DESIGN OF ENERGY STORAGE UNIT FOR THE SPARTAN SUPERWAY TRANSPORTATION SYSTEM

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The Undersigned Committee Approves

Design of Energy Storage Unit for The Spartan Superway Transportation System

of

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APPROVED FOR THE DEPARTMENT OF MECHANICAL ENGINEERING

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ABSTRACT

The Spartan Superway program offers an opportunity to mitigate and eliminate effects of typical transportation methods on the environment and public. The proposed north-south campus route plans to connect the north and south campuses of San José State University. The 14.9 km route will consist of 14 stations. To collect energy to power the system, a canopy of solar photovoltaic (PV) panels above the guideways has been proposed by designers. The energy generated is expected to be stored with some form of energy storage that will be allow the system to operate under low-light conditions or at night. Although various technologies for energy storage are available, batteries are proposed to be used to store energy from the solar panels. Such energy would be used during the nighttime when solar panels are not generating much energy. The solar canopied route is estimated to generate an annual 31.8 GW. Research and analysis is needed to determine design options.

Literature review was done on current journal articles related to the Spartan Superway. Analysis was conducted through a computer simulation, developed during a previous project, to obtain energy demand and supply models of the system. The data was analyzed through spreadsheets, and assumptions were made to determine a size of energy storage required. Commercially available products that could meet the needed capacity were researched. A cost projection report provided by the U.S. Department of Energy Office was used to estimate the cost of storage system.

The current literature found showed a declining cost trend in solar photovoltaic and battery storage technologies. A worst-case scenario showed the energy required to run the system for one day solely on energy stored. Various commercially available storage unit designs of different scales were found to be applicable to the Superway system. High, middle, and low-cost projections for the storage system were calculated and graphed.

A case study was conducted to further analyze the option of purchasing a market unit or creating a custom unit. Computer modeling programs were used to model the custom unit and create a rendering of the unit at a station. New developments in the Superway project throughout the year by other teams led to updated recommendations. The custom energy storage unit was designed to compare to a market available unit. The design process is described in the report with a focus on readily available hardware and materials. Detailed drawings and renderings were created to visually demonstrate the custom unit in more detail. An interconnection diagram was created to visually summarize the process and timeline for grid tied systems. Two decision matrices were created to determine the best choice with the information obtained to the point when the project was concluded. Custom unit and market unit costs were compared with recent up to date research. A final recommendation concluded the project at the end of the report.

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NOMENCLATURE

GHG – Global greenhouse gas
PV – Photovoltaic
ATN – Automated Transportation Network

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1.0 INTRODUCTION

Current transportation methods and systems in place have environmental, safety, livability, convenience, and economical adverse implications. Global greenhouse gas (GHG) emissions are among the leading causes of climate change, making methods focused on renewable energy to fight climate change essential (Furman, et al., 2017). Automobiles, trolleys, trucks, buses, pedestrians, and bicyclist are in constant competition for the same space which results in over millions of accidents and injuries around the world every year (Furman, et al., 2017). Current transportation options continue to challenge livability in cities as either gas powered or electric cars can be noisy, introduce hazards that discourage walking, shopping, street markets, and require a lot of space (Furman, et al., 2017). Convenient public transportation can be rare, or missing, due to undependable scheduled services and ample separations between station and origin points (Furman, et al., 2017). Economical transit options can be an issue considering that expensive fares compete with cheap gas and parking prices (Furman, et al., 2017). To add, the transportation sector is one of the largest contributors to GHG emissions. San Jose's largest carbon emissions, over 60%, are from the mobile sources (Furman & Swenson, 2019). At the moment, according to the U.S. Environmental Protection Agency (2019), the transportation sector in the U.S. contributes 29% of GHG to the overall emissions (U.S. Environmental Protection Agency, 2019). From those emissions, 59% are due to light-duty vehicles and 23% from medium and heavy-duty trucks. These GHG, consisting of gases such as carbon dioxide and methane, are caused from the combustion of fuels (U.S. Environmental Protection Agency, 2019). These gases have adverse implications on the environment and health of the population, especially when excess amounts are emitted. Studies conducted have confirmed a relationship between "respiratory diseases and air pollution" caused by air pollutants from the transportation sector (Liu, et al., 2018). Efforts to reduce emissions through electric vehicles have had challenges.

The Spartan Superway research program is a "long-term research initiative at San Jose State University to establish solar powered automated rapid transit ascendant network systems for urban environments" (Furman, et al., 2017). The planned Spartan Superway, comprised of networks of elevated infrastructure that vehicles are suspended from, is a revolutionary and truly sustainable form of urban transportation. Vehicles referred to as podcars, the size of a car or minivan, will be used to transport people across elevated solar-canopied stations without long waits, the need for transferring, or taking any intermediate stops (Furman, et al., 2017). It is headed by Professor Furman and its goal is to cut "travel times, transit costs, and greenhouse gas emissions, while dramatically improving public health and safety" (Furman & Swenson, 2019). It is intended to provide transportation services around school campus through a suspended podcar system powered from a solar panel canopy (Furman & Swenson, 2019). The Superway will reduce emissions by having net zero energy use and support the renewable energy industry (Furman, et al., 2017). The elevated guideway will eliminate traffic and collisions, yielding more room for bicyclist, pedestrians, wildlife, and operations (Furman, et al., 2017). Through a reduced need for parking, it can potentially create spaces for "affordable, transient-oriented housing development" (Furman, et al., 2017). People will be able to travel and take a break rather than dealing with driving stress and congested traffic (Furman, et al., 2017). It will offer vehicles on demand with availability all day at all times where users can schedule a vehicle within a mobile app or terminal at a station (Furman, et al., 2017). Being connected to other transit systems will give more communities with infrequent public transit easier accessibility, discouraging the need for a car to travel to a station (Furman, et al., 2017). Current transit infrastructures are aging and will require investments and support (Furman, et al., 2017). The Superway will offer "fair, dynamic pricing" to encourage use and improve access to "lower socioeconomic communities" that may not be able to afford increasing costs of transit use and car ownership (Furman, et al., 2017). The Spartan Superway is currently offering educational benefits to many disciplines to provide students with skills and experience to use outside of school (Furman, et al., 2017). The Spartan Superway is an opportunity to reduce or eliminate effects of fossil fuels that move typical transportation methods forward, while helping society reduce and eliminate inimical impacts of modern transportation methods (Furman, et al., 2017).

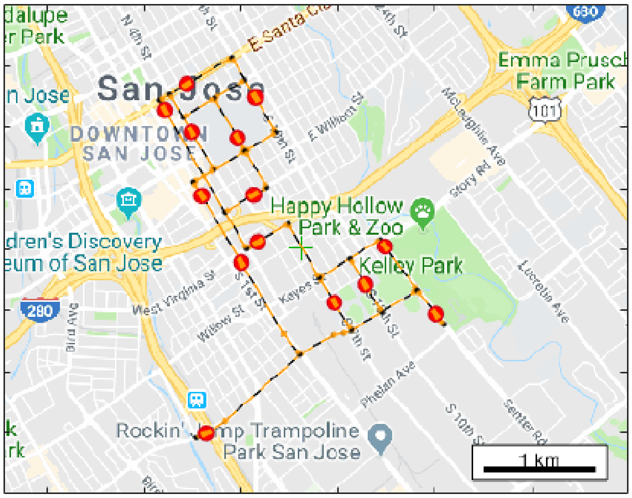


Figure 1 – Proposed north-south campus route. Source: (Fogelquist, 2019).

For this system, a proposed north-south route is intended to connect the north and south campuses of San José State University. This 14.9 km route will consist of 14 stations and approximately 155 vehicles at maximum operation. To collect enough energy to power the system all day, a canopy of solar photovoltaic (PV) panels above the guideways has been proposed by designers. To do so, some form of energy storage will be required for the system to operate under low-light conditions or at night. The energy system of the superway can be broken down into subsystems which include the PV panel collection system, distribution system, on-pod energy storage, and evening and low light-level storage. The podcar energy storage may consist of supercapacitors used to quickly get the podcar up to speed again after a stop. Evening and low light-level storage systems can be look at in terms of medium and long-term storage. Medium term storage could be batteries used to store energy from the solar panels. Such energy would be used during the nighttime when solar panels are not generating much energy. Two examples of long-term storage systems are pumped heat energy storage (PHES) and pumped hydro gravity piston storage (PHGS). As discussed by Nguyen in his research, although energy density of PHES is lower than lithium ion, the "costs scales well as energy storage requirements increase, beating out lithium ion" (Nguyen, 2019). Fogelquist estimated the solar canopied path to generate an annual 31.8 GW, or an average hourly of 3.6 MW (Fogelquist, 2019).

The focus of this project will be battery storage for energy generated through the photovoltaic panels. An energy storage solution proposed will take into consideration a hybrid system with the grid. Looking into current and global situations, trends, and technologies related to Automated Transit Networks (ATN) and energy storage will give further insight on a solution. This project investigates and proposes a design of a modular energy storage unit solution that can be deployed throughout the network in appropriate configurations to match localized power needs.

1.1 Objective

The objective of this project is to propose a design for an energy storage unit that can be deployed for the Superway network in configurations that can be used to capture, store, and supply the energy needed to power the Superweed system. The research done aims to:

- Investigate current research and technology related to ATN, photovoltaics, energy storage, utility-scale systems, and the grid and standards.
- Approximate the energy generated by the network
- Determine the anticipated energy demand for the N-S campus transportation network
- Investigate the granularity of design
- Determine the location of battery unit(s) relative to energy demand source
- Determine the major components/hardware required for the storage solution
- Investigate commercially available solutions
- Investigate projected costs

1.2 Literature Review

The following literature review provides background information relevant to the Spartan Superway. Automatic transit networks and their characteristics will be discussed, followed by photovoltaic and battery technology. Additionally, utility-scale systems and grid related information will be discussed.

1.2.1 Automatic Transit Networks

An ATN can be defined as an autonomous off-line guided system that provides "on-demand, non-stop, origin-to-destination services" and consists of "relatively small, lightweight vehicles that carry just a few passengers" (Furman, et al., 2014). Unlike autonomous personal vehicles that depend on integrated sensors to get around, ATN depend primarily on a central control management for vehicles within the network (Furman, et al., 2014). Typically, the complex systems of an ATN will consists of software, electric and electronic hardware, guideways, vehicles, stations along with equipment and materials, power source, and operations and maintenance facilities (Furman, et al., 2014). The market and supplier availability for ATN projects is limited, with credible suppliers being able to deliver an ATN project of 5-15 stations after two or three years from the start of construction (Furman, et al., 2014). Currently, there are only five systems in the world that qualify to be classified as ATNs (Furman, et al., 2014). The Spartan Superway plans to be another, with the ability to operate from stored energy. An ATN coupled with solar power generation can offer a new form of urban transportation with "excellent levels of service and environmental sustainability" (Furman, et al., 2014).

Figure 2 – Concept of a solar powered automated transit system. Source: (Furman, et al., 2017).

The Spartan Superway is an automatic transit network project being undertaken at San Jose State University that can offer development in public health and transportation. In addition to cutting down on emissions, ATNs can also increase traffic safety. Aspects associated with traffic safety in the transportation sector include traffic accidents and road congestion. A study conducted on the relationship of accidents and commercially gentrified areas, such as the Bay Area, determined that "commercially gentrified transit-oriented districts in both Los Angeles County and the Bay Area have 2.25 and 2.1 times higher collision rates per year respectively than those station areas that have not experienced commercial gentrification" (González, et al., 2019). One of the many factors contributing to higher collision rates is having more cars on the road. As mentioned in a journal about implications of global shift towards electric transportation, there would be a reduction of vehicle congestion and road infrastructure (Kim & Chaturvedi, 2015). An autonomous transportation network that operates from solar panel generated energy would serve as an example to changes that can be implemented locally and globally for the betterment of transportation, environment, and public safety.

Determining energy requirements for the system is needed. A simulation based on Madagascar City's personal rapid transit system decided on an average vehicle power consumption of 250 Wh/km while estimating an average energy consumption of 4000 kWh per day (Mueller & Sgouridis, 2011). Determining power demand of an ATN will be critical when sourcing battery storage components. In a simulation to determine traction power of an ATN-PRT vehicle, a peak power demand of about 22.5 kW with an average value of 2.75 kW was calculated (Kozlowski, 2018). An article by Dasczuk (Daszczuk, 2019) proposes "several benchmarks of ATN systems and their characteristics" that can be taken into consideration to further analyze such systems. Although many of the systems and technologies discussed are not identical to the Spartan

Superway, they may share similarities that can make the findings or calculation a good reference when designing a battery package for the Spartan Superway.

1.2.2 Photovoltaic Technology

Within an hour, the sun provides enough energy to meet global energy needs for approximately one year (Messenger & Abtahi, 2017). PV panels are one type of renewable energy technology. They generate electrical energy from the energy provided by sun in the form of light. The design foundation of PV systems are PV cells (Messenger & Abtahi, 2017). In general, a "photovoltaic cell produces less than 5W at approximately 0.5 V_{DC}" (Messenger & Abtahi, 2017). As a result, cells are connected in series-parallel configurations to meet the power demands of high-power applications (Messenger & Abtahi, 2017). Research done in 2011 listed crystalline, thin film, compound, and nanotechnology as four major types of PVs are (Chaar, et al., 2011). Recent research shows that current solar PV technologies are crystalline, thin film, hybrid PV, dye-sensitized, and organic (Kumar & Kumar, 2017). This section will focus on crystalline and thin film technologies. Crystalline PVs use silicone for cells and can be classified as mono-crystalline, poly-crystalline, and emitter wrap through (Chaar, et al., 2011). At the moment, 25.6% has been the highest reported efficiency for a single crystalline silicon solar cell (Kumar & Kumar, 2017). Thin film PVs are made by depositing thin layers of certain materials on a glass, polymer, or metal substrates (Kumar & Kumar, 2017). Thin film PVs can be made from amorphous silicon cells, Cadmium Telluride/CdS cells, Copper-Indium-Selenide and Copper-Indium-Gallium-Diseleni cells, and Copper zinc tin sulfide cells (Kumar & Kumar, 2017). Efficiencies of thin film solar cells generate concerns due to their high capture loss (Kumar & Kumar, 2017). Many solar cells are put together to make one PV module and modules are grouped to create a solar array.

PV Cell Technology	Band-gap [eV]	Manufacturing Processes	Efficiency Record [%]	Record Holder/Yr. [Country]	Market Share	Applications
Crystalline Silicon						***Civil Applications*** (e.g. *devices, residential, commercial, and utility-scale power plants*)
Mono-crystalline	1.11	Cz-Si, float-zone, BST	27.6 (26.1)[a]	Amonix/2005 [US] (ISFH/2018 [DE])	24%	
Poly-crystalline	1.11	BCG, block-casting	22.3	FhG-ISE/2017 [DE]	69%	
HIT	1.11	Deposition	26.6	Kaneka/2016 [JP]	< 1%	
Micro	1.11	PECVD, HWCVD	21.2	Solexel/2014 [US]		
Thin-film						
CIGS	1.7	scr.-print, coat, MOCVD	23.3 (22.9)[a]	NREL/2014 [US] (Solar Frontier/2018 [JP])	< 2%	
CdTe	1.5	sputter., HVE, MOCVD	22.1	First Solar/2015 [US]	3%	
Amorphous Si:H	1.5–1.8	PECVD	14	AIST/2016 [JP]	3%	
GaAs	1.42	VGF, BST, LEC, MOCVD	30.5 (29.1)[a]	NREL/2018 [US] (Alta-devices/2019 [HK])	Non-cml.	***Spacecraft Applications***
Multi-junction	multiple	MOCVD, mech.-stacking	46	FhG-ISE|Soitec/2015 [DE|FR]		
Emerging						***Research***
Organic	1–4	Roll-to-roll mfg.	15.6	SCUT-CSU/2018 [CN]		*(still under development)*
Dye-sensitized	≈ 3.2	Roll-printing	11.9	Sharp/2012 [JP]		
Perovskite	≈ 1.5	spin-coat, scr.-print, VD	28 (24.2)[a]	Oxford PV/2019 [UK] (KRICT-MIT/2019 [KR-US])		

Figure 3 – Current characteristics overview of solar photovoltaic cell technologies. Source: (Shubbak, 2019).

PV modules, or panels, can have an output power peaking anywhere from a few watts to more than 400 W (Messenger & Abtahi, 2017). A "typical array output power is in the 100 W-to-kW, although megawatt and gigawatt arrays are now becoming more commonplace" (Messenger & Abtahi, 2017). PV systems may benefit from battery storage through energy storage, transient suppression, system voltage regulation, and a source of current that can be more than the PV array capabilities (Messenger & Abtahi, 2017). A PV module and array have a DC output which might be required to go through an inverter to convert to AC (Messenger & Abtahi, 2017). A PV system connected to the utility grid has the option of giving the grid excess energy generated or using energy from the grid when PV generation is not enough (Messenger & Abtahi, 2017). When connecting PV systems to the grid, certain considerations must be considered. For instance, "a grid connected system needs to incorporate suitable interfacing circuitry so that the PV system will be disconnected from the grid in the event of grid failure" (Messenger & Abtahi, 2017).

Looking at trends of materials prices going down and global studies in the storage field is of importance to build an optimized system. PV systems costs are expected to decrease around 30% until 2026, with modules and inverters showing the most reduction of cost (Trube, 2016). This will make such systems much more accessible.

1.2.3 Energy Storage

Energy can be stored through various methods. Current types of storage include electrochemical and battery, pumped hydro, magnetic, chemical and hydrogen, flywheel, and thermal (Koohi-Fayegh & Rosen, 2020). Furthermore, batteries can be under the solid electrode or flow battery category. Battery energy storage systems operate on a similar principle where each cell containing two electrodes, a cathode and anode, and an electrolyte, convert energy between electrical and chemical energy (Luo, et al., 2015). During discharge, electrons are provided from the anodes and collected at the cathodes. During charging, the reverse happens as voltage is applied at the two electrodes (Luo, et al., 2015). Different chemistry combinations are available, such as sulfur and oxygen for lithium ion batteries, each having certain characteristics (Van Noorden, 2014).

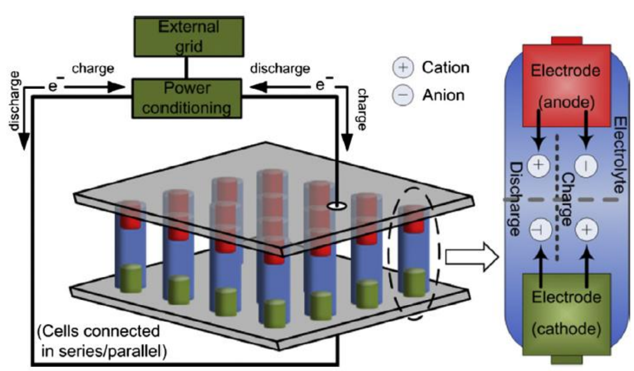


Figure 4 – General setup and internal structure of batteries. Source: (Luo, et al., 2015).

1.2.3.1 Lithium and Related Battery Storage

Various options within the solid electrode battery category are available and are constantly being studied. A recently published article compared four different battery types for electric vehicles. The batteries compared were Lithium Ion (Li-Ion), Molten Salt ($Na\text{-}NiCl_2$), Nickle Metal Hydride (Ni-MH), and Lithium Sulphur (Li-S). The authors concluded that Molten Salt batteries where the best choice in terms of energy consumption, with a consumption of 12.6 kWh/100 km (Iclodean, et al., 2017). Additionally, they offer low prices, "increased lifecycle or great functioning under normal parameters in harsh environments" (Iclodean, et al., 2017). A disadvantage is the need to have an external system to maintain the battery's temperature due to the possibility of the electrolyte solidifying if the vehicle is not used (Iclodean, et al., 2017). Nickle Metal Hydride batteries had a fair energy consumption of 15.7 kWh/100 km. Moreover, they are not too efficient, have an increased energy density, are heavy, and the technology can be considered outdate (Iclodean, et al., 2017). Lithium Sulphur had a consumption of 17.2 kWh/100 km, making it the highest energy consumption battery of the four (Iclodean, et al., 2017). Their light weight, high energy storage capacity, and low price compared to other batteries make it one of the best solutions for systems with high storage requirements (Iclodean, et al., 2017). Lithium ion batteries have a modest energy consumption of 14.7 kWh/100 km (Iclodean, et al., 2017). They are useful where "response time, small dimension, and weight of equipment are important" (Luo, et al., 2015). In general, lithium ion batteries have an energy capital cost of 3,800 $/kWh, they can have cycle efficiencies up to 97% with a cycle life of 20,000 cycles, energy density of 500 kWh/m^3, and specific energy of 200 Wh/kg (Luo, et al., 2015). They are the most used technology in electric vehicles due to their declining cost, manufacturing technology, cycle life, low weight, and high energy potential (Iclodean, et al., 2017). On the other hand, they can have high operating temperatures, which could have negative implications on performance and lifecycle (Iclodean, et al., 2017). An additional consideration to take into account with lithium ion batteries is the effect the depth of discharge can have on the lifetime of the battery (Luo, et al., 2015).

As with other design challenges, safety must be considered. Lithium-ion batteries have been known to pose a flammability hazard (Messenger & Abtahi, 2017). Some electrolytes used in lithium-ion batteries may consist of dimethyl carbonate which "has a flammability rating of 3 on a scale of 0 – 4, indicating a high risk of ignition" (Wong, et al., 2014). This may require lithium batteries to have a "more sophisticated battery management system (BMS) that monitors voltage and temperature of every cell" to control cell voltage and charge (Messenger & Abtahi, 2017). Searching for possible batteries with nonflammable or less flammable characteristics could be of interest. To properly design a battery storage unit, it is necessary to understand and make reasonable assumptions about energy consumption and the factors affecting it.

1.2.3.2 Lead Acid Battery Storage

Lead acid batteries are the most widely used rechargeable batteries (Luo, et al., 2015). They have a lead dioxide cathode, lead anode, and sulfuric acid electrolyte. Characteristics of these batteries are low capital costs of 50-600 $/kWh, cycling life of up to 2000 cycles, energy density of 50-90 kWh/m^3, and specific energy of 25-50 Wh/kg (Luo, et al., 2015). The charging characteristics of lead acid batteries differ from those of other battery chemistries. For example, when compared to lithium iron phosphate batteries, lead acid batteries require a float charge while on stand-by to be maintained close to 100% state of charge, are capable of lower full cycles per day, and have a slower charging rate (Power Sonic, 2020). The life of a lead acid battery can be drastically reduced if subjected to temperatures change. For instance, the lifetime of the battery can be "shortened to 44% of its expected lifetime at 25°C" if it operates at 35°C (Messenger & Abtahi, 2017). To add, proper ventilation for battery is needed "to vent any hydrogen or other gases" (Messenger & Abtahi, 2017). Like pumped hydro, lead acid batteries can be considered a mature technology, which have only seen a small change in cost over the past two decades (Koohi-Fayegh & Rosen, 2020). A list of facilities that have implemented a lead acid system can be seen in an article on current developments in electrical energy storage (Luo, et al., 2015).

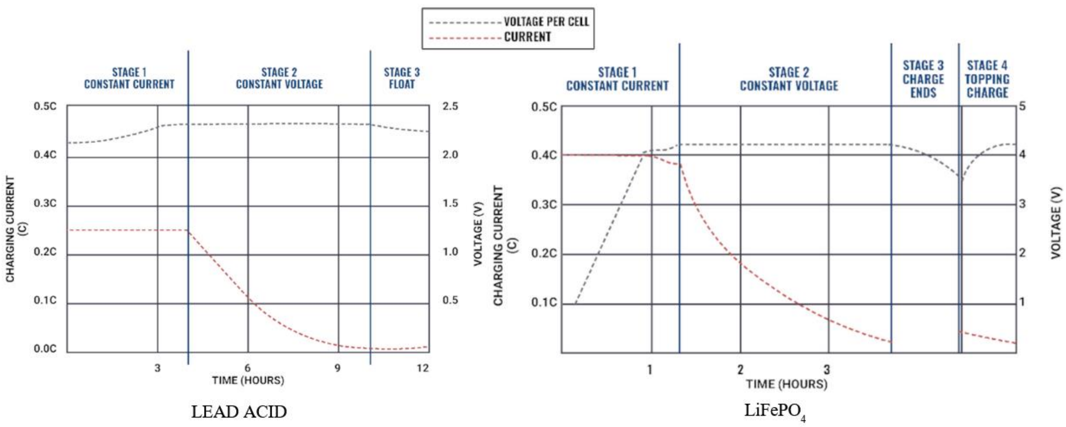


Figure 5 – Charging profile of lead acid and lithium iron phosphate batteries.
Source: (Power Sonic, 2020)

1.2.3.3 Flow Battery Storage

Flow batteries can store energy using two electrolyte reservoirs, electrochemical cell, cathode, anode, and membrane separator (Koohi-Fayegh & Rosen, 2020). The electrolytes can be pumped from the reservoirs to the cell stack, or electrochemical cell (Luo, et al., 2015). The cell stack consists of two electrolyte flow compartments divided by an ion selective member (Luo, et al., 2015). The electrolyte solutions go through reduction oxidation reactions when charging and discharging (Luo, et al., 2015). During charging, an electrolyte is oxidized at the anode and the other electrolyte is reduced at the cathode (Luo, et al., 2015). Flow batteries may suffer from "lower volumetric energy storage, higher energy losses between charge and discharge than nonflow units", and some utilize toxic chemicals (Messenger & Abtahi, 2017). During discharge, the process is reversed to output electrical energy (Luo, et al., 2015). Currently, the vanadium redox flow battery (VRFB) is one of the most mature flow battery system (Luo, et al., 2015

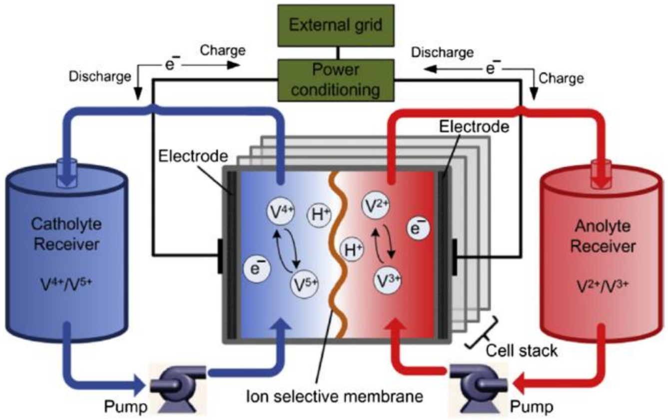


Figure 6 – Vanadium redox flow battery diagram. Source: (Luo, Wang, Dooner, & Clarke, 2015).

VRFBs have an energy capital cost of 1,000 $/kWh, can operate for about 10,000–16,000 cycles with efficiencies up to 85%, energy density of 33 kWh/m^3, specific energy of 30 kWh/kg, and can be designed to provide continuous power while discharging for 24 hours or more (Luo, et al., 2015A study conducted to monitor capacity loss for a VRFB showed that after 140 charge and discharge cycles, the cell capacity dropped from 1245.4 mAh to 651.5 mAh (Wei, et al., 2018). The capacity loss was "attributed to the electrolyte imbalance in the two-half cells associated with the volumetric transfer of electrolyte from the positive into the negative half-cell and the build-up of vanadium in one half-cell caused by the differential rates of diffusion of the different vanadium ions across the membrane" (Wei, et al., 2018). Furthermore, a recent study on a VRFB examined the reaction of the battery under short circuit conditions. Under such conditions, the flow battery was found to be "stable to external shorting, with no leakage, smoke or fire occurring under several realistic scenarios" (Whitehead, et al., 2017). To be suitable for varying applications, VRFBs can be adjusted in physical size. Recent work has been done for nontoxic organic electrolytes to be used in flow batteries (Messenger & Abtahi, 2017). However, challenges that remain include low energy density due to electrolyte instability and relative high cost of operation (Luo, et al., 2015). The "increased capital and operating costs in comparison to batteries" is influenced by the needed pump system and control of flow for external storage (Koohi-Fayegh & Rosen, 2020). A small list of facilities that have implemented a VRFB system is shown in an article on current developments in electrical energy storage (Luo, et al., 2015).

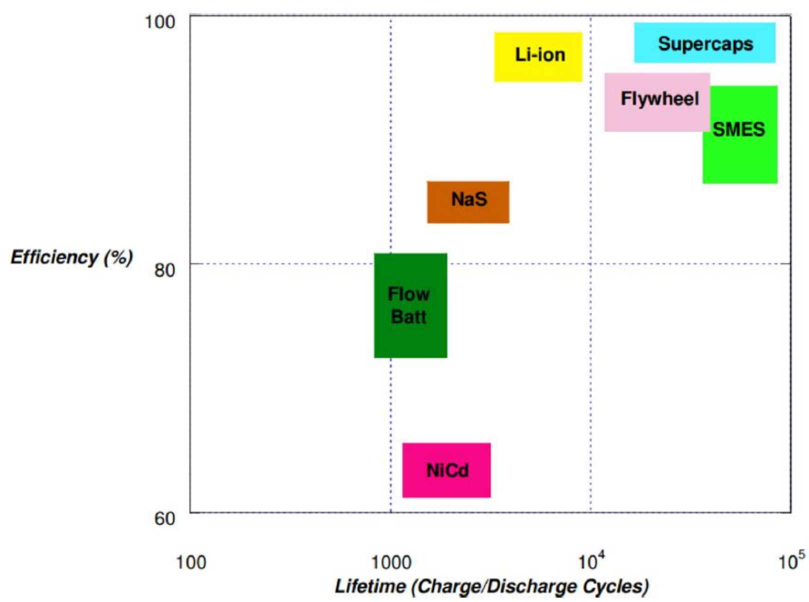


Figure 7 – Efficiency and lifetime graph of energy storage technologies. These include flow battery, Nickle-Cadmium, Sodium-Sulfur, Lithium-ion, flywheel, supercapacitors, and superconducting magnetic energy storage. Source: (Koohi-Fayegh & Rosen, 2020).

1.2.3.4 Battery Cost Trends

One common goal that all battery combinations move towards is increasing capacity and reliability while driving cost and size down. As with PV systems, there is a trend of cost of batteries going down. A study conducted on battery packs for electric vehicles showed how there was a decline of battery cost from about $1,000 per kWh to $410 per kWh in a span of seven years (Nykvist & Nilsson, 2015). A recent update on lithium ion utility-scale storage system costs projected that there would be a reduction in capital cost of 10-52% by 2025 (Cole & Frazier, 2019). This will be of benefit when it is time to purchase batteries.

1.2.4 Utility-Scale Systems

Utility-scale systems are globally present, and they provide examples of technology that can be applied to similar projects. Research done for energy storage has resulted in various recommendations for utility-scale systems. For renewable energy storage, lithium iron phosphate (LFP) batteries are recommended as most stable and plausible technology for the application (Messenger & Abtahi, 2017). Alternatively, researchers have found that flow batteries have offered acceptable energy densities recently and some believe that they can offer “a more cost-effective technology for utility-scale energy storage” (Messenger & Abtahi, 2017). For flow batteries, good energy density has been achieved and some believe that they can offer “a more cost-effective technology for utility-scale energy storage” (Messenger & Abtahi, 2017). Various options are available for any application.

Recent research done in the utility-scale system area can give insight into options available for larger scaled systems. An analysis on European policy and market was recently conducted to study the effects of reusing electric vehicle batteries for their electricity grid. The analysis concluded that "despite falling prices of new batteries," the reuse of electric vehicle batteries should be considered to have a more "sustainable battery supply chain" (Gur, et al., 2018). Doing so could also generate employment when having batteries repurposed and lower the demand for new batteries (Gur, et al., 2018). This could be something to consider when it is time to purchase batteries when the full build takes place. Similarly, UC Davis set up a microgrid electrical energy storage system intended to store energy generated from solar panels utilizing used Nissan Leaf electric vehicle batteries for their winery and food science building (Park). A journal on utility-scale power tower solar systems discusses two types of test runs that test performance. The two tests are essentially a power test and a reliability test (Kearney, 2014). The two tests described can serve as guidelines for what testing procedures can be used to check the functionality of the battery storage system being designed.

Planning a grid tied system must take into consideration costs and layouts. An analysis conducted on residential PV systems with battery storage showed insight of costs associated with renewable energy storage systems. Emphasis was placed on the importance of "battery and PV size optimization to balance battery utilization, self-sufficiency, and self-consumption" (Tervo, et al., 2018). Although specific values can vary by location, a minimum levelized cost of electricity of about $0.11 per kWh was calculated for 7 kWh of storage (Tervo, et al., 2018). A U.S. utility-scale PV and storage costs benchmark report concluded that the cost of a lithium ion system with 60 MW installed capacity with an assumed battery price of $209/kWh could be between $380/kWh and $895/kWh, for a 4 hour and 0.5 hour system respectively (Fu, Remo, & Margolis, 2018). In addition, "co-locating the PV and storage subsystems produces cost savings by reducing costs related to site preparation, land acquisition, permitting, interconnection, installation labor, hardware, overhead, and profit" (Fu, et al., 2018). DC-coupled systems were found to have an 8% lower cost than a separately sited system (Fu, et al., 2018). DC-coupling had a 1% lower cost than AC-coupling (Fu, et al., 2018). The report offers more information on DC and AC systems differences.

Adaptations of technology and methods used in current systems around the world can be implemented onto the Spartan Superway project accordingly. Other than cost savings, "retrofit considerations, system performance, design flexibility, and operations and maintenance" are added factors to consider (Fu, et al., 2018). Studying and analyzing these systems will allow for a better overall design.

1.2.5 The Grid and Standards

The grid is made up of several main components that allow electricity to be transferred. Pacific Gas & Electric Company (PG&E) is a gas and electricity utility company, based in California, that provides its services to areas such as the Bay Area. Their electric grid system consists of PG&E generators, independent generators, out-of-state generators, transmission systems, substations, distribution systems, and individual services. They use voltages ranging from 120V to over 500 kV to deliver electricity. Understanding the grid and its components is important when planning for a grid tied system.

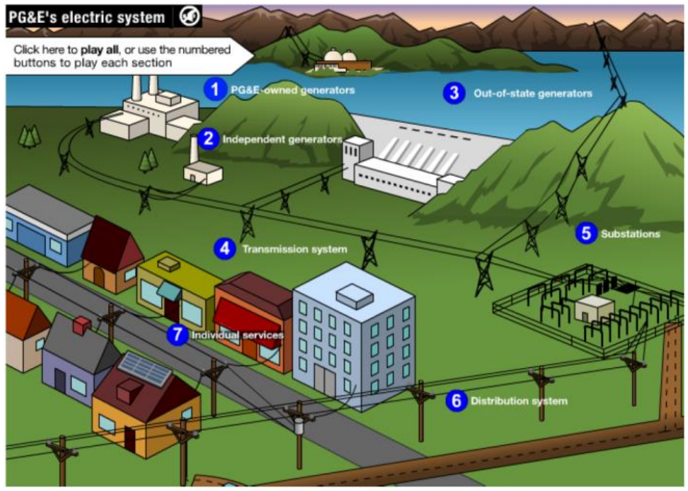


Figure 8 – PG&E's electric system and components. Source: (Shoemaker, n.d.).

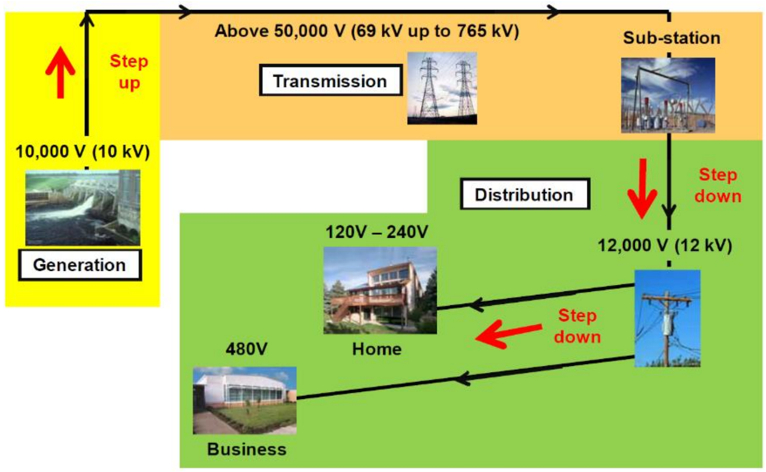


Figure 9 – Typical voltages used in the electric grid. Source: (Shoemaker, n.d.).

In California, the California Independent System Operator (CAISO) "manages the flow of electricity across the high-voltage, long-distance power lines for the grid" (CAISO, n.d.). They provided a curve, known as the duck curve due to its shape, that presents the electrical load on the grid throughout the day. As a result of the substantial renewable energy generated, there has been an over generation challenge (Park, n.d.). With PV systems, there is over generation during the daytime yielding grid energy generation to quickly ramp down their power output (Park, n.d.). During the evening or towards the night, the solar panels do not generate much, if any, electricity, leading the grid to having to quickly ramp up their generation (Park, n.d.). Energy storage can help alleviate this issue by storing some of the excess energy and discharging during the night to lower the demand of electricity from the grid (Park, n.d.). The college of engineering at UC Davis set up their own microgrid, using Nissan Leaf "second-life" batteries, for a campus building to experiment and address the over generating challenge. They found that electrical energy storage helped more during the summer regarding cost and CO_2 reductions (Park, n.d.). During the winter, grid power was used to charge the energy storage system as there was less energy generated by the solar panels. Having a system integrated with the grid can be of benefit to the grid and the system being worked on.

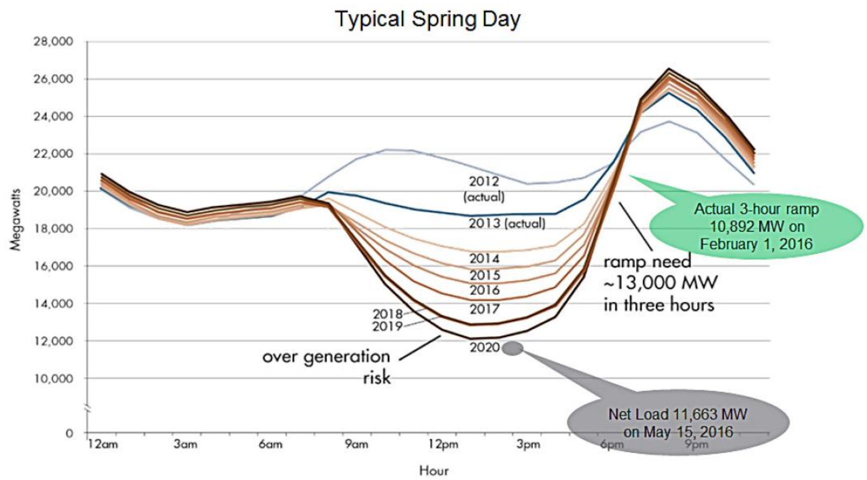


Figure 10 – Duck curve provided by CAISO's. Source: (CAISO, 2016).

