# ZERO EMISSION FACILITY AND FLEET TRANSITION PLAN

## TASK 2: FACILITY POWER NEEDS AND TECHNOLOGY ASSESSMENT


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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ADAS | Automated Driving-Assistance Systems |
| ART | Adapting to Rising Tides |
| BEB | Battery-Electric Bus |
| CARES | Coronavirus Aid, Relief, And Economic Security Act |
| CM | Construction Management |
| CNG | Compressed Natural Gas |
| CPUC | California Public Utilities Commission |
| EIS | Environmental Impact Statement |
| FCEB | Fuel Cell Electric Bus |
| FTA | Federal Transit Administration |
| GGRA | Greenhouse Gas Reduction Act |
| GHG | Greenhouse Gas |
| GTFS | General Transit Feed Specification |
| ICA | Integration Capacity Analysis (PG&E tool) |
| kV | Kilovolts |
| kW | Kilowatt |
| kWh | Kilowatt-Hour |
| LF | Linear Foot |
| LV | Low-Voltage |
| MV | Medium Voltage |
| MW | Megawatt |
| NEC | National Electric Code |
| NEPA | National Environmental Policy Act |
| NFPA | National Fire Protection Association |
| NREL | National Renewable Energy Laboratory |
| O&M | Operation & Maintenance |
| OEM | Original Equipment Manufacturer |
| OSHA | Occupational Safety and Health Administration |
| P3 | Public-Private-Partnership |
| PG&E | Pacific Gas & Electric |

| | |
|---|---|
| PPE | Personal Protective Equipment |
| PM | Preventative Maintenance |
| RFP | Request for Proposal |
| RNG | Renewable Natural Gas |
| ROM | Rough Order of Magnitude |
| SFFD | San Francisco Fire Department |
| SFMTA | San Francisco Municipal Transportation Agency |
| SFPUC | San Francisco Public Utilities Commission |
| SMR | Steam Methane Reformation |
| SOC | State of Charge |
| TOU | Time-of-Use |
| VOMS | Vehicles Operated in Maximum Service |
| YOE | Year of Expenditure |
| ZE | Zero-Emission |
| ZEB | Zero-Emission Bus |

## GLOSSARY OF TERMS

| | |
|---|---|
| Availability | The number of days the buses are actually available compared to the days that the buses are planned for operation, expressed as percent availability. |
| Blocks | The work assignment for a single vehicle during a service workday. |
| Charging Ratio | The number of buses able to charge using a single charging cabinet with one or more charging dispensers. Typically configured as 1:1, 1:2, or 1:3 (bus to charger). |
| Deadhead | The miles and hours that a vehicle travels when out of revenue service with no expectation of carrying revenue passengers. Deadhead includes leaving or returning to the garage or yard facility and changing route. |
| Efficiency | A measure of a vehicle's performance, expressed in kilowatt-hours per mile throughout this report. |
| Energy | Energy is the ability to create a change (expressed as kWh). |
| Miles Between Road Calls (MBRC) | A measure of reliability calculated by dividing the number of miles traveled by the total number of road calls, also known as mean distance between failures. MBRC results in the report are categorized as follows: |
| On-Peak Period | In time-of-use utility rate structures, the time in which electricity is priced at the most expensive rates. |
| Peak Demand | The highest electrical power demand that has occurred over a specified time period. |
| Power | Power is how fast energy is used or transmitted (expressed as kW). |
| Revenue Service | The time when a vehicle is available to the general public with an expectation of carrying fare-paying passengers. Vehicles operated in a fare-free service are also considered revenue service. |
| Spares | Percent of maximum service fleet, reserved for contingency operations (typically 20%). |
| State of Charge | The available energy use of a bus, not to go below 20% of battery capacity for safety reasons. |

# 1 INTRODUCTION

## 1.1 STUDY BACKGROUND

The San Francisco Municipal Transportation Agency (SFMTA) is a national leader in confronting climate change and is already embracing the prospects of a zero-emission (ZE) future. The SFMTA is taking multiple steps to meet the requirements of the California Air Resource Board's (CARB) Innovative Clean Transit (ICT) regulation, which requires all transit agencies to operate 100% zero-emission buses (ZEBs) by 2040.

Pursuant to the SFMTA's electrification goals, in February 2020 the SFMTA partnered with WSP to provide a roadmap for the SFMTA's transition to an all-ZEB fleet which will serve over 500,000 passengers on a typical weekday[1]. Project elements include facility modification recommendations at the SFMTA's six bus yards, battery electric bus (BEB) modeling and analysis, financial modeling, and other supporting activities.

## 1.2 REPORT PURPOSE AND STRUCTURE

The purpose of the Facility Power Needs and Baseline Assessment Report is to define the power needs and infrastructure required to support a 100% BEB fleet. This assessment begins with an evaluation of existing conditions, which provides an overview of the SFMTA's current service requirements as well as a description of the layout, siting, and electrical infrastructure of the six operations facilities with consideration to future service. Using existing conditions as a baseline (sourced from the SFMTA, site visits, and local utilities), performance modeling was conducted for each service block to determine energy requirements, technology projections for BEB fleet readiness, and any necessary adjustments to fleet size or service scheduling to meet service requirements. The modeling results establish power needs of the SFMTA's future BEB fleet, which informs recommendations for charging infrastructure and facility designs. To support the SFMTA in resilient fleet operations, a risk and mitigation analysis is also provided.

The Facility Power Needs and Baseline Assessment Report provides yard-specific information for each of the SFMTA's six bus yards presented in alphabetical order (not order of transition). Each yard's section is structured as follows: 1) Existing Conditions; 2) Modeling Results; 3) Power Needs; 4) Preliminary Costs Estimates[2]; and 5) Recommendations.


1 "Public Transportation Ridership Report: Fourth Quarter 2019" (PDF). American Public Transportation Association. 27 February 2020.

2 Costs to be discussed in more detail in Task 3: BEB Implementation Facility Master Plan.

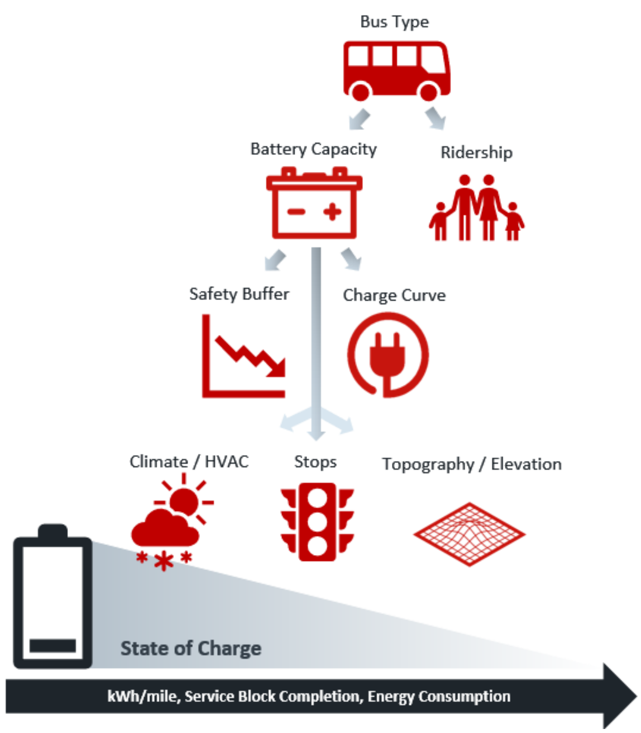
# 2 METHODOLOGY AND APPROACH

## 2.1 SERVICE MODELING

An essential element for accurately assessing the performance of BEBs on a route is understanding how the vehicle's capabilities align with the route's service requirements. To determine the feasibility of electrifying the SFMTA's fleet, WSP used its proprietary, formula-based model, Lighting Bolt. Lightning Bolt is a dynamic tool that uses a series of inputs tailored to regional characteristics as well as the preferences of the SFMTA, delivering refined expectations for BEB performance within the SFMTA's service requirements.

To provide a comprehensive understanding of the SFMTA's service requirements, a range of information was collected, including a fleet inventory, service conditions, facility locations, and scheduling data such as general transit feed specification (GTFS). Using the Original Equipment Manufacturer (OEM) vehicle efficiency specifications and Altoona reports (a Federal Transit Agency bus testing program) as a baseline, adjustments were made to the following inputs to simulate BEB performance in real-world operating conditions: 1) heating, ventilation, and air conditioning (HVAC); 2) frequency of stops; and 3) topography/elevation (with consideration to regenerative braking). In addition to these metrics, adjustments were made to battery operating capacities and charge rates to account for safety buffers and charge curves. This level of information provides an understanding of the percentage of the SFMTA's fleet that can be electrified based on currently available and future BEB technologies. A detailed overview of the assumptions and adjustments made in the SFMTA performance model are outlined below.

Figure 2-1. Modeling Metrics

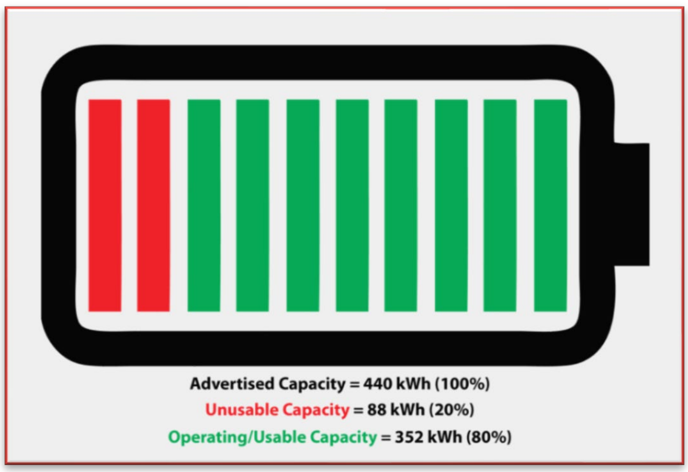



Source: WSP

### 2.1.1 *BATTERY ASSUMPTIONS*

The SFMTA's current fleet is comprised of 30-foot, 40-foot, and 60-foot buses, all of which were assessed in this analysis. The vehicle inputs that provide the foundation for BEB performance modeling are the *operating* battery capacity and the vehicle efficiency. The operating battery capacity differs from the *advertised* capacity in that it measures a realistic BEB range by accounting for only the usable or chargeable portions of the battery. Generally, 20% or more of a battery's capacity is deemed unusable in order to support the health of the battery and reduce range anxiety for operators. This restriction also supports future planning efforts as the battery capacity declines with age. Another benefit of providing a safety buffer is that the battery (while charging) can maximize the usage of a charger and reduce charging times. For the purposes of the analysis, WSP assumed 80% of the advertised battery capacity as the operating battery capacity.

Figure 2-2. Advertised and Operating Capacity




Source: WSP

To support BEB transition planning, the SFMTA recently procured 12 40-foot BEBs from four manufacturers - BYD, Proterra, Nova Bus, and New Flyer. The specifications of these vehicles provided the foundation for determining the advertised battery capacities for BEBs modeled in this analysis. The 40-foot battery assumption was 573 Kilowatt Hour (kWh), representing the average advertised capacity of the four BEB models purchased for the pilot. With few 30-foot BEBs currently available on the market, the 30-foot BEB assumption (215 kWh) directly reflects OEM specifications. As with the 30-foot BEBs, 60-foot BEBs are also currently limited, albeit rapidly developing. For this reason, at the request of the SFMTA, a projected battery capacity of 600 kWh was used for 60-foot buses based on the anticipated technology release by 2022 according to OEM representatives (Table 2-1). It is important to note that BEB technology is rapidly advancing, thus larger battery capacities and improvements in performance may be available by the release of this report. For example, ARBOC plans to release a 30-foot BEB with a battery capacity of 437 kWh by the end of 2021.

Table 2-1. Battery Capacities Used in Performance Modeling

| Bus Size | Assumed Battery (kWh) | Operating Battery (kWh) |
|---|---|---|
| 30-Foot | 215 | 172 |
| 40-Foot | 573 | 458 |
| 60-Foot | 600 | 480 |

Source: WSP

### 2.1.2 *EFFICIENCY ADJUSTMENTS*

A BEB's performance is typically measured by its range (miles). This is a direct factor of its "efficiency," as expressed in kilowatt-hours per mile (kWh/mi.). Thus, a battery with a higher numerical efficiency has a shorter range, whereas a battery with a lower numerical efficiency has a longer range. Efficiencies can vary based on several factors, including battery health, operator behavior, temperature (HVAC usage), speed, and vehicle weight. This analysis provides three degrees of efficiency (optimistic, moderate, and conservative) to demonstrate various scenarios of how the BEBs may perform under a range of conditions with consideration to these factors.

To define this range of performance and remain OEM-agnostic, a baseline (optimistic) efficiency was established by analyzing multiple OEM's performance data (by vehicle length). Under the optimistic scenario, efficiencies represent advertised ranges; if multiple models were assessed for a single BEB size, an average efficiency was calculated (as described in Section 2.1). It should be noted that the majority of these values are based on Altoona reports which do not account for HVAC, elevation gain, and other factors that affect BEB performance, thus the optimistic efficiency represents a best-case scenario for the SFMTA and is not used to inform further recommendations. In this analysis, the optimistic efficiency used for 30-foot BEBs is 1.43 kWh/mile (assuming a 215 kWh battery), 2.04 kWh/mile for 40-foot BEBs (assuming a 573 kWh battery), and 2.68 for 60-foot BEBs (assuming a 600 kWh battery).

To establish the moderate and conservative efficiencies, the model built upon the optimistic efficiency by tailoring several metrics with a known effect on BEB efficiency based on the SFMTA's unique operating conditions. These adjustments were made using data garnered from existing performance evaluations, research, and physics-based calculations. The distinction between moderate and conservative efficiencies is based on more conservative estimates for the three metrics assessed (ambient air temperature, elevation gain, and number of stops). Though this analysis aims to capture significant influences on BEB performance, the applied metrics are not exhaustive and are limited to current published data and the methodologies used therein. To capture the "most-likely" performance scenario, recommendations throughout this report are built upon the moderate efficiency assumption. The metrics and methodologies used in this analysis are outlined below.

As previously mentioned, moderate and conservative efficiencies considered the following: 1) regional ambient air temperature (HVAC usage); 2) elevation gain with regenerative braking per trip; and 3) number of stops per trip. The energy consumption calculations for elevation gain and the number of stops drew upon the SFMTA's anticipated average weekly passenger loads to determine the total vehicle weight with passengers. This analysis used the industry standard passenger weight of 150 pounds when calculating total vehicle weight with passengers. Table 2-2 outlines the passenger load assumptions used in the elevation and stop energy consumption calculations.

Table 2-2. Passenger Load Assumptions Applied to Elevation and Stop Calculations

| Bus Size | Anticipated Average Passenger Load | Total Passenger Weight (lbs.) |
|---|---|---|
| 30-Foot | 22 | 3,300 |
| 40-Foot | 52 | 7,800 |
| 60-Foot | 70 | 10,500 |

Source: WSP

Ambient air temperature (HVAC): Ambient air temperature and the resulting HVAC usage is reported to have one of the greatest impacts on BEB efficiency. To account for this, the model adjusts the optimistic efficiency for extreme climate conditions using regional weather averages. In this study, the annual average high (72° F) and low temperature (46° F) for the City of San Francisco was compared against the annual average (57° F) to identify BEB performance during inclement weather. Drawing upon existing research, two levels of efficiency adjustments are made for each 1° F increase above and decrease below the annual average temperature, providing moderate and conservative estimations for days with peak HVAC usage. Currently, the SFMTA requires OEMs to set HVAC temperatures between 68° F and 72° F to limit energy expenditures. HVAC energy consumption may be refined with demonstration pilot data.

Elevation gain: Using the SFMTA's GTFS shapefiles (containing geographic points for the individual route variants) with the United States Geological Survey's digital elevation model for San Francisco, WSP staff assigned elevation data to each route variants' points. WSP then applied an estimate for the additional energy required to move a loaded bus over each individual segment based on the degree of the slope and the bus weight with a typical passenger load. The accumulative slope energy required for each segment was assigned to each vehicle block's trips and their respective route variants.[3]

Stops: Energy consumption from stops throughout the block were accounted for using physics-based formulas to provide a tailored efficiency adjustment to every trip within a service block. The number of stops were calculated for each trip using GTFS data. The acceleration force (work) drew upon typical passenger loads supplied by the SFMTA to calculate vehicle weight.

## 2.1 FACILITY ANALYSIS

During preliminary concept discussions, both conductive and inductive charging solutions were considered and analyzed by the SFMTA and the design team. Based on several factors, including the space constraints at each yard, the SFMTA committed to an inverted pantograph strategy for all yards. However, where applicable, such as in maintenance areas, plug-in dispensers may be utilized.

Plug-in dispensers may also serve as an interim solution as facilities are being fully prepared for a 100% BEB fleet (such as Kirkland Yard). In these instances, full electrical service can be brought to the site early in the transition process to allow for a select number of ground-mounted charging cabinets and necessary infrastructure. Most of the necessary infrastructure, such as switchboards, transformers, and charging cabinets, could be removed and re-installed in a later phase. The plug-in dispensers would have to be replaced with pantographs but could be reused in the maintenance building for maintenance bay charging. To utilize plug-in dispensers in the parking area for a given facility, ground space will have to be sacrificed, which likely could include bus parking spaces. All the

3 In a previous study conducted by the SFMTA, a maximum grade of 22% percent was identified across the service area.

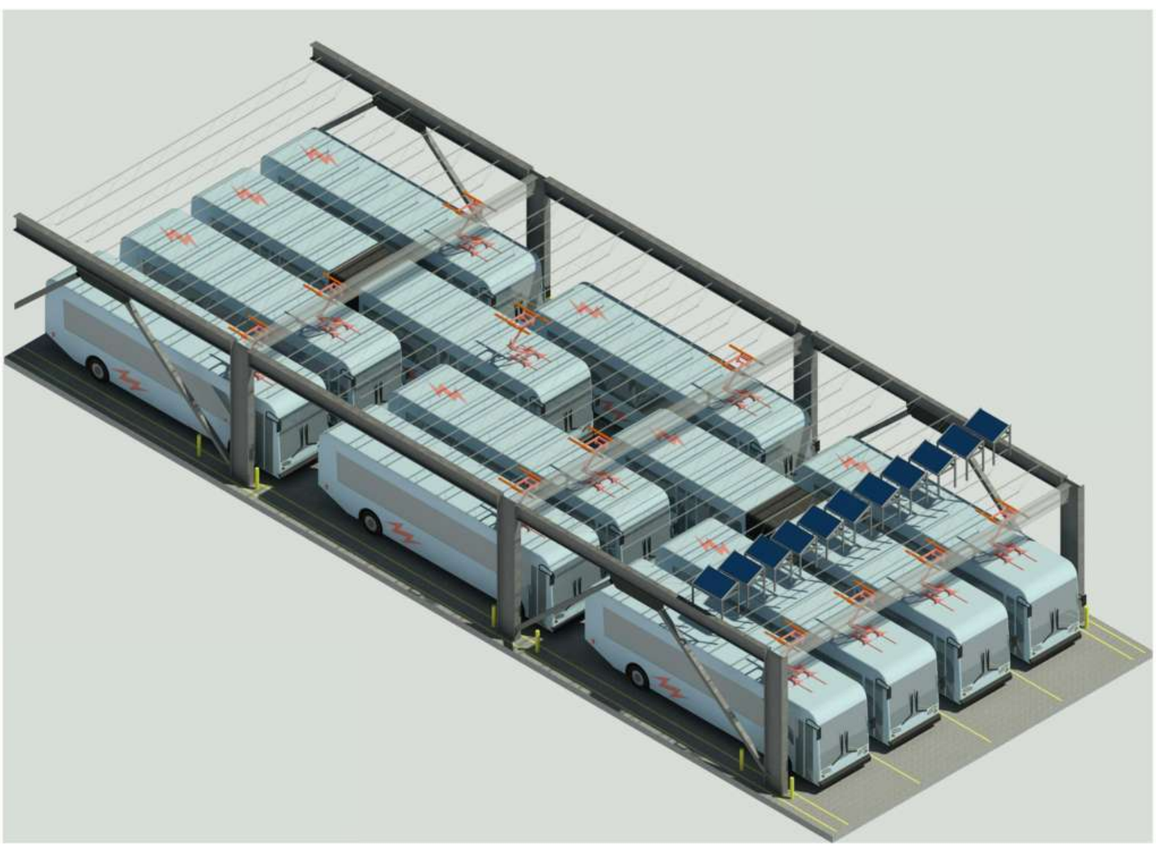
yards are operating at, or near, full capacity, and thus plug-in is not considered as a long-term facility charging option.

Each yard's BEB designs are modeled around overhead frames that distribute power to inverted pantograph charging dispensers in the bus parking areas. This scalable and modular overhead support structure will enable the SFMTA to retain the maximum amount of bus parking while implementing BEB charging and can be rapidly modified to meet changes in the SFMTA's fleet mix. The system consists of an overhead structure spanning up to four tracks of bus parking with pantographs mounted at various five-foot intervals as required by the assigned bus fleet. Charger cabinets, switchboards, transformers, on-site battery storage, and all electrical distribution will be kept above the bus parking area, where possible, to avoid costly trenching and reduce service interruptions during the transition.

In the maintenance areas, in-bay charging is proposed to be installed in select bays via plug-in dispensers with cable management systems or cable reels to avoid the challenges associated with the existing structure clearance heights as well as the safety issues associated with performing maintenance of roof-mounted bus systems with overhead charging.

Figure 2-3 illustrates inverted pantographs mounted to the modular overhead support structure.

Figure 2-3. Inverted Pantographs and Modular Support Structure



Source: WSP
Note: The frame can also support plug-in dispensers.

The proposed layouts are based on utilizing a 150 kW DC charging cabinet in a 1:2 charging orientation (one DC charging cabinet energizes two separate dispensers/buses). Note that a 1:3 (or more) charger to dispenser ratio can also be considered without modifications to the space required for the 1:2 design and can be evaluated in subsequent tasks of this study, or during design of the facility transition projects.

### 2.1.1 *STAGING AND PHASING*

To avoid service disruptions and operational impacts, the SFMTA's yards will undergo BEB upgrades in several on-site stages. These "stages" are segments of the yard that will be temporarily shut down to install the necessary BEB-supporting infrastructure. To electrify the fleet by 2040, it will be necessary to have multiple yards undergoing construction, concurrently. "Phases" are essentially classifications of when and how these yards are grouped.

### 2.1.2 *CURRENT AND PROJECTED FLEET*

The SFMTA has six bus yards, all of which will require significant capital improvements to accommodate a 100% BEB transition. Table 2-3 summarizes the number and type of buses that are currently stored at each facility.

Table 2-3. Summary of Existing Yards and Fleets

| Yard | Address | Total | Diesel-Hybrid Buses | | | Trolley Buses | |
|---|---|---|---|---|---|---|---|
| | | | 30' | 40' | 60' | 40' | 60' |
| **Flynn** | 1940 Harrison St. | 119 | - | - | 119 | - | - |
| **Islais Creek** | 1301 Cesar Chavez St. | 115 | 10 | - | 105 | - | - |
| **Kirkland** | 2301 Stockton St. and 151 Beach St. | 91 | - | 91 | - | - | - |
| **Potrero** | 2500 Mariposa St. | 146 | - | - | - | 53 | 93 |
| **Presidio** | 949 Presidio Ave. | 132 | - | - | - | 132 | - |
| **Woods** | 1095 Indiana St. | 241 | 20 | 221 | - | - | - |
| | **Total** | 844 | 30 | 312 | 224 | 185 | 93 |

Source: *The SFMTA Master Fleet Assign Ratio*, September 2020

Each facility will have completed its respective ZE transition by 2040 to serve the projected ZE fleet presented below in Table 2-4.

Table 2-4. Summary of Projected Battery Electric Fleet in 2040

| Yard | Address | Total | Battery-Electric Buses | | | Trolley Buses | |
|---|---|---|---|---|---|---|---|
| | | | 30' | 40' | 60' | 40' | 60' |
| **Flynn** | 1940 Harrison St. | 119 | - | - | 119 | - | - |
| **Islais Creek** | 1301 Cesar Chavez St. | 115 | 10 | - | 105 | - | - |
| **Kirkland** | 2301 Stockton St. and 151 Beach St. | 91 | - | 91 | - | - | - |
| **Potrero** | 2500 Mariposa St. | 206 | - | - | 206 | - | - |
| **Presidio** | 949 Presidio Ave. | 217 | - | 185 | 32 | - | - |
| **Woods** | 1095 Indiana St. | 241 | 20 | 221 | - | - | - |
| | **Total** | 989 | 30 | 497 | 462 | - | - |

Source: The SFMTA

## 2.2 UTILITY ANALYSIS

The San Francisco Public Utilities Commission (SFPUC) provides electrical service for the SFMTA service area by way of Pacific Gas & Electric (PG&E) electrical infrastructure. SFPUC acts as the major provider for all San Francisco public services, including the SFMTA, and has ties to the Hetch Hetchy water storage and delivery project, which provides some power. However, for all the facilities that are near the SFMTA sites, the distribution grid in the area is owned by PG&E, and SFPUC serves as an intermediary between PG&E and the SFMTA. SFMTA currently falls under a wholesale energy rate established by SFPUC.

The WSP team collaborated with SFPUC and the SFMTA staff to collect data and assess existing conditions. From there, an estimate of the total grid capacity that PG&E may have in the area was analyzed. It is important to note that estimates, assumptions, and utility infrastructure upgrades need to be verified by both PG&E and SFPUC. The verification process is currently ongoing. WSP has assisted the SFMTA with submitting Potrero and Presidio yards to SFPUC. Once accepted by SFPUC, the applications will be forward to PG&E for further analysis. Until this process is complete, the only data available from PG&E is the publicly available data provided by their distribution maps.

### 2.2.1 *UTILITY*

According to SFPUC, primary power (typically 12 kilovolts (kV) to large new developments is usually provided for up to 12 Megawatt (MW) of total power load. Currently, there are several PG&E 12 kV distribution lines within one or two blocks of each SFMTA facility. A typical 12 kV line conductor has a 600-amp allowable ampacity and a typical power capacity of 10 MW with a maximum 12 MW power capacity limit, per PG&E. Each new service will be connected to the SFMTA's infrastructure through one 12 kV interrupting device on the SFMTA side and one 12 kV interrupting device on the PG&E side.

Once the new service applications are received, PG&E will perform a study and confirm the appropriate feed, capacity, and potential infrastructure upgrades. For the purpose of this report, each 12 kV distribution line source substation will be discussed, including: how some of these distribution lines share the same source substation; the available capacity on the nearby circuits; and what the future load requirements are for the new charging infrastructure. The PG&E study is needed to confirm the circuit that feeds the site, available capacity, utility infrastructure upgrades and the associated costs, if applicable, for new service.

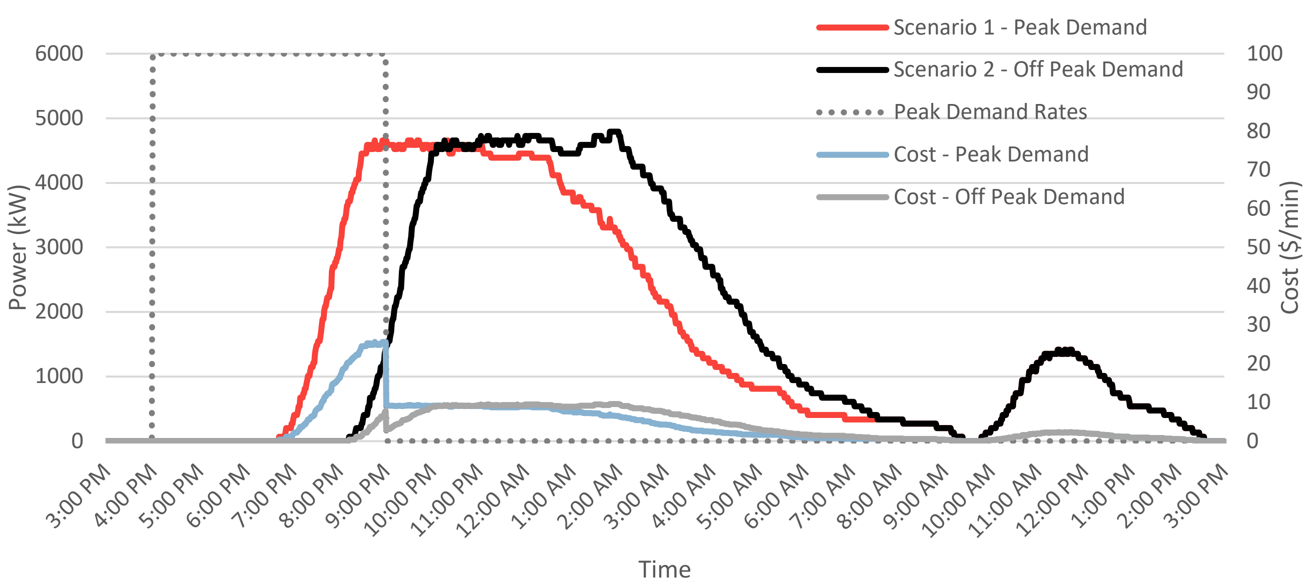
### 2.2.2 *ENERGY USAGE*

Estimates of energy usage at each of the SFMTA's yards built upon the fleet energy consumption results from the performance model as described in Section 2.1. Using the assumption that buses will begin charging immediately after pull-in servicing, the energy usage at each yard was calculated for a 24-hour period. An example is provided in Figure 2-4 of the power in kW per minute that makes up the energy usage in kWh. Each yard typically begins with buses charging at 7:00 PM and completes bus charging by 2:00 PM each day. From this, monthly and annual energy consumption, as well as the peak demand (the highest electrical power demand that occurs over a specified time period) are determined for each yard. Depending on the yard, the peak demand typically occurs between 8:45 PM and 12:30 AM when the highest number of buses are charging at the same time. Charge management software and strategies, such as off-peak charging, should be considered in the future to more efficiently disperse and reduce peak loads and costs.

By establishing a 24-hour period of current energy needs, the future energy requirements and associated costs can be estimated based on different rates (discussed in Section 2.2.4). This information will help facilitate discussions with SFPUC and PG&E in determining energy needs for each yard, the impact to their network, and future infrastructure upgrades, if necessary.

To obtain the 2040 projections, the peak demand and monthly and annual energy consumption were then multiplied by the ratio of the future fleet size to current fleet size. The peak demand calculations assume a "non-optimized" charge management system that is based on first in-first out priority. Further optimization of a smart load management system would lead to even larger reductions in peak demand needs.

Figure 2-4. Energy Usage Example




Source: Jacobs

## 2.2.3 *CHARGING ASSUMPTIONS*

There are several options for chargers at the SFMTA's disposal. The power (kW), OEM, and dispenser type (pantograph, plug-in, etc.) will be dictated by the SFMTA's service needs and charging strategy. Depot chargers, deployed at a yard, provide a relatively low amount of power (125 or 150 kW, for example) since buses can spend longer durations charging. On-route chargers provide a relatively high amount of power (in excess of 300 kW) since buses only charge for small periods of time, such as during a layover. Based on the power and service needs of the SFMTA's fleet, depot chargers have been determined the best-fit technology to be deployed across the fleet. In future analyses, the SFMTA may look to on-route charging options where service blocks cannot be immediately electrified. On-route charging locations will likely be located at the termini of routes where longer layovers take place. New development sites such as Transbay Terminal and Treasure Island may provide promising opportunities for the introduction of on-route charging

Depot chargers have advantages over on-route charging in terms of "charge ratio," which is expressed as the number of charging cabinets (where the actual rectifiers that convert AC power to DC power to charge the battery resides) to the number of possible dispensers. A ratio of 1:1 means that each charger plugs into one bus. A ratio of 1:2 means that each charger plugs into two buses. There are two basic ways to manage charging multiple buses with a single cabinet: sequential charging and concurrent charging. Sequential charging is when the charging cabinet chooses which of its plugs it provides power to, like a switch. It can either charge Bus A at 150 kW or Bus

B at 150 kW, but it cannot charge both at once. Concurrent chargers can split the charging capacity between the two buses so that both charge at the same time, but at a lower rate. For example, Bus A and Bus B are both charging, but each are charging at a peak of 75 kW. Given enough time to charge, both charging scenarios finish charging the buses at the same time.

Each bus has a "charging curve," as well as a peak power draw. The battery itself determines how much power can be drawn in at once based off its battery chemistry and current state of charge. Peak power draw often occurs between roughly 30% and 80%, with substantially reduced peak power draw from 80% to 100% (and especially reduced during the last 10% when the battery system is doing cell balancing). The charge curve is often OEM proprietary and can vary by technology. For this study, WSP assumes that the time average of these curves is roughly 90% of their peak rated power. If a charger has a maximum power output of 150 kW, the actual power to the vehicle is closer to 135 kW based on its charge curve. For concurrent charging, this would drop the peak power per bus from 75 kW to 67.5 kW. The type of equipment selected will dictate the flexibility when splitting power, with some manufacturers capable not only of a 50-50% split, but also variants such as 30-70%.

To account for realistic expectations, and in lieu of charge curve and rate information and any loss of efficiencies (via dispensers), it is assumed that each charger provides a sustained output at 90% of the advertised power, meaning that with a 1:2 charging ratio each bus would receive concurrent charging with a constant flow of 67.5 kW of power (Table 2-5). Note that future implementation of charging infrastructure may also be achieved via a 1:3 charging cabinet-to-dispenser ratio. The current assumptions were developed to provide the most efficient charging opportunity window and available space at the depots. This assumption will be reviewed throughout the transition plan's process in subsequent tasks.

The charging dispensers are assumed to be inverted pantographs, which require a small buffer of time to engage and disengage the charge rails on the bus (approximately one-minute to engage and to disengage). It is assumed that at PM pull-in, it will take 30 minutes before a bus can begin charging due to fare retrieval, cleaning, and routine service on a typical weeknight. As with BEBs, the model does not specify the OEM of the chargers; however, the available kW is based on what power is available on the market.

Table 2-5. Modeled Charger Outputs

| Advertised Charger | Modeled Charger | 1:2 Charging |
|---|---|---|
| 150 kW | 135 kW | 67.5 kW |

Source: WSP
Note: Assumed a 1:2 (charging cabinet-to-dispenser/bus ratio)

### 2.2.4 *UTILITY RATES*

It is expected that SFPUC will use a wholesale rate for the cost of energy, which is a flat rate of $0.079/kWh and is not dependent on the time of day. In addition to the wholesale rate, the typical PG&E EV time-of-use (TOU) rates are provided for a worst-case-scenario in Table 2-6. This is due to an ongoing rate study being conducted by SFPUC that may include TOU rates. Therefore, PG&E Electric Vehicle (EV) time-of-use rates have been assumed as a conservative baseline in determining the energy costs at each site.

Table 2-6. SFMTA Wholesale Rate and PG&E EV Time-of-Use Rates

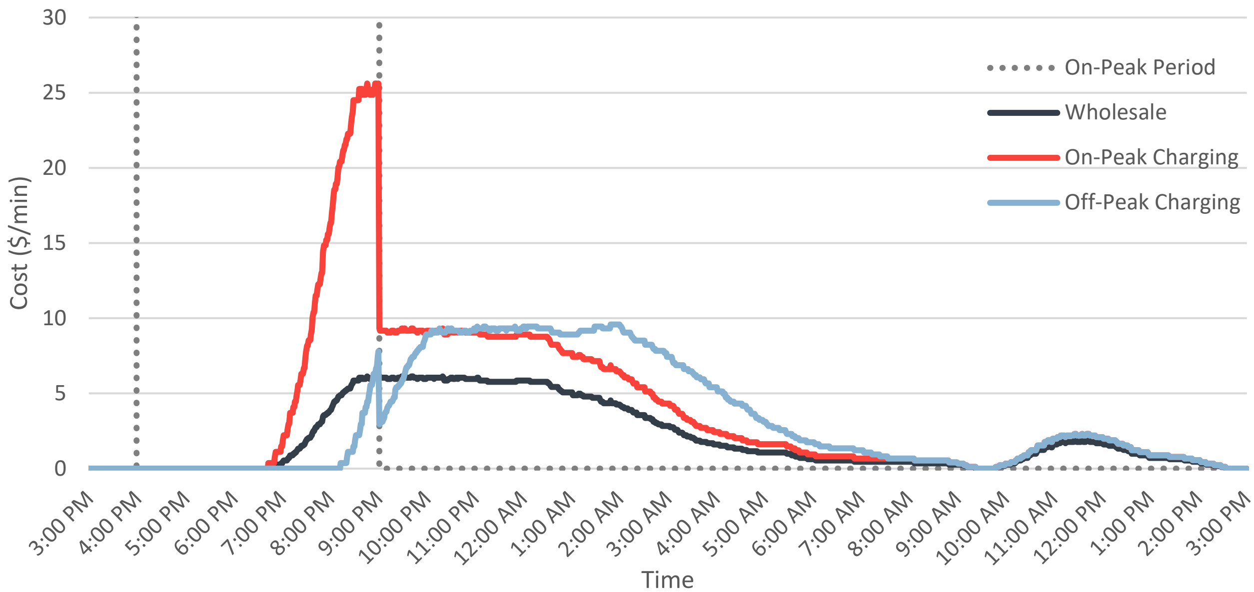
| Time Category | Time Frame | Cost Per kWh |
|---|---|---|
| Wholesale | -- | $0.079 |
| Super Off-Peak | 9:00 AM – 4:00 PM | $0.098 |
| Peak Energy | 4:00 PM – 9:00 PM | $0.33 |
| Off-Peak | 9:00 PM – 9:00 AM | $0.12 |

Source: PG&E

The wholesale rate was applied to the energy consumption based on buses that begin charging immediately following pull-in service to identify the best-case scenario for costs due to the flat rate. For comparison, the PG&E EV TOU rates were also applied to the energy consumption immediately following pull-in service, which is the on-peak period (the time in which electricity is priced at the most expensive rates) to provide a worst-case-scenario. In addition, the energy consumption was also adjusted for the off-peak period. The adjustment for off-peak charging follows the assumption that an hour-and-a-half adjustment to the start of the charging window will be applied for buses returning to the yard from 6:00 PM to 10:00 PM. Charging for these buses will subsequently begin at 8:00 PM through midnight, thereby minimizing energy consumption during the on-peak period and optimizing energy costs. The daily energy cost without adjustments for on-peak charging is roughly $1,000 higher for each site compared to charging during off-peak times. Again, for comparison, if TOU rates are applied, there is a 14% decrease in cost by adjusting for off-peak charging. Using a wholesale rate provides the highest cost savings with a 34% to 43% decrease in cost from TOU rates. When using a wholesale rate, charging immediately following pull-in service during the on-peak period will be assumed in the discussion of the report. Refer to Figure 2-5 for a depiction of the energy cost per minute at the wholesale rate and TOU for both the on-peak and off-peak period. This is provided in further detail in Table 2-7 and Table 2-8 for both daily and annual cost.

SFPUC's rate study, that may include TOU rates, is currently ongoing. It is advised to check with SFPUC annually for the status of the rate study.

Figure 2-5. Energy Cost for Wholesale, On-Peak and Off-Peak Charging




Source: Jacobs

Table 2-7. Current Fleet Energy Cost at Wholesale, On-Peak, and Off-Peak

| Yard | Energy Model | Wholesale | On-Peak Period | Off-Peak Period |
|---|---|---|---|---|
| **Flynn** | Daily Cost | $2,961 | $5,620 | $4,514 |
| | Annual Cost | $1,1080,718 | $2,051,409 | $1,647,428 |
| **Islais Creek** | Daily Cost | $2,581 | $4,586 | $3,858 |
| | Annual Cost | $942,234 | $1,674,015 | $1,408,337 |
| **Kirkland** | Daily Cost | $3,105 | $5,497 | $4,684 |
| | Annual Cost | $1,133,432 | $2,006,256 | $1,709,707 |
| **Potrero** | Daily Cost | $2,824 | $4,773 | $4,274 |
| | Annual Cost | $1,030,794 | $1,742,245 | $1,559,927 |
| **Presidio** | Daily Cost | $2,279 | $3,883 | $3,453 |
| | Annual Cost | $831,778 | $1,417,153 | $1,260,212 |
| **Woods** | Daily Cost | $5,270 | $8,924 | $7,895 |
| | Annual Cost | $1,923,525 | $3,257,238 | $2,881,528 |

Source: Jacobs

Table 2-8. Future Fleet Energy Cost at Wholesale, On-Peak, and Off-Peak

| Yard | Energy Model | Wholesale | On-Peak Period | Off-Peak Period |
|---|---|---|---|---|
| **Flynn** | Daily Cost | -- | -- | -- |
| | Annual Cost | -- | -- | -- |
| **Islais Creek** | Daily Cost | -- | -- | -- |
| | Annual Cost | -- | -- | -- |
| **Kirkland** | Daily Cost | -- | -- | -- |
| | Annual Cost | -- | -- | -- |
| **Potrero** | Daily Cost | $3,985 | $6,735 | $6,030 |
| | Annual Cost | $1,454,408 | $2,458,236 | $2,200,993 |
| **Presidio** | Daily Cost | $3,747 | $6,383 | $5,677 |
| | Annual Cost | $1,367,393 | $2,329,714 | $2,071,712 |
| **Woods** | Daily Cost | -- | -- | -- |
| | Annual Cost | -- | -- | -- |

Source: Jacobs

### 2.2.5 *SITE ANALYSIS AND INFRASTRUCTURE*

Information on existing infrastructure and as-built information was gathered by the SFMTA staff and WSP team during site visits.

For each yard, single line diagrams based on the below information can be found in Appendix E: Single Line Diagrams. The new BEB charging infrastructure will require a PG&E Interconnection to a SFPUC Interconnection both comprised with one 12 kV interrupting device and a 12 kV visible disconnect switch. A new service connection for 12 kV will require a 600A meter to be installed upstream of the new main switchgear per utility requirements.

The main switchgear will then feed the 12 kV – 480-volt step-down pad-mounted transformer with the quantity of transformers based on the BEB fleet size. The step-down transformers will range from 1,000 kVA to 3,325 kVA. These will then feed the new downstream 480-volt switchboard at each facility (refer to PG&E standard 045292).

Each switchboard will then be connected to:

— 480-volt AC distribution panels feeding the charging stations with a 2,000 A – 6,000 A rating

— 15 kVA 480V-208V/120V step-down transformer that feeds control power panel

— PV solar generation, refer to Table 2-11

— Battery storage unit, refer to Table 2-12

— Portable diesel backup generator 500 kW AC (one at each site)

### EQUIPMENT RATING SELECTION

The exact size and capacity of each BEB charger will depend on the selected manufacturer at the time of design. For this study, WSP assumes a conservative charging cabinet AC input power of 166 kVA and a DC output power of 150 kW, with a 1:2 charging ratio and concurrent charging at an average rate 67.5 kW.

### LOAD MANAGEMENT

Without a load management system, each 2,000-amp AC distribution panel can feed up to six 150 kW charging cabinets. Each 6,000-amp AC distribution panel and 3,325 kVA transformer can feed up to 20 150 kW charging cabinets.

With load management and power control systems, additional charging units can be connected to each transformer. Bus rating of the AC distribution panels on the transformer low voltage side will comply with National Electric Code (NEC) 2020 sections 705.12 and 705.13. With a load management system, each pantograph's charging rate will be limited to ensure the total charging rate is equal or below the maximum allowable charging capacity of each transformer size or AC distribution panel bus rating at any time. There is no limit to the maximum number of charging units connected to each AC distribution panel or transformer, as long as the total energy consumption is below the equipment bus current rating at all times based on NEC requirements.

The preliminary single line diagrams provided in Appendix E are designed based on 1:2 concurrent bus to charger ratio equal to 67.5 kW DC charging rate. For example, a 3,325 kVA transformer unit can feed a maximum of 40 charging units being charged at 67.5 kW DC rate simultaneously.

Standard PG&E transformer size including a 1,000 kVA, 1,500 kVA, 2,000 kVA, 2,500 kVA and 3,325 kVA, 12 kV – 480V transformers have been selected. The design is based on total peak AC power values modeled at 67.5 kW DC charging rate. Peak demand values may be higher if sequential charging rates of 135 kW charging rate are assumed. Each charging cabinet input will be protected by a 250A circuit breaker at the 480V switchboard. Transformer sizes assume a maximum of 200A per charging cabinet, and each charging cabinet would have 2 dispensers. This calculates to 166 kVA per EVSE. Refer to Table 2-9 for each transformer size capacity feeding pantographs units charging at the 67.5 kW DC rate. An electrical infrastructure summary for each yard is provided in Table 2-10.

Table 2-9. Transformer Size and Estimated Max. Number of Charging Units Charging Simultaneously

| Transformer Size | Charging Dispensers* |
|---|---|
| 3325 kVA | 40 |
| 3000 kVA | 38 |
| 2500 kVA | 30 |
| 2000 kVA | 24 |
| 1500 kVA | 18 |
| 1000 kVA | 12 |

Source: WSP

*Estimated max number of (pantographs/plug-in) units charging @ max. 67.5 kW charging rate simultaneously

Table 2-10. Electrical Infrastructure Summary

| Site | PV Solar | Battery** | Peak Load AC Power | Transformer |
|---|---|---|---|---|
| **Flynn** | N/A*** | 4 MWh | 7.3 MVA | (2)-3325 kVA, (1)-1000 kVA |
| **Islais Creek** | 629 kW | 4 MWh | 4.6 MVA | (2)-2500 kVA |
| **Kirkland** | 255 kW | 4 MWh | 7.3 MVA | (2)-3325 kVA, (1)-1000 kVA |
| **Potrero** | TBD* | 4 MWh | 6.7 MVA | (2)-3325 kVA |
| **Presidio** | TBD* | 4 MWh | 5.5 MVA | (1)-3325 kVA, (1)-2500 kVA |
| **Woods** | 815 kW | 4 MWh | 10 MVA | (3)-3325 kVA |

Source: WSP

* Potrero and Presidio solar coverage will be dependent on new building design

** Battery size is estimated minimum capacity needs, further storage evaluation to be done as part of emergency response and resilience efforts in next report

*** No solar analysis was performed for Flynn. The proposed new structure is independent of the existing structure and below the roof, and no structural analysis was done to determine what quantity of PV equipment could be installed on the roof of the existing building

### Solar and Battery Analysis

Per the San Francisco Environment code, certain site improvements require adding PV to municipal projects. Solar analysis was done using NREL's PV Watts tool and estimated the surface area that is available per site to support solar panel deployments. Battery storage is an ongoing analysis that has both economic and resiliency concerns. The SFMTA is under mandate to also transition support and non-revenue vehicles to ZE forms as well, however this report only addresses the BEB load.

Stationary battery storage totaling 4 MWh per site is WSP's recommendation for minimum viable backup power and this would be able to support roughly 6% of the SFMTA's BEBs from 25% to 100% SOC in the event of a multi-hour, overnight outage. Supporting 100 vehicles with stationary battery storage would require a total of roughly 46 MWh of storage. The expansion, placement, and size of backup power to support the resiliency requirements of the SFMTA's emergency plan will be further evaluated in the Task 3 report.

The possible solar arrays with peak power outputs and battery storage are summarized for each site in Table 2-11 and Table 2-12.

Table 2-11. Solar Generation

| Yard | Solar Array (kW) | Solar Generation (kWh per day) |
|---|---|---|
| **Flynn** | N/A | N/A |
| **Islais Creek** | 629 | ~2,600 |
| **Kirkland** | 255 | ~1,000 |
| **Potrero** | TBD | N/A |
| **Presidio** | TBD | ~2,600 |
| **Woods** | 815 | ~3,400 |

Source: WSP

Table 2-12. Battery Storage Unit

| Yard | Battery Size (kWh) | Number of Units | Total Storage (kWh) |
|---|---|---|---|
| **Flynn** | 2,000 | 2 | 4,000 |
| **Islais Creek** | 2,000 | 2 | 4,000 |
| **Kirkland** | 2,000 | 2 | 4,000 |
| **Potrero** | 2,000 | 2 | 4,000 |
| **Presidio** | 2,000 | 2 | 4,000 |
| **Woods** | 2,000 | 2 | 4,000 |

Source: WSP

### 2.2.6 *RESILIENCY*

Resiliency is discussed as the capacity of each yard to recover from power disruption. Several contingencies are considered to prolong service durations during power disruptions.

Table 2-13. Resiliency

| Duration of Outage | Contingency |
|---|---|
| 10 seconds to 15 minutes | On-Site Battery Storage System |
| 15 minutes to 2 hours | Mobile Generator |
| | Permanent GenSet |
| More than 2 hours to multi-day outages | Redundant Utility Feed |
| | Mobile Generator |

Source: WSP

An auxiliary battery storage system can be integrated to reduce the effect of unexpected power outages on operations. PG&E reliability data from 2006 to 2015 indicates that there is an average of approximately one power outage every two years. On average, a power outage in the San Francisco service environment lasts 78 minutes before service is restored.

WSP will assume an on-site battery storage system as the recommended contingency to address the risk of power disruptions. Due to the high cost of purchasing on-site battery storage system, WSP recommends a total of 4 MWh of battery storage for each site. This provides the minimum viable backup power and assumes that all buses are stored with 25% of their total capacity, resulting in the reserve systems accounting for 75% of the usable battery capacity.

Resiliency concerns remain a high priority for the SFMTA facility analysis. WSP will continue to analyze the best mix of resiliency options to ensure fleet operations remain minimally impacted during a prolonged utility outage. Strategies of redundant feeds, battery storage, and dispatchable generators will be used to make recommendations for SFMTA's emergency operation fleet needs for Task 3.

## 2.3 FINANCIAL ANALYSIS

The specific costs for a fleet transition are difficult to determine due to rapid (and uncertain) technological developments, inflation, varying EV charging tariffs, economies of scale, market and political factors, etc. This report leveraged industry experience and partnerships to source and develop estimates for both capital and operational (annualized) expenditures that can serve as the framework for the SFMTA to begin earmarking and seeking funds.

The following section provides a brief overview of the methodology and assumptions that were applied in determining capital expenditures (i.e., fleet acquisition, yard enhancements, and utility infrastructure). A detailed discussion of costs and fiscal tradeoffs are included in Task 3.

### 2.3.1 *CAPITAL EXPENDITURES*

Capital costs for the following four yards were analyzed: Flynn, Kirkland, Woods, and Islais Creek. Potrero and Presidio yards will be fully rebuilt and planning/design efforts are being undertaken by other teams. A high-level estimate was performed for both yards based on the average infrastructure cost per dispenser at the other four yards.

The capital cost estimate covers four major cost elements:

— Utility infrastructure

— Yard enhancements

— Construction markups

— Project markups

The planning level cost estimate for capital expenditures has been prepared for the purpose of establishing a preliminary opinion of probable project cost based on 2021 dollars. Task 3 will contain more details of the costing scope as well as more refined cost estimates.

## 2.4 RISK ASSESSMENT

A Risk Management Plan is provided in Appendix C to evaluate a series of risks that could delay or compromise the successful roll-out of the SFMTA BEB fleet. Within the plan, assets are identified for each yard along with an assessment of the criticality of the asset failing based on the resulting impact on the project implementation and operations. Using assets as a baseline, the plan examines potential threats such as earthquakes, extreme climate, pandemics, and power disruption to provide management and mitigation strategies.

# 3 SUMMARY OF RESULTS

## 3.1 SERVICE MODELING

This analysis assessed 853 weekday service blocks within the SFMTA's network to determine the feasibility of current and future BEB technologies to meet service requirements. Each of the yards operate between 109 and 224 blocks per weekday, serving more than 69,000 miles. The average daily service block distance at each yard ranges between 75 and 86 miles, with 47 service blocks exceeding 160 miles (Table 3-1). Under these conditions, BEBs performed well throughout the SFMTA service area, completing 73% of service blocks under the most conservative assumptions. When using moderate efficiency adjustments, only 14% of the service blocks failed (Table 3-2).

Currently, BEB technology cannot meet the demands of the SFMTA's blocks or vehicles for a 1:1 replacement ratio (conventional bus to BEB), however, the WSP model calculated the additional vehicles required assuming currently available technology with no service adjustments. This analysis considers only percent block completion and does not examine available space nor the increased capital and operating costs. It should be noted that the fleet replacement ratio is calculated based on the number of blocks rather than vehicles in the absence of vehicle-level data, however, this estimation provides a reasonable assumption for calculating fleet transition costs. Without any adjustments to service or the introduction of on-route charging, the current fleet replacement ratio required for a full BEB fleet transition is approximately 1 to 1.16 (Table 3-2).

Table 3-1. Summary of Block Distance at Each Yard

| | | | Total Bus Blocks Greater Than 160 Miles | |
|---|---|---|---|---|
| Yard | Bus Blocks Per Weekday | Average Block Distance Per Weekday (mi.) | Number | Percentage |
| **Flynn** | 124 | 75 | 0 | 0% |
| **Islais Creek** | 116 | 77 | 8 | 7% |
| **Kirkland** | 150 | 83 | 15 | 10% |
| **Potrero** | 110 | 85 | 0 | 0% |
| **Presidio** | 109 | 74 | 0 | 0% |
| **Woods** | 244 | 86 | 24 | 10% |

Source: WSP

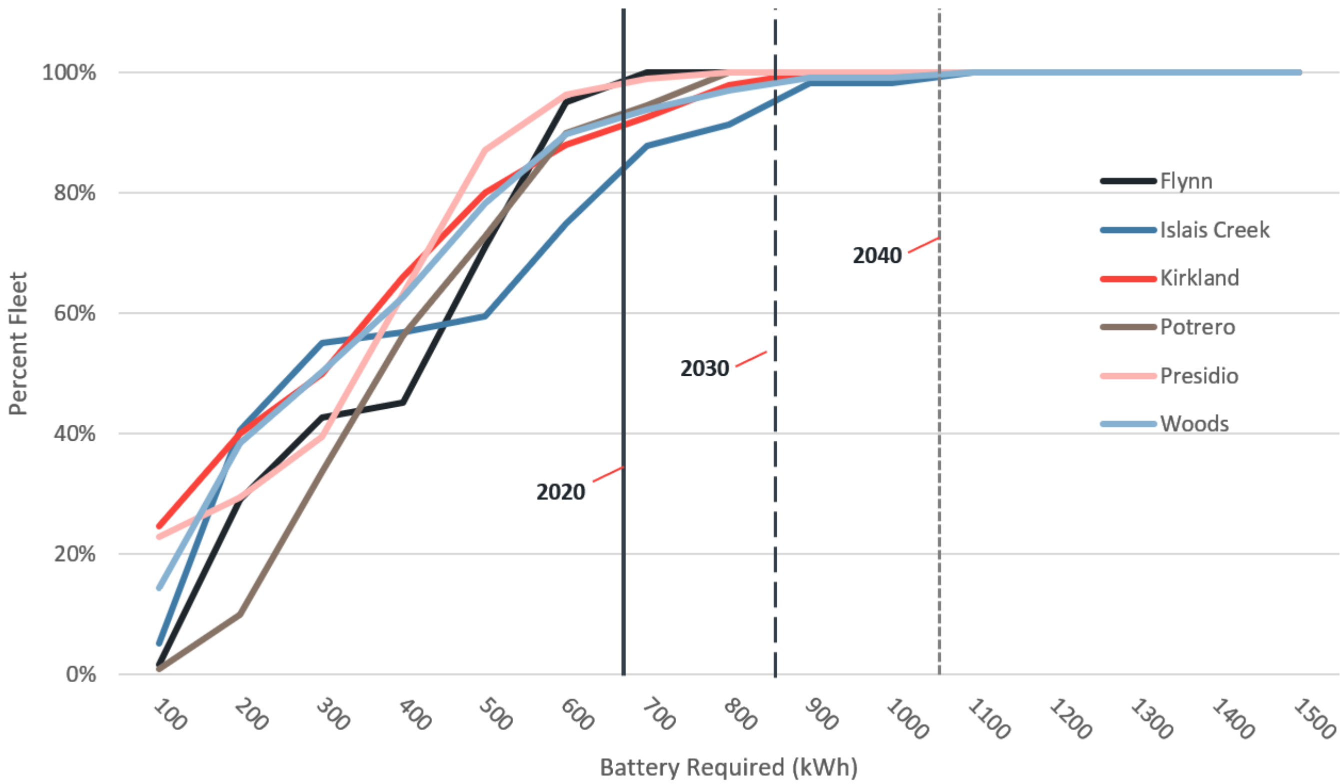
Table 3-2. Summary of Fleetwide Block Completion and Replacement Ratio

| | | | Number of Blocks | 853 |
|---|---|---|---|---|
| Sensitivity | Blocks Failed | Percent of Fleet | Fleet Required | Fleet Replacement Ratio |
| **Optimistic** | 15 | 2% | 868 | 1:1.02 |
| **Moderate** | 118 | 14% | 981 | 1:1.16 |
| **Conservative** | 228 | 27% | 1101 | 1:1.30 |

Source: WSP

The fleet replacement ratio can be further reduced by delaying transition of the more energy intensive blocks until later in the SFMTA's transition goal window. To illustrate this, Figure 3-1 demonstrates the percentage of the SFMTA's fleet that can be electrified based on maximum current and projected battery capacities. In this analysis, projections of BEB viability are based on battery size; however, it should be noted that several advances in BEB technology, such as improved efficiency and vehicle weight, may improve vehicle performance. Based on these assumptions, more than 94% of the fleet will be suitable for electrification by 2030 and 98% of the fleet will be electrifiable by 2040. A complete summary of block failures and the respective battery sizes required can be found in Appendix B: Failed Service Blocks.

