet ready for commercialization.

[1] This is based on battery efficiency, and does not account for other auxiliary equipment required to run the batteries such as HVAC, lighting, and monitoring systems.

[2] Specific maintenance is required in order to achieve these numbers based on manufacturer preference.

*- See Hydrogen Section for pricing breakdown

Based on the findings in Table 4 Lithium-ion and Flow Battery technology would be the ideal candidates for energy storage considering their relatively high cycle counts, high energy density, and lowered costs. To verify and compare options all technologies were sized according to a standard

Energy Storage - Beyond Backup Power

A quick introduction to how revenue might be generated from introducing energy storage systems into a grid connected system

Revenue Generation

Demand for energy during the day typically exhibits two peaks, at which time the cost to produce energy is higher and in jurisdictions that have relatively clean baseload energy, produces the highest amount of pollutants when compared with other times of the day [35, 36]. This increase in cost and emissions is because the demand for peak energy is usually fulfilled by localized peaking plants that use Natural Gas or other quick ramp up energy supply. As a result, utilities have resulted to various pricing schemes in order to try and create behavioural change in their consumers designed to reduce peak demand, and to provide a more accurate reflection of actual electricity costs for utilities. For instance, Ontario has a Time of Use (TOU) system that charges a low price (0.064 $/kWh) for energy during low demand (middle of the night) but charges more than double that price (0.136 $/kWh)during peak times (6-8pm in winter). When a utility decides to implement tiered pricing for energy, such as in Ontario, it presents a potential revenue stream for any energy storage system. The way to create revenue is during low peak times when energy is cheap, energy is stored and when peak demand rolls around later in the day, the stored energy is discharged either to the building itself, reducing building demand, or sold directly to the energy grid for the high price of electricity. The value of the revenue generated would be based on a simple equation:

$$(CPE) \times (SC) - (COPE) \times (SC) \times (Eff) = R$$

Where, CPE is the Cost of Peak Energy in $/kWh, SC is Storage Capacity in kWh, COPE is Cost of Off Peak Energy in $/kWh, Eff is the efficiency of the battery, and R is Revenue generated in $USD. This equation assumes that the entire storage capacity is discharged to generate revenue, which is not always possible due to design constraints, as well as depth of discharge limits for varying technologies. The equation is a representation of the simplistic logic behind potential TOU or peak energy pricing revenue generation. In scenarios where energy prices remain constant throughout the day, there is no potential to create additional revenue sources creating a net zero value for the revenue equation above.

Emergency Power Options

This section will discuss the specific solutions for resilient emergency power solutions that could challenge the Diesel generator model. Based on the research conducted, a set of 5 options are chosen for the case study:

Baseline – Diesel Generator (D)

This option will be used as the baseline understanding for costs, environmental impacts, and implementation.

Propane Generator (P)

This will serve to understand how a Propane generator might compare in terms of pricing and environmental impacts. Although BC Housing currently does not allow contractors to use Propane as a backup power source, this should provide some insight into what the potential benefits would be to switching to this fossil fuel.

Diesel Generator + Battery (DB)

This system will be optimized to handle nighttime power loads during an outage for an 8 hour period over the required 72 hours of backup. This means the battery will hold 24 hours of energy supplied in three bursts of 8 hours. For this reason, the generator will only run for 48 hours reducing the total impact during operation, but will not effectively change the diesel generator being implemented because all loads will stay the same during the daytime. The energy storage in the battery during non-outage conditions will be used to create as much revenue (see section on Revenue Generation) as possible to help payback the initial investment. Because this system is required for backup power, if peaking or time of use pricing structures are in place, the battery will discharge only 50% of its full capacity to generate daily revenue.

Diesel Generator + Battery + PV Solar (DBP)

This system is optimized for the battery to hold 8 hours of nighttime load, and would have enough solar capacity to recharge the battery during the other 16 hours of the day, based on average yearly solar irradiance. This reduces the running time of the generator from 72 hours down to 48 hours, reducing required on-site storage and environmental impact during operation. The battery system, when not in outage conditions would fully discharge during high value energy times, if peaking or time of use pricing structures are in place because the solar energy is assumed to be able to recharge the system during daylight. This should maximize the revenue potential from the energy produced by the solar panels.

Propane + Battery + PV Solar (PBP)

This would be optimized in the same way as the diesel option though allows us to understand the impact of implementing a Propane system versus diesel in terms of cost and environmental impact.

Analysis – Case Study (MURB)

In order to understand the potential options presented it is useful to review their potential in context of a real-world application. For this reason, a case study was performed to analyze a typical building to understand how these technologies might perform, in the hopes to narrow down on an optimal application of the proposed solutions.

Arbutus Housing Co-op located in Kitsilano British Columbia was chosen as the case study site for an analysis into sizing and including a low carbon, resilient focused emergency backup power system. The building is 6 storeys above gradient for residence, and 2 floors below gradient for parking and a single low height floor for maintenance and storage.

Figure 2: An aerial view of Arbutus Housing Co-op in Kitsilano, BC.

Arbutus Housing Co-op was chosen because it satisfied the three main constraints for a building that BC Housing is interested in analyzing, namely:

1. Mid-Rise Building.
2. Residents include Seniors and people with disabilities.
3. Built relatively recently
    a. LED lighting, and low energy demand envelope.

Backup Power Loads

To analyze the building backup power load requirements, multiple site visits were organized with on-site management to review electrical rooms, on-site suites, and pumping systems. Using these site visits and the guidelines provided by BC Housing for emergency backup power a list of loads was tabulated and is summarized in Table 5 below.

Table 5: Summary table of loads required to satisfy emergency power backup constraints for Arbutus Housing co-op considering the recommended emergency loads provided by BC Housing guidelines [37].

Load Name	Running Load (kW)	Startup Loads (kW)
Jockey Pump	2.7	13.8
Sump Pump	2.1	16.1
Room Lighting	5	5
Misc. Plug Loads*	2	2
Security + Fire Monitoring	2.04	2.04

Hallway Lighting*	1.8	1.8
Refrigerators*	0.72	0.72
Elevator	36.1	54
Safety Factor	20%	
Total	63	95.46

*Common Room – one per floor.

These generator loads will serve as the basis to perform our case study, allowing for the sizing of generators and battery requirements. It is worth noting that the elevator values are assumed numbers based on elevator speed, height, and load capacity which were all observed on-site at the Arbutus location.

What has been assumed in these values are the following conditions:

1. Due to improved building code in future, the resident comfort level should be maintained without the need for mechanical cooling/heating.
2. Mechanical fresh air is not required because of the operable windows in the building.
3. Cooking equipment is omitted as this is not part of the BC Housing Guidelines.
4. Hallway lighting includes egress lighting and will be left on at all times.
5. Values taken are labelled energy loads and have not been monitored for accuracy.

Sizing and Costs for Each System

Generator

Using the values from the energy analysis of the critical loads a generator can be sized and priced based on requirements for 63 kW running, and 95.46 kW during start-up. In order to run the generator at 63 kW a generator sized for 80 kW will be chosen, allowing the generator to run at 79% of full capacity, properly allowing the system to run efficiently while still allowing a high level of increased load. This generator is also chosen capable of handling start-up loads if used in a 2 step configuration that segregates loads and putting the elevator on a separate start-up curve from other equipment. This recommendation is in line with CAT "SpecSizer" software freely available online [38].