A PV system with energy storage must be up to certain established standards if it is to be connected to the grid. These standards "are critical to the development of solar power generation and will support the commercialization of the PV technology, reduce manufacturing operating costs, and ensure a safe and reliable operation of power systems" (Wu, et al., 2017). International standards such as IEEE 157, IEC 61727, and IEEE Std 929 have been modified and merged into national standards by the US (Wu, et al., 2017). A book on PV systems engineering discusses codes and standards at a more national level (Messenger & Abtahi, 2017). More of these codes and standards that are relevant can be seen in the Appendix. In addition to these electrical system standards the structural side of the project will have to be up to other standards. The American society of civil engineers (ASCE) incorporate ATN in the family of automated people movers (APM). As a result, they are subjected to safety standards that apply to driverless metros, shuttle, and circulators (Furman, Fabian, Ellis, Muller, & Swenson, 2014). To add, existing standards might need to be broaden for ATN as they can be more complex (Furman, et al., 2014). Standards are in place for various reasons and they must be looked at and built upon to have a system that can be integrated into an area.

2.0 METHODOLOGY

The methodology section of this report will describe the steps taken to achieve the project objectives. Designing an energy storage unit requires determining the size of storage needed through energy demand and supply analysis. A Matlab computational model created by Fogelquist (Fogelquist, 2019) is used to calculate energy demand and supply for the transit route. The purpose of this is to build on top of previous research done for the route. Energy demand and supply are converted to values based on time for clearer analysis on google sheets.

Additional factors, such as safety, standards, and costs, are considered as well. A design case study is done to explore a custom solution and determine logistics of a storage unit for the system.

2.1 Energy Demand

The energy demand of the system will be of help to determine the energy storage capacity needed. The model created by Fogelquist is used to approximate the annual energy demand of the transit route.

The trip time equation is used to evaluate the time it takes a vehicle, or podcar, to travel from one location to another. For the Superway, this will represent the time interval when traveling between two stations. As displayed by Anderson (Anderson, 1978), the trip time can be calculated with the following equation:

$$t_s = t_D + \frac{D_s}{V_L} + \frac{V_L}{a_m} + \frac{a_m}{J_1} + \frac{a_m^3}{24V_L}\left(\frac{1}{J_2^2} + \frac{1}{J_1^2}\right) \quad (1)$$

The variables and their descriptions for equation (1) are:

- t_s (trip time): Time for station to station travel (s) (Anderson, 1978) (Fogelquist, 2019) (Furman, 2016).
- t_D (dwell time): Time spent at a station (s) (Anderson, 1978) (Fogelquist, 2019) (Furman, 2016).
- D_s (average trip distance): Average distance traveled between station to station, or in time t_s (m) (Anderson, 1978) (Fogelquist, 2019) (Furman, 2016).
- V_L (line speed): Operating speed of vehicle (m/s) (Anderson, 1978) (Fogelquist, 2019) (Furman, 2016).
- a_m (maximum acceleration): Maximum vehicle acceleration (Anderson, 1978) (Fogelquist, 2019) (Furman, 2016).
- J (jerk): Derivative of acceleration with respect to time (m/s^3). J_1 is the rate when a_m is reached. J_2 is the rate when a_m reaches zero (Anderson, 1978) (Fogelquist, 2019) (Furman, 2016) .

Anderson mentions that the relationship $J_1 = J_2$ can be assumed when "dealing with off-line station systems" (Anderson, 1978). As a result, the equation is further simplified by allowing $J_1 = J_2 = a_m$ for an ATN (Fogelquist, 2019). The simplified equation is shown by Fogelquist as:

$$t_s = t_D + \frac{D_s}{V_L} + \frac{V_L}{a_m} + 1 \quad (2)$$

An energy equation established by Anderson is used to determine energy required for a vehicle, or podcar, to travel from one station to another in trip time (t_s) (Anderson, 1978).

$$E(t_s) = \frac{1}{\bar{\eta}_m}\left\{(1-\eta_{regen})N_T\frac{m_v V_L^2}{2} + \frac{1}{2}\rho_{air}C_D A_v\left[(V_L^2 + \langle V_w^2\rangle)d_s - \frac{V_L^4}{2a_m}\right] + N_T m_v\left[\frac{C_{srr}gd_s}{R_w} + C_{drr}V_L\left(d - \frac{V_L^2}{3a_m}\right) + \Delta h_{avg}g\right]\right\} + N_T P_{aux}t_s \quad (3)$$

The equation was modified by Furman to incorporate a static rolling resistance correction factor (Fogelquist, 2019) (Furman, 2016). The correction factor was intended to account for "rolling resistance of the switching wheels and wayside pickup shoes" (Fogelquist, 2019). Taking into consideration these additional characteristics of ATNs can yield better results. The modified equation with the static rolling resistance correction factor (k_{srr}) is displayed as (Fogelquist, 2019):

$$E(t_s) = \frac{1}{\bar{\eta}_m}\left\{(1-\eta_{regen})N_T\frac{m_v V_L^2}{2} + \frac{1}{2}\rho_{air}C_D A_v\left[(V_L^2 + \langle V_w^2\rangle)D_s - \frac{V_L^4}{2a_m}\right] + N_T m_v\left[k_{srr}\frac{C_{srr}gD_s}{R_w} + C_{drr}V_L\left(D_s - \frac{V_L^2}{3a_m}\right) + \Delta h_{avg}g\right]\right\} + N_T P_{aux}t_s \quad (4)$$

Variables for equation (4) can be describes as follows:

- $\bar{\eta}_m$ (average motor efficiency): Average efficiency of motor in vehicle (Fogelquist, 2019) (Furman, 2016).
- η_{regen} (regenerative braking efficiency): Kinetic energy proportion recovered through the regenerative braking system during one trip (Fogelquist, 2019) (Furman, 2016).
- N_T (number of vehicles in train): Amount of vehicles traveling together within the network (Fogelquist, 2019) (Furman, 2016).
- m_v (vehicle mass): Mass of one vehicle (kg) (Fogelquist, 2019) (Furman, 2016).
- ρ_{air} (air density): Density of air (kg/m^3) (Fogelquist, 2019) (Furman, 2016).
- C_D (drag coefficient): Coefficient of drag (Fogelquist, 2019) (Furman, 2016).
- A_v (frontal area): Frontal are of one vehicle (m^2) (Fogelquist, 2019) (Furman, 2016).
- $\langle V_w^2\rangle$ (mean square wind speed): Average of the squared hourly wind speed (Fogelquist, 2019) (Furman, 2016).
- k_{srr} (static rolling resistance correction factor): Correction factor for static rolling resistance used to integrate switching wheels and wayside pickup friction forces of an ATN vehicle (Fogelquist, 2019) (Furman, 2016).
- C_{srr} (static rolling resistance coefficient): Coefficient for static rolling resistance (Fogelquist, 2019) (Furman, 2016).
- g (acceleration due to gravity): Acceleration due to gravity (m/s^2) (Fogelquist, 2019) (Furman, 2016).
- R_w (wheel radius): Radius of wheels on vehicle (m) (Fogelquist, 2019) (Furman, 2016).
- C_{drr} (dynamic rolling resistance coefficient): Coefficient of dynamic rolling resistance (Fogelquist, 2019) (Furman, 2016).

- Δh_{avg} (average change in elevation): Change in elevation for an average trip from one station to another (m) (Fogelquist, 2019) (Furman, 2016).
- P_{aux} (auxiliary power): Auxiliary power demand of a single vehicle (W). This can include items such as air conditioning load, door control, and lights (Fogelquist, 2019) (Furman, 2016).

The hourly system energy demand will be calculated with results from the computational model. The results of the model include number of vehicles on route, average system power demand, and annual system energy demand (Fogelquist, 2019). The following equation is used to determine hourly demand of a vehicle on the transit route.

$$E_{vhd} = \frac{E_{ahd}}{N_v} \tag{5}$$

The variables are:

- E_{vhd} (vehicle hourly demand): Hourly energy demand of one vehicle within the system. Fogelquist uses $E(t_s)$ in place of this variable in (Fogelquist, 2019).
- E_{ahd} (average system demand): Average hourly energy demand of the system. This value is calculated from Fogelquist's model (Fogelquist, 2019).
- N_v (number of system vehicles): Number of vehicles in the system.

To better approximate the energy demands the system might face on an hourly basis, data from a local shuttle transit system is implemented (Ngo, 2016). Since the shuttle and Superway have a similar route, the hourly passenger data pertaining to the shuttle will represent the number of passengers the Superway system might have to transport within a day. Passenger data from the busiest day is used. Doing so will yield results for what a most power demanding day would look like. First, the number of vehicles needed is calculated based on a maximum occupancy of six passengers in a Superway vehicle using equation (6). This value is calculated hourly for one day and rounded up when the answer is a decimal. This is done to get a whole number for number of vehicles.

$$N_{vn} = \frac{N_{sp}}{N_p} \tag{6}$$

The variables are descried as follows:

- N_{vn} (number of vehicles needed): Number of vehicles needed for the Superway to transport a number of passengers based on park and ride shuttle data. This value is calculated for each hour, for one day.
- N_{sp} (number of shuttle passengers): The number of passengers that used the park and ride shuttle. This value is not constant each hour.

- N_p (maximum number of passengers): The maximum number of passengers that can use one Superway vehicle.

The hourly system demand is computed using the following equation:

$$E_{hsd} = N_{vn} E_{vhd} \quad (7)$$

Where:

- E_{hsd} (hourly system demand): Hourly energy demand of system based on statistics for park and ride shuttle.

2.2 Energy Supply

The energy supply for the Spartan Superway is intended to approximate the electrical power supplied by the PV system. This is done through a simulation using the computer model created by Fogelquist (Fogelquist, 2019). An excel sheet with hourly data of power generated for a year is obtained from the simulation. The model considers the route, irradiance, shading, and array profile (Fogelquist, 2019).

The hourly array power output is calculated with equation (8) (Fogelquist, 2019).

$$P_{A,h} = \eta_{elec} \sum_{N_{sub}} \left(P_{mod,un,h} N_{un,h} + P_{mod,sh,h} N_{sh,h} \right) \quad (8)$$

The variables can be detailed as follows:

- $P_{A,h}$: Hourly array power output (Fogelquist, 2019).
- η_{elec}: Electric efficiency system (Fogelquist, 2019).
- N_{sub}: Number of subarrays in the array (Fogelquist, 2019).
- $P_{mod,un,h}$: Hourly DC power output of a single unshaded module (Fogelquist, 2019).
- $N_{un,h}$: Hourly number of unshaded modules in subarray (Fogelquist, 2019).
- $P_{mod,sh,h}$: Hourly DC power output of a single shaded module (Fogelquist, 2019).
- $N_{sh,h}$: Hourly number of shaded modules in subarray (Fogelquist, 2019).

Electrical efficiency includes the efficiency of the inverter (η_{inv}), wiring (η_{wire}), electrical connections (η_{con}), and module mismatch (η_{mis}). This is seen in equation (9) (Fogelquist, 2019).

$$\eta_{elec} = \eta_{inv} \eta_{wire} \eta_{con} \eta_{mis} \quad (9)$$

The hourly power outputs of the leg and canopies of the station are added to get the hourly power output of the system ($P_{sys,h}$) (Fogelquist, 2019).

$$P_{sys,h} = \sum_{N_A} P_{A,h} \tag{10}$$

The overall power output for each day in a year is calculated from the computed hourly power outputs of the system. From the 365 values calculated, the least productive day is chosen, and its hourly power outputs are collected for further analysis.

2.3 Surplus

The net power surplus was analyzed per day for the year to get a better understanding of the power generated and the power demand. A positive net power surplus shows that excess power is available for storage or exporting to the utility while a negative net power surplus will be a result of power demand being greater than the power being generated. This will be calculated by taking the difference of the power generated per hour a day for a year and the power demand per hour a day for a year. The hourly demand values for the most demanding day based on the shuttle data will be used for all days of the year when calculating the difference. The following equation will be used to calculate the surplus where S_P is the net surplus power, $P_{A,h}$ is the hourly power output, and E_{hsd} is the hourly system demand.

$$S_P = P_{A,h} - E_{hsd} \tag{11}$$

2.4 Electric Energy Storage Size

Sizing of the storage is based on the electrical demand and electrical supply values calculated on an hourly basis for a day. The electrical demand uses data from the park and ride shuttle to establish what a most demanding day could look like. The day with the least amount of electrical energy generated is used to establish the least producing day. A graphical comparison of these two data sets will represent what an overall worst-case scenario for a day could be.

To simplify calculating the amount of energy storage needed, the hourly electrical demands (E_{hsd}) are summed to obtain the total electrical demand (E_{td}) of the most demanding day.

$$E_{td} = \Sigma E_{hsd} \tag{12}$$

The same is done for energy supply. The hourly electrical supply ($P_{sys,h}$) is summed to obtain the total electrical energy supplied (E_{ts}) during the least producing day.

$$E_{ts} = \Sigma P_{sys,h} \tag{13}$$

The values are subtracted to evaluate the total amount of electrical energy available to be stored. This is done under the assumption that no further loses are present.

$$E_{tea} = E_{ts} - E_{td} \tag{14}$$

This method is an alternative to finding the area under both curves produced by the data set. The value calculated represents the minimum amount of energy storage needed to store energy produced by Superway's PV system on a worst-case scenario day. Moreover, looking at the overall electrical demand for the busiest day shows how much storage would be needed to operate the Superway system solely on stored electrical energy.

To properly determine load on batteries (L_B), a wiring (n_{wir}) and inverter (η_{inv}) efficiency are accounted for as shown in equation (15) (Messenger & Abtahi, 2017).

$$L_B = \frac{E_{tea}}{\eta_{inv} n_{wir}} \tag{15}$$

To further characterize the battery and system based on voltage or current, the general equation (16) can be used.

$$P = VI \tag{16}$$

A rearranged and slightly modified version of equation (16) is used to covert the load on the batteries to current loads in Amp hours as shown in equation (17) (Messenger & Abtahi, 2017). The load on the batteries (L_B) is divided by the nominal voltage (V_{batt}) of the system. It can be multiplied by a factor of 1.25 to account for batteries needing to shut down and recharge once they supply no more than 80% of their capacity (Messenger & Abtahi, 2017).

$$I = \frac{L_B}{V_{batt}} \tag{17}$$

2.5 Storage Design and Layout

The storage unit design and layout consist of taking the size of storage needed and determining how to physically integrate it to the Superway network. A high-level mind map was created to show what a battery storage unit could involve and how it relates to other aspects of the system.

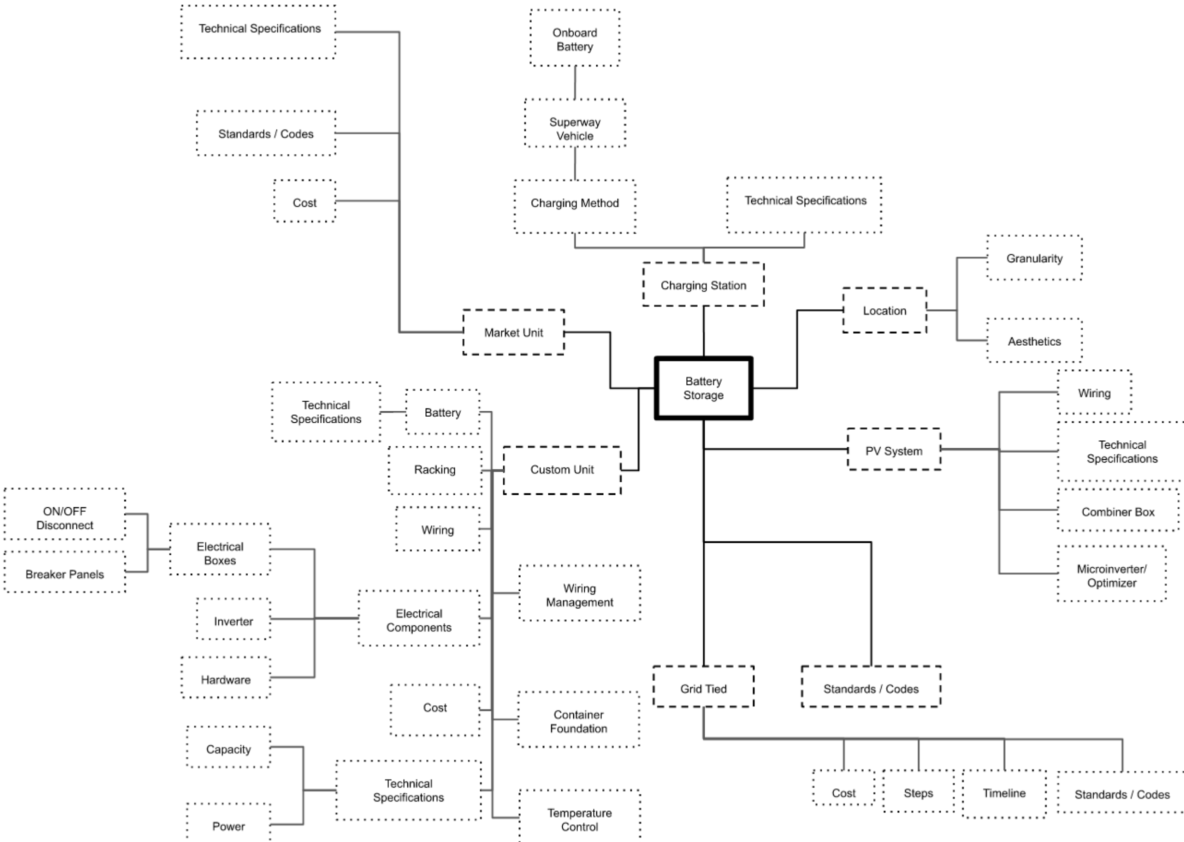


Figure 11 – Mind map of a battery storage unit for the Superway.

The design of the storage unit must be able to support a necessary number of batteries. Two considerations for the design include designing a unit from scratch or searching for units readily available in the market. For this project, both options were explored. Utility-scale storage units currently available in the market were looked at for the latter option. Examples of companies that offer utility-scale storage include Tesla’s Megapack (Tesla, 2020), Oilfield’s lithium battery storage units (Oilfield Instrumentation, 2020), Generac’s storage (Generac, 2018), Aggreko’s storage (Aggreko, 2020), ABB (ABB, 2020), and EOS (EOS, 2020). Many of these units have temperature control, safety features, and can be scaled depending on storage needs (Oilfield Instrumentation, 2020). A comparison of such storage units can be done to show the most potentially applicable for the Superway network.

The type of electrical coupling used between components in the system is considered for a more optimized design. The two coupling options considered are AC-coupled or DC-coupled systems. Their characteristics are evaluated to determine the best option for the system design presented. Typically, in an AC-coupled system the electrical output of the solar panels is converted from dc to ac with a microinverter before it is distributed throughout the rest of the system. Another inverter is used before the battery to convert from AC to DC and allow electricity to be stored. In a DC-coupled system, the electrical output of the solar panels typically remains as DC throughout most of the system. An inverter is used to convert from DC to AC before entering the grid for compatibility.

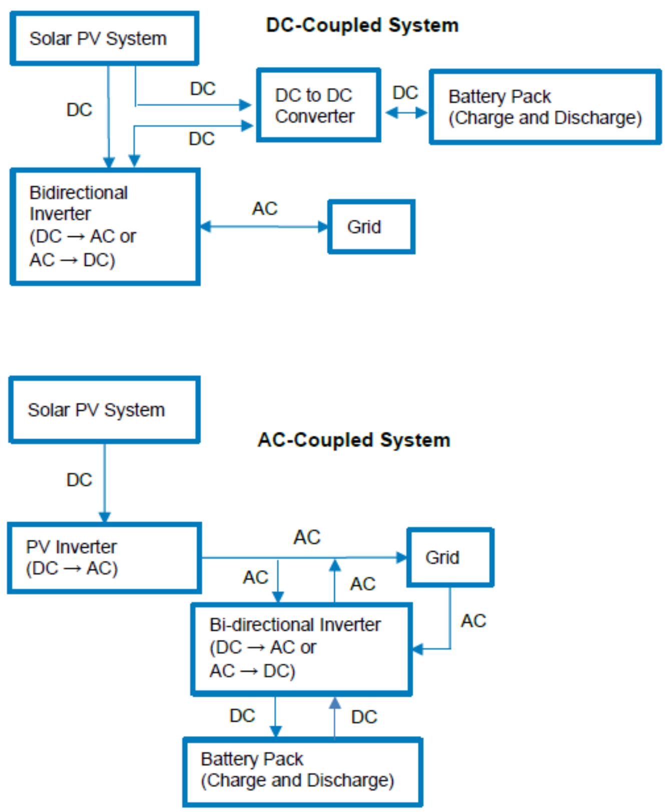


Figure 12 – Configuration examples of DC and AC-coupled PV and storage systems. Source: (Fu, et al., 2018).

Depending on storage capacity needed, the layout of storage unit(s) can be centralized, distributed, or partially distributed. Units that are distributed would be located at each station of the network. A centralized location of storage unit(s) could result in less storage units used and offer higher convenience for maintenance and servicing of units. On the other hand, it will have a larger footprint, wire lengths may have to reach far network sections, and a failure could damage the whole storage system. Distributed storage units would have a smaller footprint per storage location, less wiring between units and network, and a failing storage unit would not risk the whole system. Alternatively, the number of units needed increases according to the number of stations and maintenance and servicing may be more demanding. Partially distributed units could be a compromise between the centralized and distributed options.

2.6 Projected Cost

Approximating a cost for the system can be complex due to changing costs, changes in technology due to developments, and some unknown costs for components. An energy storage installation cost can be approximated using equation (17) provided in a storage system cost benchmark report (Fu, et al., 2018).

$$\textit{Energy storage installation cost}\left(\frac{\$}{kWh}\right) = \textit{Battery cost}\left(\frac{\$}{kWh}\right) + \frac{\textit{Other cost components (\$)such as battery inverter and labor}}{\textit{Storage system size }(kW) \times \textit{Duration (hours)}} \quad (18)$$

Similarly, a report on cost projections for utility-scale storage uses equation (19) to establish an anticipated cost trend (Cole & Frazier, 2019).

$$\textit{Total Cost}\left(\frac{\$}{kWh}\right) = \textit{Energy Cost}\left(\frac{\$}{kWh}\right) + \textit{Power Cost}\left(\frac{\$}{kW}\right) / \textit{Duration }(hr) \quad (19)$$

The cost trend established in Figure 13 is used to approximate the cost of the needed storage for the Superway.

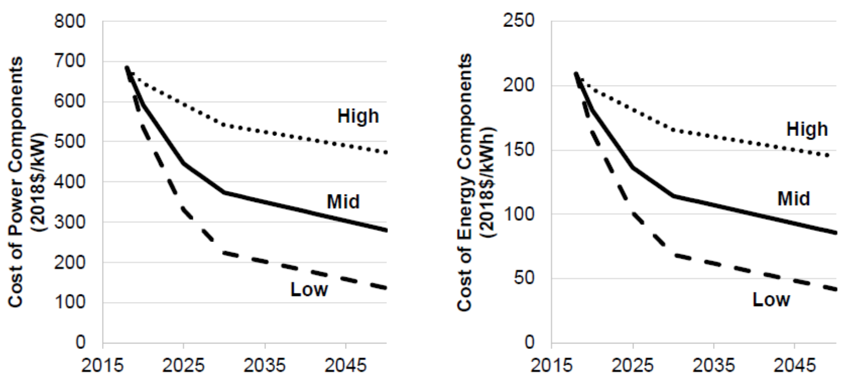


Figure 13 – Cost projections for lithium-ion systems. Source: (Cole & Frazier, 2019).

3.0 RESULTS AND DISCUSSION

This section of the report will discuss the analytical results obtained and discuss a proposed design and layout of the storage unit for the north-south route of the Superway.

3.1 Analytical Results

The following analytical sections show and explain results obtained to understand the demand and supply of electrical energy for the Superway. The demand and supply simulated values were obtained through a computational simulation for PV canopies for solar-powered transit designed by Fogelquist (Fogelquist, 2019). The data obtained was further analyzed and manipulated to show a worst-case scenario for the route on an hourly basis for one day. This information was used to determine size of electrical energy storage needed for the system to operate solely from stored energy and no other source of energy.

3.1.1 Energy Demand Results

To determine energy demand of the system, various values and characteristics shown in Table 1. were used in the simulation. The simulation used equation (4) to calculate power and energy values.

Table 1 – Superway transit system characteristics for simulation.

System and Route Characteristics	
Vehicle Mass (kg)	1900
Vehicle Frontal Area (m^2)	4
Wheel Radius (m)	0.1524
Static Rolling Resistance Coefficient (m)	0.0014478
Drag Coefficient	0.51
Average Electric Motor Efficiency	0.85
Regenerative Braking Efficiency	0.3
Auxiliary Power Demand (W)	3500
Line Speed (m/s)	13.4
Headway (s)	5
Dwell Time (s)	20
Average Elevation Change (m)	0
Number of Vehicles	155
Number of Stations	14
Route Length (m)	14,900
Average Station Distance	1.49
Average Trip Duration (min)	2.29

The yearly energy demand of the system was calculated to be 14.1 GWh. The vehicle hourly energy demand was determined to be 10.4 kWh. This yields an approximate average efficiency of .27 kWh/km per individual vehicle. The efficiency is among typical electric vehicle efficiencies in the market (U.S. Environmental Protection Agency, 2020).

3.1.2 Energy Supply Results

The computer model sized a PV canopy to meet the electrical demand of the system and simulated the hourly electrical generation for a whole year using equation (10). The total power generated each day was calculated for a whole year, or 365 days. A function within google sheets was used to highlight the lowest and highest value from all the values. The highlighted values corresponded to a specific day. The hourly data from the highlighted days were gathered and graphed. A total power of 7.3 MW in a day was the lowest generated power for the year. A total power of 131.9 MW was the highest generated power for the year. Hourly energy generated results can be seen in Table 2 for lowest producing day.

Table 2 – Energy supply to system.

		Time (hour)	Energy Output (kWh)			Time (hour)	Energy Output (kWh)
December 27 (Min)	1	12:00 am - 1:00 am	0	June 7 (Max)	1	12:00 am - 1:00 am	0
	2	1:00 am - 2:00 am	0		2	1:00 am - 2:00 am	0
	3	2:00 am - 3:00 am	0		3	2:00 am - 3:00 am	0
	4	3:00 am - 4:00 am	0		4	3:00 am - 4:00 am	0
	5	4:00 am - 5:00 am	0		5	4:00 am - 5:00 am	0
	6	5:00 am - 6:00 am	0		6	5:00 am - 6:00 am	655.41
	7	6:00 am - 7:00 am	0		7	6:00 am - 7:00 am	2,496.71
	8	7:00 am - 8:00 am	0		8	7:00 am - 8:00 am	4,718.38
	9	8:00 am - 9:00 am	319.47		9	8:00 am - 9:00 am	8,022.70
	10	9:00 am - 10:00 am	733.64		10	9:00 am - 10:00 am	11,353.48
	11	10:00 am - 11:00 am	1,004.81		11	10:00 am - 11:00 am	14,109.19
	12	11:00 am - 12:00 pm	1,187.19		12	11:00 am - 12:00 pm	15,764.78
	13	12:00 pm - 1:00 pm	1,181.39		13	12:00 pm - 1:00 pm	16,337.58
	14	1:00 pm - 2:00 pm	1,072.75		14	1:00 pm - 2:00 pm	15,799.92
	15	2:00 pm - 3:00 pm	1,258.78		15	2:00 pm - 3:00 pm	14,526.06
	16	3:00 pm - 4:00 pm	519.66		16	3:00 pm - 4:00 pm	12,256.73
	17	4:00 pm - 5:00 pm	51.50		17	4:00 pm - 5:00 pm	8,469.55
	18	5:00 pm - 6:00 pm	0		18	5:00 pm - 6:00 pm	5,248.03
	19	6:00 pm - 7:00 pm	0		19	6:00 pm - 7:00 pm	2,184.21
	20	7:00 pm - 8:00 pm	0		20	7:00 pm - 8:00 pm	0
	21	8:00 pm - 9:00 pm	0		21	8:00 pm - 9:00 pm	0
	22	9:00 pm - 10:00 pm	0		22	9:00 pm - 10:00 pm	0
	23	10:00 pm - 11:00 pm	0		23	10:00 pm - 11:00 pm	0
	24	11:00 pm - 12:00 am	0		24	11:00 pm - 12:00 am	0

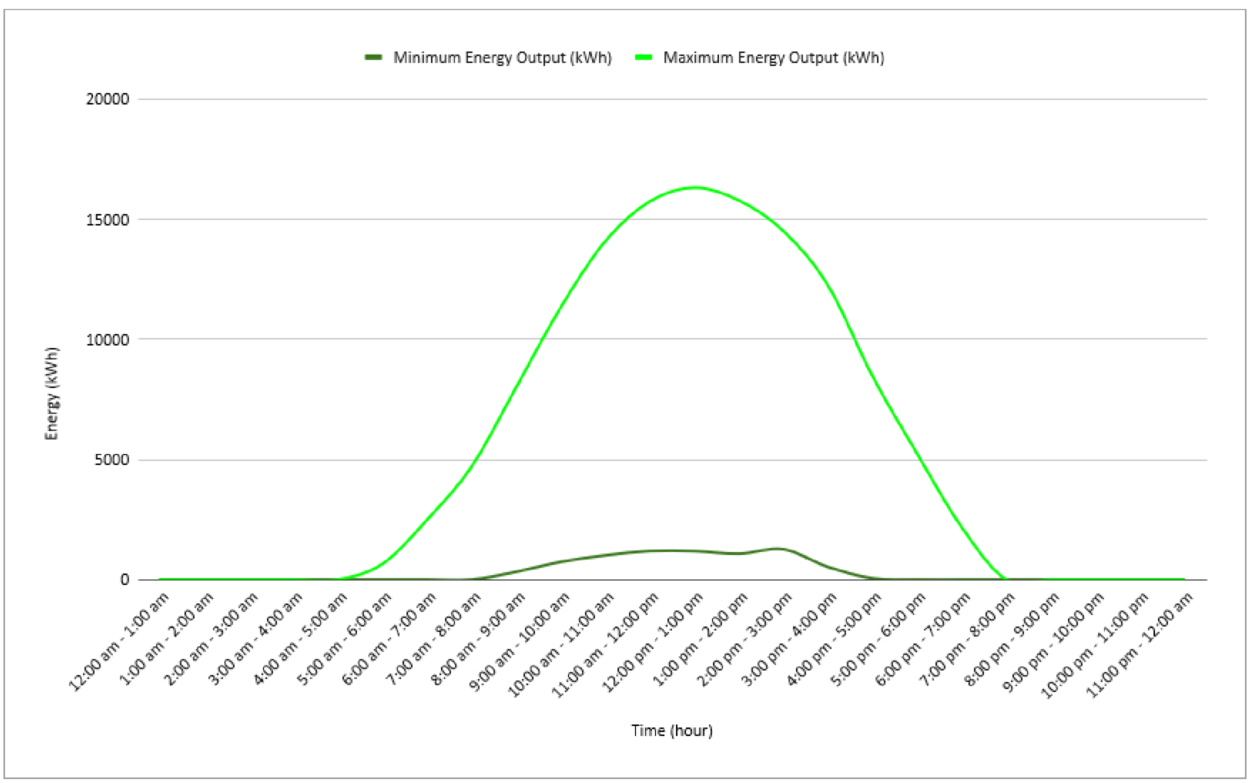


Figure 14 – Minimum and maximum energy outputs of system.

3.1.3 Power Surplus Results

The power surplus was calculated using equation (11). The differences between hourly power supply and power demand were calculated for each hour of a day for a whole year. The net power surplus was then calculated per day for a whole year. Looking at the results from an hourly perspective gives insight into what time of a day the system may need utility energy supplied and when it would be able to operate only from the PV generated energy. Looking at the results from a daily perspective gives insight into how much energy would be available for storage at the end of the day.

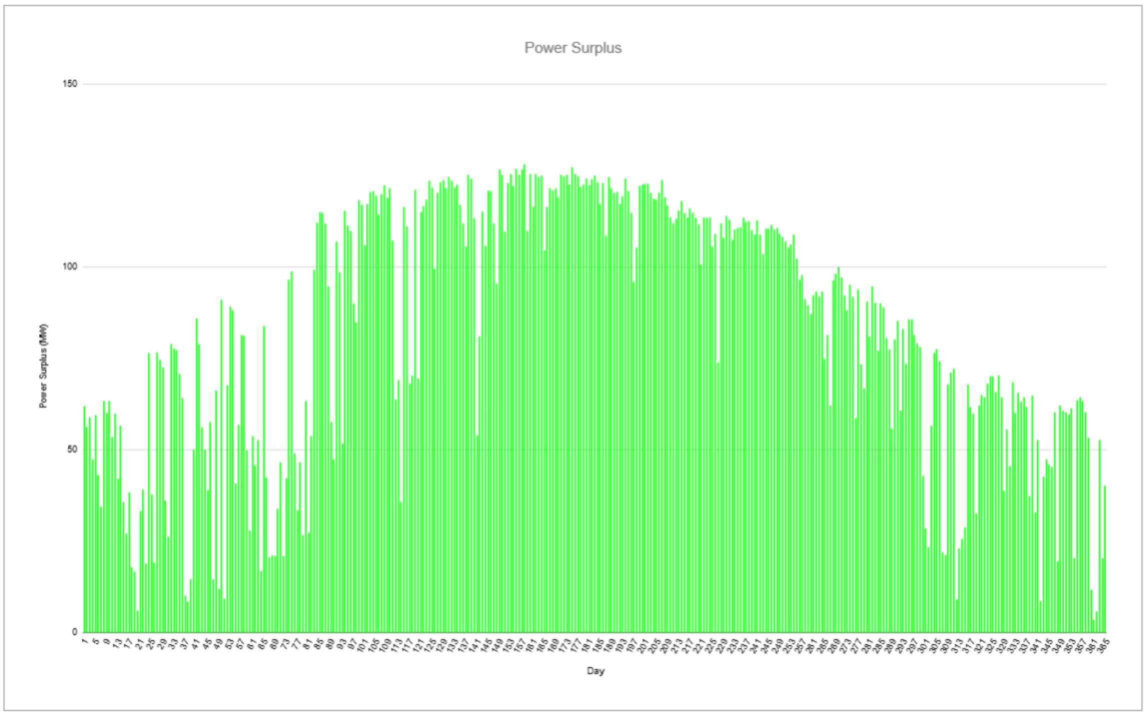


Figure 15 – Daily net power surplus for year.

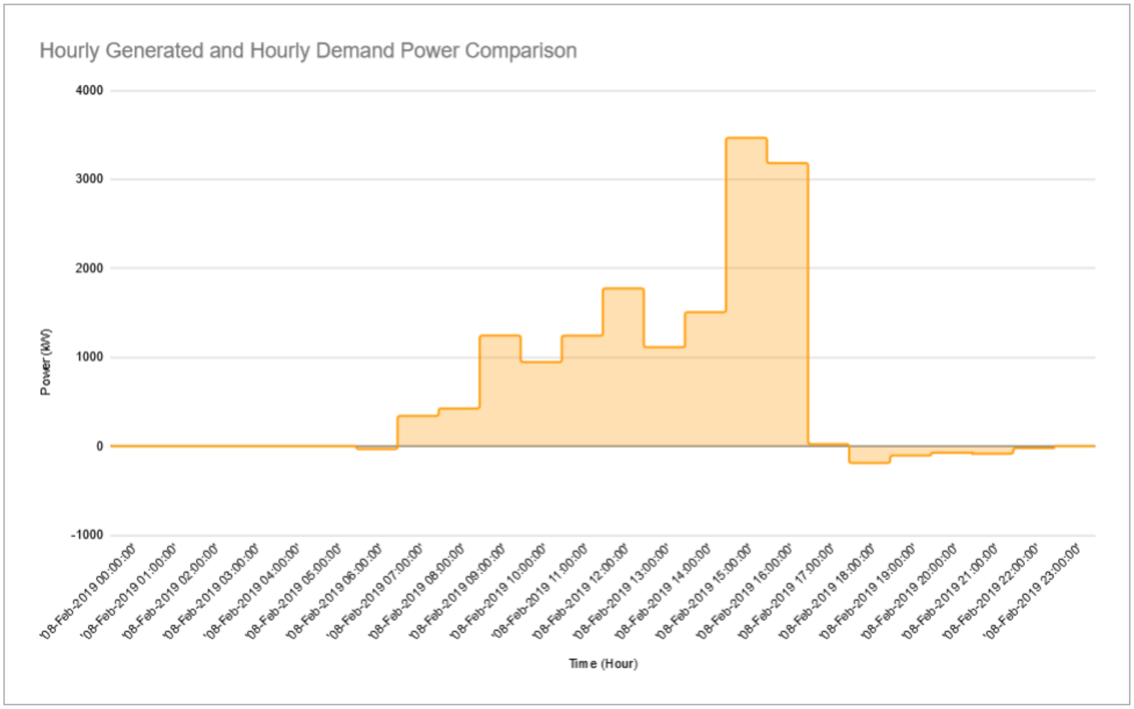


Figure 16 – Hourly power generated and demand for most busy day in model.

3.1.4 Electrical Energy Storage Size

The energy demand and supply were compared to determine the required storage size. The hourly number of passengers collected from the park and ride shuttle is shown in Table 3 for the busiest day. The number of vehicles needed was calculated using equation (6) while assuming a maximum occupancy of six passengers per vehicle. The vehicle hourly energy demand was used to calculate the hourly system demand based on passenger data with equation (7). The hourly demand of the system calculated represents what a most demanding day could look like based on passenger data from a transportation shuttle that has a similar route.

Table 3 – Energy demand on system based on passenger data.