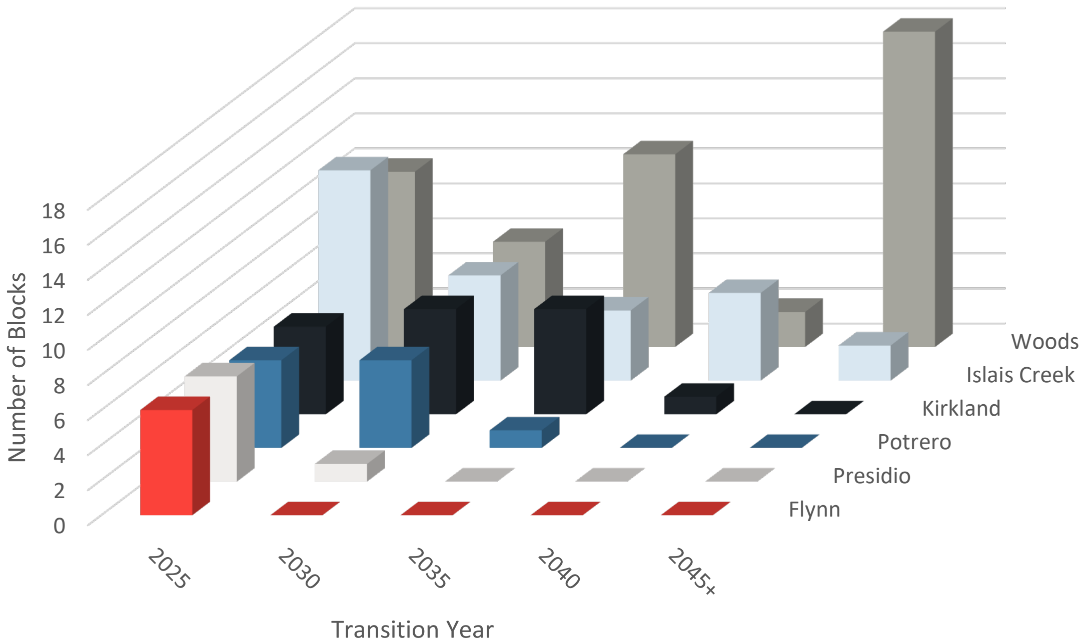
Figure 3-1. Battery Size Required and Availability (Based on Moderate Efficiencies)




Source: WSP

Figure 3-2 provides a foundation for planning procurement phasing at each yard. This figure is built from the assumed battery capacities used in this analysis rather than maximum battery capacity currently available to provide greater flexibility in the selection of OEMs. Based on these projections, BEB technology will fully meet the needs of the most energy-demanding service blocks at the Flynn, Presidio, and Potrero yards by 2035 and Kirkland Yard by 2040. This figure also highlights service challenges in meeting a 2040 transition goal for the Islais Creek and Woods fleets. Often, each yard's most energy-demanding service blocks represent a small proportion of the overall fleet operating profile, hence the majority of service blocks will be BEB-ready by 2030 or sooner with only a few outliers extending to 2040 and beyond.

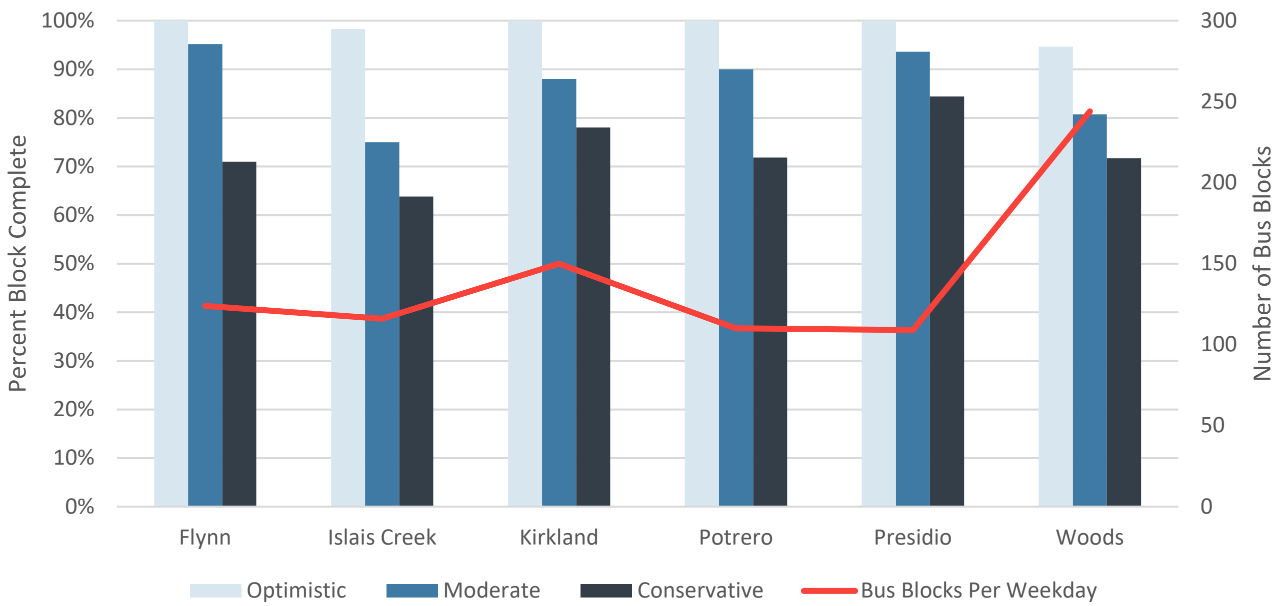
Figure 3-2. BEB Transition Readiness Division (Based on Moderate Efficiencies)




Source: WSP

A focus on performance by yard reveals that all six of the yards appear to be promising for electrification, with a minimum of 60% of the fleet qualifying for a BEB transition under the worst-case scenario. Currently, at least 90% of the service blocks operating out of Flynn, Potrero, and Presidio yards are BEB-ready under moderate efficiencies. It should be noted that Potrero and Presidio yards currently operate fully electric trolley fleets, thus transitioning these yards does not bring the SFMTA closer to their electrification goals. At Kirkland and Woods yards, 80% of the service blocks are BEB-ready; a significant number of block failures at Woods Yard is linked to 30-foot bus operations, which is expected to quickly improve as more OEMs begin to produce these buses. The yard with the lowest block completion is Islais Creek with only 75% of the fleet currently BEB-ready under moderate conditions (Figure 3-3). The performance at Islais Creek yard is likely due to the 60-foot fleet it operates along service blocks requiring high energy consumption. As 60-foot BEBs become more available on the market and the vehicle range increases, this performance should dramatically improve.

Figure 3-3. Summary of Block Completion by Yard




Source: WSP

To provide insight into the modeling outcomes, the average bus efficiency calculated for each yard is presented for all three degrees of sensitivity in Table 3-3. These efficiencies are further broken down by vehicle size for the moderate estimations in Table 3-4. It should be noted that the hilly topography within the SFMTA's service area significantly impacted the estimated efficiency for each block, with additional energy demands for slope drawing between 22% and 31% of the available battery capacity at each yard. Figure 3-4 demonstrates the dramatic variation of elevation for two of the SFMTA's service blocks (2305 and 2808) to highlight this impact. The specific energy loss resulting from each efficiency adjustment metric used in this analysis is explained in detail for each yard in the sections that follow.

Table 3-3. Average Block (kWh/mile)

| Yard | Optimistic | Moderate | Conservative |
|---|---|---|---|
| **Flynn** | 2.68 | 3.93 | 4.72 |
| **Islais Creek** | 2.67 | 3.87 | 4.64 |
| **Kirkland** | 2.04 | 3.01 | 3.60 |
| **Potrero** | 2.35 | 3.78 | 4.50 |
| **Presidio** | 2.04 | 3.52 | 4.20 |
| **Woods** | 1.98 | 3.07 | 3.67 |

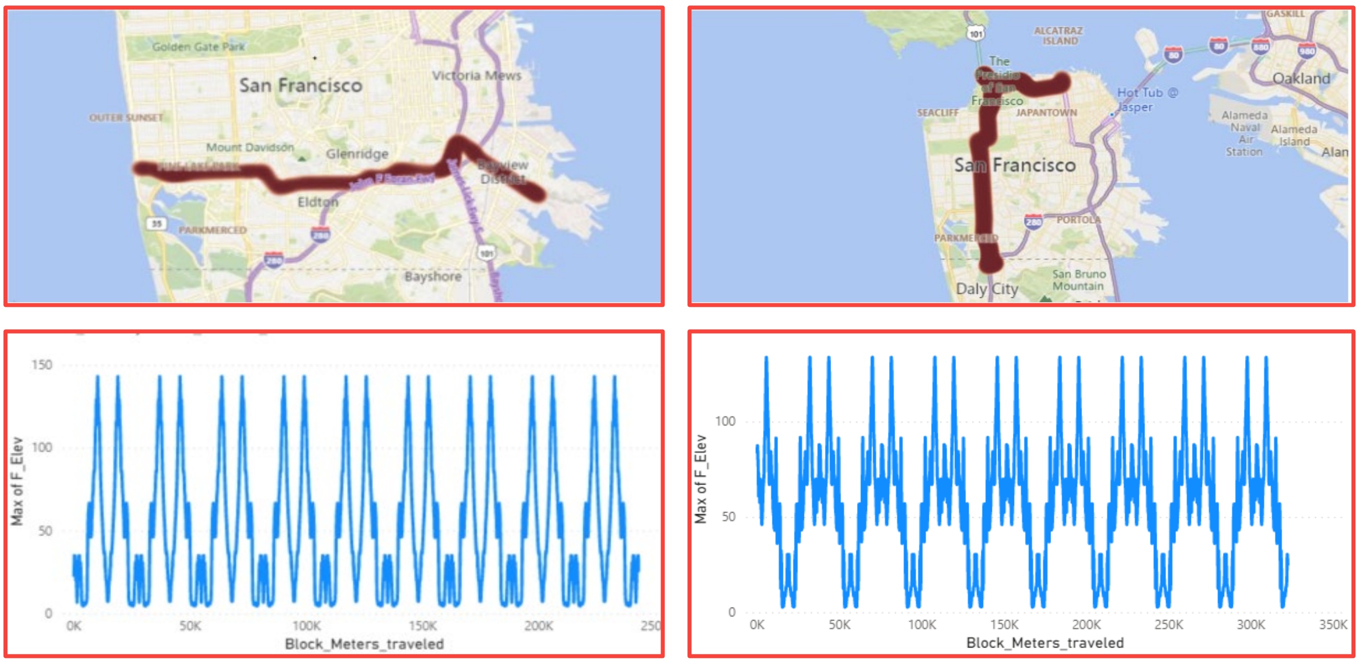
Source: WSP

Table 3-4. Average Moderate Block Efficiency by BEB Size (kWh/mile)

| Yard | 30-Foot | 40-Foot | 60-Foot |
|---|---|---|---|
| **Flynn** | NA | NA | 3.93 |
| **Islais Creek** | NA | 2.98 | 3.88 |
| **Kirkland** | NA | 3.01 | NA |
| **Potrero** | NA | 3.36 | 4.22 |
| **Presidio** | NA | 3.52 | NA |
| **Woods** | 2.82 | 3.09 | NA |

Source: WSP

Figure 3-4. Examples of Elevation Variation (ft)



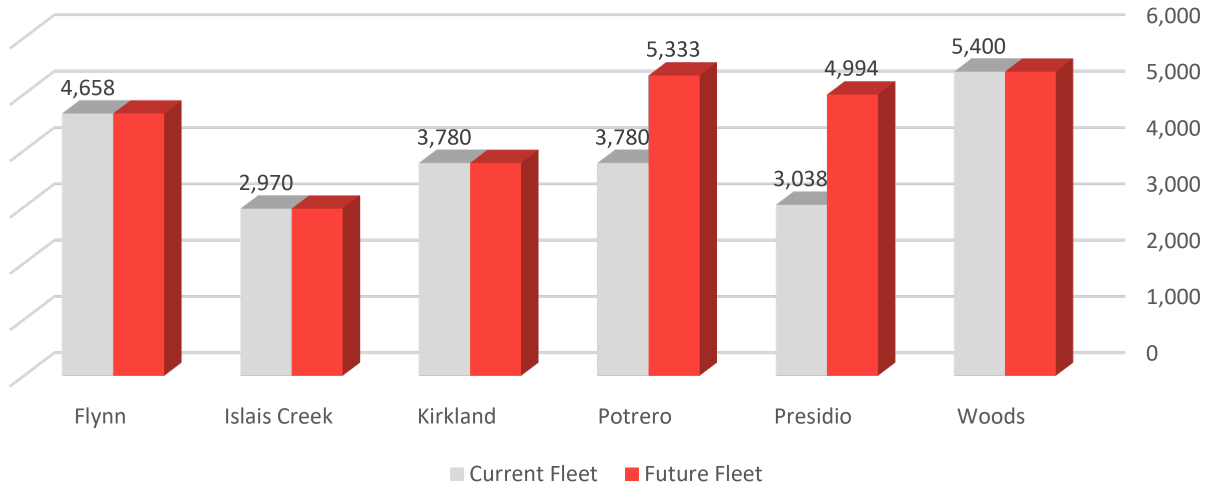

Source: WSP
*Note: The images represent Blocks 2305 and 2802, respectively

# 3.2 UTILITIES

The peak demand and energy consumption at each yard was determined by the modeling parameters outlined in Section 2 and is provided in Table 3-5 for the current fleet size. Utilizing these values as a basis, the future demand and energy consumption is approximated by the ratio of future fleet size to current fleet size (as presented in Table 3-5 and Table 3-6). This provides a rough order of magnitude of the energy needs required for the 2040 BEB fleet and will facilitate discussions with SFPUC and PG&E for utility capacity and infrastructure upgrades to meet the current and future demand at each yard.

WSP will assume the approach that charging will occur immediately following pull-in service during the on-peak period. The peak demand in kW for each yard is provided in Figure 3-5, including the current and future projections to determine the ability of the utility network to support electrifying the BEB fleet. The peak demand for concurrent 1:2 charging occurs between 8:45 PM and 12:30 AM when the majority of buses are charging. Peak demand is dependent on the number of buses charging at the same time and the rate at which they are charging (67.5 kW for 1:2 charging). Further detail is provided specific to each yard in their corresponding sections.

Figure 3-5. Peak Demand (kW)




Source: Jacobs

The power in kW required to charge the fleet is analyzed per minute and used to determine the energy consumption or the total energy used in the 24-hour period and is provided in kWh. The energy required to charge the fleet is not dependent on the time of day or the rate of charging but dependent on the parameters of the fleet. The peak demand, monthly and annual energy consumption for each yard are summarized in Table 3-5 for the current fleet and Table 3-6 for the future fleet.

Table 3-5. Energy Consumption based on Current Fleet

| Usage Information | Flynn | Islais Creek | Kirkland | Potrero | Presidio | Woods |
|---|---|---|---|---|---|---|
| BEB Fleet Size (Current) | 119 | 115 | 91 | 146 | 132 | 241 |
| Peak demand (kW) | 4,658 | 2,970 | 3,780 | 3,780 | 3,038 | 5,400 |
| Monthly energy consumption (kWh) | 1,125,706 | 1,095,388 | 1,179,287 | 1,071,672 | 865,545 | 2,001,189 |
| Annual energy consumption (kWh) | 13,508,476 | 13,144,658 | 14,151,449 | 12,860,066 | 10,386,543 | 24,014,270 |

Source: Jacobs

Table 3-6. Energy Consumption based on 2040 Fleet

| Projected Usage Information | Flynn | Islais Creek | Kirkland | Potrero | Presidio | Woods |
|---|---|---|---|---|---|---|
| BEB Fleet Size (projected 2040) | 119 | 115 | 91 | 206 | 217 | 241 |

| Projected Usage Information | Flynn | Islais Creek | Kirkland | Potrero | Presidio | Woods |
|---|---|---|---|---|---|---|
| Peak demand (kW) | 4,658 | 2,970 | 3,780 | 5,333 | 4,994 | 5,400 |
| Monthly energy consumption (kWh) | 1,125,706 | 1,095,388 | 1,179,287 | 1,512,085 | 1,422,904 | 2,001,189 |
| Annual energy consumption (kWh) | 13,508,476 | 13,144,658 | 14,151,449 | 18,145,025 | 17,074,847 | 24,014,270 |

Source: Jacobs

The WSP team evaluated existing grid capacity with tools such as PG&E's Integration Capacity Analysis (ICA) system which provided existing circuit[4] capacities, peak demand, time of demand peaks, and loads at circuits' substations. From there, an estimate of the total grid capacity that PG&E may have in the area was analyzed. Again, it is important to note that assumptions and utility infrastructure upgrades need to be verified by both PG&E and SFPUC.

Table 3-7 provides a summary of nearby 12 kV circuits for each yard based on the study of PG&E's ICA system. Four bus yards have a primary feed from the Potrero Substation, while the other two yards are separately fed from Mission Substation and SF G Substation. Adjacent circuits will be a factor in providing additional power to each yard. Each yard has viable options from the nearby circuits through at least one new interconnection with PG&E's utility grid. Due to the energy demand estimated for Potrero yard and in conjunction with the plan for new buildings, two new interconnections with PG&E's utility grid are likely required.

The summary shows that close coordination with PG&E is needed to determine the actual available capacity to support fully electrifying the current and 2040 fleet.

Table 3-7. Electrical Substation and 12kV Circuit Summary

| Site | PG&E Substation | Current Feeder | Available Capacity (MW) | Nearby Feeder (1) | Available Capacity (MW) | Nearby Feeder (2) | Available Capacity (MW) |
|---|---|---|---|---|---|---|---|
| **Flynn** | Potrero | Potrero 1112 | 2.30 | Potrero 1118 | 6.21 | Mission 1124 | 4.49 |
| **Islais Creek** | Potrero | Potrero 1105 | 4.85 | Potrero 1103 | 3.90 | N/A | N/A |
| **Kirkland** | Mission | Mission 1111 | 5.50 | Larkin 1119 | 3.32 | Larkin 1136 | 1.12 |
| **Potrero** | Potrero | Potrero 1119 | 2.50 | Mission 1125 | 4.73 | Potrero 1101 | 1.70 |
| **Presidio** | SF G | SF G 1102 | 5.95 | SF G 1101 | 7.29 | Larkin 1135 | 1.03 |
| **Woods** | Potrero | Potrero 1116 | 1.99 | Potrero 1101 | 1.70 | Potrero 1118 | 6.21 |

Source: PG&E

## 3.3 FACILITIES

All of the SFMTA's yards will move forward with an overhead mounted pantograph system with all of the electrical infrastructure and equipment mounted on new independent support frames at the Flynn, Islais Creek, Kirkland,

4 For the purposes of this report, circuit and feeder are synonymous, however, the main distinction is that a feeder can serve many different customers and that a circuit is a connection to said feeder.

and Woods divisions. A ”kit of parts” design that outlines the requirements for charging a BEB has also been developed for Potrero, Presidio, and a full rebuild of Woods. This kit of parts provides generic modules for the design of a charging equipment overhead mounting platform structure with the required charging infrastructure, as well as a module for distribution and dispensing in the bus parking areas, and considerations for connecting the charging equipment and infrastructure to the utility-owned equipment in the electrical system.

The process of integrating BEBs into the SFMTA’s fleet is very complex. Each yard will need to have sufficient power (utility enhancements) and charging infrastructure in place before buses are delivered. While the utility enhancements can generally be done without impacting normal operations, the installation of the support structure and charging equipment (chargers, switchgear, transformer, etc.) could negatively impact operations. For that reason, the planning of distinct on-site construction stages and program-level phasing is essential. Considerations for capacity redundancy across facilities to enable shutdowns will be included in Task 3, which focuses on developing phasing schedules based on bus procurement and construction timetables.

The SFMTA must make considerations for the value of investing in standalone BEB infrastructure improvements versus full facility rebuilds. The significant capital cost of an upgrade to allow for the charging and storage of BEBs at a site may, in some instances, cause the SFMTA to consider a full rebuild of the site, rather than upgrading the site to a bare minimum BEB charging and storage requirement. The electrical infrastructure can be reused in the event of a site rebuild, but any overhead structure would likely be lost.

# 4 FLYNN YARD

## 4.1 EXISTING CONDITIONS

This section summarizes Flynn Yard's current service parameters, location and facilities configuration, and existing electrical infrastructure.

### 4.1.1 *SERVICE DESCRIPTION AND REQUIREMENTS*

Flynn Yard operates 124 service blocks served by 60-foot buses. This fleet travels a total of 9,304 miles during a typical weekday. The average weekday block distance is 75 miles and the longest distanced traveled is 120 miles. The number of stops for each block varies widely, with an average of 247. The service blocks at this yard travel along an accumulative grade of 21% (Table 4-1).

Table 4-1. Existing Service Conditions at Flynn Yard

| Total Distance Traveled (mi.) | Average Distance Traveled (mi.) | Max Distance Traveled (mi.) | Average Number of Stops | Accumulative Slope |
|---|---|---|---|---|
| 9,304 | 75 | 120 | 247 | 21% |

Source: WSP

### 4.1.2 *LOCATION AND FACILITIES*

Flynn Yard is located at 1940 Harrison Street in the City of San Francisco.

Currently, 119 60-foot diesel-hybrid buses are stored, maintained, fueled, and serviced at Flynn Yard. The yard includes a maintenance area with drive-through bays, transportation area, stand-alone wash canopy, and a stand-alone fuel canopy. All facilities are integrated into the lone, single-story building on the site. A tire shop is located separately from the main facility in a building across Harrison Street. The southeast corner of the main Flynn Yard has a cutout that houses separate businesses not related to or owned by the SFMTA. Electrical utility service is provided by the SFPUC.

An aerial and existing site plan of Flynn Yard are presented in Figure 4-1 and Figure 4-2, respectively.

Figure 4-1. Flynn Yard – Existing Conditions (Aerial)


Source: Google Earth

## SITE CIRCULATION

Buses enter from Harrison Street and are parked in unassigned, stacked (nose-to-tail), 11’6”-wide lanes in the northern circulation area. Individual buses are then pulled from the storage area and taken by nightly service staff to the fuel lanes for fare retrieval, interior cleaning, and fueling before pulling forward to the bus wash lanes. After fuel and wash, buses are re-parked in the storage area. Buses remain parked until morning pullout unless a maintenance issue has been identified. Non-revenue vehicles (NRVs) are parked in a row of spaces near the transportation area adjacent to the bus circulation northernmost lane.

Figure 4-2. Flynn Yard – Existing Site Plan


Source: WSP

### 4.1.3 *ELECTRICAL INFRASTRUCTURE*

The following section provides information on the existing substation and circuit that support Flynn Yard's electrical needs.

#### SUBSTATION

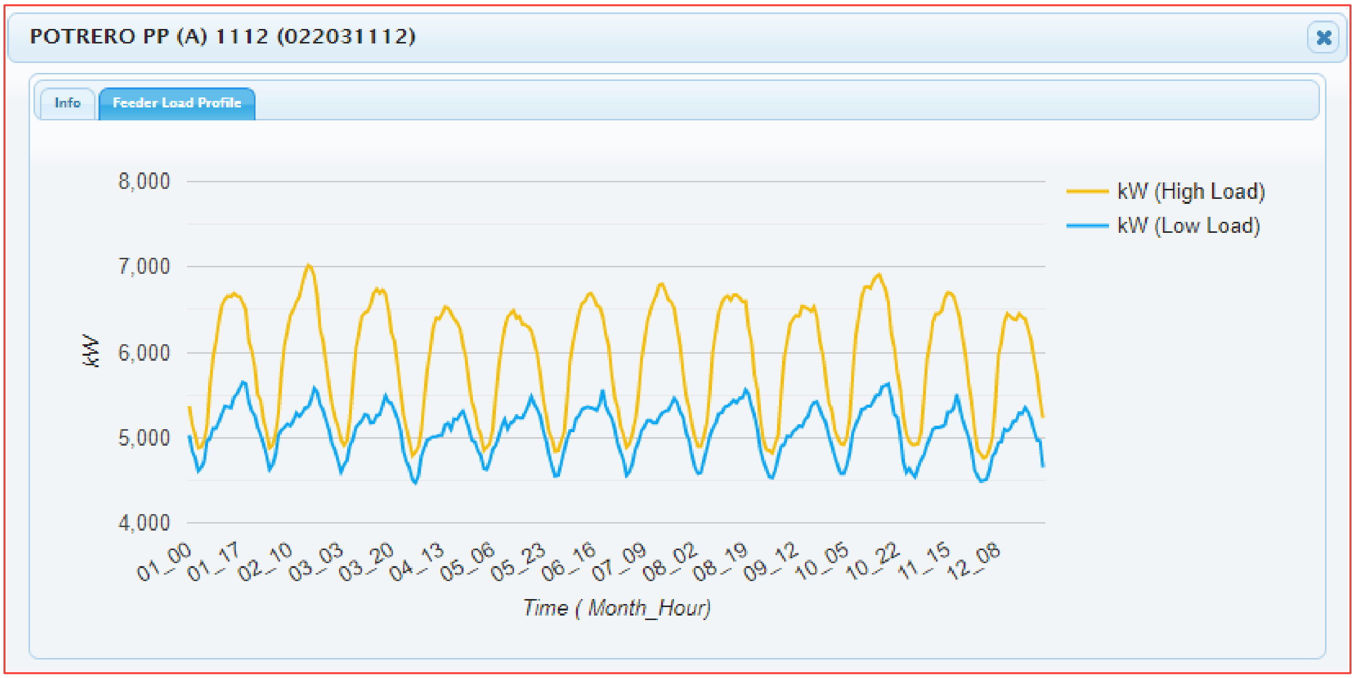
Flynn Yard's power is provided by the Potrero Substation that is located along Illinois Street between 23rd Street and 24th Street, approximately 2.2 miles from the yard. The Potrero Substation serves multiple SFMTA sites, including Islais Creek, Potrero and Woods yards. The Potrero Substation has a distribution capacity of 74 MW. The POTRERO PP (A) 1112 Circuit (Potrero 1112 Circuit) feeds Flynn Yard.

#### CIRCUIT

The Potrero 1112 feeder provides a 12 kV circuit that is fed from the Potrero Substation. The Potrero 1112 feeder has an existing capacity of 9.5 MW. PG&E estimates that the projected peak load of this circuit is 7.2 MW, leaving approximately 2.3 MW of available capacity. The circuit enters the yard on the ground floor of the southeast side of the property on Harrison Street and is one of two circuits that provide service to Flynn Yard.

Peak loads for the Potrero 1112 Circuit are monitored by PG&E and published on the ICA map. The ICA map shows averages of the feeder's load profile for peak usage of power on the Potrero 1112 circuit by month and time of day for all customers who are served by this feeder. The load increases in winter months and has peaks at 9:00 AM and 8:00 PM. Usage is at its minimum between 2:00 AM and 6:00 AM. The x-axis on Figure 4-3 shows the month and hour of the load profile for the circuit. For example, the period from 01_00 to 01_17 shows the average load profile of the circuit between the hours of 1:00 AM and 5:00 PM for the month of January. The high loads show the maximum average recorded loads for high demand days during that month, such as an unusually cold or hot day when HVAC usage is at its maximum. The low load shows the minimum average load, for when power usage was not as high. Table 4-2 shows load information for all customers in the area, not limited to the SFMTA Flynn Yard, who are served by the Potrero 1112 circuit. The metrics for this circuit are shown in Figure 4-3 and Table 4-2.

Figure 4-3. Flynn Yard - Potrero 1112's Load Profile




Source: PG&E

Table 4-2. Flynn Yard – Potrero 1112's Load Information

| Description | Data |
|---|---|
| Feeder Name | POTRERO PP (A) 1112 |
| Feeder Number | 022031112 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 9.52 |
| Circuit Projected Peak Load (MW) | 7.23 |
| Substation Bank | 1 |
| Substation Bank Capacity (MW) | 74.30 |
| Substation Bank Peak Load (MW) | 46.68 |
| Existing Distributed Generation (MW) | 0.42 |
| Queued Distributed Generation (MW) | 0.20 |
| Total Distributed Generation (MW) | 0.62 |
| Total Customers | 685 |
| Residential Customers | 480 |
| Commercial Customers | 119 |
| Industrial Customers | 73 |
| Agricultural Customers | 1 |
| Other Customers | 12 |

Source: PG&E

## 4.2 MODELING RESULTS

The following section presents the blocks completed, fleet requirements, and service phasing strategies emerging from the simulation model for the service blocks operating out of Flynn Yard.

### 4.2.1 *BLOCK COMPLETION*

Between 71% and 100% of all the blocks operating out of Flynn Yard (operated by 60-foot buses) can complete current service requirements with current BEB technology based on the three degrees of efficiency described in Section 2.1. Under conservative efficiency estimations, 36 blocks exceed the energy requirements that can be provided by current BEB technologies. Under the moderate scenario, six blocks failed. Zero blocks failed under the optimistic scenario (Table 4-3).

Figure 4-4 illustrates the percent of service completion of the modeled BEBs for the fleet housed at Flynn Yard. This figure helps to identify the degree to which the technology falls short of service requirements to support long-term planning. For example, a BEB may have completed 99% of the block and still technically fail. At Flynn Yard, many of the failed blocks only slightly fall short of service requirements under moderate efficiency assumptions. Although only 95% of the fleet meets 100% of the service requirements, the block failures fall short of service needs by less than 10% of the total block distance. This indicates that 100% service block completion can likely be achieved with minor improvements to battery technology or minor adjustments in service planning (e.g. midday charging or reduced stops).

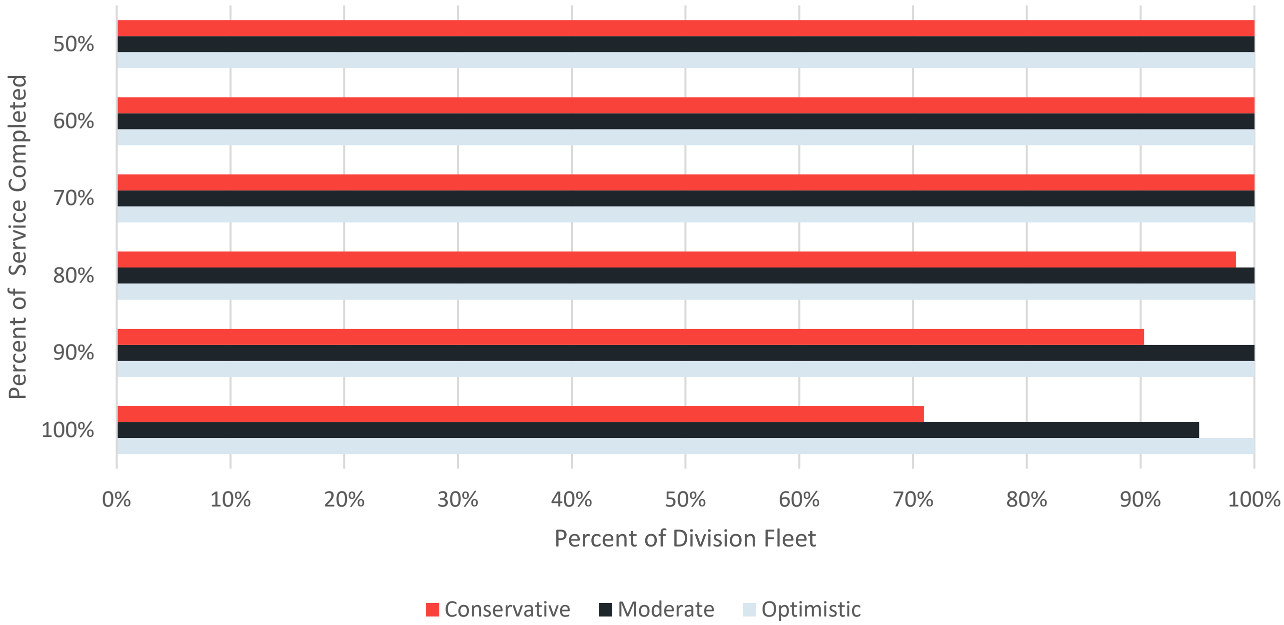
A comprehensive list of failed blocks and the percent block completion can be found in Appendix B: Failed Service Blocks.

Table 4-3. Summary of Failed Blocks at Flynn Yard

| Sensitivity | Blocks Failed | Percent Failed |
|---|---|---|
| Optimistic | 0 | 0% |
| Moderate | 6 | 5% |
| Conservative | 36 | 29% |

Source: WSP

Figure 4-4. Percent of Service Requirements Completed for the Flynn Yard Fleet

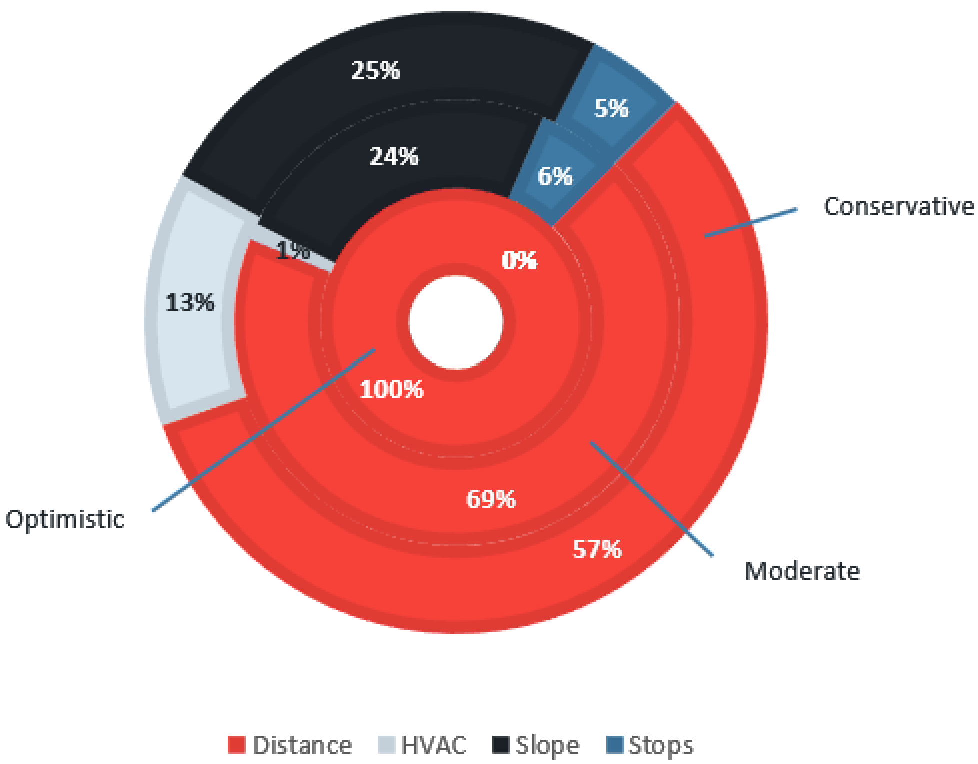



Source: WSP

### 4.2.2 *BLOCK ENERGY CONSUMPTION*

To better understand the modeling performance outcomes, each of the metrics evaluated to determine BEB efficiency were isolated. Figure 4-5 identifies the percent energy used from various metrics: distance traveled, HVAC, number of stops, and slope for each sensitivity range. As expected, this analysis revealed that slope has a considerable effect on BEB energy consumption, drawing 24% and 25% of the battery's available capacity for moderate and conservative efficiencies, respectively. The greatest shift in energy consumption distribution between sensitivity ranges is the impact of HVAC. Under the moderate sensitivity range (reflecting a fair-weather day), HVAC has only a 1% influence on energy consumption. When assuming the most extreme climate conditions in San Francisco, however, HVAC may be expected to draw up to 13% of the battery's available energy. Though the region will rarely experience sustained temperatures at the annual high and low, this impact should be considered, especially in the event that climate change creates a notable effect on regional climate.

Figure 4-5. Percent of Energy Used by Consumption Factors at Flynn Yard




Source: WSP

### 4.2.3 *FLEET REQUIREMENTS*

Based on the energy required to operate 124 60-foot blocks out of Flynn Yard, the fleet size would need to increase by six buses if transitioned under today's technology to meet service requirements under moderate estimations. Under conservative estimations, an additional 36 buses are necessary to meet service requirements (Table 4-4). It should be noted that the fleet replacement ratio is based on number of block failures and the percent service completion. For this reason, blocks that failed by only a short distance will require additional fleet vehicles (without service schedule modifications), which explains the steep fleet increase between moderate and conservative efficiencies. The vehicle replacement ratio for moderate and conservative efficiency estimations, without service changes or technology advancements, is 1 to 1.05 and 1 to 1.30 (conventional bus to BEB), respectively (Table 4-5). This report recommends strategic transition phasing to allow the technology to advance or optimized service adjustments to minimize increases to the replacement ratio.

Table 4-4. Flynn Yard Vehicles Required

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles | Net Increase from Existing |
|---|---|---|---|---|
| Optimistic | NA | 124 | 124 | 0 |
| Moderate | NA | 130 | 130 | 6 |
| Conservative | NA | 160 | 160 | 36 |

Source: WSP

Table 4-5. Flynn Yard Vehicle Replacement Ratio

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles |
|---|---|---|---|
| Optimistic | NA | 1:1 | 1:1 |
| Moderate | NA | 1:1.05 | 1:1.05 |
| Conservative | NA | 1:1.30 | 1:1.30 |

Source: WSP

# 4.3 POWER NEEDS

The following section presents current and future energy needs based on various charging ratios and resiliency strategies at Flynn Yard.

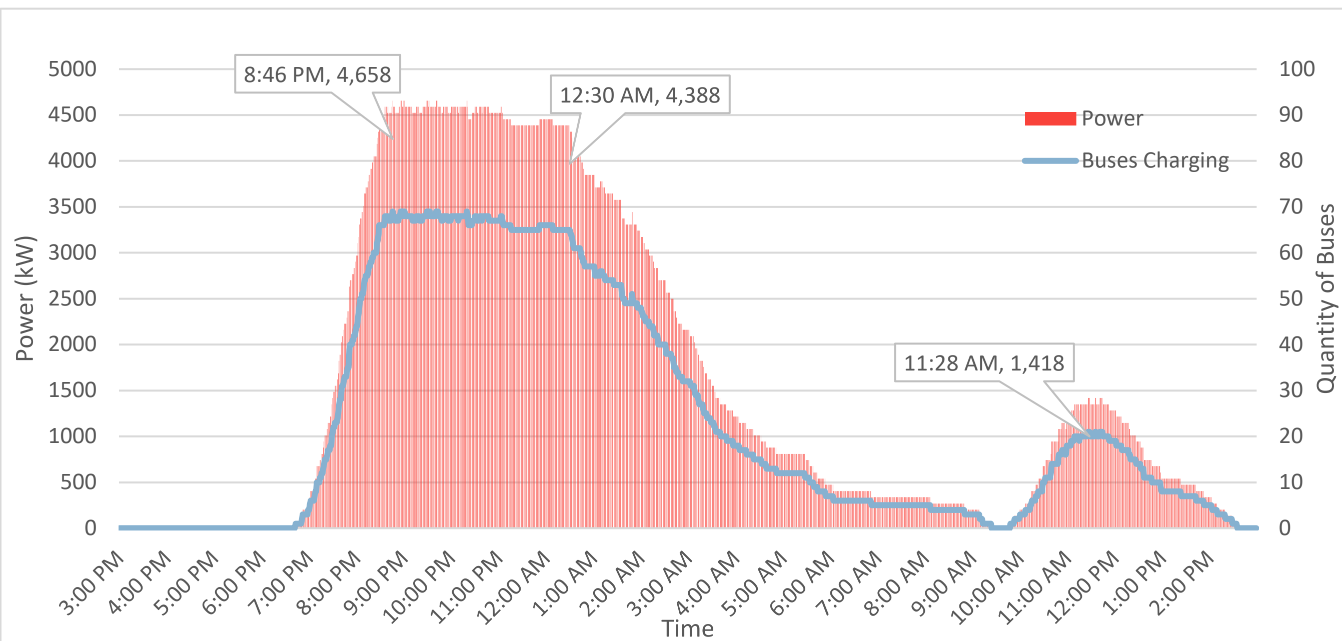
## 4.3.1 *CURRENT AND FUTURE SERVICE ENERGY NEEDS*

From the BEB service modeling, WSP was able to simulate the energy consumption for the current fleet parameters assuming that the chargers will split power to each bus to enable concurrent charging at an average rate 67.5 kW with a 1:2 charger to dispenser ratio. This takes into consideration battery buffer, efficiency, and pull-in servicing as previously defined in Section 2.1.

Figure 4-6 shows a large spike in demand as buses begin charging after returning to the yard at 7:00 PM and continue through 9:00 PM where the demand then plateaus through 12:30 AM, with the peak demand occurring from 8:46 PM to 10:00 PM. From 12:30 AM the demand slowly declines until 9:15 AM where there is a break in charging before buses start to return to the yard. This creates a smaller demand curve from 10:00 AM until 2:30 PM.

The power shown in Figure 4-6 is used to determine the monthly and annual energy in kWh, as well as the average and peak demand in kW which are summarized in Table 4-6.

Figure 4-6. Flynn Yard – Energy Consumption




Source: Jacobs

Electrifying the current fleet of 119 BEBs at Flynn will consume 1,125,706 kWh a month and 13,508,476 kWh annually, with an average demand of 1,561 kW and a peak demand of 4,658 kW. This yard will be electrifying the current fleet size of 119 BEB's without an increase in 2040 projections.

The current energy needs at Flynn Yard can be supported by a new service from nearby 12 kV circuits based on the available capacity provided from PG&E. Referring to Table 4-7, there are three nearby circuits, Potrero PP (A) 1118, Mission (X) 1124 and Mission (X) 1125, that are viable options with available circuit capacity. Current and future service energy needs are provided in Table 4-6.

Table 4-6. Flynn Yard Energy Consumption

| | BEB Fleet Size | Average Demand (kW) | Peak Demand (kW) | Monthly Electric Consumption (kWh) | Annual Electric Consumption (kWh) |
|---|---|---|---|---|---|
| Current Fleet | 119 | 1,561 | 4,658 | 1,125,706 | 13,508,476 |
| Future Fleet | 119 | 1,561 | 4,658 | 1,125,706 | 13,508,476 |

Source: Jacobs

### 4.3.2 *RESILIENCY*

Flynn Yard has an existing 60 kW diesel generator on-site to serve as a backup for critical loads as part of their current resiliency strategy. The onsite 60 kW diesel generator is assumed to be reserved for the yard building and will not charge buses during an emergency.

Auxiliary battery storage can be implemented to reduce the effect of unexpected power outages on operations. PG&E reliability data from 2006 to 2015 show that there is an average of approximately one power outage every two years. On average, a power outage in the San Francisco service environment lasts 78 minutes before service is restored.

In 2040, it is estimated that 119 buses will be stored at Flynn Yard. For emergency response, Flynn Yard is expected to maintain enough auxiliary power to charge a minimum of 10% of the buses stored at the yard. This would require 12 buses to be available during an unexpected loss of power.

The recommendations for the Flynn Yard BEB design includes two 2,000 kWh (4,000 kWh total) of onsite battery storage to provide energy to charge buses during power outages. At an estimated discharge rate of C/4 (i.e. one-fourth of total battery capacity can be discharged per hour), approximately 1,000 kW will be available to charge buses during a continuous four-hour period. Assuming 60-foot buses (with a 480 kWh usable battery capacity) charged at 135 kW, this would provide enough energy to fully charge eight buses from 0% to 100%. Realistically, assuming that all buses are stored with 25% of their total capacity, those same auxiliary batteries would be able to charge 11 buses up to 100% (approximately 9.2% of the fleet stored at Flynn Yard).

To charge a fleet of 12 buses (from 25% to 100%) for emergency response, an additional 320 kWh of auxiliary battery storage would need to be installed on the premises. This would result in a total of 4,320 kWh that would be able to fully charge emergency response buses within a four-hour period.

## 4.4 COSTS

Cost information at Flynn Yard for the battery electric bus charging equipment, on-site electrical infrastructure, utility modifications, and facility upgrades have been developed based on the concepts contained in this report. The estimated costs are $15.2 million for BEB infrastructure and $9.1 million for yard enhancements, resulting in a total direct construction cost of $24.3 million. Construction markups are applied cumulatively to the direction construction cost to arrive at an estimated construction cost of $54.4 million. Project markups are then applied to the estimated construction cost to arrive at the estimated project capital cost of $84.3 million. Detailed cost estimates will be found in Task 3.

# 4.5 RECOMMENDATIONS

The following section provides recommendation for transitioning the fleet at Flynn Yard to 100% BEB.

## 4.5.1 *FLEET AND OPERATIONS*

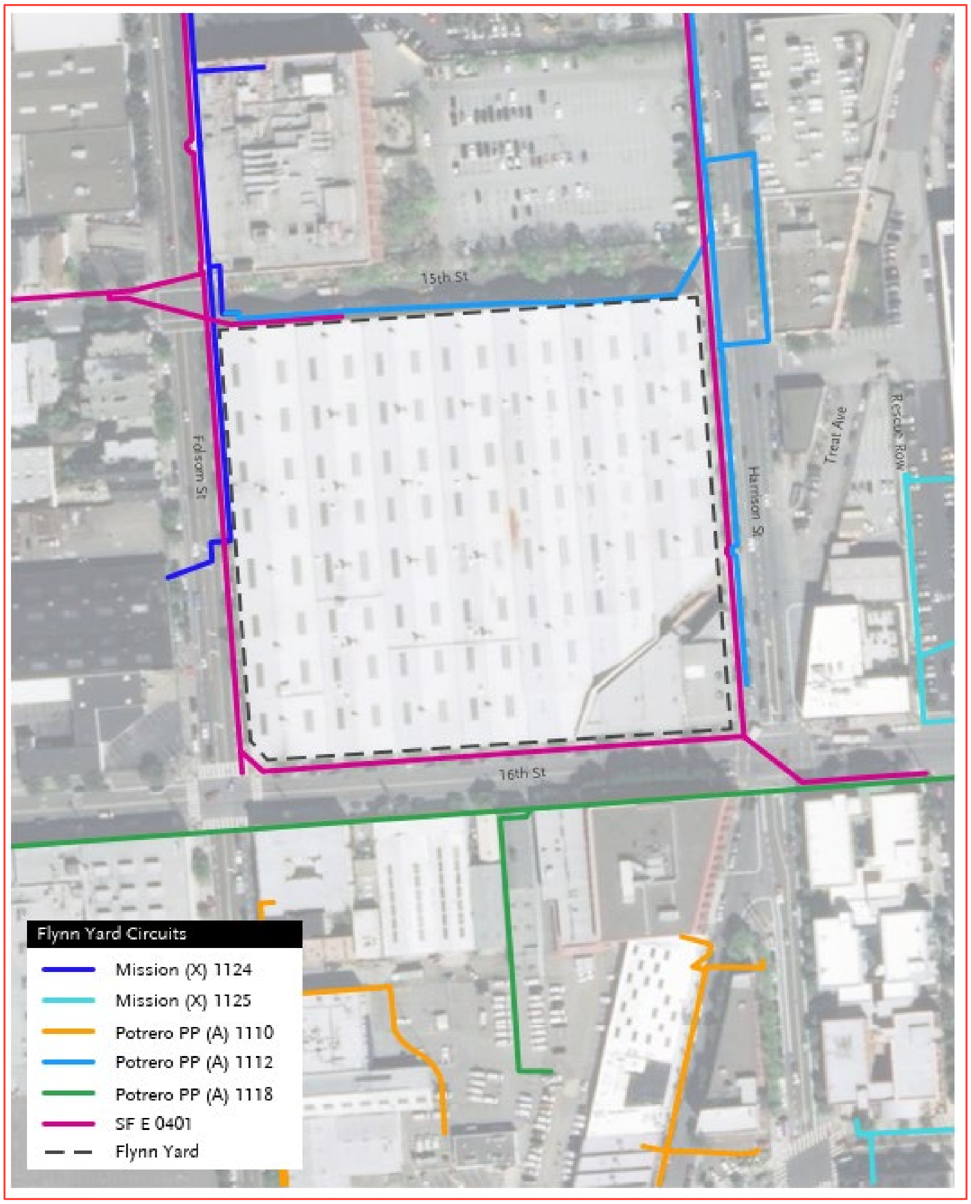
Based on results from the simulation model, the majority of the Flynn Yard fleet can be electrified with current technologies. This analysis recommends first transitioning the blocks with the lowest energy requirements and waiting until later in the transition period to transition the failed blocks.

## 4.5.2 *ELECTRICAL ENHANCEMENTS*

As previously mentioned, there is approximately 2.3 MW of available capacity on the Potrero 1112 Circuit that currently feeds the yard, which can support approximately half of the current demand when charging at a 1:2 charging ratio. Pending confirmation with SFPUC and PG&E, a new interconnection to feed the yard is recommended to support the future BEB fleet. According to PG&E's PVRAM tool for mapping electric distribution lines, substations, and transmission lines, there are three 12 kV and one 4.2 kV circuits in the vicinity of Flynn Yard.

The adjacent 12 kV circuits may be a factor in providing additional power to Flynn Yard, and based on PGE's available capacity, can support the current demand. For example, the nearby POTRERO PP (A) 1118 has an available circuit capacity of 6.2 MW. Mission (X) 1124 and Mission (X) 1125 both have an available capacity of 4.49 MW and 4.73 MW, respectively. All three circuits are viable options to support electrifying the fleet with a peak demand of 4.7 MW. For reference, Table 4-8 provides the peak demand and energy consumption for Flynn Yard and Figure 4-8 and Table 4-7 provide information on nearby circuits. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to select exactly which circuit will feed the yard.

Figure 4-7. Flynn Yard – Nearby Circuits




Source: PG&E

Table 4-7. Flynn Yard – Nearby Circuits Summary

| Circuit Name | Voltage | Circuit Capacity (MW) | Circuit Max Load (MW) | Substation Bank Capacity (MW) | Substation Bank Max Load (MW) | Available Circuit Capacity (MW) | Available Bank Capacity (MW) |
|---|---|---|---|---|---|---|---|
| POTRERO PP (A) 1112 | 12 kV | 9.52 | 7.23 | 74.3 | 46.68 | 2.29 | 27.62 |
| POTRERO PP (A) 1118 | 12 kV | 9.99 | 3.78 | 74.3 | 46.68 | 6.21 | 27.62 |
| MISSION (X) 1124 | 12 kV | 9.96 | 5.47 | N/A | N/A | 4.49 | N/A |
| MISSION (X) 1125 | 12 kV | 12.19 | 7.46 | N/A | N/A | 4.73 | N/A |
| POTRERO PP (A) 1110 | 12 kV | 9.99 | 6.31 | 74.3 | 46.68 | 3.68 | 27.62 |
| SF E 0401 | 4 kV | 2.35 | 1.78 | 9.88 | 5.42 | 0.57 | 4.46 |

Source: PG&E
Note: POTRERO PP (A) 1112 is Flynn Yard's existing circuit.

### 4.5.3 *FACILITIES*

The Flynn Yard will be capable of storing and charging 109 total BEBs. 107 buses can be charged with pantographs via an overhead supporting structure that spans the area of the existing parking tracks. An additional two buses can be charged in the maintenance bays via plug-in dispensers.

Table 4-8 summarizes the ZEB infrastructure planned at Flynn Yard.

Table 4-8. Flynn Yard ZEB Infrastructure Summary

| Primary Charging Strategy | Overhead Inverted Pantograph |
|---|---|
| No. of Existing Buses (September 2020) | 119 |
| No. of Charging Cabinets | 55 |
| No. of Dispensers/Charging Positions | 109 |

Source: WSP
Note: It is assumed that one charger will provide power for two charging positions/buses/dispensers (1:2 ratio)

The following BEB equipment and locations are proposed:

— 56 DC charging cabinets located on a platform attached to the overhead support structure. 55 of these charging cabinets will distribute to 107 pantograph-charging positions over the existing storage tracks and satellite spaces. An additional charging cabinet will power two dispensers installed in the maintenance bays.

— The support structure columns are to be placed every two to three tracks. These columns will also provide the support for the overhead mounted pantographs.

The charging cabinets will be served by the following electrical infrastructure:

— Two interrupter switches and a meter to be installed on the southern exterior of the building along 16th Street. The first interrupter will be owned and operated by PG&E, and the second interrupter and meter will be owned by SFPUC. Power will be distributed from the meter up along and through the building exterior to the medium-voltage switchgear.

— One medium-voltage switchgear and three medium- to low-voltage transformers with corresponding low-voltage switchgear will be installed on the proposed platforms.

— Each 3,325 kVA transformer can feed a maximum of 20 charging cabinets charging at 150 kW or 40 pantographs charging at 75 kW rate. This calculation is based on maximum AC input rating of 200A at 480V 3 phase, or 166 kVA, for each charging cabinet and is equal to dividing 3,325 kVA by 166 kVA value. See Table 4-9 for the number of charging cabinets connected to other transformers based on the assumption that two or more pantographs are fed by one charging cabinet. Exact transformer configurations should be re-evaluated once a specific EVSE vendor has been selected.

Table 4-9. Transformer Size Requirements

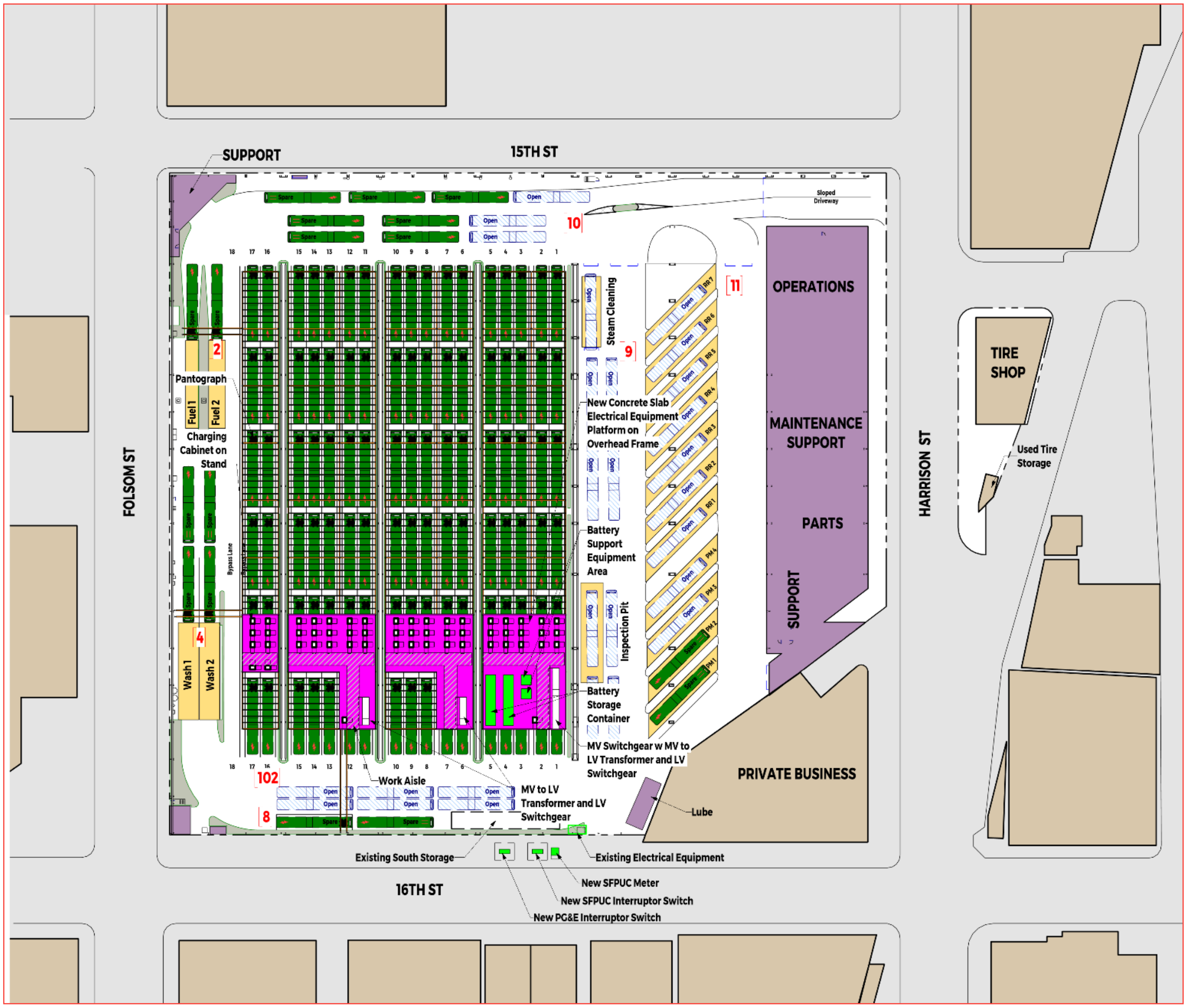
| Transformer Size | Charging Cabinets | Dispensers at 1:2 ratio (Concurrent Charging) |
|---|---|---|
| Transformer 1: 3,325 kVA | 20 | 40 |
| Transformer 2: 3,325 kVA | 20 | 40 |
| Transformer 3: 2,500 kVA | 15 | 24 |
| **Total** | **55** | **110** |

Source: WSP

While not all EVSE will be in use at once based on the facility modeling tool, the feeder can be sized for a load that is managed by an automatic load management system, but each 480V transformer must be sized assuming its full connected load can be handled.

Figure 4-8 illustrates the Flynn Yard at full build-out, in which green buses represent 60-foot BEBs.

Figure 4-8. Flynn Yard – Full ZEB Build-Out




Source: WSP

## 4.5.4 *FACILITIES STAGING*

As discussed, the specific staging for each yard is still being analyzed, with detailed staging and phasing to be included in Task 3. The following section provides an overview of the proposed improvements in Stage 1, along with a conceptual framework for subsequent stages. Figure 4-9 demonstrates a draft staging plan, illustrating which sections of the yard will be impacted by each stage.