In order to calculate costs for these generators, values were gathered from various discussions with suppliers which were then used to verify the numbers using a "Generac Total Cost of Ownership calculator" [39]. Systems for 100 kW and 50 kW were analyzed and linear interpolation was used to find the approximate capital and maintenance costs for an 80 kW Generac system. Based on these values a total initial cost for Diesel and Natural Gas of $41,516 and $41,800 was calculated respectively. Annual maintenance costs were also calculated to be $2,455 and $987 for Diesel and Natural Gas respectively. It should be clearly noted that because Natural Gas generators are designed to run on Propane as well, these numbers are used assumed to be identical for either NG or Propane with an added charge of $3,000 for a 1000 Gallon tank and initial fuel costs [40].

The required running time of the building in power outage situations is set at 72 hours. For standalone systems, the size of on-site fuel storage will be 72 hours because this is the only source of power for the building. In the systems designed with batteries and/or PV, the running time of the generators is reduced to 48 hours because the PV system is sized as such to provide 8 hours of expected nighttime loads, reducing the running time needed by the generator by 24 hours. The running time of the generator does not affect initial costs, and were calculated to be about $400, therefore the main benefit of the reduced running time is in the reduction of space required for the storage tanks on-site.

Solar

Using Google Maps an approximated space on the roof of Arbutus Housing co-op to be used for solar PV was calculated. This area was chosen because there are no clear needs by the residents for this space and would be primarily covering a mechanical room and pebbled walkway. This area was calculated to be 312 m^2. Using a conversion efficiency of 18% and power production of 300W per 1m x 1.6m solar panel a system size and potential power production can be calculated. The average energy potential per m^2 is then found using NASA irradiance values for Kitsilano, BC of 4.03 $kWh/m^2/day$ if tilted at an optimal angle of 40 degrees[3] [41]. Considering all of these values, a 58.5 kW system is possible for this space assuming the entire area is used and there are no adverse shading affects.

To account for spacing considerations to avoid shading, the area considered will be reduced by 15% to 265 m^2 resulting in a system size of 49.7 kW. Using the conversion efficiency of 18% and 4.03 $kWh/m^2/day$, this translates to a total energy potential of 192.2 kWh/day from the solar array.

Actual Solar Potential Analysis

A major consideration has to be made for the time of year that this system is being sized for. Using the yearly average of 4.03 $kWh/m^2/day$ means that the actual energy produced in winter will be lower than expected and higher than expected during summer months. To illustrate the potential variation of energy production, the relative energy potential from the sun for Kitsilano, BC with the average value set to 4.03 $kWh/m^2/day$ as shown in Figure 3.

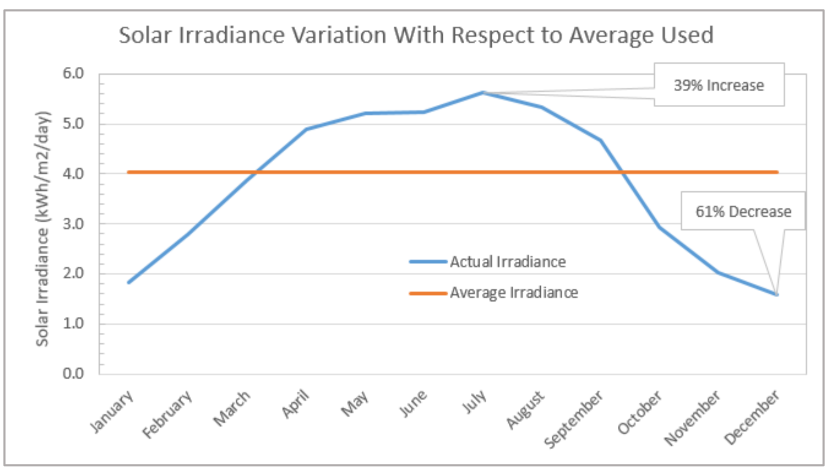

Figure 3: Irradiance for Kitsilano, BC. Orange depicts the average irradiance value that is being used for analysis of 4.03kWh/m²/day compared with the actual irradiance values in blue during various parts of the year.

The variation shown in Figure 2, shows that the potential energy can decrease by as much as 61% in December and increase as much as 39% in the summer. During an outage, the energy that is not able to be stored, when producing excess in the summer, can be used in the building to reduce generator load, or can be used for auxiliary equipment that would otherwise be excluded from outage loads such as cooling. During periods of reduced sun, generators will have to take on the gap in energy and thus shorten their overall running time without refuelling.

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[3] Data is using Nasa values based on optimal angle calculations, this approach is deemed valid for the depth of this analysis, but in real world situations this tilt angle would have to be designed specific to the building and cost requirements.

Costing for solar is assumed to be $1,830/kW as reported by NREL in 2019 for US solar market installations above 10 kW but below 100 kW. With a system size of 49.7 kW the overall cost is calculated to be $90,928. Maintenance costs are reported to be $18/kW/yr meaning a yearly maintenance cost of $894 per year.

Battery

The battery system has the potential to be sized in many variations, whether to cover peak loads on the generator, act as an intermediate between generator and building to ensure optimal generator efficiency and reduce running times, sizing the system to be optimized to earn money back on the investment depending on incentive numbers, among many others. This decision is of major importance to the function and workings of the overall system and should be taken with care when designed for an actual building situation. For this case study, a simplified but valuable use of the batteries is going to be used. The batteries will be sized to take on middle of the night loads for the mid-rise building, where loads are assumed to be lowest and the generator would be working at its least efficient. The design goal will be to allow the generator to turn off for a total of 24 hours during a 72-hour period (8 hours a night).

In order to keep the analysis simple, a single battery type is chosen based on its suitability discussed in previous sections. Lithium-ion is chosen in this case study because of the reliability of data on final system costing, and the maturity of the technology. This should of course be subject to current market trends and availability of other technology, namely flow battery and hydrogen technologies in years to come.

In order to calculate the energy required to supply these loads, a few assumptions were made:

1. Elevator will not be used during the allocated 8 hours during the night.
    a. This does not imply the elevator can't run, as this is necessary for egress, but simply that if the elevator is used at night, the 8 hours expected from the batteries will be less than expected.
2. Running loads are assumed. If required, start-up loads can initially be handled by the battery but in the event that all pumps and elevators need to be turned on for an emergency, then the generator will subsequently turn on to support this event.
3. Battery will not be discharged to below 20% DoD during a power outage scenario.

Assuming cycle counts for the lifetime of a Li-ion battery of 3000+, and cycling the battery once every day, it can reasonably be assumed that the battery will last for a total of 10 years before the need to replace the system. Upon replacement, it is also assumed that these batteries will be more efficient with longer lifetime, able to last for the remaining 15 years of the project life. Therefore, for this analysis, a replacement of batteries only once is required to fulfill the intended life of the entire project. This replacement cost only absorbs the cost of the battery pack itself and assumes the rest of the equipment will still be operable. With the average cost of Lithium-Ion batteries alone will be $62/kWh by 2030, the replacement cost will be $27,365 in present value dollars [42].

