San Bernardino County Transportation Authority

San Bernardino Countywide Zero-Emission Bus Study Master Plan

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Master Plan

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Acronyms and Abbreviations

AFCB	American Fuel Cell Bus
BEB	Battery Electric Bus
BOLT	Battery Optimization Lifecycle Tool
BRT	Bus Rapid Transit
BVEC	Bear Valley Electric Service
BYD	Build Your Dreams
CAIDI	Customer Average Interruption Duration Index
CAISO	California Independent System Operator
CARB	California Air Resources Board
CCW	Complete Coach Works
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPI-U	Consumer Price Index for all Urban Consumers
CPUC	California Public Utility Commission
DAC	Disadvantaged Community
ESS	Energy Storage System
FCEB	Fuel Cell Electric Bus
GHG	Greenhouse Gas
GTFS	General Transit Feed Specification
HV	High Voltage
ICT	Innovative Clean Transit
I	Interstate
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt Hour
kWh/mi	Kilowatt Hour per Mile
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
MBTA	Morongo Basin Transit Authority
Metro	Los Angeles County Metropolitan Transportation Authority

MT	Mountain Area Regional Transit Authority
MV	Medium Voltage
NAT	City of Needles
NRV	Non-revenue Generating
O&M	Operations and Maintenance
OCTA	Orange County Transportation Authority
OEM	Original Equipment Manufacturer
OTM	Off the Mountain
PM	Particulate Matter
PPE	Personal Protective Equipment
psi	Pounds per Square Inch
RNG	Renewable Natural Gas
RTA	Riverside Transit Agency
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SBCTA	San Bernardino County Transportation Authority
SBTC	San Bernardino Transit Center
SCE	Southern California Edison
SMR	Steam-Methane Reformation
SOC	State of Charge
VVTA	Victor Valley Transit Authority
WVC	West Valley Connector
ZE	Zero Emission
ZEB	Zero-emission Bus
ZEBRA	Zero Emission Bus Resource Alliance

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1 INTRODUCTION

1.1 Study Background

Highlighting the growing environmental concerns over the overuse of fossil fuels and pollution caused by greenhouse gases (GHGs), regulatory agencies now require transit agencies to comply with standards regarding the reduction of fossil fuel reliance and the integration of zero emission technology. In accordance with the California Air Resources Board's (CARB) Innovative Clean Transit (ICT) regulation, a mandate for the full conversion of bus fleets to zero-emission (ZE) by 2040,[1] San Bernardino County Transportation Authority (SBCTA) is developing the *San Bernardino Countywide Zero-Emission Bus Study* (Master Plan) to guide the five transit operators within San Bernardino County in their transition.

Throughout San Bernardino County, which is the largest geographic county in the United States, five transit operators provide transit accessibility to their communities: Morongo Basin Transit Authority (MBTA), Mountain Area Regional Transit Authority (MT), City of Needles (NAT), Omnitrans, and Victor Valley Transit Authority (VVTA). Geographic constraints, extreme heat and cold temperatures, as well as steep road grades and winter blizzard conditions in some areas are some of the challenges of a ZE fleetwide transition in San Bernardino County. The purpose of this analysis is to survey the current available technology and provide tailored solutions to each operator given its unique operating circumstances.

The analysis will consider the strengths and weaknesses of existing technology: battery electric buses (BEBs), which require capital infrastructural upgrades such as in-depot and on-route charging (overhead pantograph and in-ground inductive), power grid capacity enhancements, and bus range limitations due to battery capacity. Additionally, hydrogen fuel cell electric buses (FCEBs) require additional capital infrastructure, such as hydrogen fuel production, storage, and sourcing – which are in limited supply due to their technological infancy. However, FCEBs offer similar range to conventional fueling technologies and allow for existing, long-distance routes to be completed, largely, with fewer range concerns.

1.2 Report Purpose and Structure

This purpose of this report is to provide the framework for each agencies' transition to ZEBs pursuant to the CARB's ICT regulation. The Master Plan outlines the existing conditions, methodologies and analyses, and proposed technologies and facility recommendations for each of the five transit agencies. By itemizing the existing conditions, assessment, and findings by operator, this document provides a robust and comprehensive study of how ZEB could be implemented in San Bernardino County.

This document is organized into four main categories: 1) introductory content and background information on ZEB technologies; 2) agency-specific conditions and ZEB solutions; 3) agency-

[1] The ICT regulation requires California transit agencies to gradually transition their buses to zero-emission technologies by 2040. The regulation is structured to allow transit agencies to take advantage of incentive programs by acting early and in a manner to implement plans that are best suited for their own situations. Developed by the CARB Dec. 14, 2018: For the operators MBTA, MT, NAT, and VVTA, a ZEB transition rollout plan must be submitted to CARB by July 1, 2023. Omnitrans, the only "large" transit operator in the county (>100 buses), must begin ZEB conversion by 2024, with 25 percent of purchases required to be ZEB. In the following years, 2026-2029, 50 percent of purchases are required to be ZEB, with full conversion required by 2040. Omnitrans' rollout plan is due to CARB by July 1, 2020.

specific disadvantaged communities' analysis; and 4) conclusions and recommendations for each agency.

1.3 About San Bernardino County Transportation Authority

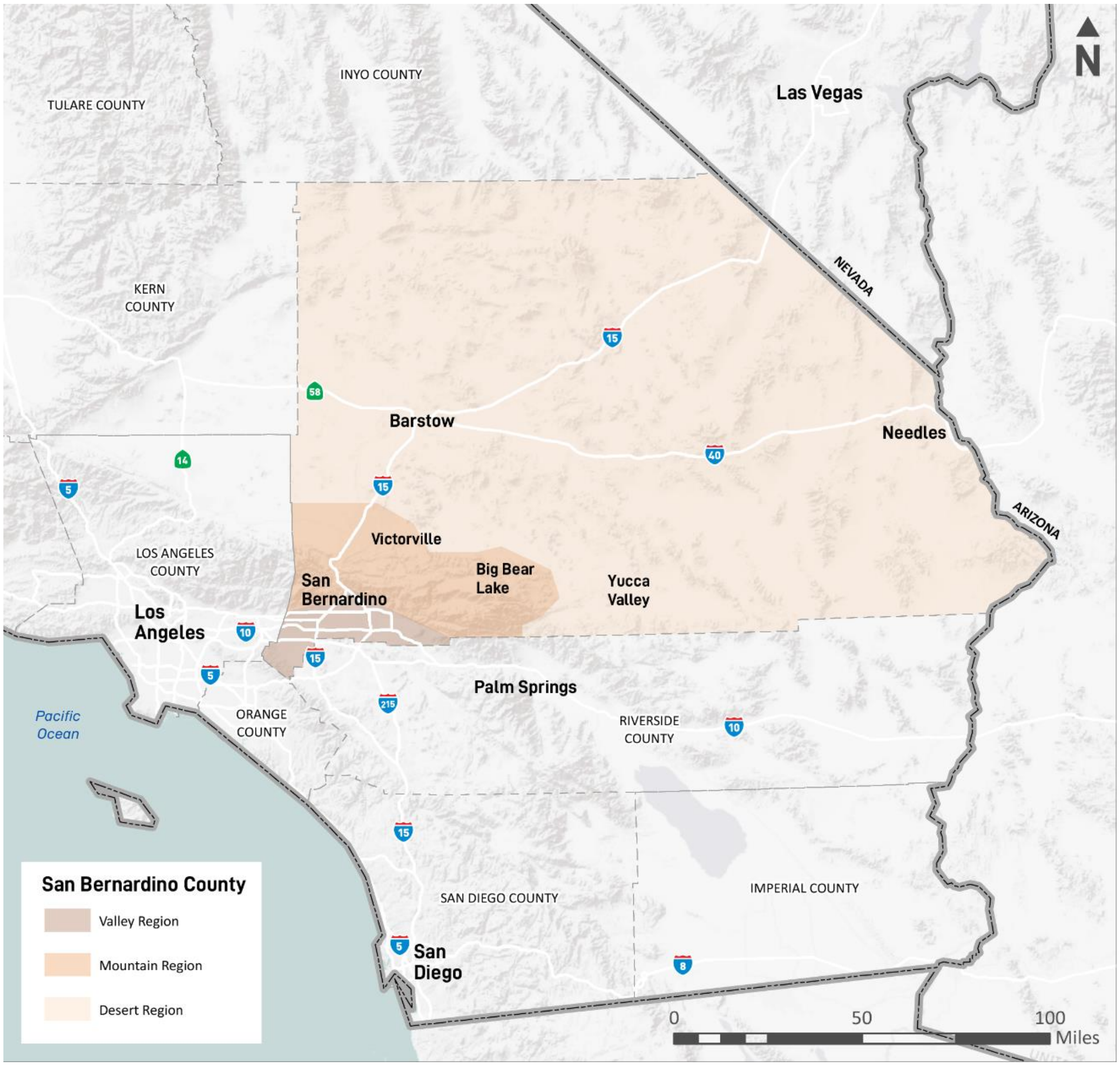
SBCTA is responsible for cooperative regional planning and implementing the countywide transportation system. Established in 1973, SBCTA is statutorily designated to serve as the county's transportation commission, service authority for freeway emergencies, countywide transportation authority, and congestion management agency. It also administers Measure I, a half-cent transportation sales tax in place since 1989. Measure I is the largest single source of annual transportation funding available to the county, and in 2004, voters approved to extend the measure's life for an additional 30 years to 2040. To administer the collected funding, the county was divided into six subareas with distinct expenditure plans and policies; all money raised in a given subarea must be only used in that subarea. These subareas roughly corollate to the five operator territories, particularly in the case of Morongo Basin, the Mountains region, and Victor Valley.

SBCTA's mission is to improve the quality of life and mobility in San Bernardino County. achieve this by:

- Prioritizing safety and ensuring it is cornerstone in all that they do.
- Making all transportation modes as efficient, economical, and environmentally responsible as possible.
- Envisioning the future, embracing emerging technology, and innovating to ensure transportation options are successful and sustainable.
- Promoting collaboration among all levels of government.
- Optimizing our impact in regional, state, and federal policy and funding decisions.
- Using all revenue sources in the most responsible and transparent way.

SBCTA's annual budget for Fiscal Year 2019-2020 is $972 million. Major projects are the biggest expenditure at $459 million, largely due to capital investments in the I-10 Corridor, the Redlands Passenger Rail Project and the Mount Vernon Viaduct. Expenditures for transit total $333 million. A central mission for SBCTA is to allocate federal, state, and county (Measure I) transportation funds to projects and operators around the county. Figure 1-1 is a geographical map of San Bernardino County.

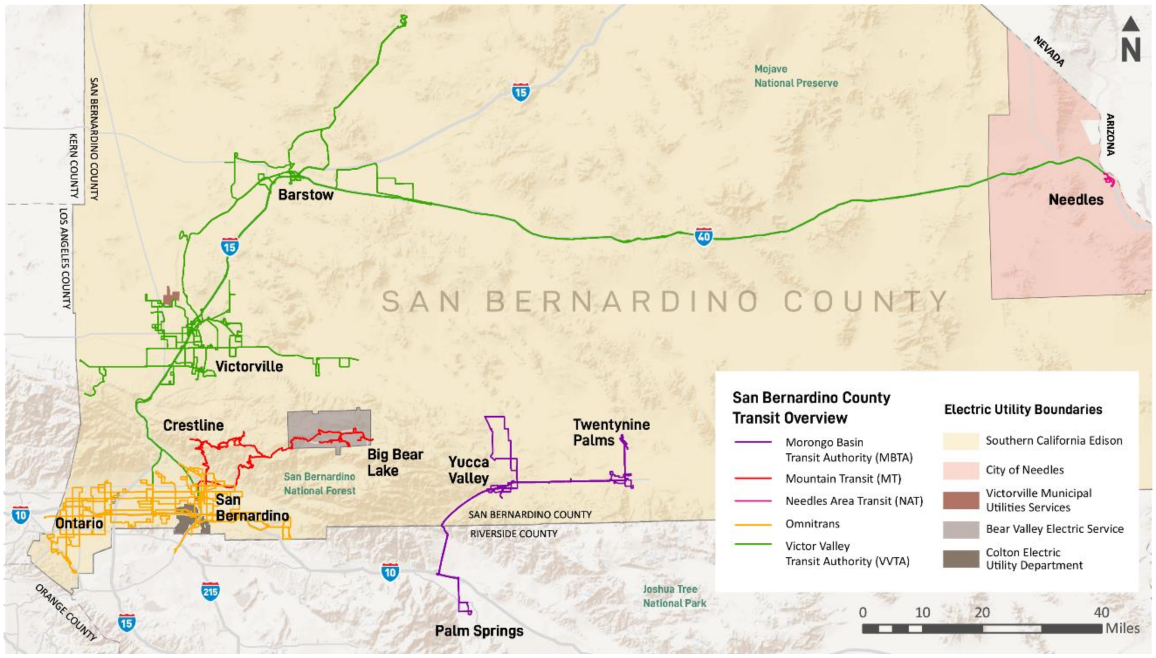
Figure 1-1: San Bernardino County, California



Source: WSP

Public transportation in San Bernardino County is largely provided by five local transit operators: MBTA, MT, NAT, Omnitrans, and VVTA. While there are six utilities providers in the service area, Southern California Edison (SCE) provides the majority of electricity to the service region. These utilities are crucial in the ZEB electrification process because they will provide the future power for ZEB charging and fueling infrastructure. Figure 1-2 shows transit and utility service boundaries in the county and Table 1-1 presents each operator's annual operating budget, and annual unlinked passenger trips.

Figure 1-2: Transit Service and Electric Utility Boundaries in San Bernardino County



Source: WSP

Table 1-1: Transit Agency Budgets, Fleets, and Passenger Counts

Operator	Annual Operating Budget (FY 2019)	Annual Unlinked Passenger Trips
MBTA	$3,463,581	248,560
MT	$3,073,781	181,789
NAT	$383,487	27,853
Omnitrans	$91,456,968	10,927,524
VVTA	$26,434,124	1,077,823

Source: WSP

More broadly, San Bernardino County is served by three major interstate freeways: Interstate (I) 10, I-15, and I-40. Ontario International Airport provides commercial passenger flights and is a major regional cargo hub. The San Bernardino Valley is also supported by commercial flights at San Bernardino International Airport, while Southern California Logistics Airport in Victorville provides major cargo service. Amtrak provides long-distance passenger rail, and Metrolink commuter rail connects the San Bernardino Valley with Los Angeles, Orange, and Riverside Counties.

Major travel destinations in San Bernardino County include Big Bear Mountain and Lake Arrowhead skiing and recreation areas, Joshua Tree National Park, four major universities (University of Redlands, California State University San Bernardino, Loma Linda University, and University of La Verne College of Law), and several community colleges. Additionally, the county is home to three minor league baseball teams and the Auto Club Speedway in Fontana.

1.4 Technology Overview

1.4.1 Battery-Electric Buses (BEBs)

BEBs provide many environmental benefits to the community and region, as well as life-cycle cost savings to the operating agency. However, BEBs currently lack the range capabilities of compressed natural gas (CNG) and diesel (and/or diesel-hybrid) buses. For this reason, it is essential to analyze and understand how BEBs will perform under existing operating conditions before procuring buses and charging infrastructure. Depending on the length of vehicle blocks and conditions under which the buses operate, various strategies may need to be considered to extend the operating range of some or all the BEBs in operation, including, but not limited to, on-route charging at one or multiple locations, larger capacity batteries, higher-powered chargers for overnight or on-route charging, and changes to route alignments or schedules.

The performance of a BEB is typically measured by the range of the vehicle. This can be expressed in miles or hours of operation but can be highly variable depending on a myriad of factors, including regional climate and weather conditions, geographical topography, road sinuosity, ridership, battery health, operator driving style, and traveling speeds. Before an agency commits to BEBs, it is important to model and analyze performance capabilities tailored to the agency's unique operating and service conditions.

The resulting service evaluations help determine the optimal mix of battery sizes and charging infrastructure, location and sizes of on-route chargers, and changes to bus schedules, which can significantly affect operational and capital investments. Shadow service or pilots should also be used on the planned or proposed route to ensure that modeled results reflect actual performance.

1.4.1.1 Energy Storage System (ESS) and Batteries

BEBs depend on batteries to store and retrieve energy. There are many different types of batteries; however, recent developments over the past decade have shown that lithium-ion batteries have the greatest capacity for reliable, safe, and cost-effective energy storage.

The buses' duty cycle, operating environment, availability of sufficient electrical supply, and other factors will help determine the size of the energy storage system (ESS). Several factors will have a negative effect on the range, such as heat and cold, terrain, operator driving style, and the ability to take advantage of regenerative braking. If estimated ranges are below approximately 200 miles, a battery size of 450 kilowatt hours (kWh) may be sufficient to allow a single charge to meet the range requirements (depending on efficiency). If the required range is greater than 200 miles, there will likely need to have charging infrastructure to recharge at some point while in service or an additional bus will be needed to complete the service. Later chapters include a detailed review of range and charging options. All United States-based bus manufacturers that offer BEBs have models with different sizes of batteries to meet different operating range and charging options.

The buses' batteries are capable of storing a substantial amount of energy for use to propel the buses and supply the electrical energy required by the other systems on the buses. The ESS has provisions to control the amount of current flow into and out of the batteries to prevent damage. Additionally, technical solutions have been designed and are manufactured into the ESS to prevent damage due to accidents and other incidents.

BEBs and their use will also introduce new terminology to the transportation industry. Table 1-2 lists several of the terms used to describe BEB use and their corresponding traditional equivalent.

Table 1-2: Terms for BEB Use and Corresponding Traditional Equivalent

Term	Unit	Meaning	Example	Traditional Equivalent
Kilowatt	kW (1,000 watts)	Power	A 100 kW motor is equivalent to a 75-horsepower engine	Horsepower
Kilowatt-hour	kWh	Energy	A 400 kWh ESS should be able to supply 400 kW for an hour and 200 kW for 30 minutes	1 gallon of diesel is equivalent to 38 kWh of electricity
Kilowatt-hour per mile	kWh/mi	Energy consumed per mile	An average city transit bus uses 1.7 kWh/mi in the spring but 2.9 kWh/mi with the air conditioning on	Miles per gallon (mpg)

Source: WSP

1.4.1.2 Propulsion and Regenerative Braking

Electric motors that turn the electricity into work are incorporated into the buses in several unique ways. The bus manufacturer, Build Your Dreams (BYD), uses wheel motors, which are an electric motor driving each rear wheel. Proterra uses dual-independent motors attached to a two-speed gear box. New Flyer uses a single-traction motor with no transmission, while NOVA and Greenpower use a single permanent traction magnet motor.

An additional feature, regenerative braking, can also generate electricity on buses that are in service. Regenerative braking uses the momentum of the bus and converts it into electricity, which can then recharge the batteries. The motor that drives the bus can be switched into a generator when a bus operator takes their foot off the accelerator. A motor and a generator are built the same way but are electrically different in the way in which internal components are energized to create a magnetic field. During regenerative braking, the bus will be slowed without the use of brakes because the kinetic energy associated with the momentum is used to create electricity, which requires energy and slows the bus. An added benefit to regenerative braking is reduced brake wear.

Other systems on the bus will also require electricity to operate. An electrically-driven air compressor provides the air needed to operate the brakes. Power steering will be made possible by an electric-driven hydraulic pump. Doors and windshield wipers are also operated electrically. Heating and cooling will be provided by an electric HVAC system. Overall energy consumption to cool the buses during summer will clearly have an effect on the range of the buses. The primary propulsion system is going to be the largest draw on the energy storage, and the heating and cooling system will be the next largest drain. Another factor that can have a significant impact on BEB efficiency is the operator’s driving style. In some studies, driving style reduced efficiency by up to 1 kWh/mile[2]. To reduce state-of-charge (SoC) loss from aggressive driving, some original equipment manufacturers (OEMs) are providing the option to install driver management systems.

[2] Kontou & Miles. 2015. “Electric Buses: Lessons to be Learnt from the Milton Keynes Demonstration Project.”

Though few third party companies are beginning to develop software that improves BEB efficiencies through driving controls, these modification are more typically proprietary to each OEM. Upon request, many OEMs can integrate acceleration controls and customized regenerative braking options within the master control system to improve BEB range. One criticism surrounding driver control systems is the impact they may have on safety. In some circumstances, it may be necessary for a driver to accelerate or brake rapidly to avoid a collision. Inclusion of these systems may not be necessary if tailored BEB training for operators is provided. These issues are a part of the considerations taken when determining the overall size of the battery system and methods to charge them.

1.4.1.3 Charging

There are multiple charging technologies available for depot-based charging. The four depot charging types are:

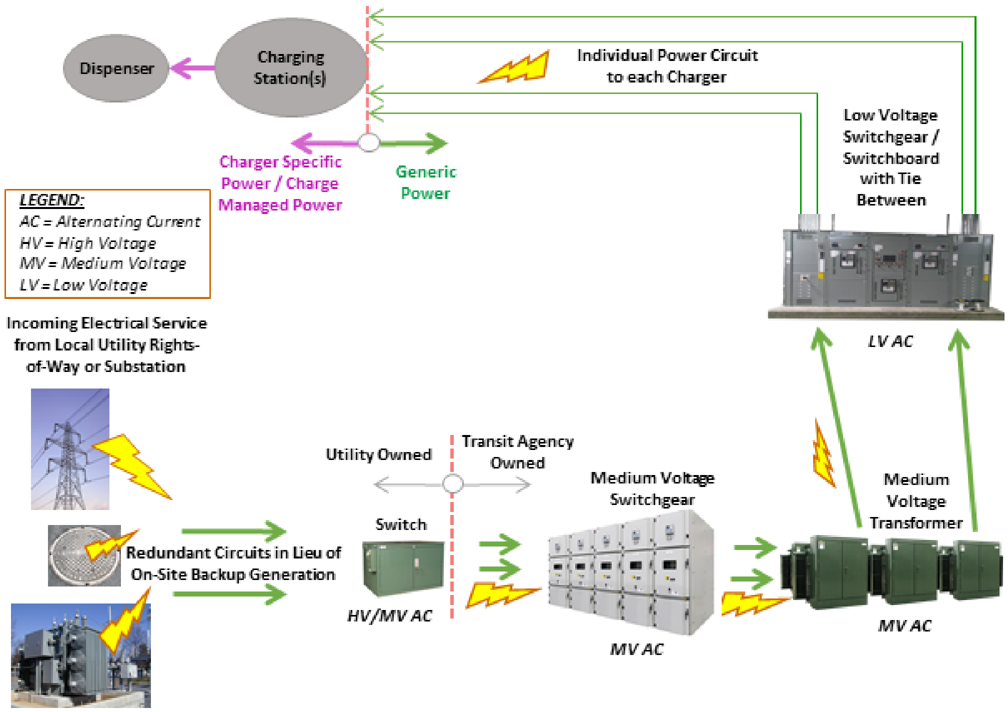
- Plug-In alternating current (AC) Charging
- Plug-In direct current (DC) Automatic Charging
- Overhead Pantograph DC Charging
- Inductive Charging

The common elements of all charging systems are discussed first in this section, followed by an overview of the four charging systems with individual sections explaining each technology.

1.4.1.3.1 Charging System Components

Regardless of the specific charging technology, all charging systems will likely require an enhancement to utility-provided electrical service to the site, on-site electrical distribution, charging equipment, and a charge management system. The basics for each of these components are described in the following sections. Figure 1-3 is a representation of a typical BEB charging system.

Figure 1-3: Typical BEB Charging System



Source: WSP

1.4.1.3.2 Electric Service from Local Utility

Due to the high power demand for charging BEBs and the small amount of spare capacity left in existing circuits, expanded or new electrical service is usually required to serve incoming BEBs.

Depending upon the load to be served, a local utility provides two types of service – high-tension (HT), which is above 1,000 volts (V) (such as 2,400 V, 4,160 V, 13.8 kV, or 115 kV) or low-tension (LT), which is below 600 V (480 or 208 V). HT service tariffs are typically much less expensive than the LT service rates. Given the significant loads required for BEB charging, HT service will most likely be brought to the site at either 13.8 kV (referred to as medium voltage [MV]) or 115 kV (referred to as high voltage [HV]). Utility metering would be located at the service entrance point to the site with customer-owned and maintained transformers converting the higher voltage power to the end user voltage.

If the customer's load to be served is large and needs high reliability, utility companies usually meet these customer requirements by providing two or three service feeders from different utility substations. This way, if one of the feeders is out for any reason (such as ground fault), the second or third feeder would be able to carry the entire load. To allow anything on the site to be fed by any of the service feeders, the main breakers are arranged in what is referred to as a main-tie-main configuration.

The feeder breakers connect typically to MV transformer (i.e., 13.8 kV to 480 V 3-phase transformers located as close to the loads as possible). From these MV transformers, low-voltage (LV) power, typically at 480 V three-phase, is distributed to the loads through LV switchgear or switchboards. If redundancy is required, the main breakers of two of these LV switchgears or switchboards would be tied together in a main-tie-main configuration. This type of arrangement on the LV side is called secondary-selective. Depending upon the requirements, the equipment could be primary-selective or secondary-selective only or could be both primary and secondary selective.

For large proposed BEB facilities (possibly 100 buses or more), the local utility may opt to bring the redundant HT service feeders to the site at even higher voltages than a standard 13.8 kV circuit. In this case, additional utility-provided and installed transformers would be required to step the voltage down to 13.8 kV. This setup is commonly referred to as a substation and would consist of primary switches, step-down transformers, and secondary MV switchgear with protective relay and other components. To provide redundancy, a double-ended substation, with two service feeders and two sets of transformers, would be used. All this equipment would require a large fenced or wall-enclosed area (in the range of 30 by 60 feet) on the customer's site. While the initial capital expense of constructing an electrical substation and providing and installing the equipment is borne by the local utility, if used solely to provide power to a single customer's property, the cost of the substation would be passed on to the customer either through a one-time charge or amortized on the monthly electrical bill.

1.4.1.3.3 On-Site Electrical Distribution

On-site electrical distribution includes the step-down (13.8 kV to 480 V) MV transformers, LV switchgears/switchboards with feeder circuit breakers, and a raceway distribution system to bring power to the chargers. This equipment can be customer-owned and maintained, which provides flexibility in choosing transformer size and equipment location, however this is more costly.

On-site MV transformers will step down the incoming 13.8 kV electrical service to 480 V, which is the voltage that buildings and vehicle electric charging equipment typically require. The number of transformers required will depend on the number of chargers and the size of the transformers. Two or more of these transformers can operate in parallel and feed into a 480 V collector bus through spot network protectors that can accommodate larger ampacities. The network protectors have circuit breakers and relays that do not let current flow in the reverse direction (i.e. to protect the utility grid from the customer's distribution network). The number of transformers for each electrical service feeder is set at one greater than the number needed to support all the chargers at the facility (referred to as an N-1 configuration). By operating transformers in a N-1 configuration, if a transformer fails the other(s) should be able to carry the entire load.

Switchgear and Switchboards

The 480 V three-phase AC power is fed from the secondary side of the MV transformers to two LV switchgears or switchboards. These switchgears or switchboards are tied in a main-tie-main configuration so that power can be delivered to all feeder breakers through the tie breaker, even if one of the main breaker trips for any reason. Regardless of whether switchgear or a switchboard is used, they both distribute 480 V power to each of the individual bus charging cabinets through smaller-sized breakers. Typical switchboards are shown in Figure 1-4.

Figure 1-4: Interior and Exterior Switchboard

Source: WSP

AC Power Distribution to Switchboards

Because the switch is the connection point between the utility and customer-owned service, the switch is typically located at the property line so that the utility can gain access without entering the facility. Power must then be carried from the switch to the on-site MV transformers. Operator-owned transformers could be located anywhere on the site as long as they are outdoors in an accessible location for installation and servicing. This could include locations on the roofs of buildings as well as at ground level. Higher, rooftop elevations are preferable in any areas subject to flooding. Switchboards, on the other hand, may be located either indoors or outdoors but should be located as close as possible to the chargers they serve to reduce cost of distributing power. Because switchboards can be located indoors or outdoors, the location may be determined by the availability of interior space, especially in existing facilities. The location of the transformers relative to the switch and the switchboards is not critical, as there are just a few connections to and from the transformers and no significant distance restrictions with distribution of AC power.

AC Power Distribution to Chargers

A separate AC power circuit is required for power distribution from the LV switchgear equipment to each individual charging cabinet. Depending on the number of charging cabinets installed on a site, the AC power distribution circuits can be sizable both in quantity (125 conduits for a 250-bus garage utilizing 1:2 shared charging) and in space. For example, a 250-bus facility using shared 1:2 charging requires an AC distribution bundle of (125) 3.5-inch conduits, stacked five deep, and would be approximately seven-feet wide by two-feet deep. Because of this large space impact, the path of the AC power distribution should be coordinated with the structure of a building, and the length should be minimized by locating the switchboards as close to the chargers as is feasible.

There are different possible routes for distributing the power from the switchgear/switchboard to the charging stations/charging cabinets. The first is to distribute the power underground. Distributing the power underground ensures that the conduit cannot be damaged by any buses. Phasing for this option, however, becomes difficult, as the existing slab needs to be cut, meaning that circulation around the site will be limited during installation, as buses cannot move across the torn-up slab and concrete without extensive plating after each day of construction. This same challenge is presented during the installation of inductive charging pads. The other alternative to distribute power is via an overhead structure. In this scenario, conduit is suspended from either existing overhead structure or new overhead framing to allow an individual power dropdown to each charging station/charging cabinet. This makes phasing simpler, limiting disturbances to the existing pavement and slab so that buses can continue to circulate around the entire site unimpeded.