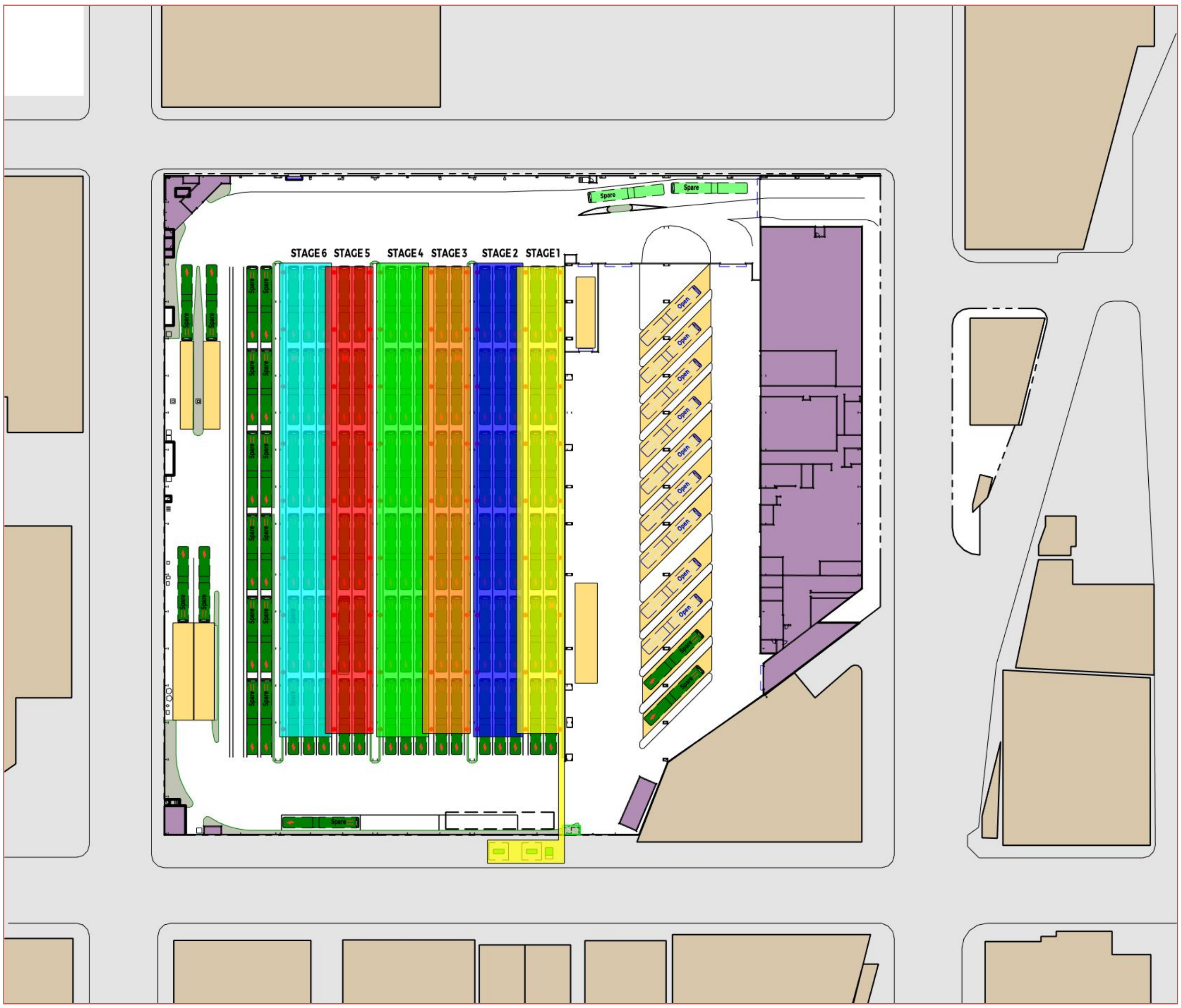
### STAGE 1

The recommended first stage for the Flynn Yard would include the installation of two new interrupter switches on the exterior of the facility along 16$^{th}$ Street, routing the utility-provided power into the facility to the site's new transformers. Conduit and routing from the utility should be sized to serve the yard's full fleet. Stage 1 will also include the construction of the overhead support structure with distribution conduit, transformers and switchgears, pantographs, and charging cabinets to serve the easternmost four tracks of bus parking.

## FUTURE STAGES

Each subsequent stage of deployment will be accomplished by adding a similar modular overhead support structure and the required charging infrastructure to support the number of buses to be charged in the stage. The breakdown of this staging will follow the SFMTA's growth plans and prioritization schedule.

Figure 4-9. Flynn Yard Staging Plan




Source: WSP

# 5 ISLAIS CREEK YARD

## 5.1 EXISTING CONDITIONS

This section summarizes Islais Creek Yard's current service parameters, location and facilities configuration, and existing electrical infrastructure.

### 5.1.1 *SERVICE DESCRIPTION AND REQUIREMENTS*

Islais Creek Yard operates 116 service blocks, 115 of which are served by 60-foot buses with one block served by 40-foot buses. This fleet travels a total of 9,304 miles during a typical weekday. The average weekday block distance is 77 miles and the longest distanced traveled is 189 miles. The number of stops for each block varies widely with an average of 316. The service blocks at this yard travel along an accumulative grade of 19% (Table 5-1).

Table 5-1. Existing Service Conditions at Islais Creek Yard

| Total Distance Traveled (mi.) | Average Distance Traveled (mi.) | Max Distance Traveled (mi.) | Average Number of Stops | Accumulative Slope |
|---|---|---|---|---|
| 8,894 | 77 | 189 | 316 | 19% |

Source: WSP

### 5.1.2 *LOCATION AND FACILITIES*

Islais Creek Yard is located at 1301 Cesar Chavez Street in the City of San Francisco.

Currently, 115 diesel-hybrid buses (10 30-foot and 105 60-foot) are stored, maintained, fueled, and serviced at Islais Creek Yard. The yard includes the following separate structures and major site areas: a two-story maintenance building, two-story transportation building, and a combined fuel, wash, and tire repair building. Interstate 280 (I-280) traverses the western side of the site with support columns located in the bus parking yard. Electrical utility service is provided by the SFPUC.

Islais Creek Yard is in an area expected to be affected by sea level rise flooding as early as 2030 (Appendix C: Risk Management Plan). This site currently experiences intermittent flooding due to major rain events and seasonal high tides, due to poor drainage surrounding the site. A majority of the BEB infrastructure will be installed overhead on an elevated platform, out of the usual flood zones. However, until capital improvements to mitigate flooding caused by poor drainage around the site beyond the control of this site are implemented, additional planning will be required to minimize the effect of flood waters to new BEB infrastructure that will be installed at grade.

In addition, portions of the site are not owned by the SFMTA. The site is bisected by the I-280 freeway. The west side of the freeway is leased to the SFMTA by Caltrans, and there are no-build provisions for the area underneath the freeway. Additional planning will need to be done to ensure that any permanent structures are not intruding in any no-build zones.

An aerial and existing site plan of Islais Creek Yard are presented in Figure 5-1 and Figure 5-2, respectively.

Figure 5-1. Islais Creek Yard – Existing Conditions (Aerial)

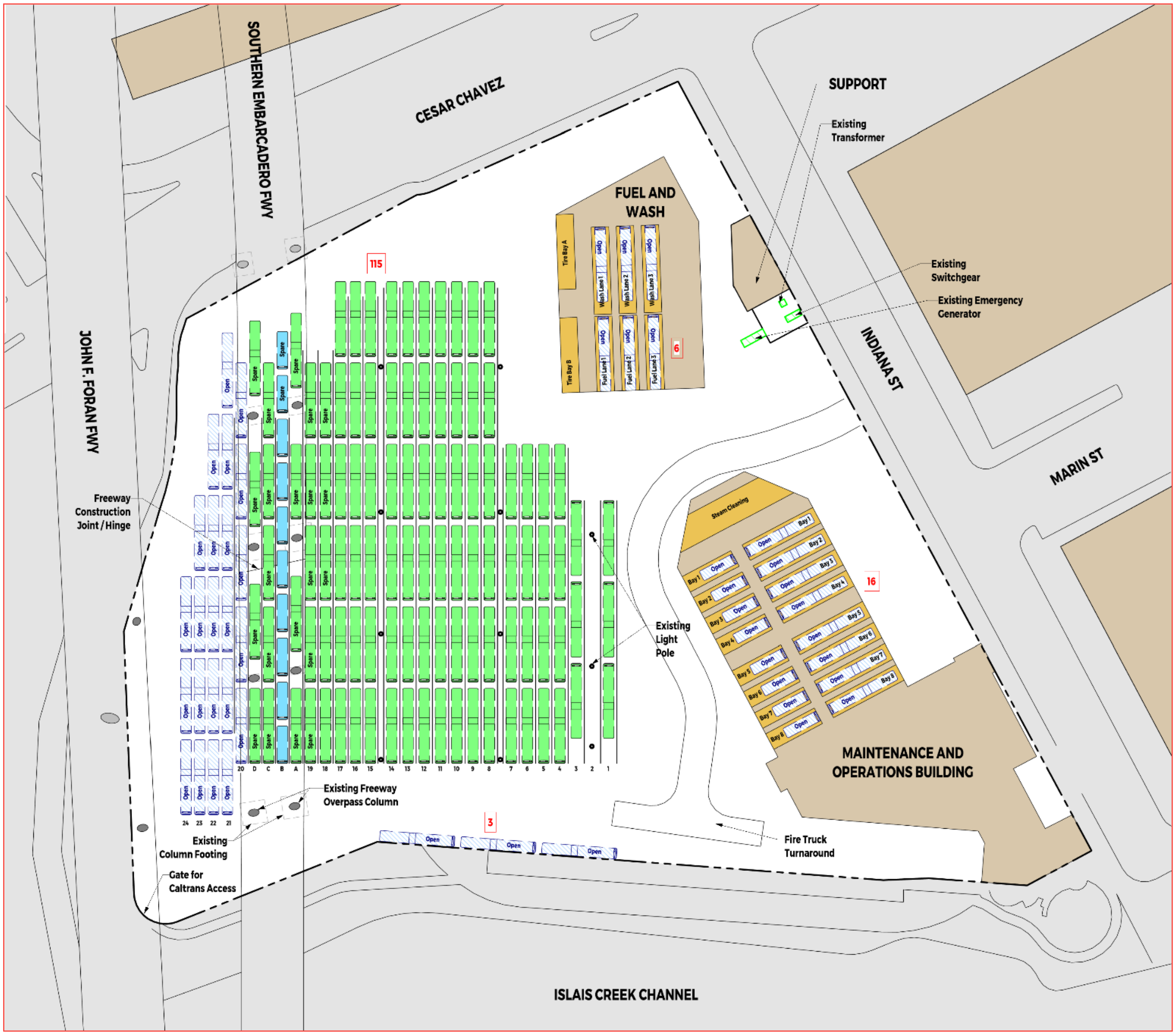

Source: Google Earth

## SITE CIRCULATION

Buses enter from Indiana Street and are parked in numbered spaces and stacked (nose-to-tail) in 11 or 13 foot-wide lanes (Track 1 is easternmost). Individual buses are then pulled from the storage area and taken by nightly service staff to the fuel lanes for fare retrieval, interior cleaning, and fueling before pulling forward to the bus wash lanes. After fuel and wash, buses are re-parked in the storage area. Buses remain parked until morning pull out unless a maintenance issue has been identified. NRVs are parked throughout the site on facility exteriors and the yard perimeter.

Figure 5-2 presents Islais Creek Yard's existing parking and facilities with I-280 crossing above the site. Green buses represent 60-foot buses, yellow buses represent 40-foot buses, and blue buses represent 30-foot buses.

Figure 5-2. Islais Creek Yard – Existing Site Plan




Source: WSP

### 5.1.3 *ELECTRICAL INFRASTRUCTURE*

The following section provides information on the existing substation, circuit, and transformer that support Islais Creek Yard's electrical needs.

#### SUBSTATION

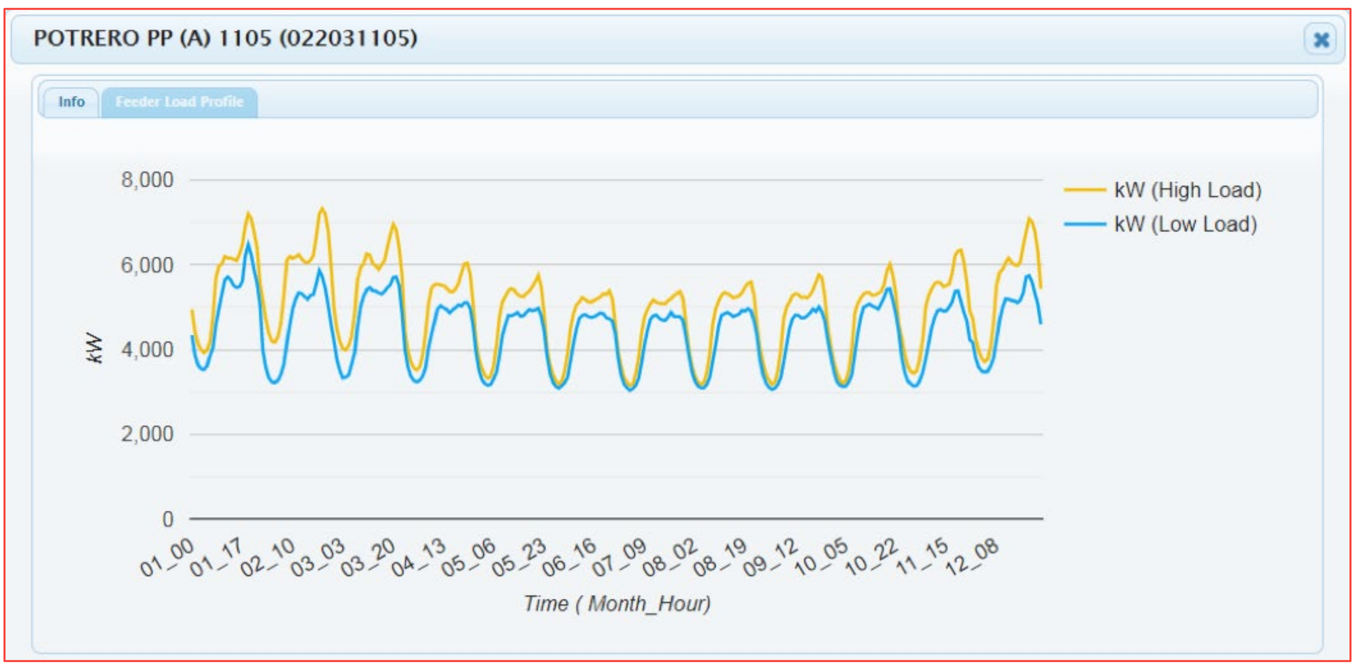
Islais Creek Yard's power is provided by the Potrero Substation that is located along Illinois Street between 23rd Street and 24th Street, approximately 0.5 miles from the yard. The Potrero Substation serves multiple SFMTA sites, including Flynn, Potrero and Woods yards. The Potrero Substation has a distribution capacity of 74 MW. The POTRERO PP (A) 1105 Circuit (Potrero 1105 Circuit) feeds Islais Creek Yard.

#### CIRCUIT

The Potrero 1105 Circuit is a 12 kV circuit that is fed from the Potrero Substation A. The Potrero 1105 circuit has an existing capacity of 9.99 MW. PG&E estimates that the projected peak load of this circuit is 5.14 MW, leaving approximately 4.85 MW of available capacity. The circuit enters the yard from the Indiana Street side of the property which enters the Annex Building.

Peak loads for the Potrero 1105 Circuit are monitored by PG&E and published on their ICA Map. The load increases in winter months and has peaks at 9:00 AM and 8:00 PM. Usage is at its minimum between 2:00 AM and 6:00 AM. The metrics for this circuit are shown in Figure 5-3 and Table 5-2.

Figure 5-3. Islais Creek Yard - Potrero 1105's Load Profile




Source: PG&E

Table 5-2. Islais Creek Yard – Potrero 1105's Load Information

| Description | Data |
|---|---|
| Feeder Name | POTRERO PP (A) 1105 |
| Feeder Number | 022031105 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 9.99 |
| Circuit Projected Peak Load (MW) | 5.14 |
| Substation Bank | 1 |
| Substation Bank Capacity (MW) | 74.3 |
| Substation Bank Peak Load (MW) | 46.68 |
| Existing Distributed Generation (MW) | 0.43 |
| Queued Distributed Generation (MW) | 0 |
| Total Distributed Generation (MW) | 0.43 |
| Total Customers | 203 |
| Residential Customers | 1 |
| Commercial Customers | 136 |
| Industrial Customers | 57 |
| Agricultural Customers | 0 |
| Other Customers | 9 |

Source: PG&E

### TRANSFORMER

Islais Creek Yard's transformer is located in the electric yard of the Annex Building.

## 5.2 MODELING RESULTS

The following section presents the blocks completed, fleet requirements, and service phasing strategies emerging from the simulation model for the service blocks operating out of Islais Creek Yard.

### 5.2.1 *BLOCK COMPLETION*

Between 75% and 98% of all the blocks operating out of Islais Creek Yard (operated by 40-foot and 60-foot buses) can complete current service requirements with current BEB technology based on the three degrees of efficiency described in Section 2.1. Under conservative efficiency estimations, 42 blocks exceed the energy requirements that can be provided by current BEB technologies. Under the moderate scenario, 29 blocks failed. Only two blocks failed under the optimistic scenario (Table 5-3).

Figure 5-4 illustrates the percent of block distances that can be completed with current BEB technologies for the fleet operating out of Islais Creek Yard. This figure demonstrates the degree to which the technology fell short of service requirements, for example, a BEB may have completed 99% of the block and still technically fail. Under the most optimistic scenario, the full fleet at Islais Creek Yard can only complete 90% of the service requirements in a typical weekday. Under moderate efficiency estimations, the full fleet could only achieve approximately 50% of the service distance required. This low performance is likely the result of the lower vehicle range provided by 60-foot buses. This indicates that the transition phasing for 20% to 30% of the Islais Creek Fleet may need to be delayed until later in the transition goal period as technology improves. Alternatively, modifications to service scheduling or on-route charging may be required.

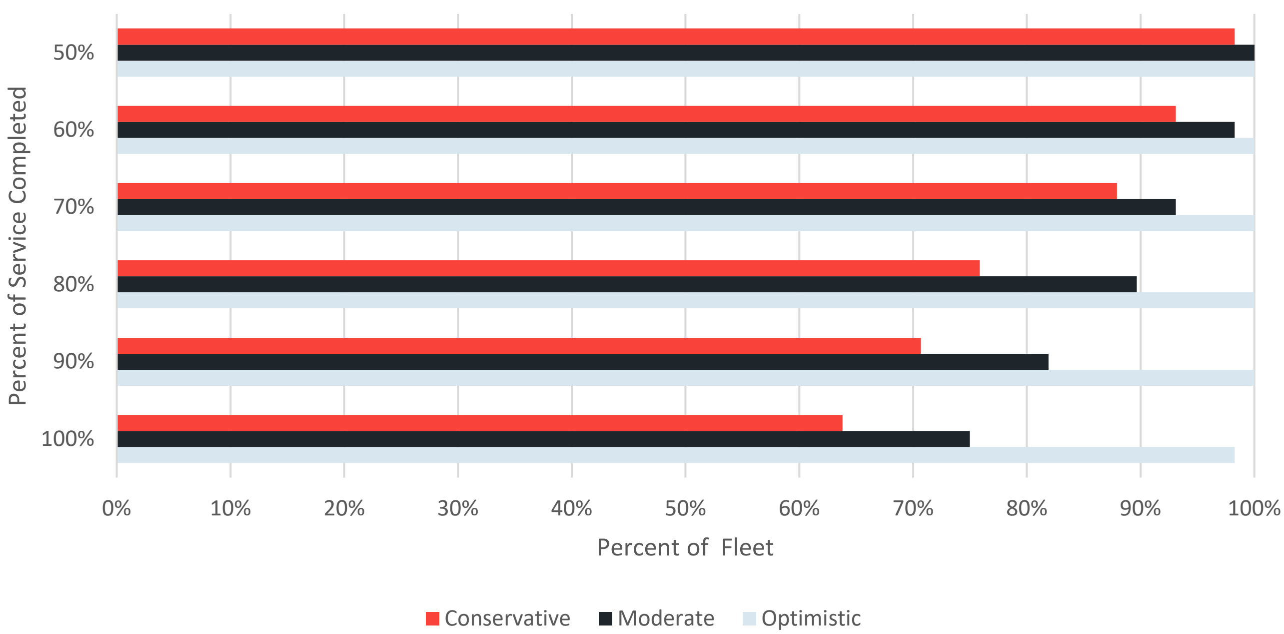
A comprehensive list of failed blocks and the percent block completion can be found in Appendix B: Failed Service Blocks.

Table 5-3. Summary of Failed Blocks at Islais Creek Yard

| Sensitivity | Blocks Failed | Percent Failed |
|---|---|---|
| Optimistic | 2 | 2% |
| Moderate | 29 | 25% |
| Conservative | 42 | 36% |

Source: WSP

Figure 5-4. Percent of Service Requirements Completed for the Islais Creek Yard Fleet

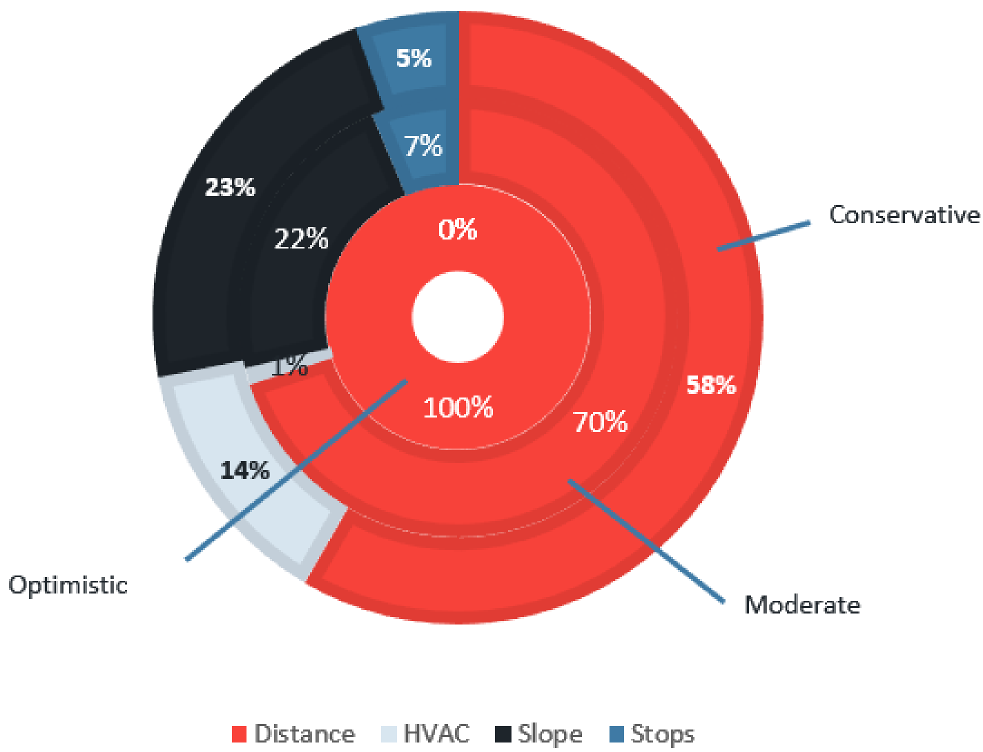



Source: WSP

## 5.2.2 *BLOCK ENERGY CONSUMPTION*

Figure 5-5 identifies the percent energy consumption from distance traveled, HVAC, number of stops, and slope for each sensitivity range. Slope in this service area has a considerable effect on BEB energy consumption, drawing 22% and 23% of the battery's available capacity for moderate and conservative efficiencies, respectively. The greatest shift in energy consumption distribution between sensitivity ranges is the impact of HVAC. Under the moderate sensitivity range (reflecting a fair-weather day), HVAC has only a 1% influence on energy consumption. When assuming the most extreme climate conditions in the San Francisco, however, HVAC may be expected to draw up to 14% of the battery's available energy. Though the region will rarely experience sustained temperatures at the annual high and low, this impact should be considered, especially in the event that climate change creates a notable effect on regional climate.

Figure 5-5. Percent of Energy Used by Consumption Factors at Islais Creek Yard




Source: WSP

## 5.2.3 *FLEET REQUIREMENTS*

Based on the energy required for each of the 116 service blocks operating out of Islais Creek Yard, the fleet size would need to increase by 29 to 44 buses to meet service requirements under moderate and conservative estimations, respectively (Table 5-4). The vehicle replacement ratio under moderate and conservative estimations (without service changes or technology advancements) is 1.26 to 1.38 BEBs to every one conventional bus (Table 5-5). This report recommends strategic transition phasing to allow the technology to advance or optimized service adjustments to minimize increases to the replacement ratio.

Table 5-4. Islais Creek Yard Vehicles Required

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles | Net Increase from Existing |
|---|---|---|---|---|
| Optimistic | 1 | 117 | 118 | 2 |
| Moderate | 1 | 144 | 145 | 29 |
| Conservative | 1 | 159 | 160 | 44 |

Source: WSP

Table 5-5. Islais Creek Yard Vehicle Replacement Ratio

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles |
|---|---|---|---|
| Optimistic | 1:1 | 1:1.02 | 1:02 |
| Moderate | 1:1 | 1:1.26 | 1:1.26 |
| Conservative | 1:1 | 1:1.39 | 1:38 |

Source: WSP

# 5.3 POWER NEEDS

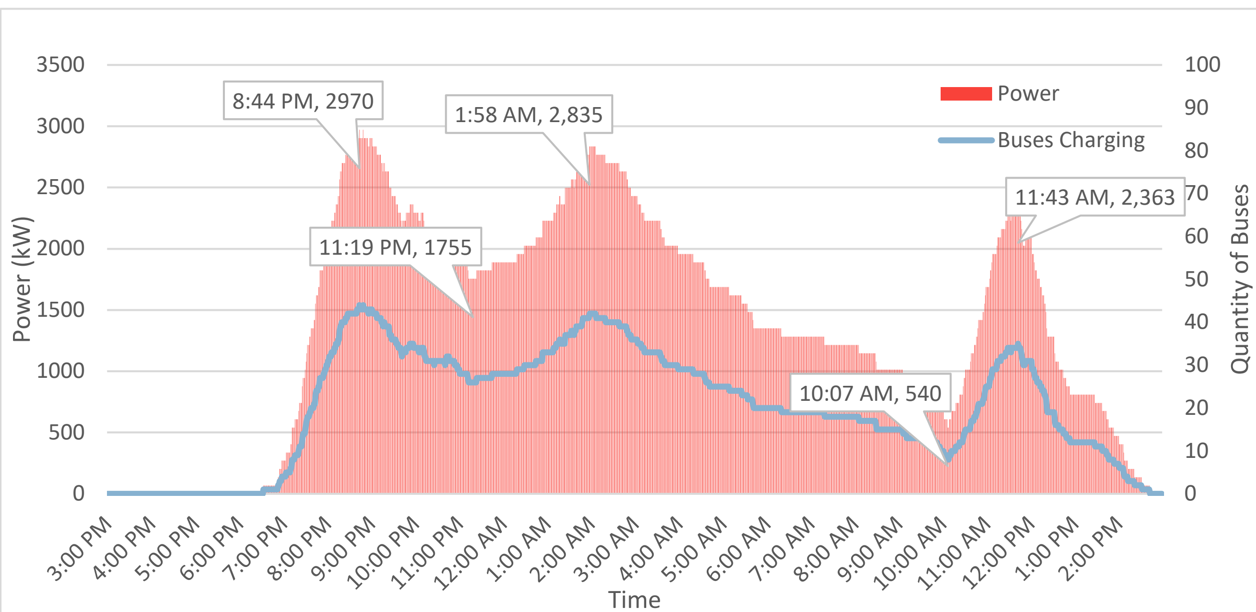
The following section presents current and future energy needs based on various charging ratios and resiliency strategies at Islais Creek Yard.

## 5.3.1 *CURRENT AND FUTURE SERVICE*

From the BEB service modeling, WSP was able to simulate the energy consumption for the current fleet parameters assuming that the chargers will split power to each bus to allow concurrent charging at an average rate 67.5 kW for a 1:2 ratio. This takes into consideration battery buffer, efficiency, and pull-in servicing, as previously defined in Section 2.1. Figure 5-6 shows an incline in demand as buses begin charging at 7:00 PM. The demand first peaks at 8:44 PM and drops slightly through 11:19 PM where it again increases to reach a lesser peak demand at 1:58 AM. Buses continue to charge throughout the morning period reaching the lowest point at 10:00 AM. The demand never reaches zero and begins to increase again when buses return after morning service. The smaller demand curve occurs from 10:00 AM and ends at 2:40 PM where there is a break in charging until buses return in the evening from daily service.

The power shown in Figure 5-6 is used to determine the monthly and annual energy in kWh, as well as the average and peak demand in kW which are summarized in Table 5-6.

Figure 5-6. Islais Creek Yard – Energy Consumption




Source: Jacobs

Electrifying the current fleet at Islais Creek Yard of 115 BEBs will consume 1,407,007 kWh a month and 16,884,087 kWh annually, with an average demand of 1,361 kW and a peak demand of 2,970 kW. This yard will be electrifying the current fleet size of 115 BEB's without an increase in 2040 projections.

The current energy needs at Islais Creek can be supported by a new service from nearby 12 kV circuits based on the available capacity provided from PG&E. Referring to Table 5-7, the two nearby circuits, Potrero 1105 and Potrero 1103 are viable options with available circuit capacity. Current and future service energy needs are provided in Table 5-6.

Table 5-6. Islais Creek Yard Energy Consumption

| Islais Creek Yard Energy Consumption | BEB Fleet Size | Average Demand (kW) | Peak Demand (kW) | Monthly Energy Consumption (kWh) | Annual Energy Consumption (kWh) |
|---|---|---|---|---|---|
| Current Fleet | 115 | 1,361 | 2,970 | 1,095,388 | 13,144,658 |
| Future Size | 115 | 1,361 | 2,970 | 1,095,388 | 13,144,658 |

Source: Jacobs

### 5.3.2 *RESILIENCY*

Islais Creek Yard currently has a 750 kW standby generator with a 1,600A breaker. There is also a photovoltaic system that provides power through the inverter distribution panel, which is rated 600A at 480V. It is assumed that this generator will only be used to power the building and will not charge buses during an emergency.

In 2040, it is estimated that 115 buses will be stored at Islais Creek Yard. For emergency response, Islais Creek Yard is expected to maintain enough auxiliary power to charge a minimum of 10% of the buses stored at the Yard. This would require 12 buses to be available during an unexpected loss of power.

The Islais Creek Yard design recommendations include two 2,000 kWh (4,000 kWh total) of onsite battery storage to provide energy to charge buses during power outages. At an estimated discharge rate of C/4 (i.e. one-fourth of total battery capacity can be discharged per hour), approximately 1,000 kW of battery power will be available for a continuous four-hour period. Assuming 30-foot and 60-foot buses (with a 172 kWh and 458 kWh usable battery capacity) are charged at 135 kW, this would provide enough energy to fully charge eight buses from 0% to 100%. Realistically, assuming that all buses are stored with 25% of their total capacity, the reserve systems would be able to charge 11 buses up to 100% (approximately 9.5% of the fleet stored at Islais Creek Yard).

To charge a fleet of 12 buses (from 25% to 100%) for emergency response, an additional 89 kWh of auxiliary battery storage would need to be installed on the premises. This would result in a total of 4,089 kWh that would be able to fully charge emergency response buses within a four-hour period.

Islais Creek Yard is expected to use 629 kW solar panels to charge the onsite battery storage. It is estimated that the solar panels will generate an average of 2,600 kWh on a daily basis.

Islais Creek Yard is located in San Francisco's city sea level rise vulnerability zone, which may require the installation of these backup power systems to be placed on an elevated platform. This would reduce the operational risk during periods of flooding and/or rise of sea level during the useful life of the battery systems.

## 5.4 COSTS

Cost information at Islais Creek Yard for the battery electric bus charging equipment, on-site electrical infrastructure, utility modifications, and facility upgrades have been developed based on the concepts contained in this report. The estimated costs are $23.3 million for BEB infrastructure and $8.2 million for yard enhancements, resulting in a total direct construction cost of $31.4 million. Construction markups are applied cumulatively to the direction construction cost to arrive at an estimated construction cost of $65.5 million. Project markups are then applied to the estimated construction cost to arrive at the Estimated Project Capital Cost of $101.5 million. Detailed cost estimates will be found in Task 3.

## 5.5 RECOMMENDATIONS

The following section provides recommendation for transitioning the fleet at Islais Creek Yard to 100% BEB.

### 5.5.1 *FLEET AND OPERATIONS*

All of the service block failures out of the Islais Creek Yard fleet are operated by 60-foot buses, which are currently offered by few manufacturers and do not perform as well as 40-foot buses. Significant advancement in 60-foot BEB capabilities are expected in the near future, however, the transition of 20% to 30% of the Islais Creek Yard fleet may need to be delayed until later in the transition goal period as the technology improves. To meet service needs, the SFMTA may also consider modifications to service scheduling or on-route charging.

### 5.5.2 *ELECTRICAL ENHANCEMENTS*

As previously mentioned, there is approximately 4.85 MW of available capacity on the Potrero 1105 circuit that currently feeds the yard which can support the BEB peak demand of 2.97 MW.

Additionally, the nearby 12 kV POTRERO PP (AA) 1103 circuit has a capacity of 8.4 MW with a peak load of 4.5 MW, leaving approximately 3.9 MW of additional capacity. The nearby circuit may be a factor in providing additional power to Islais Creek Yard. Pending confirmation with SFPUC and PG&E, a new interconnection to feed the yard is recommended to support the BEB fleet. For reference Table 5-6 provides the peak demand and energy consumption for Islais Creek Yard and Figure 5-7 and Table 5-7 provide information on nearby circuits. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to select exactly which circuit will feed the yard.

Figure 5-7. Islais Creek Yard – Nearby Circuits


Source: PG&E

Table 5-7. Islais Creek Yard – Nearby Circuits Summary

| Circuit Name | Voltage | Circuit Capacity (MW) | Circuit Max Load (MW) | Substation Bank Capacity (MW) | Substation Bank Max Load (MW) | Available Circuit Capacity (MW) | Available Bank Capacity (MW) |
|---|---|---|---|---|---|---|---|
| POTRERO PP (A) 1105 | 12 kV | 9.99 | 5.14 | 74.3 | 46.68 | 4.85 | 27.62 |
| POTRERO PP (A) 1103 | 12 kV | 8.42 | 4.52 | 74.3 | 43.36 | 3.9 | 30.94 |

Source: PG&E
Note: POTRERO PP (A) 1105 is Islais Creek Yard's existing circuit. PG&E to verify.

### 5.5.3 *FACILITIES*

The Islais Creek Yard will be capable of storing 153 total BEBs, of which, 149 can be charged simultaneously. 145 buses can be charged with pantographs via an overhead supporting structure that spans the area of the existing parking tracks. An additional four buses can be charged in the maintenance bays via plug-in dispensers.

Table 5-8 summarizes the ZEB infrastructure planned at Islais Creek Yard.

Table 5-8. Islais Creek Yard ZEB Infrastructure Summary

| Primary Charging Strategy | Overhead Inverted Pantograph |
|---|---|
| No. of Existing Buses (September 2020) | 115 |
| No. of Charging Cabinets | 75 |
| No. of Dispensers/Charging Positions | 149 |

Source: WSP
Note: It is assumed that one charger will provide power for two charging positions/buses/dispensers (1:2 ratio)

The following BEB equipment and locations are proposed:

— 73 DC charging cabinets located on a platform attached to the overhead support structure spanning a portion of the bus storage tracks and terminating at the edge of the overhead I-280 offset limits. These charging cabinets will distribute to 145 pantograph-charging positions over the existing main storage tracks with a gap in charging positions under I-280 for storing spare buses. The charging positions begin again in the parking area west of I-280's offset limits.

— The overhead support structure columns are to be placed every three to four tracks. These columns will also provide the support for the overhead mounted pantographs.

— Two charging cabinets and four dispensers located in the maintenance building (with four dispensers) will charge the eight remaining spare buses that cannot be charged in the main parking area.

The pantographs and charging cabinets will be served by the following electrical infrastructure:

— Two interrupter switch pairs and two meters will be installed in the existing electrical yard. The first interrupter in each pair will be owned and operated by PG&E, and the second interrupter in each pair and both meters will be owned by SFPUC. Power will be distributed from the meter up along the fuel and wash building before crossing to the platform to the medium-voltage switchgear.

— One medium-voltage switchgears and two medium- to low-voltage transformers with corresponding low-voltage switchgear will be installed on the platform, above the bus parking area. The switchgear and transformers will be rated for exterior use.

— Each 3,325 kVA transformer can feed a maximum of 20 charging cabinets charging at 150 kW or 40 pantographs charging at 75 kW rate. This calculation is based on maximum AC input rating of 200A at 480V 3 phase, or 166 kVA, for each charging cabinet and is equal to dividing 3,325 kVA by 166 KVA value. See Table 5-9 for the number of charging cabinets connected to other transformer based on the assumption that two or more pantographs are fed by one charging cabinet.

Table 5-9. Transformer Size Requirements

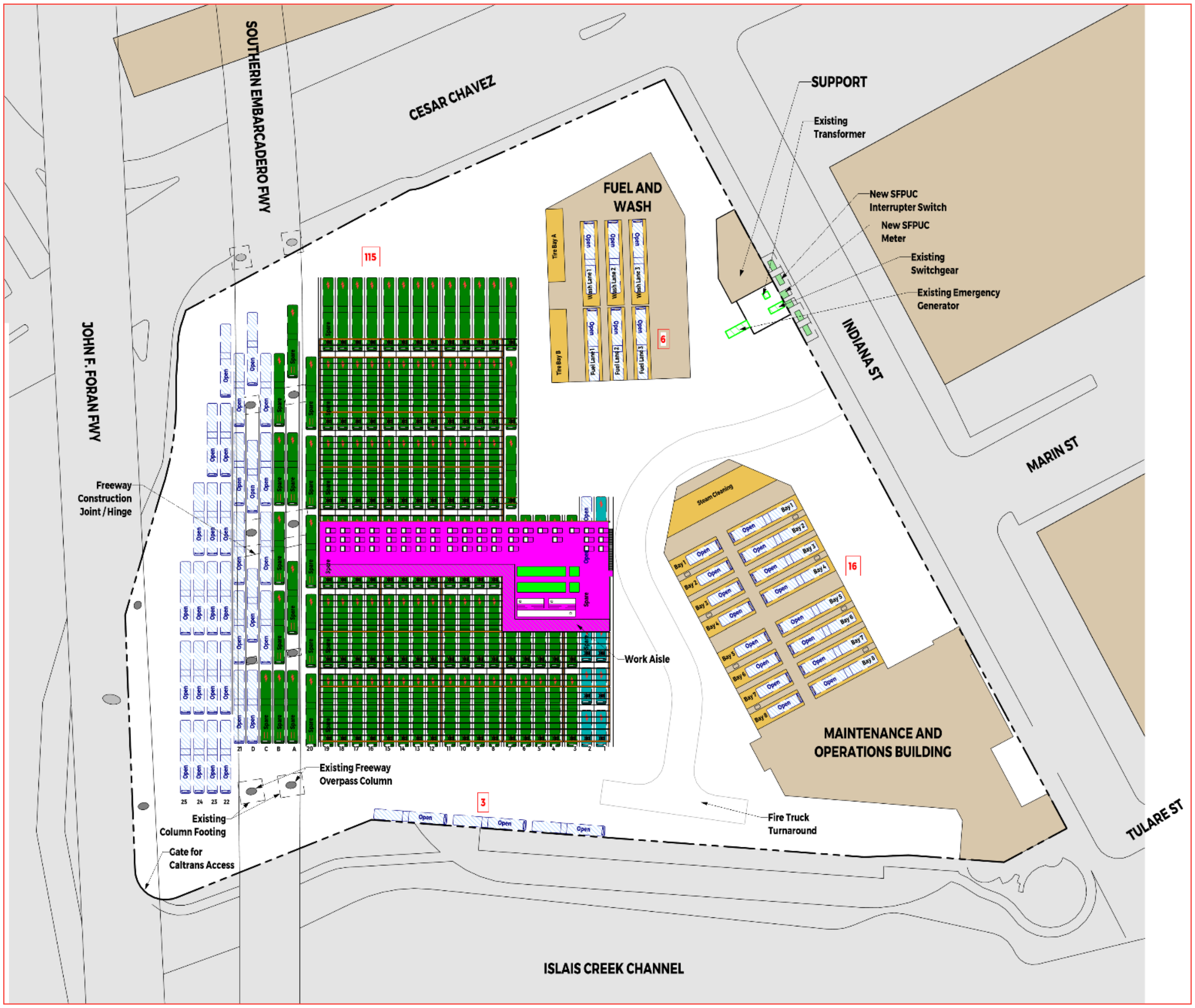
| Transformer Size | Charging Cabinets | Dispensers at 1:2 ratio (Concurrent Charging) |
|---|---|---|
| Transformer 1: 3,325 kVA | 20 | 40 |
| Transformer 2: 3,325 kVA | 20 | 40 |
| Transformer 3: 3,320 kVA | 20 | 20 |
| Transformer 4: 2,500 kVA | 15 | 30 |
| Total | 75 | 150 |

Source: WSP

While not all EVSE will be in use at once based on the facility modeling tool, the feeder can be sized for a load that is managed by an automatic load management system, but each 480V Transformer must be sized assuming its full connected load can be handled.

Figure 5-8 illustrates the Islais Creek yard at full build-out, in which green buses represent 60-foot BEBs, and yellow buses represent 40-foot BEBs.

Figure 5-8. Islais Creek Yard – Full ZEB Build-Out




Source: WSP

## 5.5.4 *FACILITIES STAGING*

As discussed, the specific staging for each yard is still being analyzed, with detailed staging and phasing to be included in Task 3. The following section provides an overview of the proposed improvements in Stage 1, along with a conceptual framework for subsequent stages. Figure 5-9 demonstrates a draft staging plan, illustrating which sections of the yard will be impacted by each stage.

### STAGE 1

The recommended first stage for the Islais Creek Yard involves the installation of the four interrupter switches and two meters in the existing electrical yard and the routing of utility-provided power into the facility to the site's new transformers. Conduit and routing from the utility should be sized to serve the yard's full fleet. Stage 1 will also include the construction of the overhead support structure with distribution conduit, transformers and switchgears, pantographs, and charging cabinets to serve the easternmost seven tracks of bus parking.

## FUTURE STAGES

Each subsequent stage of deployment will be accomplished by adding a similar modular overhead support structure and the required charging infrastructure to support the number of buses to be charged in the stage. The breakdown of this staging will follow the SFMTA's growth plans and prioritization schedule.

Figure 5-9. Islais Creek Yard Staging Plan


Source: WSP

# 6 KIRKLAND YARD

## 6.1 EXISTING CONDITIONS

This section summarizes Kirkland Yard's current service parameters, location and facilities configuration, and existing electrical infrastructure.

### 6.1.1 *SERVICE DESCRIPTION AND REQUIREMENTS*

Kirkland Yard operates 150 service blocks served by 40-foot buses. This fleet travels a total of 12,429 miles during a typical weekday. The average weekday block distance is 83 miles and the longest distanced traveled is 189 miles. The number of stops for each block varies with an average of 402. The service blocks at this yard travel along an accumulative grade of 27% (Table 6-1).

Table 6-1. Existing Service Conditions at Kirkland Yard

| Total Distance Traveled (mi.) | Average Block Distance (mi.) | Max Block Distance (mi.) | Average Number of Stops | Accumulative Slope |
|---|---|---|---|---|
| 12,429 | 83 | 189 | 402 | 27% |

Source: WSP

### 6.1.2 *LOCATION AND FACILITIES*

Kirkland Yard is located at 2301 Stockton Street and 151 Beach Street in the City of San Francisco.

Currently, 91 standard diesel-hybrid buses are stored, maintained, fueled, and serviced at Kirkland Yard. The yard includes the following separate structures and major site areas: a maintenance canopy, one-story maintenance support building, one-story transportation building, wash lane (centered in the yard), stand-alone fuel building, and fuel storage yard with support equipment. Electrical utility service is provided by the SFPUC.

The *Building Progress Program* originally envisioned a full rebuild of Kirkland Yard following completion of Presidio Yard. However, due to the operational necessity of Woods Yard and the high capital cost of converting to BEB at Woods, the SFMTA is now prioritizing the rebuild of Woods Yard in advance of Kirkland Yard. This means that Kirkland would be upgraded to BEB in its existing configuration as an interim improvement before the planned buildout of the site near 2027.

During the development of Task 2, SFMTA has identified interim improvements to the Kirkland site which are will be introduced prior to the full redevelopment to alleviate existing operation issues at the site. These interim improvements are still in development and expected to include the following:

— Repaving the site.

— Demolishing the existing wash lane and installing a new wash lane in a different location on the site.

— Demolishing the existing operations building and utilizing a temporary building to house operation on the site.

— Installing charging infrastructure, likely in a ground-mounted deployment, to achieve the maximum number of charging positions to serve SFMTA's upcoming BEB procurement.

Note that these improvements will be further defined and documented in the BEB Implementation Facility Master Plan (Task 3) report and schedule.

An aerial and existing site plan of Kirkland Yard are presented in Figure 6-1 and Figure 6-2, respectively.

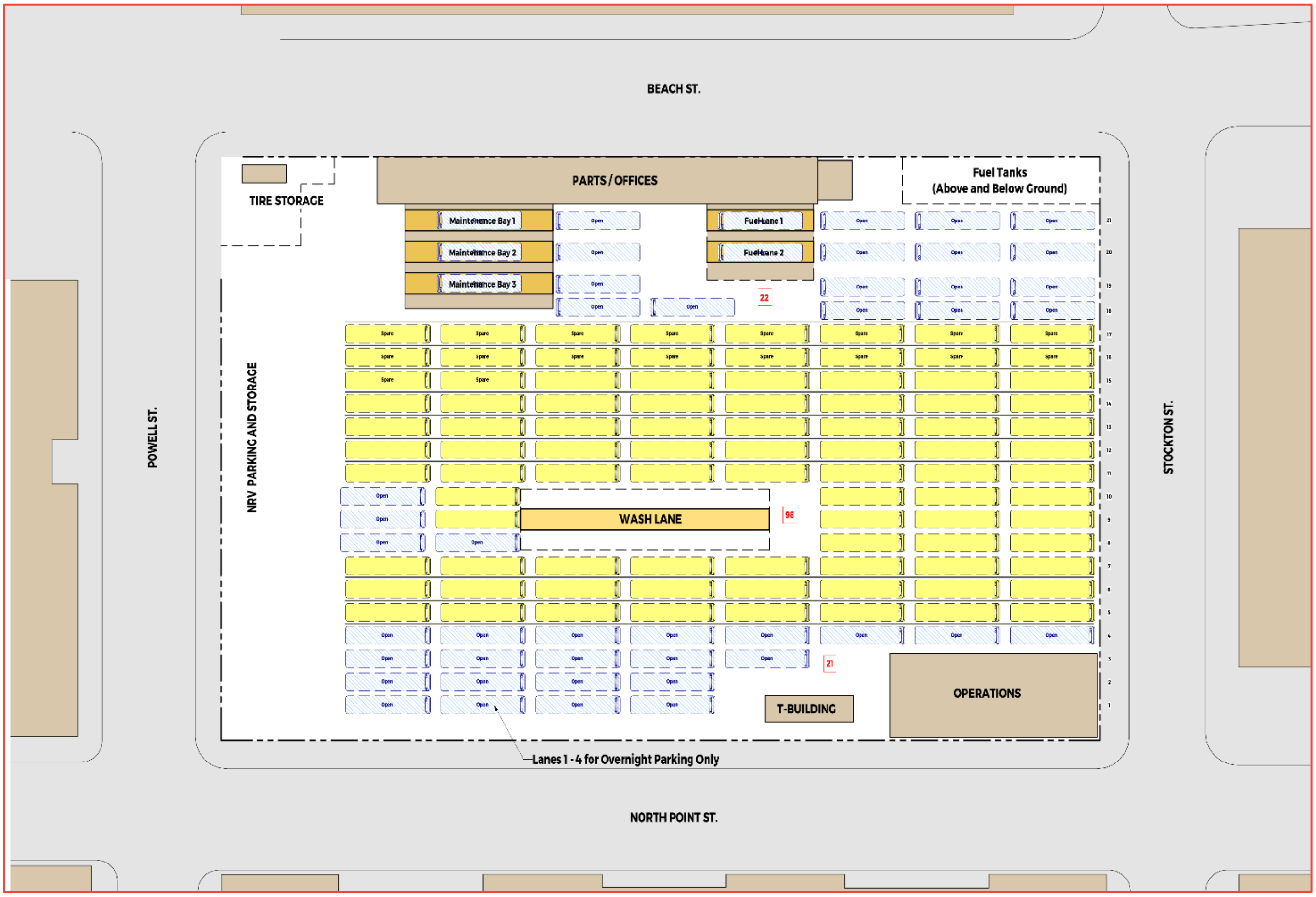
Figure 6-1. Kirkland Yard – Existing Conditions (Aerial)


Source: Google Earth

## SITE CIRCULATION

Buses enter from Stockton Street and are parked in unassigned, stacked (nose-to-tail) 11-foot wide lanes, consisting of two lanes east of the fuel canopy. Individual buses are then pulled from the lanes and taken by nightly service staff to the fuel lanes for fare retrieval, interior cleaning, and fueling before pulling forward to the bush wash lane, Track 9, if being washed (not all buses are washed due to site restrictions). After fuel and wash, buses are re-parked in the lanes. Buses remain parked until morning pull out unless a maintenance issue has been identified. NRVs are parked in a row of spaces along the northern site perimeter, where possible.

Figure 6-2. Kirkland Yard – Existing Site Plan




Source: WSP

## 6.1.3 *ELECTRICAL INFRASTRUCTURE*

The following section provides information on the existing substation and circuit that support Kirkland Yard's electrical needs.

### SUBSTATION

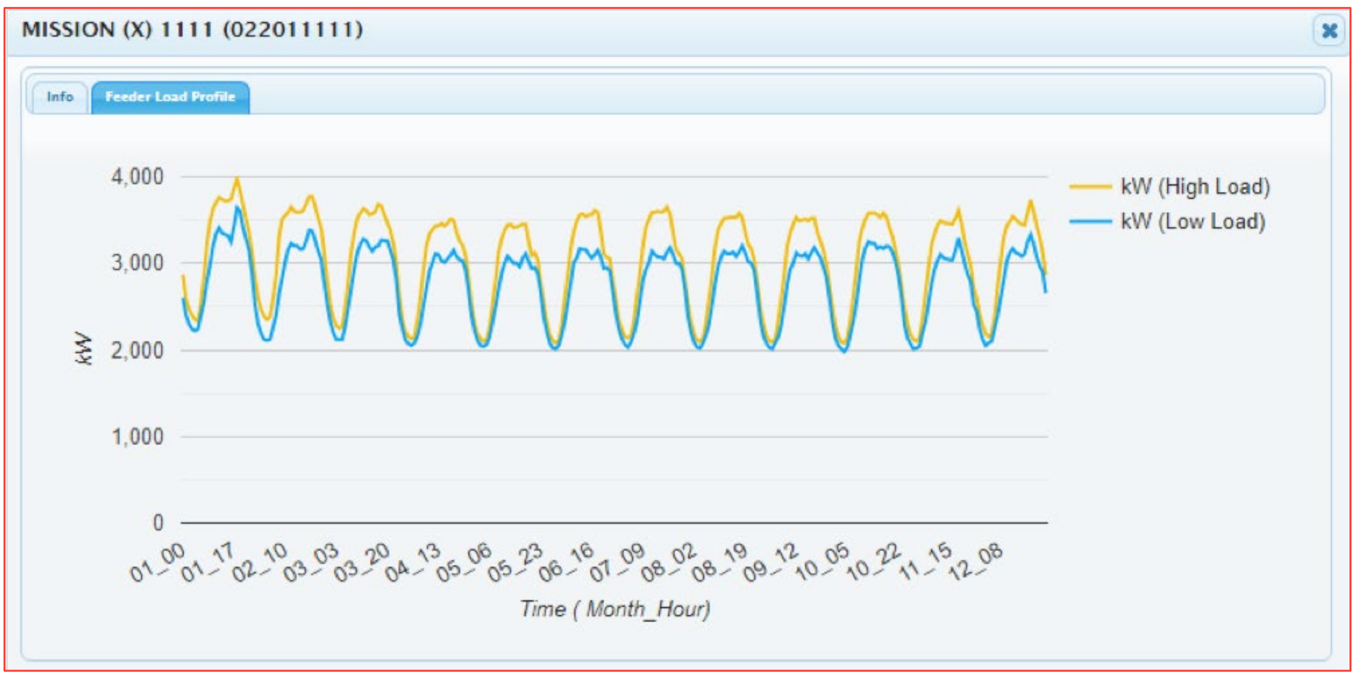
Kirkland Yard's power is the only SFMTA site served by the Mission Substation. The detailed data for this substation is not in PG&E's PVRAM or ICA systems, which increases the importance of working with PG&E in future phases of this project.

### CIRCUIT

The Mission 1111 Circuit is a 12 kV circuit that is fed from the Mission Substation. The Mission 1111 circuit has an existing capacity of 9.9 MW. PG&E estimates that the projected peak load of this circuit is 4.4 MW, leaving approximately 5.5 MW of available capacity. The circuit enters the yard (underground) on the north side of the property on Beach Street.

Peak loads for the Mission 1111 Circuit are monitored by PG&E and published on their ICA Map. The load increases in winter months and has peaks at 9:00 AM and 8:00 PM. Usage is at its minimum between 2:00 AM and 6:00 AM. The metrics for this circuit are shown in Figure 6-3 and Table 6-2.

Figure 6-3. Kirkland Yard - Mission 1111's Load Profile




Source: PG&E

Table 6-2. Kirkland Yard – Mission 1111's Load Information

| Description | Data |
|---|---|
| Feeder Name | MISSION (X) 1111 |
| Feeder Number | 022011111 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 9.94 |
| Circuit Projected Peak Load (MW) | 4.43 |
| Substation Bank | N/A |
| Substation Bank Capacity (MW) | N/A |
| Substation Bank Peak Load (MW) | N/A |
| Existing Distributed Generation (MW) | 0.06 |
| Queued Distributed Generation (MW) | 0 |
| Total Distributed Generation (MW) | 0.06 |
| Total Customers | 2364 |
| Residential Customers | 1958 |
| Commercial Customers | 319 |
| Industrial Customers | 81 |
| Agricultural Customers | 0 |
| Other Customers | 6 |

Source: PG&E

## 6.2 MODELING RESULTS

The following section presents the blocks completed, fleet requirements, and service phasing strategies emerging from the simulation model for the service blocks operating out of Kirkland Yard.

### 6.2.1 *BLOCK COMPLETION*

Between 78% and 100% of all the blocks operating out of Kirkland Yard (operated by 40-foot buses) can complete current service requirements with current BEB technology based on the three degrees of efficiency described in Section 2.1. Under conservative efficiency estimations, 33 blocks exceed the energy requirements that can be provided by current BEB technologies. Under the moderate scenario, 18 blocks failed. No blocks failed under the optimistic scenario (Table 6-3).

Figure 6-4 illustrates the percent of block distances that can be completed with current BEB technologies. This figure demonstrates the degree to which the technology fell short of service requirements, for example, a BEB may have completed 99% of the block and still technically fail. There is a minimal degree of technology shortfall at Kirkland Yard even under moderate and conservative efficiency estimations. Though 12% of the service blocks failed under moderate efficiency estimations, the majority of the fleet was able to complete at least 90% of the block distances. Under conservative estimation 81% of the fleet was able to complete 90% of the block distances. This indicates that 100% service block completion can likely be achieved with minor improvements to battery technology or minor adjustments in service planning (e.g. midday charging or reduced stops).

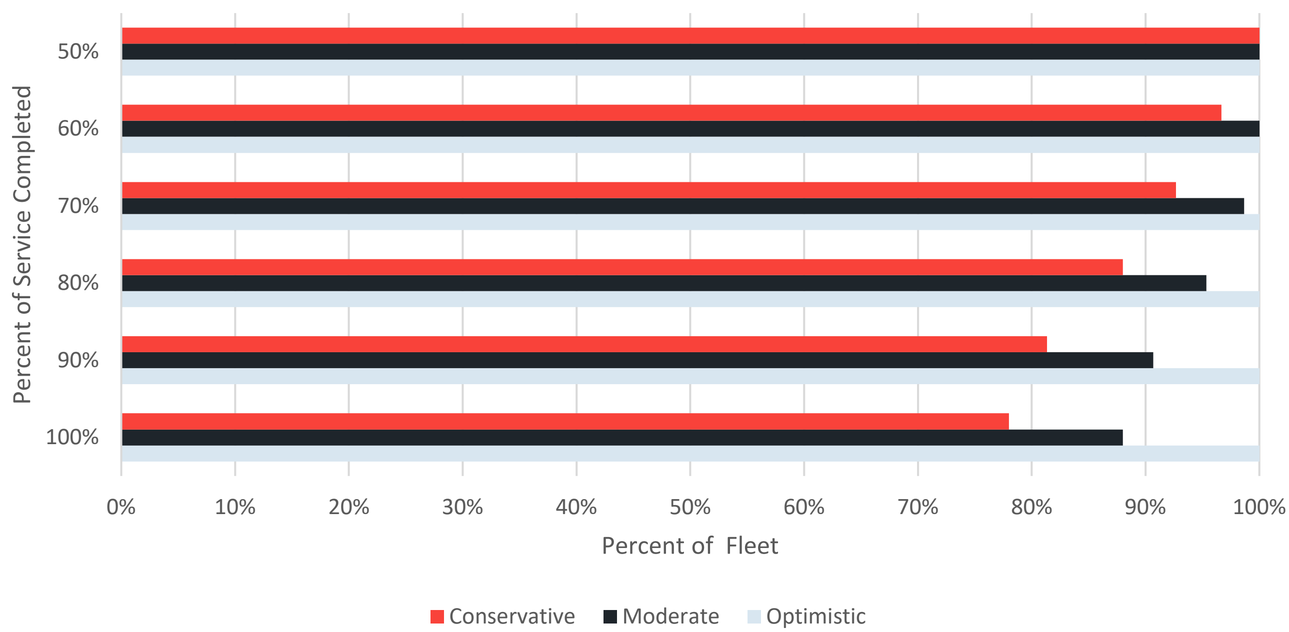
A comprehensive list of failed blocks and the percent block completion can be found in Appendix B: Failed Service Blocks.