It should be noted that transformer losses, and auxiliary systems required to run the equipment such as HVAC are not being considered, and fall outside of the scope of this report but would definitely negatively affect the overall power output of the system.

With these constraints in mind, the total load (if all running loads are running at 100%) is 16.4 kW, adding a safety factor to this number of 20%, the expected design load would be 20 kW. For the design conditions, there are two situations which must be considered separately for sizing and costing.

Diesel + Battery

In this scenario a battery system is sized to deal with 3 evening loads for 8 hours each over the required 72-hour period by BC Housing. This means the battery needs to be sized for 24 hours of load, as there is no expected method by which you could reasonably expect to recharge the battery system.

Therefore, a load of 20 kW for 24 hours, sizing the battery to account for a Depth of Discharge of 85%, the size of the battery is 565 kWh and using the average cost for a Li-Ion system of $525/kWh, the initial cost is calculated to be $296,471. Maintenance costs are calculated using 8 $/kW/yr numbers, resulting in an annual maintenance cost of $160/yr [30].

Diesel + Battery + PV

For a system with a battery and a PV system, it can be assumed that the battery will be recharged by the solar energy produced during the day (average potential of 192 kWh based on a 51 kW system). Therefore, to size the system the battery will only have to operate for 8 hours and then can be recharged any number of times. Considering therefore an 8 hour run time and a 20kW load, the battery will be sized to deliver 160 kWh of continuous energy to the building.

As mentioned previously in this report the average cost of a Lithium-ion battery system is taken as $525/kWh. Accounting for a recommended 85% Depth of Discharge (DoD) the battery size is then calculated as 188 kWh resulting in a final cost of $98,824 for a Lithium-ion system delivering 160 kWh of energy. Maintenance costs are calculated using 8 $/kW/yr, resulting in an annual maintenance cost of $160/yr [30].

The battery costs are assumed to be the same for the Propane + Battery + PV system because battery size and demand is identical.

Environmental Impact

Two situations must be considered when calculating the environmental impact of these systems. The first situation is during a long power outage where the entire fuel storage is consumed, and the second being the total average yearly emissions of a backup power system factoring in maintenance and average outage expectations.

To calculate the environmental impact related to a generator use during a long outage, first the total consumption of fuel must be calculated during the running time of the generator. To do this, consumption values for both Propane and diesel were pulled from spec sheets for Generac model SD080 and QT080 respectively, where consumption in L/hr is provided. From here the running time of either 72 or 48 hours will provide the total amount of fuel consumed. Finally, liters can be converted to tons of CO_2 and kg of Particulate Matter (PM_{10}) by applying emission factors assuming these generators are best modelled by a stationary reciprocating engine [14, 43]. CO_2 emission factors for diesel are reported to be 252 kg CO_2/GWh and 210 kg/GWh for Propane [16]. PM_{10} emission factors for diesel are 1.3 kg/GWh and 0.01 kg/GWh for Propane [43]. PM_{10} and CO_2 final emission values are tabulated in Table 6 seen in brackets of the table.

To calculate the emissions related to maintenance of the generators on a yearly basis, the fuel consumption of the maintenance tasks must be known. The yearly maintenance fuel requirements of an 80kW diesel generator is 720 L/yr and 1250 L/yr for Propane. The same emissions factors are used for bother maintenance values and outage condition use. The final yearly emissions is provided in Table 6.

To calculate emissions created by yearly outages, an average outage time in BC is used to calculate the expected fuel consumption per year. The average power outage time in 2018 is 5.56 hours [44]. For systems that have a battery system installed, the emissions related to yearly outages will be set to zero, this is because these outages will likely last much less than 5.56 hours, and the batteries are sized for up to 8 hours of storage time.

To calculate emission reductions, the total energy created for all scenarios except for those with PV installed will be zero. This is because these systems are not generating cleaner energy, and are re-using the energy from the grid. Further to this point for the scenarios with batteries, the emissions intensity of the grid is assumed constant and held to the average provided by BC Hydro, creating no reductions in emissions for power sold back to the grid at varying times of day.

The systems with PV, the energy produced by the solar panels will offset the CO_2 created by the BC power grid, which in 2018 is 11 tCO_2/GWh. Thus the energy produced by the solar panels is then converted to CO_2 emissions that will be counted toward the system on a yearly basis. For a 49.7 kW solar array, the average power produced will be approximately 192kWh/day meaning a total of 59.1 MWh of production yearly. This would translate to a yearly emissions reduction of 650 $kgCO_2$ for the system. PM_{10} is assumed to not be saved by using solar because of the cleanliness of the grid, though would have been a consideration if coal power was still used in the energy grid in BC. For the Diesel + Battery scenario, there will be no offset CO_2 because this system is unable to produce energy and can only use existing energy from BC Hydro to charge and discharge.

To get a better grasp of the actual meaning of these calculated emissions, their percentage of the yearly emissions of an average BC resident is taken. This practice is known as normalizing emissions. The percentages are based on a BC resident per capita emissions of 13.7 tCO_2/yr and 10.69 $kgPM_{10}$/yr [45, 46].

*Table 6: Summarizing the GHG and Particulate Matter impacts yearly, including both maintenance and 5.56hrs of outages for an 80kW Propane and diesel generator. Values shown in **bracket** are the emissions related to running the generator during a long power outage for the specified running time.*

System Type	Diesel	Propane	Diesel + Battery*	Diesel + Battery + PV*	Propane + Battery + PV*
tCO_2	2.3 (3.8)	2.2 (3.7)	2.0 (2.6)	1.2 (2.6)	1.1 (2.5)
$kgPM_{10}$	11.9 (20.4)	1.0 (1.8)	10.3 (13.6)	10.3 (13.6)	0.9 (1.2)
CO_2 Normalized[1]	0.15%	0.15%	0.13%	0.09%	0.08%
PM_{10} Normalized[1]	1.04%	0.09%	0.91%	0.91%	0.08%

1- Represents the percentage of emissions relative to the total emissions released by a BC resident in a calendar year. Assumes an occupancy load of 106 residents.

**- Values shown in bracket represent a running time of 48 hours due to reduced generator running requirements created by PV and Battery systems.*

When comparing the CO_2 emissions of the standalone diesel and propane generators, the CO_2 emissions are almost identical, with a slight edge to propane of 100 kg less CO_2 annually, and 100 kg less CO_2 per 72 hour power outage. This is initially counter intuitive because of the low carbon intensity of burning propane compared with diesel, but the operation of propane generators requires more fuel, making the carbon intensity of the fuel burning almost negligible.

The major benefit for propane compared to diesel is the reduction in PM_{10} which is a major contributor to poor air quality, smog, and other adverse health effects. In all situations, because maintenance is the same no matter the auxiliary systems, propane reduces PM_{10} by 10.9 kg yearly when compared with Diesel, which in normalized terms means a reduction from 1.04% down to just 0.09% for Propane.