		Time (hour)	Passengers	Vehicles Needed	Energy Demand (kWh)
February 11, 2019 (Least Busy)	1	12:00 am - 1:00 am	0	0	0
	2	1:00 am - 2:00 am	0	0	0
	3	2:00 am - 3:00 am	0	0	0
	4	3:00 am - 4:00 am	0	0	0
	5	4:00 am - 5:00 am	0	0	0
	6	5:00 am - 6:00 am	0	0	0
	7	6:00 am - 7:00 am	4	1	10.40
	8	7:00 am - 8:00 am	16	3	31.20
	9	8:00 am - 9:00 am	169	29	301.64
	10	9:00 am - 10:00 am	56	10	104.01
	11	10:00 am - 11:00 am	147	25	260.04
	12	11:00 am - 12:00 pm	144	24	249.63
	13	12:00 pm - 1:00 pm	89	15	156.02
	14	1:00 pm - 2:00 pm	132	22	228.83
	15	2:00 pm - 3:00 pm	132	22	228.83
	16	3:00 pm - 4:00 pm	47	8	83.21
	17	4:00 pm - 5:00 pm	101	17	176.82
	18	5:00 pm - 6:00 pm	92	16	166.42
	19	6:00 pm - 7:00 pm	55	10	104.01
	20	7:00 pm - 8:00 pm	49	9	93.61
	21	8:00 pm - 9:00 pm	28	5	52.01
	22	9:00 pm - 10:00 pm	25	5	52.01
	23	10:00 pm - 11:00 pm	8	2	20.80
	24	11:00 pm - 12:00 am	0	0	0

		Time (hour)	Passengers	Vehicles Needed	Energy Demand (kWh)
February 8, 2019 (Most Busy)	1	12:00 am - 1:00 am	0	0	0
	2	1:00 am - 2:00 am	0	0	0
	3	2:00 am - 3:00 am	0	0	0
	4	3:00 am - 4:00 am	0	0	0
	5	4:00 am - 5:00 am	0	0	0
	6	5:00 am - 6:00 am	0	0	0
	7	6:00 am - 7:00 am	15	3	31.20
	8	7:00 am - 8:00 am	50	9	93.61
	9	8:00 am - 9:00 am	142	24	249.63
	10	9:00 am - 10:00 am	134	23	239.23
	11	10:00 am - 11:00 am	232	39	405.66
	12	11:00 am - 12:00 pm	272	46	478.47
	13	12:00 pm - 1:00 pm	208	35	364.05
	14	1:00 pm - 2:00 pm	229	39	405.66
	15	2:00 pm - 3:00 pm	160	27	280.84
	16	3:00 pm - 4:00 pm	147	25	260.04
	17	4:00 pm - 5:00 pm	146	25	260.04
	18	5:00 pm - 6:00 pm	76	13	135.22
	19	6:00 pm - 7:00 pm	104	18	187.23
	20	7:00 pm - 8:00 pm	55	10	104.01
	21	8:00 pm - 9:00 pm	37	7	72.81
	22	9:00 pm - 10:00 pm	43	8	83.21
	23	10:00 pm - 11:00 pm	7	2	20.80
	24	11:00 pm - 12:00 am	0	0	0

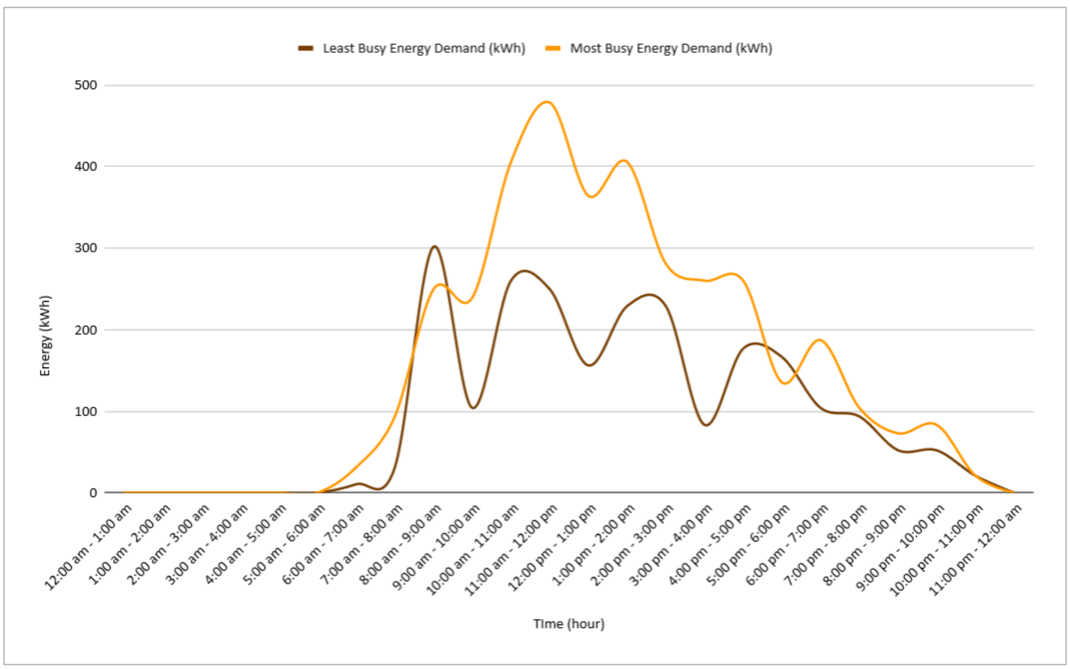


Figure 17 – Least and most busy energy demands on system based on park and ride shuttle data.

Figure 18 shows a graphical representation of the hourly energy demand and supply. This was used to analyze a worst-case scenario for the route.

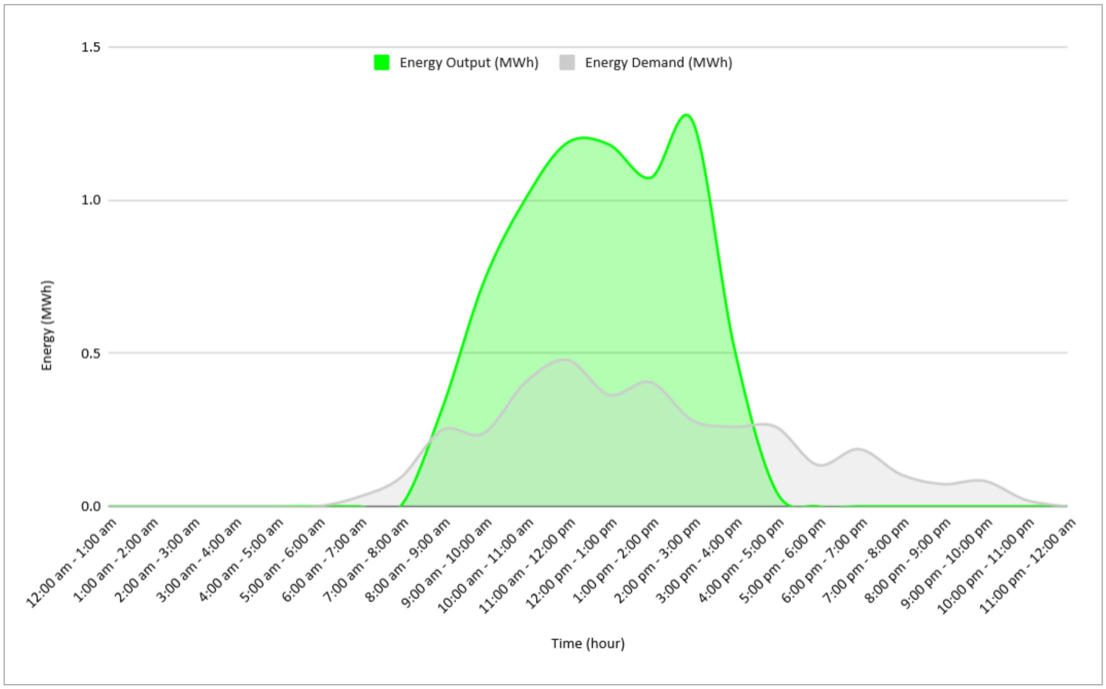


Figure 18 – Energy supply and energy demand in worst-case scenario.

As seen on the graph in figure 19, the mornings and evenings have an energy demand that is not covered by generated energy. Energy generation is concentrated more towards the middle of the day. The total energy demand of the system was calculated to be 3.67 MWh for the busiest day. This value was used to establish the energy storage size needed to operate the system for one day. Being that the system is intended to be connected to the grid, the storage system will be sized to operate the system for about two days since PG&E can take up to 24 hours to restore electric service unless otherwise planned or factors that are out their control arise (PG&E, 2020). A 2% energy loss for wiring between inverter and loads was considered as recommended by Messenger and Abtahi (Messenger & Abtahi, 2017). Equation (15) and a multiplication factor of 1.25 suggested by Messenger and Abtahi were used to account for more efficiencies and a discharge safety. The actual storage size needed was computed to be 4.97 MWh for one day. For two days the storage size required would be approximately 9.95 MWh. This storage size could also serve as a supplement to make up for any discrepancies in energy demand and supply under normal operation.

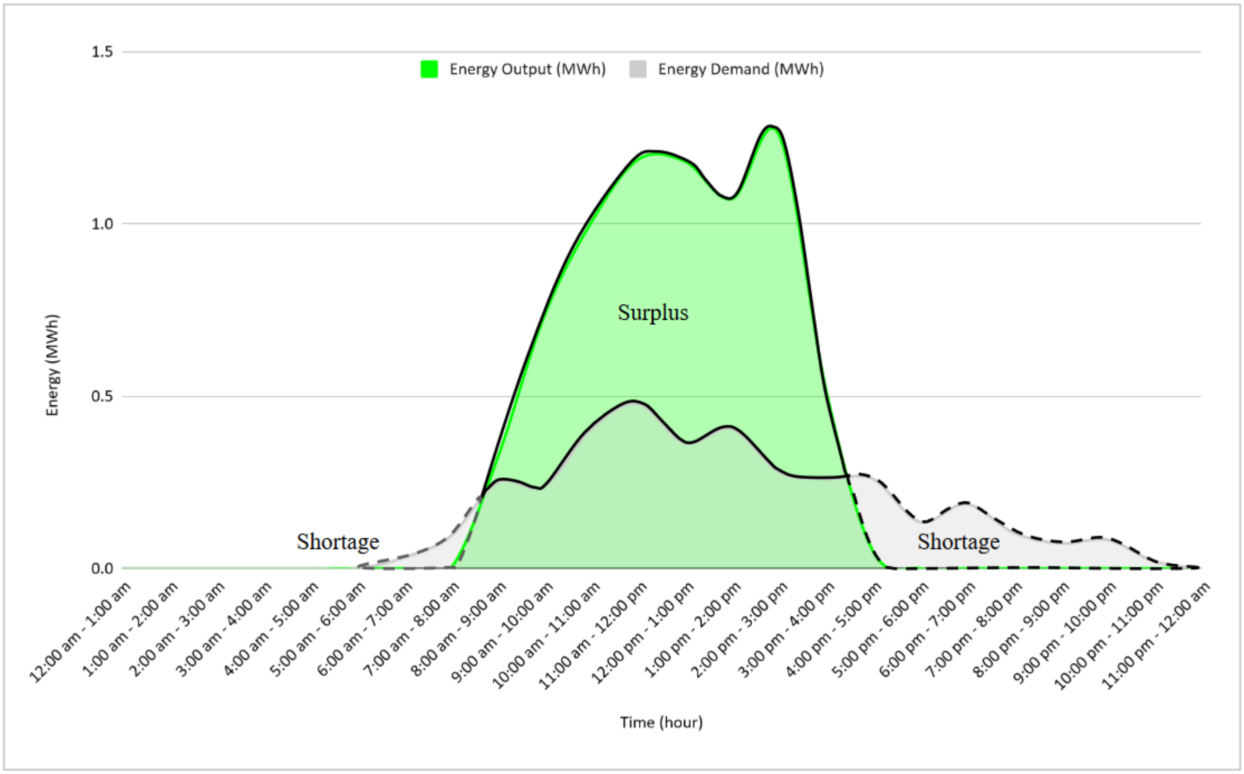


Figure 19 – Regions of overgeneration and shortage of energy for energy supply and demand worst-case scenario.

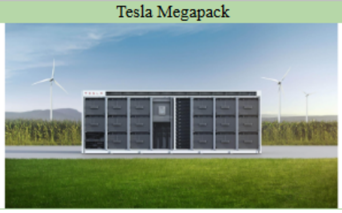
3.2 Electrical Energy Storage Unit

The designs for the electrical energy storage unit proposed in the following sections are based off values provided by the computational model and recommended sizing calculations for PV systems. The recommended layout and distribution of the system is intended to improve overall system reliability and maintain safety as a priority.

3.2.1 Design

The storage unit design can be based off a storage container design or a more compact unit. The larger units can have dimensions close to dimensions of typical storage containers. These could be close to eight by twenty feet. Four unit designs readily available in the market were chosen based on their foreseen potential and applicability to handle the demands of the Superway project. One unit design option is Tesla's Megapack which offers a complete storage system rated at 3 MWh maximum energy capacity (Tesla, 2020). Their product is scalable, offers an all-in-one tested system, has low installation times, and the company helps with planning and installation (Tesla, 2020). Similarly, Tesla offers the Powerpack with a capacity of 232 kWh and smaller footprint (Tesla, 2020). They offer an even more compact storage unit known as the Powerwall which offers 13.5 kWh (Tesla, 2020). The other larger unit design option is Oilfield instrumentation's lithium battery storage units. Their units are available in different sizes and are designed with features to safely handle battery storage (Oilfield Instrumentation, 2020). To add, an article on safety in large scale energy storage deployments suggests isolating battery racks to help with fault detection (Fishman, 2020). This can be considered as Oilfield's units do not include batteries with their storage units which leaves more flexibility to choose battery types and more control over electrical storage size. Table 4 shows the units and number of units needed at each station or at four stations to meet storage requirements. Additional technical specifications, such as operating voltage, dimensions, and certifications, can be seen in the Appendix section of the report.

Table 4 – Possible unit designs. Source: (Tesla, 2020), (Oilfield Instrumentation, 2020), (Tesla, 2020), & (Tesla, 2020).

Specifications	Tesla Megapack	Oilfield Instrumentation Model 20-2
		
Storage Capacity	3 MWh	N/A
Dimensions	23 ft 5 in x 5 ft 3 in x ~ 8 ft	20 ft x 8 ft x ~ 8 ft
Components / Features	Battery modules, bi-directional inverters, thermal management system, AC main breaker, Controls	Combustion resistant materials, thermostat, HVAC controls, humdity indicator, audible and visual strobe warnings, and electric panels
Assembly Required	No	Yes
Applications	Renewable smoothing, T&D investment deferral, voltage support, capacity support, microgrid, market participacttion, and frequency regulation	Lithium battery storage and related
Support	Team helps to identify custom site requirements and design a solution for application	Can contact for custom project options
Weight	N/A	13,800 lbs
Full Distribution	0.24	N/A
Partial Distribution	1	N/A
	Tesla Powerpack	Tesla Powerwall
		
Storage Capacity	232 kWh	13.5 kWh
Dimensions	41.1 in x 54.9 in x 86.2 in (inverter - 41.1 in x 54.9 in. x 86.2 in)	45.3 in x 29.6 in x 5.75 in
Components / Features	16 battery pods, DC-DC converter, cell monitoring sensors, thermal control system (liquid cooling)	Connection point, liquid cooling, inverter, battery pack
Assembly Required	No	No
Applications	Outdoor rated, peak shaving, emergency backup, load shifting, demand response, microgrid, power production, grid reliability	Weatherproof, solar self-consumption, back-up power, time-based control, off-grid capabilities
Support	Company support, certifications	Company support, 10 year warranty, certifications
Weight	4,847 lbs (inverter - 2,470 lbs)	251.3 lbs
Full Distribution	4	53
Partial Distribution	11	185

3.2.2 Layout

The distribution of the electrical storage units was determined by taking into consideration the number of units needed, reliability, and safety. A partially distributed layout was found to be a compromise between a fully distributed or centralized layout. A partially distributed systems can offer less to the whole storage system if one unit fails, require less wiring to reach a station, reduce the total footprint taken at each location, and maintain reasonable maintenance and servicing capabilities. Additionally, the suggested locations of the units are surrounded by a few fire stations. This is beneficial as batteries can pose flammability hazards if they fail. Four suggested locations to place the storage units are next to Superway stations that are surrounded by open spaces owned by San Jose State University.

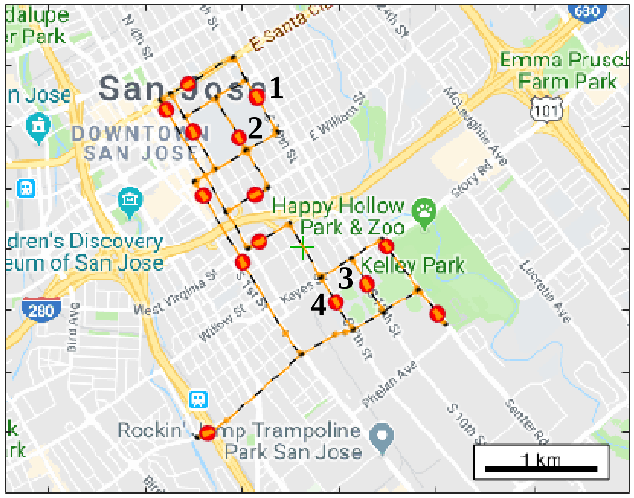


Figure 20 – Recommended locations for storage units at station locations.

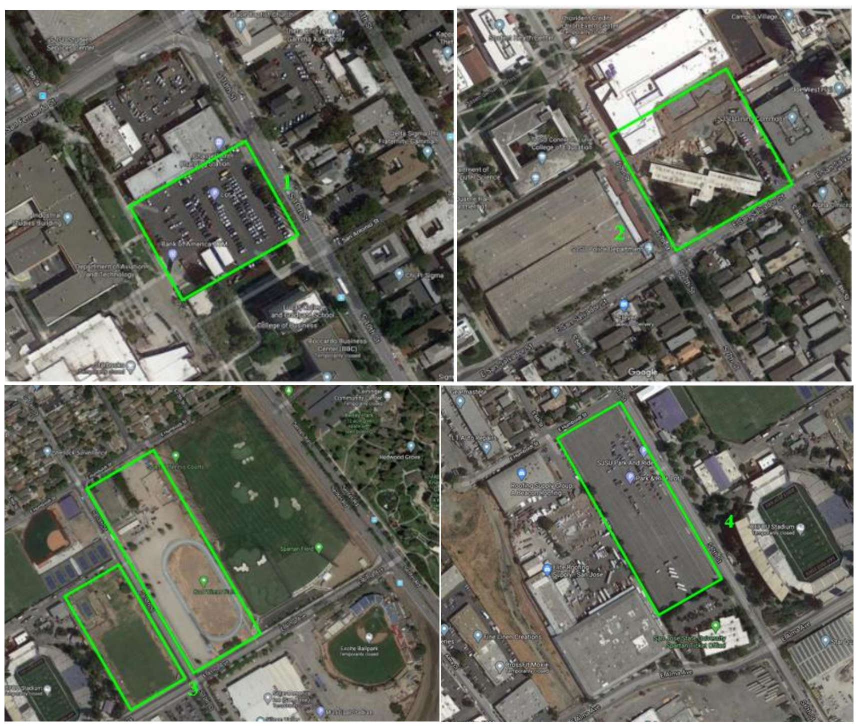


Figure 21 – Possible locations for storage units. Source: google maps.

An electrical coupling system for the main components was defined to have a system in place incase an electrical energy storage unit purchased does not. The two options for the storage unit were AC-coupling and DC-coupling. As there are still many unknowns for the overall Superway project, for this project it is probably best to present scenarios rather than specific recommendations. If maximum efficiency is a driving factor for this project, a DC-coupled system can be recommended as it offers lower costs and maximizes efficiency between PV array and battery (Fu, Remo, & Margolis, 2018). Cost are lowered due to only needing one bidirectional inverter which lowers the amount of hardware and materials needed (Fu, Remo, & Margolis, 2018). Overall efficiency of the system is maximized as having less components helps with roundtrip efficiency and PV array and batteries are directly connected (Fu, Remo, & Margolis, 2018). To add, if batteries are purchased separately it is recommended to isolate the battery racks to help with fault detection (Fishman, 2020). A general DC-coupled system configuration can be seen in figure 22. An AC-coupled system is recommended if retrofitting and more flexibility with installation location of various components is desired (Fu, Remo, & Margolis, 2018).

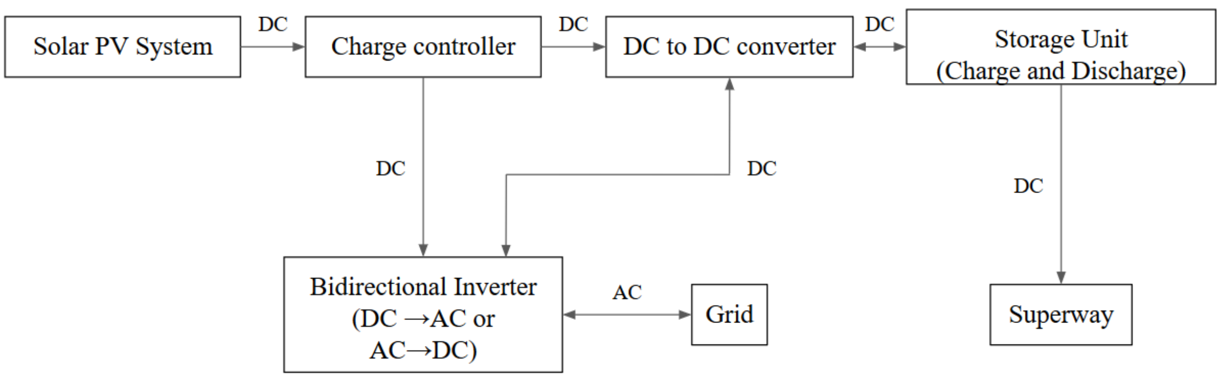


Figure 22 – DC-coupled system general configuration. Adapted from: (Fu, Remo, & Margolis, 2018).

With a larger storage unit, two option are to either have a unit directly next to a station or a distance away. Having a larger unit directly next to a station would require shorter lengths of wire and related materials, avoid planning for other site, more visible impact on station area, and closer to pedestrians, potentially putting safety of surroundings at higher risk. Similarly, a smaller unit may impose similar effects on the area, but it might be able to blend in more with some sort of suspended installation. Having a larger unit installed away from a station would require longer lengths of wire and related materials, need more planning for the site, less visible impact on station area, and further from pedestrians, potentially resulting in less of a safety hazard in the case of failure. A smaller unit placed away from a station would share similar characteristics. Another possibility would be to use a combination of larger and smaller units. The larger units can be used to storage the energy for the podcars while smaller units can be used to power stations. Wiring for a unit far away from a station could have cables ran underground or overhead. If a unit can be placed next to a station, then the wiring could run along the station. While "utilities report that it can cost five times more to install underground power line than overhead line," underground wiring could be safer during severe weather conditions and will keep wires away from people, wildlife, or objects (Thiele, 2019). Wiring for a unit at the station will require choosing proper conduit, conduit fittings, wire gauges, and routing methods that meet specification and standards. For instance, under the national electric code (NEC), a 600V circuit would have additional depth requirements that lower or higher voltage circuits (Csanyi, 2014).

Figure 23 – What a unit the size of a storage container would look like in a parking lot located next to a Superway station. Source: google earth.

3.2.3 Cost

The cost of the energy storage system was estimated to determine its financial impact on the Superway project. The cost was estimated using equation (19) and graphs provided in (Cole & Frazier, 2019). Figure 24 shows the projected high, medium, and low costs of the system based on the year it is built.

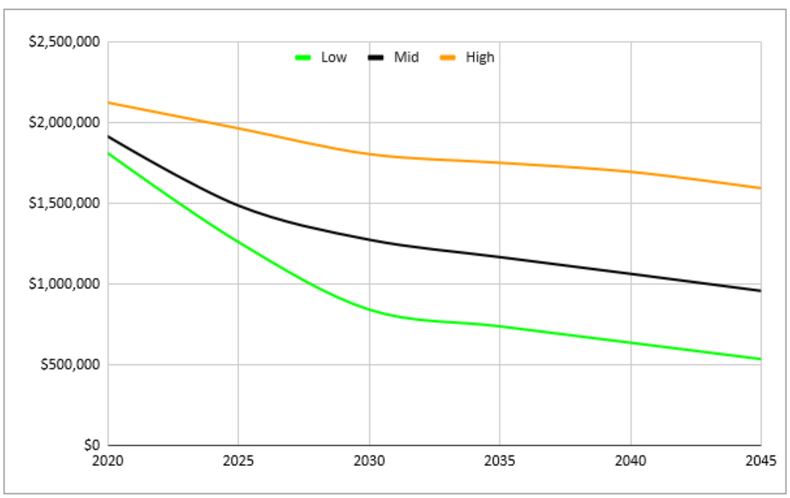


Figure 24 – Projected cost of system.

3.3 Case Study

A case study was conducted to further analyze the factors associated with implementing a storage unit into the system and the option of buying units available in the market or building custom units. For comparison of storage units, the Tesla Megapack was chosen as the market available storage unit solution due to its availability, storage capacity, and since it is widely used in utility scale applications. A custom unit was modeled entirely in Solidworks with a focus on off the shelf parts, to keep the need for custom parts down, and high-level system components for it to be compatible for comparison. Detailed drawings of the custom unit can be found in the Appendix.

3.3.1 Market Available Solution

The Tesla Megapack was chosen to be the product for comparison due to their availability and battery storage solutions being widely implemented into utility scale systems. For example, Tesla recently started the deployed of Megapacks at a PG&E substation in Moss Landing, California. This project is planned to consist of 256 Megapacks to have a capacity of up to 182.5 MW or 730 MWh. When operation, the "battery system will be one of the largest utility-owned lithium-ion battery storage systems in the world" (Lambert, 2020). It is projected to be completed within a year and expected to offer over $100 million in savings to the utility company (Lambert, 2020). An electrical utility reseller of power in Saint John, Canada recently signed a contract with Tesla to install a Megapack unit to alleviate costs and greenhouse gas emissions. They estimate a total savings of up to $200,000 a year. The total cost of the project, including the "design, construction, purchase of materials such as a Tesla battery, and others, is $1.5 million" (Fox, 2020). A recent article on Tesla's Megapack with questions answered by Elon Musk, Tesla's CEO, determined that "the battery pack portion of it is less than $200/kWh" while "the power electronics and servicing over 15 to 20 years take the price up to roughly $300/kWh" (Shahan, 2020). These articles provide insight on the cost of a Megapack unit which can be used to compare to a custom unit. With a price of roughly $300/kWh and a storage capacity of 3 MWh, the total cost can be approximated to about $900,000 per Megapack unit. If the Canadian project install cost of $1.5 million is taken into consideration, then it can be approximated that for a complete install after batteries and servicing costs, the remaining costs for things such as design, construction, materials, and labor can be about $600,000. Emails were sent out to the company throughout the project to validate the estimated costs and to get more accurate numbers. However, no replies were received and as a result the numbers given and cited from the company's CEO were the closest to actual pricing out there based on research conducted.

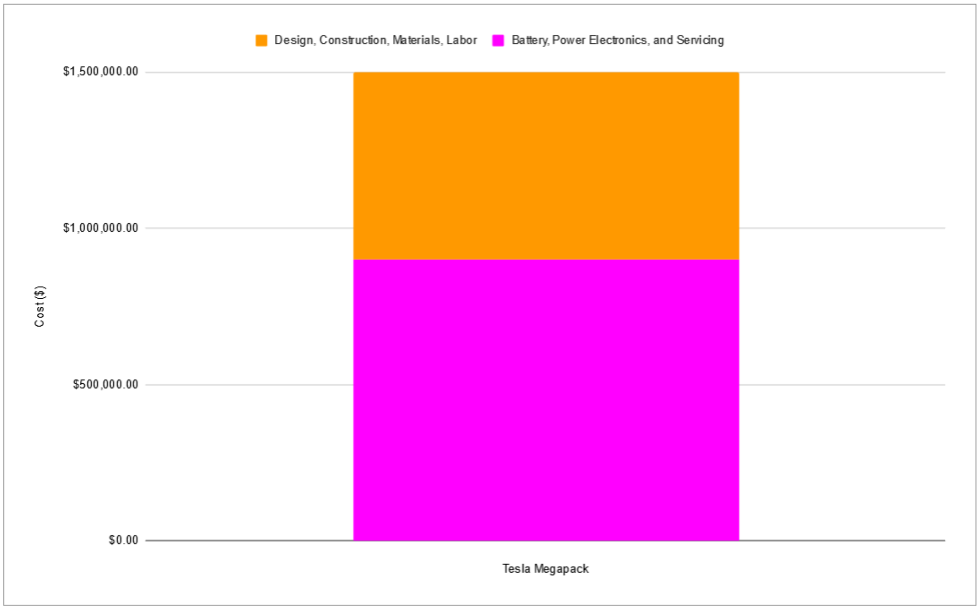


Figure 25 – Tesla Megapack's estimated cost based on market research.Source: (Fox, 2020) & (Shahan, 2020)

3.3.2 Custom Energy Storage Unit

A custom unit was modeled using Solidworks to get an idea of what a possible battery storage unit could consist of. A bill of materials (BOM) was created along with drawings for documentation purposes and cost analysis. Simplified heat load and floor loading analysis was conducted to size adequate thermal management and to verify that the container floors would be able to withstand the battery occupied racks. The model was set up to have an AC-coupled and a DC-coupled configuration to show both scenarios. The model shows the system at a high-level design. The electrical components on the side of the container were modeled and placed at their location to show the components involved with energy storage. It is not uncommon for those components to be found closer to the solar panel systems. They can be mounted to the structures supporting the solar panels. This section of the report will show additional items that influenced the design of the custom unit.

Figure 26 – Inverter and individual solar panel power optimizers mounted on structure. Location: Santa Cruz, CA.

3.3.2.1 Storage Unit Container

The storage unit was modeled after a typical 8 ft. x 20 ft. x 8.6 ft. shipping container. This was done as research has shown that many utility scale energy storage unit suppliers tend to use a similar design for their enclosures. Although a 40 ft. length container would offer more space inside for components, it was avoided as its mobility would be more difficult. The 10 ft. length container was not an option as it would not offer enough space inside for many components. The 20 ft. length container can also have forklift tube access holes to allow for easier transportation. Additionally, these containers are typically weather proof allowing electronics inside to be safe from outside conditions.

3.3.2.2 Electrical Components

The battery chemistry of choice for the custom unit was lithium iron phosphate. They are recommended as most stable and plausible technology for renewable energy storage applications (Messenger & Abtahi, 2017). The battery was modeled after a LiFePo4 battery module found on Amazon.com. They are rated at a total capacity of 400 Ah. With 192 batteries, there would be a storage capacity of 960 kWh. More details on the battery, found on the manufacturer's website, can be found in the Appendix.

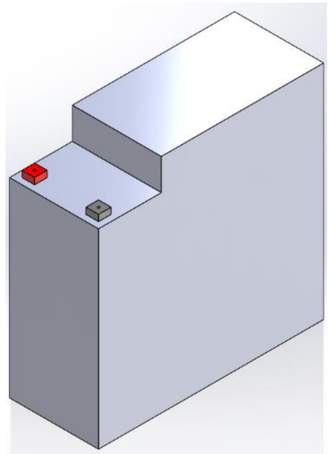


Figure 27 – Battery model used for storage unit.

The method of connection for batteries was determined to be Anderson connectors. These connectors can accommodate a range of wire gauges and power ratings. The connectors will allow for a quicker and toolless battery disconnect process when servicing a battery. An attachment handle can also be added to make pulling the connectors apart easier. They can also be secured to a surface, in this case the bottom of the shelf, for a cleaner installation. Although the manufacturer’s website does not specify a specific screw size, it appears as if the terminals are threaded. As a result, on the battery terminal side, a wire with crimped on ring terminal can be screwed down onto the terminal.

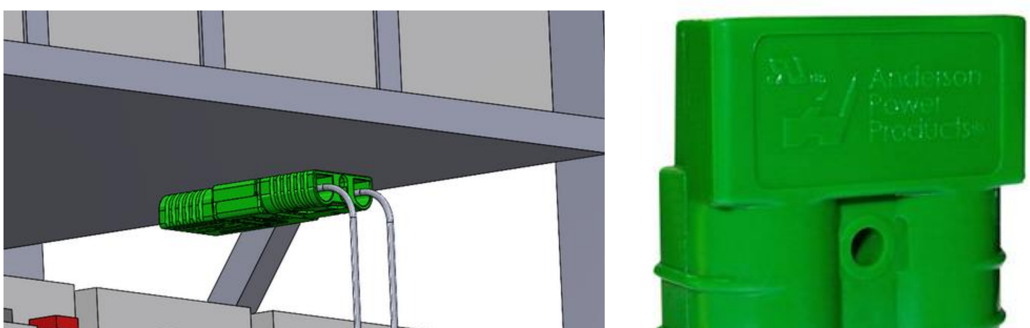


Figure 28 – Anderson connector used in the model (left) and available SB50 Anderson connectors for 6 to 16-gauge wire (Right).Source: (APP, 2020).

Solar panels can easily be connected through various MC4 connectors. These connectors are offered in a variety of configurations to help connect panels in series or parallel configurations.

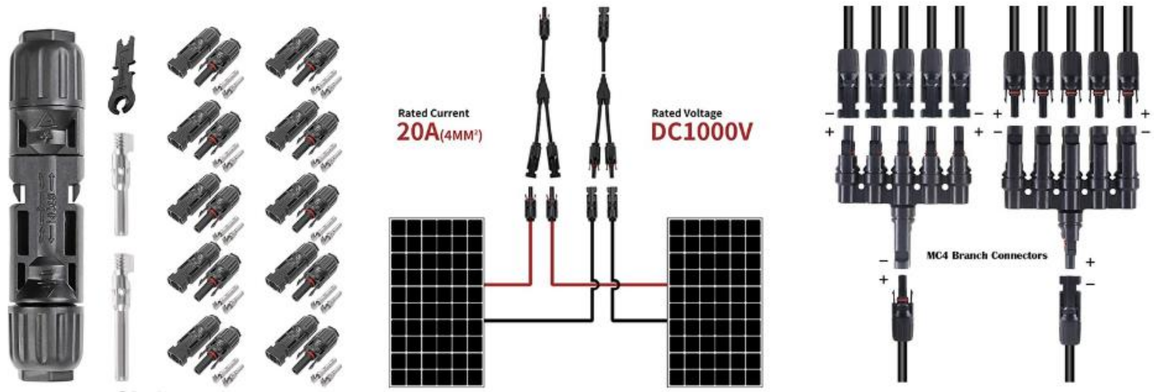


Figure 29 – Typical MC4 connectors. Source: Amazon.com.

From research conducted on the grid interconnection process, approved equipment documents were found on the PG&E distribution interconnection handbook website. The PG&E website provides links to documents regarding safety switches, primary voltage disconnect switches, eligible inverters, and incentive eligible photovoltaic modules (PG&E, 2020). However, when attempting to open some of the links, the website was redirected to another website stating that it is being updated. Some of the working links showed documents, found in the Appendix, that can be used to source electrical equipment for a project that needs to be approved for interconnection.

For the AC-coupled configuration, the components were modeled after Enphase's components and connection diagram.

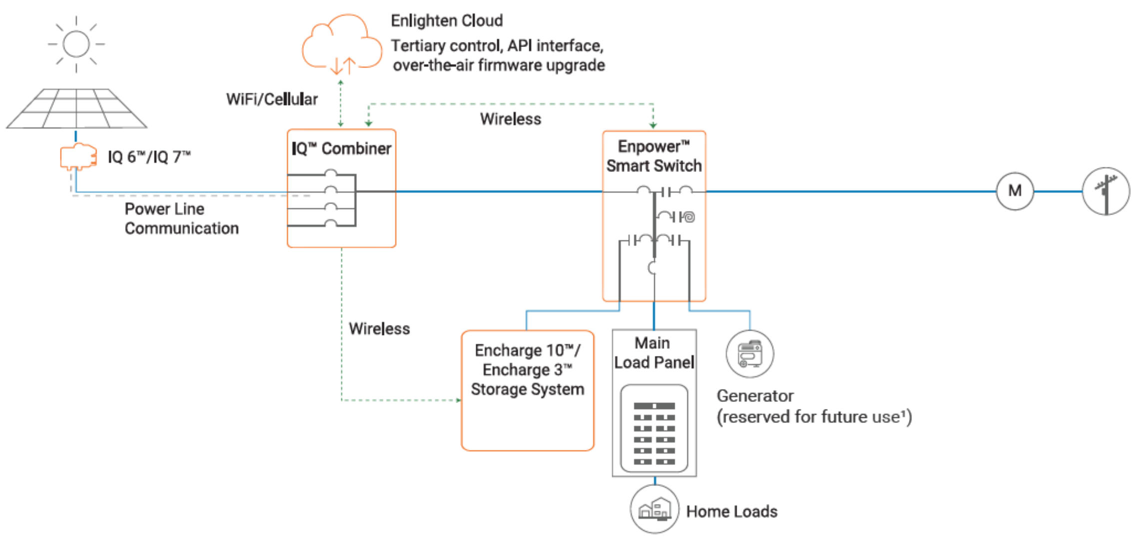


Figure 30 – Enphase component installation diagram. Source: (Enphase, 2020)

For the DC-coupled configuration, the components were modeled after Solar Edge's components and connection diagram.

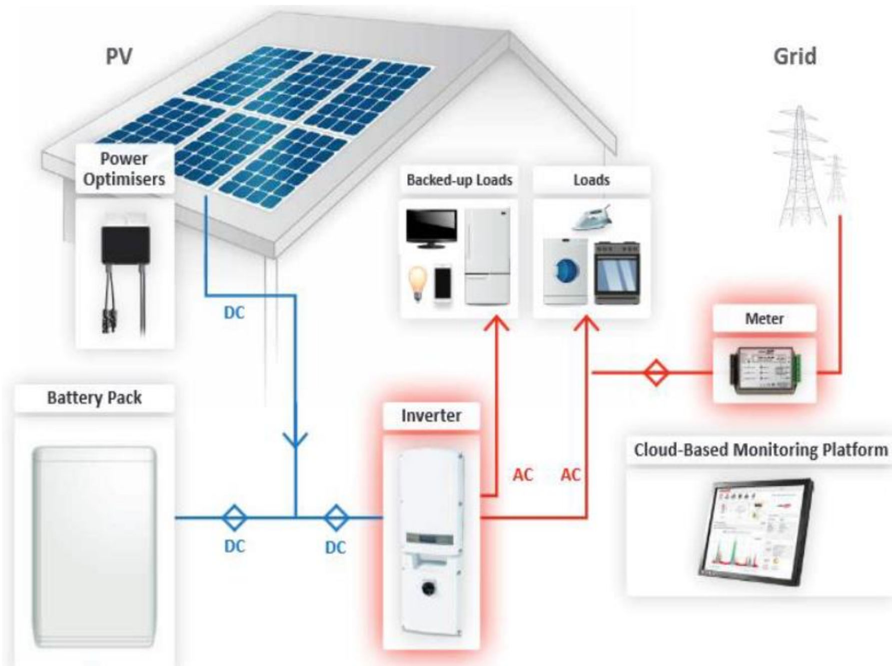


Figure 31 – Solar Edge component installation diagram.Source: (Solar Edge, 2020).

Additional large scaled vendor installation diagrams can be found in the Appendix. It is important to note that there can be various installation possibilities. Both the AC-coupled and the DC-coupled scenarios have the major components connected to a central component that should be able to direct the flow of energy depending on the status of the system. A general flow diagram shown in the figure below outlines some major decisions that would need to be considered during the flow of electricity in the storage system.