Table 6-3. Summary of Failed Blocks at Kirkland Yard

| Sensitivity | Blocks Failed | Percent Failed |
|---|---|---|
| Optimistic | 0 | 0% |
| Moderate | 18 | 12% |
| Conservative | 33 | 22% |

Source: WSP

Figure 6-4. Percent of Service Requirements Completed for the Kirkland Yard Fleet

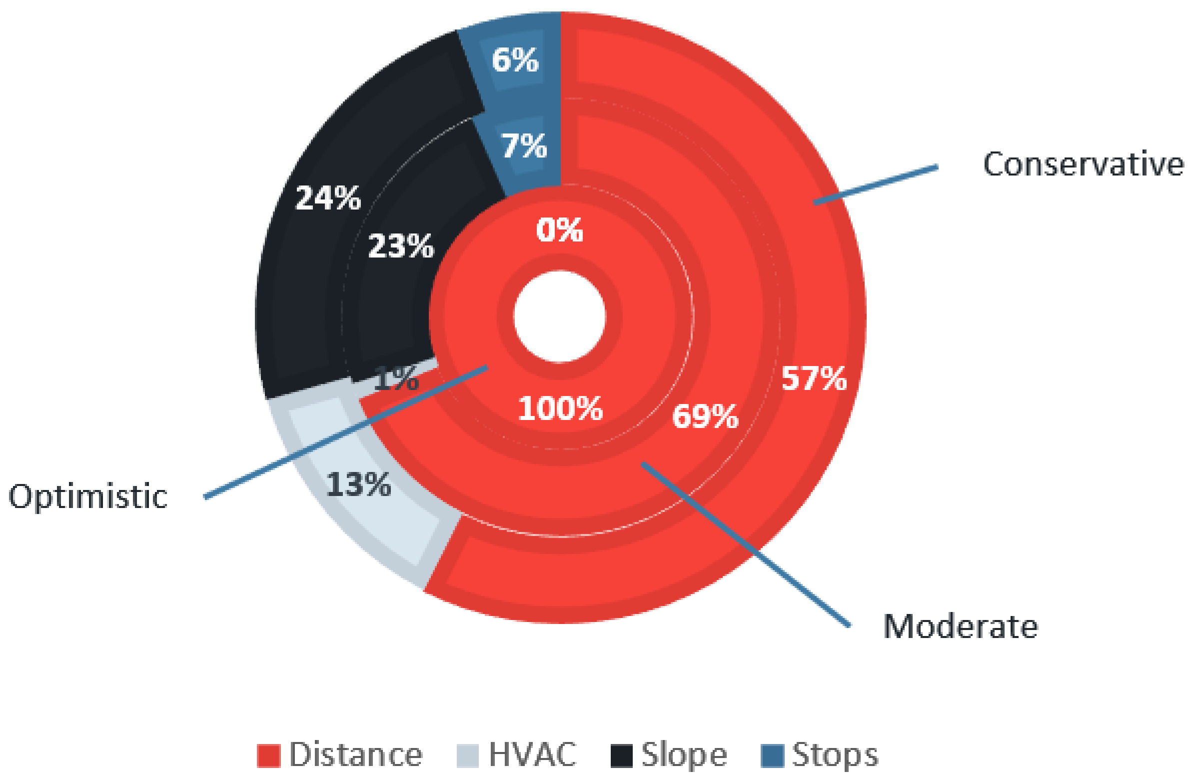



Source: WSP

## 6.2.2 *BLOCK ENERGY CONSUMPTION*

Figure 6-5 identifies the percent energy used from various metrics: distance traveled, HVAC, number of stops, and slope for each sensitivity range. Slope in this service area has a considerable effect on BEB energy consumption, drawing 26% and 24% of the battery's available capacity for moderate and conservative efficiencies, respectively. The greatest shift in energy consumption distribution between sensitivity ranges is the impact of HVAC. Under the moderate sensitivity range, HVAC has only a 1% influence on energy consumption, reflecting a fair-weather day. When assuming the most extreme climate conditions in the San Francisco, however, HVAC may be expected to draw up to 13% of the battery's available energy. Though the region will rarely experience sustained temperatures at the annual high and low, this impact should be considered, especially in the event that climate change creates a notable effect on regional climate.

Figure 6-5. Percent of Energy Used by Consumption Factors at Kirkland Yard




Source: WSP

### 6.2.3 *FLEET REQUIREMENTS*

Based on the energy required for each of the 150 service blocks operating out of Kirkland Yard, the fleet size would need to increase by 18 to 33 buses to meet service requirements under moderate and conservative estimations respectively (Table 6-4). The vehicle replacement ratio is 1 to 1.12 (conventional bus to BEB) under moderate estimations and 1 to 1.22 under conservative estimations (Table 6-5). This report recommends strategic transition phasing to allow the technology to advance or optimized service adjustments to minimize increases to the replacement ratio.

Table 6-4. Kirkland Yard Vehicles Required

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles | Net Increase from Existing |
|---|---|---|---|---|
| Optimistic | 150 | NA | 150 | 0 |
| Moderate | 168 | NA | 168 | 18 |
| Conservative | 183 | NA | 183 | 33 |

Source: WSP

Table 6-5. Kirkland Yard Vehicle Replacement Ratio

| Sensitivity | 40' Vehicles | 60' Vehicles | All Vehicles |
|---|---|---|---|
| Optimistic | 1:1 | NA | 1:1 |
| Moderate | 1:1.12 | NA | 1:1.12 |
| Conservative | 1:1.22 | NA | 1:1.22 |

Source: WSP

## 6.3 POWER NEEDS

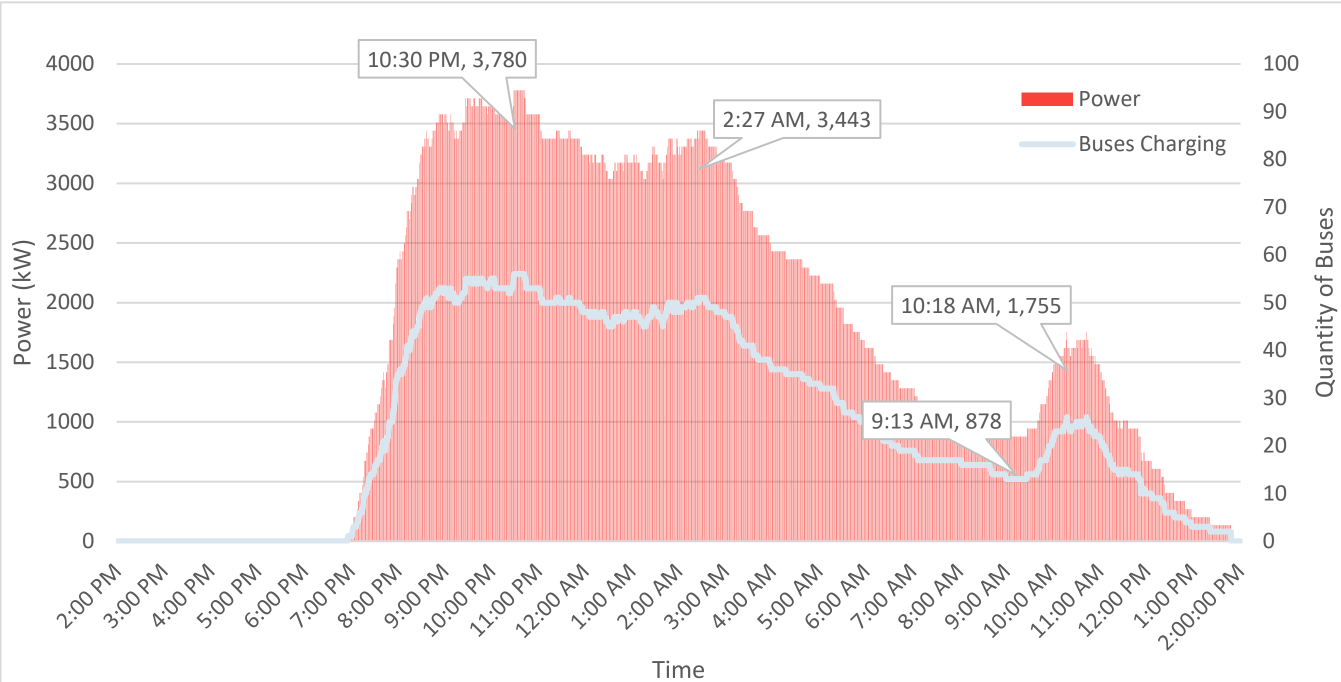
The following section presents current and future energy needs based on various charging ratios and resiliency strategies at Kirkland Yard.

### 6.3.1 *CURRENT AND FUTURE SERVICE*

From the BEB service modeling, WSP was able to simulate the energy consumption for the current fleet parameters assuming that the chargers will split power to each bus to allow concurrent charging at an average rate 67.5 kW for a 1:2 ratio. This takes into consideration battery buffer, efficiency, and pull-in servicing, as previously defined in Section 2.1. Figure 6-6 shows a sharp increase as buses begin charging at 7:00 PM, with the peak demand occurring at 10:30 PM. The demand fluctuates through 2:27 AM before slowly decreasing. Buses continue to charge throughout the morning period reaching the lowest point at 9:13 AM. The demand never reaches zero and begins to increase again when buses return after morning service, reaching a morning spike at 10:18 AM. The demand slowly drops and ends at 2:00 PM, where there is a break in charging until buses return in the evening after daily service.

The power shown in Figure 6-6 is used to determine the monthly and annual energy in kWh, as well as the average and peak demand in kW which are summarized in Table 6-6.

Figure 6-6. Kirkland Yard – Energy Consumption




Source: Jacobs

Electrifying the current fleet at Kirkland yard of 91 BEBs will consume 1,179,287 kWh a month and 14,151,449 kWh annually, with an average demand of 1,637 kW and a peak demand of 3,780 kW. This yard will be electrifying the current fleet size of 91 BEBs without an increase in 2040 projections.

The current energy needs at Kirkland yard can be supported by a new service from nearby 12 kV circuits based on the available capacity provided from PG&E. Referring to Table 6-7, there are several nearby circuits, including Mission (X) 1111, Mission (X) 1120 and LARKIN (Y) 1119, that are potential options with available circuit capacity. Current and future service energy needs are provided in Table 6-6.

Table 6-6. Kirkland Yard Energy Consumption

| Kirkland Yard Energy Consumption | BEB Fleet Size | Average Demand (kW) | Peak Demand (kW) | Monthly Energy Consumption (kWh) | Annual Energy Consumption (kWh) |
|---|---|---|---|---|---|
| Current Fleet | 91 | 1,637 | 3,780 | 1,179,287 | 14,151,449 |
| Future Size | 91 | 1,637 | 3,780 | 1,179,287 | 14,151,449 |

Source: Jacobs

## 6.3.2 *RESILIENCY*

Currently, there are no emergency electrical generators located at Kirkland Yard.

Auxiliary battery storage can be implemented to reduce the effect of unexpected power outages on operations. PG&E reliability data from 2006 to 2015 show that there is an average of approximately one power outage every two years. On average, a power outage in the San Francisco service environment lasts 78 minutes before service is restored.

In 2040, it is estimated that 91 buses will be stored at Kirkland Yard. For emergency response, Kirkland Yard is expected to maintain enough auxiliary power to charge a minimum of 10% of the buses stored at the Yard. This would require 9 buses to be available during an unexpected loss of power.

The Kirkland Yard design plans include two 2,000 kWh (4,000 kWh total) of onsite battery storage to provide energy to charge buses during power outages. At an estimated discharge rate of C/4 (i.e. one-fourth of total battery capacity can be discharged per hour), approximately 1,000 kW of battery power will be available for a continuous four-hour period. Assuming 40-foot buses (with a 458 kWh usable battery capacity) are charged at 135 kW, this would provide enough energy to fully charge 8 buses from 0% to 100%. Realistically assuming that all buses are stored with 25% of their total capacity, the reserve systems would be able to charge 11 buses up to 100%. The designed onsite battery and generator would be able to meet the charging requirements of 12% of the fleet stored at Kirkland Yard.

Kirkland Yard is expected to use 255 kW solar panels to charge the onsite battery storage. It is estimated that the solar panels will generate an average of 1,000 kWh on a daily basis.

Kirkland Yard is located in San Francisco's city sea level rise vulnerability zone, which may require the installation of these backup power systems to be placed on an elevated platform. This would reduce the operational risk during periods of flooding and/or rise of sea level during the useful life of the battery systems.

## 6.4 COSTS

Cost information at Kirkland Yard for the battery electric bus charging equipment, on-site electrical infrastructure, utility modifications, and facility upgrades have been developed based on the concepts contained in this report. The estimated costs are $12.2 million BEB infrastructure and $3.6 million for yard enhancements, resulting in a total direct construction cost of $15.7 million. Construction markups are applied cumulatively to the direction construction cost to arrive at an estimated construction cost of $33.4 million. Project markups are then applied to the estimated construction cost to arrive at the estimated project capital cost of $51.8 million. Detailed cost estimates will be found in Task 3.

## 6.5 RECOMMENDATIONS

The following section provides recommendation for transitioning the fleet at Kirkland Yard to 100% BEB.

### 6.5.1 *FLEET AND OPERATIONS*

Based on results from the simulation model, the majority of the fleet housed out of Kirkland Yard can be electrified with current technologies. For a cautious transition, this analysis recommends first transitioning the blocks with the lowest energy requirement. It is recommended that the failed blocks transition to BEB toward the end of the transition goal period.

### 6.5.2 *ELECTRICAL ENHANCEMENTS*

As previously mentioned, there is approximately 5.5 MW of available capacity on the Mission 1111 Circuit that currently feeds the yard which can support the demand when charging at a 1:2 charging ratio. Pending confirmation with SFPUC and PG&E, a new interconnection to feed the yard is recommended to support the BEB fleet. According to PG&E's PVRAM tool for mapping electric distribution lines, substations, and transmission lines, there are three 12 kV circuits in the vicinity of Kirkland Yard.

The adjacent circuits could be another factor in providing additional power to Kirkland Yard, and based on PG&E's available capacity, can support the demand. For example, the MISSION (X) 1120 circuit has an available capacity of 5.8 MW that can fully support the BEB fleet with a peak demand of 3,780 kW. For reference, Table 6-6 provides the peak demand and energy consumption for Kirkland Yard while Figure 6-7 and Table 6-7 provide information on nearby circuits. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to verify which circuit will feed the yard.

Figure 6-7. Kirkland Yard – Nearby Circuits


Source: PG&E

Table 6-7. Kirkland Yard – Nearby Circuits Summary

| Circuit Name | Voltage | Circuit Capacity (MW) | Circuit Max Load (MW) | Substation Bank Capacity (MW) | Substation Bank Max Load (MW) | Available Circuit Capacity (MW) | Available Bank Capacity (MW) |
|---|---|---|---|---|---|---|---|
| MISSION (X) 1111 | 12kV | 9.94 | 4.43 | N/A | N/A | 5.51 | N/A |
| LARKIN (Y) 1119 | 12kV | 9.19 | 5.87 | N/A | N/A | 3.32 | N/A |
| MISSION (X) 1120 | 12kV | 11.87 | 6.03 | N/A | N/A | 5.84 | N/A |
| LARKIN (Y) 1136 | 12kV | 8.34 | 7.22 | N/A | N/A | 1.12 | N/A |
| BEACH (Q) 0402 | 4.16kV | 2.18 | 1.82 | 1.98 | 1.84 | 0.36 | 0.14 |
| LARKIN (Y) 1119 | 12kV | 9.19 | 5.87 | N/A | N/A | 3.32 | N/A |

Source: PG&E
Note: MISSION (X) 1111 is Kirkland Yard's existing circuit.

### 6.5.3 *FACILITIES*

Based on the full redevelopment scenario, Kirkland Yard will be capable of storing 81 total BEBs, of which, 77 can be charged simultaneously. 72 can be charged with pantographs via an overhead supporting structure that spans the area of the existing parking tracks. An additional five buses can be charged in the maintenance bays via plug-in dispensers. The Kirkland Yard is expected to be fully redeveloped towards the conclusion of the BEB transition phasing schedule which will be developed in Task 3.

The SFMTA is pursuing interim improvements for the Kirkland site, including bus charging capability, which are currently in development and will be incorporated into the Task 3 report and scheduling. These interim improvements are expected to occur prior to the SFMTA's initial 2025 bus procurement.

One such interim improvement could be the use of ground-mounted charging cabinets and plug-in dispensers. Before the necessary infrastructure for overhead pantograph charging is installed, the necessary utility infrastructure can be brought to the site early in the transition process. This would allow the usage of ground mounted charging throughout the yard. Most of the ground mounted charging infrastructure, such as transformers, distribution panels, and charging cabinets, can be reused for the 100% BEB transition of the yard. The plug-in dispensers would have to be replaced with overhead pantographs, but could be reused in the maintenance building for maintenance bay charging. The use of plug-in dispensers in Kirkland yard would likely result in the loss of parking spaces in the yard, as there needs to be adequate space on the ground for the charging cabinets and dispensers. Space can be taken from existing NRV parking and employee parking to accommodate as many buses as possible, while also accommodating the required BEB infrastructure.

Table 6-8 summarizes the ZEB infrastructure planned at Kirkland Yard.

Table 6-8. Kirkland Yard ZEB Infrastructure Summary

| Primary Charging Strategy | Overhead Inverted Pantograph |
|---|---|
| No. of Existing Buses (September 2020) | 91 |
| No. of Charging Cabinets | 39 |
| No. of Dispensers/Charging Positions | 77 |

Source: WSP
Note: It is assumed that one charger will provide power for two charging positions/buses/dispensers (1:2 ratio)

The following BEB equipment and locations are proposed:

— 36 DC charging cabinets located on a platform attached to the overhead support structure spanning the northwest quadrant of the parking area. These charging cabinets will distribute to 72 pantograph-charging positions mounted from overhead support structures over the bus parking tracks.

— The overhead support structure columns are to be placed every three to four tracks. These columns will also provide the support for the overhead mounted pantographs.

— Three charging cabinets installed on a mezzanine located inside the new maintenance building adjacent to or near the electrical room. These charging cabinets will be connected to five dispensers installed between every two bays. This will provide charging for the nine buses that cannot be charged in the main parking area.

The pantographs and charging cabinets will be served by the following electrical infrastructure:

— One pair of interrupter switches and a meter will be installed on the northeast side of the site along Beach Street. The first interrupter will be owned and operated by PG&E, and the second interrupter and meter will be owned by SFPUC. Power will be routed up along the new fuel lane and across to the platform to feed the new medium-voltage switchgear.

— One medium-voltage switchgear and three medium- to low-voltage transformers with corresponding low-voltage switchgear will be installed on the platform, above the bus parking area. The switchgear and transformers will be rated for exterior use.

— Each 3,325 kVA transformer can feed a maximum of 20 charging cabinets charging at 150 kW or 40 pantographs charging at 75 kW rate. This calculation is based on maximum AC input rating of 200A at 480V 3 phase, or 166 kVA, for each charging cabinet and is equal to dividing 3,325 kVA by 166 KVA value. See Table 6-9 for number of charging cabinets connected to other transformer based on the assumption that two or more pantographs are fed by one charging cabinet.

Table 6-9. Transformer Size Requirements

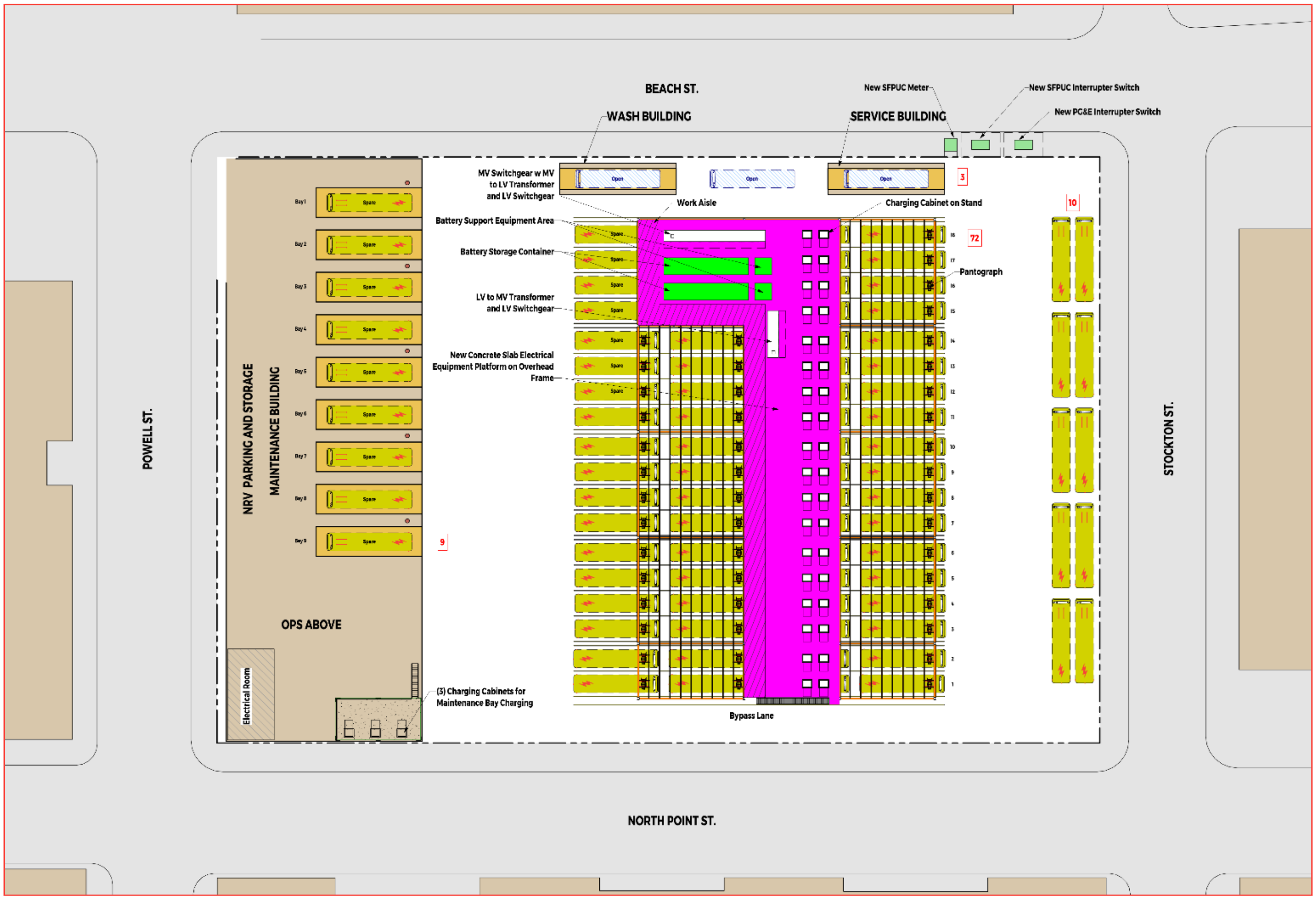
| Transformer Size | Charging Cabinets | Dispensers at 1:2 ratio (Concurrent Charging) |
|---|---|---|
| Transformer 1: 3325 kVA | 20 | 40 |
| Transformer 2: 3325 kVA | 20 | 40 |
| Total | 40 | 80 |

Source: PG&E

While not all EVSE will be in use at once based on the facility modeling tool, the feeder can be sized for a load that is managed by an automatic load management system, but each 480V transformer must be sized assuming its full connected load can be handled.

Figure 6-8 illustrates the Kirkland Yard at full build-out, in which yellow buses represent 40-foot BEBs.

Figure 6-8. Kirkland Yard – Full ZEB Build-Out




Source: WSP

## 6.5.4 *FACILITIES STAGING*

Towards the conclusion of the SFMTA ZEB transition, the Kirkland Yard is expected to be fully demolished and redeveloped. However, the SFMTA has identified a number of interim improvements to the site, which include initial BEB charging positions, which will be enacted on the existing site to allow for improved operations and safety on the site while allowing the SFMTA to operate a portion of their initial BEB procurement from Kirkland. These interim improvements are currently in development and are expected to occur by 2025. Their implications will be documented and scheduled within the overall phasing process in the Task 3 report.

# 7 POTRERO YARD

## 7.1 EXISTING CONDITIONS

This section summarizes Potrero Yard's current service parameters, location and facilities configuration, and existing electrical infrastructure.

### 7.1.1 *SERVICE DESCRIPTION AND REQUIREMENTS*

Potrero Yard operates 110 service blocks served by 40-foot and 60-foot electric trolley buses. This fleet travels a total of 9,394 miles during a typical weekday. The average weekday block distance is 85 miles and the longest distanced traveled is 155 miles. The number of stops for each block varies with an average of 529 stops. The accumulative grade of travel for the service blocks at this yard totals to 40% (Table 7-1).

Table 7-1. Existing Service Conditions at Potrero Yard

| Total Distance Traveled (mi.) | Average Block Distance (mi.) | Max Block Distance (mi.) | Average Number of Stops | Accumulative Slope |
|---|---|---|---|---|
| 9,394 | 85 | 155 | 529 | 40% |

Source: WSP

### 7.1.2 *LOCATION AND FACILITIES*

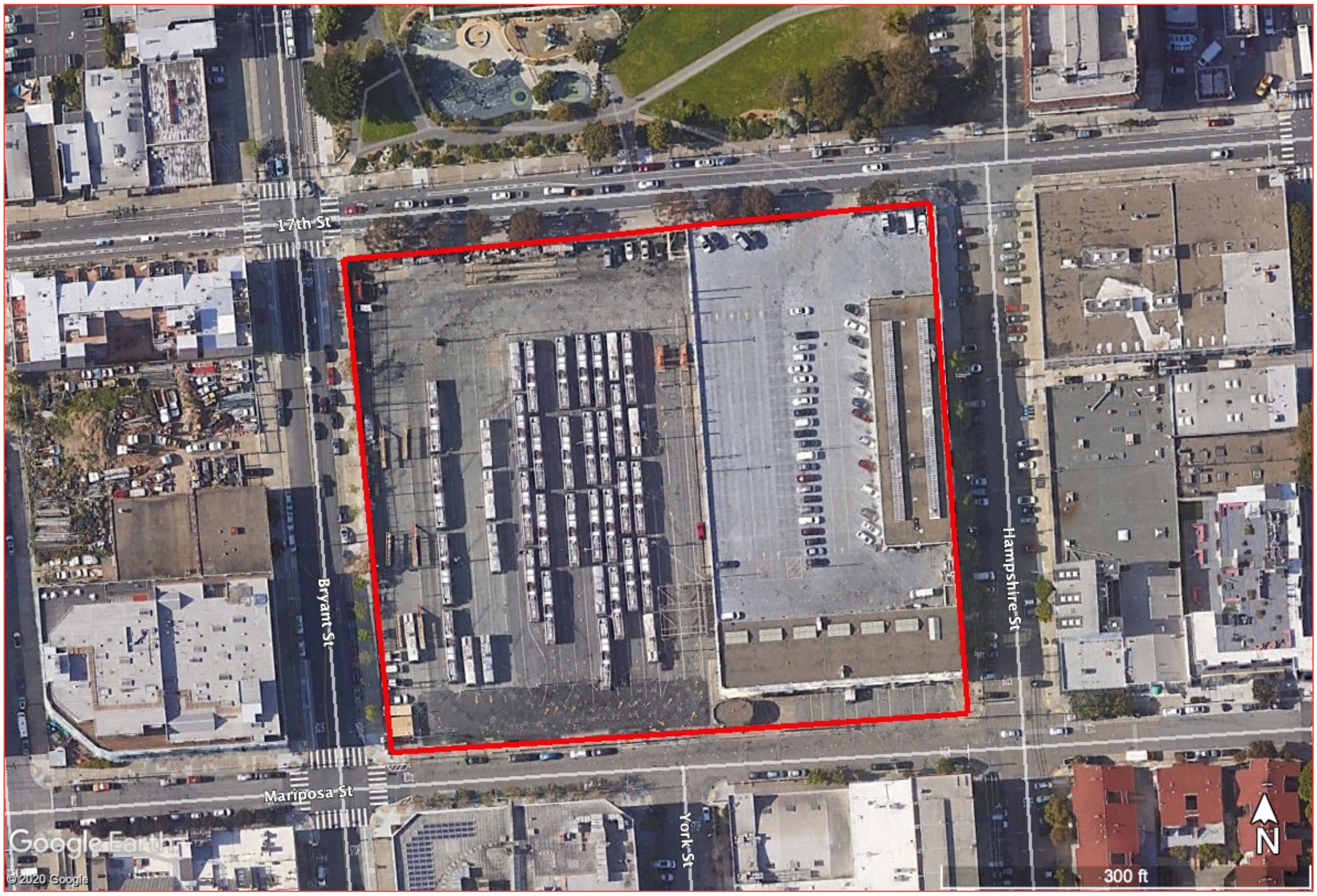
Potrero Yard is located at 2500 Mariposa Street in the City of San Francisco.

Currently, 146 trolley buses (53 40-foot and 93 60-foot) are stored, maintained, fueled, and serviced at Potrero Yard. The yard includes the following separate structures and major site areas: a two-story combined maintenance and transportation building, separate tire shop and body building, wash area, carbon-check area, and two separate bus parking yards. The upper yard and body/tire building are located on the deck above the maintenance building which is accessible from the north via 17th Street. Electrical utility service is provided by SFPUC.

Potrero Yard is over 100 years old and anticipated to be demolished and rebuilt with modern bus facilities and potential residential element per the Potrero Yard Modernization Project. The expected in-service date for the new building is end of 2026.

An aerial of Potrero Yard is presented in Figure 7-1.

Figure 7-1. Potrero Yard – Existing Conditions (Aerial)




Source: Google Earth

## SITE CIRCULATION

Buses enter the main yard from Mariposa Street and are parked in unassigned, stacked (nose-to-tail) 11'6"-wide lanes in front of the carbon check area. Individual buses are then pulled from the lanes and taken by nightly service staff to have their carbon checked, fares retrieved, and interior cleaned before pulling into the bush wash area, if being washed. After fuel and wash, buses are re-parked in the lanes. Buses remain parked until morning pull out unless a maintenance issue has been identified. NRVs are parked along the western site perimeter. No existing circulation has been developed for the Potrero site as the existing yard is not projected to be utilized in its current form for any part of the SFMTA's ZEB transition.

## 7.1.3 *ELECTRICAL INFRASTRUCTURE*

The following section provides information on the existing substation, and circuit that support Potrero Yard's electrical needs. The existing electrical equipment on-site will be replaced with construction of the new building.

## SUBSTATION

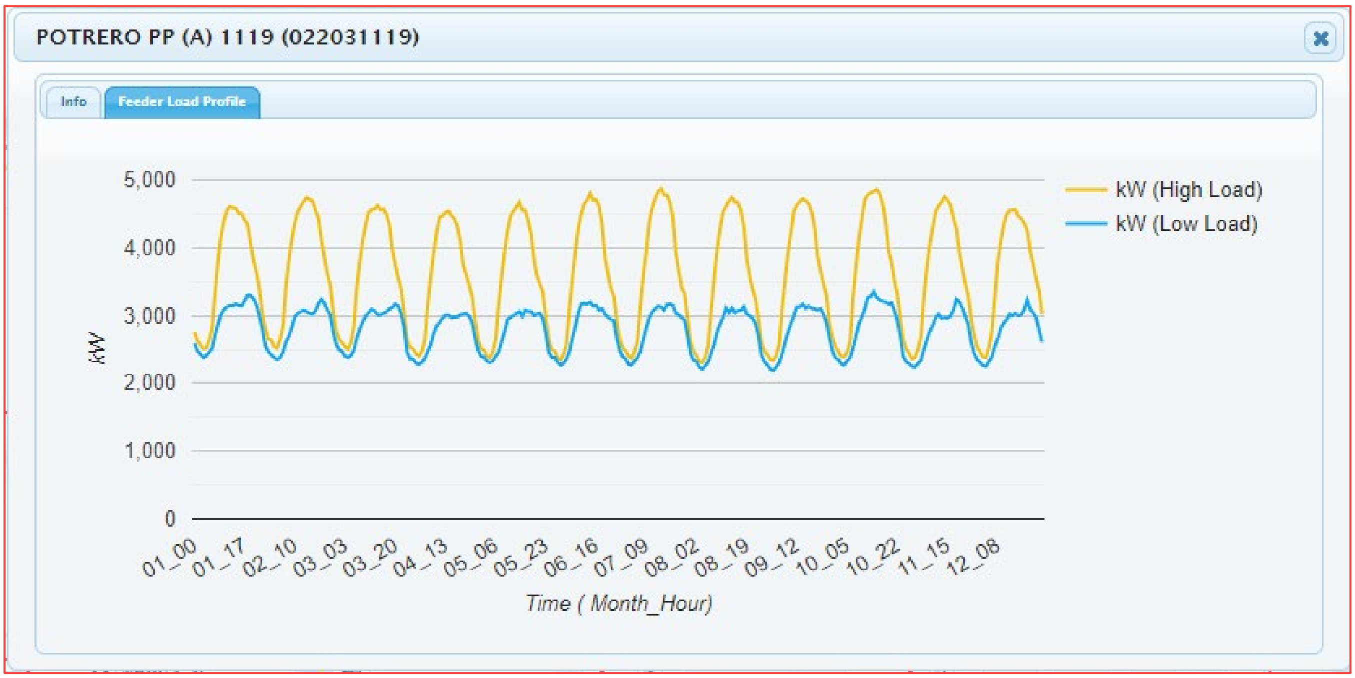
Potrero Yard's power is provided by the Potrero Substation that is located along Illinois Street between 23rd Street and 24th Street, approximately 1.7 miles from the yard. The Potrero Substation serves multiple SFMTA sites, including Flynn, Islais Creek and Woods yards. The Potrero Substation has a distribution capacity of 74 MW. The POTRERO PP (A) 1119 Circuit (Potrero 1119 Circuit) feeds Potrero Yard.

### CIRCUIT

The Potrero 1119 Circuit is a 12 kV circuit that is fed from the Potrero Substation. The Potrero 1119 circuit has an existing capacity of 8.2 MW. PG&E estimates that the projected peak load of this circuit is 5.7 MW, leaving approximately 2.5 MW of available capacity.

Peak loads for the Potrero 1119 Circuit are monitored by PG&E and published on their ICA map. The load increases in winter months and has peaks at 9:00 AM and 8:00 PM. Usage is at its minimum between 2:00 AM and 6:00 AM. The metrics for this circuit are shown in Figure 7-2 and Table 7-2 below.

Figure 7-2. Potrero Yard – Potrero 1119's Load Profile




Source: PG&E

Table 7-2. Potrero Yard – Potrero 1119's Load Information

| Description | Data |
|---|---|
| Feeder Name | POTRERO PP (A) 1119 |
| Feeder Number | 022031119 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 8.19 |
| Circuit Projected Peak Load (MW) | 5.69 |
| Substation Bank | 2 |
| Substation Bank Capacity (MW) | 44.60 |
| Substation Bank Peak Load (MW) | 39.98 |
| Existing Distributed Generation (MW) | 0.2 |
| Queued Distributed Generation (MW) | 0.04 |
| Total Distributed Generation (MW) | 0.24 |
| Total Customers | 1,304 |
| Residential Customers | 955 |
| Commercial Customers | 220 |
| Industrial Customers | 114 |
| Agricultural Customers | 1 |
| Other Customers | 14 |

Source: PG&E

## 7.2 MODELING RESULTS

The following section presents the blocks completed, fleet requirements, and service phasing strategies emerging from the simulation model for the service blocks operating out of Potrero Yard.

### 7.2.1 *BLOCK COMPLETION*

Between 72% and 100% of all the blocks operating out of Potrero Yard (currently operated by 40-foot and 60-foot electric trolley buses) can complete current service requirements with current BEB technology based on the three degrees of efficiency described in Section 2.1. Under conservative efficiency estimations, 31 blocks exceed the energy requirements that can be provided by current BEB technologies. Under the moderate scenario, 11 blocks failed. No blocks failed under the optimistic scenario (Table 7-3).

Figure 7-3 illustrates the percent of block distances that can be completed with current BEB technologies. This figure demonstrates the degree to which the technology fell short of service requirements, for example, a BEB may have completed 99% of the block and still technically fail. Under conservative estimations, 78% of the fleet is able to complete at least 90% of service requirements. Under moderate estimations, 95% of the fleet is able to meet the same benchmark. The full fleet is able to complete 60% of service requirements under conservative estimations and 70% of service requirements under moderate efficiency estimations. The disparity in performance under the moderate and conservative estimations indicate that this fleet would be a strong candidate for a performance pilot. If the BEBs perform with in the moderate range, 100% service block completion can likely be achieved with minor improvements to battery technology or minor adjustments in service planning (e.g. midday charging or reduced stops).

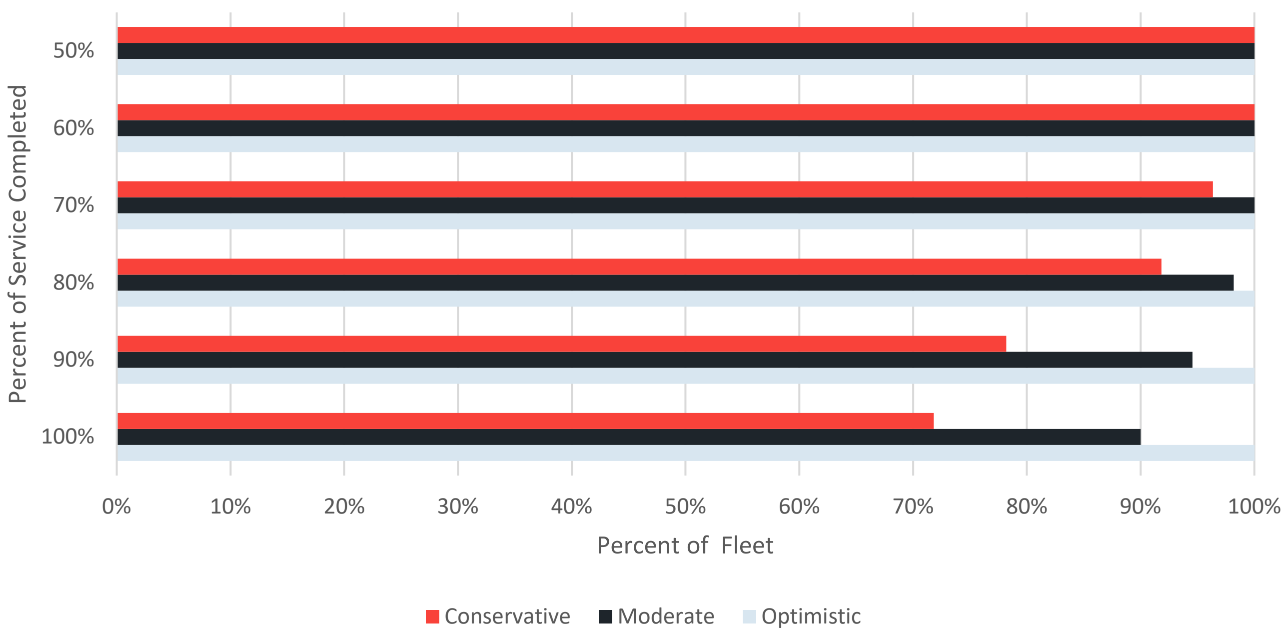
A comprehensive list of failed blocks and the percent block completion can be found in Appendix B: Failed Service Blocks.

Table 7-3. Summary of Failed Blocks at Potrero Yard

| Sensitivity | Blocks Failed | Percent Failed |
|---|---|---|
| Optimistic | 0 | 0% |
| Moderate | 11 | 10% |
| Conservative | 31 | 28% |

Source: WSP

Figure 7-3. Percent of Service Requirements Completed for the Potrero Yard Fleet

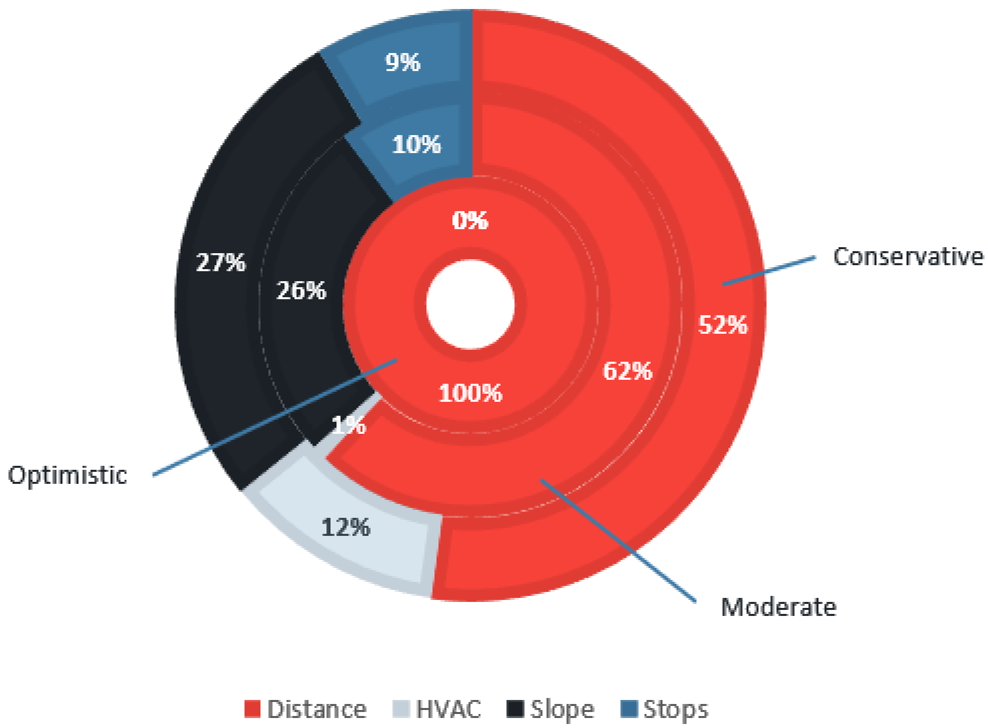



Source: WSP

## 7.2.2 *BLOCK ENERGY CONSUMPTION*

Figure 7-4 identifies the percent energy used from various metrics: distance traveled, HVAC, number of stops, and slope for each sensitivity range. Slope in this service area has a considerable effect on BEB energy consumption, drawing 26% and 27% of the battery's available capacity for moderate and conservative efficiencies, respectively. The greatest shift in energy consumption distribution between sensitivity ranges is the impact of HVAC. Under the moderate sensitivity range (reflecting a fair-weather day), HVAC has only a 1% influence on energy consumption. When assuming the most extreme climate conditions in the San Francisco, however, HVAC may be expected to draw up to 12% of the battery's available energy. Though the region will rarely experience sustained temperatures at the annual high and low, this impact should be considered, especially in the event that climate change creates a notable effect on regional climate.

Figure 7-4. Percent of Energy Used by Consumption Factors at Potrero Yard




Source: WSP

### 7.2.3 *FLEET REQUIREMENTS*

Based on the energy required for each of the 110 service blocks operating out of Potrero Yard, the fleet size would need to increase by 11 to 31 buses to meet service requirements under moderate and conservative estimations, respectively (Table 7-4). The vehicle replacement ratio under moderate and conservative estimations (without service changes or technology advancements) is 1 to 1.1 and 1 to 1.29 (conventional bus to BEB) (Table 7-5). This report recommends strategic transition phasing to allow the technology to advance or optimized service adjustments to minimize increases to the replacement ratio.

Table 7-4. Potrero Yard Vehicles Required

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles | Net Increase from Existing |
|---|---|---|---|---|
| Optimistic | 57 | 53 | 110 | 0 |
| Moderate | 57 | 64 | 121 | 11 |
| Conservative | 62 | 79 | 141 | 31 |

Source: WSP

Table 7-5. Potrero Yard Vehicle Replacement Ratio

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles |
|---|---|---|---|
| Optimistic | 1:1 | 1:1 | 1:1 |
| Moderate | 1:1.1 | 1:1.21 | 1:1.1 |
| Conservative | 1:1.1 | 1:1.5 | 1:1.29 |

Source: WSP

## 7.3 POWER NEEDS

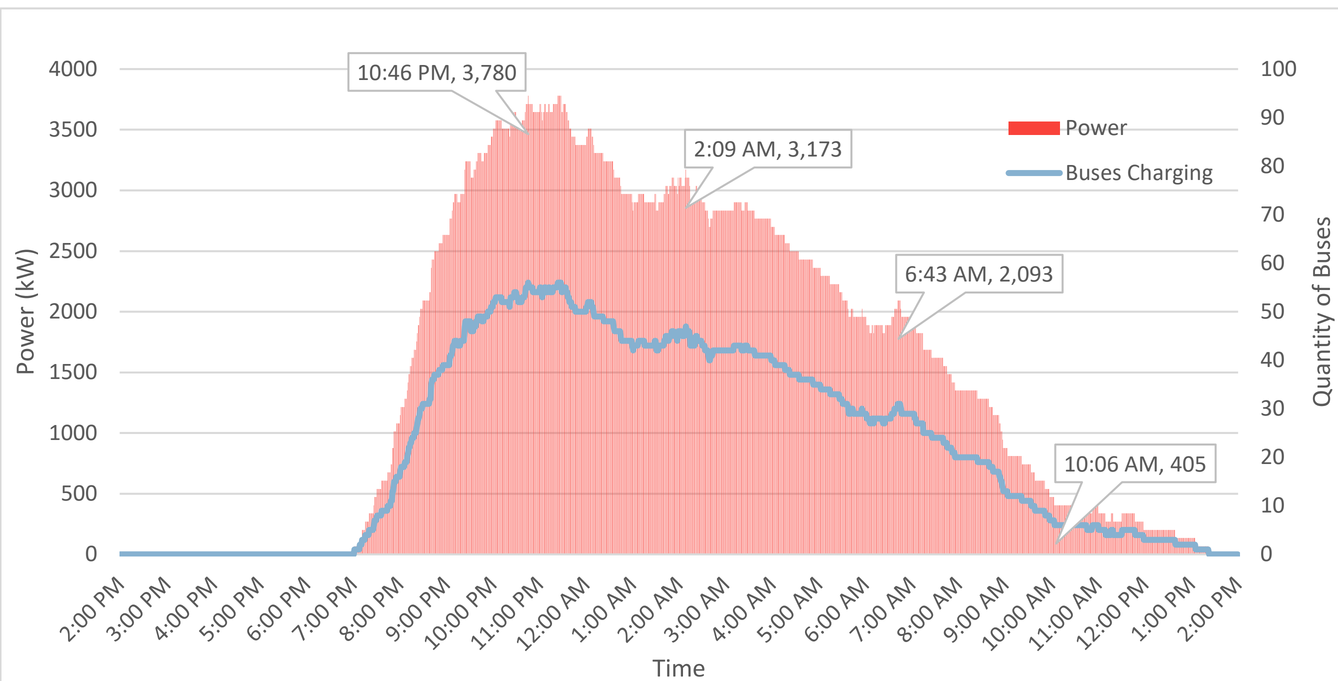
The following section presents current and future energy needs based on various charging ratios and resiliency strategies at Potrero Yard.

### 7.3.1 *CURRENT AND FUTURE SERVICE*

From the BEB service modeling, WSP was able to simulate the energy consumption for the current fleet parameters assuming that the chargers will split power to each bus to allow concurrent charging at an average rate 67.5 kW for a 1:2 ratio. This takes into consideration battery buffer, efficiency, and pull-in servicing, as previously defined in Section 2.1. Figure 7-5 shows a sharp increase in demand as buses begin charging at 7:00 PM and continue to reach the peak demand at 10:46 PM. The demand drops from 11:30 PM, with a slow ramp down to zero demand by 1:18 PM.

The power shown in Figure 7-5 is used to determine the monthly and annual energy in kWh, and the average and peak demand in kW are shown in Table 7-6.

Figure 7-5. Potrero Yard – Energy Consumption




Source: Jacobs

Electrifying the current fleet at Potrero Yard of 146 BEBs will consume 1,071,672 kWh a month and 12,860,066 kWh annually, with an average demand of 1,488 kW and a peak demand of 3,780 kW.

To determine the projected energy requirements for 2040, the ratio of future to current fleet size is used. At Potrero Yard, the fleet size will be increased from 146 to 206, producing a larger estimated demand. The future fleet size will result in an average demand of 2,100 kW and a peak demand of 5,333 kW.

The future energy needs can possibly be supported with two new services from nearby 12 kV circuits based on the information from PG&E. Referring to Table 7-7, there are several nearby circuits, including Potrero 1119, Mission 1125 and Potrero 1101, that are potential options to serve the yard. Current and future service energy needs are provided in Table 7-6.

Table 7-6. Potrero Yard Energy Consumption

| Potrero Yard Energy Consumption | BEB Fleet Size | Average Demand (kW) | Peak Demand (kW) | Monthly Energy Consumption (kWh) | Annual Energy Consumption (kWh) |
|---|---|---|---|---|---|
| Current Fleet | 146 | 1,488 | 3,780 | 1,071,672 | 12,860,066 |
| Future Size | 206 | 2,100 | 5,333 | 1,512,085 | 18,145,025 |

Source: Jacobs

### 7.3.2 *RESILIENCY*

Currently, there are no emergency electrical generators located at Potrero Yard.

In 2040, it is estimated that 206 buses will be stored at Potrero Yard. For emergency response, Potrero Yard is expected to maintain enough auxiliary battery capacity to charge a minimum of 10% of the buses on the property. This would require 21 buses to be available during an unexpected loss of grid power.

The design recommendations at Potrero Yard includes two 2,000 kWh (4,000 kWh total) of onsite battery storage to provide energy to charge buses during power outages. At an estimated discharge rate of C/4 (i.e. one-fourth of total battery capacity can be discharged per hour), approximately 1,000 kWh will be available to charge buses during a continuous four-hour period. Assuming 60-foot buses (with a 480 kWh usable battery capacity) are charged at 135 kW, this would provide enough energy to fully charge 8 buses from 0% to 100%. Realistically, assuming that all buses are stored with 25% of their total capacity, those same auxiliary batteries would be able to charge 11 buses up to 100% (approximately 5% of the fleet stored at Potrero Yard).

To charge a fleet of 21 buses (from 25% to 100%) for emergency response, an additional 3,560 kWh of auxiliary battery storage would need to be installed on the premises. This would result in a total of 7,560 kWh that would be able to fully charge emergency response buses within a four-hour period.

Potrero Yard is expected to be renovated and will include solar panels as a requirement for new building projects in San Francisco. It is currently not known how much solar energy will be generated daily when the renovation is complete.

## 7.4 COSTS

Potrero Yard will be fully rebuilt and planning/design efforts are being undertaken by other teams. For this report, the following high-level cost analysis for Potrero Yard is for the necessary BEB infrastructure and construction costs, and not for an entirely new facility. The estimated cost for 206 dispensers, as well as construction and markups, is $145.3 million. Detailed and refined cost estimates will be found in Task 3.

The above cost estimate for Potrero Yard was produced with a high-level calculation based on the average cost per dispenser of Flynn, Islais Creek, Kirkland, and Woods yards. The average cost per dispenser was determined by taking the direct construction cost, estimated construction cost with markups, and estimated project capital cost for each facility, dividing them by the number of dispensers anticipated to be at each facility, and then determining the average of these results.

## 7.5 RECOMMENDATIONS

The following section provides recommendation for transitioning the fleet at Potrero Yard to 100% BEB.

### 7.5.1 *FLEET AND OPERATIONS*

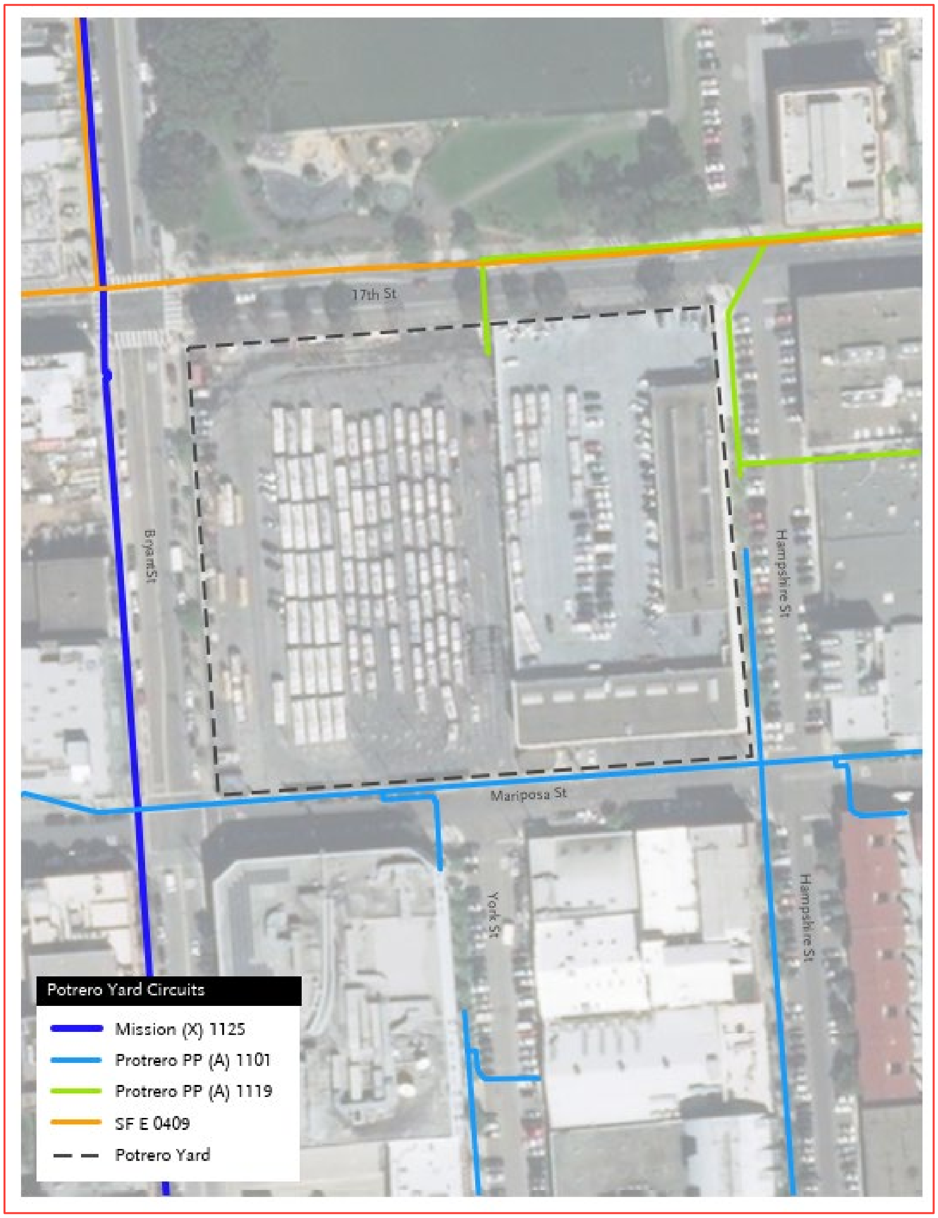
Based on results from the simulation model, the majority of the fleet housed out of Potrero Yard can be electrified with current technologies. For a cautious transition, this analysis recommends first transitioning the blocks with the lowest energy requirement and waiting until later in the transition period to convert the failed blocks.

### 7.5.2 *ELECTRICAL ENHANCEMENTS*

As previously mentioned, there is approximately 2.5 MW of available capacity on the Potrero 1119 Circuit that currently feeds the yard, which can support approximately 66% of the current BEB fleet and 47% of the future BEB fleet. Pending confirmation with SFPUC and PG&E, two new interconnections to feed the yard are recommended to support the future BEB fleet and facility with the assumption that each service can provide 10 MW each. According to PG&E's PVRAM tool for mapping electric distribution lines, substations, and transmission lines, there are three 12 kV and one 4.2 kV circuits in the vicinity of Potrero Yard.

It is likely that existing capacity at Potrero Yard from just Potrero 1119 circuit will not be sufficient to support a fleet of BEBs. The adjacent circuits may be a factor in providing additional power to the yard, possibly through a second interconnection. For example, the nearby MISSION (X) 1125 has an available circuit capacity of 4.7 MW supporting 88% of the future fleet with a peak demand of 5,333 kW. For reference Table 7-6 provides the energy consumption for Potrero Yard and Figure 7-6 and Table 7-7 provide information on nearby circuits. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to select which circuit and the number of interconnections required to support the yard.

Figure 7-6. Potrero Yard – Nearby Circuits




Source: PG&E

Table 7-7. Potrero Yard – Nearby Circuits Summary

| Circuit Name | Voltage | Circuit Capacity (MW) | Circuit Max Load (MW) | Substation Bank Capacity (MW) | Substation Bank Max Load (MW) | Available Circuit Capacity (MW) | Available Bank Capacity (MW) |
|---|---|---|---|---|---|---|---|
| POTRERO PP (A) 1119 | 12kV | 8.19 | 5.69 | 44.59 | 39.98 | 2.5 | 4.61 |
| MISSION (X) 1125 | 12kV | 12.19 | 7.46 | N/A | N/A | 4.73 | N/A |
| POTRERO PP (A) 1101 | 12kV | 9.52 | 7.82 | 74.3 | 43.36 | 1.7 | 30.94 |
| SF E 0409 | 4.16kV | 2.35 | 0.86 | 9.88 | 2.92 | 1.49 | 6.96 |

Source: PG&E
Note: POTRERO PP (A) 1119 is Potrero Yard's existing circuit.

### 7.5.3 *FACILITIES*

The existing Potrero site and facility is planned to be completely demolished and redeveloped in a separate project from this ZEB master plan project. The future expanded capacity of Potrero Yard is factored into this project and reflected in the site capacities and the staging, which will be outlined in Task 3. Potrero Yard's existing fleet is expected to be fully relocated to other sites during the complete redevelopment.

Based on the fleet projections supplied to WSP by the SFMTA, it is anticipated that the future Potrero Yard will serve an expanded fleet of BEBs and electric trolley buses. This expanded fleet, along with the fleet's new propulsion types, will require expanded maintenance, operations, and support spaces. The new facility will include bus storage and maintenance across multiple stories.

As the design of the new Potrero facility is part of a separate project, the WSP design team has not developed specific concepts for any building layout on the site. Individual BEB charging components and systems used on the SFMTA site-specific BEB master plans have been assembled into a "kit of parts" BEB charging modular system package. This "kit of parts" modular BEB charging system and equipment requirements is provided to allow a future Potrero Yard design team(s) to use similar BEB components and systems and to provide a basis of design for charging equipment, approach and charging equipment space, and utility requirements.

As the design of the future site is expected to be multi-level, it is recommended that Potrero Yard utilizes an overhead structure-mounted inverted pantograph charging solution. Depending on the design choices and criteria developed by the SFMTA and the future Potrero Yard designer, the required electrical infrastructure could be installed in multiple configurations to suit the final design of the facility. No master plan concept layouts are being developed as part of this project, but the "kit of parts" testing performed on the site has confirmed the following capacities based on the ultimate BEB full fleet conversion.

Table 7-8 summarizes the ZEB infrastructure planned at Potrero Yard.

Table 7-8. Potrero Yard ZEB Infrastructure Summary

| Charging Strategy | # of Existing Buses (2020) | # of ZEBs Supported (2040) | # of Chargers | # of Dispensers | Charger Rating |
|---|---|---|---|---|---|
| Inverted Pantograph | 146 | 206 | 103 | 206 | 150 kW |

Source : WSP

Concepts for the Potrero Yard are not included in this project and will be developed in a separate project directly related to the site's redevelopment. The "kit of parts" modules displayed below will be used as guiding design principles to allow future designs for the Potrero Yard the flexibility to achieve the capacities noted above.

The following BEB equipment is anticipated to be required to serve the proposed fleet:

— Bus Parking: 107 DC charging cabinets.

The pantographs and charging cabinets will be served by the following electrical infrastructure:

— Two pairs of interrupter switches and two meters will be ground mounted along the exterior of the facility as required by SFPUC and PG&E. The first interrupter in each pair will be owned and operated by PG&E, and the second interrupter in each pair as well as the meters will be owned and operated by SFPUC. Power will continue from the meters to the new medium voltage switchgear in the future facility.