1.4.1.3.4 Charging Equipment

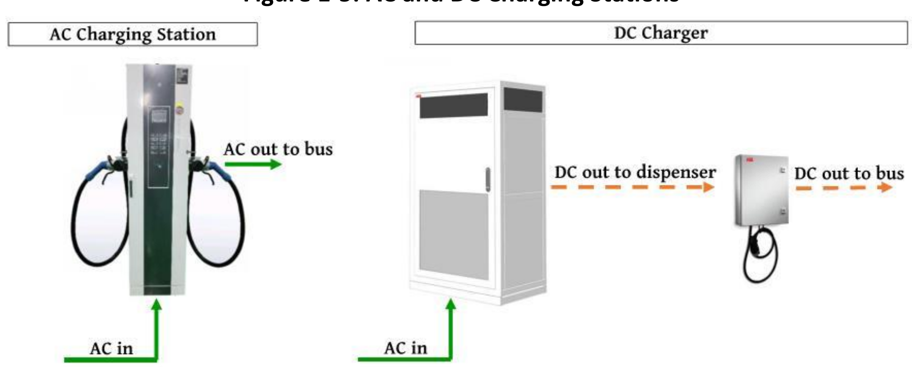
BEB charging equipment takes AC power fed from the LV switchgears, converts it to DC power, and charges the battery on one or more buses. The configuration of the charging system's components varies somewhat among the four types of charging systems. However, for each charging system, charging equipment typically comprises the following components:

- Charging cabinet (or charging station)
- Rectifier
- Charger
- One or more dispensers
- Distribution network to connect them, which in some systems may entail a distribution panel to allow multiple dispensers to be operated by a single charger

The charging cabinet (or charging station with AC systems) is equipment that monitors and manages the charging process. It is provided by a charging equipment OEM, and it has either manual and/or automated controls. The charging cabinet takes generic AC power and distributes charger specific power to the bus through one or more dispensers that are connected to the bus(es).

While batteries need to be charged with DC power, electricity is distributed as AC power due to the limitations on the distance over which DC power can be distributed. The incoming AC power is converted to DC power by a rectifier. The rectifier can either be located on the bus or within the charging cabinet. If the rectifier is located on the bus, the charging system is considered an AC charger (AC power is brought to the rectifier on the bus from a charging station). If the rectifier is located off the bus (within the charging cabinet), it is considered a DC charger (DC power is brought to the bus from the rectifier). Both types are shown in Figure 1-5.

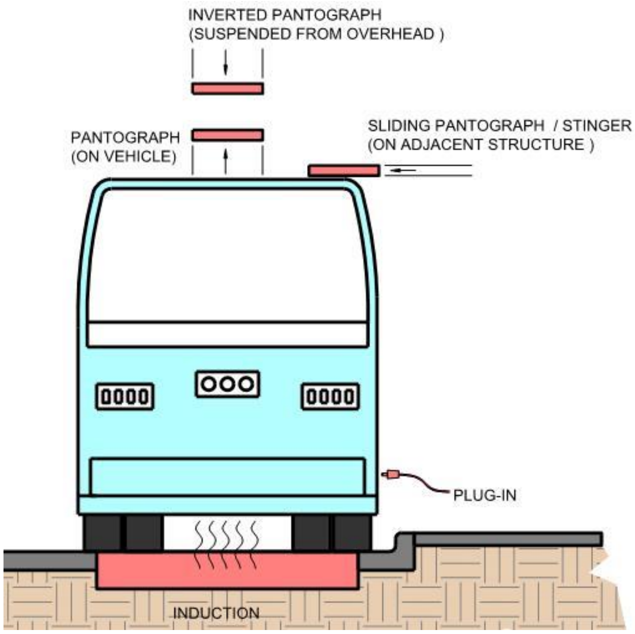
Figure 1-5: AC and DC Charging Stations



Source: WSP

The dispenser is the equipment that physically connects the charging cabinet to the bus. The type of dispenser varies by charging system type, OEM, and agency preference. Figure 1-6 illustrates the different types of dispensers for the various charging system types, and how each connects to the bus. Power is carried to the dispenser through conduits or cables. The number, diameters, and length of conduits and cables vary with the type of system and OEM.

Figure 1-6: Dispenser Types and Locations



Source: WSP

Some OEMs' DC charging systems may provide, or allow for, a distribution panel. This is an electrical power bar or "bus" with a single DC input from the charger and multiple outputs to allow a single charger to distribute power to multiple dispensers. A distribution panel can be contained within the DC charging cabinet or it can be a standalone panel near the charging cabinet, depending on the OEM.

It is also possible to have a centralized rectifier, located between the transformer and the switchboards, to feed DC power to the charging cabinets via DC switchboards. However, charging cabinets would still be required because DC charging cabinets regulate the voltage provided to each dispenser and they start, stop, and monitor the bus charging process. These functions cannot be done by a centralized DC rectifier.

1.4.1.3.5 Charge Management Systems

Charge management is the hardware or software system that monitors and controls the installed bus charging stations and cabinets on a site. With a charge management system, an on-site service manager would be able to:

- View the status of the various individual charger stations and cabinets (e.g. open, in-use, offline).
- View SOC of a specific BEB connected to a specific charger on site.

- Control prioritization of connected chargers (i.e. in a one charger to 2+ dispenser shared charging system, control which dispenser gets power and how much power).
- Monitor the total amount of power used by the site for charging, adjust charging rates and time of charging to keep daily maximum use under a desired maximum power usage.

The importance of charge management systems cannot be overstated. The charge management system on a site should be compatible with multiple OEMs. The ability to remotely monitor and control the charge management system at various sites from a central location can provide for optimal monitoring of the depot charging process, including centralized charging oversight and assessment of the status of the electrical infrastructure at each facility.

1.4.1.3.6 Dedicated vs. Shared Charging

Dedicated charging (1:1) refers to a charging system configuration where a single charger is connected to a single dispenser and can only charge a single BEB at any given time. For example, if Bus 1 pulled into a charging position and began charging at full 150 kW power, Bus 2 could pull into a second position and receive the full amount of 150 kW power from its own charger without interfering with the charging rate of Bus 1.

Shared charging (1:2, 1:3, etc.) refers to a charging system configuration when a single charger is connected to multiple dispensers. Depending on the OEM of the charging system and the charge management software installed for the site, some 150 kW shared chargers can potentially charge multiple buses at a time, although not at the same rate as a dedicated charger. For example, if a dedicated 150 kW charging system could charge a single bus in one hour, a shared charging system could charge a single bus in one hour, or two buses in two hours, etc. Once the single charging cabinet is connected to multiple buses via multiple dispensers, there are three main ways the system can charge the buses depending on the charger OEM's hardware capabilities:

1. **First in/first out charging.** In this system, the first bus to connect to a dispenser connected to a shared charging cabinet would also be the first bus to be fully charged. For example, if Bus 1 pulled into a spot and connects to a dispenser connected to shared charging cabinet, Bus 2 could pull into another parking space that has another dispenser connected to the same shared charging cabinet. However, the shared charging cabinet would continue to send all the available power to the Bus 1 until it is fully charged, and only then would the charging cabinet begin to charge Bus 2 via the other shared dispenser. If Bus 3 pulled in and plugged in to another dispenser connected to the same shared charging cabinet, the system would continue to charge Bus 2 until fully charged before charging Bus 3.
2. **Simultaneous Split Shared Charging.** In this system, if Bus 1 and Bus 2 were parked and plugged into two separate dispensers that shared the same 150 kW charging cabinet, the charging cabinet would split the power such that both buses received power from the charger at the same time. However, neither Bus 1 nor Bus 2 would be receiving the full 150 kW but would instead receive a portion of the power. Depending on the OEM, that power may not necessarily be split evenly. For example, a ChargePoint 150 kW (156 kW) charging cabinet would send 40 percent of the power (62.4 kW) to a Bus 1, and 60 percent (93.6 kW) to Bus 2, due to the specific power rectifying system inside the charger.
3. **Staggered Shared Charging.** In this system, the charging cabinet would send full power to its connected shared dispensers but in alternating timed intervals. For instance, if Bus 1 and Bus 2 are plugged into two separate dispensers that shared the same 150 kW charging

cabinet, the charger would send full power to Bus 1 for a short, specified amount of time, and then full power to the Bus 2 for the same short amount of time, and then alternate between them until one bus was fully charged. When Bus 1 is fully charged, full power would go into Bus 2 until either Bus 2 becomes fully charged, or Bus 3 takes the place of Bus 1, and the alternating would begin again, until either bus obtained a full charge.

There are many pros and cons for each charging method, but the main differentiating factors between the methods are shown in Table 1-3 and Table 1-4.

Table 1-3: Dedicated Charging Pros and Cons

Pros	Cons
▪ Any BEB parked and connected to a dispenser will receive a full amount of power available from the charger until fully charged, regardless of the number of other buses being charged on the site. ▪ A BEB plugging into any dispenser will not alter or impede the charging rate of another bus currently plugged into the system. ▪ The plan for charging the BEBs is straightforward. Any track can be used for any purpose and a bus can pull into any charging position. Pre-specified charging positions are not required. ▪ Numerous BEB OEMs and third-party charger manufacturers produce 1:1 chargers	▪ More space is required to accommodate a complete set of charging cabinets, in addition to higher costs for a 1:1 charging cabinet set ▪ Larger or more transformers and switchgear to support more chargers mean higher infrastructure costs and more space than shared charging. ▪ Potential higher electricity costs due to potential higher peak demand usage.

Source: WSP

Table 1-4: Shared Charging Pros and Cons

Pros	Cons
▪ The required electrical service is smaller than for a dedicated 1:1 charging system. ▪ Smaller or fewer transformers and switchgear means lower infrastructure cost, and a smaller space requirement. ▪ Reduced rates of charge to a battery may extend BEB battery life.	▪ Any BEB that pulls in and begins charging is not guaranteed to receive the full or any amount of power from a charger, as the power may be being directed to another bus. ▪ 1:2 charging is not commercially available from every OEM. (Two of the noted OEMs in this report, ABB and ChargePoint, can currently achieve a charging ratio of 1:2+.) ▪ Dispenser locations must be carefully considered and coordinated to establish which parking positions are expected to be filled in what order and at what time so that all BEBs assigned to the facility can receive a full charge in the requisite amount of time.

Source: WSP

1.4.1.3.7 Depot Charging Technology Options

A summary of the technical differences and requirements of the four types of charging systems is presented in Table 1-5. The definition of each column heading is described below:

Bus OEMs – BEB original equipment manufacturers (OEM) and rebuilders currently natively support each charging system type.

Charger OEMs – Third party bus charging system manufacturers and bus OEMs manufacture charging systems.

Bus OEM Fleet Compatibility – Ability of the bus charging system (charger, dispenser and charge management software) to be compatible (charge, monitor charging, record charging) with buses manufactured by other OEMs.

Bus Charger Ratio at 150 kW – The ratio between a single 150 kW charging cabinet and the number of dispensers it can support. (Note that some bus and charger OEMs make higher voltage cabinets that can support multiple dispensers at 150 kW. For purposes of consistency, this assessment only addresses the single 150 kW charging cabinets and not the larger voltage cabinets.)

Concurrent Charging from Shared Charger – Ability for multiple dispensers connected to a single charging cabinet to receive bus charging simultaneously through all connected dispensers.

Charging Cabinet Location – Required location of the charging cabinet in relation to the bus and the maximum distance from the bus.

Dispenser Location – Location of the dispenser in relation to the bus (as illustrated in Figure 1-6 in the previous section).

Ground Level Space Requirements – Amount of physical, grade-level space (mounted to pavement or raised island) next to the bus required for the charging dispensing system. Width includes space for the charging dispensing equipment and clearances for service and operation. This determines the minimum amount of space between tracks of parked buses.

Ground Level Equipment – The charging equipment, if any, that is required to be located adjacent to or near the bus at grade-level.

Operator Interaction – The actions a person would perform to charge a bus with each charging system type. This is an important distinction to know as chargers requiring limited or no interaction can be remotely located (on the roof, understructure, or not directly adjacent to bus parking) whereas chargers requiring more operator interaction may require the charger and/or dispenser to be directly adjacent to the bus being charged.

Distribution to Dispenser – The location of the power and charge management wiring from the charging cabinet to the dispenser.

Electrical Yard Needs – How much area would be needed for a new electrical yard to support each charging type system.

Rectifier Location – The rectifier that converts AC to DC can either be located on the bus or within the charging cabinet. The difference is whether the space and weight for the rectifier is located on the bus (reducing passenger capacity) or outside in the charging cabinet at the depot (taking up depot space and potentially reducing parking capacity in bus parking areas.)

Degree of Initial Commitments – When retrofitting BEB charging into existing garages and parking areas, installation of electrical distribution infrastructure for charging raises the issue of complete buildout of infrastructure conduits and ductbanks for future phases. That is, if an existing concrete slab is being trenched to install under-slab or in-pavement conduits for an initial phase, it may make sense economically and logistically to install all the empty conduits and ductbanks for the full build out to eliminate the need to re-trench and put back slabs and pavements later.

Commercially Available – Indicates whether charging systems described are currently available.

Charge Station Costs 1:1 – Estimated capital cost per bus for charging equipment and material only, assuming one bus per charger. Installation of the charging equipment is not included in these costs. Includes material cost for a single charging cabinet and dispenser set or induction support equipment per pad and single receiver on bus. The cost for the upgraded electrical service is also not included.

Table 1-5: Technical Differences and Requirements of BEB Charging System

	Bus OEMs	Charger OEMs	Bus OEM Fleet Compatibility		Bus : Charger Ratio at 150 kW			Concurrent Charging from Shared Charger		Charging Cabinet Location
Plug-In AC Charging	BYD, CCW	BYD, CCW, Custom	Not compatible across OEMs		1:1			No		Directly adjacent to bus
Plug-In DC Automatic Charging	All but BYD and CCW	ABB, Chargepoint, Proterra	ABB, Chargepoint: All bus OEMs	Proterra: all (charge management works for Proterra only)	ABB: up to 3:1	Chargepoint: up to 2:1	Proterra: 2:1	ABB, Proterra: no	Chargepoint: yes	May be up to 450 feet from dispenser
Overhead Pantograph DC Charging	All but CCW	ABB, Ebus, Heliox, Proterra, Siemens	All		ABB, Proterra, Siemens: 1:1	Heliox: up to 2:1	Ebus: up to 7:1	No		May be up to 450 feet from pantograph dispenser
Inductive Charging	All[3]	Momentum, Wave	All		Wave: up to 3:1	Momentum: up to 2:1		No		Within 100' of charging pad dispenser

Source: WSP

[3] Inductive charging pads are able to be installed on any BEB, regardless of manufacturer, as this is an after-market addition.

Table 1-5: Technical Differences and Requirements of BEB Charging System (continued)

	Dispenser Location	Ground-Level Space Requirements	Ground Level Equipment	Operator Interaction	Distribution to Dispenser	Electrical Yard Needs	Rectifier Location	Degree of Initial Commitments		Commercial Availability	Charging Station Cost 1:1
Plug-In AC Charging	Directly adjacent to bus	3' min. charging aisle every 2 tracks	One charging station per bus in charging aisles	Plug in and push button on dispenser to start	In ground or overhead	1:1 requires maximum size yard	On bus	High		Yes	Included with bus
Plug-In DC Automatic Charging	Above or adjacent to bus	2'-4' charging aisle every 2 tracks if ground mounted	One stanchion or hanging cable per bus in charging aisles	Plug in	In ground or overhead	Size depends on bus:charger ratio	In Charging Cabinet	In ground: High	Overhead: Low	Yes	Approx. $90-110k/bus
Overhead Pantograph DC Charging	Above bus	None	None	None	Set bus parking brake	Size depends on bus:charger ratio	In Charging Cabinet	Low		Yes	Pantograph: approx. $80-110k/bus
Inductive Charging	Under bus	10' equipment aisle every 6 tracks	1 power box, 1 control box, and 1 cooling box per charger in equipment aisle	None	In ground	Size depends on bus:charger ratio	In Charging Cabinet	In ground: High	Overhead: Low	Yes	Approx. $250k/bus

Source: WSP

1.4.1.3.8 Plug-In AC Charging

The charging ratio for this type of charging station is 1:1, meaning that a single charging station can only connect to a single bus at any given time. The BYD 200 kW charging station shown in Figure 1-7 has two charging cords and guns per station, and two ports per bus, which allow the operator to plug in either one or two cords to the same bus. Two cords are provided to reduce the size and weight that a single 200 kW cord would require. By plugging in only one cord, the bus can be charged at half the rate, allowing for manual power usage limiting. This does not mean, however, that the other charging gun can be plugged into another adjacent bus. A single two cord charging station can only charge one bus at a time. When the charging gun is inserted, it establishes a communication connection with charging equipment that is located on the bus (the rectifier that is converting the AC power from the charging unit to DC power that charges the batteries). The charging station is not capable of communicating with two separate rectifiers. Is it possible that in the future the few manufacturers making AC charging units (primarily BYD) will create a solution to accommodate power sharing for a single charging station, but at this point that is not the case.

Figure 1-7: 200 kW AC Charging Station

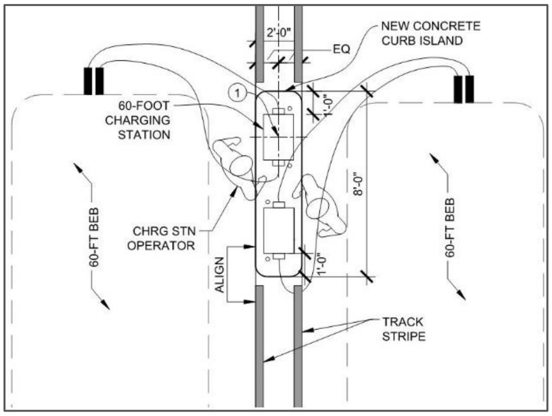
Source: WSP

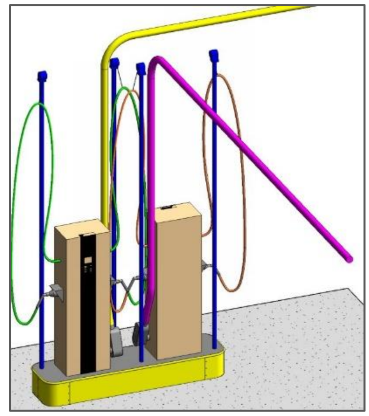
With AC charging, the rectifier is located on the bus, which can increase bus weight and potentially limit passenger capacity over other charging options. The charging stations include the dispenser and the charging control panel as a single unit that must be located close to the bus, with the controls within reach of the driver or technician.

The charging station is connected to the bus with a short cord. The plug at the end of the cord that is inserted into the charging port of the bus is referred to as a “charging gun.” Once the charging gun is fully inserted into the port, signal wires inside the gun complete a circuit and the operator can start the charging process by activating the charging controls from the charging station control panel. Unlike DC automatic plug-in charging or overhead pantograph, current AC charging technologies and standards requires user interaction with a charger control panel to start the charging process. It is this required user charger control panel access that necessitates that the charging station be directly adjacent to the bus it is charging, it does not allow for a charging station to be remotely located or located overhead.

AC chargers vary in size and space requirements. The BYD 200 kW Fast Charging Station, shown in Figure 1-8 has a large space requirement. It has a 2’5” wide by 1’4” deep footprint, and also requires a three-foot space behind it to allow for electrical service access. This means that a pair of charging stations must be placed three feet apart back to back or be placed side by side to allow for this access.

Figure 1-8: AC Charging Stations on Raised Concrete Islands





Source: WSP

For facilities which have constrained physical layouts, placing the chargers back to back would result in displacement of existing bus parking. This charging technology would therefore result in a loss of bus storage capacity at the facility. In addition to the charging station footprint, grade-level mounted charging stations adjacent to or within the bus parking area should be placed on a concrete curb to mitigate the risk of damage from bus movements.

The charging ratio for this type of charging station is 1:1, meaning that a single charging station can only connect to a single bus at any given time. The BYD 200 kW charging station shown in Figure 1-7 has two charging cords and guns per station, and two ports per bus, which allow the operator to plug in either one or two cords to the same bus. Two cords are provided to reduce the size and weight that a single 200 kW cord would require. By plugging in only one cord, the bus can be charged at half the rate, allowing for manual power usage limiting. This does not mean, however, that the other charging gun can be plugged into another adjacent bus. A single two cord charging station can only charge one bus at a time.

The AC charging option also requires more interaction from the operator than the other options presented later. The operator plugs in the bus and must interact with the console on the charger to initiate charging, and then the operator may walk away without any further steps. Once the bus is fully charged, the charger will stop on its own. The next driver must unplug the bus before operating it. The staff removing the cord also needs to store the cord in its holder/cord management rack to prevent cord damage.

A charge management system can provide oversight and controls to an AC charging system including: 1) delayed start of charging even after operator initiates charging by control operation; 2) turning off charging stations and staggering charging stations to limit power demand peak usage; and 3) allowing monitoring of charging station status and connected vehicle information. However, a separate secure Wi-Fi communication network would be needed to serve the charge management system.

As a ground-mounted unit, a charging station receives its AC distributed power from the switchboards. If this AC distributed power comes from overhead, there is a vertical power drop to each charging station, as shown in the above figure (note the 3-1/2" conduits, colored yellow and magenta, dropping from above and tying into the side of the charging stations.). If the AC distributed power comes from underground, it can be run under pavement and / or concrete slabs and stub up under the charging station. Note that installing under-slab distributed power in an existing facility would require extensive saw cutting and trenching of the existing parking garage slabs.

Table 1-6: AC Charging Station Pros and Cons

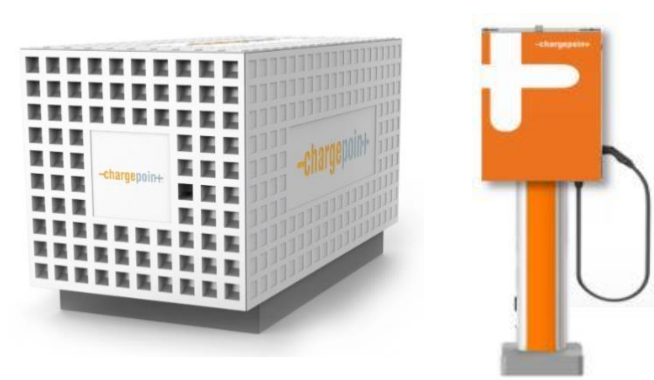
Pros:	Cons:
▪ Charging stations come at no extra cost with the provided BEBs (typical for BYD, negotiable with CCW). ▪ Does not require extra rectifying equipment taking up floor space. ▪ Power distribution to the charging station is generic single conduit AC power circuit, not charger manufacturer-specific DC power with additional control and data wiring.	▪ Chargers are limited to a specific bus manufacturer ▪ Requires the operator to interact with the charging station panel. ▪ Requires floor mounting of the charging station close to the bus. ▪ Adds weight to bus by having the rectifier on the bus. ▪ Current BYD charging stations are electrically bottom-fed-only units. This limits power to either underfloor or an overhead power drop that ties into the unit's base. ▪ There is no hard-wired data connection to a charge management controller station. A secure WI-FI connection would be needed in the garage to transmit data back from charging stations.

Source: WSP

1.4.1.3.9 Plug-In DC Automatic Charging

A Plug-in DC automatic charging system is currently available from several sources, including several BEB OEMs like GreenPower and Proterra, in addition to third party vendors such as ABB and ChargePoint (a ChargePoint cabinet is shown in Figure 1-9). A DC charger consists of a charging cabinet that contains an integrated rectifier, plus a separate dispenser. Separating the dispenser from the charger and remotely locating the charging cabinet away from the bus reduces space requirements and provides additional spatial flexibility, an advantage over current AC charging systems. (A ground mounted DC charger with an integral dispenser would have very similar space requirements to the AC chargers.) In addition, a plug-in DC automatic charging dispenser can be located overhead, which would eliminate the need for allocation of scarce floor space in the bus parking area. However, if the dispenser is located overhead, additional cord management features, such as a cord retractor with retractor power and controls, are required to access the remote cord.

Figure 1-9: ChargePoint Charging Cabinet and Remote Dispenser



Source: WSP

The third-party charging systems with CCSI SAE Level 2/3 J1772 DC compliant charging cords and guns (Figure 1-10) are compatible with multiple BEBs produced by various OEMs as long as they are specified with CCSI SAE Level 2/3 J1772 DC compliant charging plug-in ports. This includes BEB OEMs who do not produce their own plug-in charging equipment such as Gillig, New Flyer, and Ebus. Following this standard can reduce initial phase commitments to a single bus manufacturer, as opposed to Plug-In AC systems, which currently only allow for buses from the same manufacturer to use that manufacturer's charger.

Figure 1-10: Example of J1772 Plug and Port

Source: WSP

The size, weight, configuration, conduit entry and exit points, and electrical inputs and outputs of these chargers vary by manufacturer. Even the orientation of the equipment has not been standardized. The layouts shown later in this report represent the worst-case scenario dimensions and therefore can account for all the various charging system OEMs. For instance, while a ChargePoint dispenser may be wider than dispensers from the other manufacturers, it is not as tall, deep, or heavy as an ABB charger. Taking the worst-case width from ChargePoint and worst-case depth, height, and weight from ABB, a design can be made that can accommodate any available DC charging cabinet and dispenser.

The floor space requirements for DC charging systems can vary depending on where the DC charger is positioned. The DC dispenser would take up floor space similar to an AC charging station, but DC charging cabinets can be placed remotely, overhead on roofs or on the edge of a parking garage, so that the floor space required to accommodate the charging cabinets is not in the bus parking area. Due to DC power distribution constraints, there is a limit to how far the charging cabinets can be from the dispenser – between 350 and 500 feet maximum from the DC charging cabinet to a remote dispenser, depending on charger OEM. This distance would include any vertical drops or risers.

With most manufacturers, this charging system allows for both 1:1 dedicated charging and shared charging. Multiple OEM's chargers mentioned in this report can utilize shared charging (ABB, ChargePoint, & Proterra). ABB can achieve a charging ratio of up to 1:3, and the ChargePoint and Proterra systems can currently achieve a ratio of 1:2, although they can achieve a higher charging ratio using distribution panels. The only operator interaction required with a DC charging system is that an operator needs to plug and unplug the bus. Once the bus is plugged in, automatically the charge management software dictates when the bus begins charging and stops charging, monitors energy usage and battery SOC, and provides status reports.

There are multiple options for distributing the power from the charging cabinet to the dispensers, and these options can vary by manufacturer. The ABB charging system allows for the dispensers sharing a charger to be "daisy-chained" with one another from a single circuit, whereas a ChargePoint cabinet has separate conduits to each of its two connected dispensers. Depending on the location of the dispensers relative to the charger, the total amount of conduit required can be minimized by having a daisy-chained connection to the dispensers. However, balancing the spatial distribution of shared dispensers with fleet charging needs based on arrival / exit times may require separate DC power conduits from a charging cabinet to each of its shared dispensers.

At the 150 kW range, the conduit size for a single power connection between a charger and a dispenser is three to four inches. Additionally, a low voltage signal wire and data control wiring would also have to be installed between each charger and dispenser in parallel and in a separate conduit from the DC power conduits. These multiple conduits to each dispenser (two to three conduits per dispenser, so up to 750 conduits for a 250-bus facility) create a sizeable quantity of conduits to route and organize either underground or overhead.

The number of conduits required for a Plug-in DC automatic charging system is therefore significantly greater than for an AC charging system, which only requires one conduit per AC charger. This represents a tradeoff between the DC charging system's greater ability to remotely monitor and control charging and the DC charging system's demand for additional conduits. The distribution path of this DC connected power and control wiring must be carefully coordinated with any existing structure. An additional limitation to DC power is distance. AC power is not affected by distance while DC power has a relatively short distance limit of between 350 and 500 feet.

The amount of power that can be delivered to a bus using commercially available cords and charging guns ranges from 50 kW to 156 kW. Manufacturers are currently in a rapid improvement phase, with alterations and benefits to systems being introduced at a rapid rate. While manufacturers are currently working to develop a charger capable of delivering power at up to 350 kW, the voltages needed to deliver this much power require cooling systems (internally liquid cooled cords) for the dispenser cords, increasing the weight of the cord. Given these challenges, the remainder of this report assumes the current 150 kW limit. Furthermore, charging batteries at rates higher than 150 kW can lead to more rapid battery degradation, reducing the useful life of the battery.

Table 1-7: DC Automatic Charging Pros and Cons

Pros:	Cons:
▪ DC charging equipment is compatible with multiple bus OEMs if both the chargers and the bus adhere to the J1772 standard. ▪ DC charging cabinets can be remotely located overhead or away from the immediate bus parking areas. ▪ Dispensers can be remotely located overhead to eliminate the need for any ground mounted space taken up by charging equipment ▪ DC chargers save weight on the bus because the rectifier is located within the charging cabinet. ▪ Currently the DC charging cabinets are available with bottom electrical AC feed in and DC Controls out. However, if cabinets are located on the roof/overhead this feed allows for more direct overhead DC power distribution from the cabinet to the dispenser, which is important given that DC power diminishes quickly with distance of transmission. ▪ Depending on manufacturer, shared charging may be feasible. ▪ The same DC charging cabinet can support overhead pantograph charging as well as plug-in dispensers (see next section)	▪ Substantial cost for DC charging system – approximately $110,000 per charging cabinet and single dispenser. ▪ If charging cabinets are located remotely, DC power diminishes quickly with distance of transmission. ▪ Charging cabinets are larger than AC systems due to the need to accommodate the rectifier. ▪ DC power from the charging cabinet to the dispensers requires vendor-specific controls and data wiring. ▪ Remote charging cabinets require three separate conduits between the charging cabinet and each dispenser. ▪ Cord management can be a challenge, especially if the dispenser is located overhead. Additional cord retractor, power and controls are required.

Source: WSP

1.4.1.3.10 Overhead Inverted Pantograph DC Charging

An overhead inverted pantograph DC charging system is much like a DC plug-In charging system; in that it comprises a DC charging cabinet and a DC connection to charge the bus. However, in the inverted pantograph system, the dispenser is a pantograph that is hung from the underside of the bus garage roof structure or structural framing over the bus parking areas. A pantograph is an articulating arm, moved by either compressed air or an electric motor, that has exposed copper bus bars that are lowered onto charging bars located on a BEB's roof (see Figure 1-11). One pantograph is required for each bus parking position.