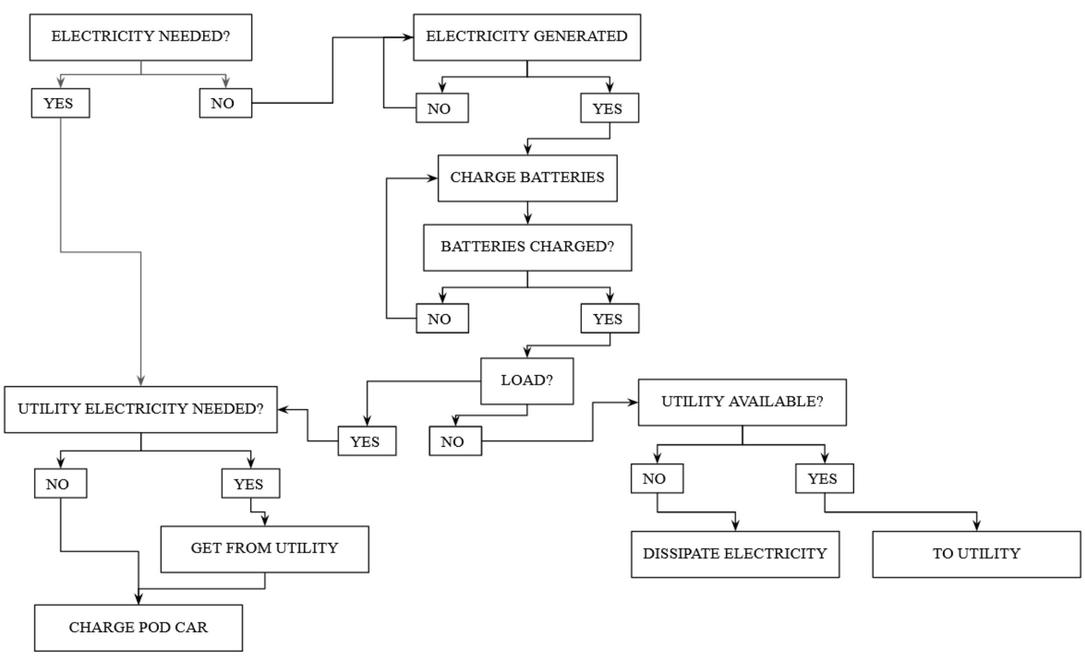


Figure 32 – Decision diagram for flow of electricity for Superway storage.

Wire gauge is an important aspect of the system since wires will be needed to conduct electricity from one point to another. If purchasing a fully assembled unit, chances are that they seller will provide more information on wire type and gauges compatible and necessary for the install of their unit. If purchasing electrical components from a company with a system that can be used for the custom energy system, then it is very probable that they will also have harnesses ready for installation. When uncertain of what wire gauge would be suitable, a table in the figure shown below can be used to determine the maximum ampacity the wire can handle at a specific temperature.

	Copper			Aluminum	
Wire Gauge Size	60°C (140°F) NM-B, UF-B	75°C (167°F) THW, THWN, SE, USE, XHHW	90°C (194°F) THWN-2, THHN, XHHW-2, USE-2	75°C (167°F) THW, THWN, SE, USE, XHHW	90°C (194°F) XHHW-2, THHN, THWN-2
14	15	20	25	---	---
12	20	25	30	20	25
10	30	35	40	30	35
8	40	50	55	40	45
6	55	65	75	50	55
4	70	85	95	65	75
3	85	100	115	75	85
2	95	115	130	90	100
1	---	130	145	100	115

Figure 33 – Ampacity chart for varying wire gauges.Source: (Cerrowire, 2020).

3.3.2.3 Hardware and Mechanical Components

Most of the hardware and materials that would be needed to build the custom unit were sourced from mcmaster.com. Hardware included a variety of ¼”-20 and ½”-13 bolt, washer, and nut fasteners with a Grade 9 rating for extra safety as a result of their higher strength. This source was used for this project due to personal experience with the store and due to the readily available specifications on components being looked at. Their catalog of parts and materials is vast while also being able to provide technical drawings and CAD files for many parts. One thing to note is that their prices can be higher than what can be found from other sources. This may be attributed to their ability to deliver orders quickly, usually within a day depending on location.

The battery rack was modeled after a rack offered on the mcmaster.com. The rack was used in the model to hold all the batteries. The 96" x 24 ½" x 100 ½" rack is rated at 2,100 lbs. per shelf. With two racks put on either side of the container, there would be a 39 inch passageway between the racks for any access needed.

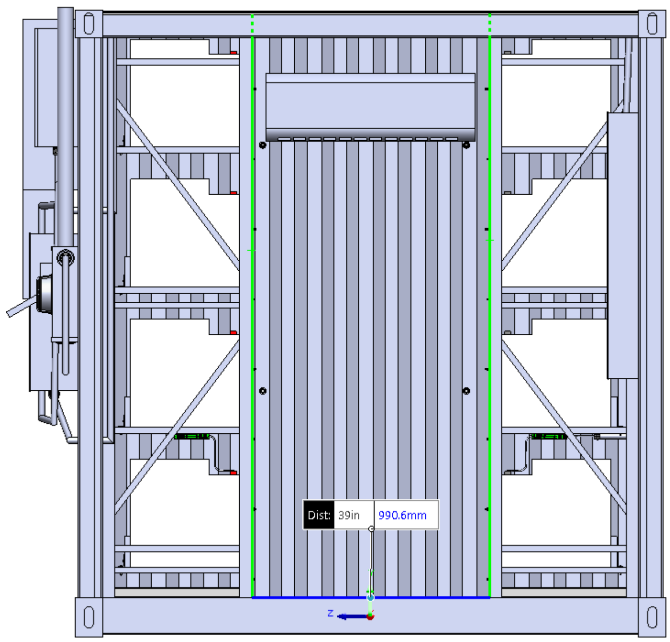


Figure 34 – Passageway inside the container with racks installed.

It was modified to include welded Unistrut members at the bottom to help the rack apply a more distributed load on the container floor when installed. The original rack would only be supported by four posts and their loading on the floor could be thought of more as point loads. The more concentrated loads at the support posts would be more damaging and concerning than a distributed load (K Line, 2015). The height of the rack would have to be cut down to 95 7/8" for better fitment inside the storage unit.

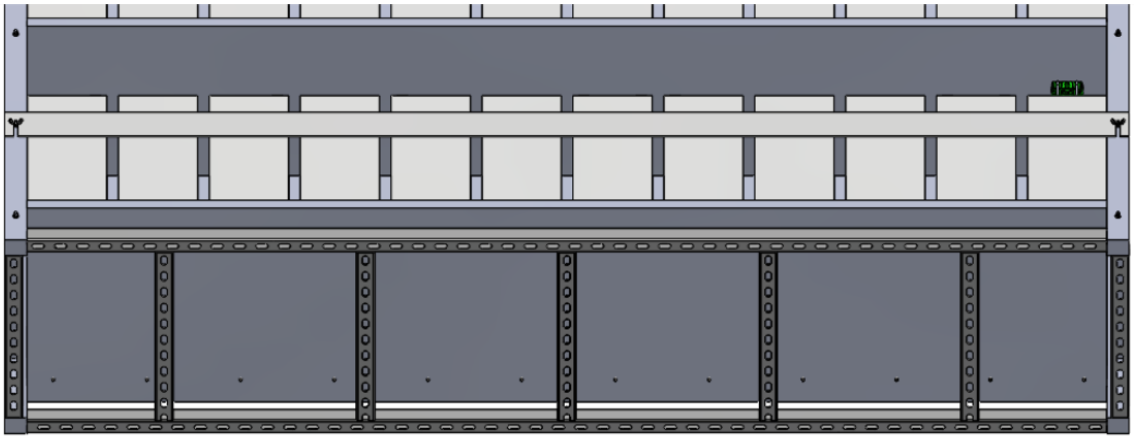


Figure 35 – Slotted Unistrut added to bottom of rack to distribute the load onto the container floor.

A battery guard was added to the front of the rack to keep the batteries from sliding forward and falling from the rack in the event that the container were to be moved. The guard was designed from aluminum T bar with material notched out and slots on both ends of the bar. Rivet studs and wing nuts were sourced to hold the guard in place. The rivet studs would offer quick and easy installation times. The wing nuts would allow the battery guard to be removed efficiently, making battery serviceability easier while maintaining safety. Safety is especially important in this area as dropping a tool across two battery terminals can cause a hazard. The wing nuts can be removed by hand or with a small tool and accidentally dropping either will not have the necessary length to touch both battery terminals at the same time.

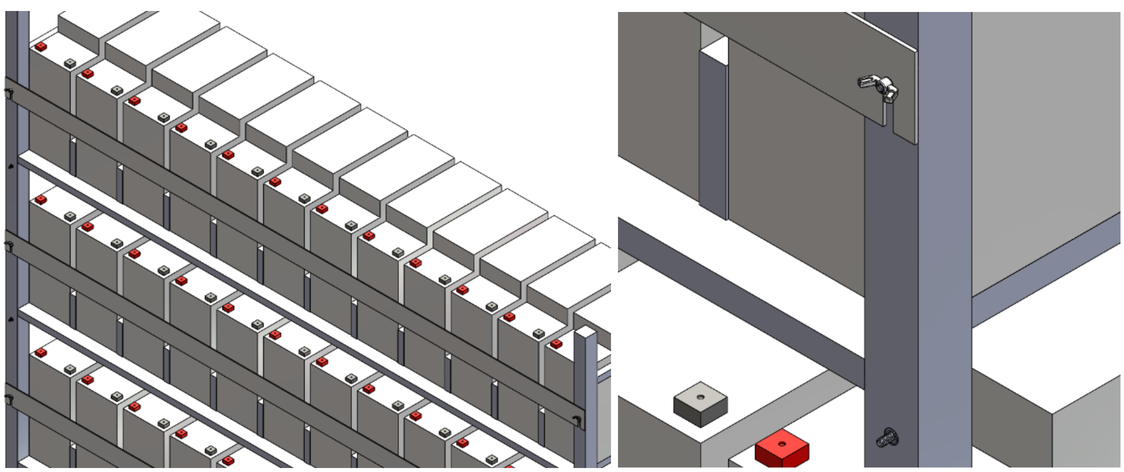


Figure 36 – Battery guard system used for the rack.

A battery guide was added to the back of the rack to keep the batteries separated, make installation of batteries more efficient by eliminating uncertainty on location of one battery with respect to another, and to keep batteries from moving side to side or falling back. The guide was designed from UHMW plastic sheet. This guide was put together with plastic screws and installed to the rack with the help of an aluminum 90-degree angle bracket riveted to the shelf of the rack. This guide would remain installed onto the rack. This set up would be able to accommodate other battery modules by simply modifying the guide or remaking a new guide and reusing the same aluminum bracket.

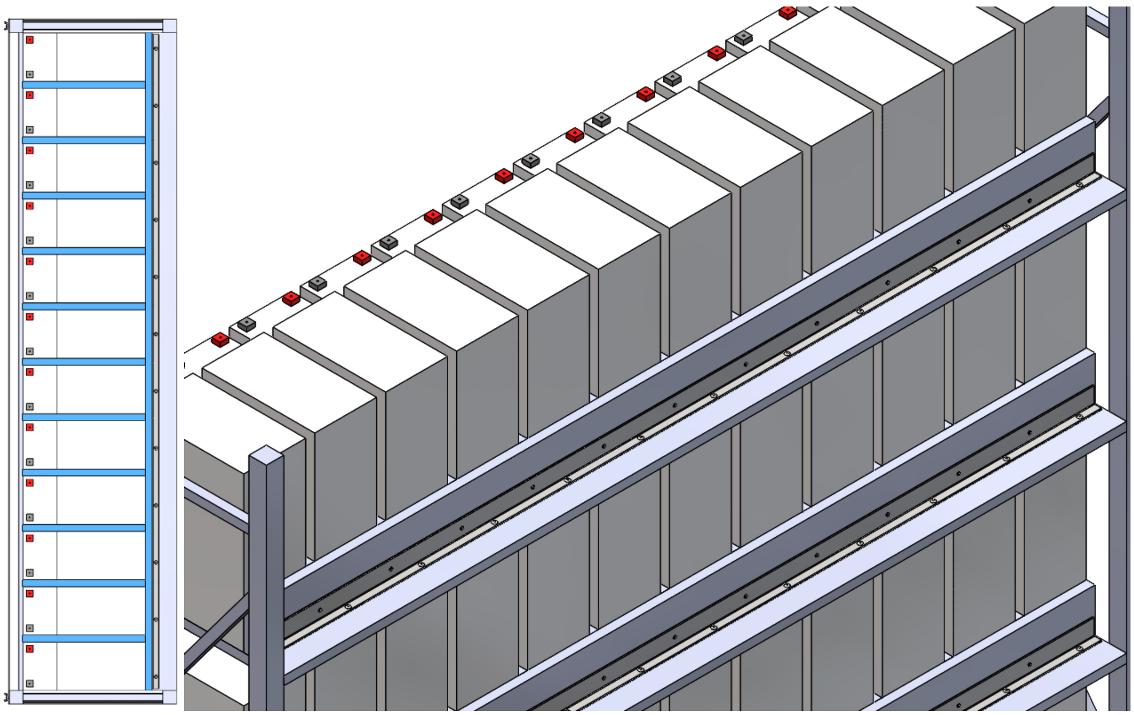


Figure 37 – Battery guide highlighted (left) and battery guide bracket (right).

The battery rack was installed into the container with various ½ inch bolts, washers, and locknuts. This hardware tied the bottom of the rack to the shipping container floor. Battery rack steel corner brackets were sourced from McMaster.com to secure the battery racks to the ceiling beams of the shipping container. Four thread-forming screws were used to secure the brackets to the shipping container roof beam. Rivet nuts were installed to the top rear rack posts to fasten the top of the rack to the brackets.

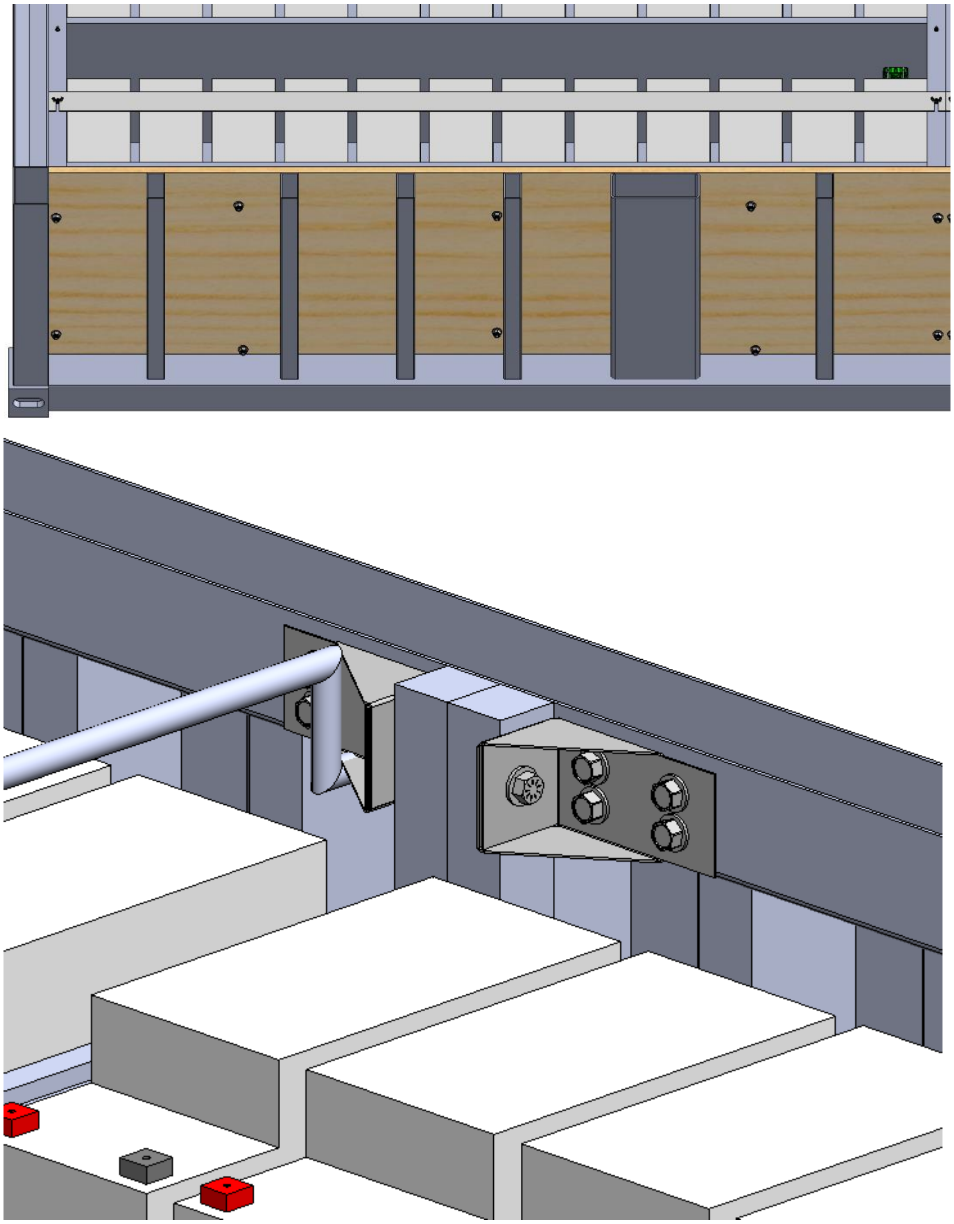


Figure 38 – Rack installation to floor (top) and ceiling beam with bracket (bottom).

A sample of the wire routing with the use of liquid tight steel conduit was done to show a possible routing solution for battery connections. This routing would route battery connections from the Anderson connectors through the back of the rack to a wiring compartment. The model does not show routing for all batteries as the program began to slow down when attempting to do so. This was perhaps due to the computer capabilities of handling so many components in the program.

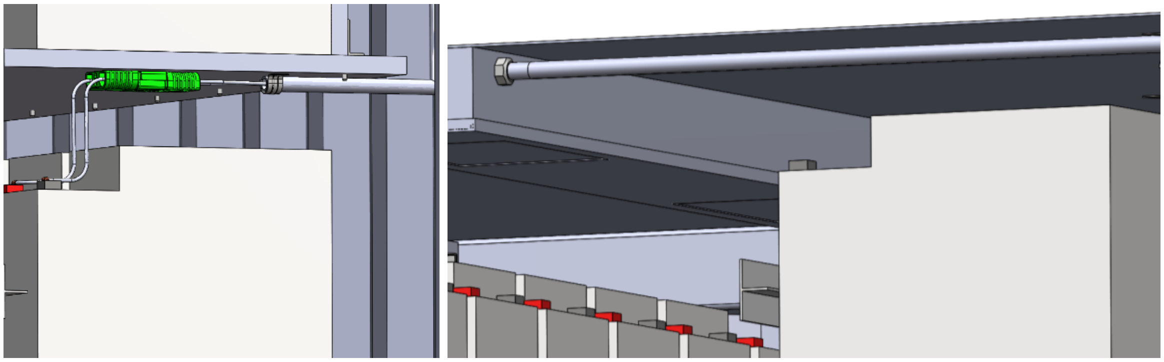


Figure 39 – Sample wire routing with conduit.

The complete battery rack and energy storage unit assembly can be seen in the figure below.

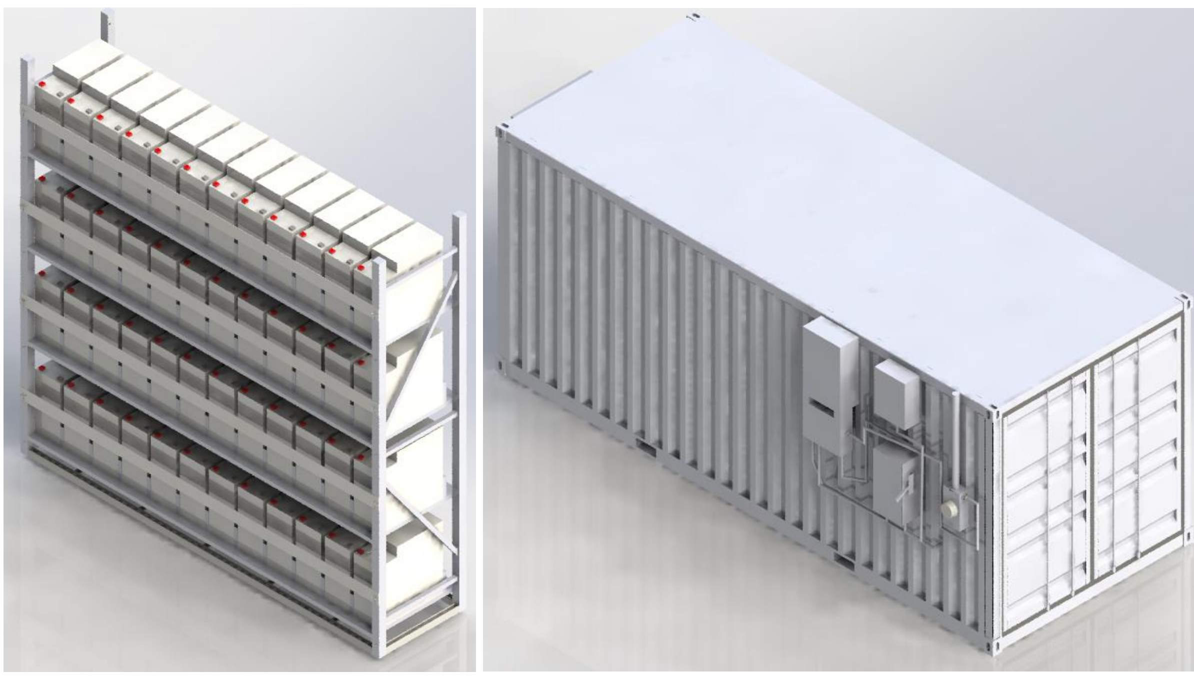


Figure 40 – Battery rack assembly (left) and energy storage unit assembly (right).

3.3.2.4 Heat Load

The heat load was determined to analyze the amount of heat dissipated by the batteries under a steady state assumption. The heat generated by the batteries during charging was calculated using the power equation, $P = I^2R$. The internal resistance of each battery module was found to be 0.02 Ohms (Ω) on the description section for the product (Ruixu, 2020). With an assumed charging current that should be about 10% of the Amp hour (Ah) rating of the battery, the charging current was calculated to 40 Amps (A) (Electrical Technology, 2020). With all 192 batteries taken into consideration, the total heat load was calculated to approximately 21,000 BTU/hr. A more detailed calculation process can be found in the Appendix.

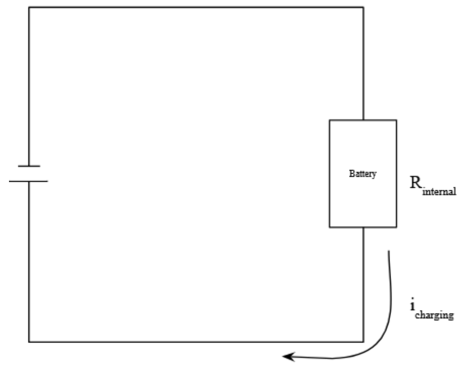


Figure 41 – Circuit model used to determine heat dissipated from batteries during charging.

3.3.2.5 Thermal Management

To simplify thermal management, an air condition system with a similar rating to that of the heat load determined was sourced to keep the battery unit at a stable temperature. A 30,000 BTU mini-split system offered by Blueridge was found after searching for an adequate ac system. A mini-split system consists of an inside and outside unit. The outside unit can also be referred to as the condensing unit and is typically larger than the inside unit, also referred to as the air handler or evaporator unit. The two units are connected by two refrigerant lines, or more specifically a liquid line and a vapor line, a drain hose for accumulated condensation drainage, and additional wires for power and communication. A mini-split configuration was chosen for this design as they are offered in the BTUs required, multiple smaller inside unit can be installed separate from larger outside unit, and the opening needed for their connections should not compromise much of the energy unit's weather sealing characteristics.

The outside unit was installed to the back of the container with slotted strut channel members, steel strut channel brackets, four rubber bumpers to mitigate vibrations, strut channel spring nuts, and various ½ inch fasteners. A custom bracket would be needed to adapt the strut channel bracket to the attachment points at the bottom of the condenser unit. The inside unit was installed to the back wall of the container with ¼ inch bolts, washers, and locknuts. According to the install instructions, a bracket for the inside unit needs to be installed first and then the rest of the unit can just be mounted to the bracket.

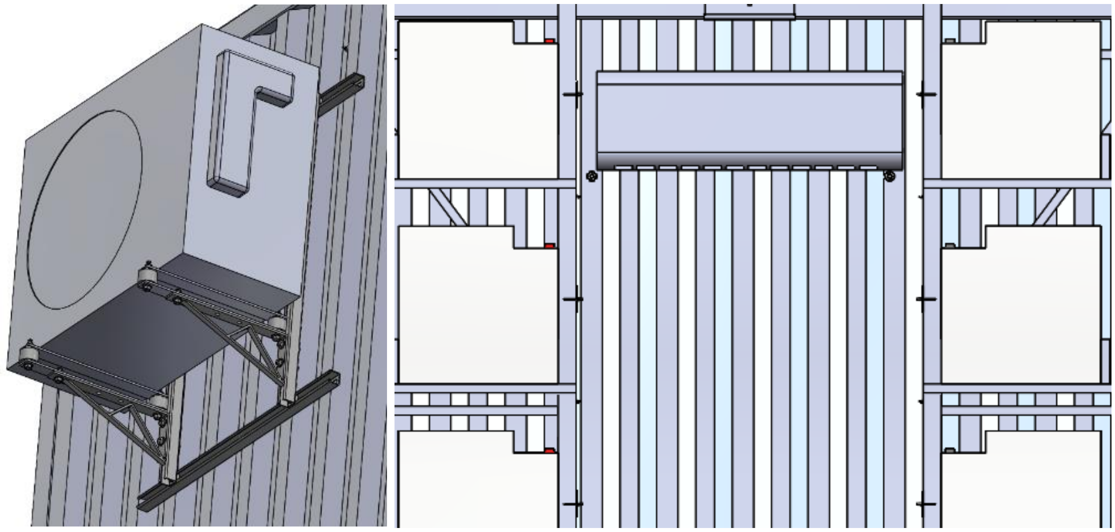


Figure 42 – Outside unit (left) and inside unit (right) installed onto container.

3.3.2.6 Floor Load

The floor load was calculated to analyze the loading on the floor of the energy storage unit imposed by the battery racks. The floor load was determined by calculating the weight per shelf and then determining the weight per rack. Each battery was specified to be 62 kilograms (kg) on the description section for the product (Ruixu, 2020). The total load of one rack was calculated to be 2,976 kg over a span of 2.55 meters. For a 20' container, the "maximum floor load is 4.5 tons per running meter" (K Line, 2015). The loading imposed on the floor by one rack with batteries would be roughly 1.29 tons per meter. This achieves a safety factor of 3.50 for one battery rack. The loading imposed on the floor by the whole system of rack was calculated to 2.57 tons per meter. This achieves a safety factor 1.75 for all four battery racks. As a result, the floor of the container should be able to withstand the weight of all the components inside.

Another consideration is the loading of the batteries on the rack and shelves. The shelves are rated to withstand 952.5 kg. The rack is rated to withstand 2,903 kg. With twelve batteries on each shelf, there is an imposed load of 744 kg. This achieves a safety factor of 1.28. All 48 batteries per rack impose a load of 2,976 kg on the rack. This load is slightly over the rated capacity of the rack, achieving a safety factor of 0.98. To help with this, supports cross members can be added to the rack structure to add strength and increase the weight capacity of the rack.

3.3.3 Logistics

This section will discuss grid interconnection, granularity, and cost logistics involved with installing energy storage units for the Superway. Most of the factors will be applicable when using a market available storage solution or a custom unit.

3.3.3.1 Grid Interconnection

Research conducted on the interconnection process gave insight on what the process could entail. A diagram was created to highlight and organize the main steps for PG&E grid interconnection. One important detail to note is a possible additional expense of having to upgrade equipment on the PG&E side to accommodate a project. The specific costs were not listed; however, they can range depending on the type and amount of equipment having to be upgraded. According to their timeline, it can take anywhere from 5 months to 17 months from the application review to the interconnection approval. This timeline may not fully represent the process of a system the scale of the Superway project.

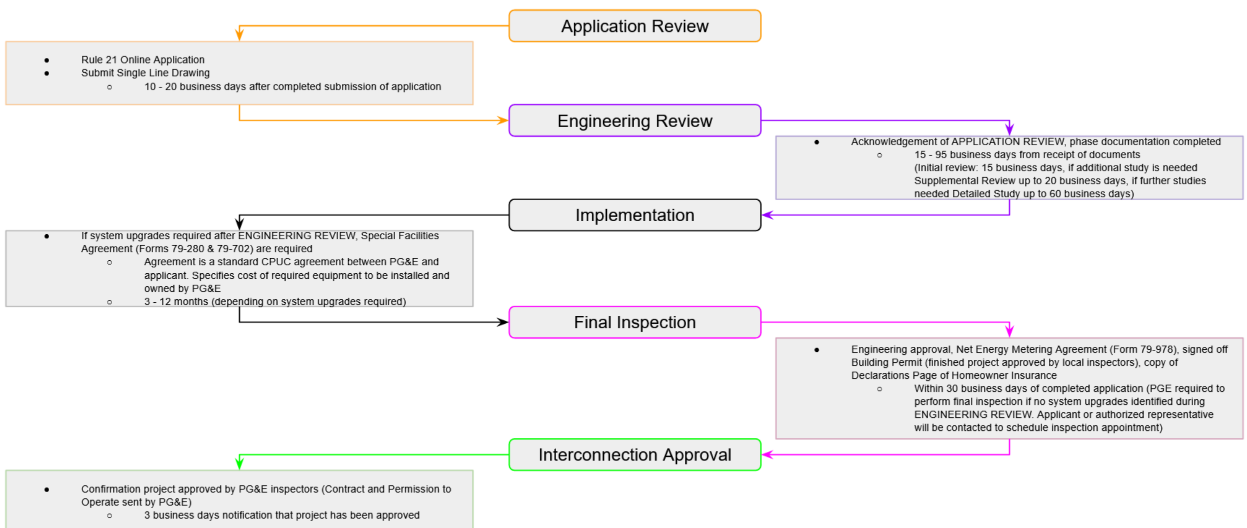


Figure 43 – General summary of interconnection process for PG&E grid. Source: (PG&E, 2020).

3.3.3.2 Granularity

The granularity of the energy storage units was taken into consideration to determine what kind of layout would make the most sense. Earlier in the semester and report, four possible locations were suggested near stations. During this point of the project, it was still unclear how much room would be available for a storage unit, if any, at a station. The four possible locations were suggested next to station in big parking lot areas as an alternative to placing the units at stations. Now that there are more station concepts, it is clear that an energy storage unit can be incorporated into a station. A decision matrix was created to further analyze a decision based on research done. The scale was set up to be from 0 to 1, where 0 is a low mark and 1 is the highest mark. The following criteria was used in the decision matrix:

- Cost: The cost associated with placing storage units close or far from stations. Placing storage units away from stations results in storage units away from solar panel arrays. The benchmark in the figure below shows that placing a storage unit close to the solar panel arrays can result in a significant lower cost. Here, 1 indicates cost is lower due to both systems being co-located and 0 indicates costs are higher due to both systems being spread apart.

- Reliability: The reliability of the storage system being able to provide energy to the transportation system at all times and multiple places. Having one unit at each station can provide a better distribution of power to all vehicles. Having all units at one location can make it difficult to get power to a vehicle at the other end of the station. Additionally, one failing unit can make the other units fail. Here, 1 indicates the system can provide energy at all times and 0 indicates energy may not be able to reach a vehicle at certain parts of the station.
- Servicing: The efficiency of servicing units. Having all units centralized at one location can make servicing faster since all units would be at one location. Having units spread out can make the servicing process more time consuming as people would need to travel to all locations of storage units. Here, 1 indicates servicing can be highly efficient and 0 indicates servicing may be more time consuming.
- Space Consumption: The space consumption per area. Having a distributed layout would result in less area taken up per storage system. A centralized layout would require more space for all the storage units to be at one location. Here, 1 indicates less space taken up per location and 0 indicates more space taken up per location.
- Safety: The possible safety hazard. Any storage unit at a station has the potential to become a safety hazard to people around. A centralized system placed away from a station and people can lower its safety hazard. Here, 1 indicates it can be hazard to people and 0 indicates it may not be a safety hazard to people.
- Complexity: The complexity of the system. Storage units placed at station will be close to the solar panel arrays needed to generate electricity. Centralized units would require further investment in the systems infrastructure and components to get electricity from all solar panel arrays to travel to the central storage unit location. Here, 1 indicates less complexity and 0 indicates higher complexity.
- Aesthetics: How the layout can fit into its place from a qualitative perspective. Here, 1 indicates units can be made to fit into their surroundings and 0 indicates there are not many options to make units more alethically pleasing to the area.

Layout	Cost	Reliabilty	Servicing	Space Consumption	Safety	Complexity	Aesthetics	**Total**
Station Distributed	1	1	0	1	0	1	1	5
Partially Distributed	0.5	0.5	0.5	1	0	0.5	1	4
Centralized	0	0.5	1	0	1	0	1	3.5

Figure 44 – Unit distribution decision matrix.

Research showed that co-located solar panels and batteries can result in less overall cost compared to solar panels and batteries located in different sites.

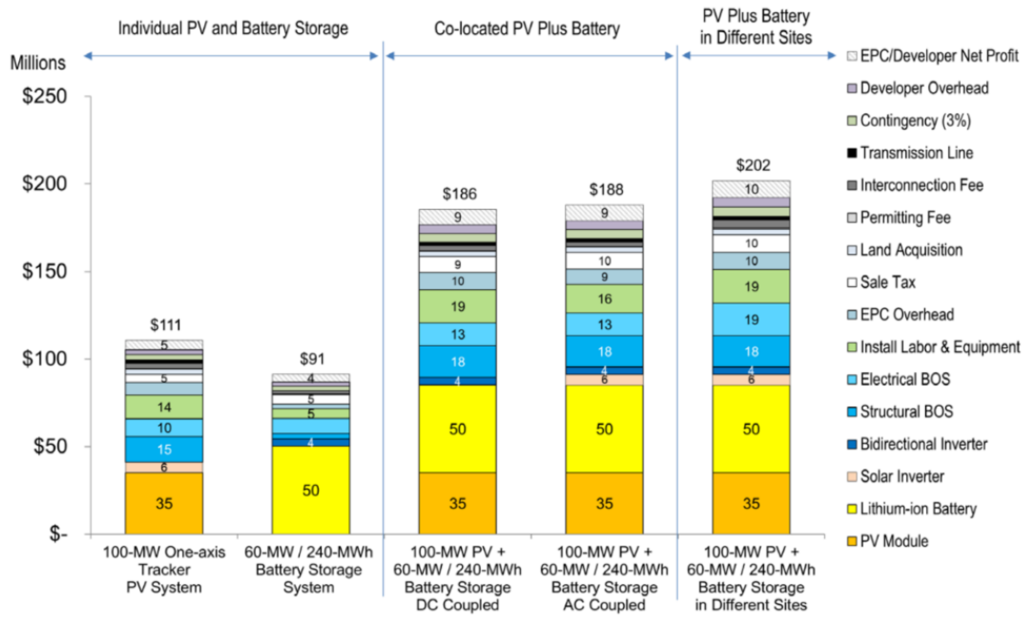


Figure 45 – Cost benchmarks for solar panel systems with energy storage.Source: (Fu, Remo, & Margolis, 2018).

As a result of these findings and design intent, the units were modeled with the intention of having them close to the solar panel structure.

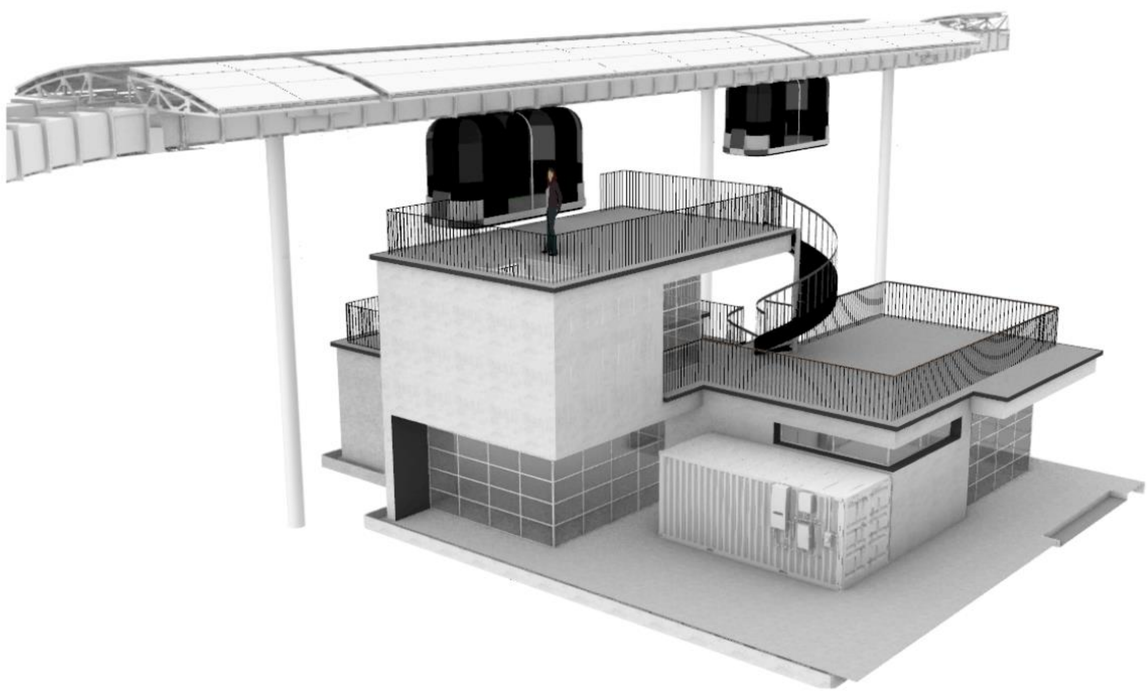


Figure 46 – Station and custom energy storage unit rendering.Source: (Chiao, 2020).

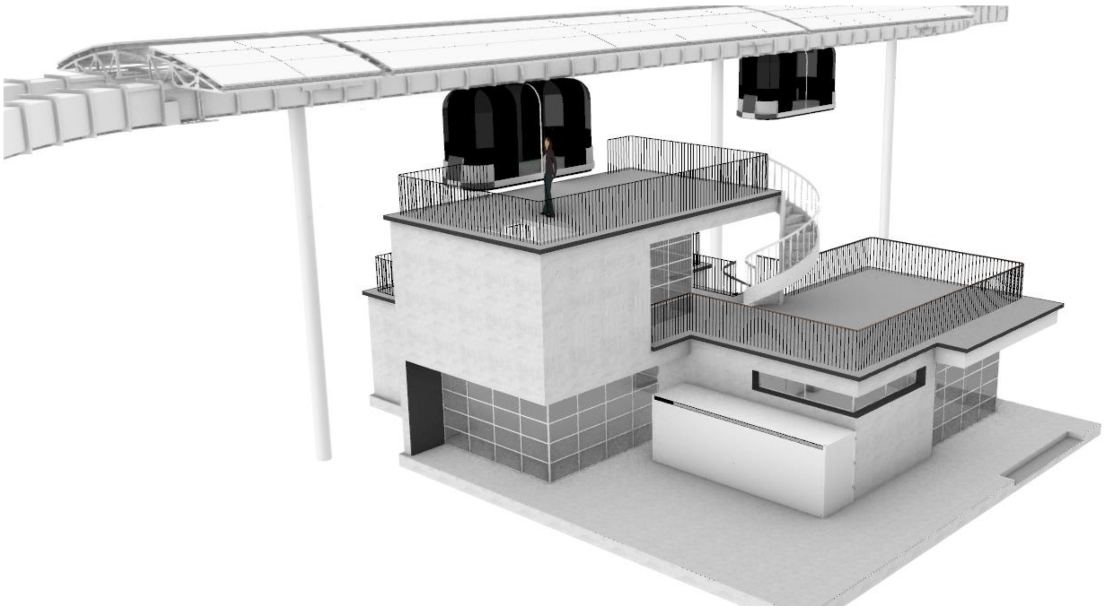


Figure 47 – Station and Tesla Megapack unit rendering.Source: (Chiao, 2020).