There is a slight reduction in CO_2 and PM_{10} in the diesel + battery scenarios compared to the baseline, because the battery provides energy during the expected 5.56hrs of yearly outages. Comparing the long power outage scenario, to the baseline of diesel, the CO_2 and PM_{10} emissions are reduced by a third, due to the reduced running time of the generator.

Diesel + Battery + PV system shows a reduction of 1.1 tCO_2 per year, a reduction of 47%. This is due to the saved energy from the grid along with shortened running time of the systems during the year. The avoided PM_{10} emissions is assumed to be negligible because the energy saved from the BC Hydro grid is assumed to have low particulate matter emissions. It should be noted that in other provinces or countries where energy is more GHG intensive, these numbers would increase linearly with the GHG intensity of the province or territory being studied. As an example; Alberta has a GHG intensity of has 790 tCO_2/GWh (compared to B.C. with just 11 tCO_2/GWh) [47] and for an identical system installed there instead of B.C., it would have avoid 46 tons of CO_2 per year instead of just 1.1 tCO_2.

The Propane + Battery + PV system has reduced CO_2 emissions of 1.2 tCO_2 per year, a reduction of 52%, and a reduction in PM_{10} emissions of 11 kg, a reduction of 92%.

For both systems, CO_2 and PM_{10} emissions show a reduction during long power outage situations because of the reduced running time to 48 hours resulting in a reduction of a third.

Emissions – Maintenance vs Yearly Outages

To analyze the ratio of emissions related to maintenance versus yearly outages of 5.56 hours, Figure 4 was created. This shows that only 15% of the yearly emissions related to generators are from actual outages, with the remainder caused by maintenance activities.

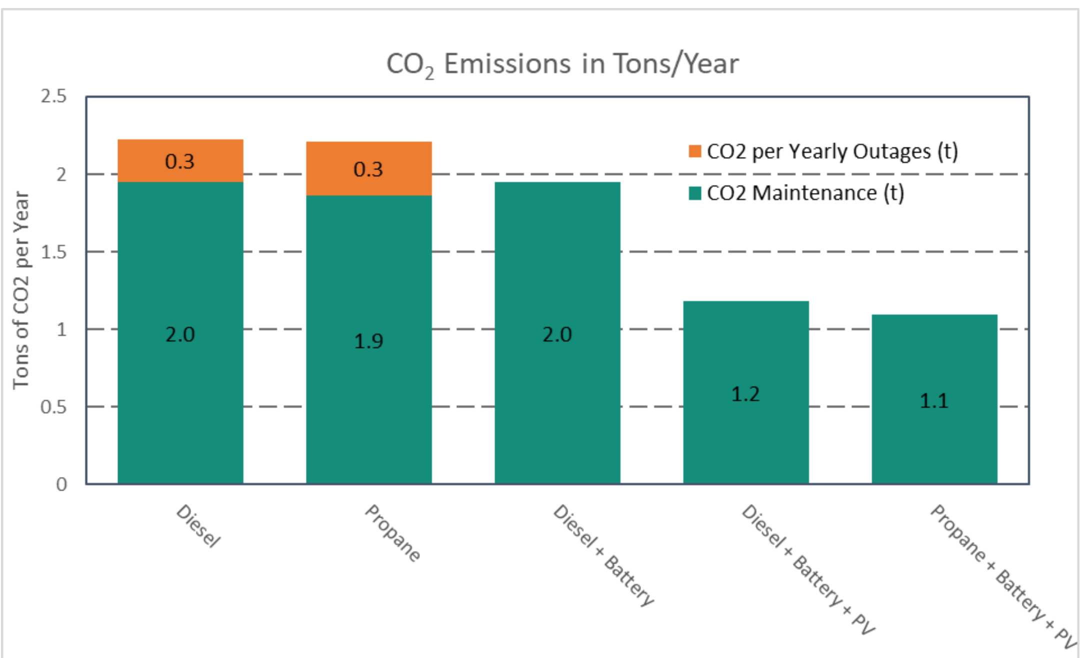

Figure 4: A comparison of CO2 emissions related to maintenance vs yearly outages in BC for all scenarios.

A major takeaway from this analysis is the amount of emissions directly related to maintenance for the generators on a yearly basis. The environmental impact of backup power should not just be thought of as a momentary impact during an outage, but as a continuous burning of fossil fuel to maintain proper running of these systems. This underscores the need to move away from dirtier fuels, and to more renewable sources as technologies mature and become more viable.

Resilience

Resilience scores were judged based on the 5 criteria of urban energy resilience explored in Table 1. All options were rated on a compliant or not compliant rating. The compliance values are summarized in a score out of 5, highlighting the relative scores of each system to one another. These scores are designed to compare the isolated backup power systems on their own and is not taken with the perspective of the building systems.

A stand-alone diesel system scores 1 out of 5 because the diesel generator doesn't actively help to reduce pre-disturbance vulnerabilities (adaptability), has a single option to be used simultaneously not multiple as required (diversity), there is a single diesel resource to pull no overlapping as required (redundancy), no tools for planners to make adjustments to (resourcefulness), and finally it does however provide long term power to disruptions in the energy grid (stability).

The stand-alone Propane system is identical to a diesel system, except that it is given an extra point because of the overlapping fuel resources available by using either Propane or Natural Gas (redundancy). For this the score for stand-alone Propane is 2 out of 5.

Diesel combined with Battery Storage scores 3 out of 5. The three points come from the stability criteria by providing long term power which does not change much from the original system, redundancy because the system now has a second method to supply power, and diversity because the system is able to simultaneously use battery and generator power either distinct or separately. With only one source of electricity coming from diesel during an outage, the system does not provide any additional tools for electricity production to allow for an adapting conditions, and it does not provide any reduction in pre-disturbance vulnerabilities required to get credit for adaptability.

Diesel combined with storage and PV scores a perfect, 5 out of 5, satisfying all criteria. The solar array provides a reduction in pre-disturbance vulnerabilities and enhances the system's ability to adapt by adding daily local power generation, reducing dependency on the energy grid and mitigating some of this vulnerability. The energy supply is diverse, allowing multiple power systems to work simultaneously. Solar, Battery, and Diesel are all overlapping resources to pull from and is why it gets full points for this criteria. By supplying a renewable power source to the system it gives planners a tool to adapt, though the incorporation of a power management system here would to make this added energy source more valuable. Finally, as the rest of the generators, this system provides long term stability more likely outperforming other systems for length of time and returning to operation quickly (stability) and scores a point in this category as well.

Table 7: Resilience score for each emergency backup power system based on the 6 resilience criterion explained in Table 1 of this report.

		Resiliency Metrics					
		Adaptability	Diversity	Redundancy	Resourcefulness	Stability	Score
Backup System	Diesel	☐	☐	☐	☐	☑	1/5
	Propane	☐	☐	☑	☐	☑	2/5
	Diesel + Storage	☐	☑	☑	☐	☑	3/5
	Diesel + Storage + PV	☑	☑	☑	☑	☑	5/5
	Propane + Storage + PV	☑	☑	☑	☑	☑	5/5

Net Present Value Analysis and Comparison

In order to summarize findings and understand the costs of each system the Net Present Value (NPV) of each project was calculated based on the maintenance and initial cost, and in the case of solar and battery systems the value of the energy that could be sold back to the grid. The life of project is assumed to be 25 years and with a rate of 3% annuity. 25 years is the expected life span of a generator and is typically the length of time guaranteed for solar panels. 3% was chosen because BC Housing tends to get good interests rates due to their size and was placed just above inflation and simply accounts for the time value of money.