Figure 1-11: Inverted Pantograph & Charging Bars on Bus Roof

Source: WSP

Traditional "pantographs arms" were located on the top of a bus and extended up and connected to overhead catenary lines similar to those on a light rail car or electric trolleybus. An inverted pantograph is located on the building and extends down to the bus. Commercially available from ABB, Ebus, Heliox, Proterra, and Siemens, inverted pantographs are currently used extensively for on route (off-depot) charging of BEBs. On route inverted pantographs are larger, more expensive models typically outputting 250-500 kW and are designed for heavy frequent duty cycles to extend and retract multiple times in an hour. To dispense 150 kW from a DC charging cabinet in the depot to a parked bus in a parking space once a day overnight (and possibly once in the mid-day if mid-day top offs are utilized), a depot inverted pantograph (Figure 1-12) is a smaller, less robust and less expensive charging unit.

Figure 1-12: Depot Charging with Inverted Pantograph

Source: WSP

Using an overhead pantograph can allow for much higher charging rates, up to 500 kW, as the voltage is not limited by a plug as it is with DC plug-in charging. All BEB manufacturers can utilize an overhead pantograph charger either as a native option or custom order. A major advantage of this system is that buses from different manufacturers can be parked and charged in the same facility, by the same pantograph charging system. This is due to the basic "open source" character of the DC connection by copper charging bars, which eliminates restrictions associated with the bus manufacturer-specific plug technology of the AC or some DC plug-in systems. While pantographs are available that can charge at the 150 kW rate used by plug-in systems, higher power pantographs are available; however, charging batteries at rates higher than 150 kW can lead to more rapid battery degradation, reducing the useful life of the battery.

The 150 kW DC charging cabinets that can be used for this system are the same as for the plug-in DC automatic charging and can be installed remotely from the pantographs, with the same conduit length limitations, so no floor space is required for the charging cabinets in the bus parking area. The pantographs are installed suspended from the existing roof structure or a new custom overhead framing system. Since the pantographs are overhead, the power would also be distributed overhead, and would require the same number of conduits as the DC plug-in systems. Unlike plug-in systems, pantograph systems would use a local wireless connection to transfer data between the bus and the pantograph, but data would be transmitted from the pantograph to the charge management system using the same data conduit that plug-in systems use. Overhead power and data distribution mean that that there are no ground level conduits for buses to hit and no new obstacles introduced. In an outdoor facility, the only new obstacles would be the support columns required for a new overhead support system. The standard location of the charging bars on the roof of the bus is centered over the front axle. If the fleet to be charged is parked in tracks the spacing of the pantographs in these tracks will be located by the size of the vehicle (i.e., every 65 feet for 60-foot articulated buses or every 45 feet for 40-foot buses).

This charging system requires limited operator interaction. The specific charging process depends on the manufacturer, but in general the operator uses painted marking on pavement to determine where to stop, and a dashboard or cockpit light illuminates indicating that an RFID receiver on the bus roof has detected an RFID transmitter on the pantograph. The operator either engages the pantograph or the pantograph is controlled by automated software. When the charging is complete, the pantograph disengages and retracts to a raised position. Pantographs typically have an installed spring system to “fail safe” (retract away back to a raised position) when power or compressed air is lost.

On Route Charging Aesthetics

Public-facing inverted pantograph chargers are being woven into the visual landscape of transit centers and bus layover points worldwide. From a design perspective, on route chargers can appear quite utilitarian and simply a result of functionality. It is of note that several solutions are available to address the aesthetics of integrating on-route charging into transit centers, both historical and newly constructed. For instance, Pomona Transit Center is located immediately adjacent to the Downtown Pomona rail station, constructed in 1940 in the Mission and Colonial Revival style. To create architectural uniformity with the rail depot, Pomona Transit Center has integrated its use of on route chargers as historic lampposts (See Figure 1-13). By serving multiple uses, the charger is more integrated into the landscape of the transit center. Furthermore, the charging cabinet and safety protector is blended in seamlessly with the station color palette and design of the mission-inspired train depot (Figure 1-14).

Alternatively, in Bern, Switzerland, a modern design approach by the manufacturer ABB is used to showcase on route charging that evokes an aesthetic of future possibilities (Figure 1-15). This type of design would allow for seamless integration into a contemporary transit center, such as the San Bernardino Transit Center, which would also elicit visibility from transit riders in their daily commutes. Finally, a branding approach may be taken to gain visibility and attempt to guise the functionality of the equipment with promotional material advocating for zero emission technology. King County Metro in Seattle has integrated zero emission branding into traditionally nondescript electric charging cabinets (Figure 1-16). By enhancing and drawing attention to normally overlooked aspects of design, utility is merged with visibility and creates enhanced brand and public awareness. Coordination amongst transit operators, architectural design firms, and on route charger OEMs allows for the creation of unique design solutions customized to the individual needs of the operator or transit interchange.

Figure 1-13: Pomona Transit Center On-Route Charger Multifunctionality

Source: WSP

Figure 1-14: Pomona Transit Center On-Route Charger Design Integration

Source: WSP

Figure 1-15: ABB Designed On-Route Charger in Bern, Switzerland

Source: ABB

Figure 1-16: King County Metro Branded On Route Charger

Source: King County Metro

Table 1-8: Overhead Inverted Pantograph DC Charging Pros and Cons

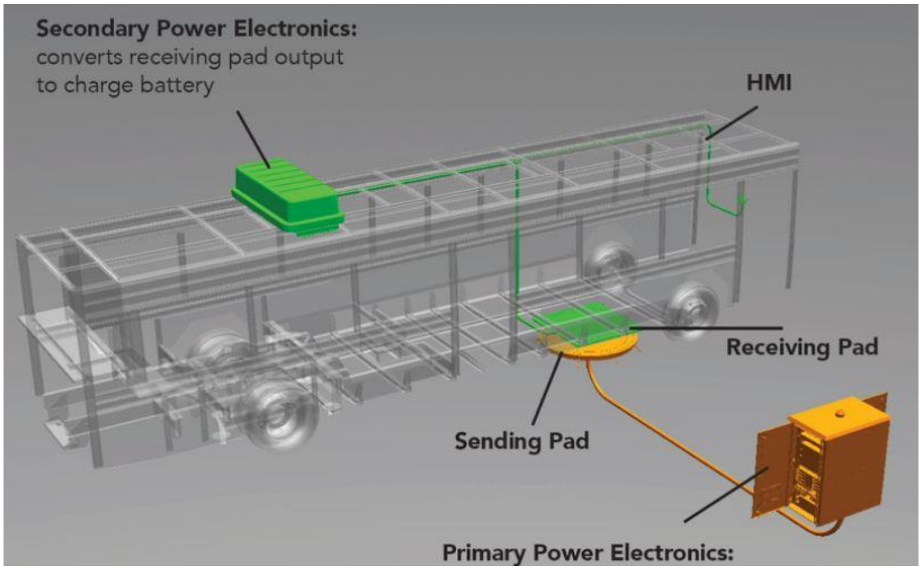
Pros:	Cons:
▪ Minimal operator intervention is required at the charging position. ▪ There is no need for cord management. ▪ DC charging by copper charging bars on the pantograph is compatible with any bus OEM charging bar set. ▪ DC charging cabinets can be remotely located overhead or to the side of the bus parking areas. ▪ The overhead pantograph eliminates the need for floor space for ground-mounted charging dispensers. ▪ A pantograph can deliver higher power than 150 kW for faster charging if connected to a higher-power charging cabinet.	▪ Pantographs cost more than plug-in dispensers. ▪ Pantographs require adequate space under existing enclosed garage roof structures or new overhead frame support structures at exterior bus parking areas. ▪ Low power pantographs for depot charging are not currently available. Additionally, there is currently no standard for low power pantograph depot charging. Currently depot pantographs fall under the same SAE J3105 Overhead High-Power standards as high-power on route chargers. ▪ Suspending equipment from the roof would require a manlift or catwalk for maintenance and service. ▪ Mixed fleet requires different spacing when in tracks. ▪ Optional higher power charging could increase peak demand usage, increase the cost of charging and could also result in more rapid battery degradation.

Source: WSP

1.4.1.3.11 Inductive Charging

Inductive charging comprises a set of wireless charging technologies that accomplish charging through an electromagnetic field, much like the wireless charging of a cell phone when placed on a charging pad. Energy is transferred from a receiver on the underside of the bus either between a transmitter "pad" located in the pavement slab in one or more locations (Figure 1-17), or through a buried catenary-type continuous power source. For buses, inductive charging has two potential applications: stationary or dynamic.

Figure 1-17: Induction Charging Schematic



Source: WSP

Inductive charging deployments and options could increase dramatically in the next decade, partially enabled by the growing interest of transit agencies, as well as rapidly-developing industry standards. For example, the much more powerful wireless power transfer (WPT) standard, WPT9, which builds on the Society of Automotive Engineers (SAE) J2954 standard developed for light duty vehicles, is being defined in the SAE technical committees as J2954/2 for 500-kW charging for heavy-duty vehicles which have the room necessary to mount a larger induction plate. The system envisioned by this standard comprises similar principles of inductive charging already in the marketplace, but emphasizes the resonant inductive coupling concept of the three technologies mentioned earlier, with a demonstrated efficiency of around 85%. This efficiency approaches that of faster-charging conductive chargers. By comparison, the most efficient medium-speed chargers employed by transit agencies for longer charging times in maintenance facilities achieve charging efficiencies of around 94%.[4]

Development of the underlying resonance transfer concept was developed by Marin Soljačić at the Massachusetts Institute of Technology (MIT) and then spun-off as WiTricity in 2007. WiTricity has led the SAE standardization efforts, which began in 2012 and have undergone two Recommended Practice releases as of 2019. The final wireless charging standard is expected to be adopted by the industry this year (2020). WiTricity has made public statements projecting that J2954 compliant wireless heavy-duty chargers will be available as add-on features beginning around 2022, which if fulfilled, would eliminate a key challenge to more widespread market adoption of these technologies, both for stationary and continuous charging applications. The following subsections cover these two types of applications.

Stationary Charging Technical Overview

For stationary applications, a bus pulls into a designated charging position aided by visual aids (such as pavement striping) for alignment, and an audio or digital indicator on the bus confirms the correct positioning over the charging pad. Once positioned, the charging begins as controlled by the nearby charge management software, the computerized interface that provides communications between the BEB, and the charging infrastructure.

This energy transmission system consists of an above-ground primary power module, a cooling module, and a controls module. These modules are contained within either a single charging cabinet or multiple cabinets (depending on the OEM). The above-ground transmission support equipment is connected to the recessed inductive charging pad by underground conduits containing both power and control wiring. A substantial amount of heat (because of inherent power loss) is generated within the charging pad during energy transfer; this heat is removed via coolant that surrounds the power cable connecting the pad with the above-ground cooling unit. The above-ground cooling unit uses an ambient air heat exchanger to dissipate the collected heat and sends chilled coolant back down to the transmission pad. The onboard induction receiver pad is surface mounted to the underside of the bus and connected to the on-board battery charge controller and batteries. The position of the receiver pad on the bus varies depending on the bus OEM and the location and configuration of the batteries.

The above ground modules should be located on a raised concrete island to protect against impact from adjacent buses. When retrofitting an existing parking lot or garage, substantial space is required to accommodate the above ground equipment islands. Another issue is the need to atmospherically vent the charging heat to the surrounding air. In an enclosed bus parking garage, an induction system requires adequate air changes per hour and proper spacing of the cooling modules to allow for ambient air cooling and heat dissipation. Induction charging requires other special conditions to successfully charge: proper

[4] Bablo J. “Electric Vehicle Standardization, EVS29 Technology Symposium, Montreal, Canada, June 19-22, 2016

position of the bus mounted receiver over the ground mounted transmitting pad, proper air gap between the receiver and the transmitter, and, depending on the charger manufacturer, certain maximum and minimum height restrictions.

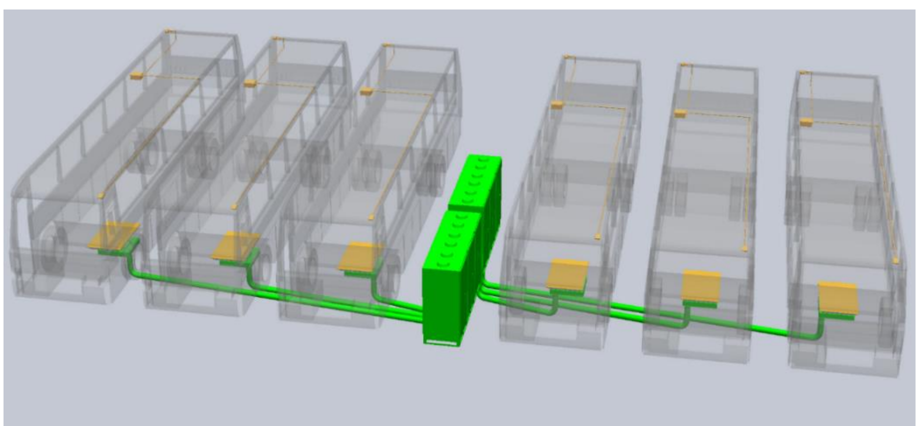
The recessed transmission pad is de-energized until a bus with a receiving pad is stationary and properly positioned over the transmission pad. The charging automatically stops and the transmission pad is de-energized when the batteries are either fully charged or the charging process is interrupted by the charge management software. There are no decoupling or other procedures to remove the bus from its charging position. The bus can simply be driven away from the parking space.

This charging system has neither moving parts (pantograph arm or charging cord), nor repetitive physical connections (plugging in charging gun or pantograph connecting above to charging bars) to the bus, which make induction charging the mechanically simplest charging option available.

Stationary Charging Application

Stationary charging is primarily used for in-service (or opportunity) charging, although it is a technically feasible solution for overnight charging at bus maintenance facilities. The charging ratio can be a dedicated 1:1 (one charger to one bus) system, or it can be a shared charging system up to 1:3 (one charger to three buses). A significant limitation of the induction system is the overall distance a transmitter pad can be from the above ground modules: 60 to 75 feet, depending on OEM. The distance covered includes the 90 degree turns from both the above ground modules and the recessed transmitter pad. Because of this distance limitation, the above-ground modules are typically installed directly adjacent to the parked bus's charging position. If shared charging is being utilized, the above ground modules can power up to three pads in three directly adjacent parking tracks – see Figure 1-18 for a graphic of a shared induction system. The distance limitations do not allow for shared charging of three buses within the same track.

Figure 1-18: Shared Induction Charging System



Source: WSP

Stationary charging systems are commercially available from four vendors: Primove (a subsidiary of Bombardier Transportation), Alstom Transportation, Momentum Dynamics, and Wireless Advanced Vehicle Electrification (known as WAVE), with additional charging OEMs expressing interest in developing their own versions of induction charging. The induction charging system is a third-party aftermarket component that is installed on the underside of a bus chassis, making it compatible with all bus manufacturers and can be used by either native AC- or DC-charged buses. Several industry standards, such as J2954, make the initial procurement phase commitment to a specific bus OEM minimal, as any bus can be outfitted with the proper equipment required to be charged via induction. Moreover, the addition of an induction charging pad to a bus does not prohibit the inclusion of a plug-in port or roof mounted charging rails on a bus.

The following subsections provide insight to some transit agencies that have piloted or adopted stationary inductive charging.

Antelope Valley Transit Authority

In 2017, Antelope Valley Transit Authority (AVTA) commissioned 50 kW WAVE chargers at two of its major transit centers (Sgt. Steve Owen Memorial Park and Palmdale Transportation Center) (Figure 1-19). While these projects were in planning and design, the AVTA Board approved in its FY 2019-20 budget to acquire 20 additional wireless charging stations at a cost of $3.66 million, scheduled for installation over the next two years, seven with a minimum requirement of 200 kW. Based on their analysis, 10 minutes of charge at this rate would yield an additional 14 miles of range. All of these chargers will be operational by the end of the current calendar year.

Figure 1-19: Construction of AVTA's WAVE Charger

Source: Mass Transit, 2016

Three of these high-powered inductive WAVE chargers (250 kW) began service deployment at the Sgt. Steve Owen Memorial Park complex in January 2019. To address increases in electrical consumption at these chargers in the current fiscal year, AVTA has budgeted an additional $600,000. At the May 2019 board meeting, AVTA CEO Macy Neshati opined that much of this additional electricity expenditures could be offset by reduced preventive maintenance costs but this would probably not be confirmed for at least another fiscal year, after AVTA completes its transition to BEBs.[5]

Long Beach Transit

In September 2018, Long Beach Transit (LBT) unveiled a 50 kW WAVE inductive charger adjacent to the Long Beach Convention Center and waterfront (Figure 1-20). This charger enables LBT's Passport Route, a free community circulator, to charge en route during regular service. The cost of the project (charger and construction) was approximately $1.6M, with the cost of the charger itself at $926K. LBT currently has 10

[5] Antelope Valley Transit Authority, FY 2019-20 Budget and Related Board Presentation, May 2019.

BEBs in service and each are outfitted to use the system to partially charge their batteries for 15 minutes, during a layover, to extend their drive time. When out of service, LBT's BEBs are plugged into chargers at the bus base.

Figure 1-20: Long Beach Transit's WAVE Charger

Source: WAVE, 2020

IndyGo

In June 2019, it was announced that IndyGo would collaborate with bus OEM BYD and inductive charging company Momentum Dynamics Corp. to install three 300-kW chargers in Indianapolis. These chargers would support IndyGo's Red and Purple Lines. These chargers will enable the Red Line to operate 20 hours per day on weekdays (approximately 275 miles per day). According to IndyGo, the estimated value of the chargers is $2.5M, approximately $833K per charger. It should be noted that much of the construction and design costs are expected to be covered by BYD.

San Bernardino County Applicability

For some of the countywide operators (namely Omnitrans, Mountain Transit, and VVTA), stationary inductive charging can be a technically feasible solution for opportunity charging, as it has the ability provide additional range and eliminate the interaction between operators and charging equipment. However, the capital costs, availability of space, and energy efficiency would need to be further analyzed as alternatives to other charging methods (AC or DC plug-in or DC pantograph) to determine viability.

Currently, there are no domestic transit agencies that have demonstrated or committed to a stationary inductive system as an overnight charging strategy at the bus base.

Dynamic Charging Technical Overview

With dynamic charging, colloquially referred to as “charging lanes”, buses can charge while in motion by driving over charging coils that are embedded in the pavement (Figure 1-21). This method of charging allows a bus to continue in-service and reduces the need and costs associated with charging overnight at the base.

Figure 1-21: Conceptual Charging Lane

Source: Highways England

Dynamic wireless charging has undergone rapid technological and market evolution, with the entry and exit of several competitors in recent years. For example, in 2011, Qualcomm purchased HaloIPT, a spin-off from the University of Auckland that was also working on wireless charging technology. This system was aimed not only at stationary locations, but also applications embedded in road surfaces to charge multiple cars as they drove, a system the organization referred to as "dynamic electric vehicle charging", or DEVH. However, Qualcomm abandoned their Halo efforts, and sold all of the associated intellectual property to WiTricity, a Watertown, Massachusetts-based wireless charging developer, in 2019. In October of the same year, South Korean charging technology supplier Green Power and WiTricity announced a licensing partnership to demonstrate a continuous charging application for all types of vehicles.

Alternatively, a similar effect has been achieved in several places in Europe, with a series of stationary inductive chargers placed at layover end points on routes as well as at key stations. This is the concept behind Bombardier’s Primove installations in Germany as well as Alstom’s SRS technology.

In 2012, SAE convened technical committees to develop an SAE J2954 wireless charging standard, with several levels (WP1 through 4) of charging speeds. In addition to defining standardized characteristics of the physical and electrical parts of the system, J2954 also standardized a Bluetooth-based communication between the vehicle and charger, incorporated triangulation sensors to facilitate proper positioning of the vehicle over the charger pad, created a test stand for vendors to test their vehicle implementations against, and standardized signage to indicate charge points. The standard has since undergone three revisions, culminating in the most recent 2019 release, J2954_201904.

Dynamic Charging Applications

The concept of dynamic charging for transit buses is compelling, considering buses typically do not deviate from their respective routes. However, due to the technology and its application being in its infancy, there is limited data available on costs, considerations, and best practices. Additionally, once the designated dynamic charging lane is configured, buses may not deviate from said routes, because of inherent range limitations of the batteries onboard. As mentioned, however, several firms continue to demonstrate the technical feasibility and viability of dynamic charging, as detailed below.

Great Britain

In 2015, the British government undertook a feasibility project comprising road tests of wireless charging lanes for electric and hybrid vehicles complete with mock roads. [6] The UK Department for Transport Highways Agency's Office for Low Emission Vehicles has committed £500 million ($784 million) between 2016 and 2020 in a research program to advancing the technology. As part of the program, Highways England is testing the wireless sync technology to transmit electricity via magnetic waves that charge light-duty vehicles as it traverses the lane. No plans as of yet have been announced regarding deployments for heaver-duty vehicles such as trucks or buses.

South Korea

In 2013, the City of Gumi started the operation of a dynamically-charged bus under a Korean government research grant led by Korea Advanced Institute of Science and Technology (KAIST). The bus(es) travels approximately 7.5 miles on an inductive lane that provides 180 kW of power. This project cost approximately $4M in 2013 dollars (Figure 1-22). The line remains in operation. Although operating costs are unavailable, Chen et al. suggests that for a bus rapid transit (BRT) line such as Los Angeles County Metro's Orange Line, the capital and operating costs could be "cost competitive" with existing technologies and planned transition to BEBs.

Figure 1-22: Gumi's Inductive Charging Lane

Source: Wall Street Journal

Israel

Electreon is an Israeli firm that specializes in smart infrastructure for public transit. In February 2019, it was announced that Electreon is planning to launch a one-kilometer electric road between Tel Aviv University and the city's train station.

Electreon is also a member of Smartroad Gotland, an e-road consortium that plans on deploying a fully-functional test road between the airport and town center of Visby, on the island of Gotland, Sweden.

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[6] Chen Z et al, A cost-competitiveness analysis of charging infrastructure for electric bus operation, Transportation Research Part C 93 (2018) 351–366.

This technology was also investigated by WSP for Massport for an application involving a shuttle service between a short-term parking lot and a terminal at Boston's Logan International Airport. Massport determined in 2015 that the technology was insufficiently tested, particularly for buses that would undergo frequent stops and acceleration to speed such as at an airport.

San Bernardino County Applicability

While dynamic charging lanes are intriguing, at this time, the limited number of pilots and assumed additional construction and implementation costs noted above make such a solution for the operators of San Bernardino County extremely challenging. First and perhaps foremost, it is not clear that any of these suppliers have a commitment to offering this technology in compliance with U.S. "Buy America" regulations, and current political and policy stances of the federal government make waivers to these regulations unlikely. Moreover, none of these systems have undergone Altoona testing. Finally, other approaches, such as a series of wireless stationary charges as being operated by AVTA and IndyGo, could obviate the need for a continuous charging approach.

However, as more data and pilots are deemed successful, the technology should be considered as an alternative for individual routes in agencies' transition programs, especially for routes with dedicated rights-of-way, higher service frequencies, and where a "branded" premium service differentiators are being considered, such as Omnitrans' existing sbX BRT route on E Street and the planned West Valley Connector. There appears to be no current applicability for bus base use.

Summary

The goal of inductive charging is to allow electric vehicles to travel longer distances without the need to stop and charge or need to supplement electricity for fuel. The benefits would ultimately cut down on air-polluting vehicle emissions and fuel usage. However, these technologies are an order of magnitude higher in capital cost (2-3 times) than overhead conductive chargers analyzed elsewhere in this document, and the energy transfer of inductive charging is typically less efficient than that of conductive approaches.

Table 1-9 summarizes the pros and cons of inductive charging.

Table 1-9: Induction Charging Pros and Cons

Pros:	Cons:
▪ Requires no mechanical moving parts. ▪ Minimal or no operator interaction required during charging process. ▪ Induction systems can support shared charging of up to 1:3. ▪ Receiving pads can be retrofitted or installed as part of original OEM equipment to any battery electric bus. ▪ Much more visually appealing as they eliminate overhead chargers and minimize above-ground equipment of plug-in chargers. ▪ Obviates tampering issues that challenge overhead and at-ground charging technologies.	▪ Distance between the above-ground modules and the transmitter pad(s) is limited to 60-75 feet. Therefore, the above-ground modules cannot be remotely installed away from bus parking. ▪ Above-ground modules require ground space in the parking area for the full length and width of a parking track. ▪ Above-ground modules vent heat into the bus parking enclosure. ▪ More energy loss and therefore her higher energy consumption than conductive alternatives. ▪ Higher capital costs vs. above-ground charging.

Source: WSP

1.4.2 Fuel Cell Electric Bus

FCEBs are electric vehicles that use compressed hydrogen as fuel to create electricity through a fuel cell. This electricity then powers an electric drivetrain in the vehicle. These vehicles share many of the same capabilities as BEBs such as zero harmful tailpipe emissions, near silent operations, and regenerative braking (a method of capturing kinetic energy when stopping to supply additional power to the battery). Unlike electric buses, FCEBs are fueled in similar manner as CNG.

A fuel cell is constructed much like a typical battery with an anode, a cathode, and an electrolyte membrane. A fuel cell works by passing hydrogen through the anode (-) of a fuel cell and oxygen through the cathode (+). At the anode side, the hydrogen molecules have the electron separated, leaving the hydrogen molecule with a positive charge. The positively charged hydrogen ion passes through the electrolyte membrane, while the electrons are forced through an electrical circuit, generating an electric current and excess heat. At the cathode, the hydrogen ions, electrons, and oxygen combine to produce water.

Hydrogen is stored in buses as a high-pressure gas in fuel cylinders designed, tested and built for 5000 pounds per square inch (psi) pressure. Currently, the most common form of hydrogen used by transit agencies is delivered by trucks to fueling stations for dispensing in either a compressed or liquid form. Fueling a FCEB is very similar to fueling a CNG bus except for the source of the hydrogen.

FCEB buses require an onboard ESS appropriately sized to meet the range requirements. ESS converts electrical energy into a form that can be stored and converted back to electricity when needed. ESS devices charge during low-power demands and discharge during high-power demands. FCEB buses generate electricity during operation to maintain a SOC sufficient for meeting the service requirements. The ESS requires various features, such as electrical interface, communication, control, remote data, and measurements.

When transitioning from CNG, hydrogen can offer benefits as well as drawbacks when compared to BEBs. CNG and hydrogen are both classified as "lighter-than-air" Class 2 flammable gases. As such, they require similar infrastructure and safety considerations (piping, compression, ventilation, etc.). Operations and maintenance with both fuels also are similar, circumventing the need to retrain personnel and restructure functions within the facility. As two completely different fuels, however, there are distinctions in the properties and behaviors of CNG and hydrogen that should be noted. To begin, hydrogen is nearly eight times lighter than CNG, increasing the risk of seepage. Hydrogen also has a lower energy content per volume compared to CNG, requiring larger storage containers to deliver the same energy[7]. Hydrogen has some advantages over CNG as well. In total, hydrogen has less cradle-to-grave efficiency losses compared to CNG with nearly 19 percent better efficiencies. In alignment with improved efficiency, hydrogen also releases less GHG emissions than CNG over its entire lifecycle, with 260 grams per mile (g/mi) of wheel-to-well CO2e emissions compared to 390 g/mi for CNG[8]. A final note for consideration when transitioning from CNG is challenges with safety regulation setbacks - throughout the transitionary period, when CNG and hydrogen are both in use at a facility, added infrastructure and adequate space for hydrogen equipment may become a significant barrier to adoption.

[7] Wallace, J. S. "A Comparison of Compressed Hydrogen and CNG Storage." International Journal of Hydrogen Energy, vol. 9, no. 7, 1984, pp. 609-611.

[8] U.S. Department of Energy. "Using Natural Gas for Vehicles: Comparing Three Technologies". 2015. Retrieved from https://www.nrel.gov/docs/fy16osti/64267.pdf

Though hydrogen technology offers a promising opportunity to diversify ZE fleets, there are limitations to this relatively nascent technology that must be considered prior to deployment. One of the most pressing challenges for FCEB operations is the amount of energy required to isolate, compress, and store this lighter-than-air element. Beyond the need to identify cost-effective methods of delivery and storage, as a highly combustible and extremely small element (indicating a high susceptibility to seepage), hydrogen safety compliance is essential. The primary considerations to production, delivery, and storage are outlined below. If any transit agency elects to move forward with FCEB adoption, ongoing conversations with local hydrogen suppliers, local fire marshals, and surrounding communities will be essential.

1.4.2.1 Hydrogen Fueling

In its natural form, hydrogen is found within larger molecules, such as water or methane. To use hydrogen as a fuel, it must first be isolated from these molecules. This is primarily achieved in one of two ways, via steam-methane reformation (SMR) and electrolysis. Alternative production methods, such as tri-generation and biological water splitting are available; however, many of these techniques are either still in development or cost-ineffective. For this reason, this analysis considers only SMR and electrolysis.

SMR is the most common method of hydrogen production in the country as it requires lower energy use and associated costs. SMR works through the use of a "water gas shift reaction," where high-pressure steam is used to produce hydrogen from a methane source, such as natural gas. Heat must be applied, which then produces carbon monoxide and hydrogen. Following a "pressure-swing absorption," carbon monoxide and other impurities are removed from the gas stream, leaving pure hydrogen. Because this method of production requires the use of natural gas and produces carbon dioxide (CO_2) emissions, it is beginning to lose favor among communities considering climate resiliency. In some instances, however, renewable natural gas (RNG) is used to increase production sustainability, as in the case of SunLine Transit in the Coachella Valley. RNG is essentially biogas captured from the decomposition of organic matter that can be used to replace conventional natural gas. This process of capturing methane from landfills, livestock operations, and wastewater treatments not only reduces methane emissions, but with California incentives, can be purchased at comparable rates as CNG.

Unlike SMR, electrolysis uses an electric current to decompose water into hydrogen and oxygen. There are no natural gas inputs to an electrolysis process. Electrolysis requires the use of an anode and a cathode separated by an electrolyte solution, similar to that of a fuel cell in reverse. In the case of an alkaline electrolyser, hydroxide ions are traversed across a membrane in a solution, which then creates pure hydrogen at the site of the cathode. Though electrolysis can be energy intensive (~60 kWh/kg), production can result in zero GHG emissions when using renewable energy sources. For long-term planning, integration with solar or wind technology can make electrolysis much less resource-intensive in terms of production and long-term scalability. Even when produced conventionally, the total GHG emissions are still cut in half from internal combustion engines fueled by petroleum.