— One medium voltage switchgear and two medium voltage to low voltage transformers with corresponding low voltage switchgear will be installed in the new facility.

— Each 3,325 kVA transformer can feed a maximum of 20 charging cabinets charging at 150 kW or 40 pantographs charging at 75 kW rate. This calculation is based on maximum AC input rating of 200A at 480V 3 phase, or 166 kVA, for each charging cabinet and is equal to dividing 3,325 kVA by 166 KVA value. See Table 7-9 for the number of charging cabinets connected to other transformer based on the assumption that two or more pantographs are fed by one charging cabinet.

Table 7-9. Transformer Size Requirements

| Transformer Size | Charging Cabinets | Dispensers at 1:2 ratio (Concurrent Charging) |
|---|---|---|
| Transformer 1: 3,325 kVA | 20 | 40 |
| Transformer 2: 3,325 kVA | 20 | 40 |
| Transformer 3: 3,325 kVA | 20 | 40 |
| Transformer 4: 3,325 kVA | 20 | 40 |
| Transformer 5: 3,325 kVA | 20 | 40 |
| Total | 100 | 200 |

Source: WSP

While not all EVSE will be in use at once based on the facility modeling tool, the feeder can be sized for a load that is managed by an automatic load management system, but each 480V Transformer must be sized assuming its full connected load can be handled. Potrero Yard transformer configuration should be revisited during detailed design as the inclusion of commercial and residential loads for the new facility will create unique challenges compared to the other sites.

### 7.5.4 *FACILITIES STAGING*

Since Potrero Yard is expected to be demolished and redeveloped prior to implementing BEBs on the site, it is recommended that the entire infrastructure and charging position deployment be included in the redevelopment project. This will allow the ZEB transition to occur concurrently to the planned redevelopment construction process and avoid any further operational interruptions.

# 8 PRESIDIO YARD

## 8.1 EXISTING CONDITIONS

This section summarizes Presidio Yard's current service parameters, location and facilities configuration, and existing electrical infrastructure.

### 8.1.1 *SERVICE DESCRIPTION AND REQUIREMENTS*

Presidio Yard operates 109 service blocks served by 40-foot electric trolley buses. This fleet travels a total of 8,046 miles during a typical weekday. The average weekday block distance is 74 miles and the longest distanced traveled is 151 miles. The number of stops for each block varies with an average of 550 stops. The accumulative grade of travel for the service blocks at this yard is totals to 54% (Table 8-1).

Table 8-1. Existing Service Conditions at Presidio Yard

| Total Distance Traveled (mi.) | Average Block Distance (mi.) | Max Block Distance (mi.) | Average Number of Stops | Accumulative Slope |
|---|---|---|---|---|
| 8,046 | 74 | 151 | 550 | 54% |

Source: WSP

### 8.1.2 *LOCATION AND FACILITIES*

Presidio Yard is located at 949 Presidio Avenue in the City of San Francisco.

Currently, 132 40-foot trolley buses are stored, maintained, fueled, and serviced at Presidio Yard. The yard includes the following separate structures and major site areas: a two-story combined maintenance and transportation building, wash area, carbon check area, and bus parking yard. Electrical utility service is provided by SFPUC.

Presidio Yard is over 100 years old and anticipated to be demolished and rebuilt with modern bus facilities. The Presidio Yard Modernization Project began pre-development and planning in early 2020. The expected in-service date for the new building is end of 2029.

An aerial and existing site plan of Presidio Yard are presented in Figure 8-1 and Figure 8-2, respectively.

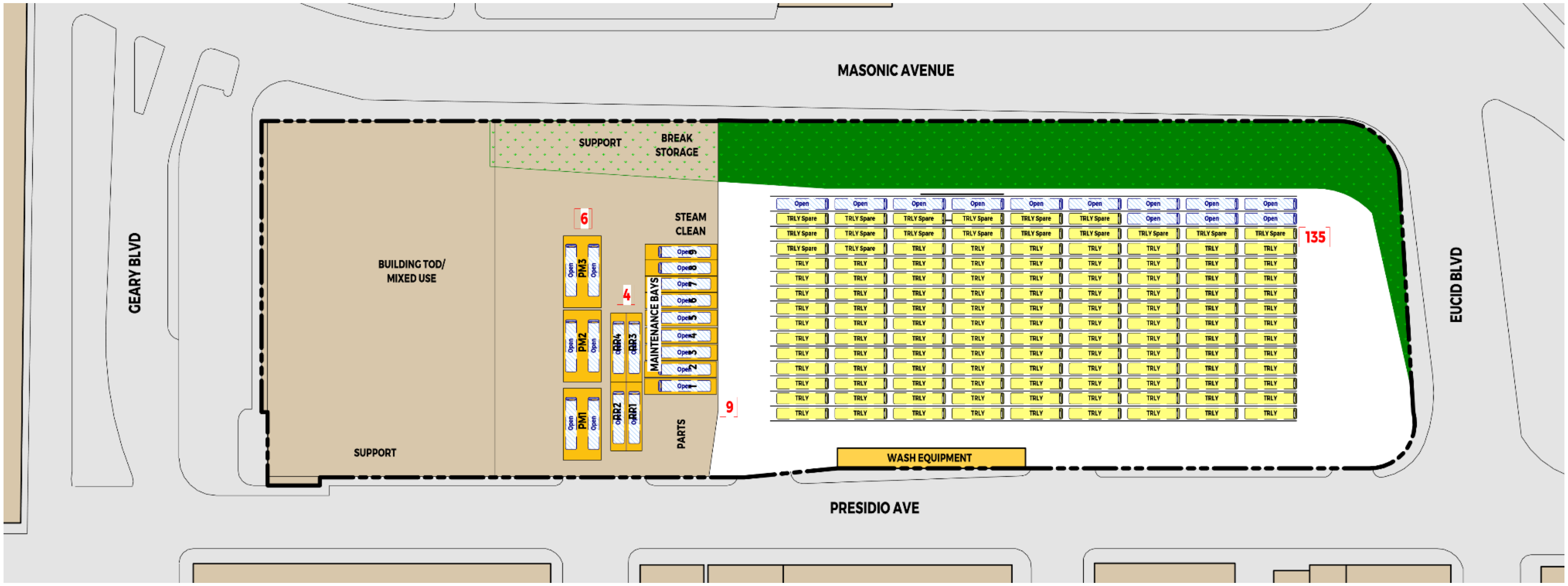
Figure 8-1. Presidio Yard – Existing Conditions (Aerial)


Source: Google Earth

## SITE CIRCULATION

Buses enter the main yard from Presidio Street and are parked in unassigned, stacked (nose-to-tail), 11’6”-wide lanes in front of the carbon check area. Individual buses are then pulled from the lanes and taken by nightly service staff to have their carbon checked, fares retrieved, and interior cleaned before pulling into the bush wash area, if being washed. After fuel and wash, buses are re-parked in the lanes. Buses remain parked until morning pull out unless a maintenance issue has been identified. NRVs are parked along the northern site perimeter.

Figure 8-2. Presidio Yard – Existing Site Plan




Source: WSP

## 8.1.3 *ELECTRICAL INFRASTRUCTURE*

The following section provides information on the existing substation, and circuit that support Presidio Yard's electrical needs.

### SUBSTATION

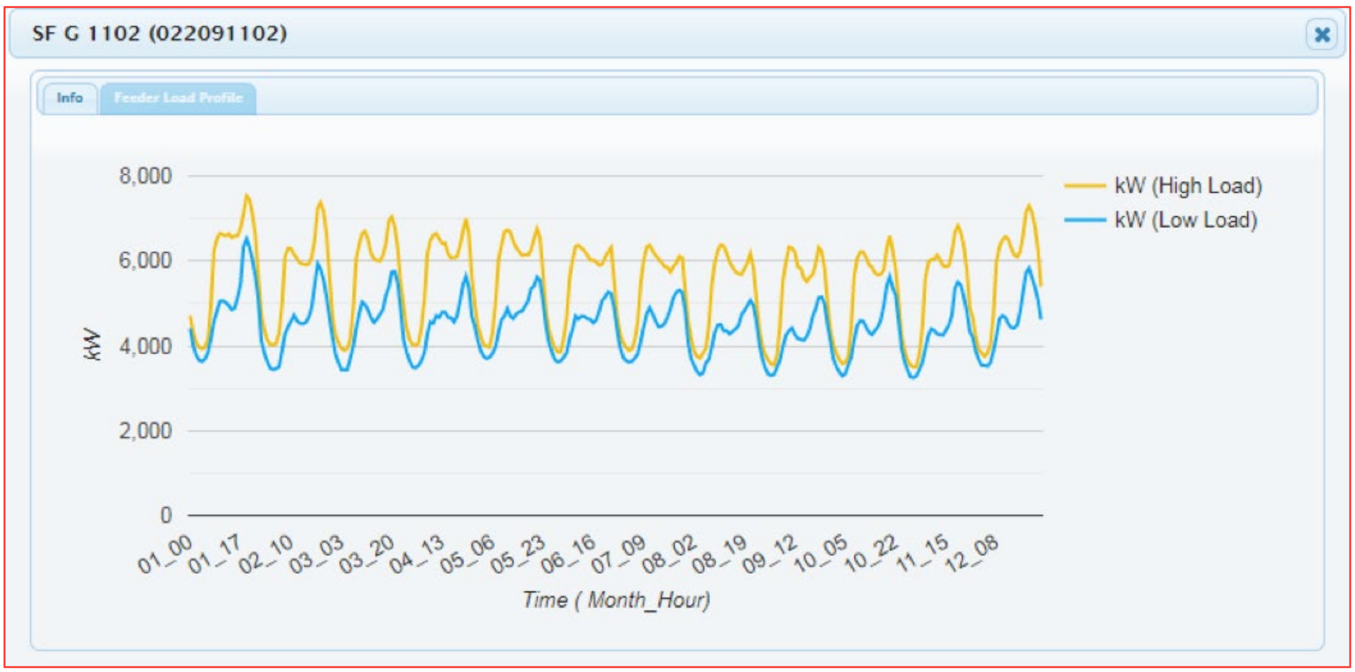
Presidio Yard's power is provided by the SF G Substation that is located on Broderick Street, between Ellis Street and Geary Boulevard, approximately 0.5 miles from the yard. The SF G Substation only serves one SFMTA site, being Presidio Yard. The SF G Substation's capacity is not available in PG&E's PVRAM system but supports at least 14 circuits, to be verified by PG&E. The SF G 1102 Circuit G feeds Presidio Yard.

### CIRCUIT

The SF G 1102 Circuit is a 12 kV circuit that is fed from the SF G Substation. The SF G 1102 circuit has an existing capacity of 11 MW. PG&E estimates that the projected peak load of this circuit is 5 MW, leaving approximately 6 MW of available capacity. The circuit enters the property on the ground floor of Presidio Avenue and is the only circuit providing service to the yard.

Peak loads for the SF G 1102 Circuit are monitored by PG&E and published on their ICA map. The load increases in winter months and has peaks at 9:00 AM and 8:00 PM. Usage is at its minimum between 2:00 AM and 6:00 AM. It should be noted that the load profile includes the usage by other customers who receive power from the same feeder. The metrics for this circuit are shown in Figure 8-3 and Table 8-2 below.

Figure 8-3. Presidio Yard – SF G 1102's Load Profile




Source: PG&E

Table 8-2. Presidio Yard – SF G 1102's Load Information

| Description | Data |
|---|---|
| Feeder Name | SF G 1102 |
| Feeder Number | 022091102 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 10.97 |
| Circuit Projected Peak Load (MW) | 5.02 |
| Substation Bank | N/A |
| Substation Bank Capacity (MW) | N/A |
| Substation Bank Peak Load (MW) | N/A |
| Existing Distributed Generation (MW) | 0.01 |
| Queued Distributed Generation (MW) | 0.01 |
| Total Distributed Generation (MW) | 0.02 |
| Total Customers | 1,317 |
| Residential Customers | 1,166 |
| Commercial Customers | 92 |
| Industrial Customers | 54 |
| Agricultural Customers | 0 |
| Other Customers | 5 |

Source: PG&E

## 8.2 MODELING RESULTS

The following section presents the blocks completed, fleet requirements, and service phasing strategies emerging from the simulation model for the service blocks operating out of Presidio Yard.

### 8.2.1 *BLOCK COMPLETION*

Between 84% and 100% of the 109 blocks operating out of Presidio Yard (currently operated by 40-foot electric trolley buses) can complete current service requirements with current BEB technology based on the three degrees of efficiency described in Section 2.1. Under conservative efficiency estimations, 17 blocks exceed the energy requirements that can be provided by current BEB technologies. Under the moderate scenario, seven blocks failed. No blocks failed under the optimistic scenario (Table 8-3).

Figure 8-4 illustrates the percent of block distances that can be completed with current BEB technologies, for example, a BEB may have completed 99% of the block and still technically fail. Under conservative estimations, 89% of the fleet is able to complete at least 90% of service requirements. Under moderate estimations, 99% of the fleet is able to meet the same benchmark. The full fleet is able to complete 60% of service requirements under conservative estimations and 80% of service requirements under moderate efficiency estimations. The disparity in performance under the moderate and conservative estimations indicate that this fleet would be a strong candidate for a performance pilot. If the BEBs perform within the moderate range, 100% service block completion can likely be achieved with minor improvements to battery technology or minor adjustments in service planning (e.g. midday charging or reduced stops).

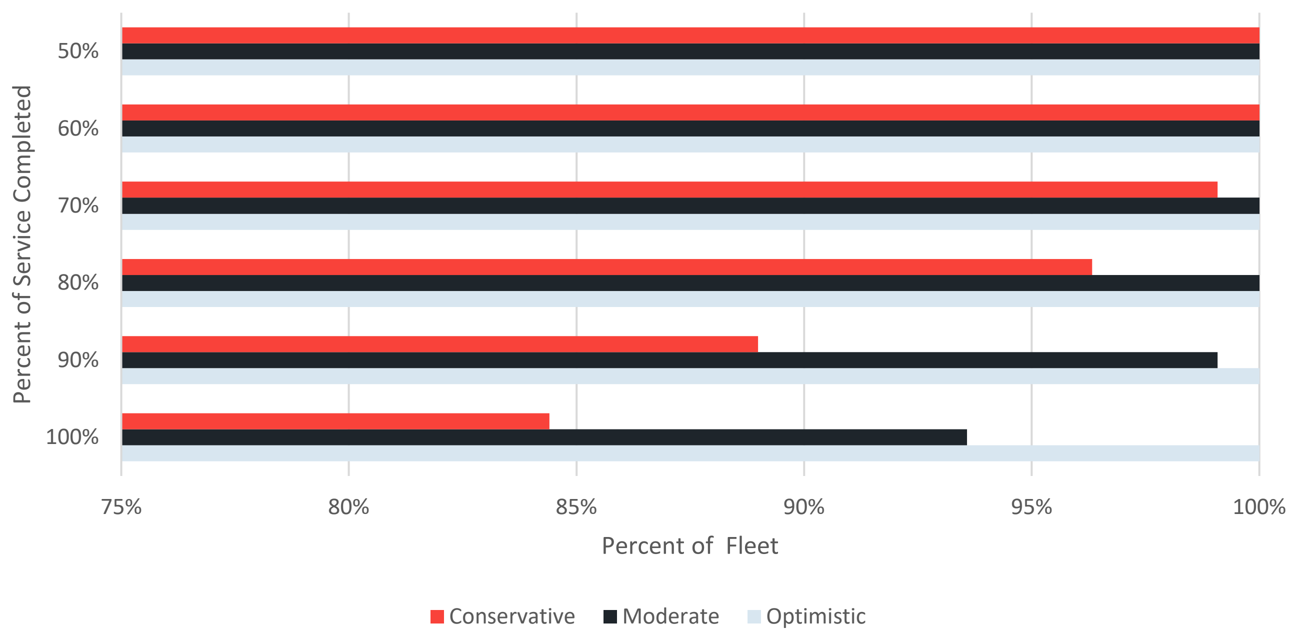
A comprehensive list of failed blocks and the percent block completion can be found in Appendix B: Failed Service Blocks.

Table 8-3. Summary of Failed Blocks at Presidio Yard

| Sensitivity | Blocks Failed | Percent Failed |
|---|---|---|
| Optimistic | 0 | 0% |
| Moderate | 7 | 6% |
| Conservative | 17 | 16% |

Source: WSP

Figure 8-4. Percent of Service Requirements Completed for the Presidio Yard Fleet

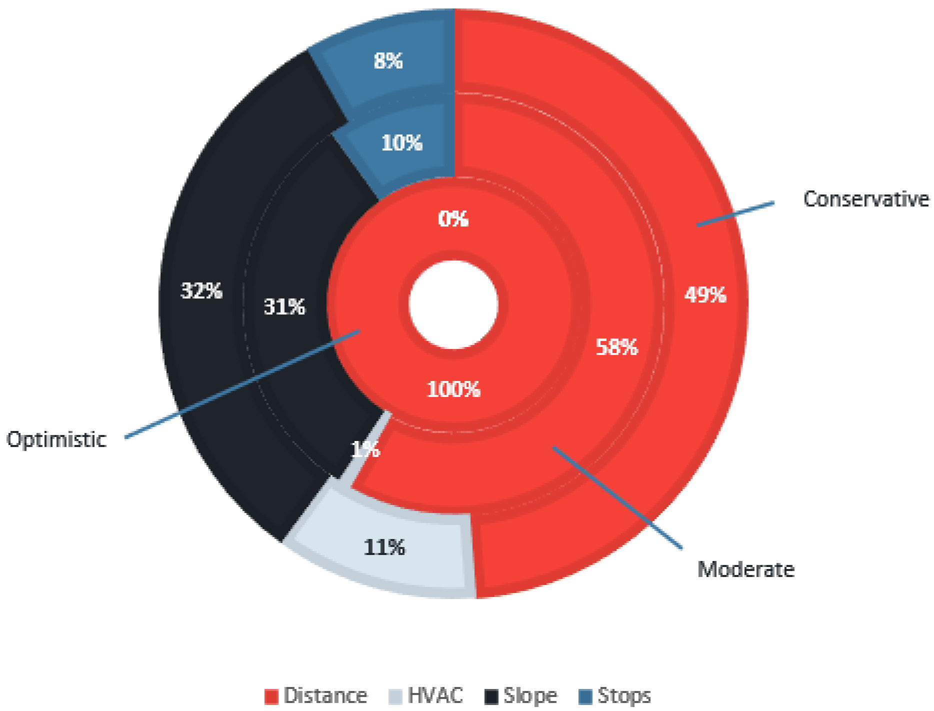



Source: WSP

## 8.2.2 *BLOCK ENERGY CONSUMPTION*

Figure 8-5 identifies the percent energy used from various metrics: distance traveled, HVAC, number of stops, and slope for each sensitivity range. In this service area, slope has a considerable effect on BEB energy consumption, drawing 31% and 32% of the battery's available capacity for moderate and conservative efficiencies, respectively. The greatest shift in energy consumption distribution between sensitivity ranges is the impact of HVAC. Under the moderate sensitivity range (reflecting a fair-weather day), HVAC has only a 1% influence on energy consumption. When assuming the most extreme climate conditions in the San Francisco, however, HVAC may be expected to draw up to 11% of the battery's available energy. Though the region will rarely experience sustained temperatures at the annual high and low, this impact should be considered, especially in the event that climate change creates a notable effect on regional climate.

Figure 8-5. Percent of Energy Used by Consumption Factors at Presidio Yard




Source: WSP

### 8.2.3 *FLEET REQUIREMENTS*

Based on the energy required for each of the 109 service blocks operating out of Presidio Yard, the fleet size would need to increase by seven buses under moderate estimations and 17 buses under conservative estimations to meet service requirements (Table 8-4). The vehicle replacement ratio under moderate and conservative estimations (without service changes or technology advancements) is 1 to 1.07 and 1 to 1.16, respectively (Table 8-5). This report recommends strategic transition phasing to allow the technology to advance or optimized service adjustments to minimize increases to the replacement ratio.

Table 8-4. Presidio Yard Vehicles Required

| Sensitivity | 40’ Vehicles | 60’ Vehicles | Total Vehicles | Net Increase from Existing |
|---|---|---|---|---|
| Optimistic | 109 | NA | 109 | 0 |
| Moderate | 116 | NA | 116 | 7 |
| Conservative | 126 | NA | 126 | 17 |

Source: WSP

Table 8-5. Presidio Yard Vehicle Replacement Ratio

| Sensitivity | 40' Vehicles | 60' Vehicles | Total Vehicles |
|---|---|---|---|
| Optimistic | 1:1 | NA | 1:1 |
| Moderate | 1:1.07 | NA | 1:1.07 |
| Conservative | 1:1.16 | NA | 1:1.16 |

Source: WSP

## 8.3 POWER NEEDS

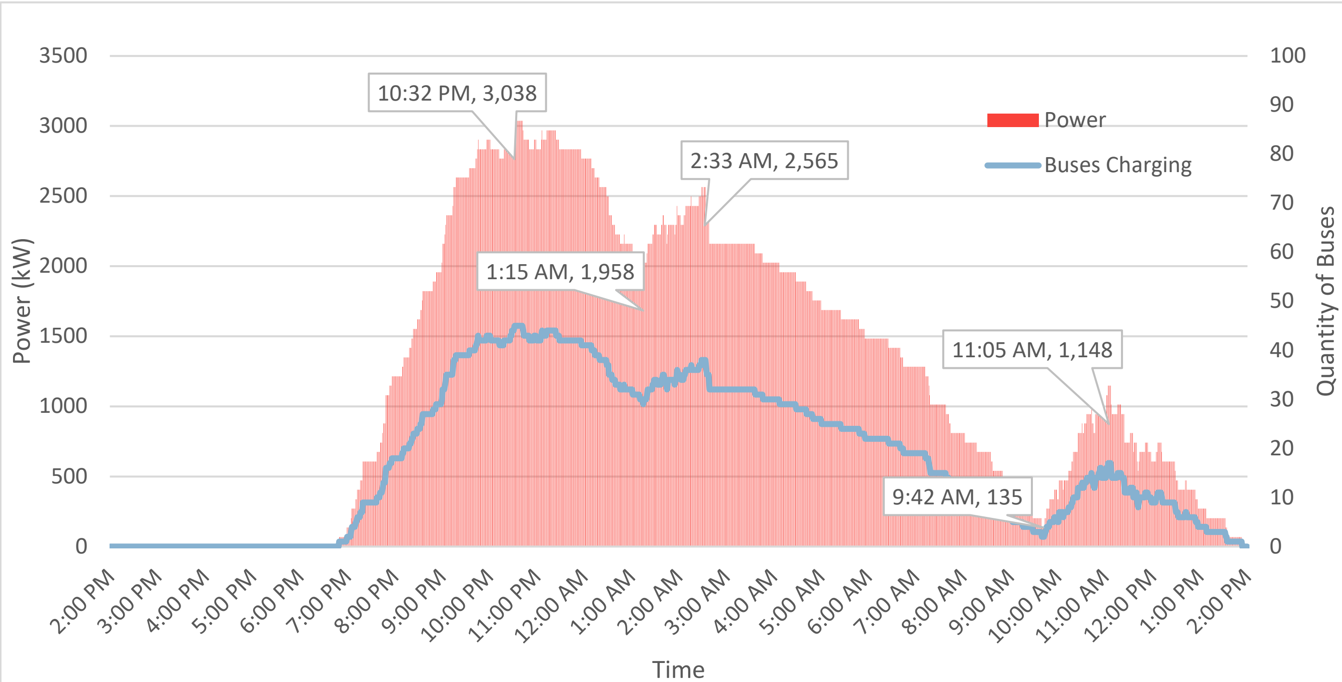
The following section presents current and future energy needs based on various charging ratios and resiliency strategies at Presidio Yard.

### 8.3.1 *CURRENT AND FUTURE SERVICE*

From the BEB service modeling, WSP was able to simulate the energy consumption for the current fleet parameters assuming that the chargers will split power to each bus to allow concurrent charging at an average rate 67.5 kW for a 1:2 ratio. This takes into consideration battery buffer, efficiency, and pull-in servicing, as previously defined in Section 2.1. Figure 8-6 shows an incline in demand as buses begin charging at 7:00 PM. The demand first peaks at 10:32 PM and drops slightly by 1:15 AM where it again increases to a  demand at 2:33 AM. Buses continue to charge throughout the morning period and reach the lowest point at 9:42 AM. The demand never reaches zero and begins to increase again when buses return after morning service. The smaller demand curve occurs from 9:42 AM and ends at 1:30 PM where there is a break in charging until buses return in the evening from daily service.

The power shown in Figure 8-6 is used to determine the monthly and annual energy in kWh, as well as the average and peak demand in kW which are summarized in Table 8-6.

Figure 8-6. Presidio Yard – Energy Consumption




Source: Jacobs

Electrifying the current fleet at Presidio Yard of 132 BEBs will consume 865,545 kWh a month and 10,386,543 kWh annually, with an average demand of 1,201 kW and a peak demand of 3,038 kW.

To determine the projected energy requirements for 2040, the ratio of future to current fleet size is used. At Presidio Yard, the fleet size will be increased from 132 to 217 creating a larger estimated demand. The future demand will result in an average demand of 1,974 kW and a peak demand of 4,994 kW.

The future energy needs can be supported by a new service from nearby 12 kV circuits based on information from PG&E. Referring to Table 8-7, the two nearby circuits, SF G 1102 and SF G 1101 are potential options with available circuit capacity. Current and future service energy needs are provided in Table 8-6.

Table 8-6. Presidio Yard Energy Consumption

| Presidio Yard Energy Consumption | BEB Fleet Size | Average Demand (kW) | Peak Demand (kW) | Monthly Energy Consumption (kWh) | Annual Energy Consumption (kWh) |
|---|---|---|---|---|---|
| Current Fleet | 132 | 1,201 | 3,038 | 865,545 | 10,386,543 |
| Future Fleet | 217 | 1,974 | 4,994 | 1,422,904 | 17,074,847 |

Source: Jacobs

## 8.3.2 *RESILIENCY*

Currently, there are no emergency electrical generators located at Presidio Yard.

In 2040, it is estimated that 217 buses will be stored at Presidio Yard. For emergency response, Presidio Yard is expected to maintain enough auxiliary battery capacity to charge a minimum of 10% of the buses on the property. This would require 22 buses to be available during an unexpected loss of grid power.

The Presidio Yard designs include two 2,000 kWh (4,000 kWh total) of onsite battery storage to provide energy to charge buses during power outages. At an estimated discharge rate of C/4 (i.e. one-fourth of total battery capacity can be discharged per hour), approximately 1,000 kWh will be available to charge buses during a continuous four-hour period. Assuming 40-foot buses (with a 458 kWh usable battery capacity, 480 kWh usable battery capacity for 60 foot buses) are charged at 135 kW, this would provide enough energy to fully charge eight buses from 0% to 100%. Realistically assuming that all buses are stored with 25% of their total capacity, those same auxiliary batteries would be able to charge 11 buses up to 100% (approximately 5% of the fleet stored at Presidio Yard).

To charge a fleet of 22 buses (from 25% to 100%) for emergency response, an additional 3,607 kWh of auxiliary battery storage would need to be installed on the premises. This would result in a total of 7,607 kWh that would be able to fully charge emergency response buses within a four-hour period.

Presidio Yard is expected to be renovated and will include 621 kW solar panels to charge the onsite battery storage. It is estimated that the solar panels will generate an average of 2,600 kWh on a daily basis.

## 8.4 COSTS

Presidio Yard will be fully rebuilt and planning/design efforts are being undertaken by other teams. For this report, the following high-level cost analysis for Presidio Yard is for the necessary BEB infrastructure and construction costs, and not for an entirely new facility. The estimated cost for 217 dispensers, as well as construction and markups, is $153.1 million. Detailed and refined cost estimates will be found in Task 3.

The above cost estimate for Presidio Yard was produced with a high-level calculation based on the average cost per dispenser of Flynn, Islais Creek, Kirkland, and Woods yards. The average cost per dispenser was determined by taking the direct construction cost, estimated construction cost with markups, and estimated project capital cost for each facility, dividing them by the number of dispensers anticipated to be at each facility, and then determining the average of these results.

## 8.5 RECOMMENDATIONS

The following section provides recommendation for transitioning the fleet at Presidio Yard to 100% BEB.

### 8.5.1 *FLEET AND OPERATIONS*

Based on results from the simulation model, the majority of the fleet housed out of Presidio Yard can be electrified with current technologies. For a cautious transition, this analysis recommends first transitioning the blocks with the lowest energy requirement and waiting until later in the transition period to convert the failed blocks.

### 8.5.2 *ELECTRICAL ENHANCEMENTS*

As previously mentioned, there is approximately 5.95 MW of available capacity on the SF G 1102 circuit that currently feeds the yard. The circuit can support the future peak demand of 4,994 kW. Pending confirmation with SFPUC and PG&E, a new interconnection to feed the yard is recommended to support the future BEB fleet.

According to PG&E's PVRAM tool for mapping electric distribution lines, substations, and transmission lines, there is an additional 12 kV circuit in the vicinity of Presidio Yard. The nearby SF G 1101 circuit has a capacity of 11.18

MW with a peak load of 3.89 MW, leaving approximately 7.29 MW of additional capacity. The adjacent circuit may be a factor in providing additional power to Presidio Yard and can support the future demand. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to verify which circuit will feed the yard. For reference Table 8-6 provides the peak demand and energy consumption for Presidio Yard and Figure 8-7 with Table 8-7 provide information on nearby circuits.

Figure 8-7. Presidio Yard – Nearby Circuits


Source: PG&E

Table 8-7. Presidio Yard – Nearby Circuits Summary

| Circuit Name | Voltage | Circuit Capacity (MW) | Circuit Max Load (MW) | Substation Bank Capacity (MW) | Substation Bank Max Load (MW) | Available Circuit Capacity (MW) | Available Bank Capacity |
|---|---|---|---|---|---|---|---|
| SF G 1102 | 12kV | 10.97 | 5.02 | N/A | N/A | 5.95 | N/A |
| SF G 1101 | 12kV | 11.18 | 3.89 | N/A | N/A | 7.29 | N/A |
| LARKIN (Y) 1135 | 12kV | 8.34 | 7.31 | N/A | N/A | 1.03 | N/A |
| SF G 0414 | 4.16kV | 2.42 | 1.93 | 21.4 | 8 | 0.49 | 13.4 |

Source: PG&E

## 8.5.3 *FACILITIES*

The existing Presidio Yard site and facility is planned to be either be fully or partially demolished and redeveloped in a separate project from this ZE master plan project. The future expanded capacity of Presidio Yard is factored into this project and reflected in the site capacities and the staging, which will be outlined in Task 3. Presidio Yard's existing fleet is expected to be fully relocated to other sites during the complete redevelopment of the site.

Based on the fleet projections supplied to WSP by the SFMTA, it is anticipated that the future Presidio Yard will serve an expanded fleet of BEBs and electric trolley buses. This expanded fleet, along with the new vehicle propulsion types, will require expanded maintenance, operations, and support spaces in comparison with the existing Presidio Yard facility. The new facility will include bus storage and maintenance across multiple stories.

As the design of the new Presidio Yard facility is part of a separate project, the WSP design team has not developed specific concepts for building layouts. Individual BEB charging components and systems used on the SFMTA site specific BEB master plans have been assembled into a “kit of parts” BEB charging modular system package. This “kit of parts” modular BEB charging system and equipment requirements is being provided to allow a future Presidio Yard design team(s) to use similar BEB components and systems and provide a basis of design for charging equipment, approach and charging equipment space, and utility requirements.

As the design of the future site is expected to be multi-level, it is recommended that Presidio Yard adopt an overhead structure-mounted inverted pantograph charging solution. Depending on the design choices and criteria developed by the SFMTA and the future Presidio designer, the required electrical infrastructure could be installed in multiple configurations to suit the final design of the facility. No master plan concept layouts are being developed as part of this project, but the “kit of parts” testing performed on the site has confirmed the following capacities based on the ultimate BEB full fleet conversion.

Table 8-8 summarizes the ZEB infrastructure planned at Presidio Yard.

Table 8-8. Presidio Yard ZEB Infrastructure Summary

| Charging Strategy | # of Existing Buses (2020) | # of ZEBs Supported (2040) | # of Chargers | # of Dispensers | Charger Rating |
|---|---|---|---|---|---|
| Inverted Pantograph | 132 | 217 | 109 | 217 | 150 kW |

Source : WSP

Concepts for the Presidio Yard are not included in this project and will be developed in a separate project directly related to the site’s redevelopment. The “kit of parts” modules displayed below will be used as guiding design principles to allow future designs for the Presidio Yard the flexibility to achieve the capacities noted above.

The following BEB equipment is anticipated to be required to serve the proposed fleet:

— 217 Pantographs

— 109 DC Charging Cabinets

The pantographs and charging cabinets will be served by the following electrical infrastructure:

— Two pairs of interrupter switches and two meters will be ground mounted along the exterior of the facility as required by SFPUC and PG&E. The first interrupter in each pair will be owned and operated by PG&E, and the second interrupter in each pair as well as the meters will be owned and operated by SFPUC. Power will continue from the meters to the new medium voltage switchgear in the future facility.

— One medium voltage switchgear and two medium voltage to low voltage transformers with corresponding low voltage switchgear will be installed in the new facility.

— Each 3,325 kVA transformer can feed a maximum of 20 charging cabinets charging at 150 kW or 40 pantographs charging at 75 kW rate. This calculation is based on maximum AC input rating of 200A at 480V 3 phase, or 166 kVA, for each charging cabinet and is equal to dividing 3,325 kVA by 166 KVA value. See Table 8-9 for number of charging cabinets connected to other transformer based on the assumption that two or more pantographs are fed by one charging cabinet.

Table 8-9. Transformer Size Requirements

| Transformer Size | Charging Cabinets | Dispensers at 1:2 ratio (Concurrent Charging) |
|---|---|---|
| Transformer 1: 3,325 kVA | 20 | 40 |
| Transformer 2: 3,325 kVA | 20 | 40 |
| Transformer 3: 3,325 kVA | 20 | 40 |
| Transformer 4: 3,325 kVA | 20 | 40 |
| Transformer 5: 3,325 kVA | 20 | 40 |
| Total | 100 | 200 |

Source: WSP

While not all EVSE will be in use at once based on the facility modeling tool, the feeder can be sized for a load that is managed by an automatic load management system, but each 480V Transformer must be sized assuming its full connected load can be handled. Further examination of Presidio transformer layout should be evaluated as part of the yard rebuild.

### 8.5.4 *FACILITIES STAGING*

Since Presidio Yard is expected to be fully demolished and redeveloped prior to implementing BEBs on the site, it is recommended that the entire infrastructure and charging position deployment be included in the redevelopment project. This will allow the ZEB transition to occur concurrently to the planned redevelopment construction process and avoid any further operational interruptions.

# 9 WOODS YARD

## 9.1 EXISTING CONDITIONS

This section summarizes Woods Yard's current service parameters, location and facilities configuration, and existing electrical infrastructure.

### 9.1.1 *SERVICE DESCRIPTION AND REQUIREMENTS*

Woods Yard operates 244 service blocks served by 30-foot and 40-foot buses. This fleet travels a total of 21,038 miles during a typical weekday. The average weekday block distance is 86 miles and the longest distanced traveled is 237 miles. The number of stops for each block varies with an average of 497 stops. The accumulative grade of travel for the service blocks at this yard totals to 43% (Table 9-1).

Table 9-1. Existing Service Conditions at Woods Yard

| Total Distance Traveled (mi.) | Average Block Distance (mi.) | Max Block Distance (mi.) | Average Number of Stops | Accumulative Slope |
|---|---|---|---|---|
| 21,038 | 86 | 237 | 497 | 43% |

Source: WSP

### 9.1.2 *LOCATION AND FACILITIES*

Woods Yard is located at 1095 Indiana Street in the City of San Francisco.

Currently, 221 (221 40-foot and 20 30-foot) diesel-hybrid buses are stored, maintained, fueled, and serviced at Woods Yard. The 20 30-foot buses are exclusively used for training purposes. The yard includes the following separate structures and major site areas: a two-story maintenance building, two-story tire shop, stand-alone fuel building, and stand-alone wash building. The site is bisected from north to south by Indiana Street. Electrical utility service is provided by the SFPUC.

As a result of BEB facility conversion planning and cost estimates, the SFMTA is now considering prioritizing the full rebuild and expansion of the Woods Yard following completion of Presidio Yard. Woods Yard is inefficient in its site design and the maintenance function limits it to only 40-foot buses, which constrains the SFMTA's overall maintenance flexibility. If a rebuild scenario moves forward for Woods Yard, the anticipated in-service date range would be between 2032-2035.

An aerial and existing site plan of Woods Yard are presented in Figure 9-1 and Figure 9-2, respectively.

Figure 9-1. Woods Yard – Existing Conditions (Aerial)

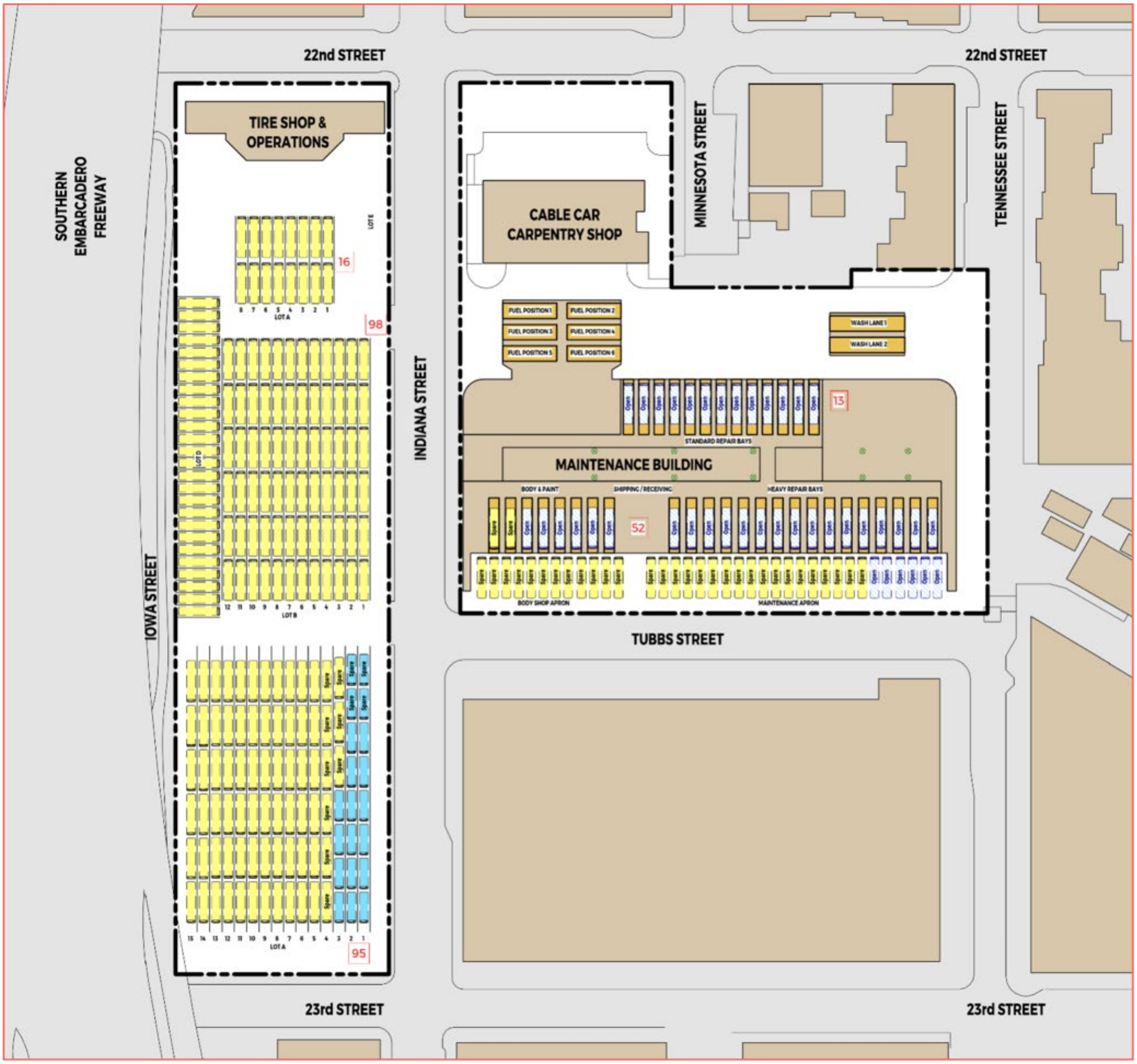

Source: Google Earth

## SITE CIRCULATION

Buses enter the bus storage area from Indiana Street and are parked in unassigned and stacked (nose-to-tail) in 12-foot lanes. Individual buses are then pulled from the storage area and taken by nightly service staff across Indiana Street to the fuel lanes for fare retrieval, interior cleaning, and fueling before pulling forward to the bus wash lane. After fuel and wash, buses are re-parked in the bus storage area. Buses remain parked until morning pull out unless a maintenance issue has been identified. NRVs are parked in a row of spaces along the northern site perimeter between fuel and wash areas.

In Figure 9-2, yellow buses indicate 40-foot buses, and blue buses indicate 30-foot buses.

Figure 9-2. Woods Yard – Existing Site Plan




Source: WSP

### 9.1.3 *ELECTRICAL INFRASTRUCTURE*

The following section provides information on the existing substation, circuit, and transformer that support Woods Yard's electrical needs.

#### SUBSTATION

Woods Yard's power is provided by the Potrero Substation A that is located at 1201 C Illinois Street (23rd Street and Illinois Street), approximately 0.25 miles from the yard. The Potrero Substation serves multiple SFMTA sites, including Flynn, Islais Creek, and Potrero yards.

The Potrero Substation A has a distribution capacity of 44.6 MW. The POTRERO PP (A) 1116 Circuit (Potrero 1116 Circuit) and the POTRERO PP (A) 1101 (Potrero 1101 Circuit) currently feed Woods Yard. The former provides power to the operations building on the west side of the Woods complex, and the latter provides power for all buildings on the east side of the complex.

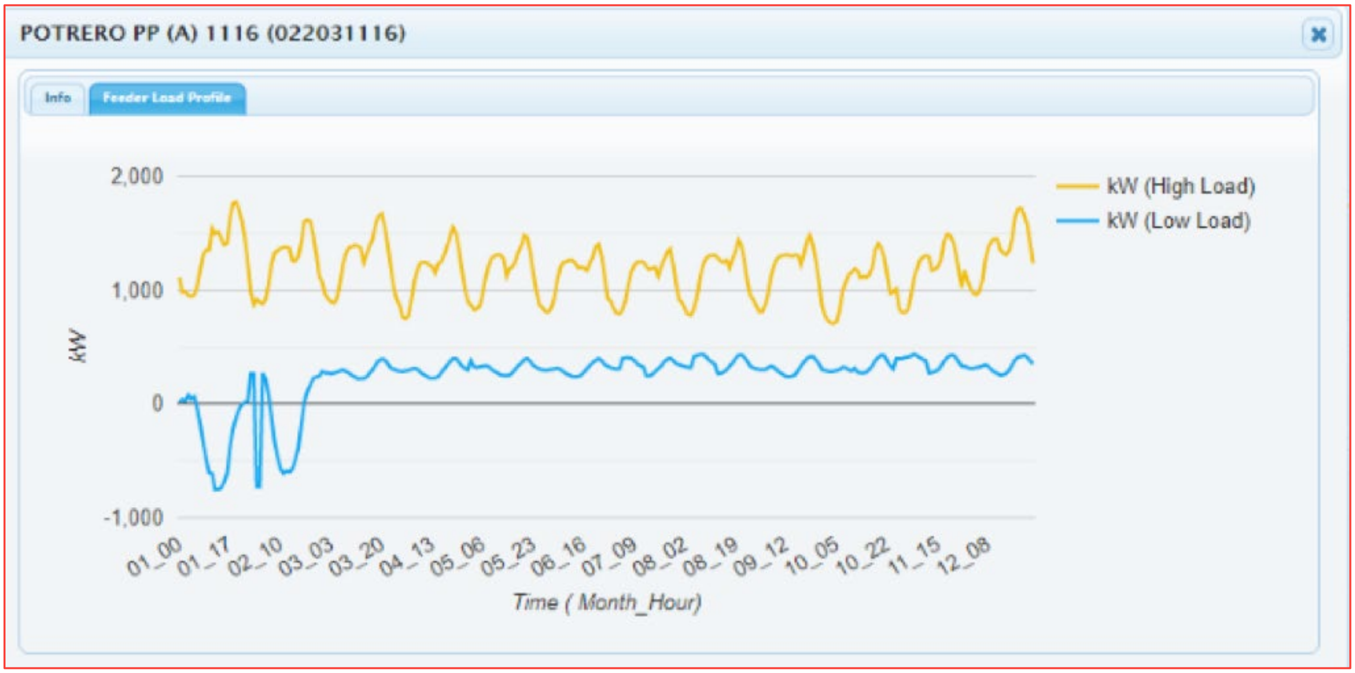
#### CIRCUIT

The Potrero 1116 Circuit is a 12 kV circuit that is fed from the Potrero Substation A. The Potrero 1116 circuit has an existing capacity of 10 MW. PG&E estimates that the projected peak load of this circuit is 8 MW, leaving approximately 2 MW of available capacity.

The Potrero 1101 Circuit is a 12 kV circuit that is fed from the Potrero Substation. The Potrero 1101 circuit has an existing capacity of 9.5 MW. PG&E estimates that the projected peak load of this circuit is 7.8 MW, leaving approximately 1.7 MW of available capacity.

Peak loads for both circuits are monitored by PG&E and published on their ICA map. The loads increase in winter months and have peaks at 9:00 AM and 8:00 PM. Usage is at its minimum between 2:00 AM and 6:00 PM. The metrics of Potrero 1116 are shown in Figure 9-3 and Table 9-2, and metrics for Potrero 1101 are shown in Figure 9-4 and Table 9-3.

Figure 9-3. Woods Yard – Potrero 1116's Load Profile



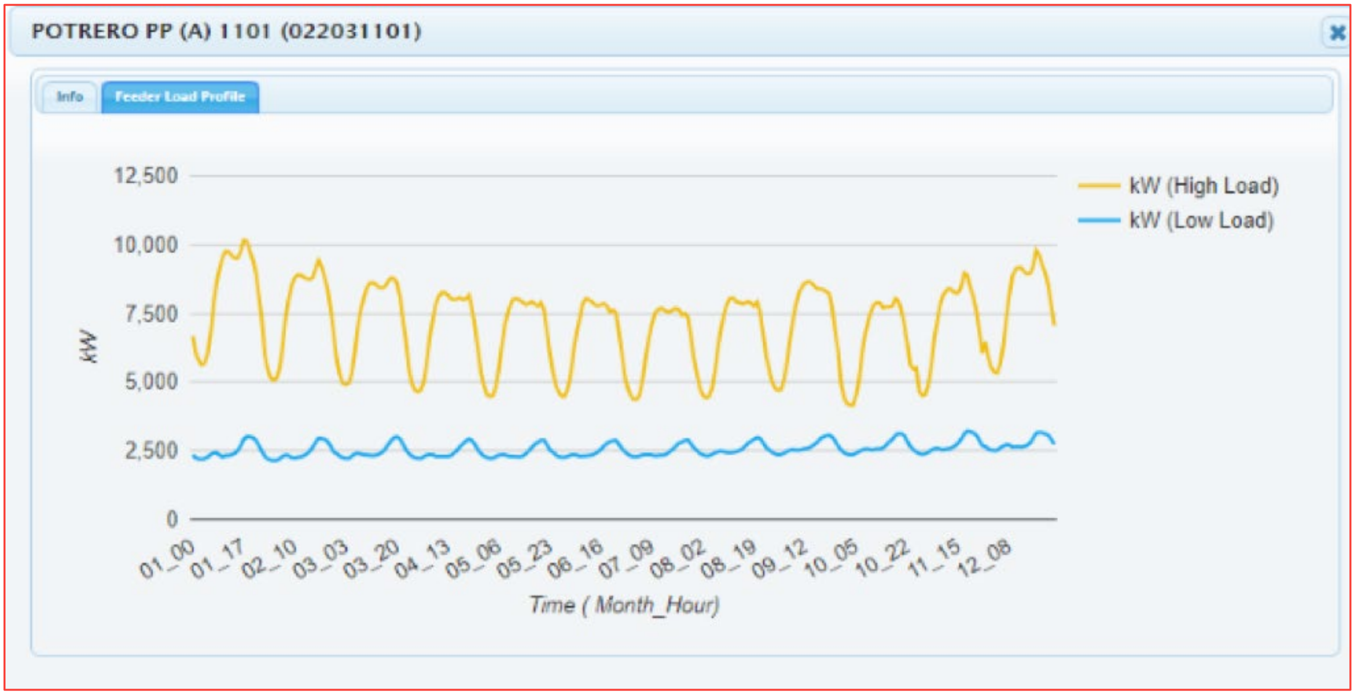

Source: PG&E

Table 9-2. Woods Yard – Potrero 1116's Load Information

| Description | Data |
|---|---|
| Feeder Name | POTRERO PP (A) 1116 |
| Feeder Number | 022031116 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 9.99 |
| Circuit Projected Peak Load (MW) | 8 |
| Substation Bank | 2 |
| Substation Bank Capacity (MW) | 44.6 |
| Substation Bank Peak Load (MW) | 39.98 |
| Existing Distributed Generation (MW) | 0.34 |
| Queued Distributed Generation (MW) | 0.01 |
| Total Distributed Generation (MW) | 0.35 |
| Total Customers | 1271 |
| Residential Customers | 1190 |
| Commercial Customers | 47 |
| Industrial Customers | 21 |
| Agricultural Customers | 0 |
| Other Customers | 13 |

Source: PG&E

Figure 9-4. Woods Yard – Potrero 1101's Load Profile




Source: PG&E

Table 9-3. Woods Yard – Potrero 1101's Load Information

| Description | Data |
|---|---|
| Feeder Name | POTRERO PP (A) 1101 |
| Feeder Number | 022031101 |
| Nominal Circuit Voltage (kV) | 12 |
| Circuit Capacity (MW) | 9.52 |
| Circuit Projected Peak Load (MW) | 7.82 |
| Substation Bank | 10 |
| Substation Bank Capacity (MW) | 74.30 |
| Substation Bank Peak Load (MW) | 43.36 |
| Existing Distributed Generation (MW) | 0.82 |
| Queued Distributed Generation (MW) | 0.02 |
| Total Distributed Generation (MW) | 0.84 |
| Total Customers | 5441 |
| Residential Customers | 4793 |
| Commercial Customers | 486 |
| Industrial Customers | 139 |
| Agricultural Customers | 0 |
| Other Customers | 23 |

Source: PG&E

#### TRANSFORMER

The site transformer for Potrero 1116 is in Room 101 on the first floor of the operations building and feeds a main distribution panel (MDP).

The site transformer for Potrero 1101 is in an exterior cage, room 189A, on the ground floor and feeds a main distribution panel MP.

## 9.2 MODELING RESULTS

The following section presents the blocks completed, fleet requirements, and service phasing strategies emerging from the simulation model for the service blocks operating out of Potrero Yard.

### 9.2.1 *BLOCK COMPLETION*

Between 72% and 95% of all the blocks operating out of Woods Yard (operated by 30-foot and 40-foot buses) can complete current service requirements with current BEB technology based on the three degrees of efficiency described in Section 2.1. Under conservative efficiency estimations, 69 blocks exceed the energy requirements that can be provided by current BEB technologies. Under moderate efficiency estimations, 11 blocks failed. No blocks failed under the optimistic scenario (Table 9-4). It should be noted that a large percentage of the failed blocks are operated by 30-foot buses, which are still in early developments throughout the industry. It is anticipated that 30-foot BEB performance will continue to improve throughout SFMTA's transition goal period; the SFMTA's next round of 30-foot bus procurements is not scheduled until 2032, which should allow substantial time for the technology to advance. Figure 9-5 illustrates the percent of block distances that can be completed with current BEB technologies. This figure demonstrates the degree to which the technology fell short of service requirements, for example, a BEB may have completed 99% of the block and still technically fail. Under conservative estimations, 75% of the fleet is able to complete at least 90% of service requirements. Under moderate estimations, 83% of the fleet is able to meet the same benchmark. Service performance for this fleet may present some of the greatest challenges for BEB fleet readiness. Even at the 50% service completion benchmark, 100% fleet completion is still not achieved. Again, this may be largely mitigated with improvements to 30-foot BEB range, though alternative strategies such as on-route charging or service changes should be investigated.

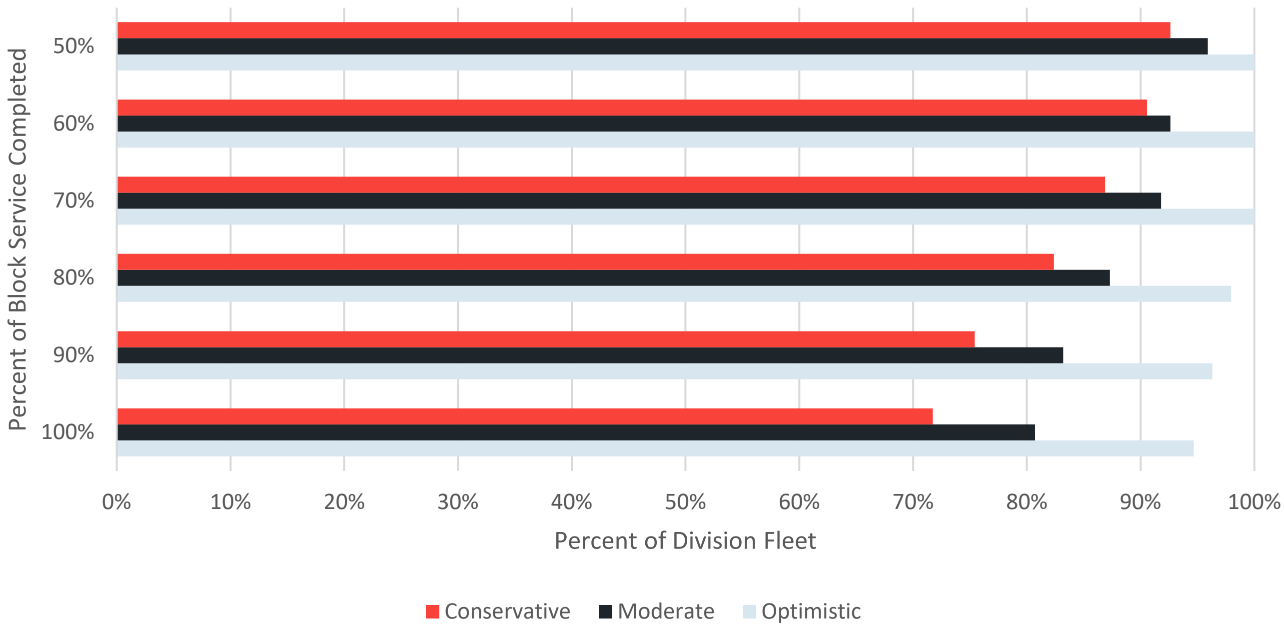
A comprehensive list of failed blocks and the percent block completion can be found in Appendix B: Failed Service Blocks.

Table 9-4. Summary of Failed Blocks at Woods Yard

| Sensitivity | Blocks Failed | Percent Failed |
|---|---|---|
| Optimistic | 13 | 5% |
| Moderate | 47 | 19% |
| Conservative | 69 | 28% |

Source: WSP

Figure 9-5. Percent of Service Requirements Completed for the Woods Yard Fleet

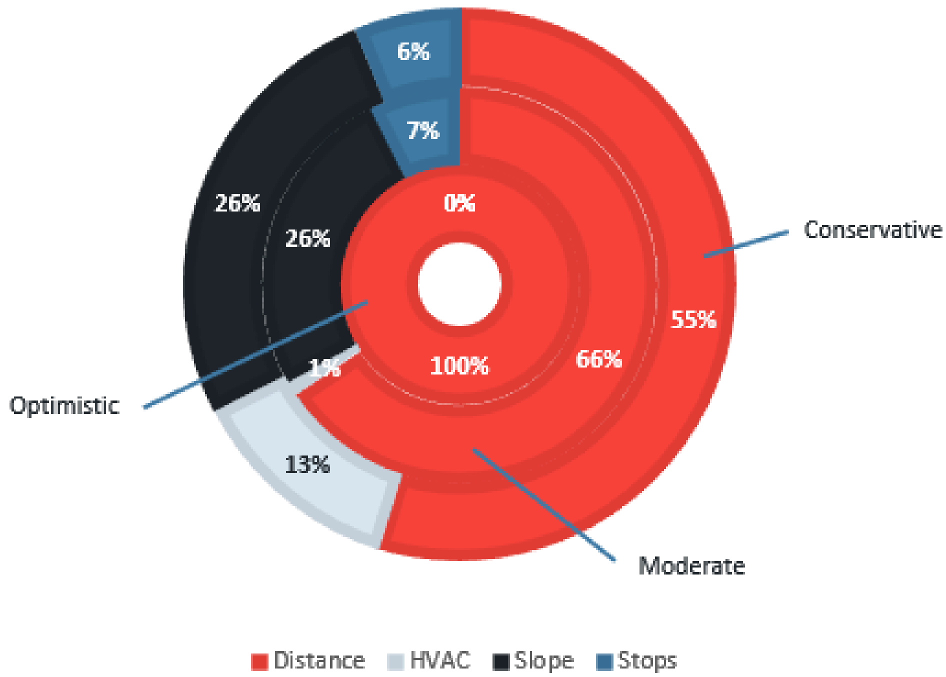



Source: WSP

## 9.2.2 *BLOCK ENERGY CONSUMPTION*

Figure 9-6 identifies the percent energy used from various metrics: distance traveled, HVAC, number of stops, and slope for each sensitivity range. Slope in this service area has a considerable effect on BEB energy consumption, drawing 26% of the battery's available capacity for moderate and conservative efficiencies. The greatest shift in energy consumption distribution between sensitivity ranges is the impact of HVAC. Under the moderate sensitivity range (reflecting a fair-weather day), HVAC has only a 1% influence on energy consumption. When assuming the most extreme climate conditions in the San Francisco, however, HVAC may be expected to draw up to 13% of the battery's available energy. Though the region will rarely experience sustained temperatures at the annual high and low, this impact should be considered, especially in the event that climate change creates a notable effect on regional climate.