Because the battery life for Lithium-ion is about 3000 cycles, and assuming a daily cycling of the batteries an approximate 10-year battery replacement cost is used. Once replaced, Li-ion would be expected to last the remaining 15 years of the project based on technology maturing over that initial 10-year period. A future value of lithium-ion is also used to calculate the NPV for this replacement of 62 $/kWh.

In order to understand the potential revenue streams created by implementing these small scale power generation and battery storage systems three various energy pricing scenarios were analyzed. NPV will summarize the cost of the systems plus the potential revenue they can produce over their lifetime of 25 years. The three scenarios considered are:

Scenario 1 - Current BC pricing of 0.1 $/kWh

Scenario 2 - Time of Use pricing based on the model in Ontario

a. Low = 0.064 $/kWh
b. Mid = 0.094 $/kWh
c. Peak = 0.1364 $/kWh

Scenario 3 - Energy peaking incentive of twice the cost of current BC power

a. Regular Pricing = 0.1 $/kWh
b. Incentive Price = 0.2 $/kWh

Scenario 1 is relatively straightforward and in the cases of generators and battery installations, there is no potential to make any money as the cost of electricity is always the same, and if discharged will actually increase cost because the value and degradation of the battery will be sped up. With PV systems there is daily power production that can be sold back to the grid if the batteries are full. In this scenario all Solar energy produced in a day is sold back to the grid for 0.1 $/kWh. In this scenario tier 2 pricing is not considered, as this might provide overly optimistic payback times, by taking a standard price of 0.1 $/kWh this analysis takes a conservative view on the application of these systems.

Scenario 2 does not incur any value added benefit for a stand-alone generator and is the reason there are no changes to the values for NPV. For Diesel + Battery system, the batteries can be used to store cheap power (0.064$/kWh) and sell it back to the grid during peak demands (0.1364$/kWh). There are limits however, the battery cannot be completely depleted in the event there is an emergency situation. Therefore, the batteries are never able to drop below 50% charge, meaning only 50% of the energy storage potential of the batteries is sold back to the grid. For Diesel + Battery + PV systems, 100% of the battery capacity can be sold back to the grid at peak values (0.1364$/kWh) with remaining solar capacity sold at a mid-peak value (0.094$/kWh) once the battery is fully charged. Full utilization of the battery can be assumed for PV systems because it is assumed the batteries have the potential to be recharged in the event of an emergency.

Scenario 3 introduces a more aggressive time of use system that uses only a two tiered pricing structure where utilities charge more for peak times (when it is most expensive for them to produce) at twice the cost of off-peak electricity. This means, that for energy sold to the grid during regular hours the value is set at 0.1$/kWh and if sold back to the grid during peak times, the value is doubled to 0.2$/kWh. This system is reflective of a common pricing structure known as Critical Peak Rebate, where a baseline energy use is set for a building, and if during peak hours the building reduces the kWh relative to this baseline, the savings are rebated at a higher value than regular pricing. Though because of the difficulty in modelling this kind of system, a simplified two tier TOU structure is used. For the stand alone systems, once again, this presents no long term revenue stream and the NPV remains the same. For the Diesel + Battery system, energy is stored in the batteries at low demand times (0.1$/kWh) and sold to the grid at peak times (0.2$/kWh). As in the last scenario, only 50% of the capacity of the energy storage can ever be used in order to ensure there is enough battery to sustain at least half of the intended use time. For Diesel + Battery + PV Systems (including Propane), energy is produced and stored during the day with any excess solar production being sold to the grid for regular pricing (0.1$/kWh) and 100% of the battery capacity is then sold to the grid at the peak price (0.2$/kWh).

A final summary showing systems costs, NPV, resilience and GHG impact are shown in **Error! Reference source not found.** below.

Table 8: Summary table for various emergency backup power solutions. Detailing costs, NPV for varying energy pricing structures, resilience scores and yearly GHG impact.

	Diesel Generator	Propane Generator[5]	Diesel + Battery	Diesel + Battery + PV	Propane + Battery + PV
Conditions	72h @ 80kW	72h @ 80kW	Battery Sized for 24h @20kW Battery Replacement @ 10yr Gen 48h @80kW	Battery Sized for 8h @20kW Battery Replacement @ 10yr Solar size for 49.7kW (265sqm) Gen 48h @80kW	Battery Sized for 8h @20kW Battery Replacement @ 10yr Solar size for 49.7kW (265sqm) Gen 48h @80kW
Gen - Capital Cost	$42,000	$47,000	$42,000	$42,000	$47,000
Gen - Maintenance	$2,000	$1,000	$2,000	$2,000	$1,000
Battery - Capital Cost			$296,000	$99,000	$99,000
Battery - Maintenance			$200	$200	$200
200Battery - Replacement Cost (in Present $)			$26,000	$9,000	$9,000
Solar - Capital Cost				$91,000	$91,000
Solar - Maintenance				$1,000	$1,000
NPV - Existing*	$(84,000)	$(64,000)	$(410,000)	$(179,000)	$(159,000)
NPV - Time of Use[1]	$(84,000)	$(64,000)	$(299,000)	$(164,000)	$(144,000)
NPV - Peaking - 0.2$/kWh[2]	$(84,000)	$(64,000)	$(257,000)	$(108,000)	$(88,000)
Resiliency Performance[3]	1/5	2/5	3/5	5/5	5/5
GHG Impact (t CO_2e/yr)[4]	2.3	2.2	2.0	1.2	1.1

* - Inflation rate of 3% and 25-year project life.

[1] - Using Ontario Values for Time of Use (0.064$/kWh, 0.094$/kWh and 0.1364 $/kWh).

[2] - Assuming Current BC Rates of 0.1$/kWh with 0.2$/kWh for power provided during peak times.

[3] - Rating based on the 6 criteria of urban energy resilience.

[4] - Peak power is assumed to be the same GHG content as non-peak times. These numbers do NOT include outage scenario GHG and represent only impact related to yearly maintenance.

[5] - Propane and Natural Gas are assumed to be the same pricing as indicated by various vendors.

The NPV of Diesel Standalone systems are $84,000 and $64,000 for Propane systems. These values will act as the baseline to compare the proposed systems against in understand the potential value of the low carbon options introduced.

Scenario 1 using existing pricing infrastructure, the NPV of Diesel + Battery solution is over $400,000, because there is no method of making any revenue therefore the full capital cost and maintenance costs must be realized. For systems with PV included, the Diesel option has an NPV of $179,000, over twice as expensive as the baseline, and Propane NPV of $154,000 which amounts to 1.8 times as expensive. This indicates that without any modifications to pricing structures, the cost of PV and Battery systems will not provide enough value to cover the costs of implementation.