1.4.2.2 Hydrogen Sourcing

One of the most essential considerations for determining FCEB fuel cost, is establishing how the hydrogen fuel is produced and sourced. When operating an FCEB fleet, agencies have four general choices for how hydrogen will be sourced: 1) hydrogen gas delivery via a high-pressure tube trailer or mobile refueler; 2) liquified hydrogen delivery via a tanker; 3) pipeline delivery of hydrogen gas; and 4) on-site production via SMR or electrolysis. Despite the source, all hydrogen, whether gaseous or cryogenically liquified must have adequate and safe on-site storage (Figure 1-19). Access to inexpensive hydrogen fuel remains a significant challenge for transit agencies deploying FCEBs, therefore careful consideration to long-term costs for hydrogen sourcing should be considered. In addition, considerations for contingency and redundancy should be considered for all technologies in case of equipment failure. A brief outline of considerations of each method is outlined below.

1.4.2.2.1 Hydrogen Delivery (Gas and Liquid)

A transit agency may elect to have hydrogen delivered and stored in either gaseous or liquid form. Hydrogen gas is compressed to pressures up to 3,000 psi and transported via a tube-trailer truck. This means of one delivery typically provides up to 300 kg of hydrogen, enough to serve a single day of operations for approximately 10 buses. Because of the limited quantity of hydrogen capable of being transported using this method, delivery is often economically restricted to a 200-mile radius. Though gas is not recommended because of economic inefficiencies, in instances where it is well-suited, only engineered cascade filling systems should be considered to eliminate the need for an outsourced fueling technician.

Alternatively, the operator may have hydrogen delivered and stored in a cryogenically liquified form. Liquid hydrogen has the benefit of allowing larger quantities of hydrogen to be shipped with less space required for storage. Cryogenically liquifying hydrogen is extremely energy intensive, requiring 30% of the hydrogen energy for compression. For this reason, liquid hydrogen is best suited where large quantities of hydrogen are required. When using diesel truck delivery, consideration should also be given to the tailpipe emission produced in transit.

The most efficient and least common form of delivery is via pipeline. Though this method is the least expensive option for large-scale deliveries, it requires expensive upfront capital investments. In the U.S., there are currently 700 miles of hydrogen pipeline, primarily located near petroleum refineries and chemical plants. Most hydrogen providers remain private about the location of existing pipelines, therefore, early conversations with potential providers will be necessary to determine if this is a viable option.

When sourcing hydrogen fuel, transit operators can put out a tender for companies to supply the hydrogen and even operate and maintain the hydrogen station. There are a variety of companies that will compete for the opportunity, such as Air Liquide, Trillium, and Clean Energy. The price of fuel is fixed over a period of time, and the transit operator pays in dollars per kilogram. Knowing that a bus typically needs 10 to 60 kilograms of hydrogen per day facilitates accurate budgeting.

Access to cost-efficent hydrogen fuel remains a significant challenge for transit agencies deploying FCEBs. This has especially been a challenge for Orange County Transportation Authority (OCTA) in California, which began operating its FCEBs before making the decision to build a station. In the early stage of the demonstration, OCTA partnered with University of California-Irvine (UCI) to use its hydrogen fueling station which provided hydrogen at an average cost of $13 per kg. After exploring alternative public fueling stations with retail prices often exceeding $16 per kg, OCTA elected to invest in its own on-site fueling station with the expectation of sourcing hydrogen at $7 to $10 per kilogram. Agencies considering FCEBs need to proactively plan to avoid this type of early deployment issue.[9]

Currently, light-duty hydrogen fueling stations, such as for personal vehicles, are becoming increasingly unavailable to FCEBs as the technology is beginning to shift. The hydrogen tanks on FCEBs are pressurized to 350 bar while modern light-duty vehicles are pressurized to 700 bar, making light-duty dispensers incompatible with FCEBs. A more financially and technologically feasible strategy for sourcing hydrogen is to maintain on-site storage. With this comes a need for increased consideration to facility maintenance.

[9] "Fuel Cell Buses in U.S. Transit Fleets" Eudy, Leslie and Post, Matthew; National Renewable Labs, September 2018

If leasing a storage tank, tank maintenance costs are included in the lease price. The most common hydrogen station issues reported by transit agencies involve compressor failures. Redundancy (multiple compressors) helps avoid station downtime, but a quick response time from station providers is important to maintain bus service. Agencies recommend negotiating the service contract with station providers to cover response time for repairs.

Figure 1-23: OCTA's 4,500 kg Hydrogen Tank

Source: WSP

1.4.2.2.2 On-site Production

To avoid the volatility of hydrogen prices and the possibility of supply shortages, some transit agencies are beginning to produce hydrogen on-site, which requires high upfront capital costs; however, it often results in savings over time. SunLine Transit Agency, for example, paid approximately $5/kg to operate an on-site steam reformer (compared to market rate of $7-$16/kg). Recently, SunLine converted their production system to a 900 kg 2MW electrolyser which cost approximately $8.3 million[10]. With limited experience operating this technology, the overall operating costs (maintenance, energy, etc.) has not yet been determined.

SMR and electrolyser systems are available in a variety of sizes with daily outputs ranging between 65 kg to 1300 kg. Many production systems are now offered as a containerized system that includes the

[10] Based on data received during interview between SunLine transit and WSP on January 29th, 2020.

compressors, storage, and station modules. These help to consolidate equipment procurements and reduce the required footprint. The availability of many of these products, however, may be limited currently as a result of Buy America restrictions. At the moment only two manufactures of SMR units (OneH2 and Linde) are U.S. based. This market restriction may ultimately result in higher capital costs.

Contingency and security should also be considered prior to investing in hydrogen production equipment. A full day of backup hydrogen should be maintained on-site to reduce the risk of service interruptions in the case equipment failure. Notwithstanding, on-site production may provide new contingency solutions when used as energy storage for local photovoltaics. When produced from renewable energy, hydrogen is a true zero-emission fuel that also enables grid-balancing and large-scale, long-term energy storage.[11]

Looking to the future, on-site hydrogen production provides opportunities to increase resiliency (ensuring fuel is always available), improve sustainability (through the use of on-site renewable energy), and potentially increase return on investment (through long-term savings or as a public fueling station).

1.4.2.3 Hydrogen Space and Safety Requirements

The space required to host hydrogen equipment can be a barrier for sites with limiting geographical constraints. OCTA's liquid hydrogen equipment station (depicted in Figure 1-24) includes a horizontal storage tank which requires a minimum of 45 by 60 feet of area. This amount space can be reduced significantly, however, when using vertical storage tanks which have a footprint of only 40 by 50 feet (not including the fueling island). The hydrogen suppliers Air Liquide and Linde both offer and emphatically recommend using vertical storage. Beyond locating adequate space, early considerations to safety code and local community support is also necessary.

Figure 1-24: View of a LH2 based fueling station with vertical storage

Source: WSP

Though relatively safe when stored properly, hydrogen storage does present some risks. Hydrogen is an extremely small molecule with a high deflagration index (combustion at subsonic speeds). This poses an increased risk of hydrogen leakage and resulting fire hazards. If stored as a gas, it is also highly pressurized (5,000 psi), increasing the risk. The minimum guidelines for hydrogen fuel safety are outlined by the National Fire Protections Association (NFPA). The NFPA, a voluntary organization focused on fire prevention and safety, publishes fire prevention safety codes across many industries along with providing training. The primary resource used for Hydrogen safety compliance is NFPA 2 *Hydrogen Technologies Code* and NFPA *55 Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers*. High level-considerations gleaned from NFPA 55 are outlined in Table 1-10 to serve as a foundation for feasibility considerations.

[11] "Hydrogen at Scale for Fuel Cell Electric Buses" *Ballard Technologies, September 2019*

Table 1-10: Summary of On-Site Hydrogen Safety Requirements (per NFPA 55)

In-Depot	Storage Site
The facility must include appropriate hydrogen gas leakage detectors with a minimum of two detector heads mounted over the maintenance area	All air intakes (heating, ventilating, or air-conditioning equipment (HVAC), compressors, other) must be located at least 75 feet from liquid hydrogen storage containers
The facility must include appropriate fire (IR- or UV-type) detectors, with a minimum of two detector heads mounted over the maintenance area.	The storage facility may not be located under overhead wires, roadways or other obstructions
A maintenance facility must have positive ventilation. Ventilation flow should be designed such that any hydrogen leaks is exhausted to the outside without dispensing throughout the maintenance shop or accumulating below the ceiling.	The storage site must be accessible to mobile delivery supply
All electrical equipment and machinery that have a potential for exposure to hydrogen should conform to NFPA 70, National Electrical Code requirements	Hydrogen storage must be located at least 50 feet from flammable liquid or gas lines
The facility must have an automatic emergency stop capability to shut down all facility hydrogen flow and electrical power	Hydrogen equipment must be located at least 25 feet from weeds or other combustible vegetation
Indoor areas where a hydrogen fueled bus is parked while fueled must contain the same hydrogen safety equipment described for maintenance facilities	Hydrogen equipment shall be positioned at least 25 feet from public ways, railroads, and property lines
Facility heating equipment must not use electrical elements, generate sparks, or present open flames within the electrical classification area	Regulatory signs must be included as required
	Hydrogen equipment may not be installed above combustible surfaces (asphalt), concrete is preferred.

Source: WSP

The final approving authority for code compliance often rests with the local fire marshal or fire protection authority. These entities may require an inspection by a certified Fire Protection Engineer to evaluate code compliance. If SBCTA elects to move forward with any transit operator within San Bernardino County hydrogen at any of the sites, early and frequent conversations with the local fire marshal will be essential. It is worth noting that many fire marshals across the nation are not yet familiar with hydrogen production and storage and may therefore, be resistant or highly cautious of hydrogen integration. If this challenge presents itself, the operator should coordinate with agencies currently using hydrogen to facilitate cross-regional communication and training. In addition to fire prevention, certain hydrogen equipment may require consideration to cybersecurity. Since the launch of their 900 kg electrolyser, Sunline Transit Agency has begun working with the Idaho National Laboratory to ensure the necessary system security is in-place to prevent weaponization of the equipment.

A final and critical consideration for successful hydrogen implementation, is adequate community engagement. Without an understanding of the safety measures that have been taken to reduce the risk and hazards to the community, "not in my backyard" sentiments could uproot any plans for hydrogen implementation. Early community outreach and education in partnership with the local fire marshal may reduce the risk of community opposition to hydrogen adoption.

1.4.3 Technology Screening

To determine the most viable solutions for each transit agency, it is pertinent to understand how various technologies comport with an agency's existing conditions and goals. In an effort to preliminarily determine which technology is feasible for each agency, the WSP team developed a methodology to compare and assess BEBs and FCEBs across a range of categories that are important to consider before deployment. The categories examined in this screening analysis include, vehicle performance, costs, site requirements, availability, sustainability, and community acceptance.

Each technology receives a score dependent on its performance by category. For vehicle performance, financial costs, and technological availability, comparisons were made between BEBs and FCEBs. In each category, comparisons are made among BEB, FCEB with off-site hydrogen delivery, and FCEB with on-site hydrogen production in which each technology receives a score between one and three. In terms of overall marking, the technology which performs the best receives a score of three, with one being the least desirable). Finally, each aspect of the screening analysis will be elaborated and scored upon in the following sections.

1.4.3.1 Vehicle Performance

Range

- The range of FCEBs exceeds that of BEBs, especially in extreme climate conditions. However, FCEB range often falls short of CNG capabilities and in many cases for the considered operators, is unable to complete service block distances. With these factors considered, FCEBs receive a score of two in the performance category.
- One of the greatest weaknesses with BEBs is the limitations of the range. The actual performance of BEBs is often much less than what is advertised by the OEM (typically around 150 miles). For this reason, BEBs received a score of zero in this category.

Refueling Time

- FCEBs have similar refueling times as CNG, requiring 10 to 30 minutes to completely fuel. Short refueling times provide an opportunity for midday fueling (if necessary) with minimal service interruption, therefore FCEBs receive a score of two in this category.
- Charging BEBs at the base (slow charging) can be time intensive as it typically requires several hours to reach 100 percent SOC. Fast charging on-route (opportunity charging) can reduce or eliminate the need to return to the base for charging, however this requires expensive additional infrastructure. For this reason, BEBs receive a score of one in this category.

1.4.3.2 Cost

Bus Costs

- There are barriers to entry for both BEB and FCEB buses, with both technologies exceeding the cost of CNG and diesel buses. BEBs have achieved better economies of scale and are currently significantly less expensive than FCEBs, largely due to BEBs being on the market for much longer, resulting in larger volumes and competition. In this category, BEBs receive a score of two while FCEBs received a score of one.

Infrastructure Capital Costs

- The cost of a typical charging cabinet ("charger") in a 1:2 ratio (one cabinet for two buses) is approximately $60K. Depending on fleet requirements and space constraints, utility and infrastructural upgrades may also be necessary. In total, capital costs for BEB-supporting infrastructure is often less than FCEBs, therefore, a score of three was issued to BEBs in this category.
- On-site hydrogen production will be more expensive in the interim compared to hydrogen delivery, however, the savings from on-site production may deem it a more cost-effective solution. Agencies are exploring the viability of scaling up from hydrogen delivery to on-site production (via an electrolyzer or steam methane reformer) to gradually ease into costly capital investments. Delivery options receive a score of two and on-site production receives a score of one in this category.

1.4.3.3 Site Requirements

Space

- Additional compliance with safety codes and space requirements are necessary to accommodate on-site hydrogen storage and/or production, often disqualifying sites from on-site solutions. Moreover, on-site hydrogen production will require additional space to accommodate storage and compression equipment. In this category, FCEB off-site delivery receives a score of two while on-site production receives a score of one.
- BEB fleets have fewer spatial constraints and safety requirements than FCEBs as there is more flexibility with the location, type, and orientation of BEB-supporting infrastructure.

Energy

- Energy for BEBs is expressed in both consumption and demand. Consumption is expressed in kilowatt-hour (kWh), and is determined by calculating the total battery capacity multiplied by the number of vehicles in the fleet. Demand is expressed in kilowatts (kW) and is typically determined by multiplying the charger's output (kW) by the number of chargers. The demand, in particular, is required to determine the extent of utility upgrades. BEBs receive a score of one in this category.
- The energy requirements for storage, compression, and dispensing of hydrogen supplied via delivery is approximately 2.5 kWh per kilogram (kg), which results in nominal energy and operational costs. Off-site delivery receives a score of three in this category.
- FCEB energy requirements for on-site production can vary dramatically depending on how the hydrogen is generated. SMR production requires very little energy (~6 kWh/kg), whereas, electrolysis requires intensive energy inputs (~50 kWh/kg). For this reason, on-site production received a score of two in this category.

1.4.3.4 Availability

Fuel

- FCEBs (with on-site hydrogen production) and BEBs have the same score (three) for fuel availability since both hydrogen and electricity will be easily accessible if produced on-site.
- For hydrogen delivery, availability will depend on the bus facility's location. For instance, at this time, it is not recommended to source hydrogen delivery for rural or mountainous transit operators. Off-site delivery receives a score of two in this category.

Technology

- BEBs are offered in all vehicle classes including cutaways, standard, double-decker, articulated, and coach buses. There are also a number of methods to charge these vehicles, ranging from conductive plug-in and pantographs to inductive charging systems. Thus, technological availability for BEBs receives a score of two in this category.
- Though fuel cells are a mature technology, FCEBs are more nascent as compared to BEBs. FCEBs are available in standard and articulated configurations, however, some operators in San Bernardino County operate exclusively cutaway bus fleets, of which FCEB cutaways

are not commercially available on the market to date. Therefore, FCEBs receive a score of one in this category.

1.4.3.5 Sustainability

- The sustainability of BEBs depends on the generation of the electricity, either from fossil fuels, such as coal, or renewables, such as wind or solar. A benefit of BEBs, if receiving energy from the grid, is that point source emissions are expected to improve over time as the grid becomes cleaner, therefore BEBs receive a score of three in this category.
- Hydrogen delivery produces the most emissions of the technologies being compared because of the delivery process (typically a diesel-powered vehicle) and the fuel production origins (95% SMR in the U.S.). For this reason, off-site delivery receives a score of one in this category.
- On-site electrolysis may require more electricity compared to BEBs depending on the fleet size. Similar to off-site delivery, production via SMR results in emissions of carbon dioxide, albeit without the delivery truck emissions. Conversely, an electrolyzer utilizes large quantities of potable water to generate hydrogen fuel. This is especially concerning in the arid desert regions which are considered for this study. Thus, the sustainability score for on-site production is a two.

1.4.3.6 Community Acceptance

- BEBs receives the highest possible points (three) for community acceptance while on-site hydrogen production gets the lowest possible points (one) due to environmental concerns. In fact, BEBs are widely accepted by communities and supported in terms of sustainability initiatives by both cities and transit agencies alike in large part due to near or zero local emissions and quiet operations.
- Communities are generally more cautious with the installation of new hydrogen storage, and on-site production near their community due to the risk of hydrogen seepage and combustion. For instance, the Omnitrans' East Valley bus division has experienced extensive resistance from neighborhood interest groups with regard to on-site fueling.

1.4.3.7 Summary

It is evident that the determination of whether an agency adopts BEBs or FCEBs is contingent on a number of variables. Based on our screening analysis, BEBs appear to be the most suitable for adoption, however, this analysis does not take into consideration an agency's goals or existing operating conditions. For instance, although this analysis finds that the initial capital infrastructure investment is more expensive for FCEBs, it does not consider if an agency's bus base is located near a hydrogen pipeline or the potential credits and funding opportunities that can make it cost-competitive with BEBs. The WSP team further explores these nuances in each agency's respective section to provide a tailored set of recommendations. Table 1-11 summarizes the results of the screening analysis.

Table 1-11: Technology Screening Summary

		Performance		Cost		Site Requirements		Availability				
		Range	Refueling Time	Bus	Infrastructure (Upfront Capital)	Space	Energy	Fuel	Technology	Sustainability	Community Acceptance	Total Coverted Score
BEB		1	1	2	3	3	1	3	2	3	3	21
FCEB	Off-Site Delivery	2	2	1	2	2	3	2	1	1	2	18
	On-Site Production				1	1	2	3		2	1	15

Source: WSP

1.5 Energy Overview

1.5.1 Energy Consumption Storage and Management

1.5.1.1 Introduction

Electric utility providers are one of the key stakeholders in the transition to ZE vehicles. This section of the report outlines the different utility providers present in San Bernardino County, ulitlity rates, reliability, and fire risk. Transit needs to be resilient and must run even if there is a power outage. Even if hydrogen fuel cell buses are chosen as the dominant technology, the transit agencies will be more reliant on electric power than the current fleets, because hydrogen steam reformation, compression, dispensing, and electrolysis all utilize electricity.

1.5.1.1.1 Southern California Edison

SCE provides electric transmission and distribution services for all facility and on route charging sites except for the Big Bear Lake bus facility for MT and the Needles garage. SCE covers the rest of the charging sites for MBTA, MT, Omnitrans, and VVTA. Thus, close coordination with SCE will be critical to the successful deployment of ZEB, especially if the dominant technology is BEBs.

SCE is an investor-owned utility (IOU), which is publicly traded on the New York Stock Exchange through its parent company, Edison International. This means that SCE is regulated by the California Public Utility Commission (CPUC). SCE has more than 2.5 million customers and is the second largest utility in the state, behind Pacific Gas & Electric.

SCE was approved by the CPUC to invest in "Charge Ready" infrastructure on behalf of their customers. This program allows transit authorities in areas where no distribution upgrades are required to have the infrastructure installed within nine months of permitting acceptance by SCE. There is no cost to the transit operator for connecting infrastructure; transit agencies would be responsible for the cost of the charging equipment itself. With this infrastructure in place, SCE will then charge the operators special electric vehicle (EV) rates for their Charge Ready program and would effectively take the place of being the "fuel provider" for the bus fleet (see "Utility Rates" sub-section of the report for more details).

However, such a generous program and ability to provide the infrastructure needed is not without certain drawbacks. For example, Alameda Contra Costa Transit District elected to build all of the infrastructure itself without involvement from its local utility due to what the agency deemed unfavorable terms and conditions in the potential contract. Regarding SCE, the utility requires transit authorities to use a set of pre-selected vendors for the charging stations themselves, and SCE does all of the engineering on its own end, which leaves some of the engineering and control of the facility and final design out of the operator's control. The cost of infrastructure and effects on operations must be carefully considered when deciding to use SCE's Charge Ready program. See Appendix X for a list of charging equipment currently approved by SCE.

From an infrastructure perspective, most of the facility and on route chargers will have low enough power requirements that zero to minimal distribution upgrades would be required. Any upgrades required that do not go through SCE's Charge Ready Transport program would have to be financed by the transit authorities. In addition, if distribution upgrades are required (which is more likely for the larger facilities if they are to be powered by all BEB or have on-site electrolysis for hydrogen) SCE has given other authorities estimates of three to five years to upgrade the infrastructure necessary to support the endeavors.

1.5.1.1.2 Bear Valley Electric Service

The facility located at Big Bear Lake for MT is serviced by Bear Valley Electric Service (BVE). The utility will provide installation and engineering for EV chargers[12]. BVE has said that it can support up to 1 MW of additional load at the existing facility and a possible new facility. With only fourteen buses, it is currently estimated that a maximum of 450 kW of additional power is needed for this circuit. More detail will be provided in the in-depth site analysis, but it is estimated that BVES can readily meet the needs of the Big Bear Lake facility.

1.5.1.1.3 City of Needles

The Needles Garage in the City of Needles service territory is a very small facility that we estimate will only need one 150 kW charger. It is not anticipated that this will be a difficult service request for this area.

1.5.1.1.4 Rancho Cucamonga Municipal Utility

Omnitrans buses travel through Rancho Cucamonga Municipal Utility territory. There were some potential considerations to add on route charging in that area, but plans have not moved forward yet.

1.5.1.1.5 Victorville Municipal Utilities Services

Victorville's Municipal Utilities services currently only serves one industrial park within Victorville. There are no current plans to add any charging to this park.

1.5.1.2 Utility Rates

Rates depend on many different factors (Table 1-12), but the biggest two are service voltage and peak demand. Within SCE territory, all of the sites fall under the TOU-EV-9 rate, with primary service voltage between 2kV to 50kV. This tariff does not have a demand charge, which helps make it more economical to run peaky loads such as a single large 600 kW charger at a transit center. However, the "time of use" component means that evening peak costs are more than four times higher than the off-peak rate (Table 1-13). There is a mid-peak alternative price as well, listed below. There needs to be a separate meter to qualify for this rate as well, this means that the existing buildings and lighting will need to stay on their own separate meter. At the current time, all costs are based on the same SCE rates, the small charging under BVES and City of Needles will not be significantly different in costs.

[12] BVE EV Program: https://www.bves.com/efficiency-&-environment/electric-vehicle-charging-pilot/

Table 1-12: Southern California Edison Utility Rate

Time of Use Period	Rates (per kWh)	
	Summer (June-September)	Winter (October-May)
On-Peak	$0.40891	
Mid-Peak	$0.20129	$0.23603
Off-Peak	$0.09854	$0.10323
Super Off-Peak		$0.06493

Source: SCE

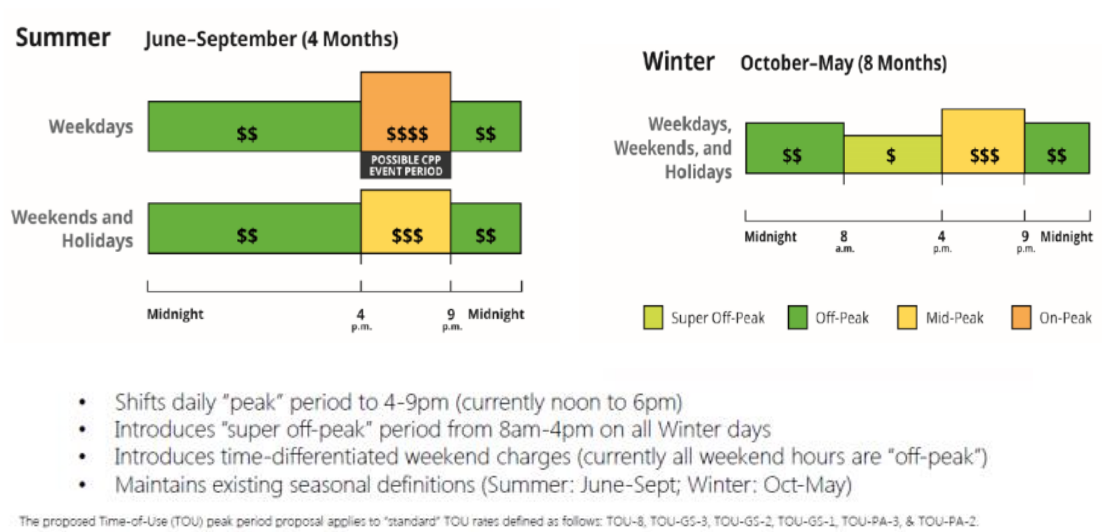
Table 1-13: Southern California Edison Time of Use Detail

Time of Use Period	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	4 p.m. – 9 p.m.	N/A	N/A	N/A
Mid-Peak	N/A	4 p.m. – 9 p.m.	4 p.m. – 9 p.m.	4 p.m. – 9 p.m.
Off-Peak	All other hours	9 p.m. – 8 a.m.	All other hours	9 p.m. – 8 a.m.
Super Off-Peak	N/A	8 a.m. – 4 p.m.	N/A	8 a.m. – 4 p.m.

Source: SCE

Figure 1-25 illustrates the utility rate relative to the Time of Use period of SCE.

Figure 1-25: Southern California Edison Utility Rate Illustration



Source: SCE

1.5.1.3 Utility Reliability

1.5.1.3.1 Introduction

Both BEBs and FCEBs are more vulnerable to electrical grid interruptions. Therefore, this section provides a summary on how utilities measure reliability in the service areas of each of the five transit operators within San Bernardino County. Most of the information is based on SCE data, because it is required by the CPUC to publicly report this data. BVES also provided some data to the WSP team for this analysis.

Table 1-14 presents the standard measurements procedures within the electric power industry to measure electric power distribution reliability.

Table 1-14: Utility Reliability Measurements

Index	Formula	Definition
CAIDI	Sum of outage CMIs/Sum of outage CIs	Average outage duration if an outage is experienced, or average restoration time
SAIDI	Sum of outage CMIs/Total number of customers served	Average outage duration per customer
SAIFI	Sum of outage CIs/Total number of customers served	How often a customer can expect to experience an outage
MAIFI	Total Momentary Interruption CIs/Total number of customers served	The frequency of momentary interruptions

Source: WSP

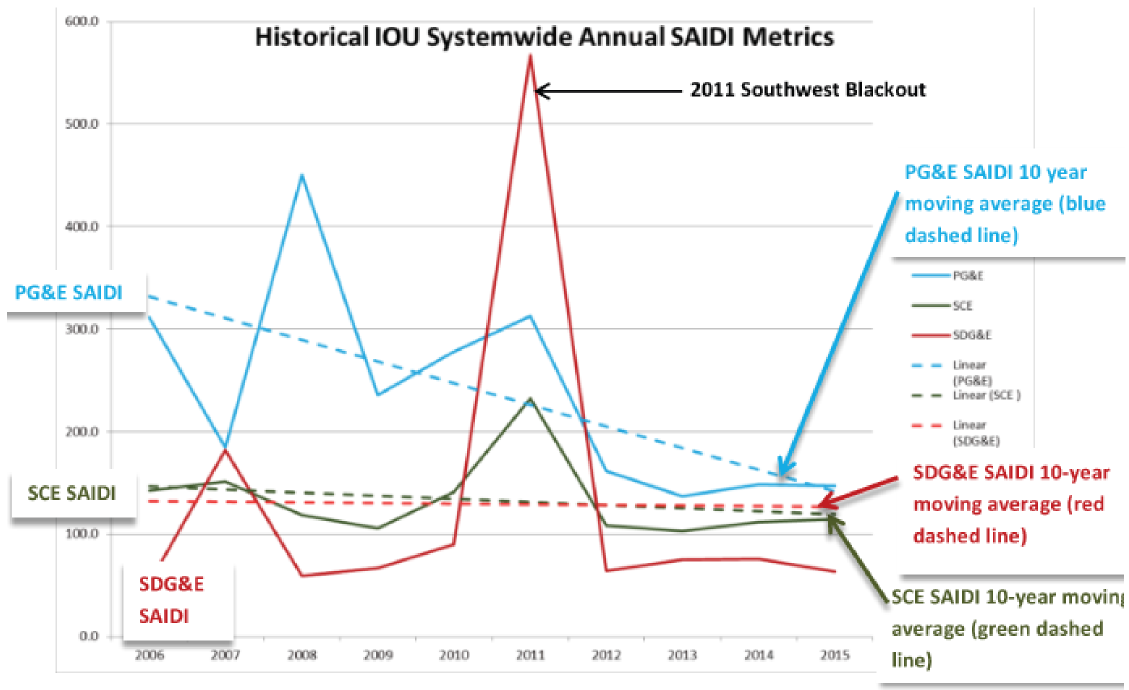
1.5.1.3.2 SCE Reliability

Reliability can change a lot from year-to-year based on single events such as wildfires and major storms. Therefore, CPUC generally uses a 10-year rolling average to show improvements over time. SCE has been remarkably stable in its overall measurements of these metrics. The exception is in Momentary Average Interruption Frequency Index (MAIFI), where SCE has improved significantly. See the charts below of all the major metrics for all three IOUs in California from the period of 2006 to 2015.[13]

Even within SCE, the different districts can have large differences in reliability. Table 1-15 shows each of the SBCTA sites and their transit operators' service areas. The table shows both SAIDI and SAIFI for the years 2014 to 2018. The chart is sorted to show the best performing districts at the top, SCE average in the middle, and the poor performing districts at the bottom.