3.3.3.3 Cost Comparison

The units were compared using another decision matrix to further analyze a decision based on research done. The scale was set up to be from 0 to 1, where 0 is a low mark and 1 is the highest mark. The following criteria was used in the decision matrix:

- Cost: The cost associated with either buying a unit available in the market or building a custom unit. A custom unit was found to be pricey while a market unit found to more cost effective. Here, 1 indicates cost is lower and 0 indicates costs are higher.
- Reliability: The reliability of the storage system based on design reliability. At this point in the project, the custom unit is still in the design phase. Assuming it were in the prototyping phase, it would still require a lot more testing to verify it works as intended. The market unit, especially one used by utility companies, indicated it has been tried and tested. Here, 1 indicates the system is at a point of good reliability and 0 indicates the system is at an early stage.
- Servicing: The ability to service the unit easily. Having a custom unit can make servicing easier due to the knowledge of the system. Having a market unit can make servicing a more tedious process and may end up needing another company do the servicing. Here, 1 indicates servicing can be done easily and 0 indicates servicing can take longer to get a handle on.
- Space Consumption: The space consumption per capacity offered by the unit. The custom unit designed for the project has a storage capacity of roughly 1 MWh. The Megapack had a similar form factor to the custom unit with three times the storage capacity. Here, 1 indicates higher capacity per area and 0 indicates lower capacity per area.
- Safety: The possible safety hazard. Any storage unit at a station has the potential to become a safety hazard to people around. The custom unit is still at an early stage of the

design to determine its safety. The market unit has been around for longer and is widely used without hearing negative things about it. Here, 1 indicates safety has been tested and 0 indicates safety is yet to be tested.

- Time: The amount of time required to acquire the unit. A custom unit would depend on the time it takes to get materials and to build it. A market unit would depend on the time required from the moment the order is placed to the time the unit is fully installed and functional. For this project, the custom unit showed it can be built from readily available parts. Timelines were not found for the market unit. Here, 1 indicates faster delivery times and 0 indicates slower delivery times.
- Grid Interconnection: Process for grid interconnection. The custom unit still requires more research to determine more specific hardware and details for grid interconnection. The market unit has been used by utility companies and it is sold with the purpose of providing energy storage support to a system or grid. Here, 1 indicates the unit can be grid tied effectively and 0 indicates more is needed for grid tie compatibility.
- Customizability: The ability to customize the unit. A custom unit may offer a wider range of custom options for a storage unit. A market unit would not allow much customization and modifying anything after purchase could lead to voiding warranty. Here, 1 indicates the unit can be customized easily and 0 indicates limited options.
- Aesthetics: The finished result of the build. Both a custom unit and market unit can be made to fit into an area. A custom unit may require more thought and work. Here, 1 indicates the unit can meet aesthetic standards and 0 indicates aesthetic standards can be hard to reach.
- Mobility: Ability to move unit. The custom unit has forklift tube holes that make the unit easier to transport. The market unit does not seem to have any forklift tube holes which may require a more drastic process to move the unit into place.

Unit	Cost	Reliability	Servicing	Space Consumption	Safety	Time	Grid Interconnection	Customizability	Aesthetics	Mobility	**Total**
Custom Unit	0	0.5	1	0	0	0.5	0.5	1	0.5	1	5
Market Unit	1	1	0	1	1	0.5	1	0	1	0.5	7

Figure 48 – Energy storage unit decision matrix.

A Bill of Materials for the custom unit was created after the model was completed. The $/kWh cost was determined from the total cost of the storage unit. The components and costs were further categorized to analyze how each part of the system contributed to the overall cost. From most to least costly: batteries, hardware and materials, electrical hardware & materials, electrical panels and equipment, container, and thermal management.

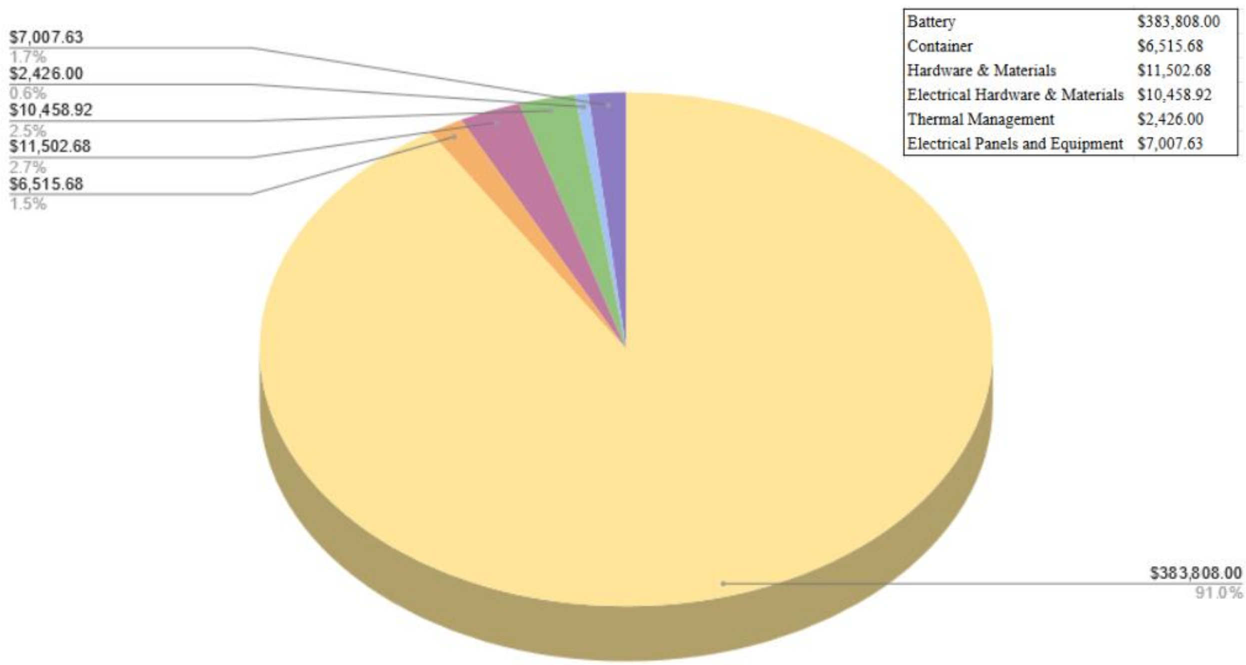
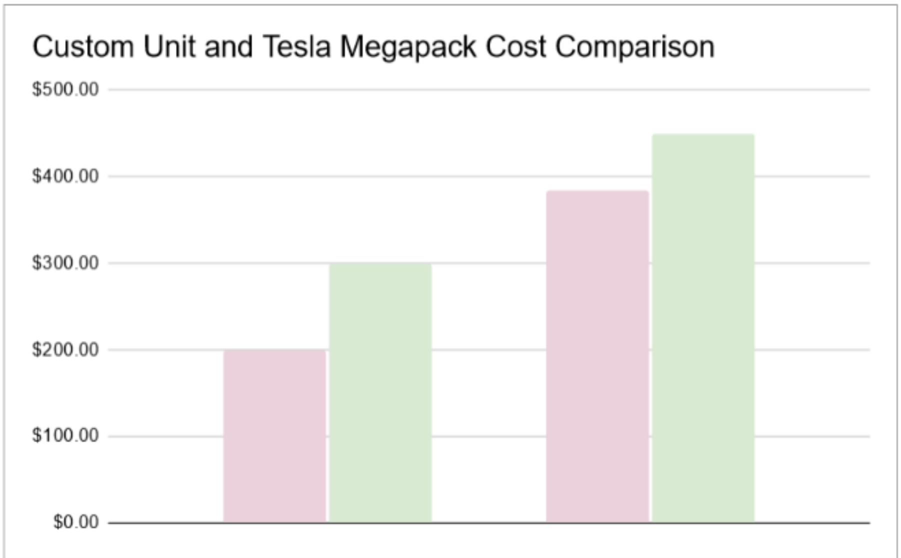


Figure 49 – Total costs per category for custom storage unit.

The total cost of the unit, including major electrical components, was used to compare to Tesla Megapack costs. This was done since those were two cost values given by Tesla's CEO. The unit offered by Tesla is rated at a storage capacity of 3 MWh, however, the actual capacity may be slightly under. To simplify the cost comparison with the custom unit the total capacity of the custom unit will be represented as 1 MWh rather than 960 kWh. The analysis shows that the Megapack costs are lower compared to a custom unit.



	Capacity (MWh)	Battery Pack ($/kWh)	Battery Pack, Electronics, Servicing ($/kWh)
Tesla Megapack	3	$200.00	$300.00
Custom Unit	1	$383.81	$450.00

*15 to 20 years, custom unit pricing shows high-level components and does not include servicing

Figure 50 – Custom unit and Tesla Megapack cost comparison.

4.0 CONCLUSIONS

This section states the conclusions of the project and recommendations for future work.

4.1 Conclusion

The Spartan Superway program was discussed to better illustrate the state of our current public transportation sector and its implications on the public and environment. Literature review was done on technologies relating to solar powered automatic transit networks and energy storage at a utility scale. The objective of the project was stated and supporting objectives were listed to show what the project intended to accomplish. The methodology of the project was explained to show a plan to properly meet the project's objectives. These objectives included determining the energy demand and supply of the proposed north-south route, calculating the required storage size, investigating storage design and implementation options, projected costs, and a custom unit design. Results were presented and discussed to show their meaning and influence on the overall design options. A design was created and modeled using Solidworks. Analysis on thermal and weight load was conducted to validate the design. Logistics, including grid interconnection, granularity, and cost, were investigated to determine a grid interconnection timeline, cost implications of placing battery storage close to or far from solar panels, and difference in cost between market available solution and custom unit. Two matrices were created to further validate the concluding recommendation.

The research done through literature review indicates a common declining cost trend with PV technologies and battery storage. The energy demand of the system was combined with data from a shuttle service with a similar route to the proposed north-south campus route to analyze energy demand on a busy day. The energy supply obtained through a computer simulation tool was used to analyze what a least energy generating day would look like. The two data sets were put together as a worst-case scenario and used to analyze an energy storage size needed. The results showed the system needed to be sized for storage capacity in the MWh range to provide energy during a generation shortage or for the entire day.

The design process of the energy storage unit was highlight in the case study section of the report. The container of choice was a shipping container based on what companies typically use for their storage units. The battery chemistry was lithium iron phosphate due to its stability in utility scale systems. High level electrical components were modeled and assembled in an AC and DC coupled configuration based on two company installation diagrams. Two scenarios were presented rather than just one to show available options. AC coupled systems can be easier to retrofit while DC coupled systems can have higher efficiencies. With developing technologies, the pros and cons to the two options continue to evolve. More research needs to be done regarding this topic as the Superway project progresses. Hardware, materials, and components were sourced from an online source that is pricier that average, however, the source has most of the parts readily available for purchase. The heat load was calculated to 21,000 BTU/hr and thermal management solution rated at 30,000 BTU was determined to be an appropriate solution. The floor load was calculated 2.57 tons per meter against a maximum recommended load of 4.5 tons per meter. These two loading analyses verified that the system would operate as intended with respect to temperature loading and weight of the batteries imposed on the container's floor.

Possible suitable locations for the storage units were shown with the help of google maps at an early stage of the project and later changed. Updated station renderings showed there was space available for a storage unit and as a result, an energy storage unit can be implemented at each station. This would require less complexity, reducing costs as shown in a benchmark presented above. Reliability would increase as energy storage units would be at every station and the chances that a vehicle could be stuck without any energy would go down. Grid interconnection research showed a varying timeline for tying to the grid, which could vary more for larger scaled systems. A market unit, in this case the Tesla Megapack, showed to be a competitive alternative to a custom unit with lower costs and higher capacity with similar outside dimensions as the custom unit.

4.2 Future Work

Future work for the project includes looking more into required hardware and standards, connecting with other professionals and companies to get their inputs on the project, creating more design plans based on more stable station designs, looking into more variables that have an impact on the project. The following list explains possible tasks and what they involve:

- Utility Interconnection: Getting a more in depth understanding of the utility interconnection process for the Superway project. This can include net metering, the application process, and line diagrams needed for the application. Connecting with utility companies and other companies dealing with this can give useful insight on to look expect when attempting to go through the process with the Superway.

- DC vs AC Coupling: Further analyzing which coupling method makes the most sense for the project and why. This can be developed more as more variables of the Superway are determined.

- Design: Thinking of design improvements if a custom energy storage unit is pursued rather than purchasing units available in the market. Improvements may involve sourcing a different battery, higher load rated rack, and method of loading and unloading batteries into rack for servicing. Finding a different source for hardware and materials that offers competitive pricing. If a market unit is pursued, based on the report's recommendation, then looking more into companies or a single company that offers a unit capable of supporting the Superway generating capabilities. Getting answers from someone in the company rather than from online research can lead to more concrete values.

- Hardware Specifications: Further research into the hardware, components, and vendors that make the most sense to for the Superway project. This could include determining which specific wiring to use for the different portions of the system, voltages, currents, and power values at different portions of the system, and type of connections between components. Making it all this information easier to understand for others can be of great benefit.

- Charging Stations: Doing research into methods of transferring stored energy or utility energy to Superway podcars and the different factors involved. For example, which technology, induction or plug in, would make the most sense for transfer of energy. There are a lot of engineering details that need to be determined regarding this topic.

- Electrical: Doing more research into the types of connections and possible harnesses that can be made to make installation of a unit easier. Adding to the diagrams in this report and creating new diagrams that help visually represent the many connections involved in an energy storage system for the Superway can be of great benefit.

- Alternative methods: Exploring alternative storing methods that can be designs and modeled using computer software. For example, looking into flow battery technologies and creating a design that can be used. In the process, finding new sources for hardware and materials that can give a more competitive price than those found on websites like mcmaster.com.

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APPENDICES

APPENDIX A – Codes and Standards relevant to energy storage systems

Reference #	Title/Contents
NEC 2014	*National Electrical Code*/Wiring methods (comprehensive)
IEEE 937	IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic Systems
IEEE 1013	IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic Systems
IEEE 1187	Recommended Practice for Design and Installation of Valve-Regulated Lead-Acid (VRLA) Storage Batteries for Stationary Applications
IEEE 1361	Recommended Practice for Determining Performance Characteristics and Suitability of Batteries in Photovoltaic Systems
IEEE 1526	Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems
IEEE 1547	IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
IEEE 1561	Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems
IEEE 1562	Guide for Array and Battery Sizing in Stand-Alone PV Systems
IEEE 1661	Guide for Test and Evaluation of Lead-Acid Batteries Used in PV Hybrid Systems
IEC TC-82	A compendium of 25 standards relating to the electrical and mechanical performance testing and measurement of PV systems
ISO 9001	An international quality standard, composed of 20 segments, dealing with all aspects of design, manufacturing, and delivery of service
UL 1741	Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems
ANSI Z97.1	Relates to safety relating to potential glass breakage
ASCE 7-10	Minimum Design Loads for Buildings and Other Structures
ASTM	A compendium of tests and standards that may apply to BIPV systems

Source: (Messenger & Abtahi, 2017).

Title	Designation
Molded-case circuit breakers, molded-case switches, and circuit-breaker enclosures	UL[a] 489
Electrochemical capacitors	UL 810A
Lithium batteries	UL 1642
Inverters, converters, controllers and interconnection system equipment for use with distributed energy resources	UL 1741
Batteries for use in stationary applications	UL 1973
Second-use batteries	UL 1974 (proposed)
Recommended practice and procedures for unlabeled electrical equipment evaluation	NFPA[b] 791
Standard for interconnecting distributed resources with electric power systems	IEEE 1547
Recommended practice and procedures for unlabeled electrical equipment evaluation	NFPA 791
Outline for investigation for safety for ESSs and equipment	UL 9540 (proposed)
Safety for distributed energy generation and storage systems	UL 3001 (proposed)
Safety standard for molten salt thermal energy storage systems	ASME TES[c]-1 (proposed)

a. UL = Underwriters Laboratory
b. NF PA = National Fire Protection Association
c. ASME TES = American Society of Mechanical Engineers Thermal Energy Storage

Source: (Cole & Conover, 2016).

Fire and smoke detection, fire suppression, fire and smoke containment	NFPA 1, NFPA 13, NFPA15, NFPA 101, NFPA 850, NFPA 851, IBC, and IFC
Ventilation, exhaust, thermal management, and mitigation of the generation of hydrogen or other hazardous or combustible gases or fluids	NFPA 1, IEEE 1635/ASHRAE 21, IFC, IMC, NFPA 70
Egress and access (normal operations and emergency), physical security and illumination	NFPA 1, NFPA 101, IBC, IFC and local zoning codes
Electrical safety, emergency shutoff, working space, electrical connections/installation for installations on the customer side of the meter	NFPA 70 and 70E
Electrical safety, emergency shutoff, working space, electrical connections/installation for installations on the utility side of the meter	IEEE C2
Anchoring and protection from natural disasters (seismic, flood, etc.) and the elements (rain, snow, wind, etc.)	IEC 60529, IEEE 1375, UL 96A, IBC, IFC and NFPA 70
Signage	ANSI S535, NFPA 1, NFPA 70, NFPA 70E, NFPA 101, IBC and IFC
Spill containment, neutralizing and disposal	NFPA 1, IPC, IFC, and IEEE 1578
Communications networks and management systems	IEC 61850

Source: (Cole & Conover, 2016).

UL 1973 Batteries for Use in Light Electric Rail and Stationary Applications	Safety standard for stationary batteries for energy storage applications, non-chemistry specific and includes electrochemical capacitor systems or hybrid electrochemical capacitor and battery systems. Includes requirements for unique technologies such as flow batteries and sodium beta (i.e., sodium sulfur and sodium nickel chloride). Includes construction requirements, tests and production tests. Also includes requirements for cells used in these systems such as lithium-ion, nickel, lead-acid and includes sodium beta and flow battery requirements.

Source: (Cole & Conover, 2016).

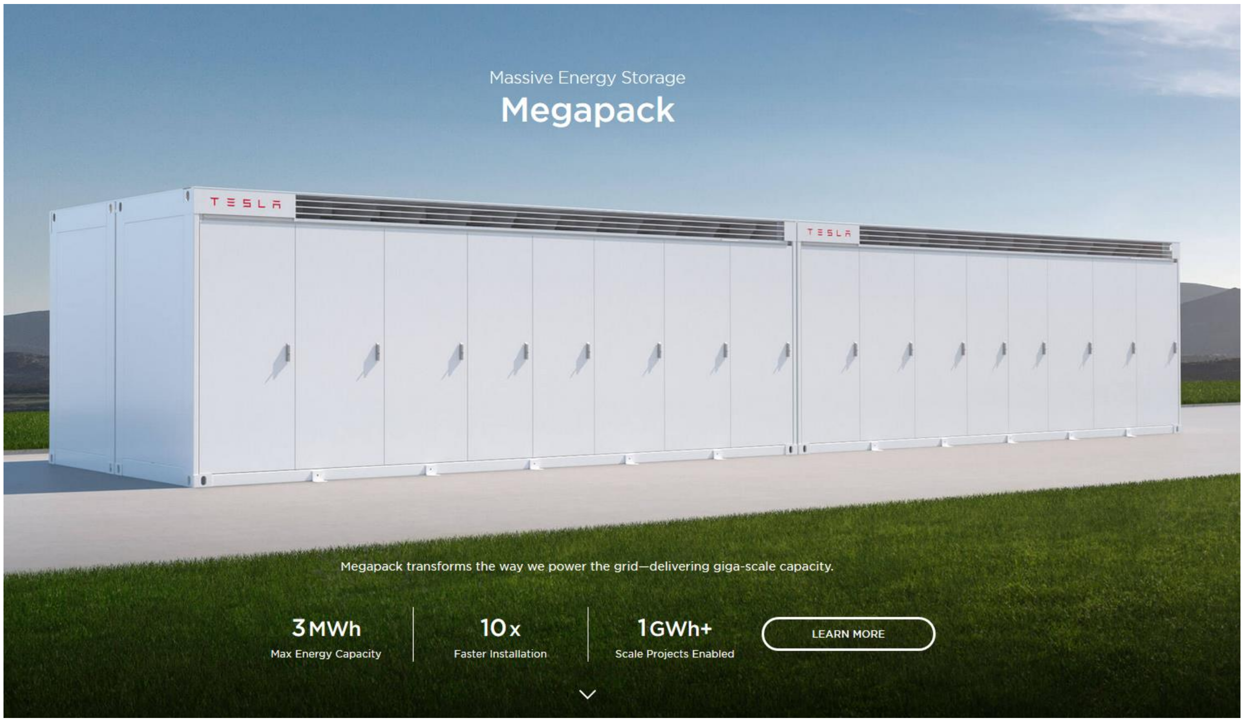
APPENDIX B – Energy Demand Model Results

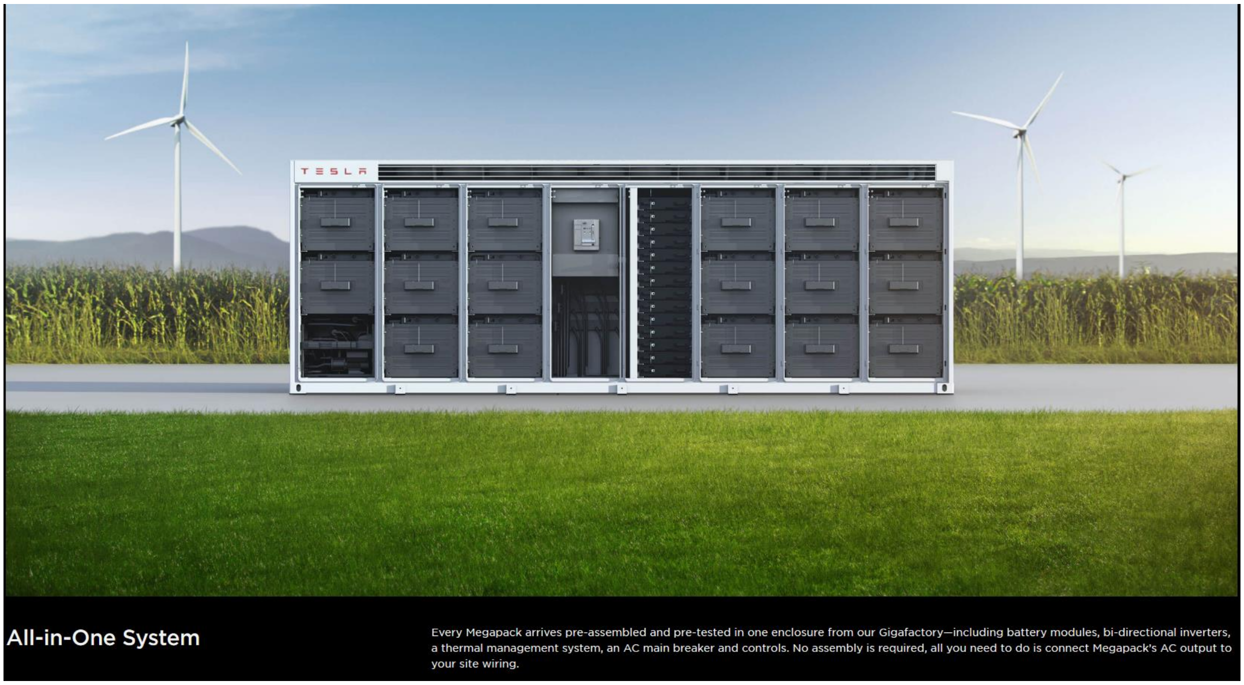
```
% Vehicle Characteristic Inputs:
massOfVehicle = 1900; % [kg] mass of a fully loaded vehicle
vehicleFrontalArea = 4; % [m²] frontal area of the vehicle
radiusOfWheel = 0.1524; % [m] radius of vehicle wheels
C_srr = 0.057; % [in] coefficient of static rolling resistance: Cast iron
on steel = 0.021 in; Polyurethane on steel = 0.030 - 0.057 in [4]
C_d = 0.51; % [dimensionless] coefficient of drag
avgMotorEfficiency = 0.85; % [dimensionless] average efficiency of the
electric motor
regenBrakingEfficiency = 0.3; % [dimensionless] regenerative braking
efficiency
auxiliaryPower = 3500; % [W] auxiliary power
% Transit Route Characteristic Inputs:
lineSpeed = 13.4; % [m/s] line speed
headway = 5; % [s] minimum headway between vehicles
dwellTime = 20; % [s] dwell time in station
avgTripElevationChange = 0; % [m] average elevation change between
stations (+ = uphill; - = downhill; zero for ATNs because they are closed
loops)
[numVehicles,tripDuration,systemPowerDemand,systemAnnualEnergyDemand] =
energyDemand(massOfVehicle,vehicleFrontalArea,radiusOfWheel,C_srr,C_d,avgM
otorEfficiency,regenBrakingEfficiency,auxiliaryPower,lineSpeed,headway,dwe
llTime,avgTripElevationChange,routeLength,avgDistBetweenStations,meanSqrWi
ndSpd); % Calculate energy demand
Number of Vehicles on Route: 155 (at practical maximum usage of 70%)
Average Trip Duration: 2.29 minutes
Average System Power Demand: 1.612 MW
Annual System Energy Demand: 14.123 GWh
```

APPENDIX C – Energy Supply Model Results

```
SIMULATION RESULTS:

Energy Supply:
Rated System Generation Capacity: 19.736 MW
Average System Power Output: 3.626 MW


Annual System Energy Output: 31.759 GWh
Energy Factor of Safety: 2.25

Leg Canopy:
Number of Modules across Leg Canopy: 8
Module Tilts on Leg Canopy: 27.0°, 27.0°, 27.0°, 27.0°, 27.0°, 27.0°, 27.0°, 27.0°
Total Length of Leg Canopy: 12150 m
Width of Leg Canopy: 7.06 m

Station Canopy:
Number of Modules across Station Canopy: 8
Module Tilts on Station Canopy: 27.0°, 27.0°, 27.0°, 27.0°, 27.0°, 27.0°, 27.0°, 27.0°
Total Length of Station Canopy: 1383 m
Width of Station Canopy: 7.06 m

System Metrics:
Total Number of Modules: 54792
Capacity Factor: 18.37%
Estimated Cost of PV System: $20,919,778 USD
```

APPENDIX D – Tesla Megapack





Fastest Installation

At the site level, Megapack requires 40% less space and 10x fewer parts than current systems on the market. As a result, this high-density, modular system can be installed 10x faster than current systems.

Applications

Renewable Smoothing

Smooth out the intermittency of renewables by storing and dispatching when needed

T&D Investment Deferral

Postpone costly grid infrastructure upgrades by supplying power at a distributed location to defer the need to upgrade aging infrastructure

Voltage Support

Inject and absorb reactive power to maintain local voltage levels on the grid

Capacity Support

Discharge at times of peak capacity to reduce demands on distribution and transmission infrastructure

Microgrid

Build a localized grid that can disconnect from the main power grid

Market Participation

Provide service to the grid in response to signals sent by system operators

Frequency Regulation

Maintain grid stability by rapidly changing charge or discharge power in response to changes in grid frequency

Megapack is designed for utilities and large-scale commercial customers. Our team of experts will work with you to identify custom site needs, and design a solution to maximize project values across multiple applications.

APPENDIX E – Tesla Powerpack

Overall System Specs

AC Voltage	380 to 480V, 3 phases
Communications	Modbus TCP/IP; DNP3; Rest API
Power	Up to 130 kW (AC) per Powerpack
Scalable Inverter Power	From 70kVA to 700kVA (at 480V)
Depth of Discharge	100%
Dimensions	**Powerpack Unit** Length: 1,317 mm (50.9 in) Width: 968 mm (38.1 in) Height: 2,187 mm (86.1 in) Weight: 2,199 kg (4,847 lbs) **Powerpack Inverter** Length: 1,044 mm (41.1 in) Width: 1,394 mm (54.9 in) Height: 2,191 mm (86.2 in) Weight (max): 1,120 kg (2,470 lbs)
Energy Capacity	Up to 232 kWh (AC) per Powerpack
Operating Temperature	-30°C to 50°C / -22°F to 122°F
Enclosures	Pods: IP67 Powerpack: IP35/NEMA 3R Inverter: IP66/NEMA 4
System Efficiency (AC) *	88% round-trip (2 hour system) 89.5% round-trip (4 hour system)
Certifications	Nationally accredited certifications to international safety, EMC, utility and environmental legislation.

* Net Energy delivered at 25°C (77°F) ambient temperature including thermal control

APPENDIX F – Tesla Powerwall

Technical Specs

Usable Capacity
13.5 kWh

Depth of Discharge
100%

Efficiency
90% round-trip

Power
7kW peak / 5kW continuous

Supported Applications
Solar self-consumption
Back-up power
Time-Based control
Off-grid capabilities (coming soon)

Warranty
10 years

Scalable
Up to 10 Powerwalls

Operating Temperature
-4°F to 122°F / -20°C to 50°C

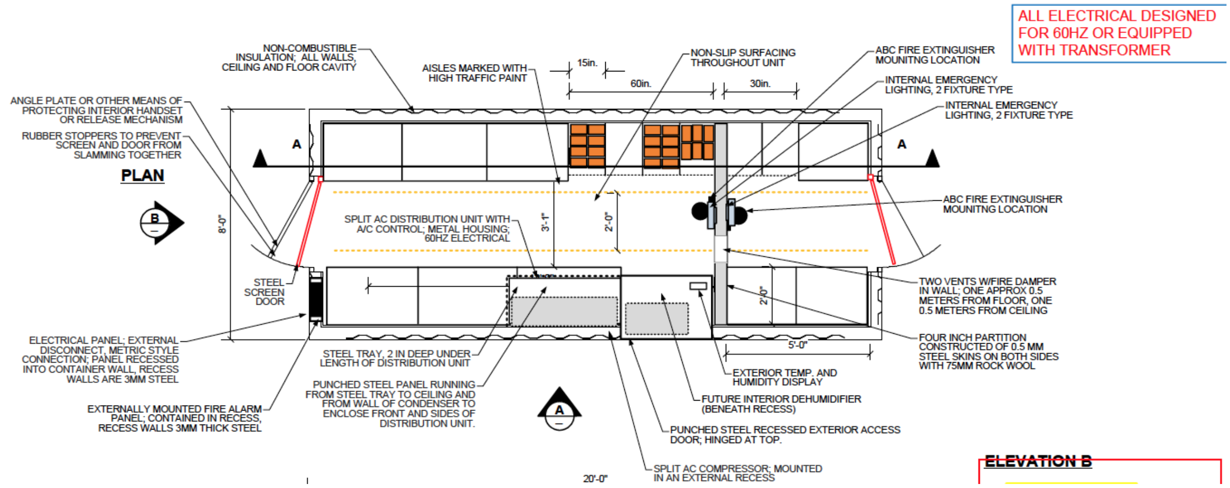
Dimensions
L x W x D: 45.3" x 29.6" x 5.75"
(1150 mm x 753 mm x 147 mm)

Weight
251.3 lbs / 114 kg

Installation
Floor or wall mounted
Indoor or outdoor

Certification
North American and International Standards
Grid code compliant

APPENDIX G – Oilfield Instrumentation Model 20-02

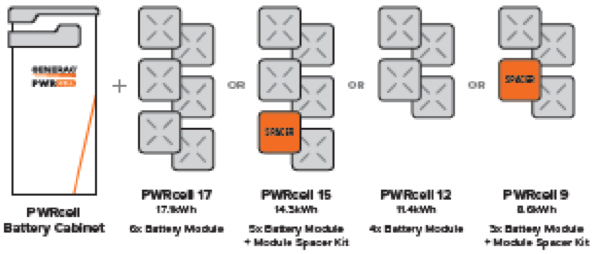



100971923
WARNING: Lithium Metal Batteries
To protect battery terminals from accidental short circuit, the terminals of all batteries whether new, usable or waste, must always be taped over when in storage.
100971923
WL 13,900 lbs

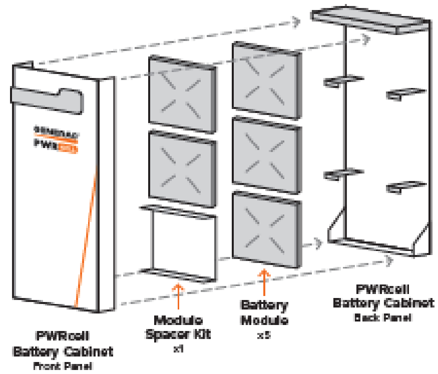

100971923
Latch Before Closing Outer Door
Latch Before Closing Outer Door

APPENDIX H – Generac Specification Sheet

BATTERY CONFIGURATION GUIDE



BATTERY CABINET ASSEMBLY



Specifications

PWRcell™ BATTERY CONFIGURATIONS	9	12	15	17
BATTERY MODULES:	3	4	5	6
USABLE ENERGY:	8.6kWh	11.4kWh	14.3kWh	17.1kWh
POWER - RATED CONTINUOUS:	3.4kW	4.5kW	5.6kW	6.7kW
POWER - 60 MINUTES:	4.2kW	5.6kW	7.0kW	8.4kW
POWER - 2 MINUTES:	5.0kW	6.7kW	8.4kW	10.0kW
REbus™ VOLTAGE - INPUT/OUTPUT:	360-420 VDC			
MODULE VOLTAGE:	46.8 VDC			
ROUND-TRIP EFFICIENCY:	96.50%			
OPERATING TEMPERATURE - FAHRENHEIT (CELSIUS):	41 to 113 °F (5 to 45 °C)			
RECOMMENDED AMBIENT TEMPERATURE - FAHRENHEIT (CELSIUS):	55 to 86 °F (13 to 30 °C)			
MAXIMUM INSTALLATION ALTITUDE - FT (M):	9834 (3000)			
DIMENSIONS, L x W x H - IN (MM):	22" x 10" x 68" (559 x 254 x 1727)			
WEIGHT, ENCLOSURE - LB (KG):	115 (52)			
WEIGHT, INSTALLED - LB (KG):	280 (127)	335 (152)	390 (178)	445 (202)
WARRANTY - LI-ION MODULES:	10 Years, (7.56MWh)			
WARRANTY - ELECTRONICS AND ENCLOSURE:	10 Years			
COMMUNICATION PROTOCOL:	REbus™ DC Nanogrid™			
COMPLIANCE:	UL 9540, UL 1973, UL 1642, CSA 22.2			

APPENDIX I – Vendors and Installation Diagrams

12V400AH LIFEPO4 BATTERY BANK WITH STEEL CASE,BMS INCLUDED

★★★★★ 0 reviews Write a review

Brands RUIXU
Product Code: RX-LFP-12-400
Availability: In Stock
Viewed: 4784
Sold: 2

$1,999.00

Available Options
Text
Text

Qty 1 ADD TO CART

Add to Wish List | Compare this Product

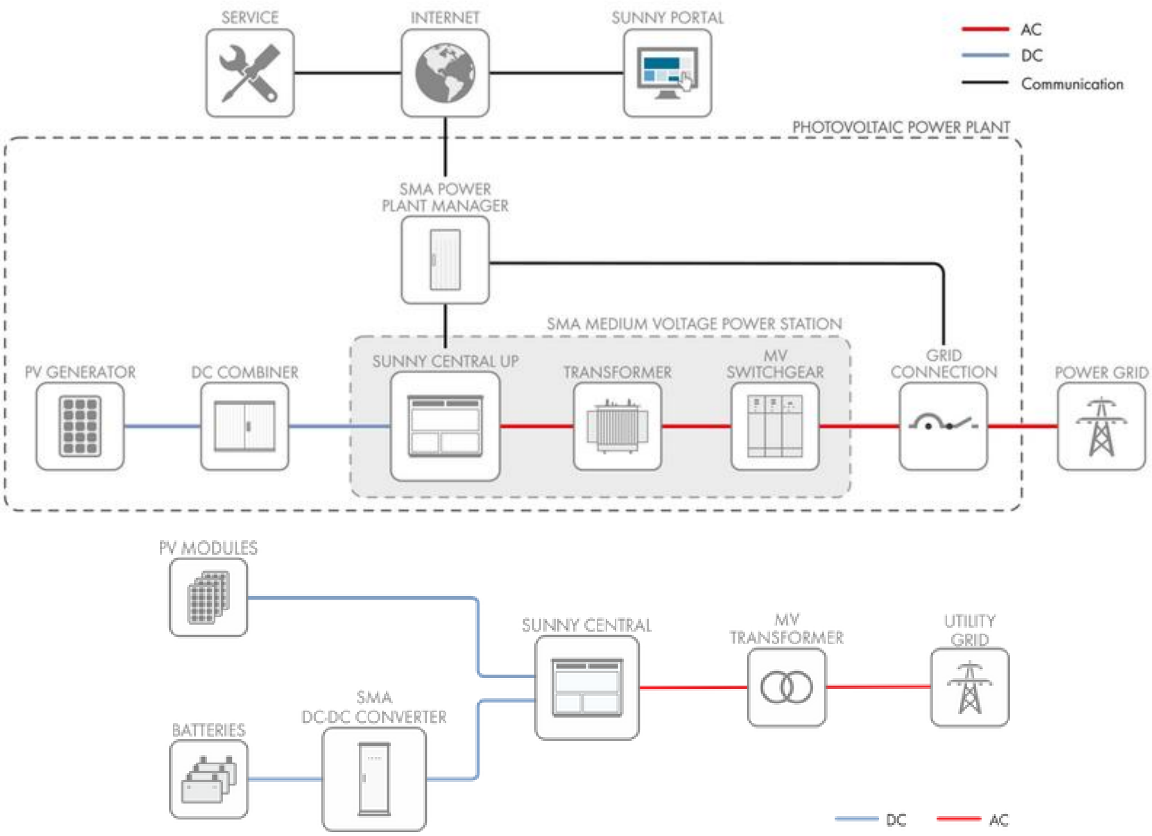
*Max continuous discharge current:100A | Weight: 62Kgs
*BMS included:Over charging protection,Over discharging protection,Over current protection,Over temperature protection,Short circuit protection,Balancing,Mult-communication
*LCD screen
*Cycle life: 80% DOD at 0.5C, 25℃ 4000cycles
*Size:Steel case,size can be customized

ELECTRICAL SPECIFICATIONS
Nominal Voltage:12.8 V
Nominal Capacity:400 Ah
Capacity @ 25A:240 min
Energy:5120 Wh
Resistance: ≤20mΩ
Efficiency:99%
Self Discharge:<3% per Month

MECHANICAL SPECIFICATIONS
Dimensions (L x W x H):455*180*450mm
Weight:137 lbs (62 kg)
Terminal Type:as required
Case Material:Steel Case
Enclosure Protection:IP56
Cell Type:Cylindrical
Battery Chemistry:LiFePO4

DISCHARGE SPECIFICATIONS
Maximum Continuous Discharge Current:100 A
Peak Discharge Current:250 A (4 s ±1 s)
BMS Discharge Current Cut-Off:450 A ±80 A (100 ±20 ms)
Working Voltage: 48.0-49.5V
Discharge cut-off voltage: 10V
BMS Discharge Voltage Cut-Off:10 V (2.0 ±0.08 vpc) (100 ±20 ms)
Reconnect Voltage:40 V (2.5 ±0.1 vpc)
Short Circuit Protection:200-600 μs

Source: (Ruixu, 2020).



s

Figure 51 – SMA's medium voltage power station (top) and DC coupling installation diagram (bottom).Source: (SMA, 2020) & (SMA, 2020).