Figure 9-6. Percent of Energy Used by Consumption Factors at Woods Yard




Source: WSP

### 9.2.3 *FLEET REQUIREMENTS*

Based on the energy required for each of the 244 service blocks operating out of Woods Yard, the fleet size would need to increase by 57 to 87 buses to meet service requirements under moderate and conservative estimations (Table 9-5). The vehicle replacement ratio under moderate and conservative estimations (without service changes or technology advancements) is 1 to 1.24 and 1 to 1.36, respectively (conventional bus to BEB). The replacement ratio for 30-foot buses nearly doubles that of 40-foot buses, an indication of the nascency of the technology (Table 9-6). This ratio would likely decrease as more 30-foot BEBs enter the market. However, the SFMTA may need to consider strategic transition phasing, service adjustments, and on-route charging to meet service needs.

Table 9-5. Woods Yard Vehicles Required

| Sensitivity | 30’ Vehicles | 40’ Vehicles | Total Vehicles | Net Increase from Existing |
|---|---|---|---|---|
| Optimistic | 36 | 221 | 257 | 13 |
| Moderate | 53 | 248 | 301 | 57 |
| Conservative | 59 | 272 | 331 | 87 |

Source: WSP

Table 9-6. Woods Yard Vehicle Replacement Ratio

| Sensitivity | 30' Vehicles | 40' Vehicles | Total Vehicles |
|---|---|---|---|
| Optimistic | 1:1.5 | 1:1.01 | 1:1.06 |
| Moderate | 1:2.21 | 1:1.13 | 1:1.24 |
| Conservative | 1:2.46 | 1:1.24 | 1:1.36 |

Source: WSP

# 9.3 POWER NEEDS

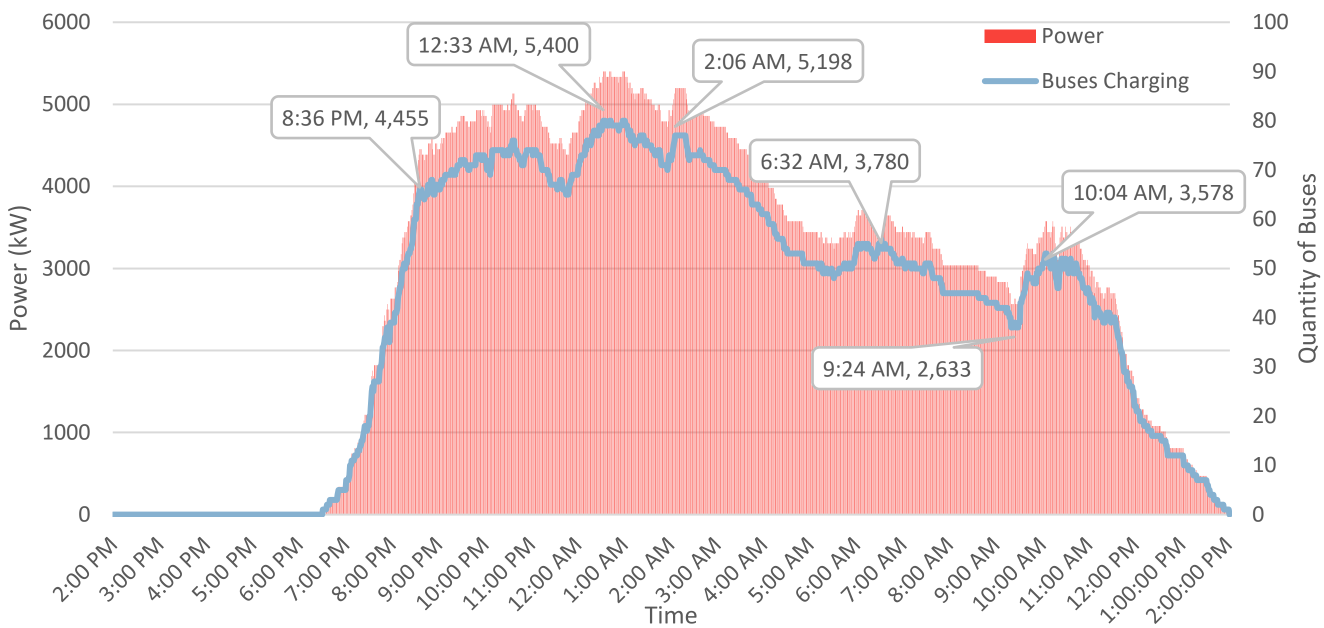
The following section presents current and future energy needs based on various charging ratios and resiliency strategies at Woods Yard.

## 9.3.1 *CURRENT AND FUTURE SERVICE*

From the BEB service modeling, WSP was able to simulate the energy consumption for the fleet parameters assuming that the chargers will split power to each bus to allow concurrent charging at an average rate 67.5 kW for a 1:2 ratio. This takes into consideration battery buffer, efficiency, and pull-in servicing, as previously defined in Section 2.1. Figure 9-7 shows a sharp increase in demand as buses begin charging at 7:00 PM and continues to reach the peak demand at 12:33 AM. The demand fluctuates and slowly drops through 9:24 AM with a small increase around 10:04 AM before dropping down to zero demand by 2:00 PM.

The power shown in Figure 9-7 is used to determine the monthly and annual energy in kWh, as well as the average and peak demand in kW which are summarized in Table 9-7.

Figure 9-7. Woods Yard – Energy Consumption




Source: Jacobs

Electrifying the fleet at Woods Yard of 241 BEBs will consume 2,001,189 kWh a month and 24,014,270 kWh annually, with an average demand of 2,778 kW and a peak demand of 5,400 kW. This yard will be electrifying the current fleet size of 241 BEB's without an increase in 2040 projections.

The current energy needs can be supported by a new service from nearby 12 kV circuits based on the information provided by PG&E. Referring to Table 9-8, there are a few nearby circuits, including Potrero 1118, Potrero 1116 and Potrero 1101, that are potential options to serve the yard. Current and future service energy needs are provided in Table 9-7.

Table 9-7. Woods Yard Energy Consumption

| Woods Yard Energy Consumption | BEB Fleet Size | Average Demand (kW) | Peak Demand (kW) | Monthly Energy Consumption (kWh) | Annual Energy Consumption (kWh) |
|---|---|---|---|---|---|
| Current Fleet | 241 | 2,778 | 5,400 | 2,001,189 | 24,014,270 |
| Future Size | 241 | 2,778 | 5,400 | 2,001,189 | 24,014,270 |

Source: Jacobs

### 9.3.2 *RESILIENCY*

There is a 450 kW diesel emergency generator onsite at Woods Yard. It is assumed that this generator will only be used to power the building and will not charge buses during an emergency.

Auxiliary battery storage can be implemented to reduce the effect of unexpected power outages on operations. PG&E reliability data from 2006 to 2015 show that there is an average of approximately one power outage every two years. On average, a power outage in the San Francisco service environment lasts 78 minutes before service is restored.

In 2040, it is estimated that 241 buses will be stored at Woods Yard. For emergency response, Woods Yard is expected to maintain enough auxiliary power to charge a minimum of 10% of the buses stored at the Yard. This would require 24 buses to be available during an unexpected loss of power.

Woods Yard BEB designs include two 2,000 kWh (4,000 kWh total) of onsite battery storage to provide energy to charge buses during power outages. At an estimated discharge rate of C/4 (i.e. one-fourth of total battery capacity can be discharged per hour), approximately 1,000 kW of battery power will be available for a continuous four-hour period. Using the assumption of all 40-foot buses (with a 458 kWh usable battery capacity, 172 kWh for 30-foot buses) charged at 135 kW, this would provide enough energy to fully charge eight buses from 0% to 100%. Realistically, assuming that all buses are stored with 25% of their total capacity, the reserve systems would be able to charge 11 buses up to 100% (approximately 4% of the fleet stored at Woods Yard).

To charge a fleet of 24 buses (from 25% to 100%) for emergency response, an additional 3,815 kWh of auxiliary battery storage would need to be installed on the premises. This would result in a total of 7,815 kWh that would be able to fully charge emergency response buses within a four-hour period.

Woods Yard is expected to use 815 kW solar panels to charge the onsite battery storage. It is estimated that the solar panels will generate an average of 3,400 kWh on a daily basis.

## 9.4 COSTS

Cost information at Woods Yard for the battery electric bus charging equipment, on-site electrical infrastructure, utility modifications, and facility upgrades have been developed based on the concepts contained in this report.

Note the costs are for improvements to the existing site only; the rebuild costs are anticipated to be on the order of $500 million, similar to Potrero Yard but subject to site design and construction escalation. The estimated costs are $30.4 million for BEB infrastructure and $8.1 million for yard enhancements, resulting in a total direct construction cost of $38.5 million. Construction markups are applied cumulatively to the direction construction cost to arrive at an estimated construction cost of $83.2 million. Project markups are then applied to the estimated construction cost to arrive at the estimated project capital cost of $129.0 million.

## 9.5 RECOMMENDATIONS

The following section provides recommendation for transitioning the fleet at Woods Yard to 100% BEB. Note that this scenario also assumes that the site would not be rebuilt but would rather be an improvement to the existing conditions. There are design considerations for a potential rebuild, such as a multi-level bus charging and storage facilities. For recommendations to support potential rebuilds, refer to Appendix A: Kit of Parts.

### 9.5.1 *FLEET AND OPERATIONS*

The Woods Yard fleet may present the greatest service challenge for the BEB transition. Delaying procurement of 30-foot BEBs and longer service blocks is recommended to allow the technology to continue to mature. The SFMTA recently purchased a 30-foot hybrid fleet, therefore the next procurement cycle should align well with this recommendation. To meet service needs, the SFMTA may also consider modifications to service scheduling or on-route charging.

### 9.5.2 *ELECTRICAL ENHANCEMENTS*

As previously mentioned, there is approximately 2 MW of available capacity on the Potrero 1116 Circuit that currently feeds the west side of the yard. There is approximately 1.7 MW of available capacity on the Potrero 1101 Circuit that currently feeds the east side of the yard. Potrero 1116 circuit can support approximately 37% of the demand. Pending confirmation with SFPUC and PG&E, a new interconnection to feed the yard is recommended to support the future BEB fleet. According to PG&E's PVRAM tool for mapping electric distribution lines, substations, and transmission lines, there are several 12 kV circuits in the vicinity of Woods Yard.

The adjacent circuits may be a factor in providing additional power to Woods Yard. For example, the nearby POTRERO PP (A) 1118 circuit has an available capacity of 6.2 MW that can fully support the BEB fleet with a peak demand of 5,400 kW. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to verify which circuit will feed the yard. For reference Table 9-7 provides the peak demand and energy consumption for Woods Yard and Figure 9-8 with Table 9-8 provides information on nearby circuits.

Figure 9-8. Woods Yard – Nearby Circuits


Source: PG&E

Table 9-8. Woods Yard – Nearby Circuits Summary

| Circuit Name | Voltage | Circuit Capacity (MW) | Circuit Max Load (MW) | Substation Bank Capacity (MW) | Substation Bank Max Load (MW) | Available Circuit Capacity (MW) | Available Bank Capacity (MW) |
|---|---|---|---|---|---|---|---|
| POTRERO PP (A) 1101 | 12 kV | 9.52 | 7.82 | 74.3 | 43.36 | 1.7 | 30.94 |
| POTRERO PP (A) 1116 | 12 kV | 9.99 | 8 | 44.6 | 39.98 | 1.99 | 4.62 |
| POTRERO PP (A) 1118 | 12 kV | 9.99 | 3.78 | 74.3 | 46.68 | 6.21 | 27.62 |
| POTRERO PP (A) 1119 | 12 kV | 8.19 | 5.69 | 44.6 | 39.98 | 2.5 | 4.62 |

Source: PG&E
Notes: POTRERO PP (A) 1101, POTRERO PP (A) 1116 are existing circuits. PG&E to confirm. There are multiple banks at the Potrero substation, so different banks will show different capacities and loads.

### 9.5.3 *FACILITIES*

The Woods Yard will be capable of storing 252 total BEBs, of which 177 can be charged simultaneously. 158 can be charged with pantographs via an overhead supporting structure that spans the area of the existing parking tracks. An additional 19 buses can be charged in the maintenance bays via plug-in dispensers. As buses finish charging, they should be moved to non-charging positions to allow the next bus to begin charging. This scenario also assumes that the site would not be rebuilt but would rather be an improvement to the existing conditions.

Table 9-9 summarizes the ZEB infrastructure planned at Woods Yard.

Table 9-9. Woods Yard ZEB Infrastructure Summary

| Primary Charging Strategy | Overhead Inverted Pantograph |
|---|---|
| No. of Existing Buses (September 2020) | 241 |
| No. of Charging Cabinets | 90 |
| No. of Dispensers/Charging Positions | 177 |

Source: WSP
Note: It is assumed that one charger will provide power for two charging positions/buses/dispensers (1:2 ratio)

The following BEB equipment and locations are proposed:

— 44 DC charging cabinets located primarily on a platform attached to the overhead support structure spanning the southern block of bus parking. These charging cabinets will distribute to 87 pantograph-charging positions mounted from overhead support structures over the existing main bus parking tracks and satellite spaces.

— 36 DC charging cabinets located primarily on a platform attached to the overhead support structure spanning the northern block of bus parking. These charging cabinets will distribute to 71 pantograph-charging positions mounted from overhead support structures over the existing main bus parking tracks and satellite spaces.

— The overhead support structure columns are to be placed every three to four tracks. These columns will also provide the support for the overhead mounted pantographs.

— In the maintenance building, 10 charging cabinets will be installed and connect to 19 dispensers. The dispensers will be mounted between every two bays. This will provide charging to 37 buses that cannot be charged in the main parking area.

The pantographs and charging cabinets will be served by the following electrical infrastructure:

— Two interrupter switch pairs and two meters will be installed on the west side of the site along Iowa Street. The first interrupter in each pair will be owned and operated by PG&E, and the second interrupter in each pair as well as both meters will be owned and operated by SFPUC. Power will transition from the meters to the medium-voltage switchgear located on the two platforms located at the north end of the site and the south end of the site, above the bus parking.

— On the northern platform, one medium-voltage switchgear and two medium- to low-voltage transformers with corresponding low-voltage switchgear will be installed. The switchgear and transformers will be exterior rated.

— On the southern platform, there is one medium- to low-voltage transformers with corresponding low-voltage switchgear will be installed. The switchgear and transformers will be exterior rated.

— Each 3,325 kVA transformer can feed a maximum of 20 charging cabinets charging at 150 kW or 40 pantographs charging at 75 kW rate. This calculation is based on maximum AC input rating of 200A at 480V 3 phase, or 166 kVA, for each charging cabinet and is equal to dividing 3,325 kVA by 166 kVA value. See Table 9-10 for number of charging cabinets connected to other transformer based on the assumption that two or more pantographs are fed by one charging cabinet.

Table 9-10. Transformer Size and Max. Number of Charging Units Charging Simultaneously

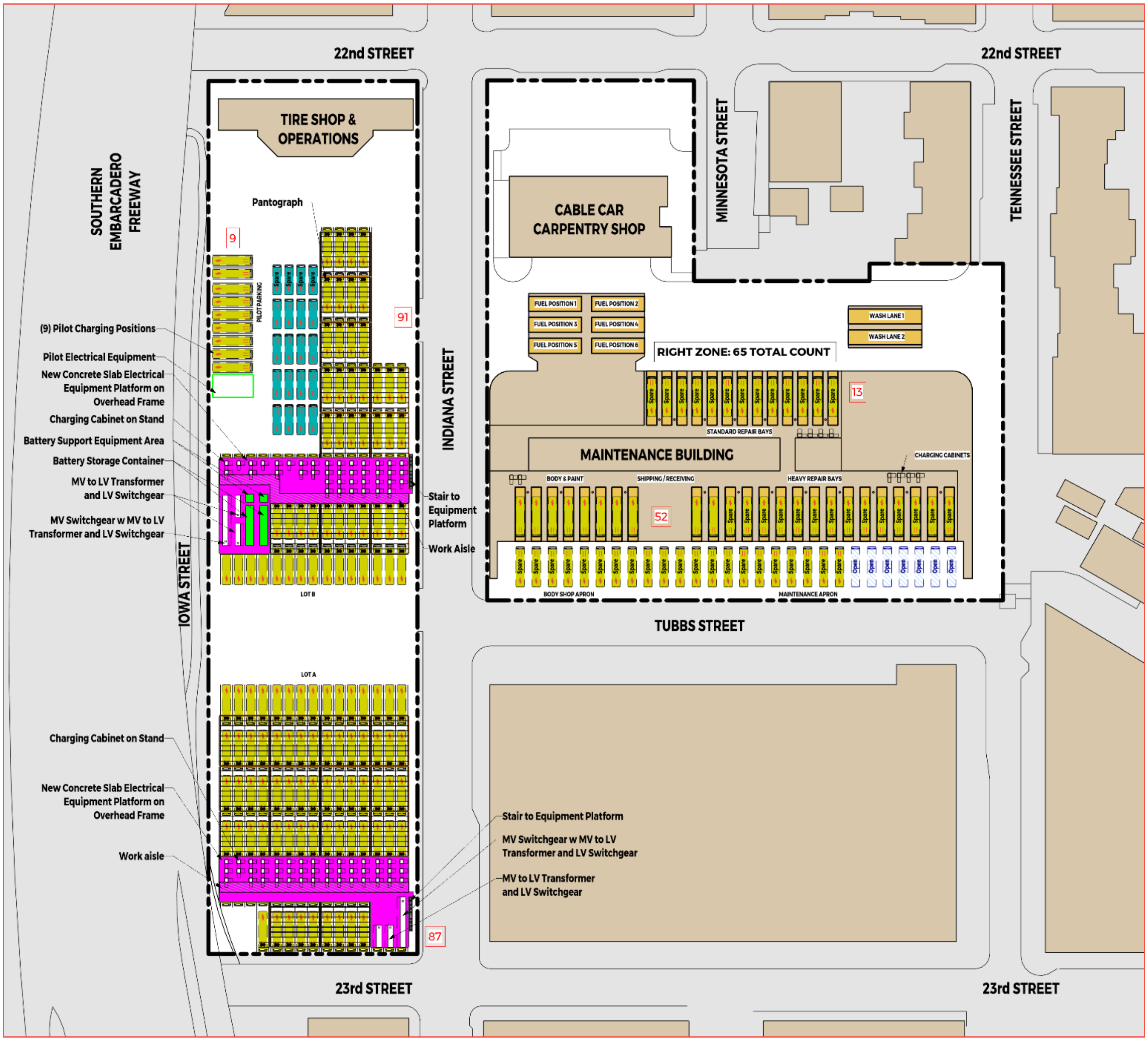
| Transformer Size | Charging Cabinets | Dispensers at 1:2 ratio (Concurrent Charging) |
|---|---|---|
| Transformer 1: 3,325 kVA | 20 | 40 |
| Transformer 2: 3,325 kVA | 20 | 40 |
| Transformer 3: 3,325 kVA | 20 | 40 |
| Transformer 4: 3,325 kVA | 20 | 40 |
| Transformer 5: 2,000 kVA | 12 | 24 |
| Total | 92 | 184 |

Source: WSP

While not all EVSE will be in use at once based on the facility modeling tool, the feeder can be sized for a load that is managed by an automatic load management system, but each 480V Transformer must be sized assuming its full connected load can be handled.

Figure 9-9 illustrates the Woods Yard with an upgrade to the existing conditions, in which yellow buses represent 40-foot BEBs, and blue buses represent 30-foot BEBs.

Figure 9-9. Woods Yard – Full ZEB Build-Out




Source: WSP

## 9.5.4 *FACILITIES STAGING*

As discussed, the specific staging for each yard is still being analyzed, with detailed staging and phasing to be included in Task 3. The following section provides an overview of the proposed improvements in Stage 1, along with a conceptual framework for subsequent stages. Figure 9-10 demonstrates a draft staging plan, illustrating which sections of the yard will be impacted by each stage.

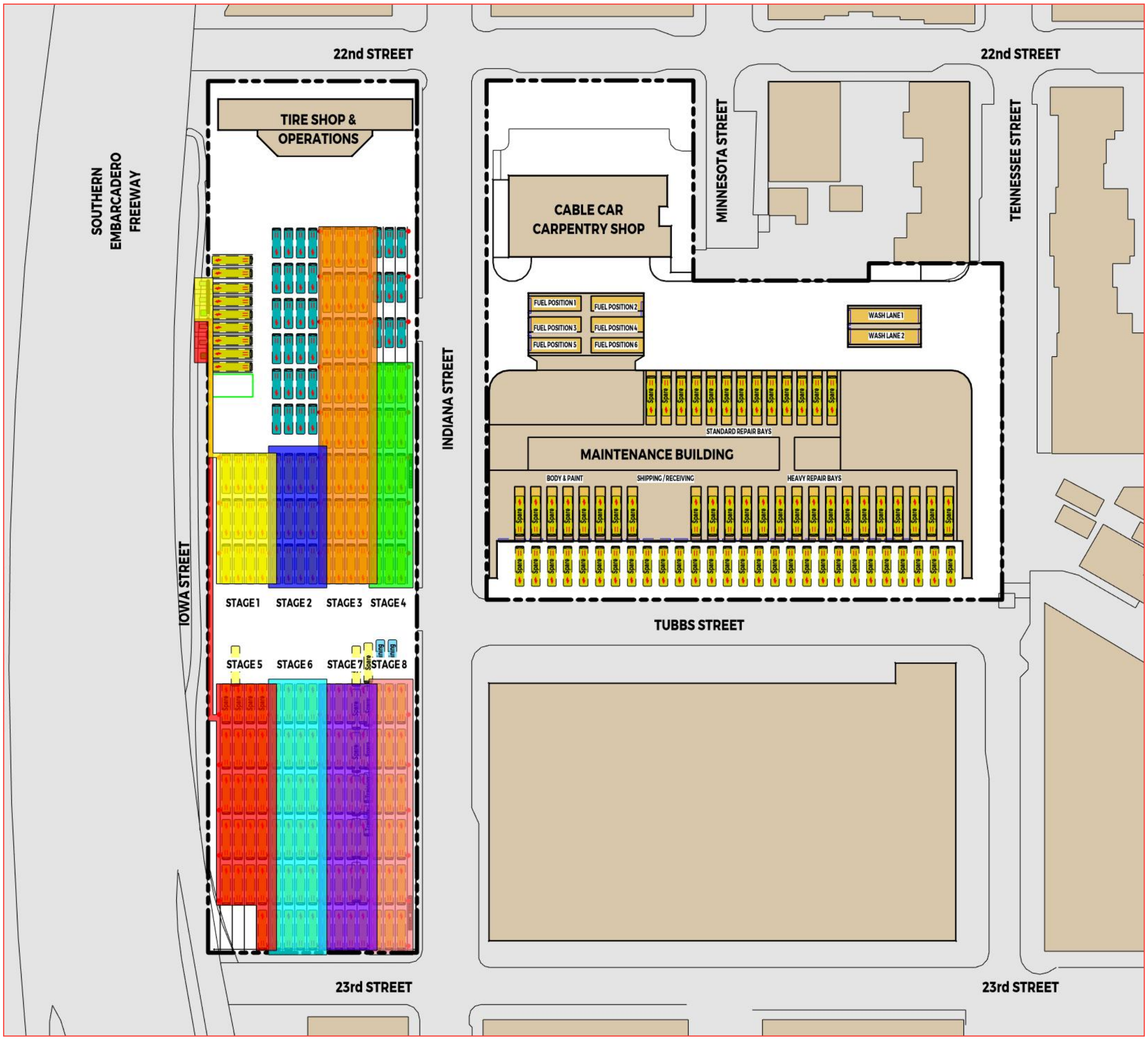
## STAGE 1

The recommended first stage for the Woods Yard includes the installation of four new interrupter switches and two meters on the exterior of the facility along Iowa Street, routing the utility-provided power into the site along the eastern wall to the site's new transformers. Conduit and routing from the utility should be sized to serve the yard's full fleet. Stage 1 will also include the construction of the overhead support structure with distribution conduit, transformers and switchgears, pantographs, and charging cabinets to serve the northern block of bus parking.

## FUTURE STAGES

Each subsequent stage of deployment will be accomplished by adding a similar modular overhead support structure and the required charging infrastructure to support the number of buses to be charged in the stage. The breakdown of this staging will follow the SFMTA's growth plans and prioritization schedule.

Figure 9-10. Woods Yard Staging Plan




Source: WSP

# 10 CONCLUSION AND NEXT STEPS

## 10.1 OPERATIONS

Based off the preliminary analysis of the SFMTA's existing service, BEB technology will largely be able to meet service requirements by the 2040 transition goal. With current BEB capabilities, 86% of the SFMTA's fleet is BEB-ready under moderate efficiency estimations, resulting in a replacement ratio of 1.16 BEBs to one conventional hybrid or trolley bus without any operational modifications or on-route charging.

Service blocks operating out of Islais Creek Yard and Woods Yard presented the greatest operational transition challenges. These results are likely due to the 60-foot and 30-foot fleets operating out of these yards. Technology advancements and greater market availability of these buses will likely contribute to significantly improved performance.

Though the technology projections used in this report are based on best available data, there are always uncertainties when predicting the evolution of emerging and rapidly developing technologies. For this reason, this report recommends considering the following next steps as the SFMTA continues forward in its BEB transition:

— **Run a pilot or shadow service.** The SFMTA is currently preparing for a 40-foot BEB pilot and plans to run a 60-foot pilot in the near future. It is recommended that pilot buses are ran on service blocks that are characteristic of typical service as well as service blocks that may present the greatest performance challenges. The observed bus performance data under various scenarios and route conditions (i.e., steep elevations, frequent stops, high occupancy, extreme and typical weather conditions, etc.) can inform and refine future modeling efforts.

— **Evaluate opportunities to optimize service to compliment BEB technologies.** A variety of service scheduling strategies can be employed to reduce fleet replacement ratios and BEB charging costs. Small schedule modifications, such as optimizing block chaining to maximize mid-day charging can result in reduced capital and operating costs.

— **Evaluate on-route charging options for operational resiliency**. In the case of an extended power outage or emergency evacuation, on-route charging may provide essential fleet power needs for meeting range requirements that exceed BEB capacity.

## 10.2 ENERGY

The peak demand and energy consumption model indicate that transitioning to an all-BEB fleet is viable for the SFMTA. Each yard has nearby circuits with the available capacity to support electrifying the fleet but will require new interconnections to PG&E's utility grid. Additional coordination with SFPUC and PG&E is required to identify and confirm the utility requirements to support each the SFMTA's yards. PG&E's infrastructure will need to be assessed, including the cost of possible upgrades and confirmation of the available capacity to verify which circuit will feed the yard. The following summarizes the recommended next steps:

— **Submit SFPUC new service applications and preliminary electrical plans**. This will initiate conversations and validate the utility infrastructure's ability to support the SFMTA's current and future BEB fleet. Early conversations with SFPUC and PG&E may possibly identify utility limitations early on for design consideration. A detailed charge and load analysis beyond "first in, first out" assumptions should also be achieved as a next step to improve the available charging window and completeness of BEB charging.

— **Continue to evaluate resiliency and backup power solutions.** Resiliency remains a high priority for the SFMTA. WSP will continue to analyze resiliency strategies to ensure fleet operations remain minimally impacted during a prolonged utility outage, such as redundant feeds, battery storage, and dispatchable generators. Additional resiliency may be able to be garnered from existing DC traction power systems at Potrero and Presidio depending on PG&E/SFPUC ability to provide redundant circuits for BEB usage and final facility design.

## 10.3 FACILITIES

For Flynn, Islais Creek, Kirkland, and Woods yards, an overhead mounted pantograph strategy - with much of the electrical infrastructure being mounted on top of a new support structure above the bus parking – is recommended. This design was chosen after several discussions with key SFMTA staff and stakeholders for the following reasons:

— Maximum yard capacity will be achieved by installing equipment overhead.

— Allows existing service and circulation patterns to be minimally modified during the transition.

— Trenching in the parking areas will be minimized. With overhead equipment and distribution, there will be minimal disruption to existing operations and circulation, and it also allows for more rapid reconfiguration of the charging dispensers if the fleet mix changes or expands.

— The 1:2 charger to dispenser ratio provides the SFMTA with cost, space, and power demand savings over a 1:1 system while still providing adequate power to charge the fleet overnight. It should be noted that charging technology is rapidly changing and other ratios may be considered in subsequent phases (ex. 1:3 charging).

— Mounting all the charging equipment and infrastructure overhead provides protection against flooding and inclement weather scenarios, vehicle strikes, and also isolates the equipment from pedestrians.

— On-site battery backup and solar generation (where possible) will support the fleet during power outages and also be used to help the SFMTA better manage energy loads during periods of highest usage.

For Potrero and Presidio yards, an overhead mounted pantograph charging strategy is also recommended. A ”kit of parts” design that outlines the requirements for charging a BEB was developed since both yards are anticipated to be fully rebuilt. The kit can be utilized by the SFMTA for Potrero, Presidio, and any other sites that may be fully rebuilt. The kit of parts provides generic modules for an overhead mounting platform structure (and charging infrastructure), a module for distribution and dispensing in the bus parking areas, and consideration for how to connect this charging equipment and infrastructure to utility-owned equipment.

During WSP’s analysis, there were several items that will need to be refined and considered in the SFMTA’s transition, including:

— **Identifying the required modifications to transition Islais Creek**. Caltrans has an easement (I-280) that traverses the site. No permanent infrastructure can be installed in this area, so trenching and other creative strategies will need to be explored.

— **Aligning the pilot program with master planning and transition efforts.** The upcoming pilot program that will be at Woods Yard needs to be coordinated with the master plan and staging steps of the site’s transition.

— **Determine and plan what the transition will look like over time.** The transition will require portions of facilities to be shut down and buses to be temporarily relocated (on site or to other yards) for construction activities. All of this is anticipated to be done without any impact to riders. WSP will explore and present staging and phasing plans in Task 3.

## 10.4 BUS SPECIFICATIONS

When developing BEB specifications it is essential that the SFMTA is precise in their expectations so that the vehicles meet operational needs as advertised. It should be noted that each bus procurement is unique and updating transit operator specifications to ZEB is an involved and often time-consuming process. Outlined below are some sample items that are recommended for inclusion in BEB specifications:

- **Explicit performance requirements**. The SFMTA should be clear with range requirements and also account for battery degradation. For example, vehicles shall be able to travel a minimum of 160 miles on all service blocks, under any climate conditions with a full passenger load, and be able to safety and efficiently navigate the hilly conditions throughout the SFMTA's service area.
- **Weight limitations.** It is likely OEMs are aware, but there are strict regulations on axle weights that must be adhered to. This comes at a time when battery capacities are increasing, so it is pertinent that the vehicle can be legally operated.
- **Charging system and equipment.** This decision should be based on operations and also provide flexibility for maintenance. For example, charging receptacles shall be placed on both sides of the bus at the rear axle and an overhead pantograph receptor (i.e., charge rail) shall be installed on the vehicle's roof above the front axle.
- **Warranty provisions**. As previously mentioned, batteries do degrade over time and OEMs are rapidly evolving and advancing new battery technologies. For this reason, it is important to consider warranties to protect the BEB investment and ensure that the performance at the beginning of a BEB's life matches (or is better) at the end of life. 12-year warranties are becoming an industry standard.

# APPENDIX A: KIT OF PARTS

## *BATTERY ELECTRIC BUS CHARGING "KIT OF PARTS" CONCEPTS*

The following drawing package presents the "kit of parts" modular battery electric bus charging designs developed to be implemented at the SFMTA's properties. This package consists of the drawings and sheets noted below.

COVER SHEET INDEX / GENERAL INFORMATION

SD 1.1 OVERHEAD FRAME MODULE SOLAR SUPPORTING

SD 1.2 OVERHEAD FRAME MODULE CONCRETE DECK EQUIPMENT SUPPORTING

SD 1.3 IDEALIZED CHARGING LAYOUT ON OVERHEAD FRAME MODULES

SD 1.4 CABLE TRAY AND RATIO SECTIONS

SD 1.5 OVERHEAD INVERTED PANTOGRAPH DETAIL AT OVERHEAD FRAME

SD 1.6 OVERHEAD INVERTED PANTOGRAPH DETAIL AT PRECAST DECK

SD 1.7 DEPOT PANTOGRAPH DETAIL AT PRECAST DECK

SD 1.8 OVERHEAD INVERTED PANTOGRAPH DETAIL AT HIGH BAY

SD 1.9 OVERHEAD INVERTED VS DEPOT PANTOGRAPH COMPARISON

SD 1.10 WALL MOUNTED PLUG-IN DISPENSER IN MAINTENANCE ADN SERVICE BAYS

SD 1.11 SUSPENDED PLUG-IN DISPENSER IN MAINTENCE AND SERVICE BAYS

## *BATTERY ELECTRIC BUS "KIT OF PARTS" PERFORMANCE SPECIFICATIONS*

The following performance specifications have been developed as part of the "kit of parts" for implementing BEB charging infrastructure at SFMTA properties.

### VEHICLE CHARGING EQUIPMENT

SECTION 11 11 36.14

COMMERCIAL ELECTRIC VEHICLE CHARGING UNIT FOR TRANSIT DEPOTS

PART 1 - GENERAL

The General Provisions of the Contract, including General and Special Conditions and the requirements of Division 1, apply to the Work in this Section.

1.01 WORK INCLUDED

A. Guide specification of equipment items as listed below by Equipment Mark Number are provided to establish minimum performance requirements, operational criteria, and standards compliance of a DC charging system for commercial battery electric vehicles charged via automated connection to overhead charging rail on vehicle roof and by handheld manually inserted plug. Alternative systems that comply with these minimum performance requirements, operational criteria and standards compliance but are achieved by physically different equipment configurations than the guide layout and the components listed but achieve the same verifiable results will be considered and reviewed by Owner as equivalents. DC overhead charging system to consist of:

1. CHARGING CABINET, BATTERY ELECTRIC BUS, 150kw DC POWER
   Equipment Mark Number: 8012

2. CHARGING PANTOGRAPH, INVERSE, FACILITY MOUNTED
   Equipment Mark Number: 8020

3. REMOTE PLUG-IN DISPENSER
   Equipment Mark Number: 8025

B. Installation of equipment with labor, services, and incidentals necessary for complete and operational equipment installation.

C. Utilities to be roughed in at location recommended by manufacturer.

D. Coordination of equipment and vehicle to allow for automated operation and communication of the Charging Pantograph, Inverse, Facility Mounted, Equipment Mark Number: 8020 with the Owner’s battery electric bus fleet. Coordination with other equipment and/or items shall include, but not necessarily be limited to, the following:

   1. Equipment Mark Number 8030 Electric Vehicle Charge Management System as specified in Section 11 11 36.20 Electric Vehicle Charge Management System

E. Coordination of equipment and vehicle to allow for corded handheld plug (charge connector) and communication of the Remote Plug-In Dispenser Mark Number: 8025 with the Owner’s battery electric bus fleet. Coordination with other equipment and/or items shall include, but not necessarily be limited to, the following:

   1. Equipment Mark Number 8030 Electric Vehicle Charge Management System as specified in Section 11 11 36.20 Electric Vehicle Charge Management System

## 1.02 QUALITY ASSURANCE

A. Equipment shall be produced by a manufacturer of established reputation with a minimum of five years’ experience supplying specified equipment.

B. Manufacturer's Representative:

   1. Installation: Provide a qualified manufacturer's representative at site to supervise work related to equipment installation, check out and start up.

   2. Training: Provide technical representative to train Owner's maintenance personnel in operation and maintenance of specified equipment.

3. Testing: Provide technical representative for final testing of equipment.

C. Installation of this equipment item requires initial mock-up and acceptance by design team and owner. Refer to Part 3.02 of this specification section Installation for more details

1.03 STANDARD AND REGULATORY REQUIREMENTS

A. Equipment indicated within this specification section shall comply with all applicable national, state and local codes and regulations, including seismic, fire, and racking codes and regulations. Additional, more specific compliance requirements may be listed under individual equipment headings.

1.04 SUBMITTALS

A. Submittal requirements for all equipment items included in this section are listed below.

B. Product Data:

1. Submit Product Data in accordance with Division 1 - General Requirements of these specifications.

2. All Product Data submittals shall identify proposed project specific items marked by arrow, circle, underline, reproducible highlight, or other markings clearly discernable by the reviewer, to show which specific items, parts and accessories are being submitted for the project product data review. Non-marked or generic product data submittals with no marks indicating specific items, parts and accessories will be a cause for rejection.

3. Restrict submitted material to pertinent data. For instance, do not include manufacturer's complete catalog when pertinent information is contained on a single page.

C. Operation and Maintenance Manual:

1. Provide a Complete parts list, operating instructions, and maintenance manual covering equipment at time of installation including, but not limited to:

a. Description of system and components.

b. Manufacturer's printed operating instructions.

c. Printed listing of periodic preventive maintenance items and recommended frequency required to validate warranties. Failure to provide maintenance information will indicate that preventive maintenance is not a condition for validation of warranties.

d. List of original manufacturer's parts, including suppliers' part numbers and cuts, manufacturer's recommended spare parts stockage quantity and local parts and service source based on anticipated frequently replaced and or long lead (more than five workdays) components.

2. Assemble and provide copies of manual in 8-1/2 by 11-inch format. Foldout diagrams and illustrations are acceptable. Manual to be reproducible by dry copy method. Provide copies per provisions of Division 1 - General Requirements.

D. Shop Drawings: Submit shop drawings in accordance with Division 1 -General Requirements of these specifications.

1. Submitted shop drawings shall be project specific and shall include a minimum 1/8 inch to 1 foot scaled (or larger standard architectural imperial scale), dimensioned, graphical representation of the size, orientation, and location for all instances of submitted equipment in a floor plan view and reflected ceiling plan view for DC charging cabinets, dispenser (pantographs and remote plug-in cabinets) and other system elements. The drawings shall further include dimensions from structural elements or architectural grid lines, to each major charging equipment item (8012, 8020 & 8025) operational clearances, locations of any utility service connection points, power and communication output points, mounting requirements, and structural supports required for the submitted equipment. Indicate which specific dispensers are connected to and energized by which specific DC charging cabinet.

2. Manufacturer's standard installation drawings will be accepted and reviewed but are not considered as a replacement to project specific shop drawings.

E. Test Reports: Testing and Commissioning reports are required for all systems included in this specification and shall be included as part of the close-out documents. Provide to the equipment consultant a copy of all testing and commissioning reports for equipment specified herein. Refer to Part 3.03 Testing, of this specification.

F. Required Documents for Permit and Local Jurisdictional Approval: Where required by local jurisdiction and/or code officials, the contractor/supplier shall be responsible for producing and submitting all documentation required for obtaining all applicable approvals related to the specified equipment. This documentation may include, but may not be limited to, engineered signed and stamped plans, details, anchorage layouts for equipment on stands and as racks to show compliance with locally adopted ASCE, seismic, fire, and other codes. A copy of these required documents shall be included with the product submittal to the Design Team/consultant team for their review.

1.05 WARRANTY

A. Warrant work specified herein for one year from substantial completion against defects in materials, function, workmanship and charging system operational design.

B. Warranty shall include materials and labor necessary to correct defects including replacement of charging system operational elements with re-designed components.

C. Defects shall include, but not be limited to loose, damaged and missing parts and abnormal deterioration of finish, excessive cord wear.

D. Operational design defects include for pantograph charger and dispenser include systemic bent or non-flexing conductor rails, non-extending / retracting of pantograph due to factory installed elements, failure or intermittent failure to instigate charging process and pantograph deployment due to inability to connect and / or non-communications with vehicle properly aligned below pantograph, failure to deploy pantograph, initiate or complete charging process due to interference from adjacent installed pantographs is an operational design defect. Pantographs conforming to this performance specification are intended to perform in a dense bus parked environment with anticipated adjacent pantographs and battery electric buses on all four sides of surrounding each installed pantograph. Operational design defects for DC charging cabinet and plug-in dispenser include systemic bent charging and charging communications connector pins, damaged charging cord conductors and internal wiring, breakage and deterioration of charging plug-in mating elements (ports, charging connector) during routine daily use of charging system. Submit warranties in accordance with Division 1 - General Requirements of these specifications.

E. All parts shall be readily available locally in the United States.

1.06 PRODUCT DELIVERY, STORAGE, AND HANDLING

A. Deliver equipment in manufacturer's containers, appropriately packaged and/or crated for protection during shipment and storage in humid, dusty conditions. Equipment shall be stored per manufacturer's recommendation.

B. Indelibly label all containers, including those contained in others, on outside with item description(s) per title and Mark Number of this specification.

C. Provide equipment and materials specified complete in one shipment for each equipment item. Split or partial shipments are not permissible.

1.07 LABELING

A. Manufacturer shall securely attach in a prominent location on each major item of equipment a non-corrosive nameplate showing manufacturer's name, address, model number, serial number, and pertinent utility or operating data.

B. All electrical equipment and materials shall be new and shall be listed by Underwriter's Laboratories, Inc. (U.L.), or other US National Recognized Testing Laboratory (NRTL) acceptable to both the design team and local code officials, in categories for which standards have been set by that agency and labeled as such in the manufacturer's plant.

PART 2 – PRODUCTS

2.01 CHARGING CABINET, BATTERY ELECTRIC BUS, 150kw DC POWER
Equipment Mark Number: 8012

A. General:

1. Description: Upright cabinet(s) connected to multiple charger dispensers including:

a. Facility mounted inverse charging pantograph, and capable of automatically charging the connected battery electric bus (BEB) utilizing direct current (DC) electrical power. Intended for long term charging of BEBs in overnight parking positions. Unit must be capable of operating in dense installation of multiple mark 8012 charging cabinet units located in same general area.

b. Facility mounted standalone stationary cabinet dispenser capable of charging a battery electric bus utilizing (DC) electrical power after being manually connected to a battery electric bus by a flexible power cord and handheld plug. Intended for short term charging of BEBs in maintenance and service bays.

2. Coordination: Specification information indicated herein is intended as general requirement only. Final design of the system shall be by the manufacturer and shall be presented in the project specific shop drawings in coordination with the Charging Pantograph, Inverse, Facility Mounted Equipment Mark Number: 8020 and Remote Plug-In Dispenser Mark Number 8025 as a fully coordinated, complete design.

3. Compliance: The equipment and final design shall comply with the most current editions of all applicable local, state, and federal codes and regulations, including, but not limited to, those listed below.

a. SAE International Standard J3105, Electric Vehicle Power Transfer System Using a Mechanized Coupler, most recent edition

b. SAE International Standard J3105/1, Infrastructure-mounted Pantograph (Cross-Rail) Connection

c. SAE J1772: SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler, most recent edition.

d. NFPA 70: National Electric Code (NEC), most recent edition.

e. NFPA 70E: Standard for Electrical Safety in the Workplace, most recent edition

f. Underwriter’s Laboratory UL 2202, Standard for Electric Vehicle (EV) Charging System Equipment, most recent edition.

g. Underwriter’s Laboratory UL 2231-1, Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: General Requirements

h. Underwriter’s Laboratory UL 2231-2, Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems.

i. ANSI/IEC 60529: Degrees of Protection Provided by Electrical Enclosures (IP Code), most recent edition.

j. IEC 61851-1; 23; 24: Electric Vehicle Conductive Charging System, most recent edition.

k. IEC 61000-6-2: Electromagnetic Compatibility (EMC) – Part 6-2: Generic Standards – Immunity Standard for Industrial Environment.

l. ISO 15118: Road Vehicles – Vehicle to Grid Communication Interface.

m. 29 CFR 1910.147: General Environmental Controls, The Control of Hazardous Energy (Lockout/Tagout), as enforced by OSHA, most recent edition.

n. International Electrotechnical Commission (IEC) 60309, most recent edition.

o. Federal Communications Commission (FCC) rules and regulations, as applicable.

p. Open Charge Point Protocol OCPP 2.0 or higher to allow charger control and monitoring by a third-party charge management system

4. Components:

a. Power Cabinet(s).

b. All components, interconnecting cabling and conduits/ducts between components, software, and accessories for a fully and properly operational device.

B. Capacities and Dimensions:

1. Total output charge power, direct current (DC): Nominal 150 kilowatts (kW), minimum capable to charge a 660kWh battery electric bus (BEB) from a thirty percent state of charge to 95% state of charge in a consecutive four-hour period from a single dispenser.

a. Systems that combine power outputs from two or more separate standalone cabinets to produce the total output charge power of the nominal 150kW minimum and charger time are acceptable and considered equivalent to a single 150kW cabinet unit.

b. Systems that employee a single larger kW cabinet with multiple outputs to dispensers that produce the total output charge power of the nominal 150kW minimum and charger time are acceptable and considered equivalent to a single 150kW cabinet unit.

c. Quantity of inverted pantographs charging dispensers in bus parking areas, excluding plug-in dispensers in maintenance and service bays, and output charge power from entire overhead DC charging system to be capable of charging full quantity of overhead electrically charged vehicles identified on the project drawings in a single consecutive (8) eight hour period minimum.

2. Output voltage range: 200-1,000 volts, DC.

3. Rated DC output current range: 3-250 Amps, bi-directional.

4. Operating temperature range: -22 degrees Fahrenheit (F) to 113 degrees F.

5. Input connections: 3 phase plus protected earth ground wire

6. Input power rating: nominal 205 kVA (full load) / 100 VA (idle)

7. Input AC line-line voltage range: 480 VAC +6/-13%

8. Input AC phase current: nominal 283 amps, maximum / 385 amps fused.

9. Power factor, total harmonic distortion: 0.95, minimum.

10. Power conversion efficiency at full load: 96%, minimum.

11. Dielectric withstand: 3,000 volts, root mean square (RMS).

12. Network connection: 3G modem, minimum, utilizing Open Charge Point Protocol (OCPP) 2.0 or later network communication.

13. Protection: IP54 and IK 10 or equivalent NEMA rating.

14. Operational noise level: 85 decibels, maximum.

15. Overall dimensions, power cabinet(s), nominal:

a. Width: 31.5 inches.

b. Depth: 31.5 inches.

c. Height: 91 inches.

d. Weight: 2,200 pounds.

C. Features and Construction:

1. Each electrical cabinet to be a standalone unit capable of meeting the specification herein. The cabinet shall include capability for entry of alternating current (AC) electrical supply, main isolation transformer cabinet, AC to DC power conversion, AC grid coupling and protective devices, DC output coupling and protective devices,

controller for charger circuit and the communication equipment, and forced-air over coolant chiller functions.

2. Capable of being connected to power supply grid or low voltage power distribution station.

3. Charge cabinet configurable to support either multiple overhead pantograph dispensers or plug-in dispensers. Individual cabinet not required to be capable of being connected to and simultaneously or concurrently energizing a mix of both pantographs and plug-in dispensers.

    a. On concurrent controlled and powered dispensers, shared dispensers connected (dispenser A, dispenser B+), to a single DC power cabinet, the nominal output (voltage, current, power, charging telemetrics and controls) to the simultaneously connected remote dispensers will be split from the DC power cabinet and, as controlled by the DC power cabinet's shared dispenser charging priority system, power one remote dispenser unit (dispenser A) up to the nominal maximum outputs while simultaneously and concurrently providing minimal or remaining DC power cabinet's output to the other shared connected remote dispenser units (dispenser B+) until all BEBs connected to the shared charging dispensers are fully energized. During this concurrent controlled charging process, after BEBs initial dispenser connection, plug-in or pantograph connection at the beginning of the charging process, no manual re-plugging / disconnection, re-plugging / reconnection, re-paring or wireless connection of charge connector or pantograph will be necessary.

    b. On sequentially controlled and powered dispensers, shared dispensers connected to a single DC power cabinet, the nominal output (voltage, current, power) to the simultaneously connected remote dispensers (dispenser A, dispenser B+) will be shifted from the DC power cabinet and, as controlled by the DC power cabinet's shared dispenser charging priority system, power one remote dispenser (dispenser A) unit up to the nominal maximum outputs while not providing output to any other connected shared remote dispenser units (dispenser B+). As controlled by the DC power cabinet's shared dispenser charging priority system, the DC power cabinet's output will then automatically switch and shift the output (from dispenser A) to another connected and shared remote dispenser unit (dispenser B) up to the nominal maximum outputs (to dispenser B) while not providing output to any other connected shared remote dispenser units (dispenser A, C+). The shifting of power output between the various connected shared remote dispenser units continues until all BEBs connected to the shared charging dispensers are fully energized. During this sequential controlled charging process, after BEBs initial dispenser connection, plug-in or pantograph connection at the beginning of the charging process, no manual re-plugging / disconnection, re-plugging / reconnection, re-paring or wireless connection of charge connector or pantograph will be necessary.

4. Capable of being configured to operate dispenser configuration and energizing a minimum quantity of:

    a. Two (2) Charging Pantograph, Inverse, Facility mounted Equipment Mark Number: 8020 and capable of providing charging power to each pantograph either sequentially or concurrently. Includes all interconnecting electrical cabling, data cabling, conduit / ducts, and all other components necessary for interconnection.

    b. Two (2) Remote Plug-In Dispenser Equipment Mark Number: 8025 and capable of providing charging power to each plug-in dispenser either sequentially or concurrently. Includes all interconnecting electrical cabling, data cabling, conduit / ducts, and all other components necessary for interconnection.

5. Capable of providing bi-directional charging to facilitate gird to vehicle (G2V) and vehicle to grid (V2G) power transfers.

6. Intended for, and fully capable of, installation in an outdoor environment, with a thermal and water-resistant enclosure. Cabinet(s) shall include an integral raised base for protection of equipment and fastening to sub-structure. Raised base should allow for mounting to an elevated steel support frame and not require direct to concrete pad installations.

7. Includes an on-board transformer / rectifier, allowing the power cabinet to receive an alternating current (AC) input power connection from the facility electrical supply and convert it to direct current (DC) electrical output to the charge box and connected bus.

8. Includes a chiller unit capable of maintaining manufacturer's required temperature for power conversion components. Chiller shall include protective air intake grill(s) and fan(s).

9. Unit is designed to be installed with multiple similar mark 8012 charging cabinet units in a dense location and vent locations of cabinets to facilitate close proximity installations between similar cabinets to sides and rear of unit.

10. Include forklift pockets at base of unit or lifting lugs on top and or side of unit. Units that utilize no mechanical connections for lifting and rely solely on wrapped / strapping connections around unit cabinet case to install, position or remove unit are not acceptable.

11. Controller shall include the protective ground connection, the DC output voltage connections, and the supervisory control components.

12. Communications portion of the controller equipment shall be capable of being connected to other computer networks, including networks with charge management systems, through Ethernet and/or wireless connection. The power

cabinet shall be capable of communicating to that charge management system by means of an open source, non-proprietary, communication protocol.

13. Includes a cellular antenna, 3G or better, enabling connection to cellular networks.

14. Includes on-board computer and/or programmable logic devices, software, and wireless communication devices that, at a minimum, also provide the following functionality to the power cabinet:

    a. Pantograph Dispenser

        1) To wirelessly detect BEB mounted transponders within each attached Facility Mounted Inverse Charging Pantograph's (Pantograph) operational area and ignore transponders outside each attached Pantograph's operational area including similar transponders located on all four sides surrounding transponder installation. This process shall be automatic, and performed at system start-up / system re-start, and at programmable intervals and times, up to and including near continuous detection.

        2) To initiate wireless signal with, receive wireless signal from, and establish a wireless communication protocol with any bus in the Owner's BEB fleet that is determined by the system as being parked within the pantograph's operational area, and that has an on-board transponder (by others).

        3) To communicate with, and automatically cause each attached individual Pantograph to descend once a BEB has been identified, communication established, and has been detected as 'parked' within that Pantograph's individual operational area. The equipment shall ignore BEBs passing through a Pantograph's operational area.

        4) Automatically cause an attached Pantograph to retract upon receiving a 'disengage' signal from a connected BEB that is parked in that Pantograph's operational area,

        5) Automatically cause each Pantograph to retract to a 'fail safe' state when receiving pertinent error codes, and upon facility power outages and major fluctuations. 'Fail safe' Pantograph retraction shall occur for individual isolated Pantographs and system wide for all Pantographs, depending on error code.

        6) Automatically terminate wireless communication with any BEB after a pre-programmed time, and after detecting the BEB is no longer in operational range, or when the BEB is disengaged.

    b. Plug-In Dispenser

1) To initiate signal with, receive signal from, and 'handshake' with any bus connected by means of the charge connector while charge connector is plugged into the charging port of a bus.

2) To automatically start, stop, and regulate any charge to any bus battery connected by means of the charge connector while charge connector is plugged into the charging port of a bus.

3) To communicate wirelessly collected bus information to a charge management system regardless of whether the charge connector is plugged into or disconnected from the charging port of a bus.

c. Once wireless communication is established with the bus, to communicate with, request and receive from the BEB the following information: bus identification and battery information such as charge status, temperature, etc.

d. Information collected shall be stored, and able to be transmitted to a charge management system.

e. To automatically start, stop, and regulate any charge to any bus battery connected by means of the Facility Mounted Inverse Charging Pantograph or charge connector.

f. To request, receive, and store bus battery information such as ID, charge status, temperature, etc. from the bus by means of wireless communication with the bus being charged.

g. To allow Owner's charge management system to control and report a minimum feature set of each charging cabinet in real time:

1) Cabinet connected dispenser / pantograph status – connected to a vehicle / not connected to a vehicle

2) Cabinet on (allowing charging to occur) / off (not allow charging to occur)

3) Total cabinet power output

4) Report vehicle ID connected to each dispenser / pantograph connected to DC charging cabinet

5) Cabinet not operational / unit issuing trouble code

15. Lock-out / Tag-out functions shall include, at a minimum, the following:

a. AC supply entry cabinet shall not be allowed to open under live grid conditions and shall only be allowed to open only if the main power supply to the charger is locked out.

b. Main transformer cabinet(s) and AC/DC converter cabinet shall not be allowed to open under live grid conditions and shall only be allowed to open if there are no live grid conditions to the charger and if the main power supply breaker is locked out.

c. The chiller cabinet shall not be allowed to open while the charger is energized but shall only be allowed to open if the charger is de-energized and the auxiliary switch is locked out.

16. Emergency Stop Button directly accessible on the outside of the power cabinet. Allows for emergency stopping of the charger and de-energizing of the charging system.

17. Group Remote Emergency Stop Button capable. Allows for connections to auxiliary emergency stop buttons remotely located in the facility and connected to multiple equipment mark 8012 charging cabinet units to stop / reset charging cabinet units as a group. Remote emergency stop reset should not require individual resetting of mark 8012 charging cabinet's factory installed cabinet integrated emergency stop button after remote emergency stop button reset.

18. Remote manual override controls for the Pantograph, capable of extending or retracting the Pantograph on demand and re-start charging wireless validation and the charging process without the need to physically re-park or reset individual vehicle parking brakes. Override controls shall include a key switch and keys for operation.

19. Includes all other components for necessary and proper function of the unit including, but not necessarily limited to, metal support frame and protective panel enclosure, foundation support base, air intake and exhaust vents, forced air cooling fans, air filters, grounding devices and connections, cables, cords, connectors, etc.

D. Finish: Exterior panels of power cabinet to have protective finish to prevent corrosion of enclosure. Provide in Owner's choice of manufacturer's standard colors.

E. Accessories:

1. Refer to Equipment Mark Number 8020 for Charging Pantograph.

2. Refer to Equipment Mark Number 8025 for Remote Plug-In Dispenser.

3. Coolant, in quantity and type as required by manufacturer.

4. Fabricated steel support stand, capable of elevating and properly supporting the DC power cabinet unit. Steel shall be hot-dip galvanized in accordance with ASTM A123 Standard. Refer to drawings for details.

5. Emergency Stop Button (E-Stop) – directly accessible on the outside of the DC power cabinet. Allows for emergency stopping / de-energizing output of all remote

dispenser units connected to a single DC power cabinet whose E-Stop button is activated

6. Group Remote Emergency Stop Button (E-Stop) – in quantities and locations as shown on the drawing. Allows for emergency stopping / de-energizing output of all remote dispenser units connected to a multiple DC power cabinets in groupings as shown on the drawings.

F. Utilities:

1. Electrical: 480 VAC, 3 Phase, 60 Hz, nominal 283 amps maximum / 365 amps, maximum inrush (fused).

2.02 CHARGING PANTOGRAPH, INVERSE, FACILITY MOUNTED Equipment Mark Number: 8020

A. General:

1. Description: An overhead facility mounted retractable pantograph capable of automatically connecting to the roof mounted charging contacts of buses in the Owner's battery electric bus (BEB) fleet, and then automatically charging the connected bus utilizing direct current (DC) electrical power via the connected Charging Cabinet, Battery Electric Bus, 150kw DC Power, Equipment Mark Number: 8012.

2. Coordination: Specification information indicated herein is intended as general requirement only. Final design of the system shall be by the manufacturer and shall be presented in the project specific shop drawings in coordination with the Charging Cabinet, Battery Electric Bus, 150kw DC Power, Equipment Mark Number: 8012 as a fully coordinated, complete design.

3. Compliance: The equipment and final design shall comply with the most current editions of all applicable local, state, and federal codes and regulations, including, but not limited to, those listed below.

a. SAE International Standard J3105, Electric Vehicle Power Transfer System Using a Mechanized Coupler, most recent edition.

b. SAE International Standard J3105/1, Infrastructure-mounted Pantograph (Cross-Rail) Connection

c. NFPA 70: National Electric Code (NEC), most recent edition.

d. Underwriter's Laboratory UL 2202, Standard for Electric Vehicle (EV) Charging System Equipment, most recent edition.

e. Underwriter's Laboratory UL 2231-1, Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: General Requirements

f. Underwriter's Laboratory UL 2231-2, Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems.

g. ANSI/IEC 60529: Degrees of Protection Provided by Electrical Enclosures (IP Code), most recent edition.

h. ANSI/IEC 61851-23: Electric Vehicle Conductive Charging Systems, DC Electric Vehicle Charging Station.

i. 29 CFR 1910.147: General Environmental Controls, The Control of Hazardous Energy (Lockout/Tagout), as enforced by OSHA, most recent edition.

j. International Electrotechnical Commission (IEC) 60309, most recent edition.

k. Federal Communications Commission (FCC) rules and regulations, as applicable.