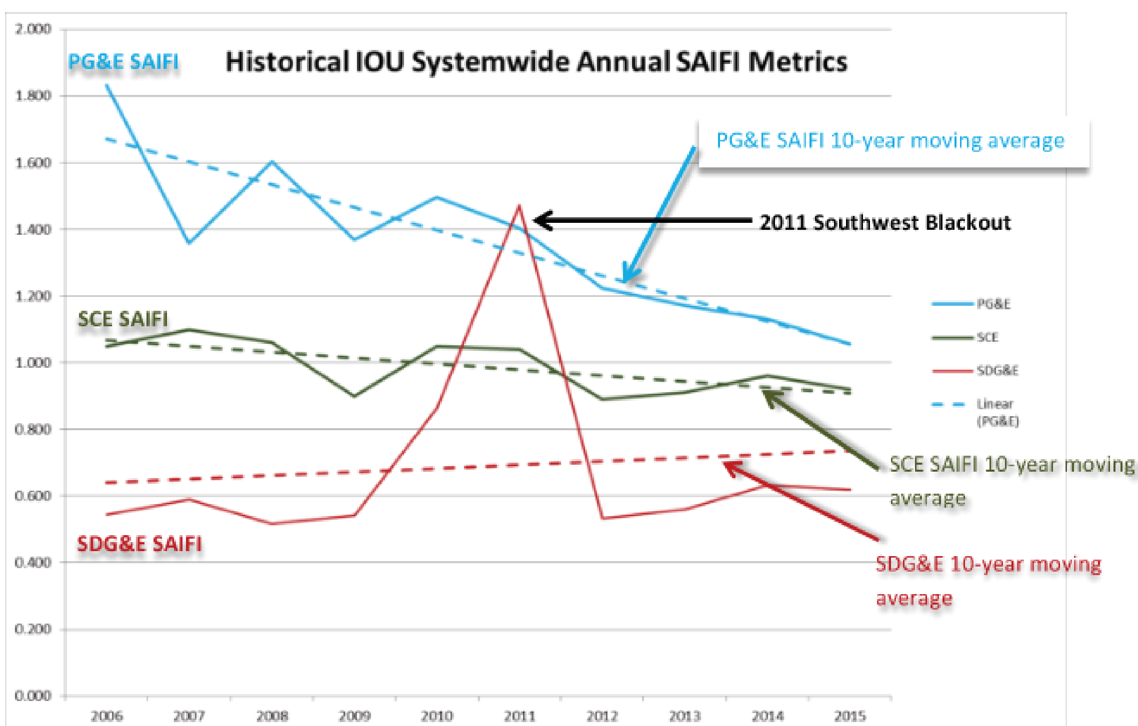
[13] http://www.cpuc.ca.gov/uploadedfiles/cpuc_public_website/content/about_us/organization/divisions/policy_and_planning/ppd_work/ppd_work_products_(2014_forward)/ppd%20reliability%20review.pdf

Figure 1-26: SCE Historical SAIDI Metrics



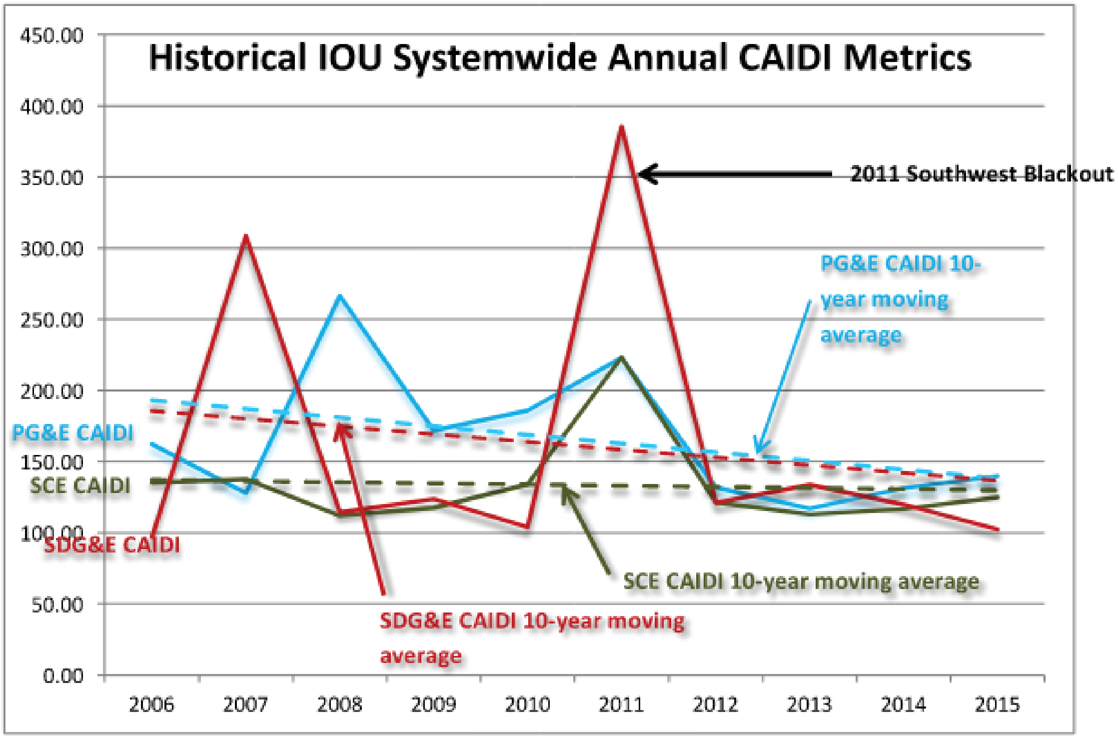
Source: California Public Utilities Commission

Figure 1-27: SCE Historical SAIFI Metrics



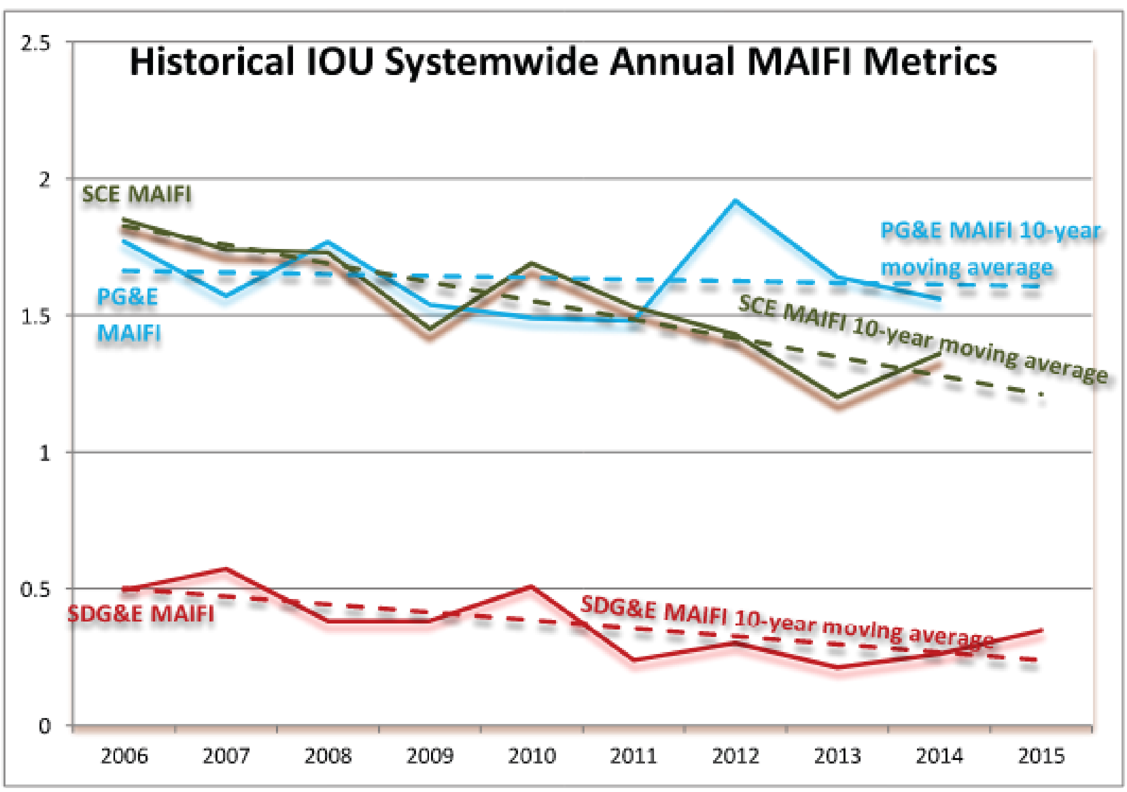
Source: California Public Utilities Commission

Figure 1-28: SCE Historical CAIDI Metrics



Source: California Public Utilities Commission

Figure 1-29: SCE Historical MAIFI Metrics



Source: California Public Utilities Commission

Table 1-15: Reliability by SCE District

District Name	SBCTA Sites	2014		2015		2016		2017		2018		Average	
		District SAIDI	District SAIFI	District SAIDI	District SAIFI	District SAIDI	District SAIFI	District SAIDI	District SAIFI	District SAIDI	District SAIFI	SAIDI Avg	SAIFI Avg
VICTORVILLE	Hesperia	58.9	0.6	87.0	0.9	79.4	0.9	84.1	0.9	125.9	0.9	87	0.8
ONTARIO	West Valley	97.9	1.0	94.0	0.7	105.1	3.9	100.4	1.1	80.0	0.7	95	1.5
FOOTHILL	Fontana	93.4	0.9	109.6	1.0	142.8	1.0	110.5	1.1	117.6	1.0	115	1.0
SCE System Wide		**112.1**	**1.0**	**114.8**	**0.9**	**134.5**	**1.1**	**139.7**	**1.2**	**136.8**	**0.9**	**128**	**1.0**
REDLANDS	East Valley, Yucaipa, SBTC	154.3	1.0	124.5	1.0	137.1	1.0	142.6	1.0	88.9	1.0	129	1.0
BARSTOW	Barstow	201.5	1.3	187.1	1.2	134.8	1.4	357.5	2.6	115.7	1.4	199	1.6
YUCCA VALLEY	Joshua T., 29 Palms, YVTC	304.3	1.5	389.1	1.8	463.7	3.4	300.3	2.0	353.8	1.9	362	2.1
ARROWHEAD	Crestline	193.3	1.6	362.6	4.0	659.5	2.9	816.5	3.9	68.5	1.5	420	2.8

Source: SCE

1.5.1.3.3 Bear Valley Reliability

Bear Valley Electric Service is not regulated by CPUC and does not use the exact same methodology as SCE in calculating all of these metrics. However, the utility published the following figures describing their performance through 2017:

Table 1-16: Bear Valley Unplanned Outages

Unplanned Outages (MED Included)

BEAR VALLEY ELECTRIC SERVICE

Year	SAIDI (Minutes)	SAIFI	MAIFI	CAIDI (Minutes)
2008	332.1	3.0	0.5	111.3
2009	13.8	0.1	1.5	150.6
2010	118.6	0.6	1.1	194.4
2011	190.0	1.5	2.1	126.3
2012	29.8	0.2	1.0	182.2
2013	95.2	2.1	0.4	46.3
2014	71.6	2.1	0.0	33.8
2015	198.2	2.8	0.3	71.6
2016	323.6	2.5	1.3	129.0
2017	80.1	1.1	2.7	73.7
Ave	**145.3**	**1.6**	**1.1**	**111.9**

MED: Major Event Day - A day in which the daily system outage exceeds a statistically derived threshold value (occurs for major storms, earthquakes or other significant external events)

19

Source: Bear Valley Electric Service

Figure 1-30: Unplanned Outages Comparison (Events Excluded)

How Do We Compare?

BEAR VALLEY ELECTRIC SERVICE

2017 Unplanned Outages MED Excluded	SAIDI	SAIFI	MAIFI	CAIDI
SoCal Edison	91.7	0.9	1.4	105.4
San Diego Gas and Electric Company	64.5	0.5	125.9	0.3
PacifiCorp	75.5	0.6	125.0	4.4
Pacific Gas & Electric	97.3	0.9	1.6	110.8
Liberty (CalPeco)	772.8	2.9	1.4	270.2
Bear Valley Electric Service	**34.7**	**0.6**	**0.1**	**57.9**

MED: Major Event Day - A day in which the daily system outage exceeds a statistically derived threshold value (occurs for major storms, earthquakes or other significant external events)

For all indices (SAIDI, SAIFI, MAIFI & CAIDI) lower is better

20

Source: Bear Valley Electric Service

Figure 1-31: Unplanned Outages Comparison (Events Included)

How Do We Compare?

2017 Unplanned Outages MED Included	SAIDI	SAIFI	MAIFI	CAIDI
SoCal Edison	139.7	1.2	1.8	117.2
San Diego Gas and Electric Company	117.5	0.6	200.9	0.3
PacifiCorp	421.8	1.4	296.0	4.4
Pacific Gas & Electric	357.7	1.5	2.4	244.1
Liberty (CalPeco)	1597.4	4.0	1.4	402.1
Bear Valley Electric Service	**80.1**	**1.1**	**2.7**	**73.7**

MED: Major Event Day - A day in which the daily system outage exceeds a statistically derived threshold value (occurs for major storms, earthquakes or other significant external events)

For all indices (SAIDI, SAIFI, MAIFI & CAIDI) lower is better

21

Source: Bear Valley Electric Service

Figure 1-32: Bear Valley Major Outages

Top 10 Major Outages

Date	Affected Circuit	Event SAIDI (minutes)	Cause
6/19/2018 to 6/24/2018	Various	498.56	Supply: Loss of Southern California Supply sub-transmission line (34.5 kV) from Lucerne Valley due to Holcomb Fire.
1/20/17	Baldwin	42.44	Weather: High winds caused Baldwin sub-transmission line to open.
8/7/2017	Garstin	8.75	Weather: PMS 3407 opened due to lightening strike.
2/18/17	Clubview	8.50	Weather: High winds caused tree branch fall across 34.5kV and 4kV lines.
4/21/2017	SCE Goldhill Ute Lines	2.62	Supply: Fault at Southern California Edison Cottonwood Substation.
11/8/2017	Radford	2.25	Equipment Failure: Pole Switch rod failed during field switching operations.
1/22/17	Goldmine	2.09	Weather: High winds caused tree branch fall across primary and secondary lines.
1/20/17	Maple	1.69	Weather: High winds caused tree branch fall across primary and secondary lines.
12/14/2017	Clubview	1.40	Other: Contractor inadvertently de-energized 4 kV switch position at Moonridge Sub-station while performing equipment testing for maintenance.
7/21/2017	Boulder	1.37	Weather: High winds caused tree to fall across primary lines.

22

Source: Bear Valley Electric Service

1.5.1.3.4 Fire Risk

California has always had major wildfire risks, especially during the hot dry fall season, which bring high winds. Following several tragic fires, the utilities, working in conjunction with CPUC, have come up with the Public Safety Power Shutoff (PSPS) system to protect from the greater harm. This preemptive power shutoff to whole power circuits has been quite disruptive when it occurs. The data about PSPS is not yet well captured, since it only occurred in 2019 and this data has not yet been incorporated into the latest reliability data discussed above. The most recent reliability data published by SCE is 2018 currently.

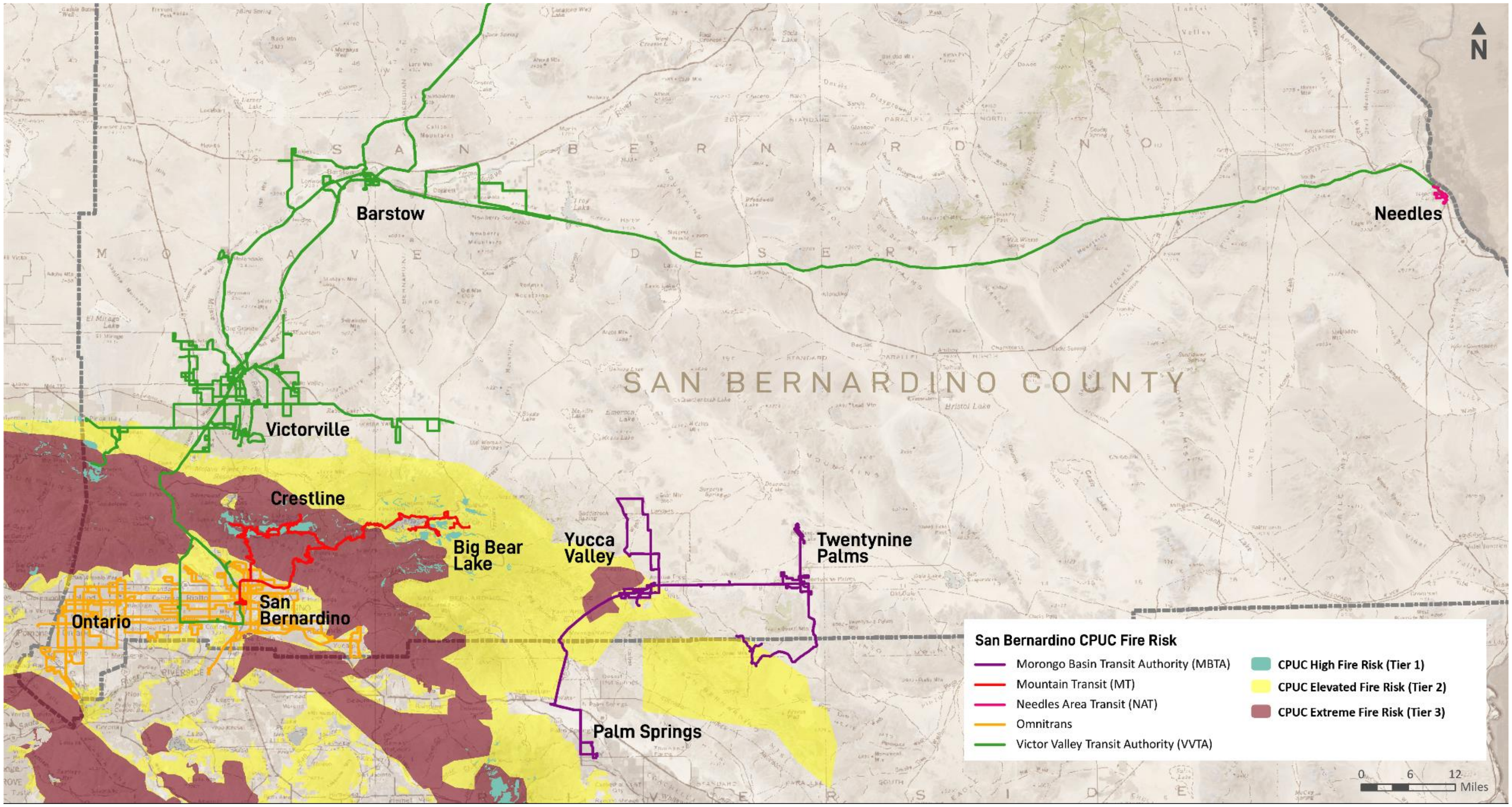
The WSP team has reviewed the literature published by SCE and CPUC and created Figure 1-33 to illustrate the high fire risk areas that encompass the transit operators' maintenance facilities and potential on route charging stations. There are five sites to highlight specifically, because SCE has noted to the CPUC that their circuits are in high fire danger areas[14]. These five sites are:

- Omnitrans East Valley maintenance facility
- MT Crestline maintenance facility
- Omnitrans Yucaipa Transit Center
- Omnitrans San Bernardino Transit Center
- MBTA Yucca Valley Transit Center

The Omnitrans East Valley Division is the largest facility in the whole system, so extra care should be taken to be resilient against both power outages and fire. The Crestline facility is not built yet, so all resilience measures should be taken into account during design and construction. Finally, the Omnitrans East Valley Transit Center and the Crestline facility each only have one single high-speed charger for on route charging, so they are less critical to have back up chargers. In addition, the San Bernadino Transit Center can potentially utilize another circuit that is not at high risk. However, if the on route chargers get extensively used and are deemed critical to a high-performance system, then Omnitrans may consider back up generators or stationary batteries to supplement them.

[14] https://library.sce.com/content/dam/sce-doclib/public/sce-high-fire-area-emergency-documents/san-bernardino-county/circuit-list-by-city/San%20Bernardino%20County%20-%20Circuit%20List%20by%20City.pdf

Figure 1-33: High Wildfire Transit Operators' Service Areas



Source: WSP

1.5.2 Methodology of Site Analysis, Terms, and Infrastructure Needs

Each detailed site analysis will vary from site to site based on the energy load required and the information the utility providing the power is able to provide. Some utilities have more robust analytics monitoring their grid than others and can give a more accurate view of current capacity with certain analytics. However, there is more to feasibility of electrical load than just how many kWhrs (kilowatt hours) a facility needs to power its buses. This will be broken down into the difference between power, energy, peak power, and what changes the grid may need (if any) to provide the new power required for ZEB at each facility. Each recommendation section will provide current circuit loads (if available from the utility), new circuit loads required based on our analysis, reliability of power in the area, and overall feasibility of implementation at the location.

Included in the analysis of each site are two pictures, if available. The first is a Google Earth aerial view of each site to provide area context, and the second is a picture from SCE's DRPEP system that shows the circuits near each site and in some cases shows how close the nearest substation is. This is a distribution circuit map, and information from SCE's system is used in our analysis and recommendations.

Power distribution lines need to be nearby the transit agency facility in order to provide a new primary connection to provide enough power for the bus chargers. However, each distribution line will have existing load already on it, and in general, each line can only support about 400 Amps of load per line. How much power that is depends on the voltage of the line. Most lines in this study are 12 kV lines, which at 400 Amps of 3 phase power brings total peak load able to be supported by the lines to 8.3 MW. Bringing in more power is possible, but can take more time to implement.

Determining the additional peak power load required for Electric Vehicle Supply Equipment (EVSE) is relatively simple. Essentially, take the maximum power of each charger and multiply it by the number of chargers. Even if not all chargers need to be active at a time under normal conditions, this is required to provide the utility with the possible additional load on the line in the event of an unforeseen circumstance, such as a power outage where, once restored, there is a shorter window to finish charging the buses for the next day's service.

Determining the additional peak power load required for hydrogen vehicles is slightly more difficult because of the different methods of hydrogen delivery. Hydrogen can be stored in two ways, either as a gas or liquid, and each requires power. In addition, depending on the site, hydrogen can be trucked in similar to regular gas or created on-site. There are two ways to create hydrogen on-site - reformation from natural gas and electrolysis (from water). How much power is required and how much time the hydrogen generators need to run for depends on how much hydrogen is required per day at the site. In general, reformation from natural gas is more energy efficient than electrolysis, but also has CO_2 as a by-product. Please refer to the master report for more detailed information on these types of storage.

In addition, the WSP team recommends that SBCTA, or each individual transit operator commission a more in-depth study on CO_2 emissions of each type of ZEB vehicle because while the vehicles themselves are ZE (by definition) there is still energy required to make them zero emission, be it from the grid for pure BEBs or electrolysis or from natural gas for hydrogen. Either technology is far more efficient than diesel and would still reduce carbon impact.

1.5.3 Alternative Energy Options

Transit operators within San Bernardino County may want to choose alternative energy options to save capital costs, save operating costs, be more resilient, or be more sustainable. This section outlines the basic details of most of the major alternative energy options.

1.5.3.1 Introduction

There are many options of distributed power generation. No power options are perfect, but all offer some benefits compared to standard grid power. We have described each of these options in further detail after Table 1-17.

Table 1-17: Distributed Generation Energy Options

DG Technology Options	Description	Size/Load	GHG Benefit	Financial Benefit	Grid Resiliency
Managed Charging, Vehicle Grid Integration (V1G)	Utility directed charge management of onsite EVs	Size of EV load	Avoids marginal emissions from additional peaks	$/kW peak demand savings and $/kWh incentives	Flattens load profile, emergency grid response
Vehicle to Grid (V2G)	Battery electric vehicles discharge power back to the grid	Depends on # of vehicles	Avoids marginal emissions from additional peaks and ramping.	$/kW incentives and $/kWh incentives	Helps reduce grid stress significantly, especially during fast ramp peak hours
Onsite Solar PV	Roof, canopy, or south facade integrated	0.5 MW/acre parking lot	Displaces midday emissions from the electric grid power	Net metering /offset to the bill	Mismatch between charging BEB at night, solar production during day.
Stationary Fuel Cell	Chemical electricity generation, made from natural gas, 55% efficiency with only CO_2 exhaust	250-400 kW per shipping container	Displaces more/less GHG intense grid electricity; declining benefit over time	Savings depends on the diff in price between gas and electricity.	Can be used to reduce baseload or buffer peaks. Can potentially be used in island mode, without the grid.

DG Technology Options	Description	Size/Load	GHG Benefit	Financial Benefit	Grid Resiliency
Stationary Battery Energy Storage Systems	Lithium-Ion electric battery with inverters	4 MWH per shipping container, ~1MW inverter	Reduces ramp rates and peaker plant marginal emissions	Peak demand management. Possible utility incentives. CAISO revenues[15] in ramp rate market	Can reduce stress on distribution grid. Can be used in island mode, but limited duration
Gas Fired Electric with Heat Recovery	Gas fired turbine or reciprocating engine using waste heat for heating or cooling demand. High (80%) efficiency if need for heat / cooling.	1 MW per shipping container, with heat recovery	Displaces more/less GHG intense grid electricity; declining benefit over time	"Free" heat or cooling. Elec savings depends on the diff in price between gas and electricity.	Can be used in island mode, without the electric grid
Wind Power	Wind turbines mounted on poles	Site specific	Displaces grid emissions	Net metering	Will back-feed to grid during low demand

Source: WSP

1.5.3.2 Managed Charging

"Managed charging" refers to the use of software and hardware that allows charging power demand to be modified to achieve a goal other than fast charging. This is sometimes referred to as vehicle grid integration (V1G). The other goals include reducing peak power demand charges, or to respond to a grid signal. Utilities throughout the country are running pilot programs to manage charging on their local grids. In California specifically, electric vehicles have the potential to either mitigate or exacerbate the "duck curve" which has a fast ramp in the early evening as people return home from work and solar power shuts down with the sunset. If all residential EVs and transit buses plug in just as the sun sets, additional dirty peaking power plants will be needed every night. However, if charging can be pushed later in the night, system wide peaks will be lower and overall carbon pollution will be minimized.

1.5.3.3 Vehicle to Grid

Another emerging technology is vehicle to grid (V2G). This takes managed charging to the next level by having a grid signal ask the vehicles to discharge power back to the grid. It requires the design engineers to make sure that all hardware components are capable of bi-directional power

[15] California Independent System Operator (CAISO) is a nonprofit benefit corporation that oversees the operation of California's bulk power systems, transmission lines, and electricity market generated and transmitted by its member utilities. www.caiso.com/about. CAISO revenues refer to the credits and other payments incurred or received by the utility from the generating facility [depot] to any CAISO administered market by the seller [agency], including costs and revenues. https://www.lawinsider.com/dictionary/caiso-revenues

flows. While there are several companies working on this, none have been piloted with transit buses and utilities. The most common vehicle types right now are light passenger vehicles or electric school buses. Therefore, this option is not yet being considered any further at the current time. At some time during the phase in of all ZEBs, this technology may reach maturity and will lower the total cost of ownership of BEBs.

1.5.3.4 Solar PV Power

Solar photovoltaic power production is the most popular form of distributed power generation. VVTA already owns a major solar installation at the Hesperia facility. On the whole, the transit agencies should strongly consider adding solar power to all of the sites that build overhead charging infrastructure, because the structural support structures are such a large component of total costs. Solar power is often paired with batteries to mitigate the disadvantages of variable solar power, but batteries are too expensive to power a site throughout the entire night. Solar power currently qualifies for a federal Investment Tax Credit, which is being phased down from 30 percent to 10 percent.

SCE has indicated that sites with over 1MW of solar can be approved and net metered as long as they are not designed to export significant amounts of power. This may include the East and West Valley facility for Omnitrans.

Advantages of Solar PV Power

Solar energy production is clean and does not have any emissions. Over the past few years, solar prices have come down to the point where it is often cheaper to produce solar power on site than purchasing power from the local utility. Solar can last more than 30 years, though the panels degrade over time, producing slightly less energy each year.

Some of the bus facility within San Bernardino County are going to build overhead support structures to hold new BEB charging infrastructure. The overhead support structures can be used to add solar power above the buses. The main structural steel is only purchased once and that reduces the total capital expenditures required to add solar power. Solar power does not occupy premium real estate within a bus facility. In addition, solar provides some shade to the facility below, improving working conditions for the bus drivers and technicians.

When solar is installed on roof tops, care should be taken to make sure that there are no leaks or other reasons to replace the roof. Replacing the roof will require solar to be removed and reinstalled. This can add significant lifecycle costs to the solar power.

Disadvantages of Solar PV Power

Solar power has a fundamental mismatch between solar power production during the day, while most BEBs will charge at night. Therefore, the solar power is mostly sold back to the grid during the day and the buses draw from the grid at night through a system known as net metering. As an alternative, solar energy can be stored during the day using stationary batteries as discussed in Section 1.5.2.8.

Another problem is that not enough power can be generated by solar compared to the BEB loads. Even if an entire parking lot is covered with solar above the bus parking, this will be only a fraction of maximum peak power draw from the buses.

The power output from the solar power is variable and can change quickly based on cloud cover. This can cause some additional stress on the local grid. Unless purposely built as a microgrid, including significant battery energy storage, solar power cannot be run during a grid blackout.

1.5.3.5 Stationary Fuel Cells

Stationary fuel cells are a technology to produce electricity through a chemical reaction. The fuels take natural gas as input and produce CO_2 and water as outputs. In the future, renewable gas or hydrogen may be able to be used as a fuel, but currently non-renewable natural gas is used. Usually fuel cells require 15 psi gas, which sometimes takes energy for compression.

It is possible to recover waste heat from fuel cells and utilize that heat for space heating or air conditioning (through absorption chillers). This is known as cogeneration. This raises the total efficiency of the system and should provide additional financial and environmental benefits. However, no transit agency within San Bernardino County is currently set up for this type of thermal distribution. In addition, the most popular fuel cell brand (Bloom Energy) does not allow for cogeneration.

Advantages of Stationary Fuel Cells

Fuel cells do not have any combustion, therefore, there are no SO_x or NO_x pollutants. However, they still produce CO_2. Fuel cells provide some GHG savings over the California grid power, but as the grid gets cleaner, there will be less GHG benefits over time.