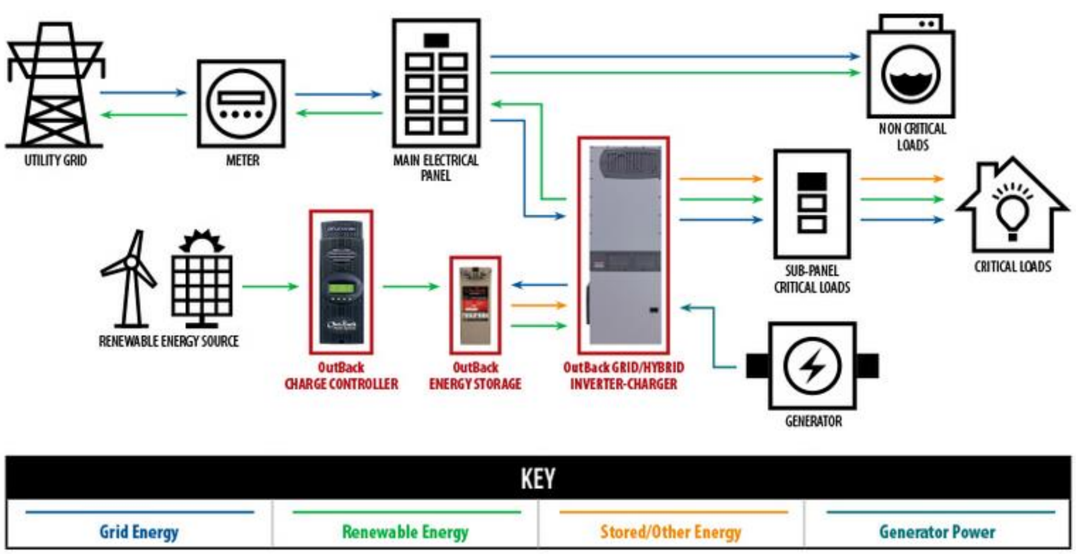


Figure 52 – Outback power grid-connected system overview.Source: (Outback Power, 2020).

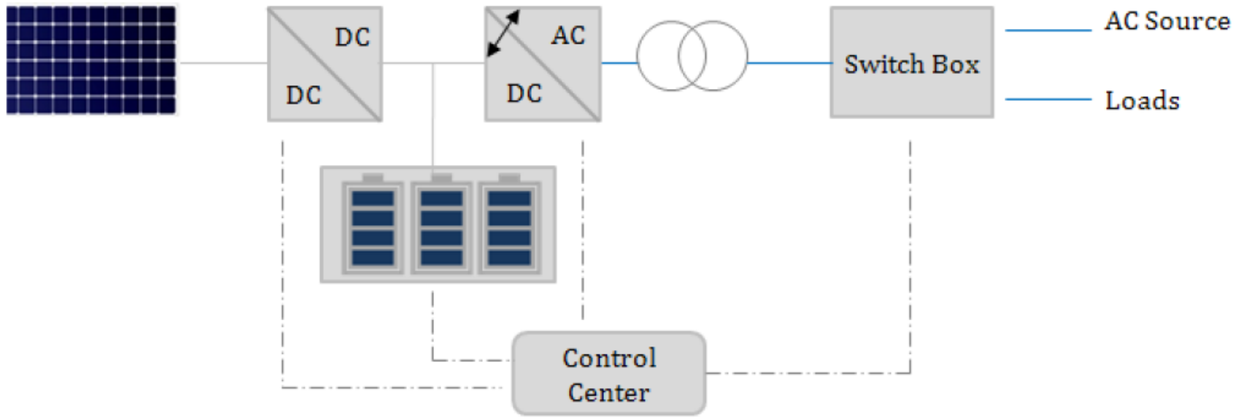


Figure 53 – BYD product installation diagram.Source: (BYD, 2020).

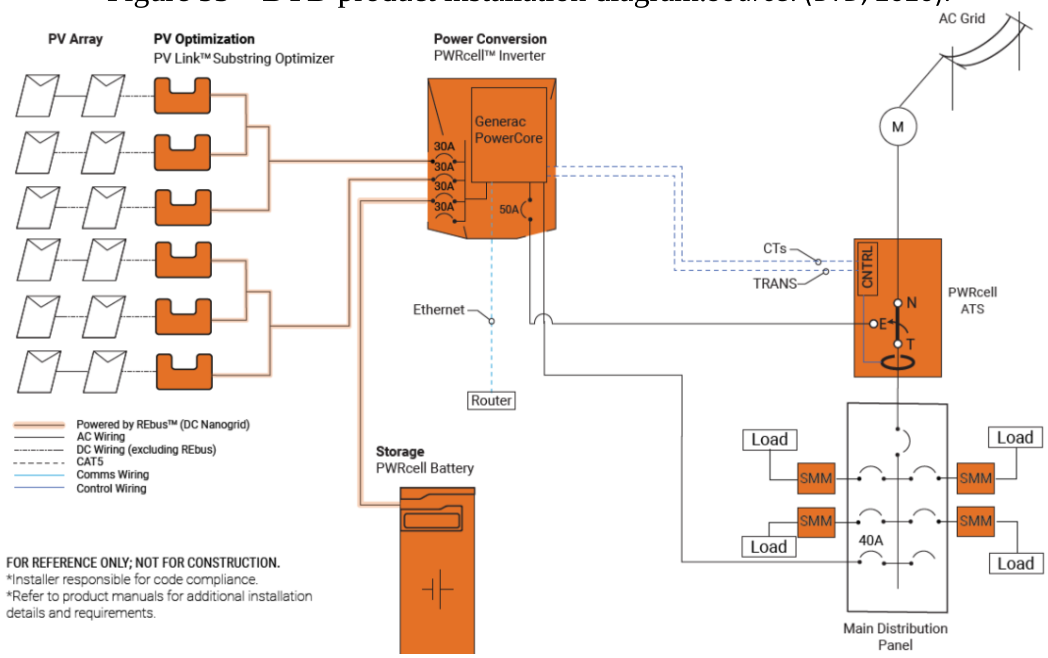


Figure 54 – Generac product installation line diagram.Source: (Generac, 2018).

The following figures are a sample of the approved equipment documents found on the PG&E website.

Safety Switch Cross-Reference Guide
Type VBII

Heavy Duty
600 Volt, Type 1 (Indoor)

HNF366

System	Ampere Rating	VBII	Vacu-Break®	Murray	General Electric	Square D	Cutler-Hammer
2-Pole, 2-Wire, 600V, Fusible							
	30	HF261	Use Two Poles of the 3-Pole 3-Wire Switch	Use Two Poles of the 3-Pole 3-Wire Switch	TH2261DC	①	DH261FGK
	60	HF262			TH2262DC	①	DH262FGK
	100	HF263			TH2263DC	①	DH263FGK
	200	①			①	①	DH264FGK
	400	HF265			①	H265	DH265FGK
	600	HF266			①	H266	DH266FGK
	800	①			①	H267	DH267FGK
	1200	①			①	H268	①
3-Pole, 3-Wire, 600V, Fusible							
	30	HF361	F351	HHN361	TH3361	H361	DH361FGK
	60	HF362	F352	HHN362	TH3362	H362	DH362FGK
	100	HF363	F353	HHN363	TH3363	H363	DH363FGK
	200	HF364	F354	HHN364	TH3364	H364	DH364FGK
	400	HF365	F355	HHN365	TH3365	H365	DH365FGK
	600	HF366	F356	HHN366	TH3366	H366	DH366FGK
	800	HF367	F357L	HLN367	TC72367	H367	DH367FGK
	1200	HF368	F358L	HLN368	TC72368	H368	DH368FGC
3-Pole, 4-Wire, 600V, Fusible							
	30	HF361N	SN451	Use 3-Pole 3-Wire Switch Order sep. Neutral	Use 3-Pole 3-Wire Switch Order sep. Neutral	H361N	DH361NGK
	60	HF362N	SN452			H362N	DH362NGK
	100	HF363N	SN453			H363N	DH363NGK
	200	HF364N	SN454			H364N	DH364NGK
	400	HF365N	SN455			H365N	DH365NGK
	600	HF366N	SN456			H366N	DH366NGK
	800	HF367N	②			H367N	DH367NGK
	1200	②	②			H368N	DH368NGC
2-Pole, 2-Wire, 600V, Non-Fusible							
	30	HNF261	Use Two Poles of the 3-Pole 3-Wire Switch	Use Two Poles of the 3-Pole 3-Wire Switch	THN2261DC	①	DH261UGK
	60	HNF262			THN2262DC	①	①
	100	HNF263			THN2263DC	①	DH263UGK
	200	①			①	①	①
	400	HNF265			①	HU265	DH265UGK
	600	HNF266			①	HU266	DH266UGK
	800	①		—	①	HU267	DH267UGK
	1200	①		—	①	HU268	①
3-Pole, 3-Wire, 600V, Non-Fusible							
	30	HNF361	NF351	HUN361	THN3361	HU361	DH361UGK
	60	HNF362	NF352	HUN362	THN3362	HU362	DH362UGK
	100	HNF363	NF353	HUN363	THN3363	HU363	DH363UGK
	200	HNF364	NF354	HUN364	THN3364	HU364	DH364UGK
	400	HNF365	NF355	HUN365	THN3365	HU365	DH365UGK
	600	HNF366	NF356	HUN366	THN3366	HU366	DH366UGK
	800	HNF367	NF357	—	TC36367	HU367	DH367UGK
	1200	HNF368	NF358	—	TC36368	HU368	DH368UGC

① Use Two Poles of the 3-Pole, 3-Wire Switch.
② Use 3-Pole, 3-Wire Switch. Order separate neutral.

APPENDIX J – Enphase Product Datasheets

Data Sheet
Enphase Microinverters
Region: AMERICAS

Enphase IQ 7 and IQ 7+ Microinverters

The high-powered smart grid-ready Enphase IQ 7 Micro™ and Enphase IQ 7+ Micro™ dramatically simplify the installation process while achieving the highest system efficiency.

Part of the Enphase IQ System, the IQ 7 and IQ 7+ Microinverters integrate with the Enphase IQ Envoy™, Enphase IQ Battery™, and the Enphase Enlighten™ monitoring and analysis software.

IQ Series Microinverters extend the reliability standards set forth by previous generations and undergo over a million hours of power-on testing, enabling Enphase to provide an industry-leading warranty of up to 25 years.

Easy to Install

- Lightweight and simple
- Faster installation with improved, lighter two-wire cabling
- Built-in rapid shutdown compliant (NEC 2014 & 2017)

Productive and Reliable

- Optimized for high powered 60-cell/120 half-cell and 72-cell/144 half-cell* modules
- More than a million hours of testing
- Class II double-insulated enclosure
- UL listed

Smart Grid Ready

- Complies with advanced grid support, voltage and frequency ride-through requirements
- Remotely updates to respond to changing grid requirements
- Configurable for varying grid profiles
- Meets CA Rule 21 (UL 1741-SA)

* The IQ 7+ Micro is required to support 72-cell/144 half-cell modules.

UL CERTIFIED

To learn more about Enphase offerings, visit **enphase.com**

ENPHASE.

Enphase IQ 7 and IQ 7+ Microinverters

INPUT DATA (DC)	IQ7-60-2-US		IQ7PLUS-72-2-US	
Commonly used module pairings[1]	235 W - 350 W +		235 W - 440 W +	
Module compatibility	60-cell/120 half-cell PV modules only		60-cell/120 half-cell and 72-cell/144 half-cell PV modules	
Maximum input DC voltage	48 V		60 V	
Peak power tracking voltage	27 V - 37 V		27 V - 45 V	
Operating range	16 V - 48 V		16 V - 60 V	
Min/Max start voltage	22 V / 48 V		22 V / 60 V	
Max DC short circuit current (module Isc)	15 A		15 A	
Overvoltage class DC port	II		II	
DC port backfeed current	0 A		0 A	
PV array configuration	1 x 1 ungrounded array; No additional DC side protection required; AC side protection requires max 20A per branch circuit			
OUTPUT DATA (AC)	**IQ 7 Microinverter**		**IQ 7+ Microinverter**	
Peak output power	250 VA		295 VA	
Maximum continuous output power	240 VA		290 VA	
Nominal (L-L) voltage/range[2]	240 V / 211-264 V	208 V / 183-229 V	240 V / 211-264 V	208 V / 183-229 V
Maximum continuous output current	1.0 A (240 V)	1.15 A (208 V)	1.21 A (240 V)	1.39 A (208 V)
Nominal frequency	60 Hz		60 Hz	
Extended frequency range	47 - 68 Hz		47 - 68 Hz	
AC short circuit fault current over 3 cycles	5.8 Arms		5.8 Arms	
Maximum units per 20 A (L-L) branch circuit[3]	16 (240 VAC)	13 (208 VAC)	13 (240 VAC)	11 (208 VAC)
Overvoltage class AC port	III		III	
AC port backfeed current	18 mA		18 mA	
Power factor setting	1.0		1.0	
Power factor (adjustable)	0.85 leading ... 0.85 lagging		0.85 leading ... 0.85 lagging	
EFFICIENCY	**@240 V**	**@208 V**	**@240 V**	**@208 V**
Peak efficiency	97.6 %	97.6 %	97.5 %	97.3 %
CEC weighted efficiency	97.0 %	97.0 %	97.0 %	97.0 %
MECHANICAL DATA				
Ambient temperature range	-40ºC to +65ºC			
Relative humidity range	4% to 100% (condensing)			
Connector type	MC4 (or Amphenol H4 UTX with additional Q-DCC-5 adapter)			
Dimensions (HxWxD)	212 mm x 175 mm x 30.2 mm (without bracket)			
Weight	1.08 kg (2.38 lbs)			
Cooling	Natural convection - No fans			
Approved for wet locations	Yes			
Pollution degree	PD3			
Enclosure	Class II double-insulated, corrosion resistant polymeric enclosure			
Environmental category / UV exposure rating	NEMA Type 6 / outdoor			
FEATURES				
Communication	Power Line Communication (PLC)			
Monitoring	Enlighten Manager and MyEnlighten monitoring options. Both options require installation of an Enphase IQ Envoy.			
Disconnecting means	The AC and DC connectors have been evaluated and approved by UL for use as the load-break disconnect required by NEC 690.			
Compliance	CA Rule 21 (UL 1741-SA) UL 62109-1, UL1741/IEEE1547, FCC Part 15 Class B, ICES-0003 Class B, CAN/CSA-C22.2 NO. 107.1-01 This product is UL Listed as PV Rapid Shut Down Equipment and conforms with NEC 2014, NEC 2017, and NEC 2020 section 690.12 and C22.1-2015 Rule 64-218 Rapid Shutdown of PV Systems, for AC and DC conductors, when installed according manufacturer's instructions.			

1. No enforced DC/AC ratio. See the compatibility calculator at https://enphase.com/en-us/support/module-compatibility.
2. Nominal voltage range can be extended beyond nominal if required by the utility.
3. Limits may vary. Refer to local requirements to define the number of microinverters per branch in your area.

To learn more about Enphase offerings, visit **enphase.com**

ENPHASE.

Enphase
IQ Combiner 3-ES/3C-ES

X-IQ-AM1-240-3-ES
X-IQ-AM1-240-3C-ES

The **Enphase IQ Combiner 3-ES/3C-ES™** with Enphase IQ Envoy™ and integrated LTE-M1 cell modem (included only with IQ Combiner 3C-ES) consolidates interconnection equipment into a single enclosure and streamlines PV and storage installations by providing a consistent, pre-wired solution for residential applications. It offers up to four 2-pole input circuits and Eaton BR series busbar assembly.

X-IQ-AM1-240-3C-ES

X-IQ-AM1-240-3-ES

Smart

- Includes IQ Envoy for communication and control
- Includes LTE-M1 cell modem (included only with IQ Combiner 3C-ES)
- Includes solar shield to match Ensemble esthetics and deflect heat
- Flexible networking supports Wi-Fi, Ethernet, or cellular
- Optional AC receptacle available for PLC bridge
- Provides production metering and consumption monitoring

Simple

- Reduced size from IQ Combiner+ (X-IQ-AM1-240-2)
- Centered mounting brackets support single stud mounting
- Supports back and side conduit entry
- Up to four 2-pole branch circuits for 240 VAC plug-in breakers (not included)
- 80 A total PV or storage branch circuits

Reliable

- Durable NRTL-certified NEMA type 3R enclosure
- Five-year limited warranty
- Two years labor reimbursement program coverage included
- UL listed

UL LISTED

To learn more about Enphase offerings, visit enphase.com

ENPHASE.

Enphase IQ Combiner 3-ES / 3C-ES

MODEL NUMBER	
IQ Combiner 3-ES (X-IQ-AM1-240-3-ES)	IQ Combiner 3-ES with Enphase IQ Envoy printed circuit board for integrated revenue grade PV production metering (ANSI C12.20 +/- 0.5%) and consumption monitoring (+/- 2.5%). Includes a silver solar shield to match the Encharge storage system and Enpower smart switch and to deflect heat.
IQ Combiner 3C-ES (X-IQ-AM1-240-3C-ES)	IQ Combiner 3C-ES with Enphase IQ Envoy printed circuit board for integrated revenue grade PV production metering (ANSI C12.20 +/- 0.5%) and consumption monitoring (+/- 2.5%). Includes Enphase Mobile Connect LTE-M1 (CELLMODEM-M1), a plug-and-play industrial-grade cell modem for systems up to 60 microinverters. (Available in the US, Canada, Mexico, Puerto Rico, and the US Virgin Islands, where there is adequate cellular service in the installation area.) Includes a silver solar shield to match the Encharge storage system and Enpower smart switch and to deflect heat.
ACCESSORIES and REPLACEMENT PARTS	(not included, order separately)
Ensemble Communications Kit (COMMS-CELLMODEM-M1)	Includes COMMS-KIT-01 and CELLMODEM-M1 with 5-year data plan for Ensemble sites
Circuit Breakers BRK-10A-2-240 BRK-15A-2-240 BRK-20A-2P-240	Supports Eaton BR210, BR215, BR220, BR230, BR240, BR250, and BR260 circuit breakers. Circuit breaker, 2 pole, 10A, Eaton BR210 Circuit breaker, 2 pole, 15A, Eaton BR215 Circuit breaker, 2 pole, 20A, Eaton BR220
EPLC-01	Power line carrier (communication bridge pair), quantity - one pair
XA-SOLARSHIELD-ES	Replacement solar shield for Combiner 3-ES / 3C-ES
XA-PLUG-120-3	Accessory receptacle for Power Line Carrier in IQ Combiner 3-ES / 3C-ES (required for EPLC-01)
XA-ENV-PCBA-3	Replacement IQ Envoy printed circuit board (PCB) for Combiner 3-ES / 3C-ES
ELECTRICAL SPECIFICATIONS	
Rating	Continuous duty
System voltage	120/240 VAC, 60 Hz
Eaton BR series busbar rating	125 A
Max. continuous current rating	65 A
Max. continuous current rating (input from PV/storage)	64 A
Max. fuse/circuit rating (output)	90 A
Branch circuits (solar and/or storage)	Up to four 2-pole Eaton BR series Distributed Generation (DG) breakers only (not included)
Max. total branch circuit breaker rating (input)	80A of distributed generation / 90A with IQ Envoy breaker included
Production metering CT	200 A solid core pre-installed and wired to IQ Envoy
Consumption monitoring CT (CT-200-SPLIT)	A pair of 200 A split core current transformers
MECHANICAL DATA	
Dimensions (WxHxD)	37.5 x 49.5 x 16.8 cm (14.75" x 19.5" x 6.63"). Height is 21.06" (53.5 cm) with mounting brackets.
Weight	7.5 kg (16.5 lbs)
Ambient temperature range	-40º C to +46º C (-40º to 115º F)
Cooling	Natural convection, plus heat shield
Enclosure environmental rating	Outdoor, NRTL-certified, NEMA type 3R, polycarbonate construction
Wire sizes	• 20 A to 50 A breaker inputs: 14 to 4 AWG copper conductors • 60 A breaker branch input: 4 to 1/0 AWG copper conductors • Main lug combined output: 10 to 2/0 AWG copper conductors • Neutral and ground: 14 to 1/0 copper conductors Always follow local code requirements for conductor sizing.
Altitude	To 2000 meters (6,560 feet)
INTERNET CONNECTION OPTIONS	
Integrated Wi-Fi	802.11b/g/n
Cellular	CELLMODEM-M1 4G based LTE-M1 cellular modem (included only with IQ Combiner 3C-ES). Note that an Enphase Mobile Connect cellular modem is required for all Ensemble installations.
Ethernet	Optional, 802.3, Cat5E (or Cat 6) UTP Ethernet cable (not included)
COMPLIANCE	
Compliance, Combiner	UL 1741, CAN/CSA C22.2 No. 107.1, 47 CFR, Part 15, Class B, ICES 003 Production metering: ANSI C12.20 accuracy class 0.5 (PV production) Consumption metering: accuracy class 2.5
Compliance, IQ Envoy	UL 60601-1/CANCSA 22.2 No. 61010-1

To learn more about Enphase offerings, visit enphase.com

ENPHASE.

Enphase Enpower

The **Enphase Enpower™** smart switch connects the home to grid power, the Encharge storage system, and solar PV. It provides microgrid interconnection device (MID) functionality by automatically detecting and seamlessly transitioning the home energy system from grid power to backup power in the event of a grid failure. It consolidates interconnection equipment into a single enclosure and streamlines grid independent capabilities of PV and storage installations by providing a consistent, pre-wired solution for residential applications.

Reliable

- Durable NEMA type 3R enclosure
- Ten-year limited warranty

Smart

- Controls safe connectivity to the grid
- Automatically detects grid outages
- Provides seamless transition to backup

Simple

- Connects to the load or service equipment[1] side of the main load panel
- Centered mounting brackets support single stud mounting
- Supports conduit entry from the bottom, bottom left side, and bottom right side
- Supports whole home and partial home backup and subpanel backup
- Up to 200A main breaker support
- Includes neutral-forming transformer for split phase 120/240V backup operation

1. Enpower is not suitable for use as service equipment in Canada.

To learn more about Enphase offerings, visit enphase.com

ENPHASE.

Enphase Enpower

MODEL NUMBER	
EP200G101-M240US00	Enphase Enpower smart switch with neutral-forming transformer (NFT), Microgrid Interconnect Device (MID), breakers, and screws. Streamlines grid-independent capabilities of PV and storage installations.
ACCESSORIES and REPLACEMENT PARTS	
XA-E3-PCBA-ENS	Replacement Enpower controller printed circuit board
Circuit breakers (as needed)[2,3] BRK-100A-2P-240V BRK-125A-2P-240V BRK-150A-2P-240V BRK-175A-2P-240V BRK-200A-2P-240V BRK-20A-2P-240V-B BRK-30A-2P-240V BRK-40A-2P-240V BRK-60A-2P-240V BRK-80A-2P-240V	Not included, must order separately: • Main breaker, 2 pole, 100A, 25kAIC, CSR2100 • Main breaker, 2 pole, 125A, 25kAIC, CSR2125N • Main breaker, 2 pole, 150A, 25kAIC, CSR2150N • Main breaker, 2 pole, 175A, 25kAIC, CSR2175N • Main breaker, 2 pole, 200A, 25kAIC, CSR2200N • Circuit breaker, 2 pole, 20A, 10kAIC, BR220B • Circuit breaker, 2 pole, 30A, 10kAIC, BR230B • Circuit breaker, 2 pole, 40A, 10kAIC, BR240B • Circuit breaker, 2 pole, 60A, 10kAIC, BR260 • Circuit breaker, 2 pole, 80A, 10kAIC, BR280
EP200G-HNDL-R1	Enpower installation handle kit (order separately)
ELECTRICAL SPECIFICATIONS	
Assembly rating	Continuous operation at 100% of its rating
Nominal voltage / range (L-L)	240 VAC / 100 - 310 VAC
Voltage measurement accuracy	±1% V nominal (±1.2V L-N and ±2.4V L-L)
Nominal frequency / range	60 Hz / 56 - 63 Hz
Frequency measurement accuracy	±0.1 Hz
Maximum continuous current rating	160A
Maximum output overcurrent protection device	200A
Maximum input overcurrent protection device	200A
Maximum overcurrent protection device rating for storage branch circuit[4]	80A
Maximum overcurrent protection device rating for PV combiner branch circuit[4]	80A
Neutral Forming Transformer (NFT)	• Breaker rating (pre-installed): 40A between L1 and Neutral; 40A between L2 and Neutral • Continuous rated power: 3600VA • Maximum continuous unbalance current: 30A @ 120V • Peak rated power: 8800VA for 30 seconds • Peak unbalanced current: 80A @ 120V for 30 seconds
MECHANICAL DATA	
Dimensions (WxHxD)	50cm x 91.6cm x 24.6cm (19.7 in x 36 in x 9.7 in)
Weight	38.5 kg (85 lbs)
Ambient temperature range	-40° C to +50° C (-40° F to 122° F)
Cooling	Natural convection, plus heat shield
Enclosure environmental rating	Outdoor, NEMA type 3R, polycarbonate construction
Altitude	To 2500 meters (8200 feet)

WIRE SIZES		
Connections	• Main lugs and backup load lugs • CSR breakers • BR breakers (wire provided) • AC combiner lugs, Encharge lugs, and generator (future) lugs • Neutral (large lugs)	Cu/Al: 1 AWG – 300 KCMIL Cu/Al: 2 AWG – 300 KCMIL 6 AWG 14 AWG – 10 AWG Cu/AL: 6 AWG - 300 KCMIL
Neutral and ground bars	Large holes (5/16-24 UNF) Small holes (10-32 UNF)	14 AWG – 1/0 AWG 14 AWG – 6 AWG
COMPLIANCE		
Compliance	UL 1741, UL 1741 SA, UL1998, UL869A[5], UL67[5], UL508[5], UL50E[5] CSA 22.2 No. 107.1, 47 CFR, Part 15, Class B, ICES 003, AC156.	

2. Compatible with BRHDK125 Hold-Down Kit to comply with 2017 NEC 710.15E for back-fed circuit breakers.
3. The Enpower is rated 22 kAIC
4. Not included. Installer must provide properly rated breaker per circuit breaker list above.
5. Sections from these standards were used during the safety evaluation and included in the UL 1741 listing.

To learn more about Enphase offerings, visit enphase.com

ENPHASE.

Enphase Encharge 10

The Enphase Encharge 10™ all-in-one AC-coupled storage system is **reliable, smart, simple,** and **safe**. It is comprised of three base Encharge 3™ storage units, has a total usable energy capacity of 10.08 kWh and twelve embedded grid-forming microinverters with 3.84 kW power rating. It provides backup capability and installers can quickly design the right system size to meet the needs of both new and retrofit solar customers.

Reliable

- Proven high reliability IQ Series Microinverters
- Ten-year limited warranty
- Three independent Encharge storage base units
- Twelve embedded IQ 8X-BAT Microinverters
- Passive cooling (no moving parts/fans)

Smart

- Grid-forming capability for backup operation
- Remote software and firmware upgrade
- Mobile app-based monitoring and control
- Support for self consumption
- Utility time of use (TOU) optimization

Simple

- Fully integrated AC battery system
- Quick and easy plug-and-play installation
- Interconnects with standard household AC wiring

Safe

- Cells safety tested
- Lithium iron phosphate (LFP) chemistry for maximum safety and longevity

To learn more about Enphase offerings, visit enphase.com

ENPHASE.

Enphase Encharge 10

MODEL NUMBER	
ENCHARGE-10-1P-NA	Encharge 10 battery storage system with integrated Enphase Microinverters and battery management unit (BMU). Includes: - Three Encharge 3.36 kWh base units (B3-A01-US001-1-3) - One Encharge 10 cover kit with cover, wall mounting bracket, watertight conduit hubs, and interconnect kit for wiring between batteries (B10-C-1050-O)
ACCESSORIES	
ENCHARGE-HNDL-R1	One set of Encharge base unit installation handles
OUTPUT (AC)	**@ 240 VAC[1]**
Rated (continuous) output power[2]	3.84 kVA
Peak output power	5.7 kVA (10 seconds)
Nominal voltage / range	240 / 211 — 264 VAC
Nominal frequency / range	60 / 57 — 61 Hz
Rated output current	16 A
Peak output current	24.6A (10 seconds)
Power factor (adjustable)	0.85 leading ... 0.85 lagging
Maximum units per 20 A branch circuit	1 unit (single phase)
Interconnection	Single-phase
Maximum AC short circuit fault current over 3 cycles	69.6 Arms
Round trip efficiency[2]	89%
BATTERY	
Total capacity	10.5 kWh
Usable capacity	10.08 kWh
Round trip efficiency	96%
Nominal DC voltage	67.2 V
Maximum DC voltage	73.5 V
Ambient operating temperature range	-15º C to 55º C (5º F to 131º F) non-condensing
Optimum operating temperature range	0º C to 30º C (32º F to 86º F)
Chemistry	Lithium iron phosphate (LFP)
MECHANICAL DATA	
Dimensions (WxHxD)	1070 mm x 664 mm x 319 mm (42.13 in x 26.14 in x 12.56 in)
Weight	Three individual 44.2 kg (97.4 lbs) base units plus 21.1 kg (48.7 lbs) cover and mounting bracket; total 154.7 kg (341 lbs)
Enclosure	Outdoor – NEMA type 3R
IQ 8X-BAT microinverter enclosure	NEMA type 6
Cooling	Natural convection – No fans
Altitude	Up to 2500 meters (8200 feet)
Mounting	Wall mount
FEATURES AND COMPLIANCE	
Compatibility	Compatible with grid-tied PV systems. Compatible with Enphase IQ Series Micros, Enphase Enpower, and Enphase IQ Envoy for backup operation.
Communication	Wireless 2.4 GHz
Services	Backup, self-consumption, TOU, Demand Charge, NEM Integrity
Monitoring	Enlighten Manager and MyEnlighten monitoring options; API integration
Compliance	UL 9540, UN 38.3, UL 9540A, UL 1998, UL 991, NEMA Type 3R, AC156 EMI: 47 CFR, Part 15, Class B, ICES 003 Cell Module: UL 1973, UN 38.3 Inverters: UL 62109-1, IEC 62109-2, UL 1741SA, CAN/CSA C22.2 No. 107.1-16, IEEE 1547
LIMITED WARRANTY	
Limited Warranty[3]	>70% capacity, up to 10 years or 4000 cycles

1. Supported in backup/off grid operations
2. AC to Battery to AC at 50% power rating.
3. Whichever occurs first. Restrictions apply.

To learn more about Enphase offerings, visit enphase.com

ENPHASE.

APPENDIX K – Solar Edge Product Datasheets

Power Optimizer

For North America

P320 / P340 / P370 / P400 / P401 / P405 / P485 / P505

POWER OPTIMIZER

PV power optimization at the module-level

- Specifically designed to work with SolarEdge inverters
- Up to 25% more energy
- Superior efficiency (99.5%)
- Mitigates all types of module mismatch losses, from manufacturing tolerance to partial shading
- Flexible system design for maximum space utilization
- Fast installation with a single bolt
- Next generation maintenance with module-level monitoring
- Meets NEC requirements for arc fault protection (AFCI) and Photovoltaic Rapid Shutdown System (PVRSS)
- Module-level voltage shutdown for installer and firefighter safety

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Power Optimizer
For North America
P320 / P340 / P370 / P400 / P401 / P405 / P485 / P505

Optimizer model (typical module compatibility)	P320 (for 60-cell modules)	P340 (for high-power 60-cell modules)	P370 (for higher-power 60 and 72-cell modules)	P400 (for 72 & 96-cell modules)	P401 (for high power 60 and 72 cell modules)	P405 (for high-voltage modules)	P485 (for high-voltage modules)	P505 (for higher current modules)	
INPUT									
Rated Input DC Power[1]	320	340	370	400		405	485	505	W
Absolute Maximum Input Voltage (Voc at lowest temperature)	48		60	80	60	125[2]		83[2]	Vdc
MPPT Operating Range	8 - 48		8 - 60	8 - 80	8-60	12.5 - 105		12.5 - 83	Vdc
Maximum Short Circuit Current (Isc)	11			10.1	11.75	11		14	Adc
Maximum Efficiency	99.5								%
Weighted Efficiency	98.8							98.6	%
Overvoltage Category	II								
OUTPUT DURING OPERATION (POWER OPTIMIZER CONNECTED TO OPERATING SOLAREDGE INVERTER)									
Maximum Output Current	15								Adc
Maximum Output Voltage	60					85			Vdc
OUTPUT DURING STANDBY (POWER OPTIMIZER DISCONNECTED FROM SOLAREDGE INVERTER OR SOLAREDGE INVERTER OFF)									
Safety Output Voltage per Power Optimizer	1 ± 0.1								Vdc
STANDARD COMPLIANCE									
EMC	FCC Part15 Class B, IEC61000-6-2, IEC61000-6-3								
Safety	IEC62109-1 (class II safety), UL1741								
Material	UL94 V-0 , UV Resistant								
RoHS	Yes								
INSTALLATION SPECIFICATIONS									
Maximum Allowed System Voltage	1000								Vdc
Compatible inverters	All SolarEdge Single Phase and Three Phase inverters								
Dimensions (W x L x H)	129 x 153 x 27.5 / 5.1 x 6 x 1.1			129 x 153 x 33.5 / 5.1 x 6 x 1.3	129 x 153 x 29.5 /5.1 x 6 x 1.16	129 x 159 x 49.5 / 5.1 x 6.3 x 1.9		129 x 162 x 59 / 5.1 x 6.4 x 2.3	mm / in
Weight (including cables)	630 / 1.4			750 / 1.7	655 / 1.5	845 / 1.9		1064 / 2.3	gr / lb
Input Connector	MC4[3]						Single or dual MC4[3][4]	MC4[3]	
Input Wire Length	0.16 / 0.52								m / ft
Output Wire Type / Connector	Double Insulated / MC4								
Output Wire Length	0.9 / 2.95		1.2 / 3.9						m / ft
Operating Temperature Range[5]	-40 - +85 / -40 - +185								°C / °F
Protection Rating	IP68 / NEMA6P								
Relative Humidity	0 - 100								%

(1) Rated power of the module at STC will not exceed the optimizer "Rated Input DC Power". Modules with up to +5% power tolerance are allowed
(2) NEC 2017 requires max input voltage be not more than 80V
(3) For other connector types please contact SolarEdge
(4) For dual version for parallel connection of two modules use P485-4NMDMRM. In the case of an odd number of PV modules in one string, installing one P485 dual version power optimizer connected to one PV module. When connecting a single module seal the unused input connectors with the supplied pair of seals.
(5) For ambient temperature above +85°C / +185°F power de-rating is applied. Refer to Power Optimizers Temperature De-Rating Technical Note for more details.