B. Capacities and Dimensions:

1. Pantograph:

a. Rated Voltage: 1,000 volts, DC, minimum

b. Rated charging current: 250 Amps (A), minimum.

c. Operating temperature range: -22 degrees Fahrenheit (F) to 150 degrees F

d. Pantograph operating range, from partial to full extension (nominal): 30 inches to 90 inches

2. Pantograph controller and motor:

a. Supply voltage: 24 volts, DC

b. Current: 40A nominal.

c. Pantograph contact force with vehicle: 112 foot-pounds, maximum

d. Total time to raise pantograph from full extension to full retraction: 5 seconds, maximum.

e. Total time to lower pantograph from full extension to full retraction: 5 seconds, maximum.

f. Compensation of pantograph to the parked bus, nominal:

1) X-axis: 30 inches to the vertical axis

2) Y-axis: +/- 12 inches to the transversal axis

3) Z-axis: +/- 12 inches to the longitudinal axis

3. Compensation of angles: 5 degrees each direction

4. Wireless Communication System:

a. Wireless system communication: CAN bus with SAE J1939 communication protocol.

b. Wireless data interface between antenna and antenna controller: RS-232, Ethernet

c. Communication protocol between antenna and antenna controller: Serial.

d. Wireless antenna:

1) Dimensions, nominal: 12 inches, 9 inches, 6 inches.

2) IP Rating: IP 66 or equivalent NEMA rating

3) Specified range: Capable of detecting bus mounted system transponder within an 8-foot radius of the antenna. Capable of transmitting to and receiving information from any bus mounted system transponder with the 8-foot radius from the antenna. Able to ignore similar surrounding transponders directly adjacent to but outside of the 8-foot radius.

5. Wireless Antenna Controller:

a. Dimensions, nominal: 36 inches, 28 inches, 16 inches.

1) IP Rating: IP 66 or equivalent NEMA rating

6. Wireless Transponder and Data Collector:

a. Connect to vehicle via SAE J1939 connectors.

7. Overall dimensions, nominal:

a. Length: 57 inches nominal maximum

b. Width: 40 inches nominal maximum

c. Height: 42 inches nominal maximum in retracted position

d. Necessary clearance in x-axis: 2 inches

e. Necessary clearance in y-axis (length of rails + clearance): 25 inches + 2 inches

8. Dimensions of interface, nominal:

a. Length (total): 57 inches

b. Length (single contact): 40 inches

c. Width: 30 inches

9. Pantograph positions, from mounting plane (underside of facility structure), as noted on drawings

C. Features and Construction:

1. Pantograph and Pantograph Controller:

a. 'Inverted' pantograph down design mounted to the facility structure and extending down to contact vehicle mounted charging contact bars.

b. Pantograph and pantograph controller shall have integrated fail-safe functions. Functions shall include automatic full retract of the Pantograph upon error code, power loss, or other system malfunction.

c. Independently insulated multi-pole contacts: positive, negative, protected earth (ground) and control pilot.

d. Zero electrical potential frame components.

e. Includes flexible head and spring-loaded connection allowing for compensation of the pantograph system.

f. Capable of raising and lowering the pantograph to pre-programmed height/positions.

g. Capable of both quick duration contact fast-charge and long duration depot charging.

h. Includes an internal sensor to provide a soft-stop landing on the bus roof rails.

2. Wireless Communications System Antenna and Antenna Controller: Shall be mounted in a fixed position near the pantograph and contain a programmable logic controller, or similar computing device, along with all accessories (such as cooling devices) necessary for proper operation. Together, the Antenna and Antenna Controller shall be able to perform the following functions:

a. The Controller shall be able to compute relative distances of bus mounted transponders from the Antenna.

b. The Controller shall be able discriminate between bus mounted transponder distances and acknowledge and communicate with any bus mounted system transponder located only within the programmed Pantograph operational area. Transponder signals outside of the operational area shall be ignored.

c. The Controller shall be able to instantly compare each Bus Identification Number received from a bus transponder signal within the specified range to a central Bus Identification Number Authorization File (or similar). The Controller shall continue to try and communicate with bus transponders allowed by the Authorization File and shall ignore signals from bus transponders disallowed by the Authorization File.

d. Upon initial detection of any bus transponder within the Pantograph operational area, and allowed by the Authorization File, the Controller will immediately search for confirmation signals that the same bus transponder is still within the operational area. If confirmation signals are detected, then the "handshake" communication protocol shall be established between the Controller and the transponder, via the Antenna. If confirmation signals are not detected, then no communication protocol shall be established, and the Antenna and Controller shall continue to search for a transponder signal within the operational area.

e. Upon successful establishment of the "handshake" communication protocol, a communication link shall be established to enable the Controller to read information from the bus mounted Transponder via wireless communication through the Antenna. For the duration of the communication link, the antenna will only accept information from the connected transponder. All other transponder signals shall be ignored.

f. During the life of the communication link, the Controller shall periodically ping the linked transponder and confirm the transponder is still within the specified range of the Antenna and Controller. If so, the communication link shall not be terminated. If not, the Controller shall immediately terminate the link, and begin to search for a transponder signal within the specified range.

g. Controller shall have a physical and/or wireless data connection to the Owner's network, and capable of periodically accessing and reading the Owner's Bus Identification Number Authorization File. Periodic access shall be programmable and shall occur at regular intervals.

h. Controller shall be capable of establishing a secure internet connection through the Owner's network to regularly and periodically download software updates.

3. Wireless Communications System Software: Programs as necessary for functioning of each individual Antenna Controller, as well as a central software program for managing multiple Antenna Controllers within a single site. Central software program shall be web based, or compatible with Owner's Windows compatible PCs.

4. Includes all other components for necessary and proper function of the unit including, but not necessarily limited to, metal support frame and protective panel enclosure, foundation support base, grounding devices and connections, cables, cords, connectors, etc.

D. Finish: Corrosion and wear resistant finish in Owner's choice of manufacturer's standard colors.

E. Accessories:

1. Modular metal framing system to provide support and stability to items suspended from facility structure. Configuration, quantity and spacing to be determined as part of contractor's final design.

2.03 REMOTE OVERHEAD DISPENSER Equipment Mark Number: 8025

A. General:

1. Description: A stationary upright cabinet with a flexible power cord and corded handheld plug (charge connector) capable of being manually connected to the charging port of buses in the Owner's electric bus fleet, and then automatically charging the connected bus utilizing direct current (DC) electrical power output generated from a connected Mark Number 8012 DC Power Cabinet.

2. Compliance: The equipment and final design shall comply with the most current editions of all applicable local, state, and federal codes and regulations, including, but not limited to, those listed below.

a. NFPA 70: National Electric Code (NEC), most recent edition.

b. SAE J1772: SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler, most recent edition.

c. ANSI/IEC 60529: Degrees of Protection Provided by Electrical Enclosures, most recent edition.

d. Open Charge Point Protocol OCPP 2.0 or higher to allow charger control and monitoring by a third-party charge management system

e. NFPA 70E: Standard for Electrical Safety in the Workplace, most recent edition.

f. CFR 1910.147: Code of Federal Regulations, Occupational Safety and Health Standards, General Environmental Controls, The Control of Hazardous Energy (Lockout / Tagout), most recent edition.

B. Capacities and Dimensions:

1. Output voltage range at the remote dispenser, refer to Equipment Mark Number: 8012

2. Output current at the remote dispenser, refer to Equipment Mark Number: 8012

3. Output power at the remote dispenser, refer to Equipment Mark Number: 8012

4. Overall dimensions, remote dispenser, nominal:

    a. Width: 24 inches.

    b. Depth: 9 inches.

    c. Height: 32 inches.

    d. Weight: 60 lbs. (including weight of cord and charge connector below)

    e. Cable length: 22 feet - nominal.

    f. Charging Connector – SAE J1772 CCS Level 2 plug-in connector with strain relief

C. Features and Construction:

1. Remote dispenser unit shall be connected to and receive power output (voltage, current, power, charging telemetrics and controls) from the DC power cabinet, then regulate and transmit that output to the bus, when manually connected by the charging connector.

    a. Include glass fiber (or similar) communications lines between the DC power cabinet and remote dispenser, as well as all necessary protective conduits, seals, and fasteners.

    b. Remote dispenser enclosure shall be rated IP65 protection, per ANSI/IEC 60529.

2. Dispenser cabinet to be mounted in locations shown on plans but anticipated to be mounted to existing facility structural elements or being suspended from overhead structural frame supported by existing facility structure. Ground mounted support stands for plug-in dispensing cabinet located in Maintenance and Service bays are not to be utilized unless specifically call for on plans.

3. Charging connector and attached cord shall be capable of being manually connected to, and disconnected from, the bus charger. Charging connector shall conform to SAE J1772 SAE standard.

4. Charger Status Indicator Light on bottom or side of remote dispenser cabinet and visible to an operator below the plug-in dispenser cabinet when mounted overhead. If charge status indicator light is standard on the top of the cabinet and cabinet orientation does not allow a user below to see the cabinet, providing a secondary cabinet mounted or adjacent mounted to facility structure remote charger status indicator light is acceptable. Three (3) color or more to indicate via color and blinking the following:

1) Charger Energized and Ready

2) Charger Connected and Charging

3) Charger Connected and Charge Complete

4) Charger Not Ready / Not Charging / Warning Indicator

5. Coordinate installation of the dispenser cord, the dispenser cabinet, and the charging connector in the field so that, once installed, there is minimal bending and/or twisting of the dispenser cord, or ‘flipping’ of the charge connector, when personnel attempt to plug the charge connector into a battery electric bus.

D. Finish: Exterior panels of charger box to have protective powder coat finish in Owner's choice of manufacturer's standard colors.

E. Accessories:

1. Modular metal framing system to provide support and stability to items suspended from existing horizontal or vertical structural facility elements. Configuration, quantity and spacing to be determined as part of contractor’s final design. Kindorf or equal.

2. Cord hook / rack to store and secure flexible power cord and charge connector at nominal five foot above finish floor when not in use.

3. Remote secondary charge status indicator light as needed.

PART 3 - EXECUTION

3.01 INSPECTION

A. Coordinate location of rough-in work and utility stub-outs to assure match and/or non-interference with equipment to be installed.

B. Inspect delivered equipment for damage from shipping and exposure to weather. Compare delivered equipment with packing lists and specifications to assure receipt of all items.

3.02 INSTALLATION

A. Perform work under direct supervision of Foreman or Construction Superintendent with authority to coordinate installation of scheduled equipment with Design Team.

B. Coordinate work with Manufacturer’s Representative indicated in Part 1.02 of this specification section

C. Install equipment in accordance with plans, approved shop drawings, and manufacturer's instructions:

1. Initial owner mockup for positioning pantograph Equipment Mark: 8020: At a parked bus charging position to be identified by owner, provide installation mockup of DC charging cabinet connected to an overhead pantograph, wireless communications system to allow for testing and proofing of DC charging system component mounting heights and overhead locations or components relative to parked bus. Mock-up to allow for in-field adjustment of individual charging components, including but not necessarily limited to, electrical junction boxes, mounting and support brackets, and pantograph orientation and auxiliary control connection points. In field adjustments shall consist of those necessary to allow the overhead pantograph to be deployed automatically when a bus is properly parked in the charging position and wireless communications system is engaged. Mock-up shall be reviewed and approved by design team and owner prior to installation of other overhead charging components. Overhead components purchased or installed prior to mock-up approval shall be modified to conform to the approved mock-up without additional material or labor charges to owner

2. Positioning: Place equipment in accordance with any noted special positioning requirements generally level, plumb and at right angles to adjacent work.

3. Fitting: Where field cutting or trimming is necessary, perform in a neat, accurate, professional manner without damaging equipment or adjacent work.

4. Anchorage: Attach DC charging cabinet equipment securely to floor or elevated support frame, in conformance with manufacturer's instructions and as directed by Design Team, to prevent damage resulting from inadequate fastening and to resist seismic movement. Installation fasteners shall be installed to avoid scratching or damaging adjacent surfaces. Upon completion of work, finish surfaces shall be free of tool marks, scratches, blemishes, and stains.

3.03 TESTING

A. After final connections are made and prior to authorizing payment, specified equipment shall be tested for compliance with specification in the presence of the Design Team using acceptance procedures provided by the manufacturer.

B. Final testing and post installation inspection are required and shall be performed by the manufacturer or the manufacturer’s designated representative only. Final testing and inspection shall not be performed by the installer, unless the installer is also the manufacturer.

C. Manufacturer / Installer shall provide a testing procedure and checklist that indicates proper testing of all major functions of the equipment. This procedure and checklist will form the basis of the testing process.

3.04 CLEANUP

A. Touch-up damage to painted finishes.

B. Wipe and clean equipment of any oil, grease, and solvents, and make ready for use.

C. Clean area around equipment installation and remove packing or installation debris from job site.

D. Notify Design Team for acceptance inspection.

3.05 TRAINING

A. Direct the technical representative to provide specified hours of training to designated Owner's maintenance personnel in operation and maintenance of the following equipment. Coordinate, with Owner, training schedule and list of personnel to be trained.

1. CHARGING CABINET, BATTERY ELECTRIC BUS, 150KW DC POWER
Equipment Mark Number: 8012
Hours Required: 16

2. CHARGING PANTOGRAPH, INVERSE, FACILITY MOUNTED
Equipment Mark Number: 8020
Hours Required: Included in training for Equipment items listed above.

3. REMOTE PLUG-IN DISPENSER
Equipment Mark Number: 8025
Hours Required: Included in training for Equipment items listed above.

B. Obtain, from technical representative, a list of Owner's personnel trained in equipment operations and maintenance.

C. Provide a Windows compatible movie file format recording on USB stick of the training session. The training movie can be a recording of a live session or a produced training video

END OF SECTION 11 11 36.14

## CHARGE MANAGEMENT

SECTION 11 11 36.20

ELECTRIC VEHICLE CHARGE MANAGEMENT SYSTEM

PART 1 - GENERAL

The General Provisions of the Contract, including General and Special Conditions and the requirements of Division 1, apply to the Work in this Section.

1.01 WORK INCLUDED

A. Guide specification of equipment items as listed below by Equipment Mark Number are provided to establish minimum performance requirements, operational criteria, and standards compliance of an electric vehicle charge management system. Alternative systems that comply with these minimum performance requirements, operational criteria and standards compliance but are achieved by physically different equipment configurations than the guide layout and the components listed but achieve the same verifiable results will be considered and reviewed by Owner as equivalents. Electrical vehicle charge management system to consist of:

1. ELECTRIC VEHICLE CHARGE MANAGEMENT SYSTEM Equipment Mark Number: 8030

B. Installation of software and equipment with labor, services, and incidentals necessary for a complete and properly operational equipment installation.

C. Utilities to be roughed in at location recommended by manufacturer.

D. Wiring, and switching between equipment and utilities.

E. Coordination of equipment, controls, system, and vehicle to allow for proper charge management of electric bus vehicles by means of multiple charge cabinets and dispensers – both inverted overhead pantographs and plug-in dispensers. Coordination with other equipment and/or items shall include, but not necessarily be limited to, the following:

1. Equipment Mark Number 8012 Charging Cabinet, Battery Electric Bus, 150kw DC Power, as specified in Section 11 11 36.14 Commercial Electric Vehicle Charging Unit for Transit Depots.

2. Equipment Mark Number 8020 Charging Pantograph, Inverse, Facility Mounted, as specified in Section 11 11 36.14 Commercial Electric Vehicle Charging Unit for Transit Depots.

3. Equipment Mark Number 8025 Remote Plug-In Dispenser, as specified in Section 11 11 36.14 Commercial Electric Vehicle Charging Unit for Transit Depots

4. The SFMTA selected and procured battery electric bus (BEB) vehicle with integrated charge management system components

5. The SFMTA selected computer terminals.

1.02 QUALITY ASSURANCE

A. Experience: Equipment shall be produced by a manufacturer of established reputation with a minimum of five years experience supplying specified equipment.

B. Manufacturer's Representative:

1. Installation: Provide a qualified manufacturer's representative at site to supervise work related to equipment installation, check out and start up.

2. Training: Provide technical representative to train Owner's maintenance personnel in operation and maintenance of specified equipment.

3. Testing: Provide technical representative for final testing of equipment.

1.03 STANDARD AND REGULATORY REQUIREMENTS

A. Equipment indicated within this specification section shall comply with all applicable national, state and local codes and regulations. Additional, more specific compliance requirements may be listed under individual equipment headings.

1.04 SUBMITTALS

A. Submittal requirements for all equipment items included in this section are listed below.

B. Product Data:

1. Submit Product Data in accordance with Division 1 - General Requirements of these specifications.

2. All Product Data submittals shall identify proposed project specific items marked by arrow, circle, underline, reproducible highlight, or other markings clearly discernable by the reviewer, to show which specific items, parts and accessories are being submitted for the project product data review. Non-marked or generic product data submittals with no marks indicating specific items, parts and accessories will be a cause for rejection.

3. Restrict submitted material to pertinent data. For instance, do not include manufacturer's complete catalogue when pertinent information is contained on a single page.

C. Operation and Maintenance Manual:

1. Provide a Complete parts list, operating instructions, and maintenance manual covering equipment at time of installation including, but not limited to:

a. Description of system and components.

b. Schematic diagrams of electrical and communications.

c. Manufacturer's printed operating instructions.

d. Printed listing of periodic preventive maintenance items and recommended frequency required to validate warranties. Failure to provide maintenance information will indicate that preventive maintenance is not a condition for validation of warranties.

e. List of original manufacturer's parts, including suppliers' part numbers and cuts, recommended spare parts stockage quantity and local parts and service source.

2. Assemble and provide copies of manual in 8-1/2 by 11 inch format. Foldout diagrams and illustrations are acceptable. Manual to be reproducible by dry copy method. Provide copies per provision of Division 1 - General Requirements.

D. Shop Drawings: Submit diagram schematic of system including graphic representations of software installations and modules and their hosting hardware, hardware components and their physical location or hosting element. Include operational decision tree including:

1. Typical operational configuration with monitoring and charging control activates noted.

2. System integration and override points available real time to on-site SFMTA personnel.

E. Test Procedure and Test Reports: Testing Procedures and Testing Reports are required for all systems included in this specification. Testing procedures shall be submitted to the Owner and Design Team prior to installation, and shall, at a minimum, outline the manufacturer's procedure for successful testing of the equipment after installation. Testing Reports shall be record documents of the post installation test, itemizing the requirements of the Test Procedure and noting if individual requirements were met or not met, with notes and comments as needed. Testing reports shall be provided to the Owner and Design team upon completion of testing, prior to final invoice. Provide duplicates of all test reports as part of the Close-Out Documents. Refer to Part 3.03 Testing, of this specification.

F. Required Documents for Permit and Local Jurisdictional and or Power Utility Approval: Where required by local jurisdiction, power utility provider and/or code officials, the contractor/supplier shall be responsible for producing and submitting all documentation required for obtaining any and all applicable approvals related to the specified equipment. This documentation may include, but may not be limited to, engineered signed and stamped plans, system features and diagrams of functionality and operational decision tree, details, anchorage layouts, as well as other documents to show compliance with locally adopted codes and utility regulations and requirements. A copy of these required documents shall be included with the product submittal to the Design Team/consultant team for their review.

1.05 WARRANTY

A. Warrant work specified herein for one year from substantial completion against defects in materials, function, and system operational design.

B. Warranty shall include materials, software, and labor necessary to correct defects including replacement of the charge management system in its entirety.

C. Defects shall include, but not be limited to substandard and intermittent operation; interference with or non-compatibility with other existing owner hardware and software systems.

D. Submit warranties in accordance with Division 1 - General Requirements of these specifications.

E. All parts shall be readily available locally in the United States.

1.06 PRODUCT DELIVERY, STORAGE, AND HANDLING

A. Deliver equipment hardware in manufacturer's containers, appropriately packaged and/or crated for protection during shipment and storage in humid, dusty conditions.

B. Indelibly label all containers, including those contained in others, on outside with item description(s) per title and Mark Number of this specification.

C. Provide equipment hardware and materials specified complete in one shipment for each equipment item. Split or partial shipments are not permissible.

1.07 LABELING

A. Manufacturer shall securely attach in a prominent location on each major item of equipment hardware a non-corrosive nameplate showing manufacturer's name, address, model number, serial number, and pertinent utility or operating data.

B. All electrical equipment hardware and materials shall be new and shall be listed by Underwriter's Laboratories, Inc. (U.L.), or other National Recognized Testing Laboratory (NRTL), in categories for which standards have been set by that agency and labeled as such in the manufacturer's plant.

PART 2 – PRODUCTS

2.01 ELECTRIC VEHICLE CHARGE MANAGEMENT SYSTEM Equipment Mark Number: 8030

A. General:

1. Description: A monitoring and charge management system for Battery Electric Buses (BEB) and the facility in which the BEBs are stored overnight. The system shall be capable of wirelessly connecting to, communicating with, and monitoring each BEB in the owner’s fleet, as well as the BEB charger cabinets and connected dispensers (pantographs, remote plug-in charging head) located within the facility. Additionally, the system shall be able to optimize the BEB cabinet chargers to provide the most efficient charging of multiple BEBs all simultaneously connected over an array of multiple charging cabinets.

2. Coordination: Specification information indicated herein is intended as general requirement only. Final design of the system shall be by the manufacturer and shall be presented in the shop drawings as a fully coordinated, complete design.

3. Compliance: The equipment and final design shall comply with the most current editions of all applicable local, state, and federal codes and regulations. Additional compliance shall include, but not necessarily be limited to, the following:

a. NFPA 70, National Electric Code (NEC), most recent edition.

b. Federal Communications Commission (FCC) rules and regulations, as applicable.

c. Open Charge Point Protocol 2.0 (OCPP 2.0), or later network communication by the Open Charge Alliance.

4. Components and Services:

a. Wireless Transponder and Data Collector (bus vehicle mounted).

b. Hosting/Charge Management Software: Access to web based software for monitoring BEBs and Charger Cabinets, as well as automatically and remotely controlling Charger Cabinets to optimize charging.

B. System Operation:

1. Wireless Transponder and Data Collector installed on each BEB shall regularly and periodically record information from the BEB to which it belongs and securely communicate specified information over both wireless and cellular networks in real-time to a web-based and private secure server(s).

2. Collected information from each Wireless Transponder and Data Collector shall be uploaded to a web based private and secure server(s). Manufacturer's/service provider's software system shall organize information and make available to the subscribing client.

3. Manufacturer's/service provider's software system shall be able to engage in two-way communication with each of the Owner's charging cabinets and optimize charging capabilities for the full array of charging cabinets.

4. Owner shall be able to access specified information gathered through the web-based software system and generate reports as needed.

C. Capacities and Dimensions:

1. Wireless Transponder and Data Collector:

a. CAN-bus ports: Two or equivalent vehicle connection method

b. Power supply voltage input: nominal 9-32 VDC, <.1W standby, 5W full load maximum.

c. Cellular and GPS: GSM/UMTE/LTE (2G/3G/4G) minimum

d. Wi-Fi: Wi-Fi 802.11 a/b/g/n (2.4 + 5GHz) minimum

e. I/O line: 5 digital outputs, 2 analog outputs, 6 analog inputs minimum or equivalent

f. Operating temperature: -40 degrees Celsius to 85 degrees Celsius

g. Shock rating: SAE J1455

h. Vibration rating: SAE J1485

i. Ingress Protection Rating: IP 65

D. Features and Construction:

1. Wireless Transponder and Data Collector:

a. Data collector shall be mounted to the individual BEB to which it is assigned, connected to the CAN-bus or equivalent collection point of that BEB and shall be capable of collecting information in real time, making pertinent calculations based on that information, and transmitting the information via the transponder. At a minimum, the information shall include:

1) Bus Identification Number

2) Location (via received GPS signals)

3) Energy usage (consumption, kWh/miles)

4) Current speed

5) Odometer reading

6) Remaining range of the bus in miles and operation time depending on the routes

7) Faults, warnings, and diagnostic messages per bus

8) Vehicle state (In service, not in service, charging)

b. The data collector shall be able to compile and generate statistic reports. At a minimum, these reports shall include:

1) Driven miles per bus/fleet per day/month/year

2) Used energy and state of charge per bus/fleet per day/month/year

3) Driven routes and usage per route.

c. Transponder shall be capable of automatically receiving signal from global positioning satellite (GPS) systems and use the signal information automatically calculate position relative to known landmarks.

d. Transponder shall be capable of automatically connecting to cellular networks and Wi-Fi networks. Using these connections, the transponder shall be capable of automatically transmitting information collected by the data collector to the manufacturer's/service provider's computer networks.

2. Web Hosting/Charge Management:

a. Hosting service shall offer storage and analysis of Owner's data on the manufacturer's/service provider's server(s), and secure, unlimited Owner access to that data 24 hours a day, 365 days a year for a minimum three year period.

1) Access shall be by means of online web based software, compatible with a wide array of both desktop and mobile devices.

2) The system shall allow the Owner to set various levels of hierarchal user access, restricting and allowing certain information to the various levels.

3) Information collected from both BEBs and Charging systems shall be accessible through the same web based software.

b. Hosting service shall be able to automatically connect and establish two-way communication (per OCPP 2.0 protocol) to each DC power cabinet of the charging system installed at the Owner's site via cellular connection and wireless connection through the Owner's network.

c. Once connected, the hosting service shall be able to automatically read, analyze, store, and monitor information from the cabinet, as well as automatically control the charging functions of the cabinet remotely based on that information, all in real-time. Categories of this service shall include, at a minimum, the following:

1) Monitor and record charging power

2) Monitor and record charging current

3) Monitor and record charging voltage

4) Monitor and record battery state of charge

a) Record battery state of charge prior to charge

b) Record battery state of charge at end of charging cycle (terminated by bus charge controller or remote emergency stop button)

5) Monitor and record charging status (charging, not charging, error state)

6) Remote reset / reboot.

7) Record and generate live and historical logs of chargers

8) Generate charger session overview

9) Store utility rate structuring configuration for generating reports

10) Record uptime monitoring

11) Remotely change the availability of chargers

12) Diagnostics messaging

13) Upload firmware updates to the charger

14) Edit charge status configuration

d. The hosting service shall be able to analyze the collected information and generate statistical reports on each charger, on demand. At a minimum, statistical reports shall include information on:

1) Recorded amount of charged energy per charging session

2) Determine efficiency of each charging session by comparing the charged energy measured at the bus side to the AC input at the charge cabinet.

3) Recorded charge sessions per day per facility

4) Charging cost per bus

a) Vehicle ID specific

b) Average of BEB fleet

5) Charging cost per day

6) Recorded automated incidents (flags and triggers)

e. The web hosting service shall, by means of two-way communication, be able to automatically control functions of each charging cabinet to dynamically ‘smart’ charge the BEB fleet. The hosting service shall be able to automatically collect, analyze and store the following information in real-time from each charging cabinet and the Owner’s computer network.

1) Owner’s schedule of the buses, including blocks and routes

2) Analyze and re-distribute load balance between charger cabinets.

3) Avoid peak time-of-use periods set by the Utility.

4) Set maximum demand limit.

5) Prioritize charge sessions manually.

6) Implement charge window and duration.

7) Energy rate structure response.

8) Analyze and calculate a charging response based on received Utility demand limits.

9) Analyze and calculate a charging response based on received renewable energy requirements.

10) Analyze and calculate a charging response based on received available back-up power requirements.

11) Control and optimize on-site energy storage systems

12) Predict optimal energy required based on BEB battery state of health and battery lifecycle cost estimates.

3. Other System Functions: Together, the data collector, transponder, and hosting service shall be able to provide the system functions listed below:

a. Record pertinent driving style information based on driver, and analyze, store, and report.

b. Record regenerative braking information, and analyze to establish a profile, store and report.

c. Compile and provide summary reporting.

d. Provide actionable insights based on recorded information.

e. Provide remote diagnostics of buses and charging system.

f. Record and compile battery statistics.

g. Balance load between all chargers.

h. Set number of maximum power peaks.

i. Prioritize chargers based on collected information.

PART 3 - EXECUTION

3.01 INSPECTION

A. Coordinate location of rough-in work and utility stub-outs to assure match and/or non-interference with equipment to be installed.

B. Inspect delivered equipment hardware for damage from shipping and exposure to weather.

C. Compare delivered equipment hardware with packing lists and specifications to assure receipt of all items.

3.02 INSTALLATION

A. Perform work under direct supervision of Foreman or Construction Superintendent with authority to coordinate installation of scheduled equipment with Design Team.

B. Install equipment hardware in accordance with plans, shop drawings and manufacturer's instructions:

1. Positioning: Place equipment in accordance with any noted special positioning requirements generally level, plumb and at right angles to adjacent work.

2. Fitting: Where field cutting or trimming is necessary, perform in a neat, accurate, professional manner without damaging equipment or adjacent work.

3. Anchorage: Attach equipment securely to floor, as directed by Design Team, to prevent damage resulting from inadequate fastening. Installation fasteners shall be installed to avoid scratching or damaging adjacent surfaces.

4. Upon completion of work, finish surfaces shall be free of tool marks, scratches, blemishes, and stains.

C. Install equipment software in accordance with manufacturer's instructions. Coordinate with Owner's IT department.

3.03 TESTING

A. Scheduling, phasing, documenting, and coordinating testing shall be the responsibility of the Contractor. Requests for items, equipment, information or personnel needed for the testing shall be put into writing and made known to the respective party no less than 30 days prior to any testing. A testing plan and schedule shall be submitted to the Owner and Design Team no less than 30 days prior to any testing.

B. After final connections and installations are made and prior to authorizing payment, specified equipment shall be tested for compliance with all specified features in the presence of the Design Team using acceptance test procedures provided by the manufacturer and testing requirements listed herein.

C. Testing of specified system shall include on-site inter-operability testing with the following equipment and systems:

1. Equipment Mark Number 8012 Charging Cabinet, Battery Electric Bus, 150kw DC Power, as specified in Section 11 11 36.14 Commercial Electric Vehicle Charging Unit for Transit Depots – DC Overhead Charging.

2. Equipment Mark Number 8020 Charging Pantograph, Inverse, Facility Mounted, as specified in Section 11 11 36.14 Commercial Electric Vehicle Charging Unit for Transit Depots – DC Overhead Charging

3. The SFMTA selected and procured battery electric bus (BEB) vehicle

4. The SFMTA selected computer terminals.

D. At a minimum, testing shall include the following:

1. Demonstration of manufacturer's software running on the SFMTA selected computer terminals and displaying specified information.

2. Linking and communication with each instance of Equipment Mark Number 8012 Charging Cabinet, Battery Electric Bus, 150kw DC Power, as specified in Section 11 11 36.14 Commercial Electric Vehicle Charging Unit for Transit Depots – DC Overhead Charging installed on site.

3. Full 24 hour charging period of a single SFMTA-provided Battery Electric Bus at a charging cabinet of the SFMTA's choosing, and a demonstration of the ability of the system to provide a full report on the history of the charge cycle.

4. Connection of a SFMTA-provided Battery Electric Bus to each charging cabinet with a demonstration of the software's ability to read and display the test bus information at each connection.

E. The testing shall demonstrate the entire system operates as intended and to the Owner's satisfaction. All testing shall be recorded in Test Reports and submitted to the Owner and Design Team for review.

1. Test reports indicating non-performance or failure of any item shall result in immediate notification to the Owner and Design Team. Manufacturer shall then submit to the Owner a schedule and plan an action to address all deficiencies. Upon agreement from the Owner any necessary repair, adjustment, etc. to bring the system into conformance with the specification shall be conducted by the manufacturer. Once complete a re-test of the system shall be conducted.

2. Continued non-performance or failures of the system or its components and/or features may result in a determination of 'non-compliance' of the entire system by the Owner.

3. Prior to authorization for final payment, all testing shall be complete with test reports indicating proper operation of the system submitted to the Owner and Design Team for final review.

3.04 CLEANUP

A. Touch-up damage to painted finishes.

B. Wipe and clean equipment of any oil, grease, and solvents, and make ready for use.

C. Clean area around equipment installation and remove packing or installation debris from job site.

D. Notify Design Team for acceptance inspection.

3.05 TRAINING

A. Direct the technical representative to provide specified hours of training to designated Owner's maintenance personnel in operation and maintenance of the following equipment. Coordinate, with Owner, training schedule and list of personnel to be trained.

1. ELECTRIC VEHICLE CHARGE MANAGEMENT SYSTEM
Equipment Mark Number: 8030
Hours Required: 16

B. Obtain, from technical representative, a list of Owner's personnel trained in equipment operations and maintenance.

C. Provide a Windows compatible movie file format recording on USB stick of the training session. The training movie can be a recording of a live session or a produced training video

END OF SECTION 11 11 36.20

# APPENDIX B: FAILED SERVICE BLOCKS

The following section provides a comprehensive list of the service blocks that failed under moderate efficiency estimations with current BEB technology at each yard.

## *FLYNN YARD*

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 3822 | 60' | 120.17 | 4.72 | 0.41 | 99.9% | 600 | 2025 |
| 3824 | 60' | 120.17 | 5.00 | 0.41 | 99.9% | 600 | 2025 |
| 3825 | 60' | 120.17 | 4.40 | 0.41 | 99.9% | 600 | 2025 |
| 3828 | 60' | 120.17 | 4.42 | 0.41 | 99.9% | 600 | 2025 |
| 4903 | 60' | 120.13 | 2.77 | 0.45 | 93.0% | 645 | 2025 |
| 4904 | 60' | 117.22 | 7.82 | 0.47 | 93.6% | 641 | 2025 |

Source: WSP

## *ISLAIS CREEK YARD*

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 801 | 60' | 188.61 | 5.84 | 0.43 | 59.5% | 1008 | 2045 |
| 802 | 60' | 132.70 | 4.00 | 0.29 | 85.9% | 699 | 2030 |
| 803 | 60' | 188.47 | 3.01 | 0.43 | 59.5% | 1008 | 2045 |
| 804 | 60' | 162.32 | 4.46 | 0.38 | 69.6% | 862 | 2035 |
| 805 | 60' | 121.67 | 4.54 | 0.27 | 93.5% | 642 | 2025 |
| 806 | 60' | 154.97 | 3.57 | 0.35 | 73.1% | 821 | 2035 |
| 807 | 60' | 132.70 | 6.91 | 0.29 | 85.9% | 699 | 2030 |
| 808 | 60' | 121.36 | 5.39 | 0.27 | 93.6% | 641 | 2025 |
| 809 | 60' | 166.19 | 1.42 | 0.38 | 67.8% | 885 | 2040 |
| 810 | 60' | 166.19 | 1.32 | 0.38 | 67.8% | 885 | 2040 |
| 812 | 60' | 165.89 | 4.94 | 0.38 | 67.8% | 885 | 2040 |
| 813 | 60' | 166.35 | 5.06 | 0.38 | 67.7% | 886 | 2040 |

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 815 | 60' | 132.84 | 5.71 | 0.30 | 85.9% | 699 | 2030 |
| 816 | 60' | 165.89 | 4.68 | 0.38 | 67.8% | 885 | 2040 |
| 823 | 60' | 154.72 | 5.21 | 0.35 | 72.4% | 828 | 2035 |
| 3801 | 60' | 144.77 | 5.18 | 0.53 | 79.1% | 759 | 2030 |
| 3802 | 60' | 138.39 | 3.43 | 0.48 | 82.6% | 727 | 2030 |
| 3803 | 60' | 127.91 | 4.04 | 0.38 | 94.7% | 634 | 2025 |
| 3804 | 60' | 125.15 | 5.17 | 0.45 | 89.5% | 670 | 2025 |
| 3805 | 60' | 129.28 | 3.58 | 0.46 | 89.6% | 670 | 2025 |
| 3806 | 60' | 124.12 | 3.76 | 0.43 | 92.4% | 649 | 2025 |
| 3807 | 60' | 150.37 | 6.46 | 0.51 | 76.7% | 782 | 2035 |
| 3808 | 60' | 128.00 | 5.64 | 0.48 | 89.2% | 673 | 2025 |
| 3809 | 60' | 137.84 | 5.36 | 0.48 | 82.1% | 731 | 2030 |
| 3810 | 60' | 118.99 | 2.21 | 0.44 | 95.8% | 626 | 2025 |
| 3811 | 60' | 128.00 | 2.06 | 0.48 | 89.2% | 673 | 2025 |
| 3812 | 60' | 119.46 | 1.45 | 0.46 | 94.1% | 638 | 2025 |
| 3813 | 60' | 124.52 | 1.58 | 0.44 | 91.1% | 658 | 2025 |
| 3815 | 60' | 123.60 | 3.93 | 0.41 | 94.1% | 637 | 2025 |

Source: WSP

## *KIRKLAND YARD*

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 1906 | 40' | 143.62 | 6.48 | 0.68 | 93.0% | 616 | 2025 |
| 2801 | 40' | 186.82 | 10.62 | 0.47 | 81.7% | 702 | 2030 |
| 2802 | 40' | 163.22 | 11.99 | 0.41 | 94.1% | 610 | 2025 |
| 2803 | 40' | 169.85 | 10.49 | 0.47 | 86.9% | 660 | 2030 |
| 2804 | 40' | 163.22 | 8.16 | 0.41 | 94.1% | 610 | 2025 |
| 2806 | 40' | 234.00 | 8.06 | 0.61 | 64.6% | 887 | 2040 |
| 2807 | 40' | 213.76 | 6.17 | 0.58 | 69.8% | 821 | 2035 |
| 2808 | 40' | 213.68 | 6.20 | 0.57 | 70.1% | 818 | 2035 |
| 2810 | 40' | 210.41 | 5.80 | 0.54 | 72.1% | 795 | 2035 |

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 2813 | 40' | 210.41 | 5.24 | 0.54 | 72.1% | 795 | 2035 |
| 2814 | 40' | 193.44 | 5.45 | 0.54 | 76.2% | 752 | 2035 |
| 4301 | 40' | 146.96 | 7.49 | 0.41 | 94.8% | 605 | 2025 |
| 4302 | 40' | 191.28 | 5.19 | 0.52 | 73.3% | 782 | 2035 |
| 4303 | 40' | 171.17 | 6.08 | 0.49 | 80.5% | 712 | 2030 |
| 4304 | 40' | 171.61 | 6.06 | 0.49 | 80.7% | 710 | 2030 |
| 4306 | 40' | 171.61 | 7.71 | 0.49 | 80.7% | 710 | 2030 |
| 4315 | 40' | 166.63 | 2.81 | 0.45 | 84.6% | 677 | 2030 |
| 4322 | 40' | 152.84 | 2.01 | 0.47 | 88.5% | 648 | 2025 |

Source: WSP

## *POTRERO YARD*

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 501 | 60' | 155.30 | 6.48 | 0.48 | 76.6% | 783 | 2035 |
| 502 | 60' | 127.06 | 7.78 | 0.40 | 94.0% | 638 | 2025 |
| 503 | 60' | 130.12 | 5.09 | 0.39 | 91.9% | 653 | 2025 |
| 508 | 60' | 127.06 | 4.38 | 0.40 | 94.0% | 638 | 2025 |
| 514 | 60' | 141.42 | 6.33 | 0.44 | 84.4% | 711 | 2030 |
| 1401 | 60' | 149.69 | 4.11 | 0.39 | 79.3% | 756 | 2030 |
| 1402 | 60' | 124.62 | 5.00 | 0.31 | 95.7% | 627 | 2025 |
| 1407 | 60' | 120.10 | 2.84 | 0.32 | 98.8% | 607 | 2025 |
| 1408 | 60' | 148.15 | 1.80 | 0.39 | 80.2% | 748 | 2030 |
| 1409 | 60' | 139.00 | 7.18 | 0.35 | 85.6% | 701 | 2030 |
| 1413 | 60' | 148.15 | 6.52 | 0.39 | 80.2% | 748 | 2030 |

Source: WSP

## PRESIDIO YARD

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 103 | 40' | 138.68 | 4.18 | 1.02 | 93.8% | 611 | 2025 |
| 2402 | 40' | 151.28 | 5.08 | 1.11 | 80.4% | 713 | 2030 |
| 2405 | 40' | 123.83 | 4.42 | 0.91 | 98.3% | 583 | 2025 |
| 2411 | 40' | 123.83 | 2.08 | 0.91 | 98.3% | 583 | 2025 |
| 2413 | 40' | 125.86 | 3.13 | 0.95 | 97.2% | 590 | 2025 |
| 3101 | 40' | 149.89 | 2.79 | 0.68 | 94.2% | 609 | 2025 |
| 3102 | 40' | 149.89 | 1.96 | 0.68 | 94.2% | 609 | 2025 |

Source: WSP

## WOODS YARD

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 1801 | 40' | 197.10 | 5.19 | 0.52 | 59.5% | 703 | 2030 |
| 1802 | 40' | 188.20 | 1.71 | 0.49 | 85.9% | 671 | 2030 |
| 1803 | 40' | 188.20 | 5.94 | 0.49 | 59.5% | 671 | 2030 |
| 1804 | 40' | 188.20 | 5.97 | 0.49 | 69.6% | 671 | 2030 |
| 2301 | 40' | 155.60 | 4.90 | 0.66 | 93.5% | 641 | 2025 |
| 2303 | 40' | 151.13 | 4.69 | 0.55 | 73.1% | 598 | 2025 |
| 2304 | 40' | 155.59 | 6.15 | 0.66 | 85.9% | 641 | 2025 |
| 2305 | 40' | 155.60 | 1.23 | 0.66 | 93.6% | 641 | 2025 |
| 2501 | 40' | 227.24 | 4.32 | 3.04 | 67.8% | 1019 | 2045 |
| 2502 | 40' | 237.34 | 5.93 | 3.17 | 67.8% | 1065 | 2050 |
| 2901 | 40' | 209.44 | 5.91 | 0.51 | 67.8% | 848 | 2040 |
| 2902 | 40' | 162.60 | 7.26 | 0.41 | 67.7% | 663 | 2030 |
| 2903 | 40' | 213.19 | 4.82 | 0.52 | 85.9% | 869 | 2040 |
| 2904 | 40' | 182.39 | 4.79 | 0.44 | 67.8% | 736 | 2035 |
| 2905 | 40' | 159.09 | 5.30 | 0.38 | 72.4% | 644 | 2025 |
| 2909 | 40' | 186.14 | 4.67 | 0.45 | 79.1% | 757 | 2035 |
| 3501 | 30' | 102.47 | 8.15 | 2.06 | 82.6% | 381 | 2045 |

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 3502 | 30' | 126.43 | 7.54 | 2.58 | 94.7% | 473 | 2055 |
| 3503 | 30' | 60.53 | 15.52 | 1.16 | 89.5% | 219 | 2025 |
| 3601 | 30' | 174.30 | 8.30 | 1.08 | 89.6% | 594 | 2065 |
| 3602 | 30' | 164.82 | 6.41 | 1.04 | 92.4% | 562 | 2060 |
| 3603 | 30' | 167.64 | 4.97 | 1.05 | 76.7% | 576 | 2060 |
| 3701 | 30' | 145.95 | 6.95 | 1.47 | 81.6% | 492 | 2055 |
| 3702 | 30' | 145.95 | 6.97 | 1.47 | 85.5% | 492 | 2055 |
| 3703 | 30' | 117.65 | 4.39 | 1.12 | 85.5% | 398 | 2045 |
| 3704 | 30' | 150.74 | 3.44 | 1.53 | 85.5% | 507 | 2055 |
| 3901 | 30' | 72.76 | 3.71 | 1.89 | 89.5% | 232 | 2025 |
| 3902 | 30' | 87.64 | 3.42 | 2.01 | 95.8% | 283 | 2035 |
| 4401 | 40' | 183.47 | 3.64 | 0.70 | 89.5% | 774 | 2035 |
| 4405 | 40' | 142.07 | 6.02 | 0.52 | 89.5% | 595 | 2025 |
| 4409 | 40' | 147.69 | 1.73 | 0.57 | 56.3% | 628 | 2025 |
| 4417 | 40' | 142.17 | 3.92 | 0.54 | 53.8% | 597 | 2025 |
| 5203 | 30' | 126.16 | 7.00 | 1.52 | 67.6% | 425 | 2050 |
| 5204 | 30' | 126.16 | 6.36 | 1.52 | 86.4% | 425 | 2050 |
| 5402 | 40' | 172.84 | 3.43 | 0.83 | 66.0% | 806 | 2035 |
| 5403 | 40' | 145.37 | 4.09 | 0.62 | 77.9% | 662 | 2030 |
| 5405 | 40' | 166.16 | 12.98 | 0.72 | 89.0% | 760 | 2035 |
| 5601 | 30' | 145.45 | 4.57 | 2.88 | 75.8% | 492 | 2055 |
| 5701 | 40' | 221.05 | 3.93 | 0.59 | 56.5% | 816 | 2035 |
| 5702 | 40' | 221.05 | 5.59 | 0.59 | 45.4% | 816 | 2035 |
| 5703 | 40' | 216.18 | 5.86 | 0.56 | 98.0% | 791 | 2035 |
| 5704 | 40' | 216.18 | 5.88 | 0.56 | 36.2% | 791 | 2035 |
| 5705 | 40' | 216.18 | 5.33 | 0.56 | 38.3% | 791 | 2035 |
| 6601 | 30' | 170.84 | 4.38 | 2.48 | 37.3% | 547 | 2060 |
| 6602 | 30' | 170.84 | 4.38 | 2.48 | 43.7% | 547 | 2060 |
| 6703 | 30' | 112.61 | 5.49 | 2.47 | 43.7% | 405 | 2050 |
| 6704 | 30' | 112.61 | 6.82 | 2.47 | 54.1% | 405 | 2050 |
| 1801 | 40' | 197.10 | 5.19 | 0.52 | 42.4% | 703 | 2030 |
| 1802 | 40' | 188.20 | 1.71 | 0.49 | 92.5% | 671 | 2030 |
| 1803 | 40' | 188.20 | 5.94 | 0.49 | 75.9% | 671 | 2030 |
| 1804 | 40' | 188.20 | 5.97 | 0.49 | 74.1% | 671 | 2030 |
| 2301 | 40' | 155.60 | 4.90 | 0.66 | 96.4% | 641 | 2025 |

| Block I.D. | Vehicle Length | Distance Traveled (miles) | Average Speed (mph) | Accumulative Slope | Percent Block Complete | Needed Battery (kWh) | Year to Electrify |
|---|---|---|---|---|---|---|---|
| 2303 | 40' | 151.13 | 4.69 | 0.55 | 91.3% | 598 | 2025 |
| 2304 | 40' | 155.59 | 6.15 | 0.66 | 96.1% | 641 | 2025 |
| 2305 | 40' | 155.60 | 1.23 | 0.66 | 50.6% | 641 | 2025 |
| 2501 | 40' | 227.24 | 4.32 | 3.04 | 50.6% | 1019 | 2045 |
| 2502 | 40' | 237.34 | 5.93 | 3.17 | 71.2% | 1065 | 2050 |
| 2901 | 40' | 209.44 | 5.91 | 0.51 | 86.6% | 848 | 2040 |
| 2902 | 40' | 162.60 | 7.26 | 0.41 | 75.4% | 663 | 2030 |
| 2903 | 40' | 213.19 | 4.82 | 0.52 | 43.7% | 869 | 2040 |
| 2904 | 40' | 182.39 | 4.79 | 0.44 | 70.2% | 736 | 2035 |
| 2905 | 40' | 159.09 | 5.30 | 0.38 | 70.2% | 644 | 2025 |
| 2909 | 40' | 186.14 | 4.67 | 0.45 | 72.5% | 757 | 2035 |
| 3501 | 30' | 102.47 | 8.15 | 2.06 | 72.5% | 381 | 2045 |
| 3502 | 30' | 126.43 | 7.54 | 2.58 | 72.5% | 473 | 2055 |
| 3503 | 30' | 60.53 | 15.52 | 1.16 | 39.3% | 219 | 2025 |
| 3601 | 30' | 174.30 | 8.30 | 1.08 | 39.3% | 594 | 2065 |
| 3602 | 30' | 164.82 | 6.41 | 1.04 | 53.0% | 562 | 2060 |
| 3603 | 30' | 167.64 | 4.97 | 1.05 | 53.0% | 576 | 2060 |

Source: WSP

# APPENDIX C: RISK MANAGEMENT PLAN

The risk management plan evaluates possible risks that could delay or compromise successful roll-out of the SFMTA Battery Electric Bus (BEB) fleet. Transit operators using BEBs have special considerations related to risks and resiliency. BEBs service reliability can be susceptible to power outages, extreme weather, service disruptions, and operator performance. Electrical infrastructure and batteries introduce different risks than do liquid fuels. In addition to BEB-specific risks, some facility locations are more susceptible to natural hazards such as sea level rise and earthquakes.

To ensure reliable and resilient daily BEB operation, transit operators need to ensure battery electric buses are appropriately charged to support operations during a range of conditions and incidents. This includes the design of facilities and equipment, as well as the adoption of BEB training and operating procedures. BEB facility designs need to anticipate longer-term trends such as global climate change, vehicle technology advances, and future levels and types of bus service. Staff training needs to address procedures for handling electrical infrastructure and batteries, as well as operator training to maximize BEB range. Operating procedures need to consider issues that can affect operations such as extreme weather events, power outages, impacts of traffic and congestion, service disruptions, and extra service needs.

This plan presents a high-level assessment of the risks identified for the SFMTA bus facilities regarding implementation of BEB service.

- Section 1 lists assets that could be at risk and the criticality of those assets in providing reliable service to the public.
- Section 2 presents potential hazards, including those that are external to the SFMTA as well as internal physical assets and personnel risks.
- Section 3 is a table of management and mitigation strategies for risks and hazards identified in Section 2.

## Assets

Assets owned by the SFMTA that are at risk include buses, battery packs, charging equipment, on-site electrical infrastructure, and operations and maintenance structures. Electrical equipment owned by utilities is not included in this list of assets. Table 1 presents a summary of physical assets by operating yard.

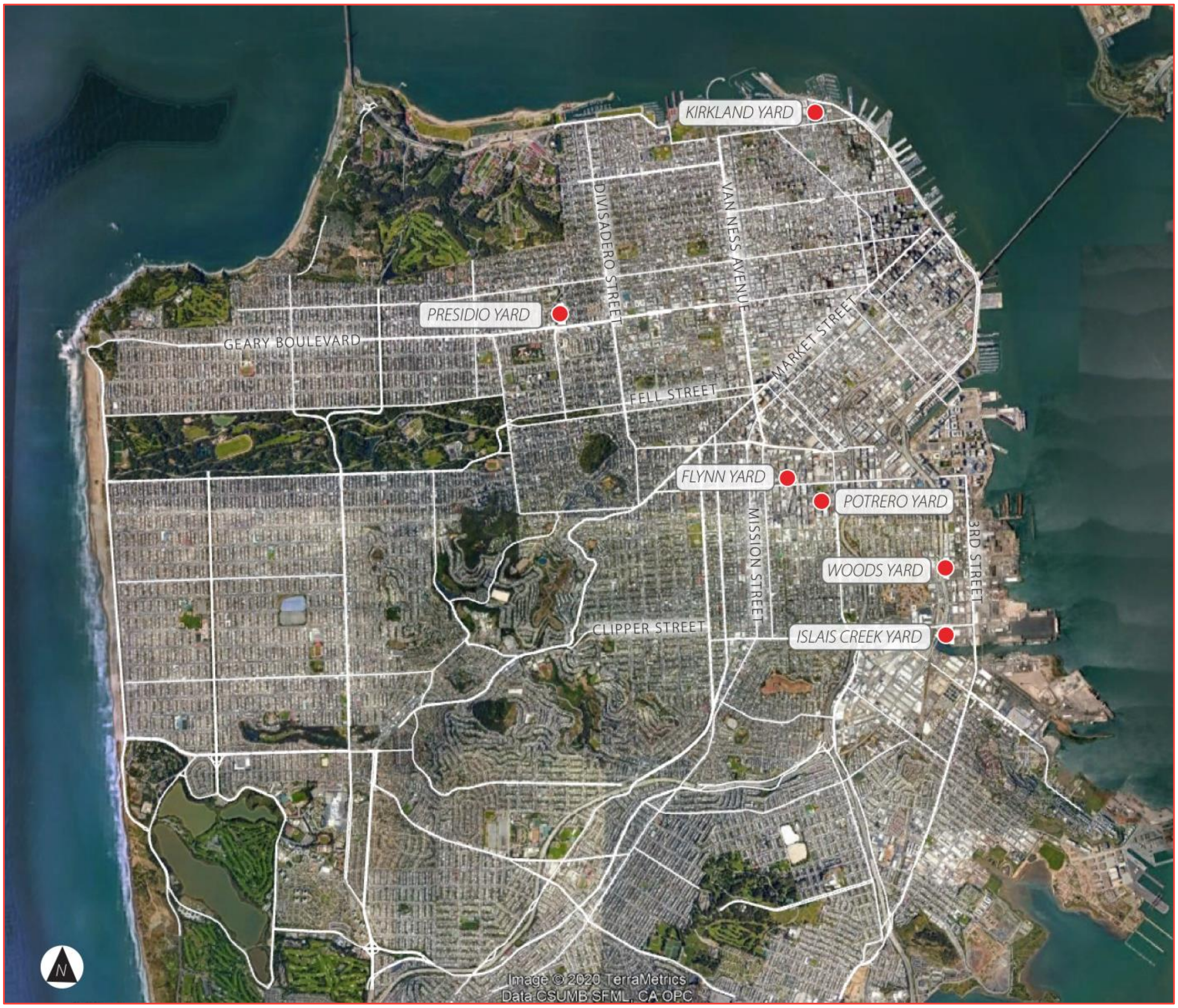
**Table 1. Physical Assets at SFMTA Yards**

| Yards | Buses | Batteries and Charging Equipment | Electrical Infrastructure (Substation, Circuit, Transformer) | Operations and Maintenance Buildings |
|---|---|---|---|---|
| Flynn | 124 | 109 dispensers, 56 charging cabinets, 2 2-MWh batteries | 1 MV transformer/ switch, 2 LV transformer/ switch | 1 combined indoor facility |
| Islais Creek | 130 | 149 dispensers, 75 charging cabinets, 2 2-MWh batteries | 2 MV transformer/ switch, 3 LV transformer/ switch | 1 combined maintenance operations building |

| Yards | Buses | Batteries and Charging Equipment | Electrical Infrastructure (Substation, Circuit, Transformer) | Operations and Maintenance Buildings |
|---|---|---|---|---|
| **Kirkland** | 112 | 77 dispensers, 39 charging cabinets, 2 2-MWh batteries | 1 MV transformer / switch, 1 LV transformer / switch | 1 combined maintenance operations building (expected – design by separate project) |
| **Potrero** | 168 | 206 dispensers, 103 charging cabinets, 2 2-MWh batteries | 2 MV transformer/ switch, 3 LV transformer/ switch | 1 combined maintenance operations building (expected – design by separate project) |
| **Presidio** | 132 | 217 dispensers, 109 charging cabinets, 2 2-MWh batteries | 2 MV transformer / switch, 3 LV transformer / switch | 1 combined maintenance operations building (expected – design by separate project) |
| **Woods** | 257 | 177 dispensers, 90 charging cabinets, 2 2-MWh batteries | 2 MV transformer / switch, 3 LV transformer / switch | 1 maintenance & 1 operations building |

Source: WSP

**Figure 1. Location of yards**




Source: WSP

## CRITICALITY OF THE ASSET

The criticality of an asset failing after it is received by the SFMTA is based on the resulting impact on the project implementation and operations, including customer dissatisfaction, employee productivity, and operating costs. In addition, failure for an asset to be delivered on schedule or to meet other contractual performance requirements could impact successful rollout of BEB service. Examples include buses, charging equipment, or software. Three categories of criticality based on impacts are summarized below. The degree of impact will depend on the number of units failing or the duration of the failure. For example, if a few BEBs do not function, those failures could likely be covered with the spare fleet. If a large number fail, then it might not be possible cover service with spare or contingency buses.

Categories of criticality include:

**High:** Asset failure immediately delays implementation of the BEB service and could create safety, operational, and environmental issues. These assets have no redundancy or restricted ability to substitute with spare assets.

**Medium:** Asset failure results in manageable schedule delays with limited impact on the implementation BEB service. Most of these assets have back-up systems and redundancy.

**Low:** Asset failure has no or minimal impact on the implementation schedule and operations.

Table 2 presents the potential criticality of assets at the SFMTA.

**Table 2. SFMTA Asset Criticality**

| Asset | Potential Criticality | Summary |
|---|---|---|
| Buses | High | Depends on number of failed buses, availability of spare and contingency fleet buses. |
| Backup Batteries | Low | Buses will be able to make pullout and operate without the on-site battery backups, but resiliency will be impacted in power outages. |
| Charging Equipment | High | Daily pullout of buses will be impacted if charging equipment fails. Risk is escalated upon full BEB transition. |
| Electrical Infrastructure | High | Daily pullout of buses will be impacted if electrical infrastructure fails to function. Risk is escalated upon full BEB transition |
| O&M Facilities Retrofit | High | Loss of facility will not allow buses to be maintained or operated safely from the site. Service could be continued using other SFMTA properties but with workforce and crew/vehicle scheduling impacts. |

Source: WSP

## HAZARDS AND RISKS

This section describes and discusses three categories of hazards/risks and the assets that could be affected by each hazard/risk. Hazards include both longer-term environmental factors such as sea level rise, as well as short-term risks associated with infrastructure procurement and installation, vehicle procurement, and initial operation.

- External Events (natural and human)
- Equipment (facilities and rolling stock)
- Organization (staffing, procedures)

**Table 7** at the end of this section is a summary of the hazards/risks, assets potentially affected, likelihood of each hazard/risk, consequence of failure, phase of project implementation during which the impact would be most likely, and mitigations for which the SFMTA can plan and implement, including coordination with external organizations.

## EXTERNAL EVENTS

### EARTHQUAKE

The San Francisco Bay Area is in a zone prone to earthquakes. The U.S. Geologic Survey concluded that there is a 72% likelihood that a strong earthquake will occur in the San Francisco Bay Area in the next 30 years[1]. Table 3 shows the potential impact to the SFMTA yards depending on various earthquake fault scenarios.

**Table 3. Potential Shaking Impacts of Earthquake to the SFMTA Yards**

| Fault | Flynn | Islais Creek | Kirkland | Potrero | Presidio | Woods |
|---|---|---|---|---|---|---|
| Calaveras | Very Strong | Strong | Very Strong | Strong | Strong | Strong |
| Hayward (North & South Segment) | Very Strong | Severe | Severe | Very Strong | Very Strong | Very Strong |
| Mount Diablo | Strong | Very Strong | Very Strong | Strong | Strong | Very Strong |
| Rodger Creek | Strong | Very Strong | Very Strong | Strong | Very Strong | Very Strong |
| San Andreas (Northern Segment) | Severe | Severe | Severe | Severe | Severe | Severe |
| San Andreas (Peninsula) | Severe | Severe | Very Strong | Severe | Severe | Severe |
| San Gregorio | Severe | Severe | Severe | Severe | Severe | Severe |

Note: Only fault scenarios resulting in very strong or severe shaking are shown in Table 3.
Source: MTC/ABAG Hazard Viewer Map, Earthquake Shaking Scenarios (accessed on October 23, 2020)
https://mtc.maps.arcgis.com/apps/webappviewer/index.html?id=4a6f3f1259df42eab29b35dfcd086fc8

Four yards are in areas with very high earthquake liquefaction susceptibility according to the MTC/ABAG Hazard Viewer Map: Flynn, Islais Creek, Kirkland, and Woods[2].