The fuel cells are partially dispatchable, and therefore, can be engineered to produce energy at the same time that the buses are charging.

If back up power is required by local codes, sometimes fuel cells can meet that requirement, avoiding the purchase or maintenance of diesel generators.

Disadvantages of Stationary Fuel Cells

Fuel cells can produce enough power to charge all of the buses in case of emergency, however, they take a significant amount of valuable real estate. Fuel cells do not contain rotating equipment, so it can be elevated if possible. Other gas fired power generation technology is more compact and would take up less space for the same output.

1.5.3.6 Natural Gas Combustion Equipment

Natural gas combustion equipment produces electricity through gas turbines or reciprocating engines. They can have high efficiency if used for cogeneration, though there are limited thermal loads and distribution at transit agency facilities. Usually gas combustion equipment requires 15 psi gas, which sometimes takes energy for compression.

Advantages of CNG Combustion

This technology is very mature and has been the default option for on-site distributed generation for a long time. In addition to low capital costs, generators can be used to island the facility, operating separately from the grid, this is also called a microgrid. The gas generating equipment can run only at night to support charging or could run 24/7, depending on how the system is engineered. They are quite flexible operationally, more than fuel cells.

If back up power is required by local codes, usually gas fired generation can meet that requirement, avoiding the purchase or maintenance of diesel generators.

If the facility has significant heating and/or cooling loads, cogeneration can lead to very high efficiency production of both electric and thermal loads. However, no transit agency within San Bernardino County is currently set up for this type of thermal distribution.

Disadvantages of CNG Combustion

Gas fired generation not only produces CO_2, which is a GHG, but they also produce SO_x and NO_x pollutants. These pollutants harm human respiratory health and therefore are regulated. Transit agencies within San Bernardino County might need to get additional environmental permits, such as U.S. Environmental Protection Agency Title V permits. While cogeneration gas fired generation may provide some GHG savings over the California grid power currently, but as the grid gets cleaner, there will be less GHG benefits over time.

Gas powered generation takes up less space than fuel cells or batteries. However, they still take up valuable real estate. Elevating rotating equipment adds significant lifecycle costs due to the need to install expensive vibration mitigation.

1.5.3.7 Wind Power

Wind turbines are the most widely used renewable energy resource in the country; however, it is difficult to make wind power work for distributed power on-site.

Advantages of Wind Power

Where applicable, wind is more energy dense than solar. A single turbine can produce hundreds of kilowatts. Buses can park underneath turbines as long as the foundations are designed properly.

Disadvantages of Wind Power

Wind power is extremely site dependent. A more detailed analysis of each transit operator's maintenance facility will be needed before making any further recommendations.

1.5.3.8 Stationary Battery Energy Storage

Stationary batteries are not an alternative energy source, but instead are simply a mechanism to store electrical energy. Batteries can be used to avoid peak demand charges by storing energy during times of low usage and discharging during peak usage times. Batteries do not currently qualify for federal incentives but can be paired with solar to be eligible for the Investment Tax Credit.

Advantages of Stationary Battery Energy Storage

Batteries can help achieve a lower utility category. For example, SCE rates change after the loads get above 500kW. There are several sites that could use 600kW max. When coordinated with the utility, a battery can be used to consume 600kW for short durations, while still pulling less than 500kW from the grid.

If backup power is required by local codes, sometimes battery energy storage can meet that requirement, avoiding the purchase or maintenance of diesel generators.

There is potential to use stationary batteries as a source of revenue from CAISO to the transit agencies. Batteries can respond to changing conditions very rapidly and can participate in frequency response or ramping markets. Transit operators may be able to use the stationary batteries during the day to participate in these markets, while then using the batteries to charge the BEB fleet at night.

Stationary battery energy storage requirements are usually less onerous than the requirements for batteries used for transportation (like BEBs). It is expected that in the next 10 years, a large secondary market will become available for buying used batteries from BEBs and electric cars.

Disadvantages of Stationary Battery Energy Storage

Batteries are expensive, but costs have been coming down every year. The costs of batteries heavily depend on the amount of energy to be stored, so short duration batteries are more cost effective than long duration.

Batteries take up valuable real estate, though they could be raised onto supporting steel since they have no moving parts.

There are energy losses in converting energy for storage and back again to grid power. This penalty is usually around 20 percent.

1.5.3.9 Back Up Power Considerations

As indicated in other alternatives, usually local codes require small generators for life safety. The transit agencies already have generators at a number of sites. These generators are usually fired by diesel, sometimes with natural gas. The current building back-up generators are too small to charge significant numbers of electric buses in an emergency. Generators which serve CNG compressors are quite large and could help to provide skeleton bus service during a true emergency, however, none of these industrial-scale generators currently exist at any of the countywide facilities. Please refer to Section 9 for resiliency planning recommendations.

1.5.3.10 Off-site Electrolysis Generation for Hydrogen

Some agencies around the nation are beginning to recognize the potential for commercialization of the zero-emission technologies they are integrating within their fleets. Following suit with SunLine Transit Agency's public alternative fueling station, VVTA is strategizing approaches to increase economic opportunity within the agency by producing their own hydrogen in excess and selling it to local consumers. Two sites are currently being considered for scaling VVTA's hydrogen production and positioning a local hydrogen retail station.

The first location is a 10-acre parcel set directly adjacent to the Barstow site. If developed, this site would serve as the only public hydrogen fueling station in the community. The location of the Barstow site also sits near the junction of I-15 and I-40, five minutes from a conventional truck fueling station. As commercial freight vehicles begin to make the transition to alternative fuels, this site could prove to be a promising location for drawing early adopters.

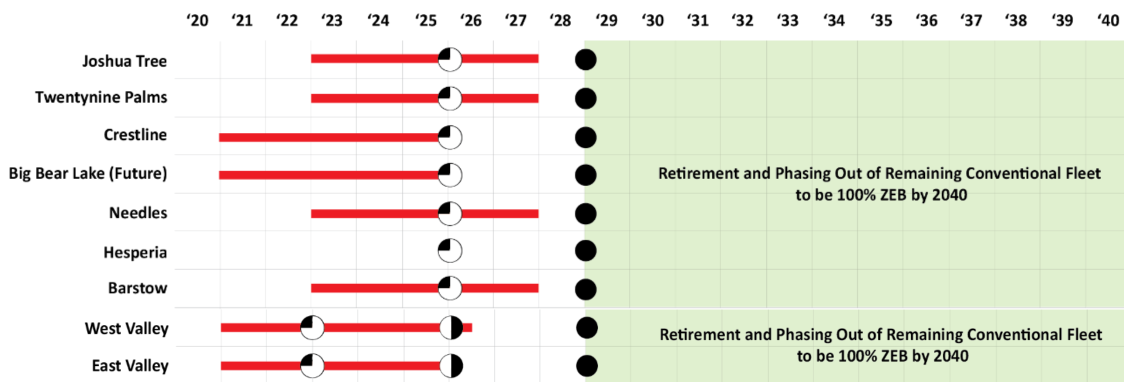
VVTA is also considering positioning a retail hydrogen station at an inactive transit center located in Hesperia. This site is located near various retail sites as well as a Burlington Northern Santa Fe railroad line, again offering the opportunity to market to intermodal freight vehicles using alternative fuels. The site in consideration currently provides CNG fueling, indicating that many of the necessary upgrades to accommodate "lighter-than-air" fuels will already be in place.

Providing adequate hydrogen to supply a full-fleet conversion at VVTA along with public fueling stations will be substantial, requiring multiple electrolyzers and/or SMR units. At each site, careful consideration to renewable power generation and renewable natural gas should be given to ensure long-term payback on capital infrastructure in addition to establishing complete energy independence.

1.6 Transition Phasing Schedule

The decision on whether to adopt BEBs and/or FCEBs is largely based on availability, applicability, and costs. Due to rapidly changing technologies, it's highly likely that strategies to adopt ZEBs today may need to be adapted and revised to account for advancements and changes in ZEB technology in the future. That said, the plans presented in the Master Plan are subject to alterations and may not necessarily reflect the implementation strategy of each individual agency. This Master Plan will serve as a guiding document for ZEB implementation, or as a baseline for agencies' subsequent studies and implementation towards ZEB adoption pursuant to the innovative clean transit (ICT) regulation. The proposed approach for each transit operator's construction and purchase schedule is outlined in Figure 1-34. The red lines depict the facilities design and construction durations and the circles indicate when and how agencies will comply with CARB purchasing requirements.

Figure 1-34: Summary of SBCTA's Joint Group's Construction and Purchase Schedule



Note: Crestline (Future) and Hesperia will store ZEBs, however, there are no plans at this time to charge (BEBs for Crestline) or refuel (FCEBs for Hesperia) at this time.

Source: WSP

The process of implementing ZEBs is broken down into a number of important tasks and phases related to construction of supporting facilities. The assumed approach is a design-bid-build strategy. Multiple requests for proposals need to be developed and put out for bid, with accompanying design and construction activities taking place. Overall, this process takes approximately five years. Durations provided here are approximate estimates. First, the design request for proposals would be developed and then advertised to the market over the course of six months. The award of the design contract and negotiations would take another six months. After implementation begins, the designer will perform their design work, which is estimated to take two years. Within the last 12 months of design, the designer will draft a request for proposals which will be used to procure a contractor, which is estimated to take six months. The award of the contractor contract and negations would take another six months during the last six months of the design. Construction would happen in three phases over 18 months. Utilities support, design, and construction would take anywhere from three to five years and could start at the beginning of the design process. Bus deliveries can be ordered 18 months before conclusion of the facilities construction.

2 MODELING METHODOLOGY

2.1 Battery Optimization Lifecycle Tool (BOLT)

To determine the feasibility of electrifying transit operator bus fleets, WSP uses its proprietary model, BOLT (Battery Optimization Lifecycle Tool), a dynamic, formula-based model to analyze BEB technologies impacts on existing service. BOLT was developed with the ability to help municipalities and transit agencies simulate the impact on range and operating costs for adoption of BEBs. Moreover, BOLT highlights the GHG emissions comparisons between diesel and electric buses. To use BOLT, a number of informational items were provided by SBCTA and the transit operators to provide a comprehensive understanding of their existing fleet, service conditions, and operating data, including general transit feed specification (GTFS), facility locations, fleet inventory, and other related data. GTFS outputs served as the foundation for modeling efforts because the data are standard between all five transit operators (and the industry) and provide information for the vehicle blocks, individual trip data, and the stop times on trips.

Knowledge of BEB performance under existing service conditions helps develop tailored strategies to improve range. WSP's model accomplishes both and is built on a framework that can respond quickly to changes in direction or assumptions. The following sections provide an overview of the approach used to model and analyze BEB performance with the transit operators in San Bernardino County under existing service levels and planned service modifications .

2.1.1 Service Data Inputs and Processing

To determine the feasibility of transitioning to BEBs, WSP first established a database of the five transit agencies' existing service and operations ("service database"). GTFS data provided by the operators was analyzed to identify and extract blocks, operating days, facilities, routes, and distance traveled. Because GTFS data do not include trips that are not in-service (deadheads between routes and pull-ins/outs), a geographic information system (GIS) based program was used to determine the locations for the facilities, trip starting points, and trip ending points to identify the distance and duration of trips to and from the facilities and deadheads between in-service trips to complete the vehicle blocks operating information.

From the information provided, routes and blocks were assigned a vehicle type (40-foot, 60-foot, cutaway) and a route type (local, rapid, or express). The route and block impact the efficiency of the service, which is discussed in subsequent sections.

2.1.2 Battery-Electric Bus Data Inputs and Processing

As previously discussed, the range of the BEB can be affected by weather, changes in elevation, traffic, and operator behavior. Batteries also deteriorate and lose capacity over time. To ensure that those factors and others are addressed, WSP made certain assumptions on the battery capacity and the efficiency of the battery. The assumptions are described in more detail in the section below.

2.1.2.1 Operating Battery Assumptions

For both the health of the battery and to reduce range anxiety, it is important to deem a portion of the battery unusable. The industry standard recommends maintaining a 20 percent battery capacity safety buffer to ensure vehicles can complete their routes. This restriction also supports future planning efforts as the battery capacity declines with age. For the purposes of the analysis, WSP assumed that 80 percent of the advertised battery capacity is usable. This ensures that the battery (while charging) can maximize the usage of a charger and reduce charging times (charge curves), while also providing the bus operator and agency with the comfort that the displayed SOC of a battery is a conservative estimate and that, if needed, there will still be a small amount available if there are any variances that can affect range.

2.1.2.2 Efficiency Assumptions

A BEB's performance is typically measured by its range (miles). This is a direct factor of its "efficiency" which is expressed in kilowatt-hours per mile (kWh/mi.). A higher efficiency value means that a battery will deplete faster, effectively reducing its range, whereas, a lower efficiency value results in a longer lasting battery and range. Efficiencies can vary based on a number of factors, including battery health, operator behavior, temperature (HVAC usage), speed, and weight. An accurate understanding of efficiency on a route can be determined via a pilot or shadow service. However, for the purposes of modeling, we calculated the "base" efficiency for each bus and battery combination as advertised by the OEM:

Operating Battery Capacity (kWh) ÷ Advertised Range (mi.) = Base Efficiency (kWh/mi.)

To account for the variances that can affect the efficiency, we added a sensitivity of plus (conservative) and minus (optimistic) 25 percent. The optimistic, base, and conservative efficiencies provide local transit agencies with an understanding of the general range in which these buses may operate. Table 2-1 presents the efficiencies modeled for each bus/battery, and route type combination used in the model.

Table 2-1: Efficiency by Vehicle and Route Type

Vehicle Type	Route Type	Advertised Battery Capacity (kWh)	Conservative Efficiency (+25% from Base)	Base Efficiency	Optimistic Efficiency (-25% from Base)
40 Feet	Local	660	4.50	3.60	2.70
	Rapid	660	3.88	3.10	2.33
	Express	660	4.25	3.40	2.55
60 Feet	Local	660	7.13	5.70	4.28
	Rapid	660	6.25	5.00	3.75
	Express	660	6.38	5.10	3.83
Cutaway	Local	118	0.84	0.67	0.50
	Rapid	118	0.84	0.67	0.50
	Express	118	0.84	0.67	0.50

Source: WSP

2.1.3 Service Delivery Options

Two service delivery models were chosen for BEB analysis. The two scenarios are described in more detail below:

Scenario 1: Base-Only Charging – Base-only charging includes charging that only occurs in the base after a block has completed its scheduled service.

Scenario 2: Base and On-route Charging – On-route charging includes the charging that occurs at the base and also at certain locations (usually transit centers or places close to terminals that a vehicle can easily deadhead) where there is enough recovery time (the time between in-service trips) to replenish at least part of the battery. On-route charging extends the range of a BEB to increase the percent of existing service covered and allow the possibility to purchase smaller batteries.

2.1.4 Base and On-Route Charging Locations

There are five agencies that operate within San Bernardino County with a total of eight facilities that can be used for charging. Three of the facilities are future sites (VVTA's Barstow facility and MT's intends to construct new facilities in both locations). Table 2-2 shows the agency and the associated facilities for base charging.

Table 2-2: Operator Facilities Locations for Base Charging

Operators	Facility	City
MBTA	Joshua Tree Yard	Joshua Tree, CA
MBTA	29 Palms Yard	Twentynine Palms, CA
MT	Crestline	Crestline, CA
NAT	Needles Garage	Needles, CA
Omnitrans	West Valley	Montclair, CA
Omnitrans	East Valley	San Bernardino, CA
VVTA	VVTA HQ – Hesperia Yard	Hesperia, CA
VVTA	Barstow Future Yard	Barstow, CA

Source: WSP

In addition to base-charging locations, eight locations were identified for potential on-route charging. Table 2-3 details the locations that can be used for on-route charging.

Table 2-3: Operator Locations for On-Route Charging

Agency Served	Facility	City
MBTA	Yucca Valley Transit Center	Yucca Valley, CA
MBTA	29 Palms Future Transit Center	Twentynine Palms, CA
Omnitrans	Fontana Metrolink Plaza	Fontana, CA
Omnitrans	Pomona Transit Center	Pomona, CA
Omnitrans	Yucaipa Transit Center	Yucaipa, CA
Omnitrans/VVTA/MT	San Bernardino Transit Center	San Bernardino, CA
Omnitrans	Kendall & Palm Park and Ride	San Bernardino, CA
VVTA/NAT	G Street at Broadway	Needles, CA
VVTA	Lorene Drive at 7th Street Station	Victorville, CA

Source: WSP

2.1.5 BEB Modeling Approach

Once the route and vehicle types were assigned to the vehicle block information, the kWh needed to operate the vehicles at the conservative, base, and optimistic efficiency scenarios was calculated for the two scenarios to determine if the service could be replaced with a 1:1 ratio (existing bus to BEB) and maintain existing service levels.

2.2 FCEB Model Methodology, Assumptions, and Inputs

This analysis sought to evaluate the performance of FCEBs in alignment with each bus block operating within the San Bernardino County. Using this information, calculations were made to determine the total amount of hydrogen required at each facility when operating a full FCEB fleet or a mixed fleet of FCEBs and BEBs. The analysis concludes with an overview of the bus blocks and facility which are the best candidates for FCEB adoption and recommendations for hydrogen sourcing.

2.2.1 Service and Performance

Service and performance of FCEBs operating in San Bernardino County began with a review of FCEB vehicle class availability and specifications followed by calculations to determine the anticipated vehicle range. A significant limitation to FCEB adoption for several agencies within San Bernardino County is the lack of several vehicle classes available on the market. Currently, the only FCEB cutaway available for purchase is still in development by ElDorado. Sunline Transit Agency recently made an advance procurement of one of these vehicles, however, there is no performance data available by Altoona or otherwise. Without the demand to justify production, FCEB coach buses also have not entered the development stage as of yet. Without any measured performance data for these vehicle classes, this analysis assumed the use of 40-foot FCEBs to represent cutaways and 60-foot FCEBs to represent coach buses. For the agencies operating vehicle classes that are currently unavailable as FCEBs, the representative vehicles in this analysis are used solely for purpose of estimated fleet hydrogen fuel consumption. It is not the recommendation of WSP to transition the fleet to alternative vehicle classes. With FCEB technology rapidly evolving, it is likely that a more diverse range of FCEB vehicle classes will become available in the near future.

The representative vehicles used in this analysis include the 40-foot New Flyer Xcelsior Charge H2 (XE40) and the 60-foot New Flyer Xcelsior Charge H2 (XE60). These vehicles were selected based on the maturity of the technology and the availability of Altoona test reports as well as documented vehicle performance provided by the National Renewable Energy Lab (NREL). The efficiencies used for performance evaluations were sourced from the 2018 Altoona vehicle demonstration reports (Table 2-4). Altoona measures vehicle efficiency in three degrees, often representing various travel patterns (i.e. arterial, commuter, or central business district). Throughout this analysis, these degrees of efficiency are referred to as optimistic, base, and conservative. Using the Altoona efficiencies and vehicle fuel tank capacity, the anticipated vehicle range was determined (Table 2-5). Though Altoona testing serves as an objective measure of vehicle performance through pilot tests conducted along various route-types, it does not fully capture the many variables that affect vehicle range, such as route grade and HVAC use. Historically, agencies operating FCEBs were reporting ranges below or near the base efficiency measures by Altoona (approximately 250 miles). For example, the Stark Area Regional Transit Authority (Stark County, Ohio) reported a measured range of 215 miles in contrast to the forecasted range of 250 miles, Alameda-Contra Costa Transit District (AC Transit) reported an average range of 266 miles, and the Orange County Transportation Authority (OCTA) typically assigns FCEBs only to blocks with less than 225 miles as a result of range issues. However, in a recent demonstration test of the New Flyer XE40, OCTA reported a measured range of 350 miles (50 miles above the most optimistic range estimation based on Altoona efficiencies). To account for this variability, this analysis evaluated FCEB performance for all three degrees of efficiency. It is recommended that each qualifying transit agency run demonstration pilots prior to FCEB acquisition to confirm results and refine planning.

The expected range of the FCEB vehicles used throughout this model was compared against the daily block distance for each block within San Bernardino County based on current GTFS data. For blocks with several variations, the longest block distance was used to evaluate performance in worst-case-scenarios.

Table 2-4: FCEB Vehicle Models and Efficiencies Based on Altoona Reports

Model	Commuter (mi/lb.) (Optimistic)	Central Business District (mi/lb.) (Base)	Arterial (mi/lb.) (Conservative)
New Flyer XE40	3.79	3.14	2.42
New Flyer XE60	3.37	2.16	1.78

Source: WSP

Table 2-5: FCEB Estimated Range based on Efficiency and Tank Capacity

Model	Commuter (mi) (Optimistic)	Central Business District (mi) (Base)	Arterial (mi) (Conservative)
New Flyer XE40	298	247	190
New Flyer XE60	435	279	230

Source: WSP

2.2.2 FCEB Fuel Consumption

The critical factors for determining fuel consumption for FCEBs is the fuel tank capacity, vehicle efficiency, and total block distance. The advertised fuel tank capacity was adjusted to account for the five percent safety buffer which is the current industry standard. The fuel tank for the 40-foot New Flyer has an advertised capacity of 37.5 kilograms (kg) with a usable tank capacity of 36 kg. The New Flyer XE60 has an advertised fuel tank capacity of 61.6 kg and a usable tank capacity of 59 kg. As noted earlier, the fuel efficiencies were determined during Altoona testing and represent vehicle performance on arterial routes, commuter routes, and within the central business district. The specifications for the FCEBs used in this analysis can be found in Table 2-6. Using vehicle efficiencies and total block distance, daily hydrogen fuel consumption at each facility was calculated to determine required on-site storage and/or on-site production needs.

Table 2-6: FCEB Representative Vehicle Specifications

OEM	Length (feet)	Advertised Fuel Tank Capacity (kg)	Usable Fuel Tank Capacity (kg)
New Flyer XE40	40	37.5	36
New Flyer XE60	60	61.6	59

Source: WSP

Fleet hydrogen fuel consumption in this analysis was calculated under three scenarios: Scenario 1- Hydrogen Fuel Consumption (kg) per Day for Full-Fleet FCEB Conversion; Scenario 2 - Hydrogen Fuel Consumption (kg) per Day for Qualifying Blocks; and Scenario 3 - Hydrogen Fuel Consumption (kg) per Day for BEB Non-Qualifying Blocks that can be served by FCEBs. Scenario 3 was adjusted slightly in the VVTA analysis to show the hydrogen needs based on the planned fleet mix.

Scenario 1 in this analysis demonstrates total hydrogen needs in the case that the transit agencies elect to transition the entire fleet network to FCEB. Scenario 1 does not take into consideration limitations to range or vehicle class availability, its primary purpose is to be used for future planning efforts (in the event that a wider range of vehicle classes enter the market and FCEB range improves). Alternatively, any agency committed to transitioning to FCEB may use these figures a as a baseline estimation of hydrogen needs. In any case, it is likely that a full FCEB conversion would require some service modifications such as mid-day fueling or driver relief. Scenario 2 provides estimation of fuel consumption with consideration to the limitations of range and vehicle availability. The results presented in this scenario highlight fuel consumption only for the blocks that are presently viable candidates for FCEB conversions. The final scenario, Scenario 3, assumes a BEB preferred adoption strategy and provides hydrogen fuel estimations only for the blocks that cannot be served by current BEB technologies and fall within the range limitations of FCEBs.

2.2.3 Space and Safety Requirements

The primary limiting factor for hydrogen feasibility from a facilities standpoint is adequate space and building ventilation. Many of the remaining safety considerations can be addressed during hydrogen integration. In this analysis, it was assumed that all future sites would comply with safety code, as requirements can be implemented during initial site design and planning. This analysis builds upon the accompanying Facilities Report to provide suggestions for hydrogen storage and placement within existing property lines as well as adjacent land (assuming the potential for land acquisition). In consideration of the feasibility of hydrogen delivery at each site (specifically those located in remote or high-altitude locations), the WSP team reached out to several hydrogen suppliers, recommendations based on these conversations will be provided throughout this document as they are received.

3 MORONGO BASIN TRANSIT AUTHORITY

3.1 Introduction

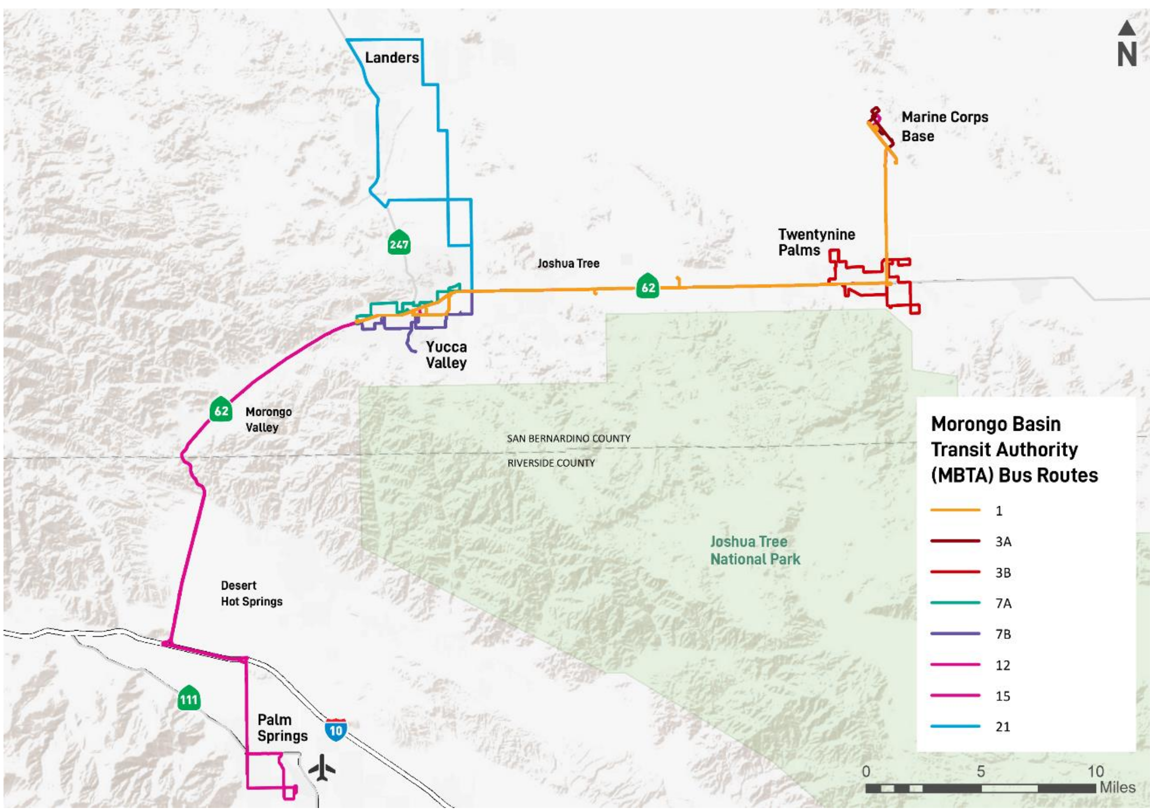
MBTA operates fixed-route bus transit services with headquarters in the unincorporated community of Joshua Tree. MBTA is a joint powers authority between the Town of Yucca Valley, the City of Twentynine Palms, and San Bernardino County.

3.2 Existing Conditions

3.2.1 Service Area and Environmental Factors

MBTA operates services in Yucca Valley, Twentynine Palms, Joshua Tree, and beyond, extending south to Palm Springs in neighboring Riverside County and north to the unincorporated community of Landers. Figure 3-1 shows MBTA's extent of service relative to its focus cities and Joshua Tree National Park. All of MBTA's service area is served by a single electric utility, SCE.

Figure 3-1: MBTA Service by Route



Source: WSP

Much of the Morongo Basin's residential and commercial development is along the State Route 62 corridor between Yucca Valley in the west and Twentynine Palms in the east. This development parallels the northern border of Joshua Tree National Park and is largely the service area for MBTA shuttle routes.

MBTA's service area is predominantly the High Desert region, with some service extending to Palm Springs in the Low Desert area. The area's summers are hot and dry with relatively cold winters. The average high temperatures in July are over 100 degrees, and average low temperatures in December through February are between 35 and 38 degrees. The region typically experiences snowfall in December (1.5-inch average) and January (0.5-inch average).

Given the immense shifts in temperature associated with the desert climate, power demand for HVAC systems is much more of a factor for MBTA's fleet. Because of the operational range issues of ZEB vehicles, as opposed to conventional diesel or hybrid buses, these temperature variances would likely reduce vehicle range in the summer and winter months. Thus, environmental conditions have a direct correlation on ZEB feasibility as a result of the operating conditions incurred by MBTA.

3.2.2 Schedule and Operations

MBTA runs three types of routes: neighborhood shuttles, intercity service, and longer-distance service to Palm Springs. MBTA's eight bus routes, shown on the map in Figure 3-1, include:

- 1 – Intercity service between Yucca Valley and Twentynine Palms Transit Center or Twentynine Palms Marine Corps Base
- 3A – Shuttle service between Twentynine Palms Transit Center and Twentynine Palms Marine Corps Base
- 3B – Neighborhood shuttle around Twentynine Palms
- 7A – Neighborhood shuttle around North Yucca Valley, servicing the Yucca Valley Transit Center and the Walmart Center
- 7B – Neighborhood shuttle around South Yucca Valley, servicing the Yucca Valley Transit Center and Walmart Center
- 12 – Long-distance service between Yucca Valley Transit Center and Palm Springs
- 15 – Long-distance service between Twentynine Palms Marine Corps Base and Palm Springs
- 21 – Shuttle service between Landers and Yucca Valley Transit Center

Copper Mountain College, located between the community of Joshua Tree and the City of Twentynine Palms, is a major destination served by Route 1. Copper Mountain College students can ride MBTA for a reduced fare of 50 cents per ride with a student ID.

MBTA's neighborhood shuttle routes run mostly between 18 and 24 miles in length, although Route 21 runs on a 48-mile loop; the intercity route runs between 27 and 43 miles; and the longer-distance routes run between 39 and 79 miles depending on point of origin relative to Palm Springs.