Scenario 2 with a scheme like Ontario's time of use, the NPV of systems with Diesel + Battery combination improves from a cost of $410,00 to $299,000 an improvement of $111,000, a difference of 22% due to the added revenue stream generated by tiered pricing. Diesel + Battery + PV system improves in NPV from $179,000 to $164,000 an increase of $15,000 a difference of 8% in NPV from the existing pricing structure. Propane + Battery + PV sees the same improvement of $15,000 because revenue potential is identical to the diesel version, which accounts for a difference of 10%. Although both diesel and Propane options improve in NPV, they are still 95% and 65%, respectively, more expensive than the baseline.

Finally, looking to scenario 3 using a peaking program the Battery + Generator system sees a modest NPV improvement of $42,000 a reduction of 14%, leaving the final cost 200% more expensive than the baseline Diesel scenario. For Diesel + Battery + PV the improvements are significant, reducing the NPV by $56,000 to $108,000, a reduction of 34%, making it 28% more expensive than the baseline Diesel option. Propane + Battery + PV sees a reduction in NPV of $56,000 as well, which is a further reduction of 41% from Scenario 2, bringing the overall cost of the system to $84,000, just 5% more expensive than the baseline Diesel option.

A visual summary of the NPV of the systems relative to a baseline of Diesel is shown in Figure 5 below

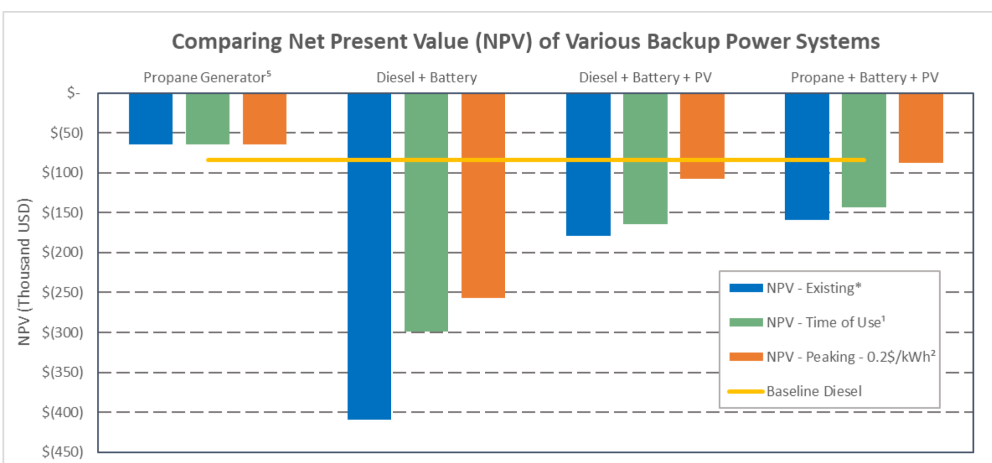

Figure 5: Visual comparison of NPV Values across varying pricing structures and system types.

Sensitivity Analysis

A sensitivity analysis was performed in order to grasp the effect of changes in market prices but more importantly understand which factors contribute the most to varying NPV values in the reported numbers. Taking the standard case of Diesel + Battery + PV and varying peaking value of energy, irradiance of the region, battery cost, solar cost, and discount rate by 20% up and down from the standard inputs reported. The results are presented in Figure 6 below.

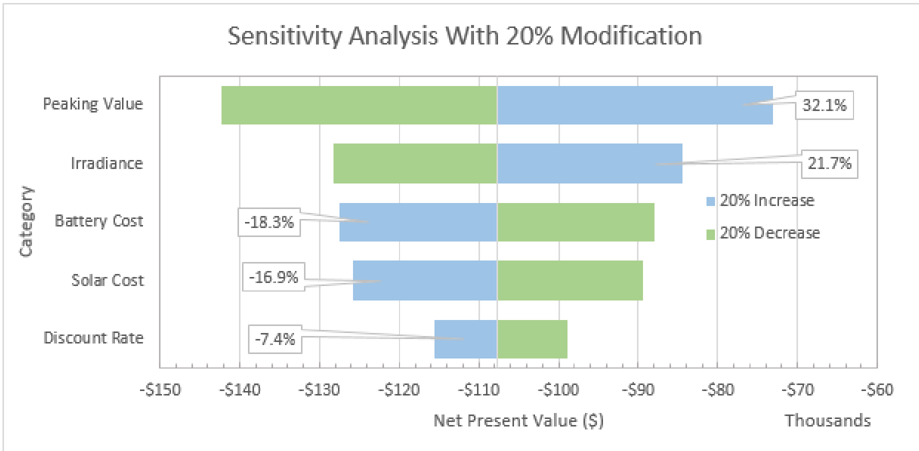

Figure 6: Tornado chart showing the relative impact of modifying various inputs to the reported NPV values. Values are shown in NPV in thousands of dollars.

The tornado plot demonstrates that the peaking value of energy is the main driver to reduce the NPV of a hybrid renewable energy system, improving NPV of the project by more than 30% with an increase in peak price of energy of 20%. Second major affect is irradiance of the region the solar panels are installed in, and improves NPV by almost 22% by increasing irradiance potential by 20%. Increasing battery costs and solar costs are 3rd and 4th most sensitive, presumably because the costs are a one-time investment, whereas solar irradiance and peaking value affect daily power transactions over a 25-year period and will have larger impacts overall. Finally, the Discount rate was analyzed and shown to reduce the NPV of the system by 7.4% for an increase of 20%. Discount rate is an assumed number and depending on the business, should be a key factor in making these decisions.

Conclusions

Threats to energy grid stability is a growing concern for developed countries as climate change induced outages, cyber threats, and volatile markets worldwide become more common place. With increased energy grid disturbances expected for British Columbia, the need for emergency backup power is essential in reducing the impacts felt by the many vulnerable populations being housed by BC Housing. Though a diversion from fossil fuel systems to lower carbon emissions, and increase resilience is necessary for the long term stability of our energy infrastructure and climate. To understand how this might be accomplished, various backup power technologies were reviewed and analyzed based on the potential impacts to the environment, resilience and their various development stages.

Various fossil fuel based generators were compared against one another, setting Diesel as the baseline. Propane generators have the benefit of reduced overall PM_{10}, and improved resilience as they can switch between Natural Gas or Propane, but are costly for generators above 150kW and require more storage space. Diesel is shown to be the highest polluting generator for particulate matter and when analyzed is almost identical in CO_2 emissions to that of a Propane. Dual Fuel systems have potential to be implemented alongside other technologies and can reduce environmental impacts and increase resilience by lengthening running time of a generator, but are still in development and access to Natural Gas may not be viable in major disaster situations.

Renewable energy options were discussed, and found that for urban based power production, solar energy is the preferred method. Solar provides a low maintenance, no noise solution that can be placed out of the view of residents, along with a 25-year warranty, provides an ideal solution to produce power. Though, with residential buildings tight on space, and the potentially large area required to produce a significant portion of the building energy this might be a major constraint for implementation.