PV System Design Using a SolarEdge Inverter[6][7]		Single Phase HD-Wave	Single phase	Three Phase for 208V grid	Three Phase for 277/480V grid	
Minimum String Length (Power Optimizers)	P320, P340, P370, P400, P401	8		10	18	
	P405, P485, P505	6		8	14	
Maximum String Length (Power Optimizers)		25		25	50[8]	
Maximum Power per String		5700 (6000 with SE7600-US - SE11400-US)	5250	6000[9]	12750[10]	W
Parallel Strings of Different Lengths or Orientations		Yes				

(6) For detailed string sizing information refer to: http://www.solaredge.com/sites/default/files/string_sizing_na.pdf
(7) It is not allowed to mix P405/P485/P505 with P320/P340/P370/P400/P401 in one string
(8) A string with more than 30 optimizers does not meet NEC rapid shutdown requirements; safety voltage will be above the 30V requirement
(9) For 208V grid: It is allowed to install up to 7,200W per string when the maximum power difference between each string is 1,000W
(10) For 277/480V grid: It is allowed to install up to 15,000W per string when the maximum power difference between each string is 2,000W

Intertek RoHS

Three Phase Inverters for the 277/480V Grid

for North America

SE20KUS / SE30KUS / SE33.3KUS / SE40KUS

INVERTERS

The best choice for SolarEdge enabled systems

- Specifically designed to work with power optimizers
- Quick and easy inverter commissioning directly from a smartphone using the SolarEdge SetApp
- Fixed voltage inverter for superior efficiency (98.5%) and longer strings
- Built-in type 2 DC and AC Surge Protection, to better withstand lightning events
- Small, lightest in its class, and easy to install outdoors or indoors on provided bracket
- Integrated arc fault protection and rapid shutdown for NEC 2014 and 2017, per article 690.11 and 690.12
- Built-in module-level monitoring with Ethernet, wireless or cellular communication for full system visibility
- Integrated Safety Switch
- UL1741 SA certified, for CPUC Rule 21 grid compliance

solaredge.com

solaredge

/ Three Phase Inverters for the 277/480V Grid[1]
for North America

SE20KUS / SE30KUS / SE33.3KUS / SE40KUS

MODEL NUMBER	SE20KUS	SE30KUS	SE33.3KUS	SE40KUS	
APPLICABLE TO INVERTERS WITH PART NUMBER	SEXXK - USXXXBXXX	SEXXK-USX8IXXXX			
OUTPUT					
Rated AC Power Output	20000	30000	33300	40000	W
Maximum apparent AC output power	20000	30000	33300	40000	VA
AC Output Line Connections	4W + PE	3W + PE, 4W + PE			
AC Output Voltage Minimum-Nominal-Maximum[2] (L-N)	244 - 277 - 305				Vac
AC Output Voltage Minimum-Nominal-Maximum[2] (L-L)	422.5 - 480 - 529				Vac
AC Frequency Min-Nom-Max[2]	59.3 - 60 - 60.5				Hz
Maximum Continuous Output Current (per Phase)	24	36.25	40	48.25	Aac
GFDI Threshold	1				A
Utility Monitoring, Islanding Protection, Country Configurable Set Points	Yes				
Total Harmonic Distortion	≤ 3				%
Power Factor Range	+/- 0.85 to 1				
INPUT					
Maximum DC Power (Module STC)	27000	45000	50000	60000	W
Transformer-less, Ungrounded	Yes				
Maximum Input Voltage DC+ to DC-	1000				Vdc
Nominal Input Voltage DC+ to DC-	850				Vdc
Maximum Input Current	26.5	36.25	40	48.25	Adc
Maximum Input Short Circuit Current	33	55			Adc
Reverse-Polarity Protection	Yes				
Ground-Fault Isolation Detection	1MΩ Sensitivity	167kΩ Sensitivity[3]			
CEC Weighted Efficiency	98	98.5			%
Night-time Power Consumption	<3	<4			W
ADDITIONAL FEATURES					
Supported Communication Interfaces	2 x RS485, Ethernet, Cellular (optional)				
Inverter Commissioning	With the SetApp mobile application using built-in access point for local connection				
Arc Fault Protection	Integrated, User Configurable (According to UL1699B)				
Rapid Shutdown	NEC2014, NEC2017 and NEC2020 compliant/certified				
RS485 Surge Protection Plug-in	Supplied with the inverter, Built-in				
DC Surge Protection	Type II, field replaceable, optional	Type II, field replaceable, Built-in			
AC Surge Protection	-	Type II, field replaceable, Built-in			
DC Fuses (Single Pole)	-	25A, Built-in			
Smart Energy Management	Export Limitation				
DC SAFETY SWITCH					
DC Disconnect	Integrated				
STANDARD COMPLIANCE					
Safety	UL1741, UL1741 SA, UL1699B, CSA C22.2, Canadian AFCI according to T.I.L. M-07				
Grid Connection Standards	IEEE1547, Rule 21, Rule 14 (HI)				
Emissions	FCC part15 class A				
INSTALLATION SPECIFICATIONS					
AC output conduit size / AWG range	3/4" minimum / 12-6 AWG	¾" or 1" / 6 - 10 AWG			
DC input conduit size / AWG range	¾" or 1" / 6 - 12 AWG				
Number of DC inputs pairs	2	4			
Dimensions with Safety Switch (H x W x D)	30.5 x 12.5 x 10.5 / 775 x 315 x 260	31.8 x 12.5 x 11.8 / 808 x 317 x 300			in / mm
Weight with Safety Switch	74.2 / 33.7	78.2 / 35.5			lb / kg
Cooling	Fans (user replaceable)				
Noise	< 50	< 62			dBA
Operating Temperature Range	-40 to +140 / -40 to +60[4]				°F / °C
Protection Rating	NEMA 3R				
Mounting	Bracket provided				

(1) For 120/208V inverters refer to: https://www.solaredge.com/sites/default/files/se-three-phase-us-inverter-208V-setapp-datasheet.pdf
(2) For other regional settings please contact SolarEdge support
(3) Where permitted by local regulations
(4) For power de-rating information refer to: https://www.solaredge.com/sites/default/files/se-temperature-derating-note-na.pdf

MIDNITE SOLAR

MidNite Solar offers a range of PV Combiners from our MNPV3 to the MNPV16. This range of combiners accommodates PV systems as small as a two string off grid cabin up to 16 strings for a 100KW commercial grid tie inverter. The MNPV series of combiners are the result of 20 years of design and manufacturing experience in the renewable energy industry. Each unit has the same quality features such as:

* Aluminum rainproof type 3R enclosure
* Internal plastic injection molded dead front covers
* Knock outs that accept waterproof strain reliefs, conduit or panel mount MC type connectors
* Knock outs for lightning arrestors
* Uses 150VDC & 300VDC breakers or 600VDC fuses depending on model number
* ETL listed to UL1741for use in the US and Canada
* Adaptable for two separate inverters or charge controllers on certain models

MNPV 6

Configured for 600VDC Fuses (Gridtie)

Configured for 150VDC Breakers (Offgrid)

MidNite Solar Inc

Been mooned lately?

www.midnitesolar.com

17722 - 67th Ave NE, Unit C, Arlington WA 98223 - Ph 360.403.7207 Fax 360.691.6862

PV Combiner: MNPV6

			PV Source Circuits			PV Output Circits					
Model	Max VDC	Max # of Input Circ.	Max OCPD Rating Amps	OCPD	Wire Range AWG	Max # of Output Circ.	Max Cont. Current Amps	Wire Range AWG	Approved Mounting Orientation	Enclosure Type/ Material	Listing
MNPV3 (LV)	150	3	20	CB 150V	14-6	1	60	14-1/0	90 to 14°	3R/Alum	UL1741
MNPV3 (HV)	600	2	20	FUSE	14-6	1	60	14-1/0	90 to 14°	3R/Alum	UL1741
MNPV6 (LV)	150	6	20	CB 150V	14-6	2	120	14-1/0	90 to 14°	3R/Alum	UL1741
MNPV6 (HV)	600	4	20	FUSE	14-6	1	80	14-1/0	90 to 14°	3R/Alum	UL1741
MNPV12 (LV)	150	12	30	CB 150V	14-6	2	200	14-2/0	90 to 14°	3R/Alum	UL1741
MNPV12 (HV)	600	10	30	FUSE	14-6	2	200	14-2/0	90 to 14°	3R/Alum	UL1741
MNPV12-250	300	6	50	CB 300V	14-6	2	168	14-2/0	90 to 14°	3R/Alum	UL1741
MNPV16 (HV)	600	16	15	FUSE	14-6	1	240	250MCM	90 to 14°	3R/Alum	UL1741
MNPV16-250	300	12	20	CB 300V	14-6	1	240	14-2/0	90 to 14°	3R/Alum	UL1741

NOTE: All of the connections have a 90 deg C rating except the 2/0 positive lug that carries a 70 deg C rating. MidNite can supply 1/0 lugs to substitute in these cases where 90 deg C is required.

MNPV6 (For 150 VDC charge controllers and 600 VDC gridtie inverters)

(The most popular PV combiner in North America.) Gray aluminum type 3R rainproof enclosure with insulating dead front, will accept six 150VDC breakers or four 600/1000VDC fuse holders. Includes 15 position PV negative bus bar, 14 position ground bus bar, 120 amp Plus bus bar for breakers and 80 amp bus bar for fuses. Punch out tabs on the plastic deadfront make for a clean installation using circuit breakers. An included snap in adapter makes for a professional looking installation when installing fuse holders. Up to three 300VDC breakers from 7 to 50 amps may be installed as a disconnect (no combining busbar) . The enclosure may be mounted to a pole or wall indoors or out.
The plus bus bar may be split to support two grid tie inverters or two charge controllers. Gridtie inverters typically can have PV minuses common. Most charge controllers can have PV minuses common (Exception XW and BlueSky).
Breakers/fuse holders sold separately
Boxed size: 9 x 14 x 4 weight: 4 Lbs.

Photo by Tim Mendenhall

ETL Listed for US & Canada

For product or purchase inquiries contact:
ecoDIRECT
CLEAN ENERGY SOLUTIONS
www.ecodirect.com

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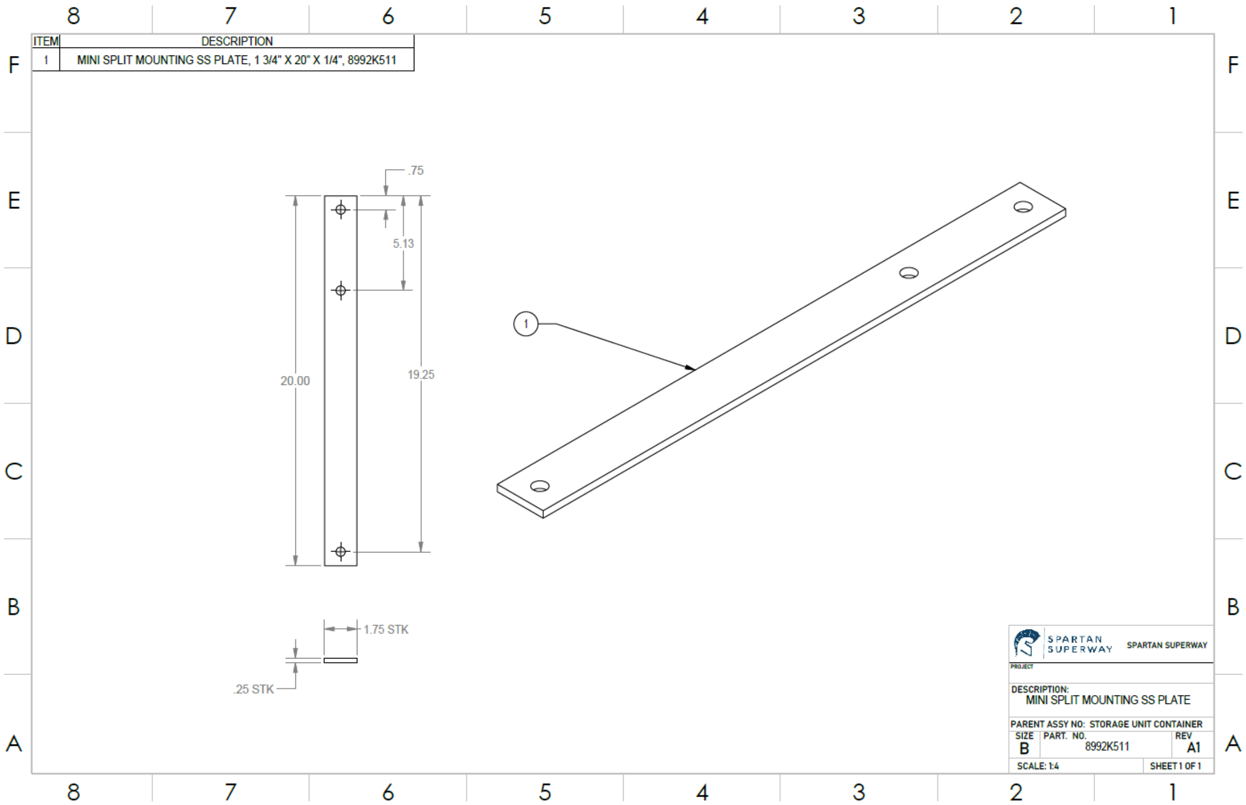
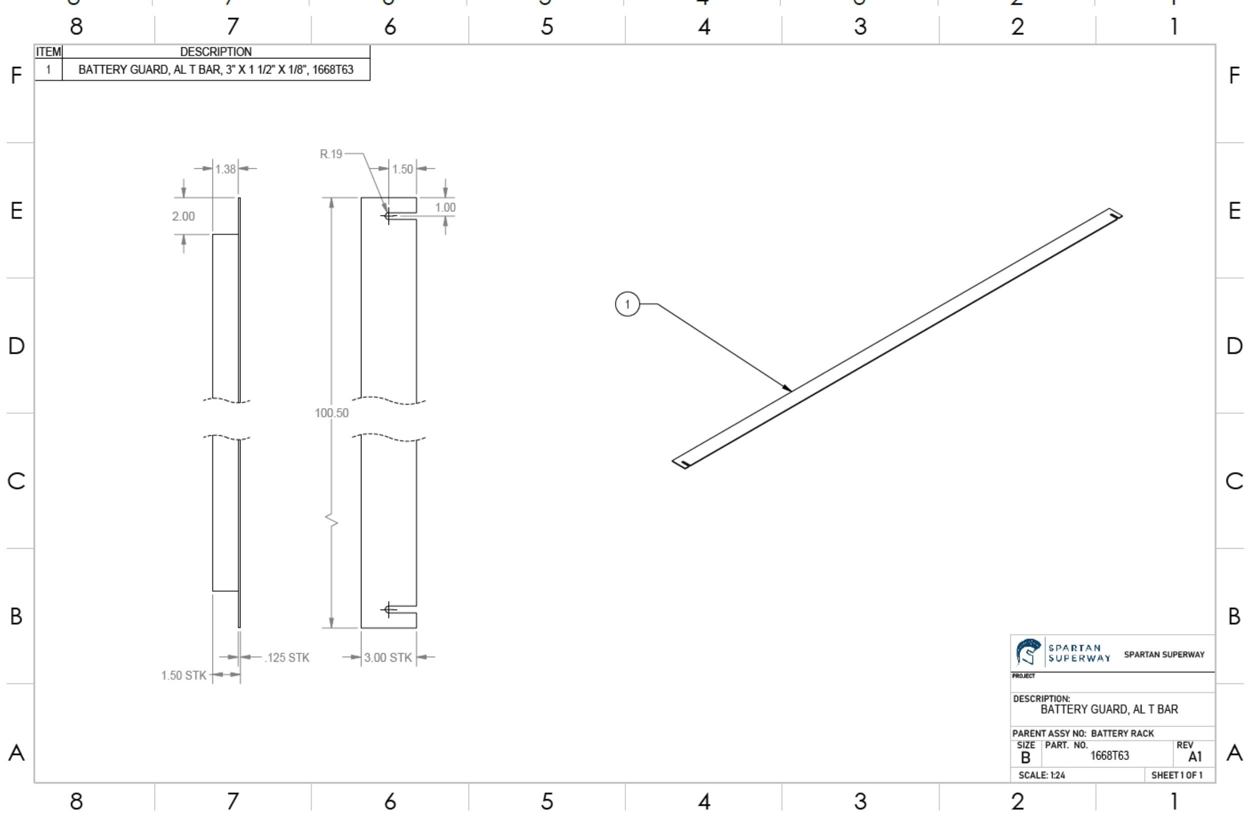
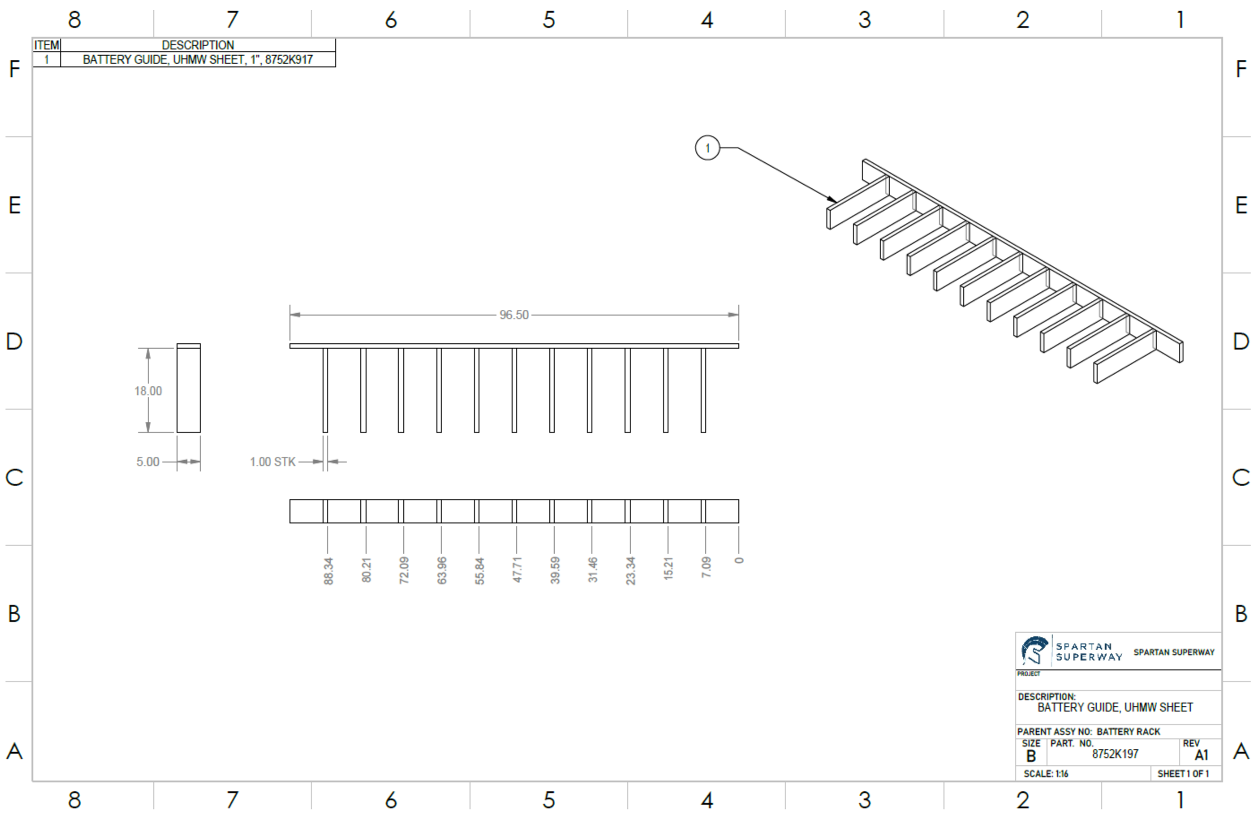
http://www.midnitesolar.com

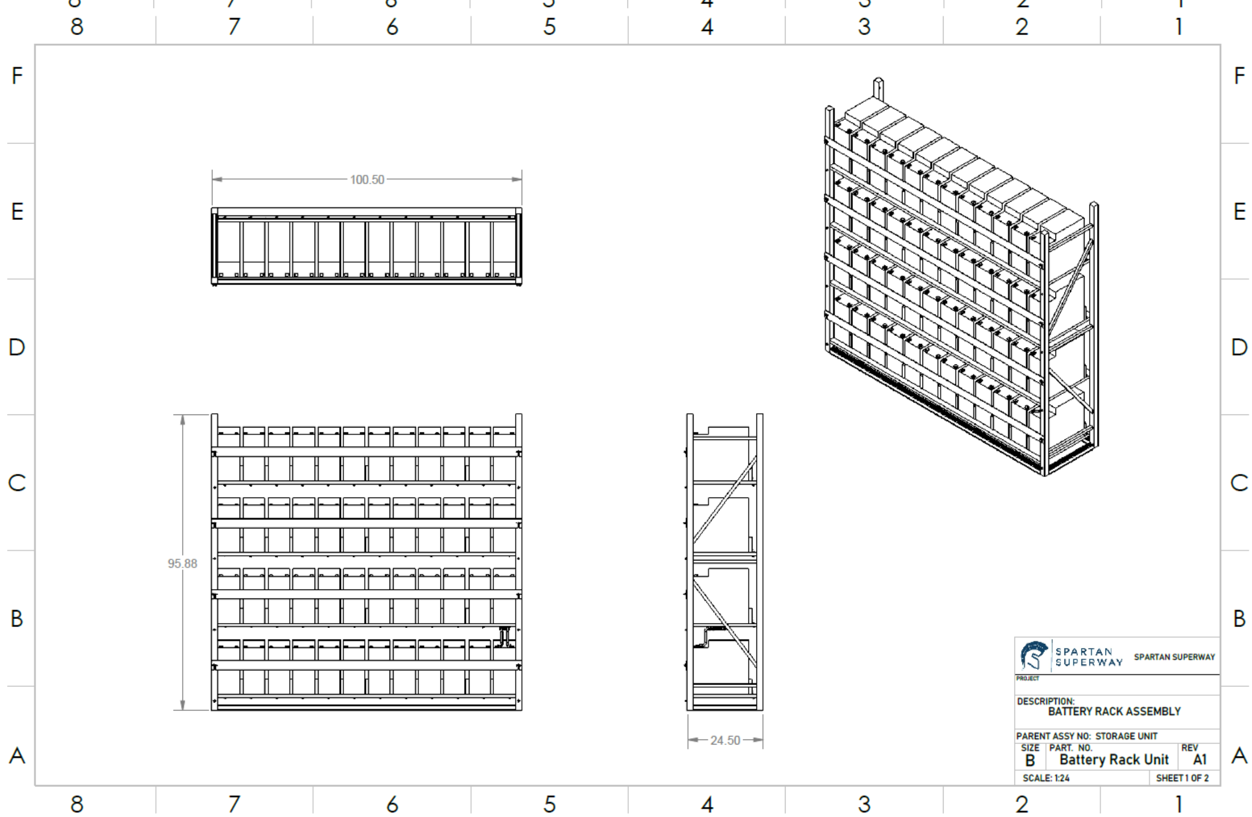
APPENDIX L – Energy Storage Unit Drawings & Bill of Materials



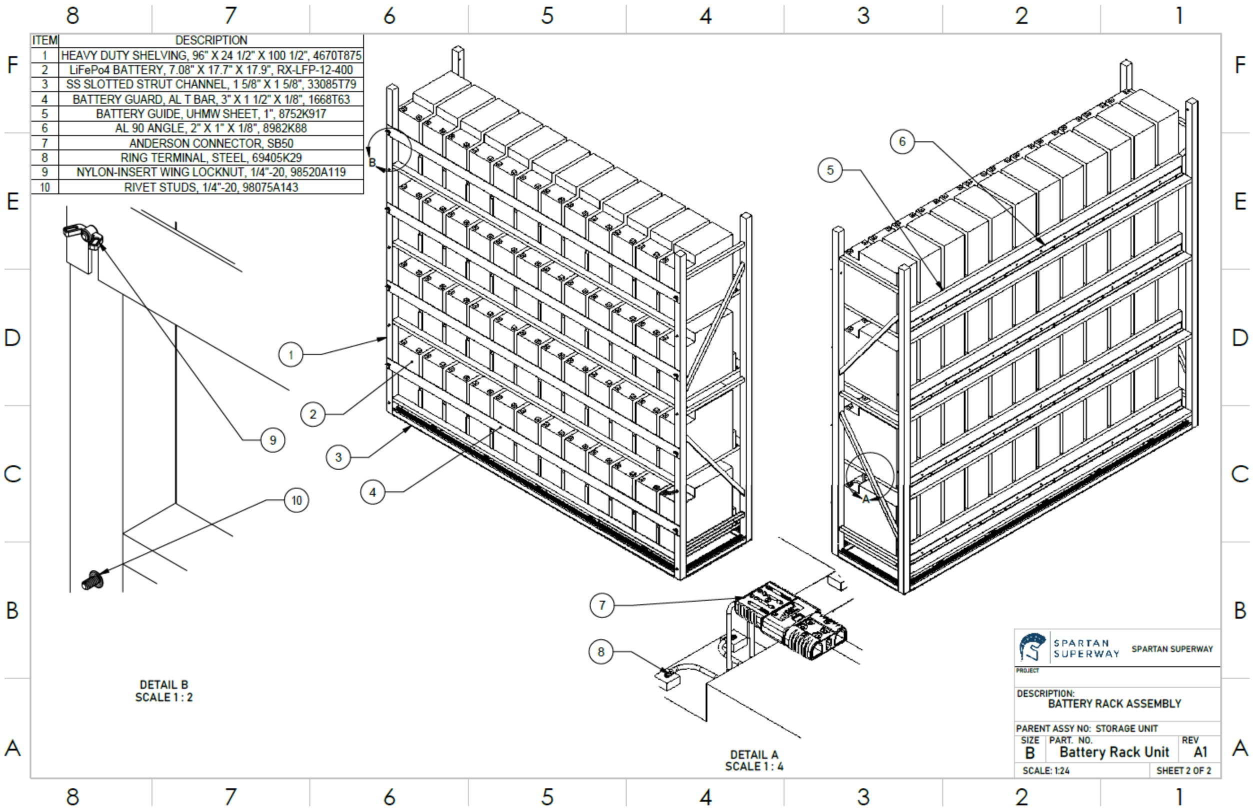




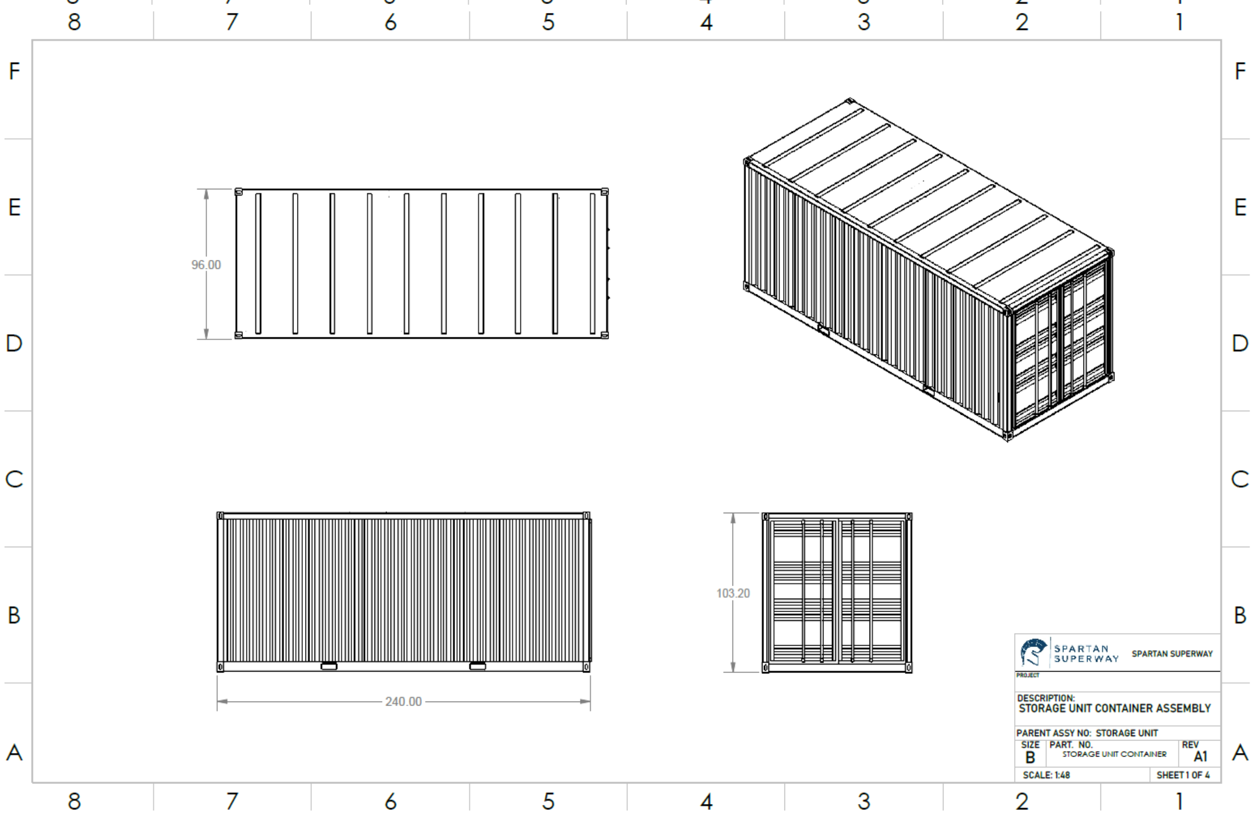
ITEM
DESCRIPTION
1
BATTERY GUIDE, UHMW SHEET, 1", 8752K917
96.50
18.00
5.00
1.00 STK
88.34
80.21
72.09
63.96
55.84
47.71
39.59
31.46
23.34
15.21
7.09
0
SPARTAN SUPERWAY
SPARTAN SUPERWAY
PROJECT
DESCRIPTION:
BATTERY GUIDE, UHMW SHEET
PARENT ASSY NO: BATTERY RACK
SIZE
B
PART. NO.
8752K197
REV
A1
SCALE: 1:16
SHEET 1 OF 1



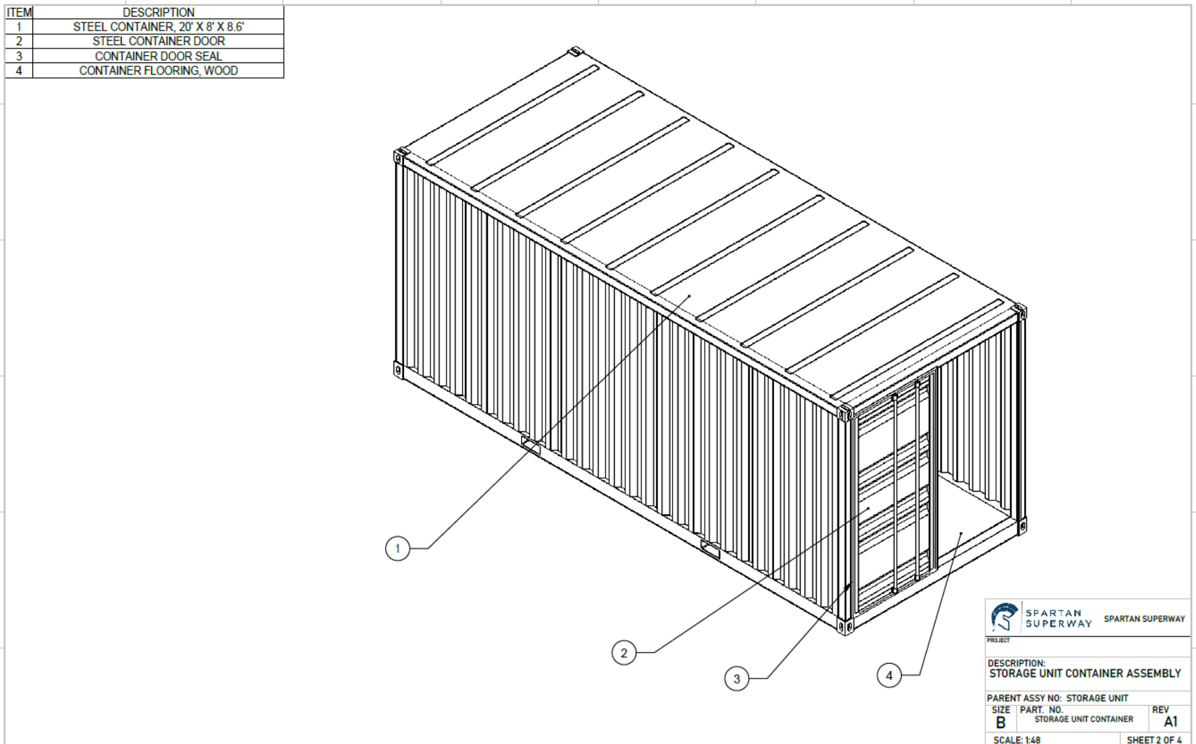
100.50
95.88
24.50
SPARTAN SUPERWAY
SPARTAN SUPERWAY
PROJECT
DESCRIPTION:
BATTERY RACK ASSEMBLY
PARENT ASSY NO: STORAGE UNIT
SIZE
B
PART. NO.
Battery Rack Unit
REV
A1
SCALE: 1:24
SHEET 1 OF 2



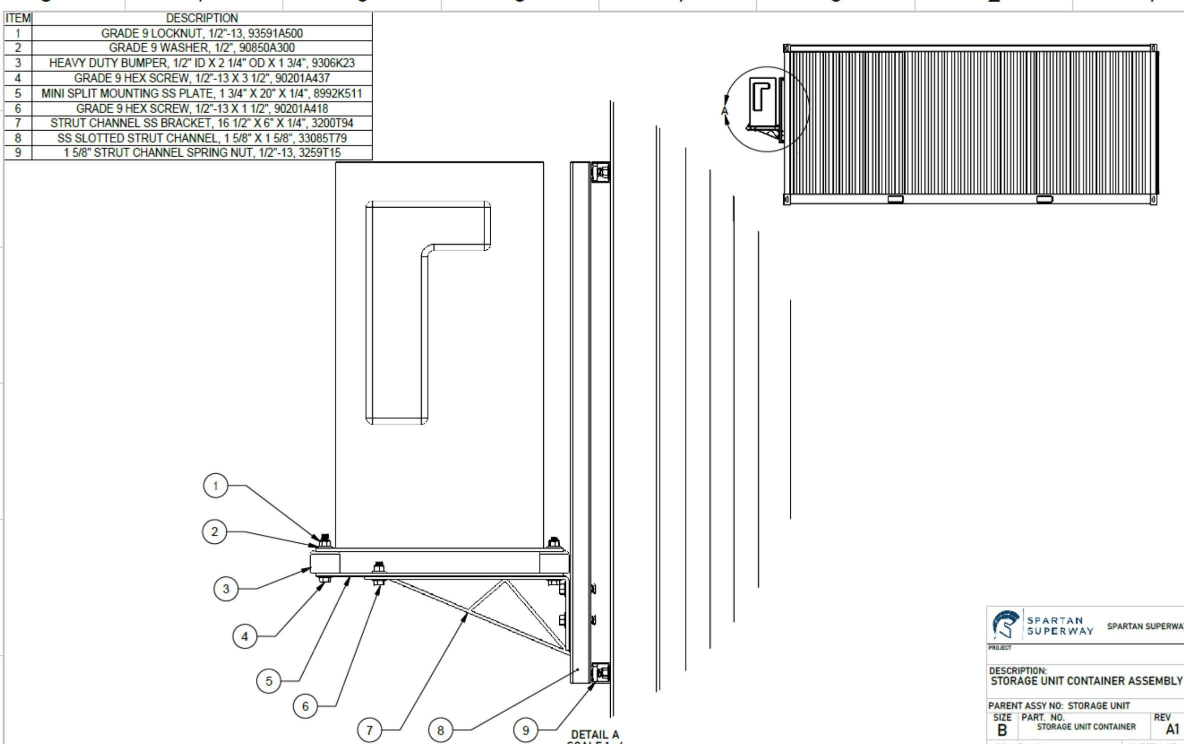
ITEM	DESCRIPTION
1	HEAVY DUTY SHELVING, 96" X 24 1/2" X 100 1/2", 4670T875
2	LiFePo4 BATTERY, 7.08" X 17.7" X 17.9", RX-LFP-12-400
3	SS SLOTTED STRUT CHANNEL, 1 5/8" X 1 5/8", 33085T79
4	BATTERY GUARD, AL T BAR, 3" X 1 1/2" X 1/8", 1668T63
5	BATTERY GUIDE, UHMW SHEET, 1", 8752K917
6	AL 90 ANGLE, 2" X 1" X 1/8", 8982K88
7	ANDERSON CONNECTOR, SB50
8	RING TERMINAL, STEEL, 69405K29
9	NYLON-INSERT WING LOCKNUT, 1/4"-20, 98520A119
10	RIVET STUDS, 1/4"-20, 98075A143

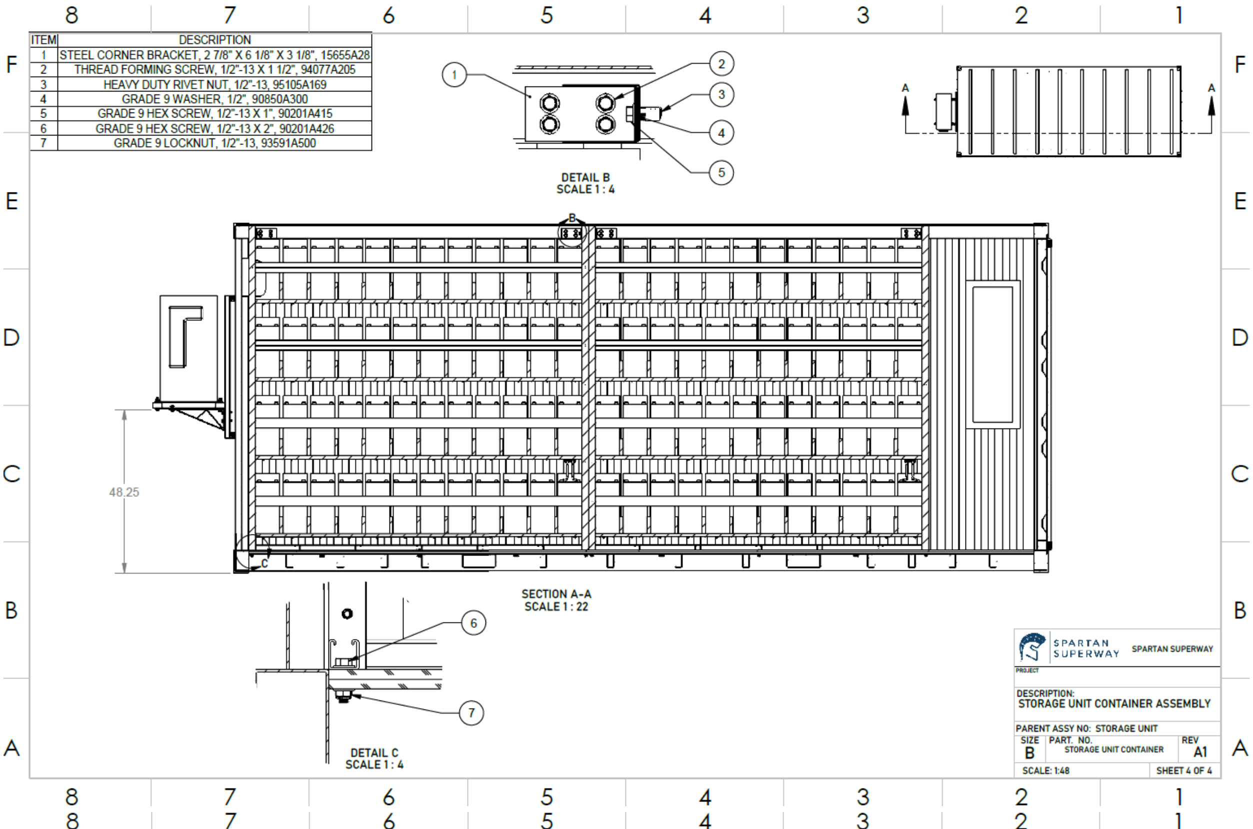


ITEM	DESCRIPTION
1	STEEL CONTAINER, 20' X 8' X 8.6'
2	STEEL CONTAINER DOOR
3	CONTAINER DOOR SEAL
4	CONTAINER FLOORING, WOOD