While most MBTA bus routes have designated fixed stops, in some areas there are no posted bus stops, and passengers may flag the driver to board. Deviations to the fixed route are also available to passengers who are unable to get to regular fixed stops by reserving at least one hour in advance. All routes will deviate up to 0.75 mile, except for Route 21, which will deviate up to 1.5 miles. These deviations add slight variability and unpredictability both to the length of runs and blocks and to the terrain over which the buses operate.

With the exception of routes 1 and 15, MBTA largely runs on a weekday-only schedule. Table 3-1 shows a more detailed view of MBTA's schedule by route, including the days each route operates, and the number of trips, span of service, and headways. Fares vary by route type: shuttle service standard fare is $1.25; intercity service standard fare is $2.50; and the long-distance routes vary by origin, from $5.00 to $20.00, with round-trip discounts offered. All fares are paid with cash or with pre-purchased passes.

Table 3-1: MBTA Summary of Service

Route	Length (mi.)	Days	Number of Trips	Span	Headways
1	27.3 –44.0	Monday–Friday Saturday Sunday	15 round trips 8 round trips 2 round trips	6:00 AM to 10:07 PM 7:15 AM to 9:49 PM 9:00 AM to 4:40 PM	Hourly until 5 PM Hourly until 3:45 PM 4:50
3A	23.7	Monday–Friday	11	7:00 AM to 5:50 PM	Hourly
3B	23	Monday–Friday	11	7:00 AM to 5:55 PM	Hourly
7A	18.8	Monday–Friday	11	7:00 AM to 5:50 PM	Hourly
7B	18.7	Monday–Friday	11	7:00 AM to 5:50 PM	Hourly
12	39.7 – 42.6	Monday–Thursday	3 round trips	7:00 AM to 6:40 PM	2:40 to 7:00
15	67.7 –78.8	Friday Saturday–Sunday	1 round trip 2 round trips	5:00 PM to 8:30 PM 10:00 AM to 7:35 PM	N/A 6:00
21	48	Monday–Friday	6	6:45 AM to 6:16 PM	1:15 to 2:40

Source: MBTA, 2019

3.2.3 Upcoming Capital Programs and Service Changes

MBTA is in the final review stages of their latest Short Range Transportation Plan (SRTP), due to be published in April 2020. Upon approval of the new plan, service changes may be recommended, as well as future planned capital projects.

3.2.4 Facilities

This section provides a summary understanding of each of MBTA's existing site and facility conditions. MBTA currently operates two bus and maintenance facilities, Joshua Tree and Twentynine Palms, and two transit centers in Yucca Valley and Twentynine Palms. The entire fleet is run on CNG. The following is a summary of the existing conditions. A more detailed catalog of the existing site condition is available in the report titled "Zero Emission Bus (ZEB) Analysis Facilities Inventory Report" issued January 2020.

3.2.4.1 Joshua Tree Yard

Joshua Tree Yard is located at 62405 Verbena Road, Joshua Tree, California, on approximately 17 acres of land (Figure 3-3). Table 3-2 describes the site consists of the facilities, equipment, and fleet.

Table 3-2: MBTA Joshua Tree Inventory

Fleet Overview	
Cutaway Bus[16]	20
30-foot Bus	-
35-foot Bus	4
40-foot Bus	-
45-foot Bus	-
60-foot Articulated Bus	
Total	**24**
Facilities	
Total Maintenance Bays	2
Paint Booths	-
CNG Fueling Positions	12 (2 fast-fill/10 time-fill)
CNG Compressor Yards	1
Diesel Fueling Positions	-
Unleaded Fueling Positions	-
Non-revenue Generating (NRV) Bays	-
Body shops	-
Bus Wash Lanes	1 (wash canopy)

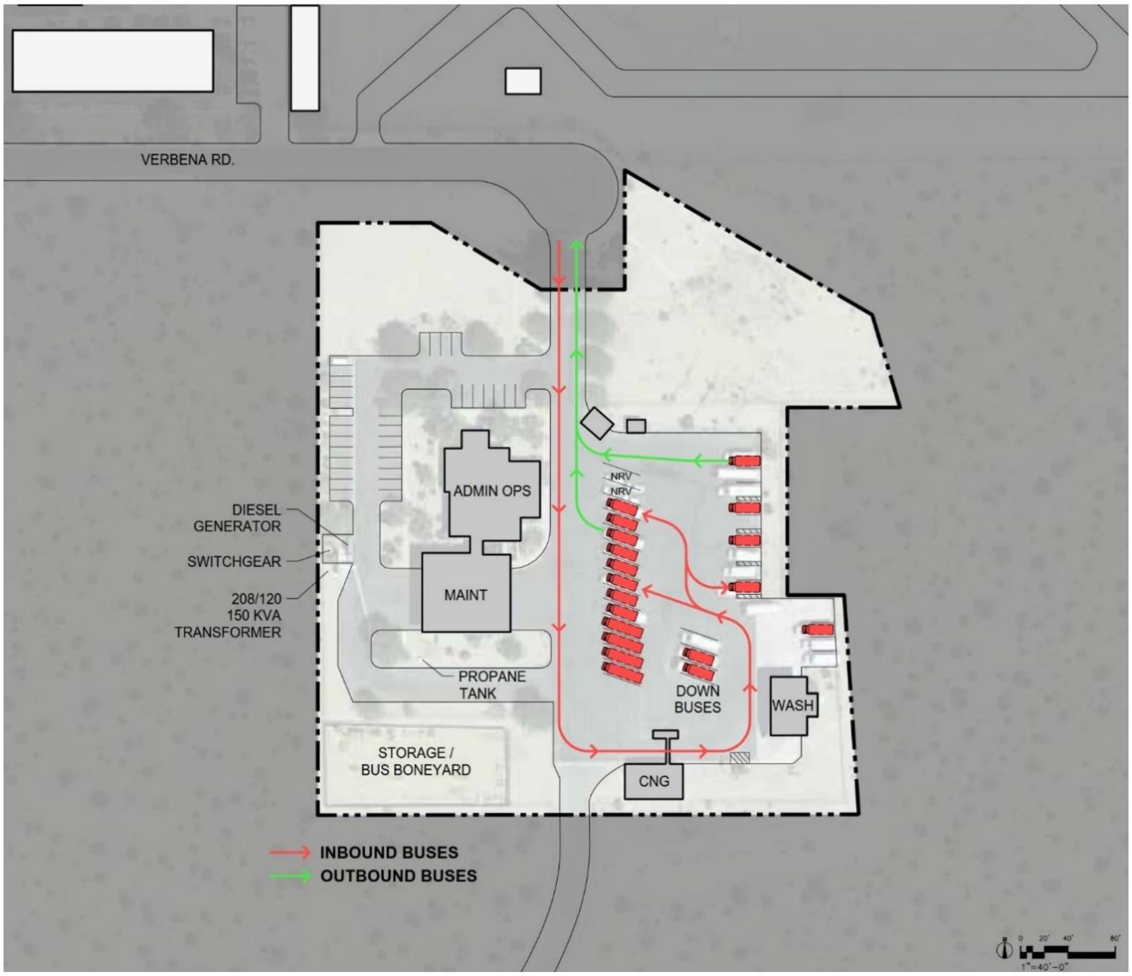
Source: WSP

[16] Cutaway bus lengths for MBTA range from 24.6 to 36 feet.

Figure 3-2: Joshua Tree Yard - Existing Conditions

Source: WSP

Figure 3-3: MBTA Joshua Tree Site Circulation



Source: WSP

Joshua Tree is powered by SCE. The facility power is fed via 12 kV underground power distribution. Joshua Tree's power distribution has been retrofitted recently to meet the upgraded demands of the facility. As a result, the old electric meter and transformer have been demolished and a new 150 kVA (12 kV-208/120 V) utility transformer, main switchboard (with 800 A main breaker), automatic transfer switch, and 250 kW standby generator have been installed in the yard near the staff parking lot. Consequently, the automatic transfer switch is feeding the old switchboard, which distributes power through the entire site. Power required for BEB charging (i.e., 480 V, 3-phase power) is not currently present on the site to support BEB charging infrastructure. Only existing 120 and 208 V service is currently available on-site.

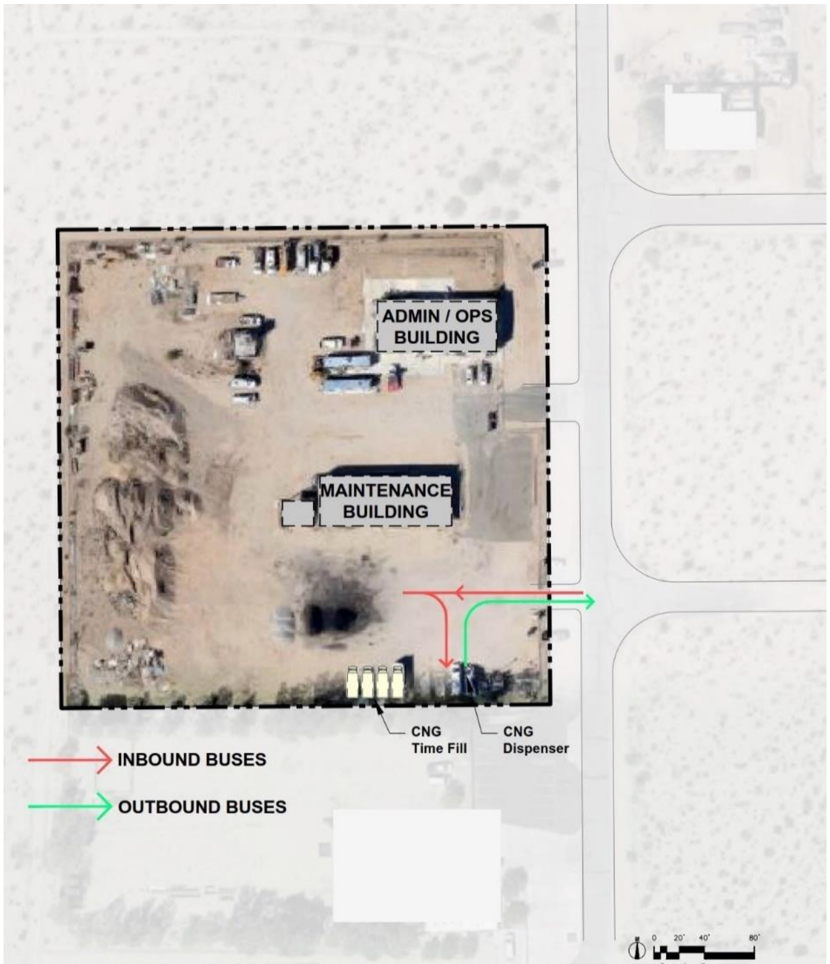
3.2.4.2 Twentynine Palms Yard

The Twentynine Palms Yard (Satellite Yard) is located at 6994 Bullion Avenue, Twentynine Palms, California, on approximately 0.4 acre of land (Figure 3-5). Table 3-3 describes the facilities, equipment, and fleet.

Figure 3-4: Twentynine Palms Yard - Existing Conditionss

Source: WSP

Figure 3-5: MBTA Twentynine Palms Yard Site Circulation Plan



Source: WSP

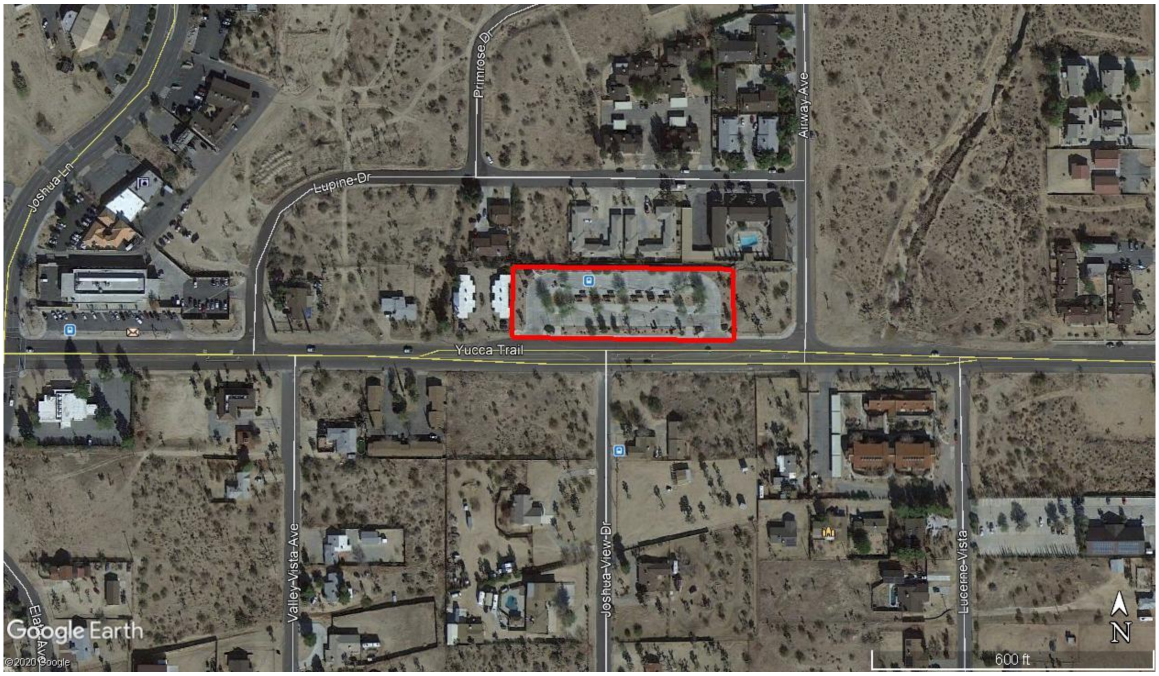
Table 3-3: MBTA Twentynine Palms Yard Inventory

Fleet Overview	
Cutaway Bus[17]	5
30-foot Bus	-
35-foot Bus	-
40-foot Bus	-
45-foot Bus	-
60-foot Articulated Bus	-
Total	**5**
Facilities	
Total Maintenance Bays	-
Paint Booths	-
CNG Fueling Positions	7 (1 fast-fill/6 time-fill)
CNG Compressor Yards	1
Diesel Fueling Positions	-
Unleaded Fueling Positions	-
NRV Bays	-
Body shops	-
Bus Wash Lanes	-

Source: WSP

[17] Cutaway bus lengths for MBTA range from 24.6 to 36 feet.

Figure 3-6: Yucca Valley Transit Center - Existing Conditionss



Source: WSP

The existing site's main electrical service is provided by SCE from pole-mounted transformers. Currently, there are two 3-phase 480/277 V pole-mounted meters with the 100 A & 200 A main breaker. The 200 A service is providing power to CNG fuel stations, while the other 100 A service distributes power to the rest of the electrical loads in the facility. The facility does not have any means of backup power.

3.2.4.3 Yucca Valley Transit Center

Yucca Valley Transit Center is located at 57430 Yucca Trail, Yucca Valley, California, on approximately 1.8 acres of land.

The existing site's main electrical service is provided by SCE from a 45 kVA 12 kV-208/120 V pad-mounted transformer. The electrical service supplying the transit center is sized appropriately for the amount of electrical load the transit center consumes; which is minuscule. The pad mounted meter contains a 200 A-208/120 V panel board that distributes power through the entire transit center.

3.3 ZEB Implementation

3.3.1 Technology

Based on MBTA's existing service needs and site configurations, WSP recommends implementing BEBs with ground mounted plug-in charging systems at the Joshua Tree and Twentynine Palms sites. The proposed full facility ZEB master plan layout is based on using a 150 kW DC charging cabinet in a 1:2 charging ratio (one DC charging cabinet energizes two separate plug-in cord dispensers). This charger to dispenser ratio would meet the requirements to power MBTA's fleet during the vehicles' servicing and dwell time on the site while minimizing the peak electrical demand for MBTA. For the

Yucca Valley Transit Center on route dispenser WSP proposes a 1:1 charger to dispenser setup utilizing a 450 kW plug-in charger with a liquid-cooled, plug-in dispenser.

For routes where modeling has identified that current BEB technology would not be capable of serving the routes, it is recommended that FCEBs be used and fueled either via future commercial/public hydrogen fueling stations located in either Twentynine Palms or Palm Springs or a purpose built MBTA containerized hydrogen storage and dispensing unit with pre-compressed hydrogen delivery on site.

The impacts of these recommendations for each site follow.

3.3.2 Analysis/Findings

MBTA provides transit service throughout the Morongo Basin to Yucca Valley, the Twentynine Palms community and Marine Base, Landers, and Palm Springs. In analyzing the GTFS and fleet data provided to WSP, MBTA utilizes around 30 vehicles to operate 14 vehicle blocks from two facilities. The shortest block travels 72 miles and the longest block travels 226 miles. As discussed in Sections 2.1.2 and 2.2, WSP analyzed base-only and base with on-route route charging at three different efficiencies (optimistic, base, and conservative) over three different types of service delivery options (local, express, rapid).

3.3.2.1 Joshua Tree Yard

Based on the recommended ground-mounted DC plug-in BEB charging solution, the Joshua Tree site is capable of parking a total of 29 buses with 26 total plug-in charging positions in a 1:2 charger to bus dispenser ratio.

Ground-mounted plug-in charging is proposed to be located in the following positions:

- Five charging cabinets with 10 plug-in dispenser charging positions along the northeastern yard pavement edge in the existing CNG slow fill area
- Two charging cabinets with four plug-in dispenser charging positions along the eastern site pavement edge in the parking space north of the wash canopy
- Six island-mounted charging cabinets with 12 plug-in dispenser charging positions in the existing angled yard parking in the center of the yard

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One MV utility service transformer in a new utility yard in the open space north of the existing parking yard and east of the site entrance
- One switchgear in a new utility yard in the open space north of the existing parking yard and east of the site entrance

WSP recommends that hydrogen fueling for the routes unable to be completed with BEBs be located in a new hydrogen fueling yard located on the southern portion of the site adjacent to the existing CNG yard if commercially available hydrogen fueling stations are not utilized. In addition, WSP recommends using a containerized hydrogen solution with hydrogen delivered pre-compressed to meet hydrogen fueling needs because the volume of hydrogen required does not justify the high infrastructure costs associated with on-site generation and/or compression.

Conceptual layouts for the proposed ZEB solutions for MBTA's facilities are present in Section 3.3.5.

3.3.2.1.1 Modeling Results

Base-Only Charging - Joshua Tree Yard

Currently, the Twentynine Palms Yard operates seven vehicle blocks. The smallest vehicle block distance traveled is 72 miles and the longest is 215 miles. As discussed in Section 2.1.2, a 118 kWh (94 kWh operating) battery was used to model the cutaway transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 118 kWh battery. Seventy-one percent of vehicle blocks could be completed at the optimistic efficiency, and 43 percent could be completed at the base and conservative efficiencies.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies for base-only charging, four vehicle blocks would need to be served by vehicles with an advertised battery capacity of around 250 kWh that also operate at the same kWh/mi as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 3-9 provides the summary of block completion for MBTA at the Twentynine Palms Yard, and Table 3-10: provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service at the conservative efficiency. Table 4-10 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 3-4: MBTA – Joshua Tree Base-Only Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	**94**	**71% (5)**	**43% (3)**	**14% (1)**
150	120	100% (7)	57% (4)	43% (3)
200	160	100% (7)	100% (7)	71% (5)
250	200	100% (7)	100% (7)	100% (7)

Source: WSP

Table 3-5: Summary of MBTA's Joshua Tree Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
1>116500	118	5.8	131	82	109	137
1>116501	118	5.8	131	82	109	137
1>116495	118	11.3	176	111	148	185
1>116496	118	11.3	182	114	152	191
1>116485	118	8.4	198	125	166	208
1>116486	118	9.2	226	142	189	237

Source: WSP

Base and On-Route Charging - Joshua Tree Yard

Currently, the Joshua Tree Yard operates seven vehicle blocks. The smallest block distance traveled is 74 miles and the longest is 226 miles. As discussed in Section 2.1.2, a 118-kWh (94-kWh operating) battery was used to model the cutaway transit vehicles with base and on-route charging.

The analysis found it would not be possible to complete all vehicle blocks with the 118-kWh battery. One hundred percent of vehicle blocks could be completed at the optimistic and base efficiencies, and 86 percent could be completed at the conservative efficiency.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies, one vehicle block would need to be served by vehicles with an advertised battery capacity between 119 and 200-kWh that also operate at the same kWh/mi efficiency as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 3-6 provides the summary of block completion percentage for MBTA at the Joshua Tree headquarters, and Table 3-7 provides a list of the current vehicle blocks that would not be able to complete 100 percent of service with the 118-kWh battery at the conservative efficiency. Table 3-7 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 3-6: MBTA – Joshua Tree Base and On-Route Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	100% (7)	100% (7)	86% (6)
150	120	100% (7)	100% (7)	86% (6)
200	160	100% (7)	100% (7)	100% (7)

Source: WSP

Table 3-7: Summary of MBTA's Joshua Tree Yard Base and On-Route Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
1>116486	118	9.2	226	109	146	182

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

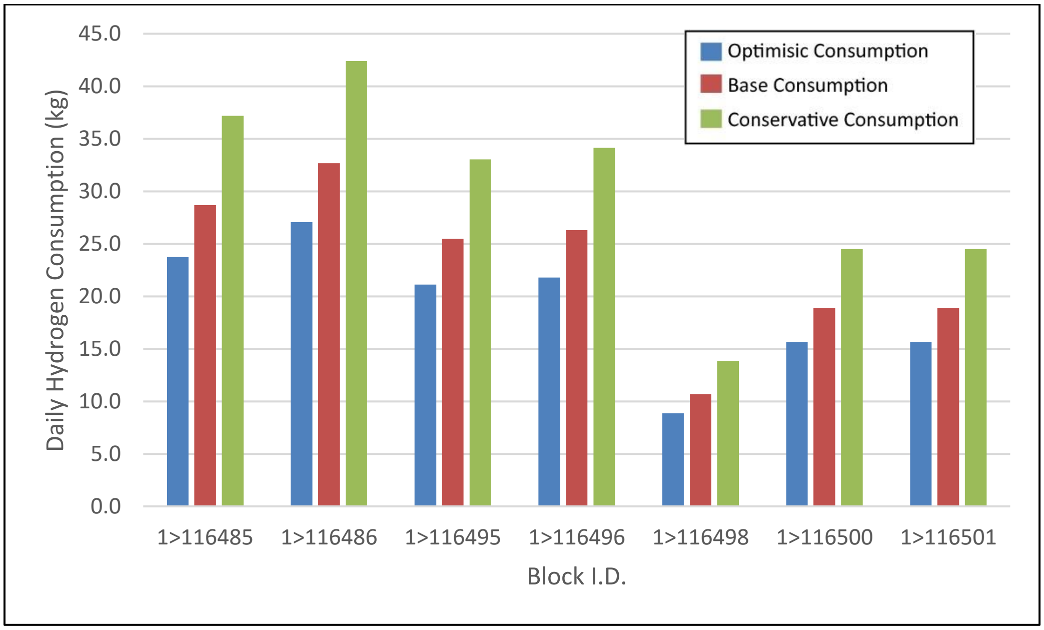
Without cutaway FCEB vehicles currently available on the market, Joshua Tree Yard does not qualify for FCEB adoption at this time.

Hydrogen Requirements

An analysis of anticipated fuel consumption for full-fleet FCEB conversions was conducted to support future planning efforts following the release of FCEB cutaways. This information may be used when considering future vehicle procurements and on-site hydrogen storage and production needs.

With only seven service blocks and daily mileage ranging between 74 miles and 226 miles, hydrogen consumption for vehicles operating out of Joshua Tree is reasonable for all methods of hydrogen production and delivery. Individual service blocks at Joshua Tree can be expected to consume between 8 kg and 42.4 kg of hydrogen per day with an average daily consumption of 24 kg (Figure 3-7). In total, the fleet operating out of Joshua Tree would require between 134 kg and 210 kg of hydrogen per day to operate a full FCEB fleet (Table 3-8).

Figure 3-7: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Joshua Tree



Source: WSP

Table 3-8: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Joshua Tree

Block ID	Block Distance	Existing Vehicle Type	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
116485	198.5	Cutaway	40	23.8	28.7	37.2
116486	226.2	Cutaway	40	27.1	32.7	42.4
116495	176.3	Cutaway	40	21.1	25.5	33.1
116496	182.1	Cutaway	40	21.8	26.3	34.1
116498	74.0	Cutaway	40	8.9	10.7	13.9
116500	130.7	Cutaway	40	15.6	18.9	24.5
116501	130.7	Cutaway	40	15.6	18.9	24.5
Total				**133.9**	**161.6**	**209.7**

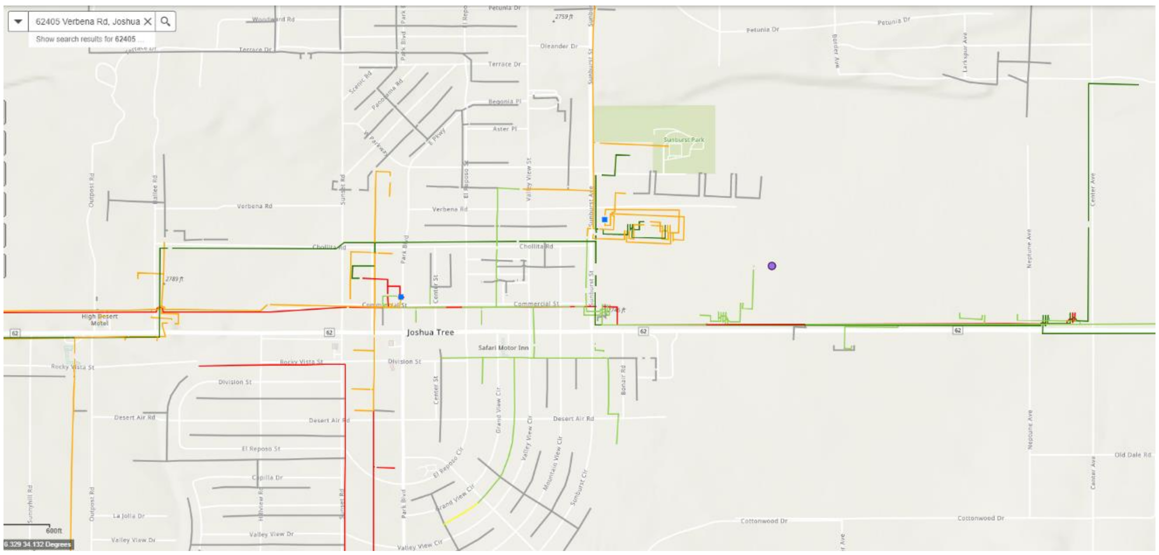
Source: WSP

3.3.2.1.2 Site Energy Analysis

The Joshua Tree facility is home to 26 buses maximum. Based on the recommended seven 150 kW ground-mounted DC plug-in charging solution, there will be 28 plug-in charging positions in a 1:4 charger to bus dispenser ratio. This will require new SCE service for 1050 kW.

According to SCE, the existing facility is served from the “Monument” circuit (Figure 3-8), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. Therefore, at full build out, the Joshua Tree facility would require ~12.5% of the circuit’s power. SCE requires a method of service (MOS) application and study for all new connections that take up more than 10 percent of the load on the circuit.

Figure 3-8: SCE Distribution Map of Joshua Tree Yard



Source: SCE

In short, it should be feasible to get this level of power service from SCE, but it would require a MOS request. This should be started immediately since the lead time for an MOS is a minimum of 18 months. There could also be options for using 60 kW chargers, which would charger slower but have a lower peak power.

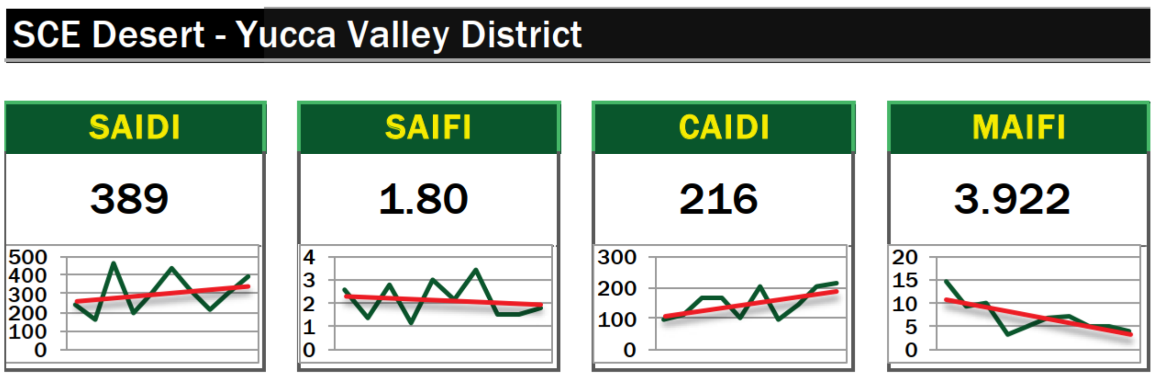
Using the current block scheme, the BEBs will require 560 - 940 kWh every day to support the seven blocks. The SCE EV-TOU rates don’t include any “demand charges”, so there is no incentive to “flatten the curve” of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9 pm. Therefore, MBTA should invest in good charge management software that avoids incurring big costs from charging during peak times.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One 1,750 kVA medium voltage utility service transformer in a new utility yard in the open space north of the existing parking yard and east of the site entrance.
- One 480V switchboard in the new utility yard.
- Underground conduits to ground mounted chargers.

From a resiliency perspective, all of the MBTA sites are located in SCE's Yucca Valley district. This district has one of the worst reliability metrics in the state of California. See Section 1.5.1.3 for more details about reliability of SCE's electric grid. WSP recommends that MBTA consider a diesel generator at this site to help improve reliability and redundancy. Figure 3-9 shows the reliability figure for Joshua Tree. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

Figure 3-9: Joshua Tree Yard (SCE Yucca Valley District) Energy Reliability Figures



Source: SCE

The 2015 SAIDI score of 389 minutes indicates that each customer was without power for an average of 389 minutes throughout the year. The SAIFI score of 1.8 indicates that most customers had less than 2 average outages per year, but it took nearly 4 hours to restore power (CAIDI). 1.8 outages * 216 minutes per outage = 389 total outage minutes. Finally, in 2015, Yucca Valley customers experienced 3.9 momentary outages, which will reset all chargers, unless they are provided with uninterrupted power supplies, which adds cost.