Four energy storage technologies were analyzed to understand their current state of development, and their suitability for building scale energy supply. Lithium-ion, and Flow batteries are considered the most relevant technologies for this application, with a potential low-cost solution for pilot testing with Lead-Acid. Lithium-ion is more developed with established supply chains and suppliers that can provide support throughout the 25-year life span, where flow batteries are still developing and have more unknowns associated to implementation. Costs of Lithium-ion as of writing this report are currently lower than flow batteries, but are expected to drop even further as electric vehicles begin to ramp up in supply, making replacements of this technology in the future more economic. Flow batteries should be considered a good option if products can be proven for longevity and prices can compete with Lithium-ion in the near future.

Performing a case study on Arbutus Housing Co-op in Kitsilano British Columbia, 5 variations of backup power options are sized and compared against one another to understand their lifetime costs in Net Present Value, environmental impacts, and resiliency. A Diesel generator was set as the baseline for the analysis, to be compared against a Propane generator; Diesel + Battery; Diesel + Battery + PV; and Propane + Battery + PV system. Two alternate pricing structures were then used to understand how the existing price structure in BC compares to the structure in Ontario which deploys a Time of Use pricing, and a peaking incentive where power at peak demand is worth twice as much as regular electricity.

After the analysis, based on a 25-year life of project the standalone Propane generator system has a 24% lower NPV compared to A baseline diesel generator system, due to the lower maintenance costs.

The Diesel + Battery never became economically viable, even under Time of Use and Peaking incentive programs, and would not be recommended unless a large incentive to subsidize the initial cost of storage is implemented.

Under existing energy pricing structures, neither the Diesel + Battery + PV or Propane + Battery + PV systems were viable as an investment compared to diesel generation alone, costing 110% and 82% more respectively in NPV. Using Time of Use pricing structure, the NPV improved but still remain 95% and 71% more expensive.

When analyzing the peaking incentive pricing structure, the NPV improved dramatically. The Diesel + Battery + PV system came to within 26% of the cost of baseline Diesel. The Propane + Battery + PV system NPV was shown to be just 5% more expensive than the baseline Diesel system over the 25-year lifetime.

The environmental impact of all systems was calculated, and found that a Propane generator releases 91% less PM_{10} than a diesel generator but does not significantly impact the CO_2 emissions. For systems incorporating a PV system into the backup power, the emissions reduced was 800kgCO_2/year and no reductions in PM_{10} for regular yearly maintenance. During outage conditions, because the required running time of the generator was cut in a third from 72 hours to 48 hours, the associated CO_2 and PM_{10} emissions were also cut by a third. During analysis, it was also found that only 15% of emissions are related to the yearly outages considering a 5.56 hour outage rate for BC, the remaining 85% are attributed directly to maintenance activities.

Standalone Diesel generators were scored a 1/5 for resilience due to the dependence on a single fuel supply, with little redundancy and alternative options should a failure occur. Resilience for Propane generators are improved over Diesel generators due to the redundant fuel supply, where Natural gas can be used in place of Propane to run indefinitely if supply is not cut-off. Diesel + Battery systems would have an improved diversity factor, allowing the building to pull from a diverse energy source in case of any kind of generator failure, resulting in a 3/5 score in resilience. Finally, the Diesel + Battery + PV and Propane + Battery + PV get a of 5/5 for resilience because of their increased adaptability, and resourcefulness.

Under current BC housing building guidelines, it is required that contractors provide a Diesel generator to supply emergency backup power. From this report, it would be wise to re-evaluate this guideline, for buildings requiring lower than 150kW, to have the potential to implement a Propane generator system to improve resilience and particulate matter emissions. This would then be a discretionary choice based on space and complexity of the requirements of the building.

Under existing pricing structures the cost to implement renewable power generation and storage technologies is not a viable option for BC Housing to implement from an economic standpoint. The addition of solar and battery storage improves all 5 criteria for resilience outlined in this report. It is recommended that in order to compare all options equitably, a value to the resilience of a system should be made in terms of economics, allowing for a more realistic comparison should an energy pricing structure in BC not be implemented.

Finally, energy pricing structures can significantly impact the NPV of a generator, battery, and PV system, and in the case of Propane, can even make it cost competitive. It is recommended that energy pricing structure is changed or incentive programs be implemented to offset the large capital cost of these systems in order to make them economically attractive to business across British Columbia.

Future Considerations/Work

Heating and Cooling Options for Long Term Outages

Heating

BC Housing currently allows various types of heating and cooling solutions for their buildings, based on their orientation and location. Though there is data to support that under current building code, livability can sustain beyond 72 hours without heating, it is imperative that this assumption is analyzed and designed for [48]. To minimize the potential demand for heating, solutions that would target local space heating for more vulnerable suites such as North facing rooms, the use of fossil fuels to provide domestic hot water, or geothermal heat pumps could be used to increase the longevity of occupants in the building. These livability requirements are based on a climate zone 6 rating, which is defined to be "cold". As this report is meant to tackle future projects, the building is assumed to not require heating loads for 72 hours of occupancy, assuming a strict adherence to local building codes. Adjustments to this assumption need to be done on a case by case basis where building codes are different or location is considered colder, such as climate zone 7 and 8 ("Colder" and "Subarctic"). An understanding of how to effectively heat particularly vulnerable suites could be a good expansion of the heating requirement loads explored in this report to provide further resilience.

Cooling

During typical summer weather, it is shown that a south facing suite can remain without cooling for up to 61h and remain within livable conditions, using standard envelope designs. Because BC Housing specifies operable windows that maximize ventilation rates, this livability is likely increased further [48, 10]. Though on the contrary, during extreme heat waves, this livability will likely decrease and is therefore advised that if passive house criteria utilizing natural ventilation, and operable shading are not possible, then localized (suite based) air conditioning or forced air might be necessary. For the purposes of this report, because BC Housing specifies ventilation and typically employs passive designs in their buildings, no air conditioning is assumed to be needed. It should also be noted that with general trends of increased wildfire across the west coast of North America, the need for forced are might become more urgent to prevent residents from breathing in polluted air while operating windows for ventilation [49].

Due to the increased irradiance in the summer, there is a high probability that there will be energy produced that a battery storage system would not be able to store. Therefore, an investigation into how this excess energy could be used most effectively during an outage should be done. The most logical use for this excess energy is to use it for localized cooling systems for residents who are south facing, bringing down peak temperatures in the building.

Distributed Energy Models

As buildings become more compact and closely pact together, more often the benefits of solar and energy storage are shut down immediately due to constraints on square footage available. Though with an increase in building density, comes other more potentially beneficial impacts. If building complexes are being designed within reasonable distances from each other, the potential to connect these buildings and distribute some of the power generation and storage across buildings could make these systems more feasible in application. By distributing the systems, buildings can take advantage of various locational benefits of some buildings and more generous space constraints on others. Consider an example where buildings facing south provide the solar power with other local buildings providing space for battery storage. Sharing the benefits could prove to be a more practical application to ensure these systems are optimized for power outages and economic viability. By increasing the reach of these systems it also then becomes possible to create more resilient shelters in local neighborhoods, providing planners and designers more flexibility in energy management to maximize the time residents can stay in building before relocating to shelters further away.