A major earthquake could lead to a large-scale, prolonged power outage in San Francisco which could impact the ability to charge buses.

### TSUNAMI

Tsunamis are most commonly caused by earthquakes, but can also be triggered by landslides or submarine volcanic eruptions[3]. The California Department of Conservation created a map of areas in San Francisco that can be impacted by tsunamis. The SFMTA's yards are on the San Francisco Bay and not on the ocean side, which would

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[1] Association of Bay Area Governments, *San Francisco Bay Area Risk Profile 2017 (accessed on October 23, 2020)* https://abag.ca.gov/sites/default/files/riskprofile_4_26_2017_optimized.pdf

[2] *MTC/ABAG Hazard Viewer Map, Earthquake Liquefaction Susceptibility (accessed on October 23, 2020)* https://mtc.maps.arcgis.com/apps/webappviewer/index.html?id=4a6f3f1259df42eab29b35dfcd086fc8

[3] California Department of Conservation, *Living on shaky ground, how to survive earthquakes and tsunamis in Northern California*, http://www2.humboldt.edu/shakyground/shakyGroundMagazine_LORES.pdf

reduce a tsunami's impacts on the facilities. Islais Creek Yard is in a tsunami inundation area and the Kirkland Yard is on the edge of the tsunami inundation area[4]. Therefore, those two properties could be at risk during a tsunami.

The City and County of San Francisco has established a Tsunami Response Plan and the SFMTA will provide service to flooded areas and re-route some of their service.

## SEA LEVEL RISE

San Francisco is one of many cities that is expected to soon be affected by rising sea level. Therefore, it is important to prepare for a changing climate. A mapping tool was developed by the non-profit organization, Adapting to Rising Tides (ART), to identify areas that are the most vulnerable to sea level rise. It identifies multiple flooding increments (varying between 0 to 108 inches).

The Kirkland and Islais Creek Yards are in areas expected to be affected by flooding according to the mapping tool. The Islais Creek Division could start to be inundated as early as 2030, while the Kirkland Division might be affected by flooding around 2050. The SFMTA should prepare both facilities for the anticipated effects of sea levels rising.

Findings on the effects of different flooding scenarios on the two yards is presented below. Maps of the area help identify the parts of the SFMTA properties that could be at risk without mitigations that can limit impacts to assets. Key findings of the analysis include:

- The Islais Creek Yard is affected by sea level rise beginning with the 52-inch scenario.
- The Kirkland Yard begins to be affected by sea level rise at the 66-inch benchmark and becomes completely inundated between the 88 and 96-inch scenarios.

Table 4 presents the area of each facility projected to be flooded with different sea level rises.

**Table 4. Area Flooded at Islais Creek and Kirkland Yards Due to Sea Level Rise**

| Flood Height (in inches) | Islais Creek Yard (1) | | Kirkland Yard *(2)* | |
|---|---|---|---|---|
| | Percent | Area (ft²) | Percent | Area (ft²) |
| 0 to 36 | 0% | 0 | 0% | 0 |
| 48 | 0% | 0 | 0% | 0 |
| 52 | 64% | 210,661 | 0% | 0 |
| 66 | 73% | 239,691 | 9% | 9,918 |
| 77 | 82% | 270,707 | 62% | 69,211 |
| 84 | 88% | 288,554 | 88% | 97,793 |
| 96 | 95% | 312,751 | 100% | 111,644 |
| 108 | 99% | 324,718 | 100% | 111,644 |

Source: WSP
(1) Total Area of Islais Creek Yard: 328,763.7 square feet
(2) Total Area of Kirkland Yard: 111,644.2 square feet)

### ISLAIS CREEK YARD

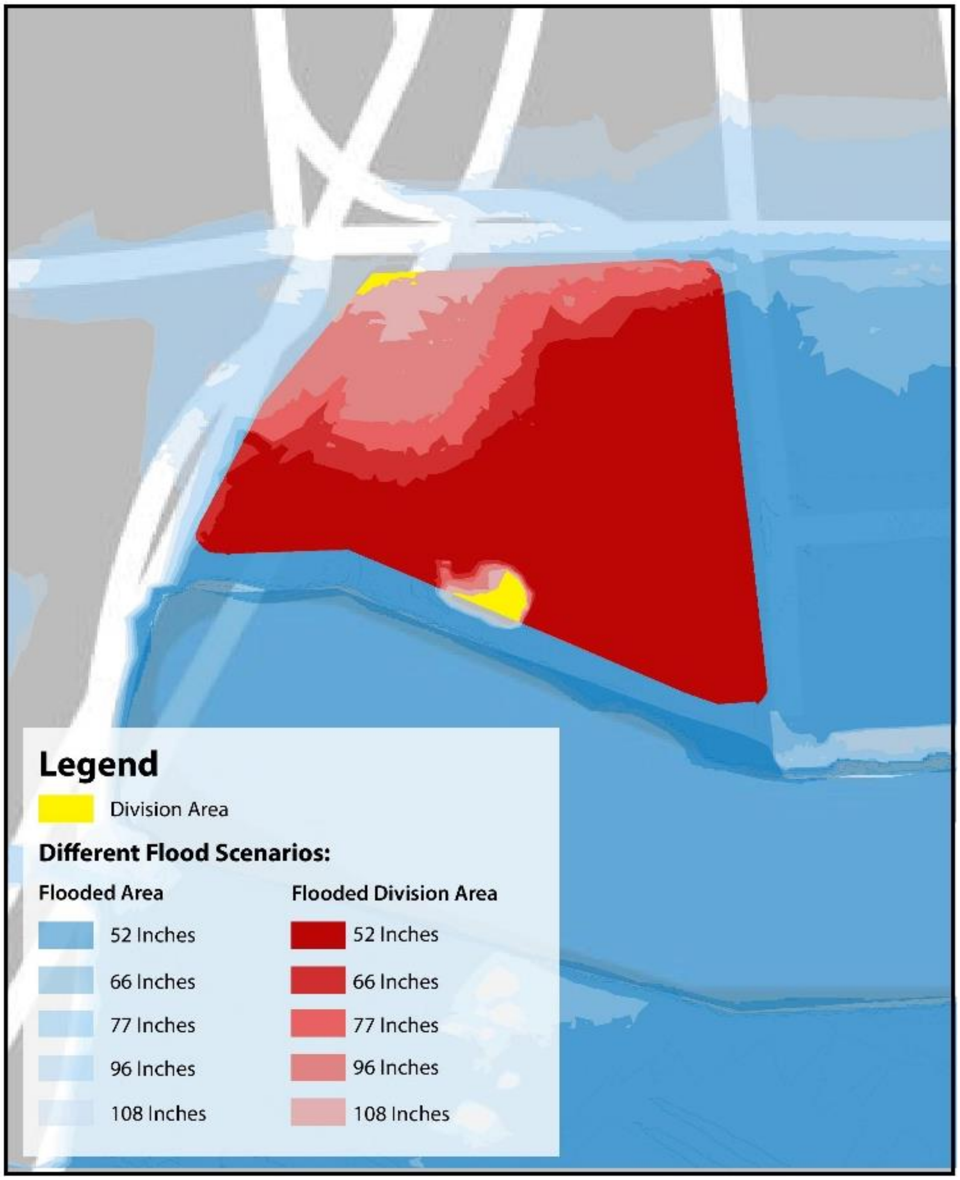
Based on various flooding scenarios, Islais Creek yard will not be affected by flood until the 52-inch sea-level rise scenario. However, once this happens, 64% of the yard will be submerged, including the main entrance from Indiana Street. Streets surrounding the yard will flood later, starting with the 96-inch flood scenario. Based on

[4] California Department of Conservation, *San Francisco County Tsunami Inundation Maps* https://www.conservation.ca.gov/cgs/Documents/Publications/Tsunami-Maps/Tsunami_Inundation_SF_Overview_SanFrancisco.pdf

ART's forecast, a 52-inch flood scenario could occur as early as 2030 if a 100-year extreme tide happens. Planning for this scenario, therefore, is an extreme risk mitigation.

Furthermore, as the flood height increases, more yards will be underwater, with 99% submerged in the 108-inch flood scenario. The northeastern part of the yard will be the last part to flood (Figure 2). ART projects that the 108-inch flood scenario would happen in 2070 if a 100-year extreme tide happens or in 2100 if a five-year extreme tide happens.

**Figure 2. Islais Creek Yard Flood Map**



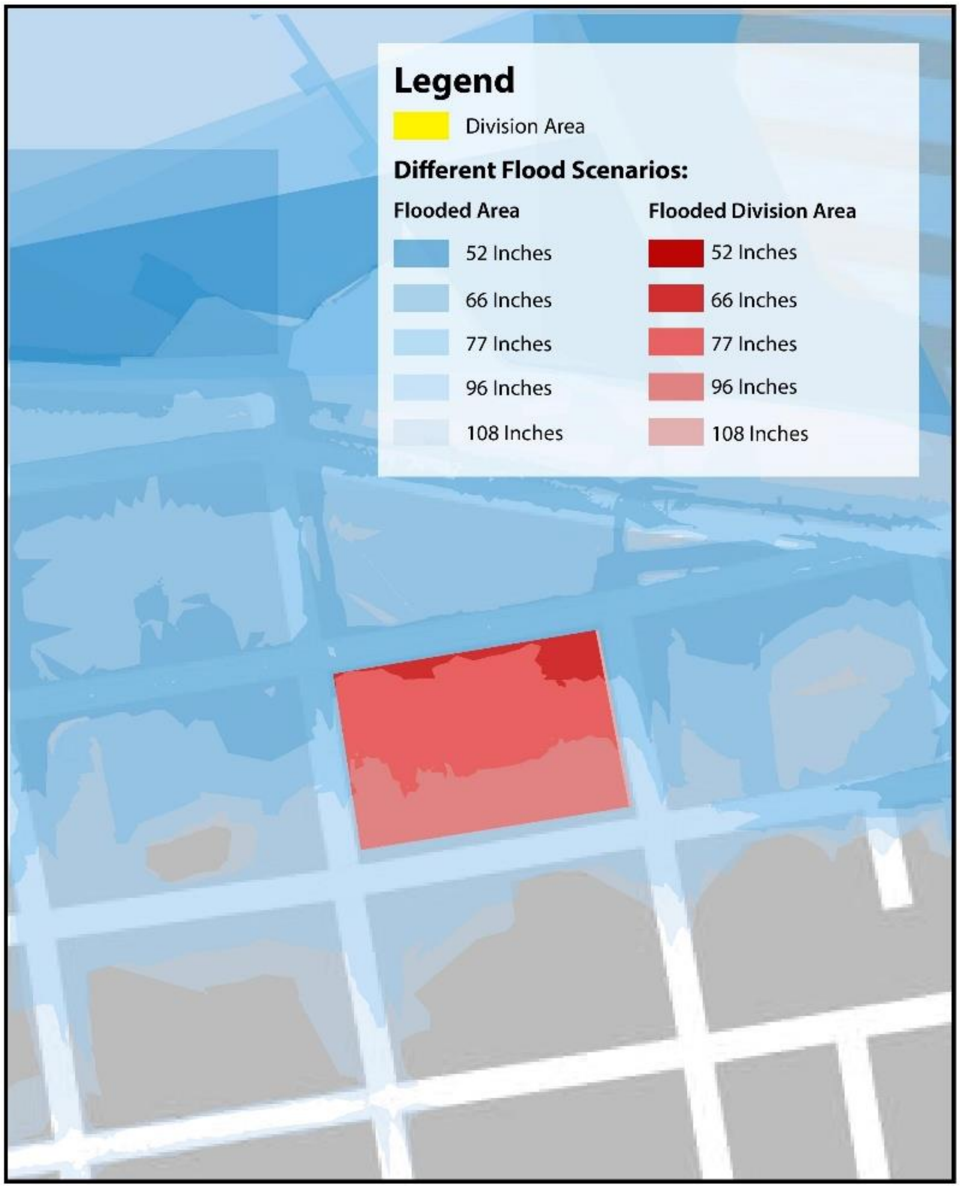

Source: Adapting to Rising Tides (ART)

KIRKLAND YARD

Based on various flooding scenarios, the Kirkland Yard will not be affected by flooding until the 66-inch sea-level rise scenario; at which point, only nine percent of the Yard will be submerged. However, once the flood height increases to 77-inches, 62% of the yard will be flooded, starting from the northeastern part of the facility (Figure 3). The main entrance to the yard from North Point Street will not get flooded until the flood is 96-inches high; thus, the southern part of the yard would still be accessible in the lower flood height scenarios. The entire yard will also become inundated if a 96-Inch flood happens.

Based on ART forecast, a 66-inch flood scenario could occur in 2050 if a 100-year extreme tide happens. Planning for this scenario, therefore, is a medium-high risk mitigation. The 96-inch flood scenario, meanwhile, could happen in 2070 if a 100-year extreme tide happens.

**Figure 3. Kirkland Yard Flood Map**




Source: Adapting to Rising Tides (ART)

## EXTREME HEAT

The number of extreme heat days each year is expected to rise in the Bay Area. In San Francisco County, by the end of the century, there could be multiple days a year where temperatures reach 95 degrees Fahrenheit. Even on days that reach 100 degrees Fahrenheit, temperatures in San Francisco exceed 90 degrees for only five hours a day as shown on Table 5. The higher temperatures could affect the battery range of the buses due to increased parasitic load from the bus's HVAC system, especially on high ridership routes with frequent door openings and on articulated buses with three doors.

**Table 5. Hourly Temperatures in San Francisco on September 2, 2017**

| Time (AM) | Temp ˚F |
|---|---|
| 12:56 AM | 81 |
| 1:56 AM | 77 |
| 2:56 AM | 75 |
| 3:56 AM | 75 |
| 4:56 AM | 75 |
| 5:56 AM | 74 |
| 6:56 AM | 73 |
| 7:56 AM | 74 |
| 8:56 AM | 78 |
| 9:56 AM | 76 |
| 10:56 AM | 78 |
| 11:56 AM | 82 |

| Time (PM) | Temp ˚F |
|---|---|
| 12:56 PM | 82 |
| 1:56 PM | 85 |
| 2:56 PM | 91 |
| 3:56 PM | 98 |
| 4:56 PM | 101 |
| 5:56 PM | 97 |
| 6:56 PM | 93 |
| 7:56 PM | 89 |
| 8:56 PM | 86 |
| 9:56 PM | 85 |
| 10:56 PM | 87 |
| 11:56 PM | 82 |

*Source: https://www.timeanddate.com/weather/usa/san-francisco/historic?month=9&year=2017 (accessed on November 10, 2020)*

### TERRORISM

Transit, particularly rail trains and stations, can be an attractive target for terrorist attacks because of crowds of people in confined environments, resulting in many casualties, disruption, and alarm. Although low probability, such high-profile events can create excessive public fear and result in economic and social disruptions.[5] BEB service can also be affected by a terrorist attacks on the electric grid if they result in power disruptions to a yard.

### PANDEMIC

Although pandemics are a rare occurrence, COVID-19 has shown that transit agencies need to consider and plan for pandemics. Agencies need to take quick action as soon as a potential pandemic incident occurs to ensure responsiveness to a range of potential impacts ranging from minimal to severe. In response to COVID-19 shelter in place, the SFMTA has made temporary service reductions including closing Muni Metro rail service and replacing it with bus service. The Muni Core Service Plan started on April 7, 2020 and focused service on the SFMTA most-used lines to serve San Francisco's medical facilities, ensuring service for riders most reliant on transit and providing enough capacity so passengers can maintain social distances. In September 2020, the COVID-19 shelter-in-place and service reductions resulted in a 71% reduction in bus boardings and 95% reduction in transit revenue compared to the same time in 2019. Service restoration will be based on lines with high ridership, that serve people who depend the most on transit, and that serve institutions.

Changes to service patterns and blocks could impact compatibility of the routes with BEB operation. The federal government, through the CARES Act, covered the pandemic's immediate impact. Longer-term service levels will depend on available revenues, ridership, and finding creative solutions to deliver that service efficiently and effectively.

Social distancing measures implemented during a pandemic could impact the supply chain by limiting the number of workers in the SFMTA facilities and manufacturer factories and thus, delay the delivery and acceptance of the buses to the SFMTA.

## EQUIPMENT

### POWER DISRUPTION

A typical customer within PG&E's San Francisco district can expect one power outage every two years, and it will probably last around 78 minutes. (By multiplying 0.575 average outages per year * 78 minutes per outage = 45 minutes of average outage minutes per year). Similarly, there are only 0.544 momentary outages per year, or approximately one every other year. Power disruption could be caused by an external event such as an earthquake, extreme heat, or terrorism.

Short outages should be manageable, but those lasting longer than an hour could impact the ability to fully charge buses overnight or during the midday. Backup power supply at a yard can mitigate the impact of power outages on bus charging. Procedures to match the scheduled mileage of a block with the battery charge on a bus should be developed so that they can be used in the event of a longer power disruption. Long outages at a yard will affect the ability to deploy BEBs from that yard and would require the use of buses from other yards and contingency buses.

The SFMTA should develop contingency plans to fill BEB blocks that cannot cover service. The following strategies may support contingency planning:

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[5] Todd Litman, Victoria Transport Policy Institute, *Terrorism, Transit and Public Safety: Evaluating the Risks*, March 2020

- Use spare buses and operators from other yards
- Transport operators from the affected yard to and back from other yards
- Selective cancellation of blocks (based on passenger loads and average headways) at the impacted yard
- Cover missed service at the impacted yard by selectively canceling and redeploying service from other yards

### FIRE (ON-BUS BATTERY AND BACK-UP BATTERY STORAGE)

Current fire and building codes do not address directly the addition of BEBs to a bus storage or maintenance facility. Most BEBs utilize Lithium-ion batteries that can catch fire if they operate outside their normal range. Lithium-ion battery cells contain reactive and flammable materials and can develop the fuel and the oxygen necessary to continue to fuel the fire and have been known to self-ignite again, hours or even days after the initial fire.

Lithium-ion battery packs used in BEBs contain a battery management system that helps to maintain a safe level of charge/discharge and temperature and they are designed to resist the spread of a fire and are contained within a protective cover. Nevertheless, unexpected rapid increase in battery temperature due to battery damage may cause flammable and toxic gas release that could ignite or result in lethal gas concentrations in the battery vicinity.

### BUS OPERATING RANGE AND BATTERY CAPACITY

Operating ranges of BEBs vary based on service characteristics such as routes, stops, vehicle schedules, and ridership as well as environmental factors such as topography and temperature. In addition, operator performance can affect achievable miles per kWh. Modeling of weekday service resulted in the following assessment of February 2020 block performance for typical weekday blocks (Table 6).

**Table 6: Summary of SFMTA Service Block Failures**

| Sensitivity | Blocks Failed | Percent of Fleet |
|---|---|---|
| Optimistic | 15 | 2% |
| Moderate | 118 | 14% |
| Conservative | 228 | 27% |

Source: WSP

If BEBs do not perform up to the projected ranges, and/or if the SFMTA changes block configurations to create more long blocks, then this could reduce service reliability, and/or increase the number of peak buses and platform hours required to provide the same level of service to customers. Likewise, if battery capacity increases due to assumed battery density improvements and advances in electrical management of parasitic loads are not achieved over the next two decades, then the percentage of non-compatible blocks could increase above those shown in Table 6.

Another consideration is degradation of battery capacity over time. Many OEMs currently warranty BEB batteries at 70% to 80% capacity within the first 12 years, thus the buses will need to meet service requirements with this assumed drop in capacity. A strategy to extend the useful life of BEBs would involve shifting older, lower capacity buses to shorter service blocks.

### BUS WEIGHT AND CAPACITY

BEBs are heavier than diesel-hybrid buses due to the weight of the larger number of batteries, particularly for the larger-capacity batteries needed to support block lengths without on-route charging. Heavier vehicles may have a greater impact on road infrastructure and maintenance facility needs. Future improvements in battery technology could reduce weight and increase efficiency to mitigate or eliminate current vehicle weight concerns. Forty-foot BEB curb weights range up to about 34,000 pounds, depending on manufacturer and battery capacity. The curb weight of a diesel-hybrid about 28,500 pounds. The SFMTA should review current weight limits on roads, bridges and structures that might be exceeded with BEBs.

Some available BEB vehicles have limited passenger carrying capacity due to the additional space needed for the batteries. In this case, passenger crowding would become more pronounced and might require additional buses and platform hours to provide the same level of capacity as provided with diesel-hybrid buses.

### TECHNOLOGY OBSOLESCENCE

As BEB is a new technology and is changing at a fast pace, new model of battery electric buses that will come on the market could differ from existing models with risks of early technological obsolescence and availability of spare parts, and with significant costs in the case of extraordinary maintenance such as the replacement of batteries. As California is at the forefront of regulation requiring all transit agencies to move to ZE buses by 2040, changes will occur in technologies to become more reliable, improve batteries, and increase range which could lead to premature obsolescence of the first roll-out of BEBs.

### UTILITY PROVIDER MANAGEMENT

Adding BEBs into the facilities will significantly impact the electrical distribution system and create a larger demand to utility providers. The demand of charging one BEB is evaluated to approximately 67.5 kW which is a direct increase to the facilities electricity consumption.

The California Public Utility Commission (CPUC) must approve all rates that each electric utility charges its customers. Once a utility's revenue requirement has been determined, a utility must propose what rate will be charged to customers to recover the revenue requirement. CPUC has supported the implementation of a Zero-Emission Vehicle (ZEV) Rate Programs and most of the providers are implementing a time-of-use rate. As the number of BEBs increase in the coming years due to the implementation of the Innovative Clean Transit regulation, new constraints will be placed on the energy grid which could result in utility providers changing their tariff structure, ultimately leading to uncertainty in the overall energy cost for transit agencies.

## ORGANIZATION

### TRAINING

The conversion of the fleet from diesel-hybrid to battery-electric buses will require that the SFMTA develop new employee training curricula for several job functions, including bus maintenance, operators, and supervisory personnel. Introducing a new type of vehicle creates a risk that the employees are not adequately trained on BEB maintenance and operation, increasing the likelihood of workplace accidents, reduced service reliability, and higher operating costs.

Many propulsion maintenance activities will require high voltage awareness and new SOP’s will be needed to document training requirements, use of Personal Protection Equipment (PPE) and tools, zero voltage verification procedures, and servicing battery packs and electrical equipment.

Initial and recurring training is also crucial for successful BEB operation, because driving habits can impact the ability of a BEB to achieve a block’s required mileage range and impact operating costs. Aggressive driving and heavy manual braking (instead of relying on regenerative braking) can affect bus performance. For example, the Antelope Valley Transportation Authority reported that two operators on the same route and under the same conditions had a 4 kWh/mile difference in efficiency due to driving technique. This equates to a range reduction from 220 miles to 80 miles.[6]

Furthermore, training many employees could take many months; implementing a training schedule and assigning necessary resources to accomplish the training is necessary in the implementation planning for BEBs.

#### BUS CHARGING PROCEDURES

Each bus must be charged before pullout so that it can complete its assigned service block. Ideally, all buses would be fully charged overnight (except those providing Owl service). There is a risk that buses will not receive adequate charge within the available charging window to complete service blocks. In addition to the Owl service buses, this could impact afternoon blocks covered with buses that were deployed in the morning and buses running longer than scheduled (e.g., due to unplanned service disruptions, unscheduled extra service, or emergency needs).

#### SCHEDULING AND TRANSPORTATION OPERATIONS

Blocking of the vehicle schedules will need to consider the achievable range of a BEB. Range depends not only on a block's mileage, but on other factors such as topography, number of stops, and passenger loads. Range could vary depending on when the bus was purchased. For example, older buses might have smaller batteries with less efficient parasitic systems than newer buses and be more affected by battery degradation. This could make assigning fleets to lines more challenging for the Scheduling Department, and, coupled with bus charging issues noted above, could even lead to assigning individual buses to individual blocks. Interlining routes to save operating costs and peak buses could also become more complicated due to the need to be mindful of the achievable range.

Daily operations challenges include the need to be aware of the remaining charge on a bus if it is needed for unplanned extra service or if it is kept in service longer than scheduled. Replacing in-service buses that unexpectedly fall below a threshold state-of-charge, particularly on very hot days, is another potential impact on operations.

#### ENVIRONMENTAL REVIEW

State Bill 288 (SB288) was signed into law by Governor Newson on September 28, 2020 providing exemptions to certain transportation projects from California Environmental Quality Act requirements. SB288 includes projects by public transit agencies to construct or maintain infrastructure to charge or refuel ZE transit buses. It also requires the exempt project to meet additional criteria as listed in SB288. It does not exempt a project from following the City and County of San Francisco regulations and procedures, as well as NEPA requirements if the SFMTA is an FTA grant beneficiary. If construction and ground disturbance reveal contaminated soils or archeological resources, that discovery could delay construction and roll-out of the BEBs.

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## *MANAGEMENT AND MITIGATION STRATEGIES*

Table 7 presents a summary of the following aspects of risk management and mitigation:

- *Hazards and Risks* – summarizes items presented previously in this report
- *Assets at risk* – identifies the assets at risk for a certain hazards or risk
- *Probability* – qualitatively assesses the likelihood that the hazard or risk will occur
    - *Low*: Unlikely to occur
    - *Medium*: Possible to occur

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[6] National Academies of Sciences, Engineering, and Medicine 2018. *Battery Electric Buses State of the Practice*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25061.

  - *High*: Likely to occur .

- *Consequences* – Lists consequences of the failure of the assets by comparing BEBs with diesel- hybrid buses
- *Project Phases* – Identifies the phase of the project in which the risk could occur and mitigation should be implemented
- *Mitigations* – Potential actions to reduce the hazard and risk to acceptable level

**Table 7. Hazard Risk and Mitigation Summary**

| Hazard/Risk | Assets at Risk | Probability | Consequences | Project Phase | | | | | Mitigations |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Planning & Permitting | Design | Construction & Procurement | Testing & Start-up | Turn Over & Operation | |
| Earthquake | - Buses<br>- Yards | Low | - Power disruption<br>- Loss of charging time<br>- Physical damages and financial impacts | | X | X | | X | - Harden all new BEB infrastructure to withstand seismic events and retrofit existing facilities where possible.<br>- Have back-up hybrid fleet for emergency evacuation in case of long-term power outage. |
| Tsunamis | - Electrical Infrastructure<br>- Yards | Low | - Physical damages and financial impacts<br>- Power disruption<br>- Loss of charging time | | X | X | | | - Raise electrical equipment above flood level.<br>- Implement flood protection measures and pumps to mitigate impacts of flooding at the facility. |
| Sea Level Rise | - Electrical Infrastructure<br>- Yards | High | - Physical damages and financial impacts | | X | X | | | - Raise electrical equipment above flood level.<br>- Implement flood protection measures and pumps to mitigate impacts of flooding at the facility. |
| Extreme Heat | - Buses<br>- Yards | Low | - Reduced performance | X | | | | X | - Use conservative assumption for modeling the climate impact on the bus fleet.<br>- Be prepared with back-up operators and buses in case a bus is unable to complete its service block.<br>- Reduce the use of air conditioning. |
| Terrorism | - Buses<br>- Yards | Low | - Employee and rider's safety<br>- Power disruption | | X | X | | X | - Develop contingency plans for vehicle charging and staffing levels to ensure support for regional evacuations and first responders. |

| | | | | | | | | | |
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| | | | - Loss of charging time | | | | | | - Secure the facilities and all infrastructure equipment from public access.<br>- Locate sensitive equipment away from public access (e.g. not on the edges of the property). |
| Pandemic | - Buses | Low | - Supply chain delays<br>- Funding shortage | X | | | | X | - Develop system-wide guidelines on social distancing and PPE use during incidents. Design spaces capable of implementing separation, barriers, and social distancing space as possible.<br>- Act quickly to increase inventory of critical supplies/parts at first signs of potential pandemic, including multiple supplier options<br>- Consider delaying bus replacement progression if funding shortfall warrants doing so to keep service operating. |
| Power disruption | - Buses<br>- Charging Equipment<br>- Yards | Medium | - Loss of charging time<br>- Potential service interruption | | X | X | | X | - Connect into secondary power supply circuits, if available. Possible options include:<br>o On-site power generation<br>o On-site battery storage: Back up stationary batteries can temporarily charge buses during a power outage. These storage batteries can also be used for mid-day charging during peak demand periods (i.e. peak shaving).<br>o Alternative charging locations (i.e. other garages or fleet facilities)<br>o On-site stationary or mobile gensets<br>- Modeling and utility rate analyses can help determine the optimal amount of back-up energy supply.<br>- Develop location specific charging plans that cover energy supply needs. This should include power supply back-up plans for responding to power outages.<br>- Analyze the average duration and frequency of power outages at each of the SFMTA operating locations to help inform the development of alternate charging strategies for periodic power outages. |
| On-Bus Battery Fire | - Buses | Low | - Employee and rider's safety<br>- Service interruptions<br>- Reputation Impact<br>- Loss of vehicles for repair time | | | X | X | X | - Implement an on-bus fire suppression system.<br>- Use a Battery Management System (BMS) to protect the batteries from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, etc.<br>- Provide staff and first responder training. |

| | | | | | | | | | |
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| Back-up Batteries Storage Fire | - Yards<br>- Batteries and Charging Equipment | Low | - Loss of vehicle for repair time | X | X | | X | X | - Ensure adequate water supply to control the fire.<br>- Implement a water-based fire protection system.<br>- Design facilities per code for electric equipment, review applicability of current code and best practices.<br>- Coordinate and consult with the San Francisco Fire Department about appropriate design.<br>- Provide staff and first responder training |
| Bus operating range | - Buses | Medium | - Increased operating cost<br>- Increased fleet size | | X | | X | X | - Minimum mileage requirement in OEM contract<br>- Increase ESS (Energy Storage System) battery system capacity<br>- Provide on-route charging at key locations<br>- Procure buses with fast and slow charging capabilities<br>- Re-blocking to shorten long blocks, to operate within range limitations<br>- Increase spare ratio |
| Bus weight | - Buses | Low | - Increased operational cost and/or complexity | X | | X | | | - Inventory existing and expected weight restrictions for current and planned routes.<br>- Require all new buses to comply with axle weight limits (CVC 35551).<br>- Consider using shorter (lighter) buses where weight is an issue.<br>- Re-route around locations with axle weight restrictions. |
| Battery Capacity | - Buses<br>- Batteries and Charging Equipment | Medium | - Increased operational cost and/or complexity<br>- Reduced performance | | X | | X | | - Focus on past performance and validated estimates of energy economy and range per charge under a nominal and worst case operating profile presented by the SFMTA during specification writing, selection criteria (evaluation of proposals), and including remedies from OEM if performance thresholds are not met (e.g., cover cost of on-route charging)<br>- Phased transition of fleet, beginning with shortest block distances to allow technology to advance as longer blocks are electrified<br>- Evaluate performance of the pilot fleet and test the bus capacity with weight in the San Francisco topography |
| Technology obsolescence | - Buses<br>- Batteries and Charging Equipment | Medium | - Reduced performance<br>- Replacement cost | | | | | X | - Choose broadly used technologies and/or those with established industry standards<br>- Require reverse compatibility in future bus and equipment specifications<br>- Consider cost/benefit of retrofitting older buses and equipment to best available technology at mid-life<br>- Adhere to established charging standards (J1772 and OppCharge) |

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| | | | | | | | | | - Purchase from established manufacturers and suppliers<br>- Avoid using custom built, one-off, or prototype equipment<br>- Develop peer review cycle with other transit agencies deploying large numbers of BEBs |
| Utility Providers Management | - Yards<br>- Batteries and Charging Equipment | Medium | - Higher cost of energy | X | X | | | X | - Confirm any rates tariff issues or concerns early with the utility provider<br>- Involve utility company early in the process of implementing BEBs (public utilities commission)<br>- Keep utility company involved as the fleet grows to more BEBs to ensure the can still support the load.<br>- Include alternate source of energy (e.g. solar panel) and power storage to reduce electricity cost and provide contingency in case of power outage. |
| Training | - Buses<br>- Electrical Equipment<br>- Batteries | High | - Reduced productivity<br>- Employee safety | | | | X | X | - Develop training curricula and resources needed to accomplish the training for operators, maintenance staff, supervisory personnel and first responders. Include recurrent training and check rides to reinforce proper BEB driving habits (e.g., use of regenerative breaking)<br>- Increase the number of hours available in new bus contracts for training to help instruction staff prepare for and train maintenance staff.<br>- Add training aids/boards/modules to the specification for the new buses delivered within a known time frame with the contract and be paid for with funds for the new ZEBs. Specific Training Boards would be utilized by the Maintenance Instruction Department at the facility to familiarize staff to the different components, features, functions, and safety aspects of ZEB systems. Specifically, training boards representing the ZEB battery Energy Storage Systems (ESS) and Battery Management System (BMS) would provide the tools necessary to instruct all levels of maintenance staff. Staff would be trained on the operational safety features as well as detail features for diagnosis and repair and provide hands on practical experience with new technology. A rough order of magnitude cost estimate is $200,000 per training board.<br>- Consider a contract or service agreement for charging facilities/infrastructure to provide time for the new technology to get broken in and problems solved as well as avoid risks associated with this type of maintenance operation. Facilities |

| | | | | | | | | | |
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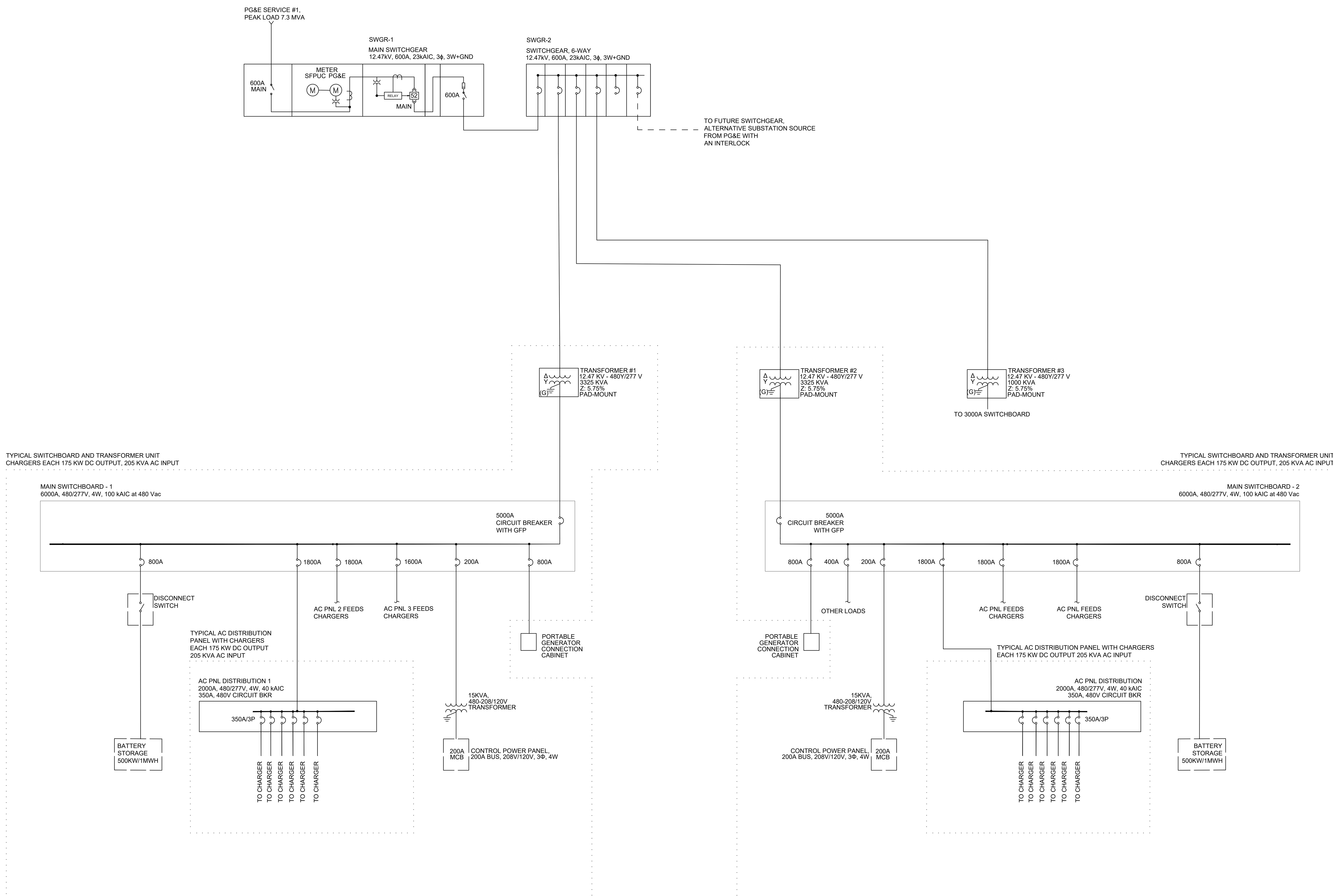
| | | | | | | | | | Maintenance staff would continue to provide the first level of diagnosis but would defer to the contractor for high voltage repair of the chargers and related infrastructure. |
| Bus charging procedures | - Buses<br>- Batteries and Charging Equipment | High | - Reduced performance and productivity<br>- Employee safety | | | | X | X | - Establish operating routines that ensure that battery electric buses are appropriately charged to support daily operations.<br>- Develop bus charge management plans and use charging system tools to help ensure there is monitoring of bus charging status. This information is then used for managing and prioritizing bus assignments (i.e. assign fully charged ZEB's to daybase blocks and less charged buses to "trippers".<br>- Charging windows may be lengthened during extreme cold conditions ("conditioning" vehicles while connected to chargers can increase cold-weather range). |
| Scheduling and Transportation Operations | - Buses | High | - Reduced productivity<br>- Customer impacts. | | | | X | X | - Develop protocols assign BEB fleets to blocks that do not exceed any operating range limitations for a given bus and its scheduled operation<br>- Establish operating protocols for Operators, dispatch, and field supervisors for using BEBs for extra service and for low battery charge (normal schedule or due to service disruption). Operators need to provide clear parameters for when buses can stay in operation, and when they need to be removed from operation due to low batteries |
| Environmental Review | - O&M Buildings | Medium | - Construction delays | X | | X | | | - Review site conditions and previous report concurrently with engineering documents.<br>- Review with the City and County of San Francisco Planning Department any environmental requirements and permits needed as part of the project.<br>- If the SFMTA receives federal funding, review with FTA Region 9 requirements of NEPA documentation. |

# APPENDIX D: SINGLE LINE DIAGRAMS

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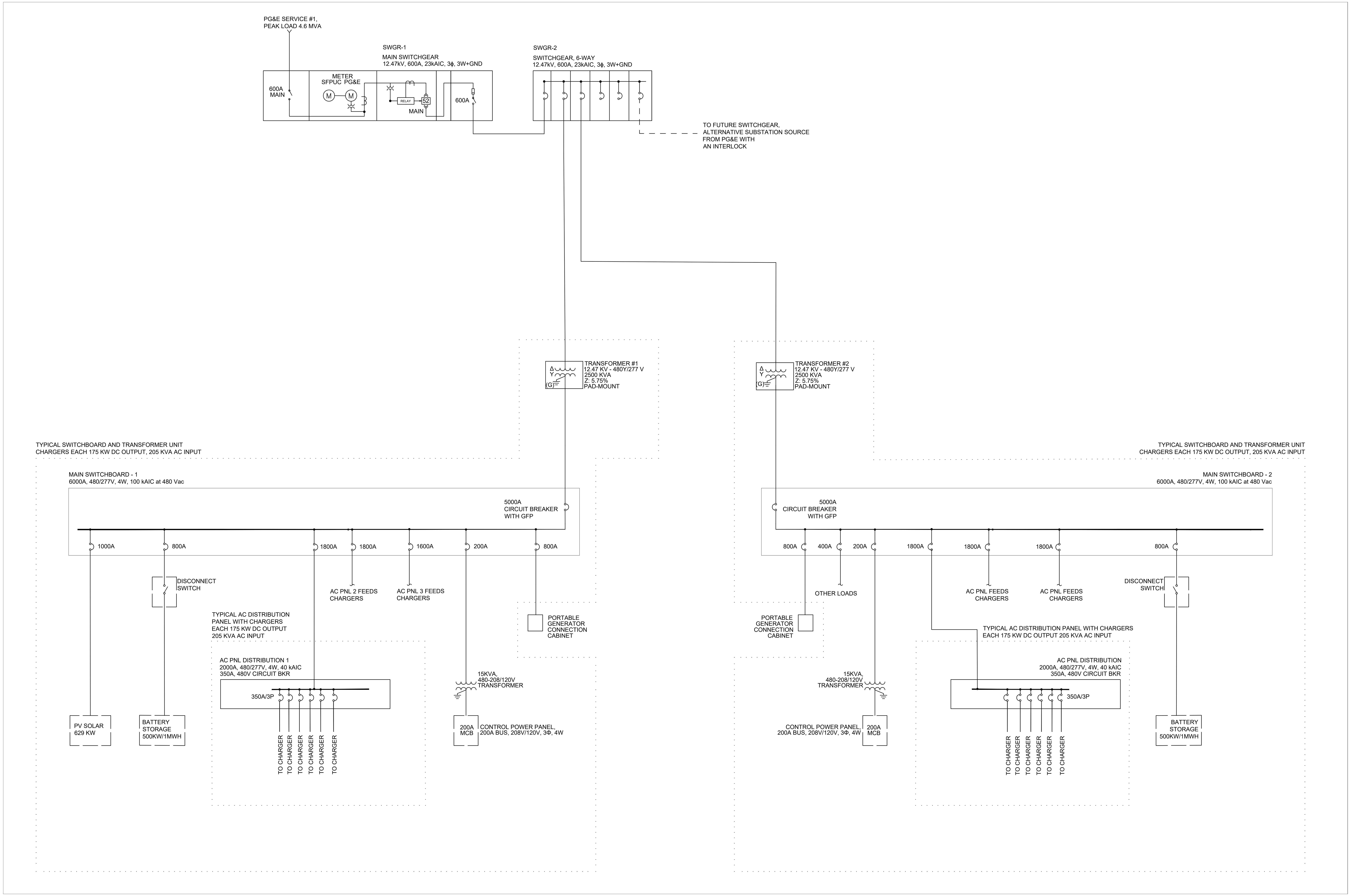
| DRAWN BY | VGG Systems |
| DATE | 02/09/21 |
| SCALE | NTS |

PROJECT TITLE
SFTMA ZE FACILITY
PLAN

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
SINGLE-LINE DIAGRAM
FLYNN YARD

DRAWING NUMBER
E.T.

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| DATE | 02/09/21 |
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PROJECT TITLE
SFTMA ZE FACILITY PLAN


WSP USA Inc.
16200 PARK ROW
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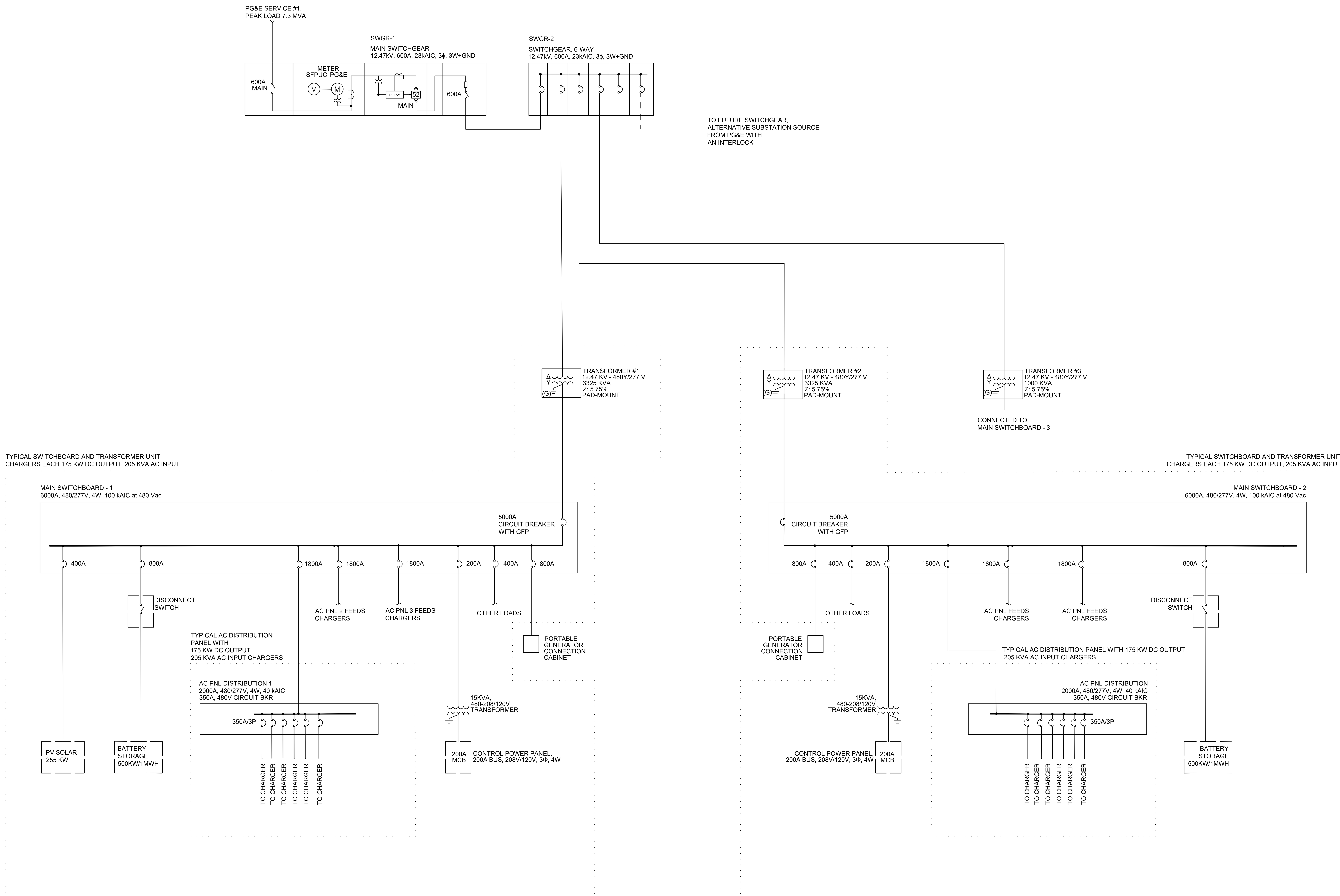
TEL: (281) 589-5900
FAX: (281) 759-5164


DRAWING TITLE
SINGLE-LINE DIAGRAM
ISLAIS YARD

DRAWING NUMBER
E.T.

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SINGLE LINE DIAGRAM
KIRKLAND YARD

DRAWING NUMBER
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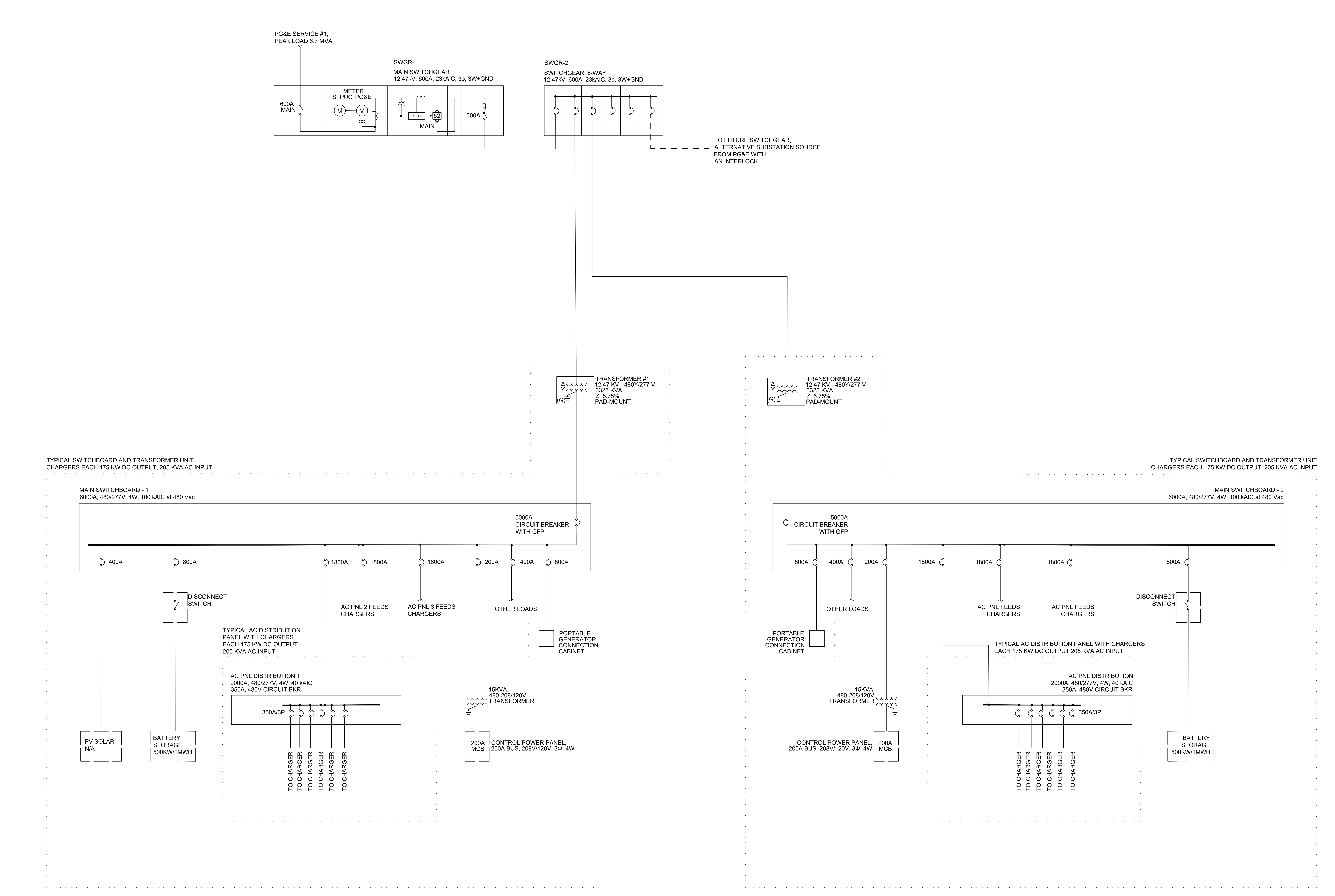


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FAX: (281) 759-5164

DRAWING TITLE
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POTRERO YARD

DRAWING NUMBER
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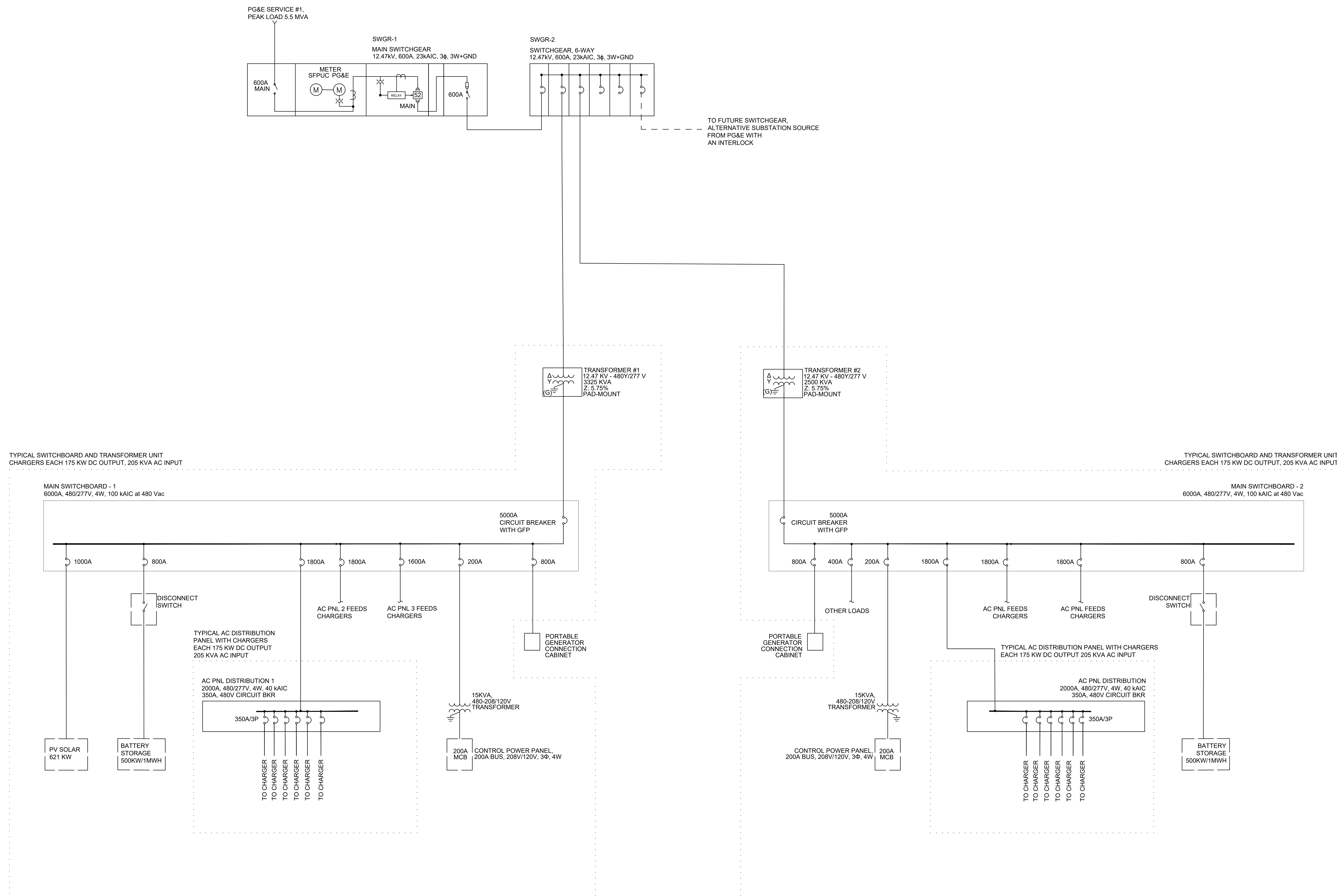


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16200 PARK ROW
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TEL: (281) 589-5900
FAX: (281) 759-5164

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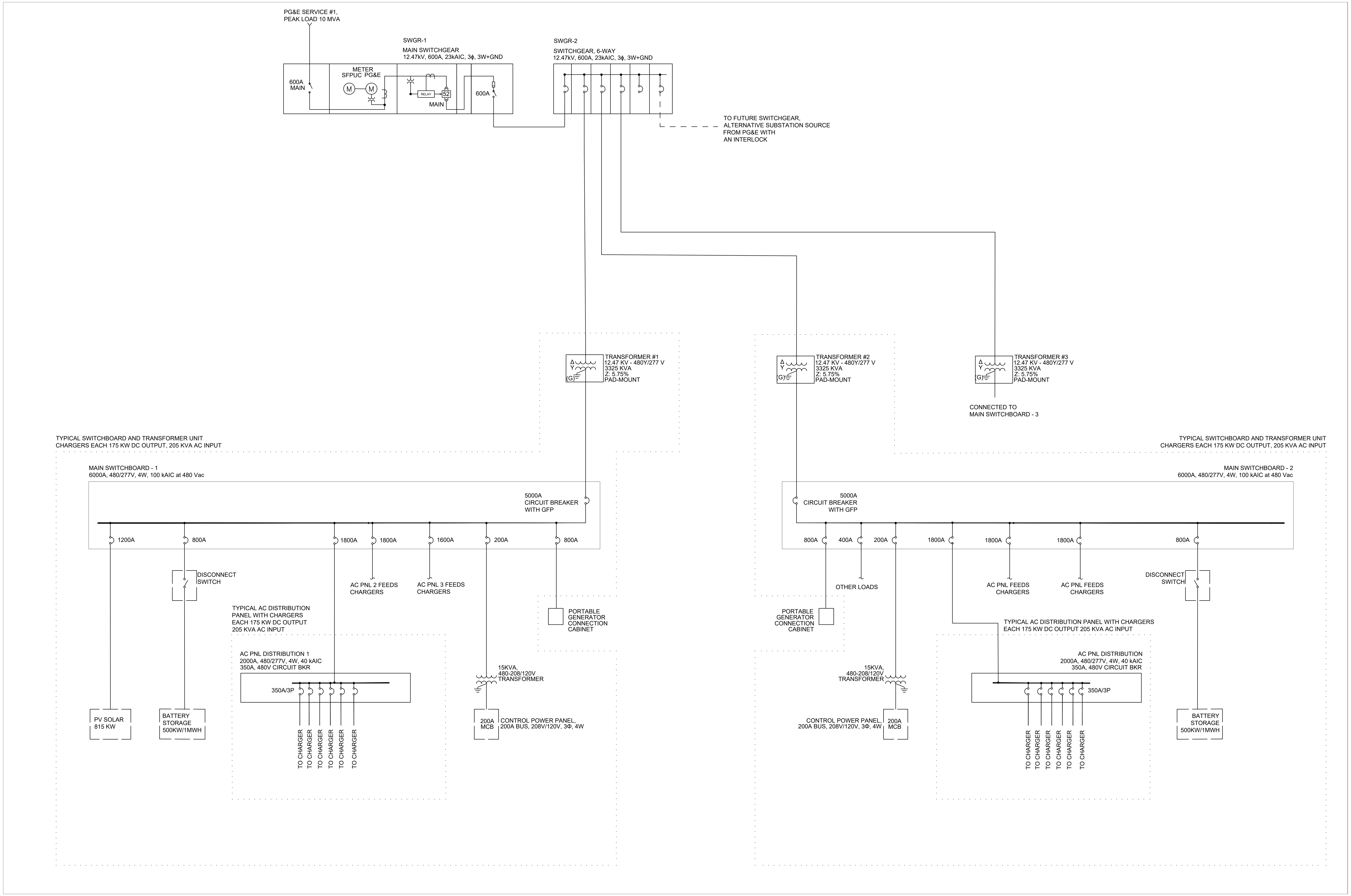


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DRAWING TITLE

SINGLE-LINE DIAGRAM WOODS YARD

DRAWING NUMBER

E.T.