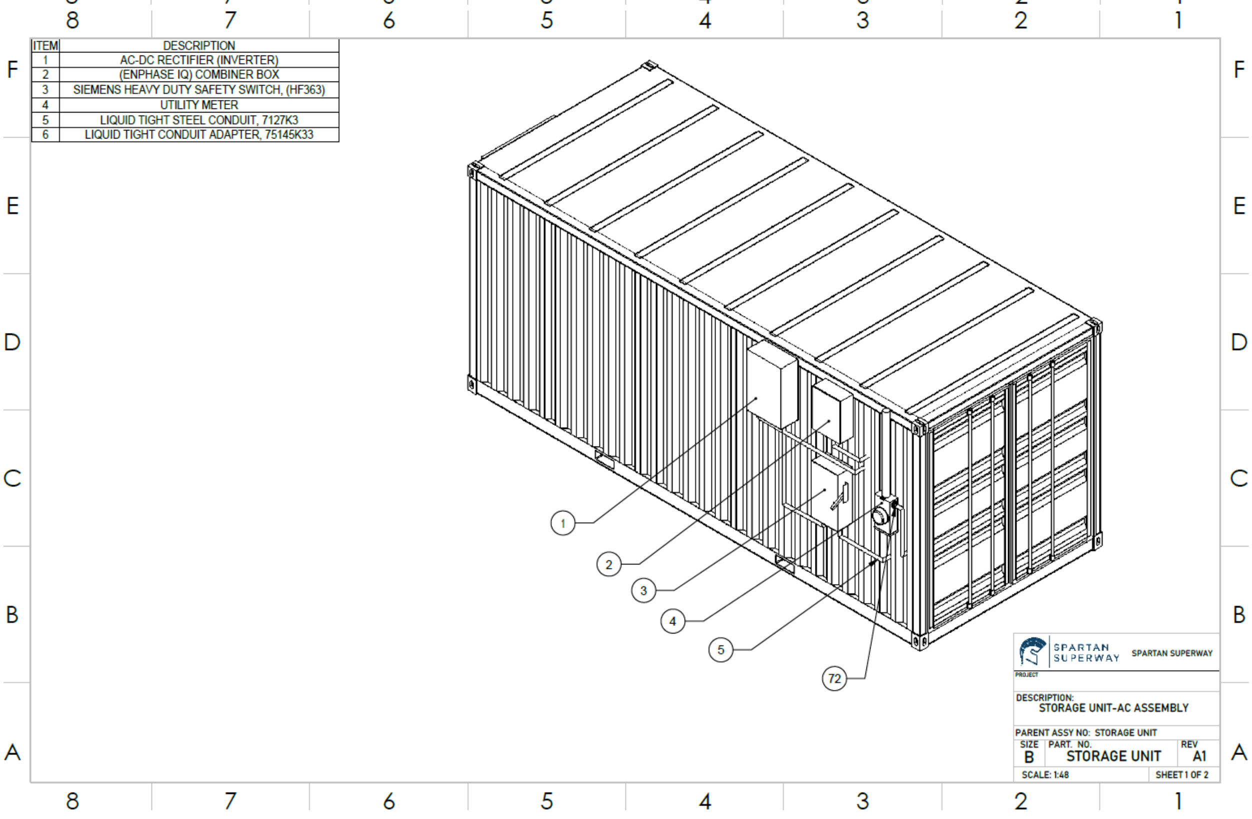


ITEM	DESCRIPTION
1	GRADE 9 LOCKNUT, 1/2"-13, 93591A500
2	GRADE 9 WASHER, 1/2", 90850A300
3	HEAVY DUTY BUMPER, 1/2" ID X 2 1/4" OD X 1 3/4", 9306K23
4	GRADE 9 HEX SCREW, 1/2"-13 X 3 1/2", 90201A437
5	MINI SPLIT MOUNTING SS PLATE, 1 3/4" X 20" X 1/4", 8992K511
6	GRADE 9 HEX SCREW, 1/2"-13 X 1 1/2", 90201A418
7	STRUT CHANNEL SS BRACKET, 16 1/2" X 6" X 1/4", 3200T94
8	SS SLOTTED STRUT CHANNEL, 1 5/8" X 1 5/8", 33085T79
9	1 5/8" STRUT CHANNEL SPRING NUT, 1/2"-13, 3259T15



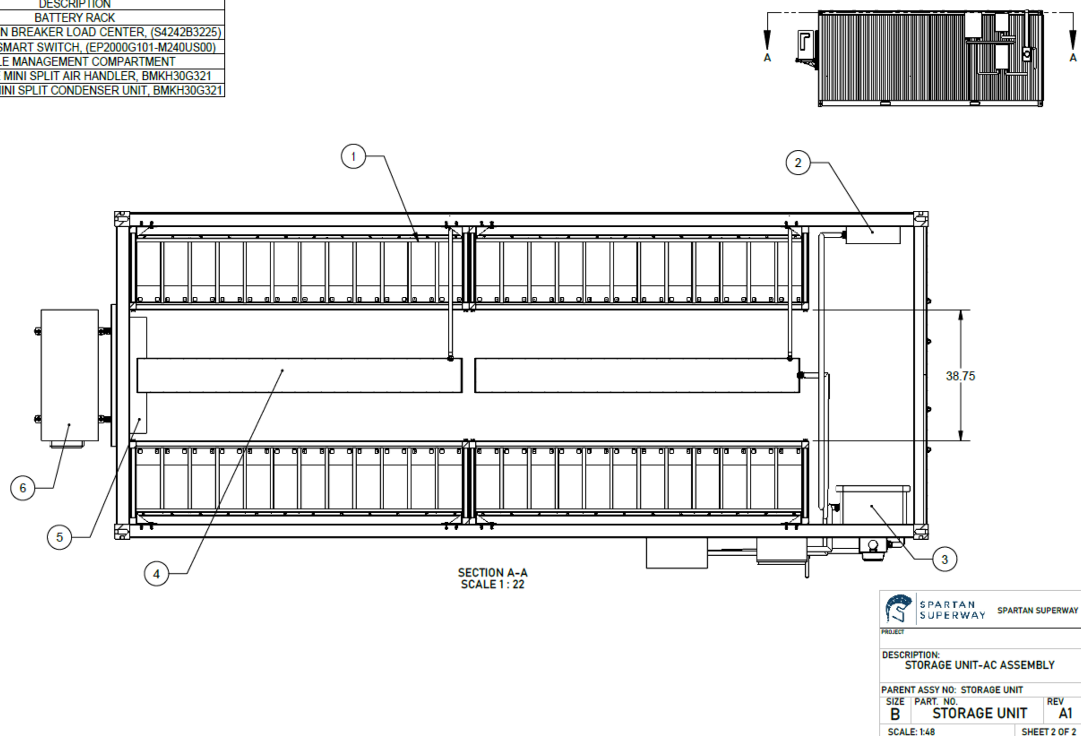


ITEM	DESCRIPTION
1	STEEL CORNER BRACKET, 2 7/8" X 6 1/8" X 3 1/8", 15655A28
2	THREAD FORMING SCREW, 1/2"-13 X 1 1/2", 94077A205
3	HEAVY DUTY RIVET NUT, 1/2"-13, 95105A169
4	GRADE 9 WASHER, 1/2", 90850A300
5	GRADE 9 HEX SCREW, 1/2"-13 X 1", 90201A415
6	GRADE 9 HEX SCREW, 1/2"-13 X 2", 90201A426
7	GRADE 9 LOCKNUT, 1/2"-13, 93591A500

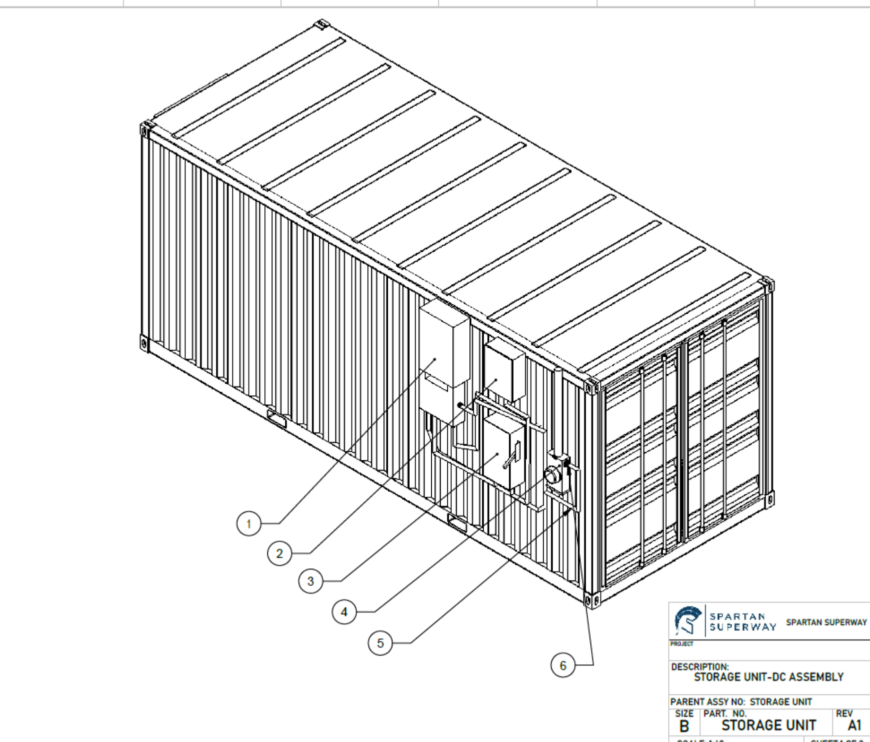


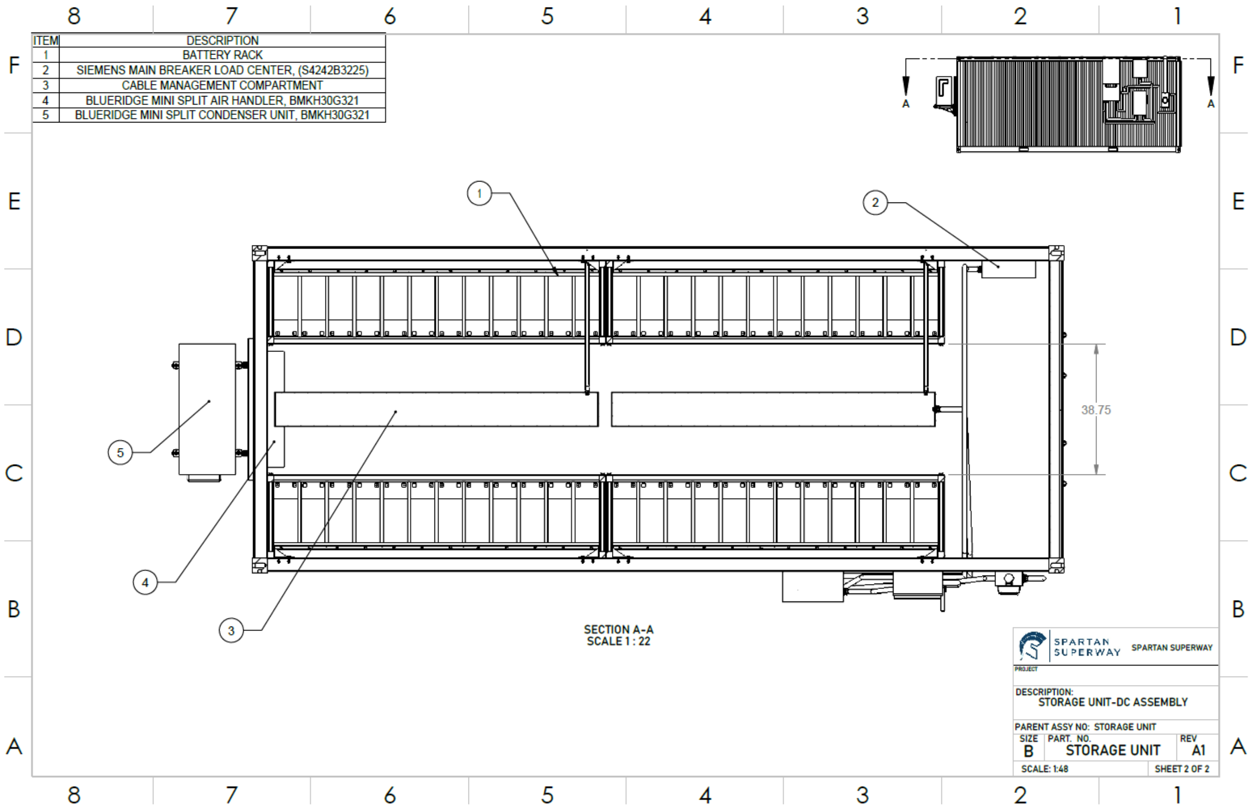
ITEM	DESCRIPTION
1	AC-DC RECTIFIER (INVERTER)
2	(ENPHASE IQ) COMBINER BOX
3	SIEMENS HEAVY DUTY SAFETY SWITCH, (HF363)
4	UTILITY METER
5	LIQUID TIGHT STEEL CONDUIT, 7127K3
6	LIQUID TIGHT CONDUIT ADAPTER, 75145K33

ITEM	DESCRIPTION
1	BATTERY RACK
2	SIEMENS MAIN BREAKER LOAD CENTER, (S4242B3225)
3	(ENPHASE) SMART SWITCH, (EP2000G101-M240US00)
4	CABLE MANAGEMENT COMPARTMENT
5	BLUERIDGE MINI SPLIT AIR HANDLER, BMKH30G321
6	BLUERIDGE MINI SPLIT CONDENSER UNIT, BMKH30G321



ITEM	DESCRIPTION
1	SOLAR EDGE INVERTER, (SE40KUS)
2	PV COMBINER BOX
3	SIEMENS HEAVY DUTY SAFETY SWITCH, (HF363)
4	UTILITY METER
5	LIQUID TIGHT STEEL CONDUIT, 7127K3
6	LIQUID TIGHT CONDUIT ADAPTER, 75145K33



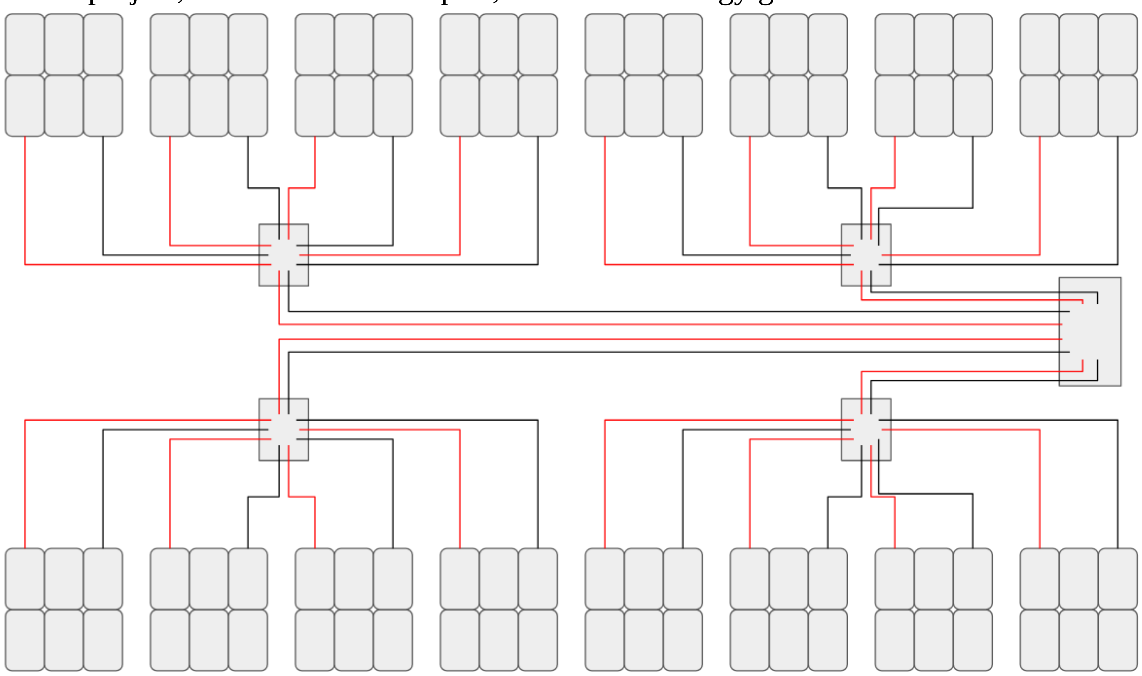


Item	Part Number	Description	Quantity	Cost	Total Cost	Source
		CONTAINER				
Shipping Container	N/A	20' x 8' x 8.6' Container, 3,257.84 for 10 ft	1	$6,515.68	$6,515.68	Link
		BATTERY RACK				
Battery	RX-LFP-12-400	LiFePo4 12V 400Ah, 7.08" (L) x 17.7" (H) x 17.9" (D)	192	$1,999.00	$383,808.00	Link
Heavy Duty Shelving	4670T875	Powder Coated Steel, 96" x 24 1/2" x 100 1/2"	4	$601.50	$2,406.00	Link
Thread-Forming Screws for hard r	94077A205	1/2"-13 x 1 1/2", Corrosion resistant coated steel, 5/pk	7	$9.86	$69.02	Link
Heavy-Duty Rivet Nut	95105A169	Zinc-plated 1/2"-13, 0.063"-.200" material thickness, 10/	1	$12.23	$12.23	Link
Grade 9 Steel Washer	90850A300	1/2" Zinc yellow-chromate plated, 10/pk	10	$6.15	$61.50	Link
Grade 9 Hex Head Screw	90201A415	1/2"-13 x 1", 5/pk	20	$6.95	$139.00	Link
Grade 9 Hex Head Screw	90201A426	1/2"-13 x 2", 5/pk	20	$11.45	$229.00	Link
Grade 9 Locknut	93591A500	1/2"-13, 5/pk	20	$6.16	$123.20	Link
Corner Bracket	15655A28	2 7/8" x 6 1/8" x 3 1/8", Galvanized steel, 50 or more/9.:	8	$13.84	$110.72	Link
Slippery White UHMW Polyethyle	8752K917	48" x 96" x 1"	8	$878.86	$7,030.88	Link
6061 Aluminum 90 Degree Angle	8982K88	1/8" Thickness, 1" High x 2" Wide Outside	16	$23.76	$380.16	Link
Strut Channel	33085T79	Slotted Hole, 316 Stainless Steel, 1 5/8" x 1 5/8" x 10'	13	$140.42	$1,825.46	Link
6061 Aluminum T-Bar	1668T63	1/8" Wall Thickness, 1-1/2" High x 3" Wide	16	$48.38	$774.08	Link
Rivet Studs	98075A143	1/4"-20 Thread, for 0.027"-0.165" Material Thickness, 10	7	$10.49	$73.43	Link
Nylon-Insert Wing Locknut	98520A119	1/4"-20 Thread Size, 20/pk	2	$13.93	$27.86	Link
Anderson Connector	SB50	16-6 AWG, 50A Max	384	$5.00	$1,920.00	Link
Ring Terminal	69405K29	Noninsulated High-Temperature Ring Terminals, 900°F N	16	$12.97	$207.52	Link
Battery Terminal Wire	3022N3	High-Voltage Stranded Outdoor Wire, 2000V AC/DC, 8 \	20	$160.97	$3,219.40	Link
Pointed Screws for Plastic	92325A103	410 Stainless Steel, Number 8 Screw Size, 2" Long, 50	4	$9.15	$36.60	Link
Aluminum Blind Rivets with Steel	97517A193	Domed Head, 1/4" Diameter, for 1.001"-1.125" Material 1	4	$10.97	$43.88	Link
		THERMAL MANAGEMENT				
Blueridge Mini Split	BMKH30G321	30,000 BTU (2.5 Ton) Mini-Split System, Condenser unit	1	$2,426.00	$2,426.00	Link
Strut Channel Shelf Bracket	3200T94	304 Stainless Steel, 16-1/2" Length	2	$60.58	$121.16	Link
Multipurpose 304 Stainless Steel	8992K511	1/4" Thick, 1-3/4" Wide, Hot Rolled, 24" Long	2	$29.89	$59.78	Link
Heavy-Duty Unthreaded Bumper	9306K23	Polyurethane Rubber, 2-1/4" OD, 1-3/4" High, 1/pk	4	$9.78	$39.12	Link
Strut Channel Nut	3259T15	with Spring, 1-5/8" High Channel, Steel, 1/2"-13 Thread,	2	$8.78	$17.56	Link
Grade 9 Steel Hex Head Screw	90201A418	1/2"-13 Thread Size, 1-1/2" Long, 5/pk	20	$9.67	$193.40	Link
Grade 9 Steel Hex Head Screw	90201A437	1/2"-13 Thread Size, 3-1/2" Long, 1/pk	10	$3.53	$35.30	Link
Grade 9 Steel Washer	90850A100	Zinc Yellow-Chromate Plated, 1/4" Screw Size, 0.64" OI	2	$7.81	$15.62	Link

Grade 9 Steel Hex Head Screw	90201A113	1/4"-20 Thread Size, 1" Long, 25/pk	4	$10.83	$43.32	Link
Grade 9 Locknut	93591A100	Top-Lock Distorted-Thread Locknut, 1/4"-20 Thread Size	4	$10.10	$40.40	Link
ELECTRICAL						
Siemens Main Breaker Load Cen	S4242B3225	ES Series 225 Amp 42-Space 42-Circuit Main Breaker I	1	$404.50	$404.50	Link
Siemens Heavy Duty Safety Swit	HF363R	Heavy Duty 100 Amp 600-Volt 3-Pole Outdoor Fusible S	1	$438.43	$438.43	Link
Utility Meter		PG&E	1	$800.00	$800.00	Link
Custom Wire Management Comp	custom		2	$500.00	$1,000.00	
Liquid-Tight Flexible Zinc-Plated S	7127K3	3/4 Trade Size, 3.13, 100 ft or more/2.36	2000	$2.36	$4,720.00	Link
Liquid-Tight Flexible Plastic Cond	75145K33	Straight, 3/4 Push-In Female x 3/4 NPT Male	100	$3.92	$392.00	Link
ELECTRICAL AC						
AC to DC Inverter (Rectifier)			1	$1,000.00	$1,000.00	Link
Enphase IQ Combiner Box	X-IQ-AM1-240-3	240VAC, 80A, 19.5" x 14.75" x 6.63", 16.5 lbs,	1	$1,133.00	$1,133.00	Link
Enphase Smart Switch	EP2000G101-M	19.7" x 36" x 9.7", 82 lbs, 200A, 120/240V	1	$2,239.00	$2,239.00	Link
ELECTRICAL DC						
Solar Edge Inverter	SE40KUS/SE1(	100KW Primary Inverter, 480V	1	$3,959.70	$3,959.70	Link
PV Combiner Box	MNPV8-MC4	600V, 200A, 8" x 13.5" x 3.5", 9 lbs, 8 strings or 2 string	1	$405.00	$405.00	Link
			Total AC System	$424,132.21	Cost / kwh	$450.82
			Total DC System	$424,124.91	Cost / kwh	$450.81

APPENDIX M – Energy Storage Unit Loading Calculations

The following calculations were done to investigate the voltages and current values that may encountered. As previously mentioned, it is important to note that there are various possibilities for wiring configurations. This particular example is based off the models shown throughout the report that were worked on during the semester. The figure below shows six solar panel modules per solar rack and a total of sixteen racks. The six panels found on the rack are set up in series and four series racks are shown to be wired in a parallel configuration and combined. After being combined, the wiring goes off to another box that represents an inverter, some sort of smart switch, safety switch, or any other component needed before getting to the inverter. The total string voltage, current, and power are then calculated where Vmp stands for voltage at maximum power, Voc stands for open circuit voltage, Imp stands for current at maximum power, and Isc stands for short circuit current. The module used for the calculation is based on a module used in a previous project, mentioned in the report, to calculate energy generation.



Module	Modules Available	Panels / Rack	Rack Quantity	Series	Parallel	Voltage (Vmp)	Current (Imp)	Total String Voltage (V)	Total String Current (I)	Total String Power (kW)
SunEdison SE-R360EzC-4y 360W	96	6	16	6	4	38.4	9.38	230.4	37.52	8.64
						Voltage (Voc)	Current (Isc)	Total String Voltage (V)	Total String Current (I)	Total String Power (kW)
						46.9	9.72	281.4	38.88	10.94

Total String Voltage = V * Quantity of modules in series   Total String Voltage = I * Quantity of modules in parallel   Total String Power = V * I / 1000

The following sheet shows the process for calculating the heat load inside the container due to the batteries.

Batteries / Shelf	Shelves / Rack	Batteries / Rack	Racks / Container	Battery Quantity	Battery Ah	Internal Resistance (Ω)	Charge Current (A)
12	4	48	4	192	400	0.02	40
Heat Load (W)	Heat Load / Rack (W)	Total Heat Load (W)	Total Heat Load (BTU/hr)				
32	1536	6144	20964				

Charge current = 10% of Ah rating   Heat Load = I^2*R, where I is I_c Heat Load / Rack = Heat Load * Batteries / Rack   Total Heat Load = Heat Load / Rack * Racks / Container   Total Heat Load (BTU/hr) = Total Heat Load * 3.41 BTU/h / W

The following sheet shows the process used for calculating the loading on the rack due to the batteries and the loading on the container's floor due to the racks.

Battery Weight (kg)	Batteries / Shelf	Shelves / Rack	Rack Quantity	Rack Length (m)	Max Shelf Capacity (kg)	Max Rack Capacity (kg)	Max Floor Load (Ton/m)
62	12	4	4	2.55	952.5	2903	4.5
Shelf Weight (kg)	Rack Weight (kg)	System Total Weight (kg)		System Length (m)			
744	2976	11904		5.11			
Shelf Weight (Ton)	Rack Weight (Ton)	System Total Weight (Ton)					
0.82	3.28	13.12					
Shelf Load (kg)	Rack Load (kg)	Rack Floor Load (Ton/m)	System Floor Load (Ton/m)				
744	2976	1.29	2.57				
1.28	0.98	3.50	1.75	Safety Factor			

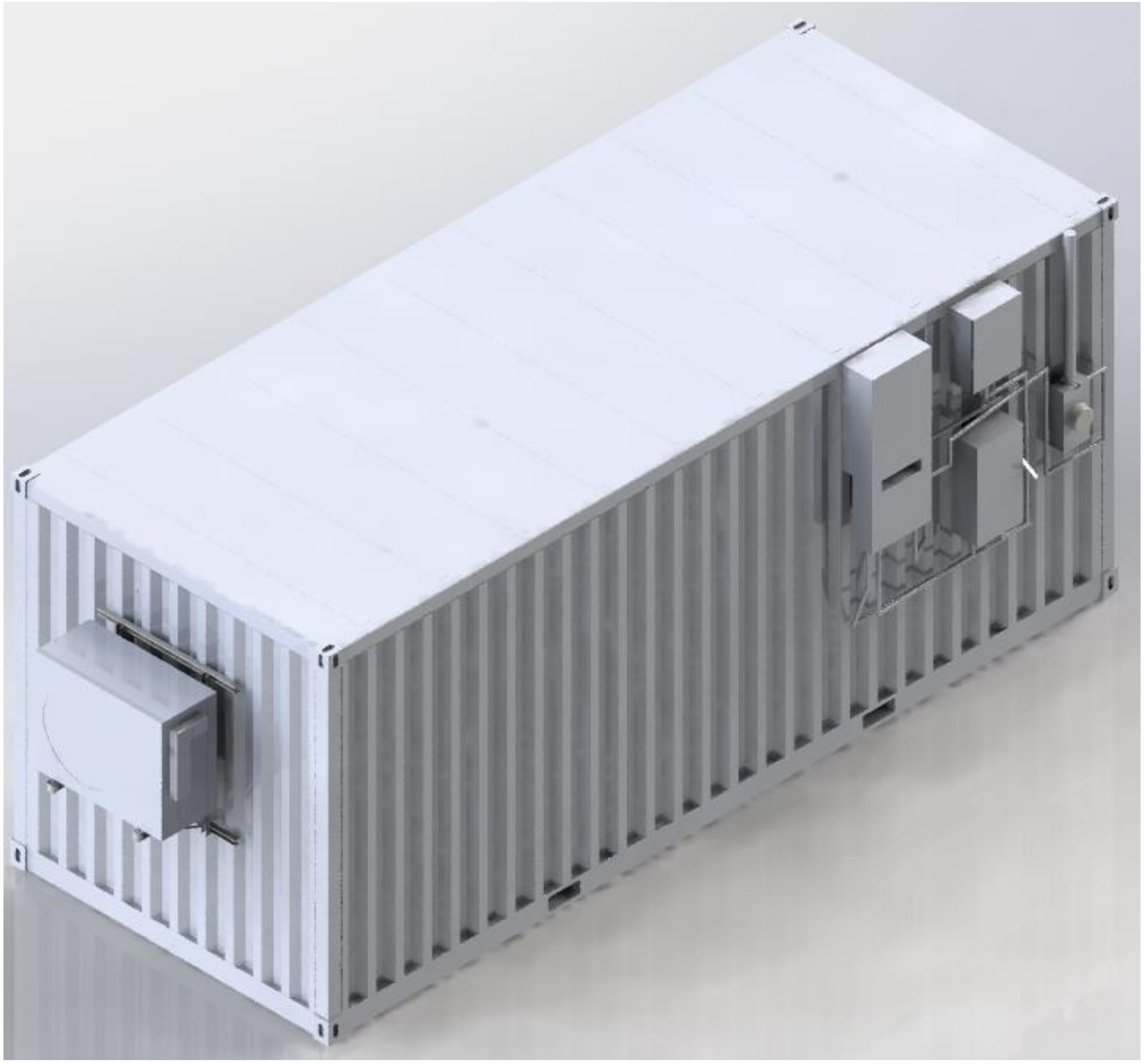
System Length = Rack Length * 2, two racks next to one another

Shelf Weight = Battery Weight * Batteries / shelf

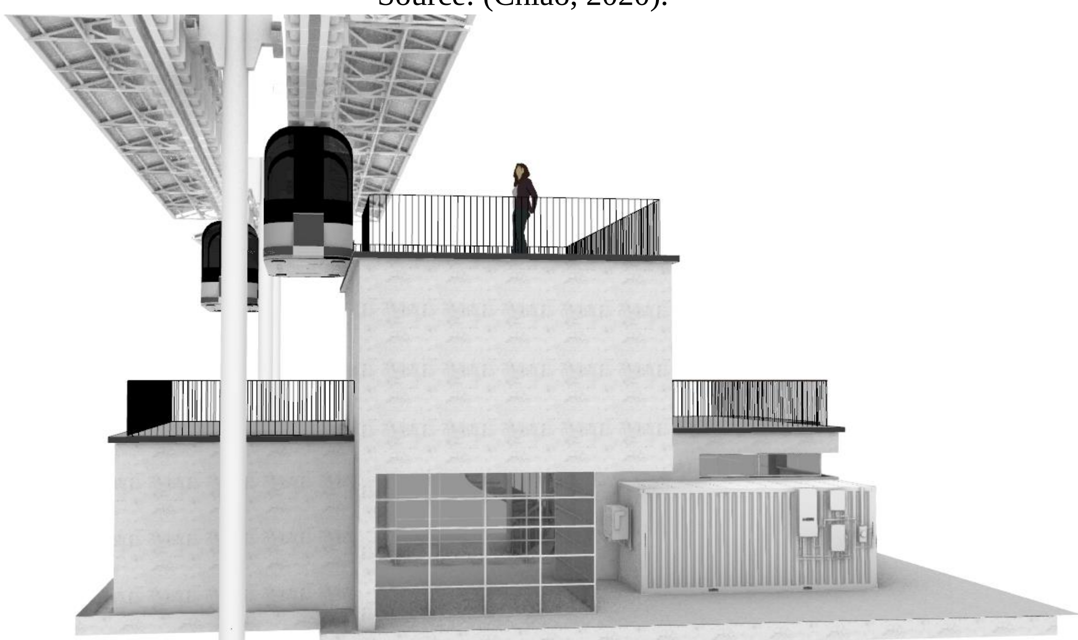
Rack Weight = Shelf Weight * Shelves / Rack

System Total Weight = Rack Weight * Rack Quantity

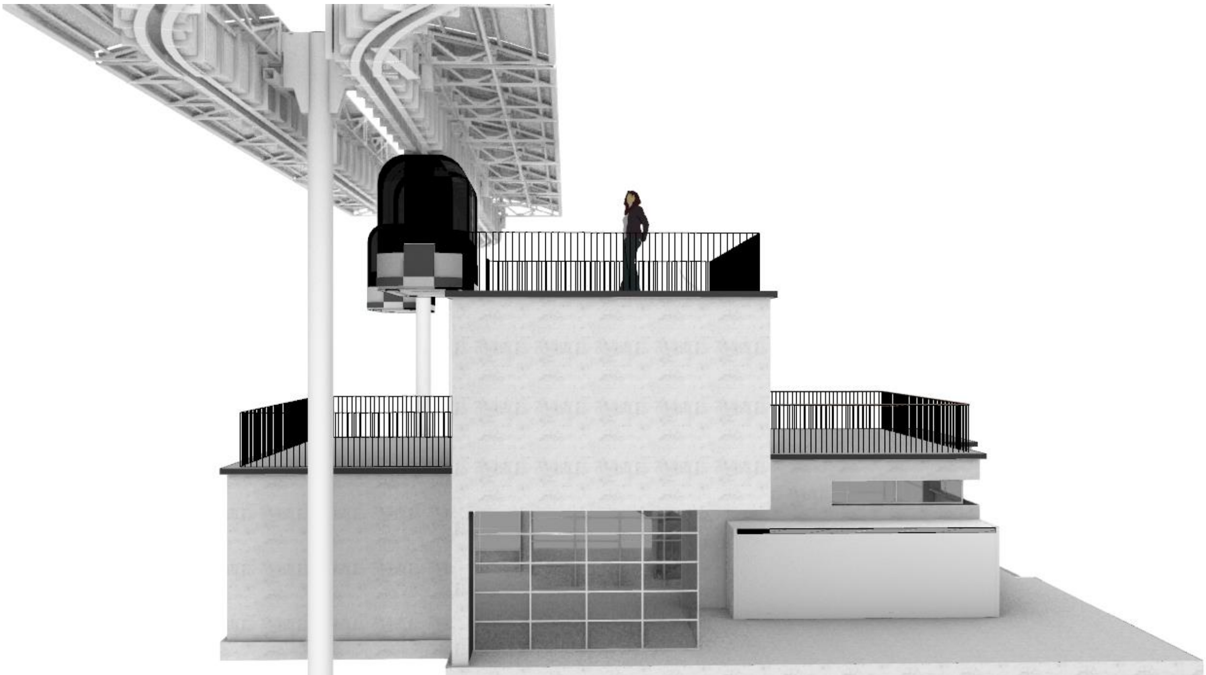
APPENDIX N – Additional Renderings



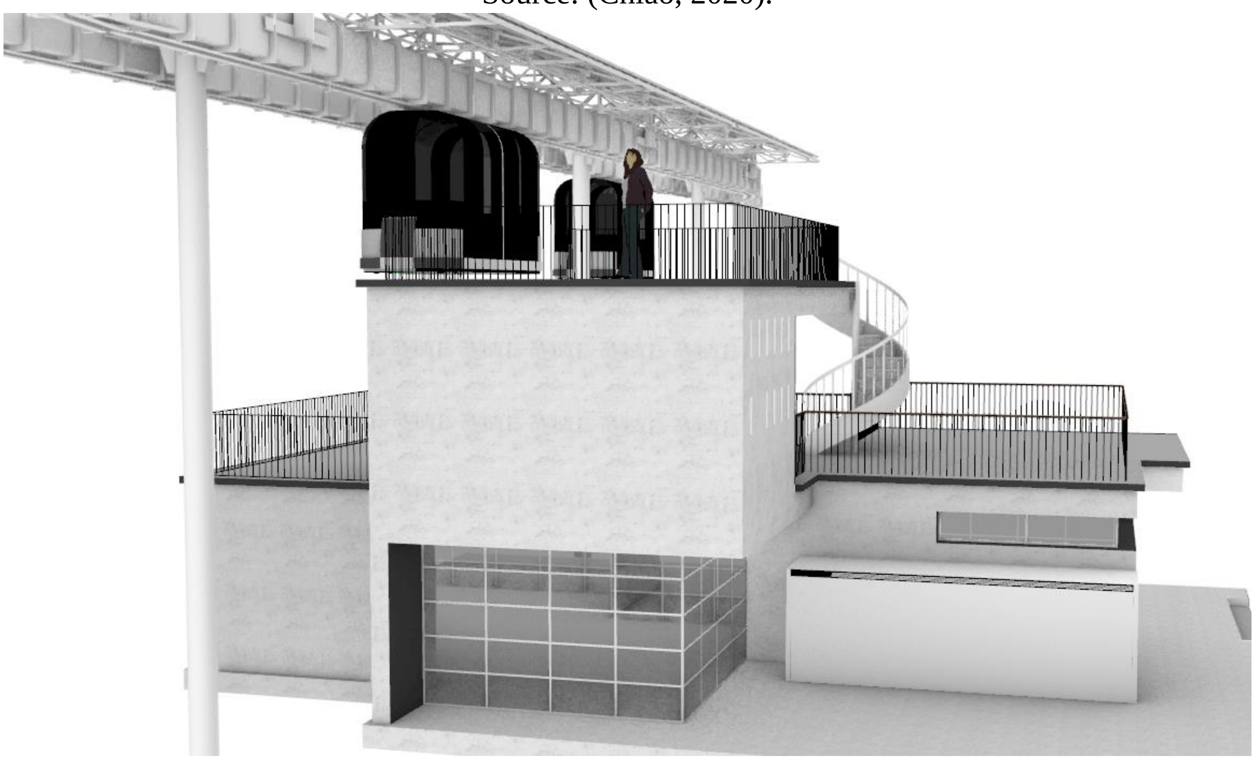
Source: (Chiao, 2020).



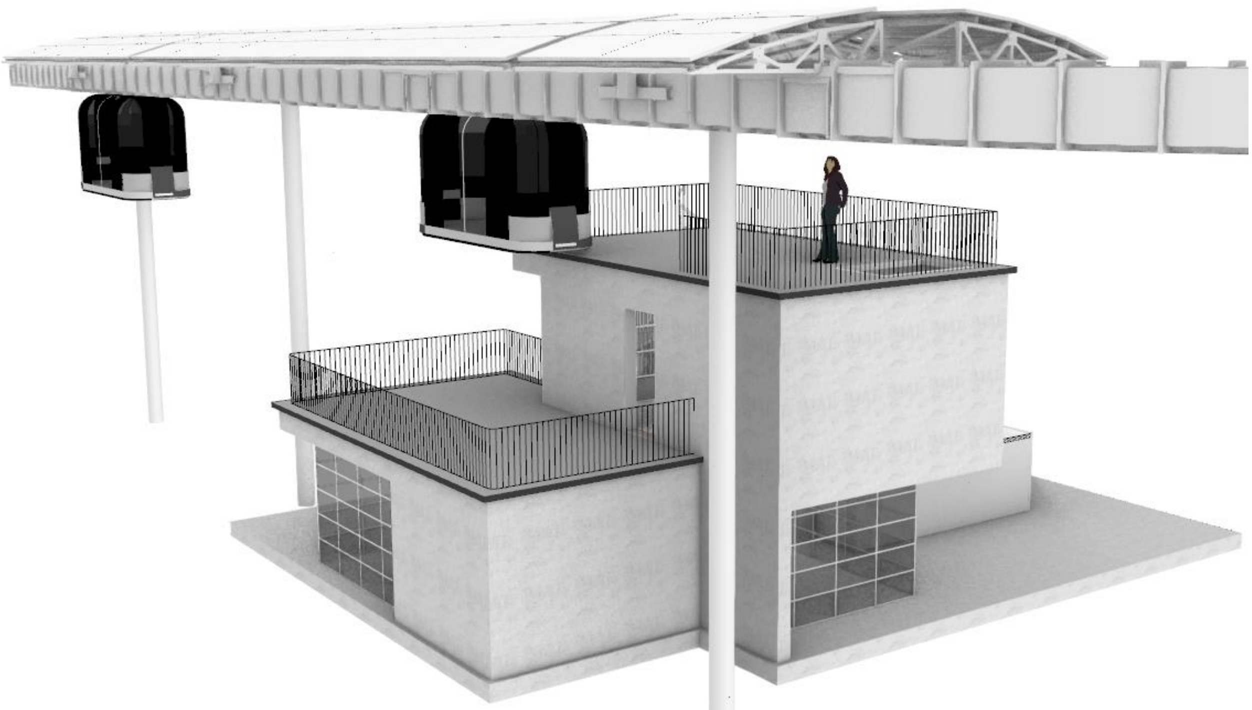
Source: (Chiao, 2020).



Source: (Chiao, 2020).



Source: (Chiao, 2020).


Source: (Chiao, 2020).