Electric Vehicles

With Electric Vehicles (EV) taking on a larger role in the transportation industry in North America, there may be potential to use this growing energy capacity in more creative ways. As is already being done by Nissan, EVs are able to be used bi-directionally, meaning energy can be stored in the vehicle, but also used in what ever circuit the vehicle is plugged into. This is known as Vehicle to Grid (V2G) or in the case of MURBs Vehicle to Buildings (V2B). With this innovation already here, and some infrastructure already in place, the potential to use EVs as a battery storage during power outages is a real possibility.

As was analyzed in the Arbutus Housing Co-Op Case Study, the building required only 160kWh of energy to run a nighttime load for 8 hours. This means that using a fully charged Leaf, which has a capacity of 30kWh, would provide power to the building for 1.5 hours. Going even further with luxury vehicles, such as Tesla, boasting battery sizes of 100 kWh could potentially power the building for 5 hours on a full charge.

Understanding the potential in the context of back-up power could be of tremendous value for long term resiliency goals. Dispatching vehicles with charged batteries may not provide a final solution but could be essential in ensuring certain populations are able to stay in their buildings temporarily until the grid power is turned back on.

Pilot Test

As is mentioned in the work, a lot of rough assumptions are made to calculate total building power demand and for this report it is sufficient. Though, to move forward from this work, a comprehensive analysis should be done on a pilot building to understand the true values of energy demand. Understanding these specific demands will allow for more accurate storage system sizing and design, more accurate price structure, and provide further insights into how these systems can be optimized. Other information such as energy required for meal preparation, and potential heating loads might be necessary to understand full capabilities of these energy backup systems.

Incentives

Seen in the sensitivity analysis, the value of incentives to reduce peak demand is the major factor in making renewable energy systems viable as a backup power option. It's recommended that a deeper analysis is done on what kind of tax breaks, tariffs, rebates, or other pricing structures that could improve the NPV of a full renewable energy and storage systems. Noted is that the Carbon Tax is not taken into consideration for this project as it is small enough to be negligible, but if considered on a larger implementation scale the GHG reductions could be significant in potentially changing some of the economics company wide.

Embodied Emissions

Another major topic that is not considered in this report, is the question of embodied emissions relating to fuel, solar panels and batteries. The emissions created in producing these products should be verified so as to understand how this might affect the GHG and PM_{10} results noted in this report. Researching and providing information on the "Energy Payback" and/or "GHG payback" for solar panels, would be valuable information to provide a broader understanding of the choice to use solar panels. The same can be said for batteries.

Further analysis into the embodied emissions of the fuels being proposed, which includes impacts related to the entire life cycle, most notable the potential effect of fugitive emissions, could provide insight into how different fuels might incur larger environmental impacts than are accounted for in this report.

Combined Heat and Power (CHP)

As it stands, the BC housing guidelines do not include heating in the requirements for backup power. Though in urban settings where temperatures can get much colder, this may be a concern for designers and would be part of the load calculations. For instances such as this, Combined Heat and Power systems are becoming more available using Natural Gas. These systems are able to power a building and produce large amounts of heat to supply to the building as well. In jurisdictions where the energy grid may use more coal, this may actually reduce CO_2 emissions by removing transmission losses and using a cleaner burning Natural Gas fuel. Currently the initial costs of these systems are prohibitive in a backup power only situation, costing upwards of $500k for an 80kW system, and would require almost constant operation to make this technology economically viable. Because of the added resilience of including these systems, there may be situations where this kind of technology could provide increased value and economic benefit. Locations that could be considered are remote communities that have high electricity cost, that might be running on diesel.

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Appendix

Environmental analysis – Full Table

Table 9: Full environmental analysis of each option.

	Diesel	Propane	Diesel + Battery	Diesel + Battery + PV	Propane + Battery + PV
Fual Consumption (l/hr)	19.7	35.0	19.7	19.7	35
Outages yearly (hr)	5.56	5.56	5.56	5.56	5.56
Hours	72	72	48	48	48
Consumption for Maint (mmBTU/yr)	26.4	30.2	26.4	26.4	30.2
CO2 Maintenance (t)	2.0	1.9	2.0	1.2	1.1
CO2 per Yearly Outages (t)	0.3	0.3	0.0	0.0	0.0
CO2 Long Outage (t)	3.5	3.7	2.4	2.4	2.5
PM10 Maintenance (kg)	10.3	0.9	10.3	10.3	0.9
PM10 per Yearly Outages (kg)	1.4	0.1	0.0	0.0	0.0
PM10 Long Outage (kg)	18.7	1.8	12.5	12.5	1.2
CO2 Levelized	0.15%	0.15%	0.13%	0.08%	0.08%
PM10 Levelized	1.04%	0.09%	0.91%	0.91%	0.08%
CO2 Levelized Long Outage	1.29%	0.26%	0.86%	0.86%	0.17%
PM10 Levelized Long Outage	1.65%	0.16%	1.10%	1.10%	0.10%

Comparison Table

Original Comparison table without rounding.

	Diesel Generator	Propane Generator[5]	Diesel + Battery	Diesel + Battery + PV	Propane + Battery + PV
Conditions	72h @ 80kW	72h @ 80kW	Battery Sized for 24h @20kW Battery Replacement @ 10yr Gen 48h @80kW	Battery Sized for 8h @20kW Battery Replacement @ 10yr Solar size for 49.7kW (265sqm) Gen 48h @80kW	Battery Sized for 8h @20kW Battery Replacement @ 10yr Solar size for 49.7kW (265sqm) Gen 48h @80kW
Gen - Capital Cost	$ 41,516	$ 47,015	$ 41,516	$ 41,516	$ 47,015
Gen - Maintenance	$ 2,455	$ 988	$ 2,455	$ 2,455	$ 988
Battery - Capital Cost	-	-	$ 296,471	$ 98,824	$ 98,824
Battery - Maintenance	-	-	$ 160	$ 160	$ 160
Battery - Replacement Cost (in Present $)			$ 26,052	$ 8,684	$ 8,684
Solar - Capital Cost	-	-	-	$ 90,928	$ 90,928
Solar - Maintenance	-	-	-	$ 894	$ 894
NPV - Existing*	$ (84,274)	$ (64,215)	$ (409,582)	$ (178,891)	$ (158,832)
NPV - Time of Use[1]	-	$ (64,215)	$ (299,144)	$ (163,910)	$ (143,851)
NPV - Peaking - 0.2$/kWh[2]	-	$ (64,215)	$ (257,043)	$ (107,706)	$ (87,647)
Resiliency Performance[3]	1/5	2/5	3/5	5/5	5/5
GHG Impact (t CO2e/yr)	2.0	1.9	2.0	1.2	1.1

Sensitivity Analysis

Values for sensitivity analysis considering only a Diesel + Battery + PV system.

Sensitivity Analysis

	Discount Rate	Solar Cost	Battery Cost	Irradiance	Peaking Value
80%	($98,956.00)	($89,520.60)	($87,941.51)	($128,191.60)	($142,281.77)
Standard	($107,725.93)	($107,725.93)	($107,725.93)	($107,725.93)	($107,725.93)
120%	($115,657.60)	($125,891.85)	($127,470.93)	($84,362.01)	($73,130.67)