3.3.2.2 Twentynine Palms Yard

Based on the recommended ground-mounted DC plug-in BEB charging solution, the Twentynine Palms facility is capable of parking eight buses with eight total plug-in charging positions in a 1:2 charger to bus dispenser ratio.

Ground-mounted plug-in charging is proposed to be located in the following positions:

- Four charging cabinets with eight plug-in dispenser charging positions along the southern yard pavement edge in the existing CNG slow fill area

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One MV utility service transformer in a new utility yard in the open space north of the existing CNG yard and south of the eastern site entrance
- One switchgear utility service transformer in a new utility yard in the open space north of the existing CNG yard and south of the eastern site entrance

Hydrogen fueling is not recommended for this site due to the limited number of vehicles operating from the Twentynine Palms Yard.

Conceptual layouts for the proposed ZEB solutions for MBTA's facilities are presented in Figure 3-15.

3.3.2.2.1 Modeling Results

Base-Only Charging - Twentynine Palms Yard

Currently, the Twentynine Palms facility operates seven vehicle blocks. The smallest vehicle block distance traveled is 72 miles and the longest is 215 miles. As discussed in Section 2.1.2, a 118-kWh (94-kWh operating) battery was used to model the cutaway transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 118-kWh battery. Seventy-one percent of vehicle blocks could be completed at the optimistic efficiency, and 43 percent could be completed at the base and conservative efficiencies.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies for base-only charging, four vehicle blocks would need to be served by vehicles with an advertised battery capacity of around 250-kWh that also operate at the same kWh/mi as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 3-9 provides the summary of block completion for MBTA at the Twentynine Palms facility, and Table 3-10: provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service at the conservative efficiency. Table 4-10 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 3-9: MBTA – Twentynine Palms Base-Only Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	71% (5)	43% (3)	43% (3)
150	120	71% (5)	71% (5)	43% (3)
200	160	100% (7)	71% (5)	71% (5)
250	200	100% (7)	100% (7)	100% (7)
300	240	100% (7)	100% (7)	100% (7)

Source: WSP

Table 3-10: Summary of MBTA's Twentynine Palms Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
1>116490	118	7.1	125	79	105	131
1>116492	118	7.2	131	82	110	137
1>116487	118	8.2	196	123	165	206
1>116488	118	8.6	216	135	181	226

Source: WSP

Base and On-Route Charging - Twentynine Palms Yard

Currently, the Twentynine Palms facility operates seven vehicle blocks. The smallest vehicle block distance traveled is 72 miles and the longest is 215 miles. As discussed in Section 2.1.2, a 118-kWh (94-kWh operating) battery was used to model the cutaway transit vehicles with base and on-route charging.

The analysis found it would not be possible to complete all vehicle blocks with base and on-route charging with the 118-kWh battery. Although all vehicle blocks could be completed at the optimistic efficiency, only 86 percent could be completed at the base and conservative efficiencies.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies, one vehicle blocks would need to be served by vehicles with an advertised battery capacity of between 119 and 200-kWh that also operate at the same kWh/mi as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 3-11 provides the summary of block completion for base and on-route charging for MBTA at the Twentynine Palms facility, and Table 3-12 provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service at the battery capacity modeled. Table 3-12 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 3-11: MBTA – Twentynine Palms Base and On-Route Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	100% (7)	86% (6)	86% (6)
150	120	100% (7)	100% (7)	86% (6)
200	160	100% (7)	100% (7)	100% (7)

Source: WSP

Table 3-12: Summary of MBTA's Twentynine Palms Base and On-Route Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
1>116490	118	7.1	125	79	105	131
1>116492	118	7.2	131	82	110	137
1>116488	118	8.6	216	93	124	155

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

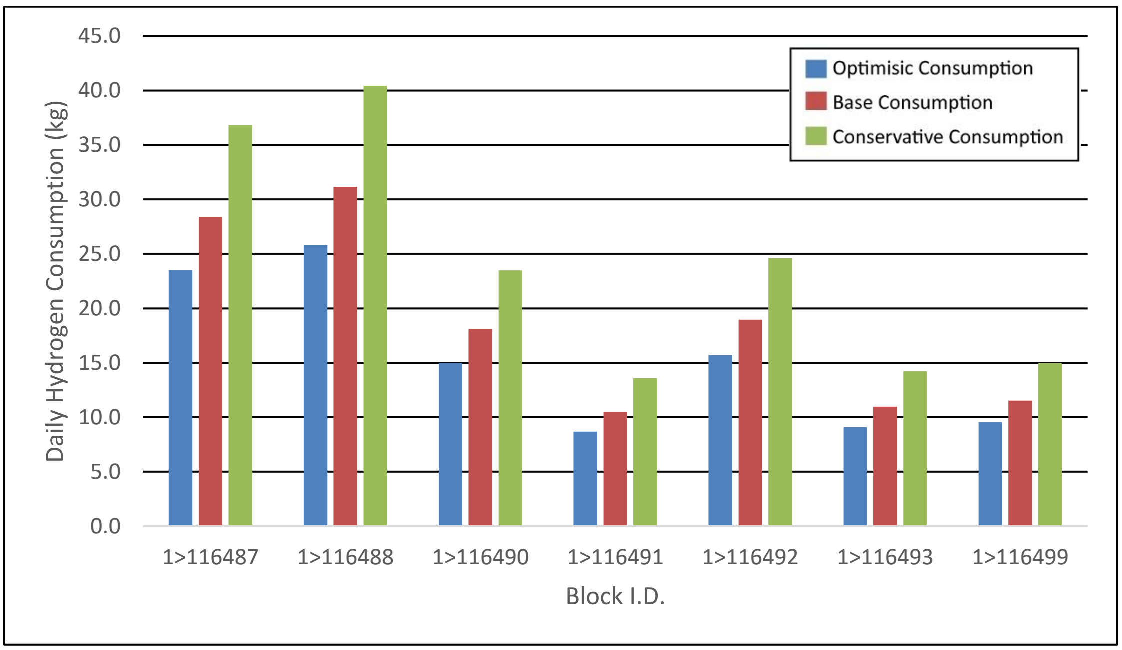
Without cutaway FCEB vehicles currently available on the market, Twentynine Palms Yard does not qualify for FCEB adoption at this time.

Hydrogen Requirements

An analysis of anticipated fuel consumption for full-fleet FCEB conversions was conducted to support future planning efforts following the release of FCEB cutaways. This information may be used when considering future vehicle procurements and on-site hydrogen storage and production needs.

Twentynine Palms Yard has a very similar service profile as Joshua Tree and yields similar results for hydrogen fuel consumption. The daily mileage per service block ranges between 72 miles and 215 miles. This translates to a daily hydrogen need ranging between 8 kg and 40 kg per service block with an average consumption of 21 kg (Figure 3-10). In total, the fleet at Twentynine Palms Yard would require between 107 kg and 168 kg of hydrogen a day (Table 3-13). This quantity could be reasonably be provided through on-site production via SMR or electrolysis as well as contracted delivery.

Figure 3-10: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Twentynine Palms



Source: WSP

Table 3-13: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Twentynine Palms

Block ID	Block Distance	Existing Vehicle Type	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
116487	196.4	Cutaway	40	23.5	28.4	36.8
116488	215.7	Cutaway	40	25.8	31.2	40.4
116490	125.3	Cutaway	40	15.0	18.1	23.5
116491	72.4	Cutaway	40	8.7	10.5	13.6
116492	131.2	Cutaway	40	15.7	19.0	24.6
116493	75.8	Cutaway	40	9.1	11.0	14.2
116499	79.9	Cutaway	40	9.6	11.5	15.0
Total				**107.3**	**129.6**	**168.1**

Source: WSP

3.3.2.2.2 Site Energy Analysis

The Twentynine Palms Yard is home to eight buses maximum. Based on the recommended four 150 kW ground-mounted DC plug-in charging solution, there will be eight plug-in charging positions in a 1:4 charger to bus dispenser ratio, and thus two 150 kW chargers. This will require new SCE service for 300 kW.

According to SCE, the existing facility is served from the "Smoke Tree" circuit (Figure 3-11), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. Therefore, at full build out, the Twentynine Palms facility would require ~3 percent of the circuit's power. SCE requires a MOS application and study for all new connections that take up more than 10 percent of the load on the circuit.

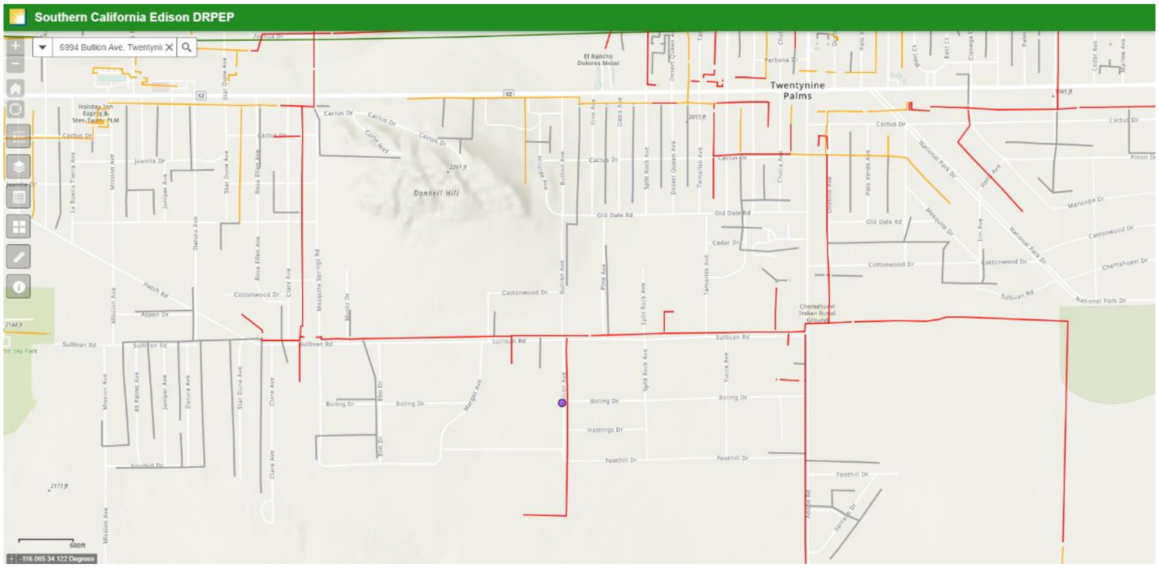
In short, it should be feasible to get this level of power service from SCE, even without an MOS. SCE indicated that the current transformer bank that serves the site is close to overloaded, but they should be able to provide this service with some minor work arounds.

Using the current block scheme, the BEBs will require 450 - 750 kWh every day to support the eight buses. The SCE EV-TOU rates don't include any "demand charges", so there is no incentive to "flatten the curve" of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9 pm. Therefore, MBTA should invest in good charge management software that avoids incurring big costs from charging during peak times.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformers in a new utility yard in the open space north of the existing parking yard and east of the site entrance.
- One 480V switchboard in the new utility yard.
- Underground or aboveground conduits to ground mounted chargers around the outside of the site.

Figure 3-11: SCE Distribution Map of Twentynine Palms Yard



Source: SCE

The EVSE could also be 60 kW chargers instead of 150 kW chargers. This would be a 1:2 charging ratio and would charge the vehicles slower and would not leave as much room for growth, but the total energy draw would be slightly less at 240 kW and the capital cost may be less.

From a resiliency perspective, all of the MBTA sites are located in SCE's Yucca Valley district. This district has one of the worst reliability metrics in the state of California. See Section 1.5.1.3 for more details about reliability of SCE's electric grid. WSP recommends that MBTA consider a back-up generator at this site to mitigate risks. Figure 3-9 shows the reliability figure for Yucca Valley District. More detailed numbers of the reliability metrics can be seen in Section 3.3.2.1.2.

3.3.2.3 On Route Charging Site Analysis

3.3.2.3.1 Yucca Valley Transit Center

Yucca Valley Transit center is the larger of MBTA's existing transit centers. The existing Twentynine Palms Transit Center is planned to be replaced. WSP recommends that MBTA add an on route charging position at the Yucca Valley Transit Center to serve the routes that require range extension.

An on route charging position is proposed for the following location:

- One ground-mounted 450 kW charging cabinet with a liquid-cooled, plug-in dispenser in a new bus layover position on the western side of the existing bus circulation and isolated from the public waiting areas

The ground-mounted plug-in charging system will be served by the following electrical infrastructure:

- One MV utility service transformer in a new utility yard adjacent to existing electrical yard on the northwest corner of the site
- One MV utility service transformer in a new utility yard adjacent to existing electrical yard on the northwest corner of the site.

No hydrogen fueling is recommended for this site because no existing fueling operations or infrastructure are in place and public access would be difficult to control.

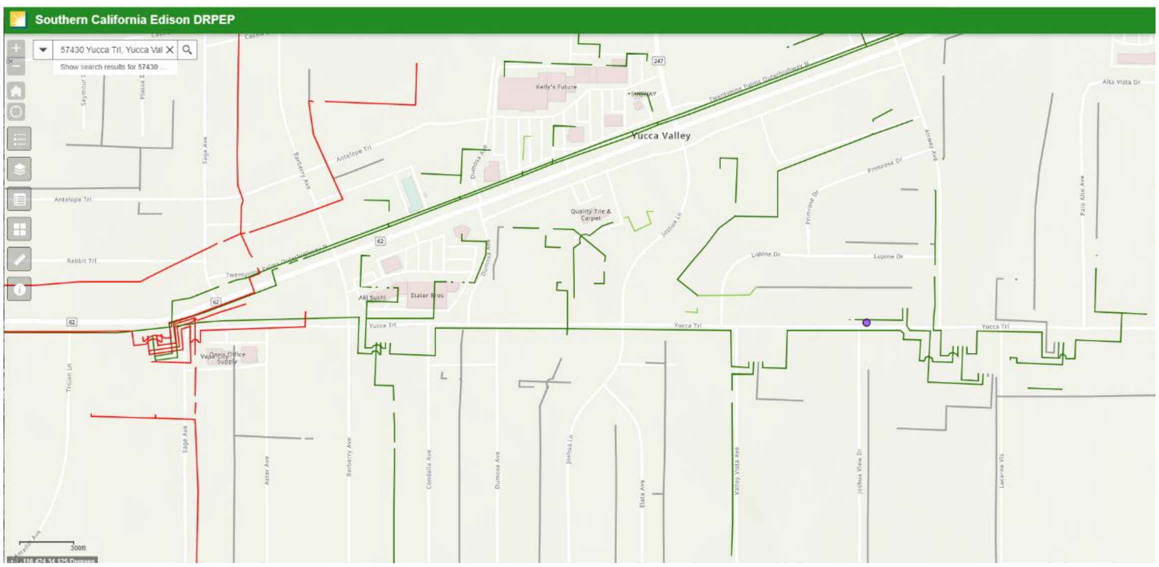
Conceptual layouts for the proposed ZEB solutions for MBTA's facilities are presented in Figure 3-15.

Site Energy Analysis

Yucca Valley Transit Center is a 1.8 acre site with very small electric service currently. WSP recommends one 150 kW ground-mounted DC plug-in charging solution, there can be two plug-in charging positions in a 1:2 charger to bus dispenser ratio. This will require new SCE service for 150 kW.

According to SCE, the existing facility is served from the "Onaga" circuit (Figure 3-12), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. It should be feasible to get this level of power service from SCE, even without an MOS. SCE already indicated that a switch is available to provide this service in the nearby vicinity.

Figure 3-12: SCE Distribution Map of Yucca Valley Transit Center



Source: SCE

The plug-in charging dispensers and charging cabinet will be served by the following electrical infrastructure:

- One 225 kVA medium voltage utility service transformers in a new utility yard in the open space north of the existing parking yard and east of the site entrance.
- One 480V switchboard in the new utility yard.
- Underground conduits to ground mounted charger.

From a resiliency perspective, all of the MBTA sites are located in SCE's Yucca Valley district. This district has one of the worst reliability metrics in the state of California. See Section 1.5.1.3 for more details about reliability of SCE's electric grid. WSP recommends that MBTA consider a diesel generator at this site to help improve reliability and redundancy. However, based on the reliability metrics, it may be more cost-effective for an operational solution rather than an infrastructure solution to count for on route charging outages. A spare bus could be deployed to help cover low range buses mid-block instead of installing a Diesel generator at sites where on route charging is not as important to maintaining service for the duration of the power outage. Figure 3-9 shows the reliability figure for Yucca Valley District. More detailed numbers of the reliability metrics can be seen in Section 3.3.2.1.2.

3.3.2.3.2 Twentynine Palms Future Transit Center

The planned future Twentynine Palms Transit Center is located at 73455 Twentynine Palms Highway, Twentynine Palms, CA 92277 (refer to Figure 3-13).

Figure 3-13: Twentynine Palms Future Transit Center - Existing conditions

Source: Google Earth, March 2020

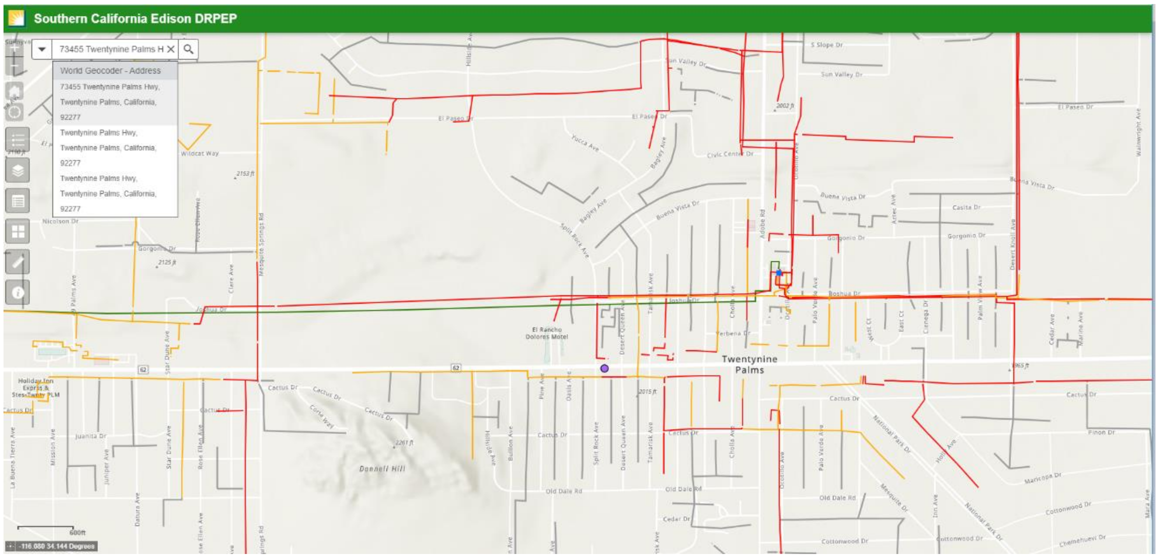
The planned future Twentynine Palms Transit Center can be built with one 150 kW ground-mounted DC plug-in charging solution. This will require new SCE service for 150 kW.

According to SCE, the existing facility is served from the "Old Dale" circuit (Figure 3-14), which delivers power rated at 4.8 kV. A rule of thumb is that a 4.8 kV circuit can hold around 2.8 MW of power. It should be feasible to get new 150 kW service from SCE, even without an MOS. SCE already indicated that a switch is available to provide this service in the nearby vicinity. While this circuit has the capacity, SCE is not performing new connections to 4kV circuits, so pulling a connection from a nearby 12kV circuit may need to be performed.

The plug-in charging dispensers and charging cabinet will be served by the following electrical infrastructure:

- One 225 kVA medium voltage utility service transformers in a new utility yard in the open space north of the existing parking yard and east of the site entrance.
- One 480V switchboard in the new utility yard.
- Underground conduits to ground mounted charger.

Figure 3-14: SCE Distribution Map Future Twentynine Palms Transit Center



Source: SCE

From a resiliency perspective, all of the MBTA sites are located in SCE's Yucca Valley district. This district has one of the worst reliability metrics in the state of California. See Section 1.5.1.3 for more details about reliability of SCE's electric grid. WSP recommends that MBTA consider a diesel generator at this site to help improve reliability and redundancy. However, based on the reliability metrics, it may be more cost-effective for an operational solution rather than an infrastructure solution to count for on route charging outages. A spare bus could be deployed to help cover low range buses mid-block instead of installing a Diesel generator at sites where on route charging is not as important to maintaining service for the duration of the power outage. Figure 3-9 shows the reliability figure for Yucca Valley District. More detailed numbers of the reliability metrics can be seen in Section 3.3.2.1.2.

3.3.3 ZEB Procurement Schedule

In accordance with the ICT regulation, MBTA will prioritize ZEB purchases and progressively increase the percentage of ZEB purchases over time. Based on initial analysis, the last conventional bus is expected to be purchased in 2027. All new buses purchases are anticipated to be ZEB starting in 2029.

Early retirement should not be an issue pursuant to the ICT regulation based on MBTA's assumed procurement schedule. However, if it becomes one, MBTA will deploy a number of strategies to ensure that buses fulfill their "useful life." One potential strategy is to place newly acquired buses on MBTA's longest (distance) blocks of service. This will ensure that these buses meet their distance-based useful life requirement more rapidly.

MBTA's existing fleet consists of 24 cutaway buses. Assuming a 1:1 replacement ratio, each existing bus will eventually be replaced with a BEB cutaway bus (of similar size). However, the number of ZEBs required may increase based on service requirements.

Table 3-14 presents a summary of MBTA's anticipated bus procurements through 2040. Years 2026 and 2029 are highlighted because these indicate when MBTA's new purchases should be 25 percent and 100 percent ZEBs, respectively.

Table 3-14: Summary of MBTA's Future Bus Purchases (through 2040)

Year	Total Buses	Zero-Emission Buses				Conventional (CNG) Buses			
		Number	Pct.	Bus Type	Fuel Type	Number	Pct.	Bus Type	Fuel Type
2020	1	0	0%	-	-	1	100%	Cutaway	Diesel
2021	4	0	0%	-	-	4	100%	Cutaway	Diesel
2022	3	0	0%	-	-	3	100%	Cutaway	Diesel
2023	5	0	0%	-	-	5	100%	Cutaway	Diesel
2024	4	0	0%	-	-	4	100%	Cutaway	Diesel
2025	6	0	0%	-	-	6	100%	Cutaway	Diesel
2026	1	1	100%	Cutaway	BEB	0	0%	-	-
2027	2	1	50%	Cutaway	BEB	1	50%	Cutaway	Diesel
2028	0	0	0%	-	-	0	0%	-	-
2029	3	3	100%	Cutaway	BEB	0	0%	-	-
2030	11	11	100%	Cutaway	BEB	0	0%	-	-
2031	8	8	100%	Cutaway	BEB	0	0%	-	-
2032	0	0	100%	-	-	0	0%	-	-
2033	0	0	100%	-	-	0	0%	-	-
2034	1	1	100%	Cutaway	BEB	0	0%	-	-
2035	6	6	100%	Cutaway	BEB	0	0%	-	-
2036	4	4	100%	Cutaway	BEB	0	0%	-	-
2037	6	6	100%	Cutaway	BEB	0	0%	-	-
2038	4	4	100%	Cutaway	BEB	0	0%	-	-
2039	0	0	100%	-	-	0	0%	-	-
2040	6	6	100%	Cutaway	BEB	0	0%	-	-

Note: All new purchases were assumed to have a useful life of five, seven, and 10 years per FTA Circular 9030.1D, Ch. VI, paragraph 4.a

Source: WSP, February 2020

3.3.4 Morongo Basin Transit Authority Cost Analysis

This analysis should be considered a conservative assessment of battery bus costs, as the industry in North America is in the preliminary stages of product development. Production costs are anticipated to decrease as production increases to meet future demand.

3.3.4.1 Battery Electric Buses – General Assumptions

The WSP team is actively engaged with electric vehicle manufacturers to understand trends in the industry and VVTA, the only county operator currently operating BEBs, to inform assumptions vehicle operations. The values presented throughout this document are subject to change and based on the best available information at the time of this analysis.

Compared to conventional diesel, gasoline and natural gas fueled vehicles, electric vehicles incur different capital and operating costs that vary based on the type of vehicles and operating environments. For example, the cost of installation and maintenance of charging infrastructure will differ in both magnitude and the types of resources required in comparison to the replacement and maintenance of a diesel fueling facility. Other examples include battery replacement schedules, mid-life overhaul, and disposal value.

Electric buses and garages may offer the opportunity to lower some operations and maintenance costs while increase others and similar to conventional fueled vehicles are highly dependent on the size and complexity of the vehicle fleet being supported. Additionally, an electrification strategy would entail replacing Compressed Natural Gas (CNG) with electric power, which would incur very different energy pricing structures and exposure to energy price volatility. Table 3-15 outlines the major cost categories associated with bus electrification. Estimated costs in each of these categories were developed for electrification scenarios, as well as a "business as usual" baseline which assumes no change in the current types of vehicles in the fleet.

The total cost of each operator's transition will be contingent upon their specific fleet size, bus acquisition plan, facility sizes, charging strategy, and construction schedule, among other details.

Table 3-15: Cost Components Attributed to Electric Bus Operations

Capital	Vehicle and Equipment Purchase
	Training, Capital Spares & Contingency
	Charging Infrastructure
	Mid-Life Fleet Overhaul
	Battery Replacement
Operating	Vehicle Maintenance
	Vehicle Tools, Training and Equipment
	Vehicle Energy Costs
	Charger Maintenance
	Fueling/Charging Labor
Disposal	Battery Disposal/Salvage
	Bus Salvage

Source: WSP

3.3.4.1.1 BEB Vehicle Costs

Battery electric vehicle procurement costs continue to evolve as new vehicle models are developed and production increased to meet demand. Anticipated cost reductions through economies of scale may be somewhat offset by discounted prices that may be offered by some manufacturers to establish market share, specifically new entrants to the market. Furthermore, battery technology and production continue to evolve offering further potential reductions to production costs but also potential exposure to volatility in the pricing structures for critical battery production inputs. Additional considerations also need to be considered for specific agency requirements and features, delivery schedule requirements, and battery size requirements to meet operating conditions. Assumptions regarding procurement costs for BEBs as compared to MBTA's CNG buses are provided in Table 3-16 below:

Table 3-16: Vehicle Cost Assumptions

Vehicle Type	Vehicle Cost Estimates ($2019)
Battery electric 25.3 ft	$223,608
Battery electric 26 ft	$295,306
Battery electric 27 ft	$258,100
Battery electric 32 ft	$252,066
Battery electric 33 ft	$261,081
Battery electric 35 ft	$904,490
Battery electric 36 ft	$904,490
CNG 25.3 ft	$123,608
CNG 26 ft	$195,306
CNG 27 ft	$158,100
CNG 32 ft	$152,065[18]
CNG 33 ft	$161,078
CNG 35 ft	$521,195
CNG 36 ft	$397,531

Source: WSP

Conventional CNG bus acquisition costs ranged from $123,608-$397,531 for cutaway vehicles ranging in size between 25.3 feet to 36 feet and are based on information provided by current cutaway vehicle manufacturers. The cost assumptions for battery electric vehicles are based on information from the California Air Resources Board (CARB), which determined that the incremental cost of zero-emissions cutaway vehicles is approximately $100,000 as compared to CNG vehicles.

3.3.4.1.2 Charging Infrastructure Costs

Charging infrastructure cost estimates include equipment, design and installation costs which primarily consist of materials and labor. The cost estimates also include general contractors and subcontractor's markups which are comprised of field overhead, home office overhead, and subcontractor earnings. The estimates also include a pricing contingency markup, to allow for unexpected design and installation Issues.

Plug-in chargers are assumed to cost $70,701, based on a recent VVTA contract.[19] Additionally, the cost to install chargers, including labor and permits, is assumed to be $8,500 per charger. On-route opportunity chargers are assumed to cost $330,000 for both the charger and installation, based on the experience of Foothill Transit. With the recommended ground-mounted plug-in charging strategy, the Joshua Tree Yard would be capable of parking 29 buses with 26 plug-in charging positions (13 chargers), and the Twentynine Palms Yard capable of accommodating 8 buses with 8 plug-in positions (4 chargers), in a 1:2 charger to bus dispenser ratio. The financial analysis assumes that plug-in chargers would be purchased in the year that buses are ordered,

[18] Average between four of MBTA's historic 32' bus purchases ($148,466; $158,100; $156,098; $145,597).

[19] VVTA New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6, 2018.

when the cost of purchasing the charger would be incurred, and the cost of installing the plug-in charger would be incurred in the year of vehicle delivery, which is assumed to be one year after the bus order. As such, the exact year and number of plug-in chargers purchased correleates with the fleet procurment plan, presented in Section 3.3.4.2.2. En-route chargers include one at Yucca Valley Transit Center and one at the 29 Palms New Transit Center.

The analysis did not include on-site stationary battery energy storage for resiliency. If MBTA elects to include a generator for resiliency of their battery electric buses, a generator at Twentnine Palms Yard is estimated to cost $421,500 based on a full load of 300 kW, and a generator at Joshua Tree Yard is estimated to cost $1,475,250 based on a full load of 1,050 kW.

3.3.4.1.3 Mid-life Overhaul and Battery Replacement

At the half-year point of each vehicle's operational life, a full vehicle overhaul, is assumed on all vehicles. MBTA's historical data shows $25,000 is incurred on a fleet of 24 vehicles. This translates to a per vehicle cost of approximately $1,042.

The analysis assumes that MBTA's battery electric vehicles will include battery warranties, and as such, battery replacement costs are not assumed to be incurred by MBTA.[20] Battery replacements on the CNG fleets are assumed to be minimal and part of existing maintenance costs.

3.3.4.1.4 Tire Replacement Cost

The analysis assumes that MBTA Vehicles undergo regular tire replacements, which have a contribution to costs. Specifically, MBTA spends about $3,500 on tire replacements every 25-30 thousand miles, for their 36-foot vehicles; $2,300 every 20-23 thousand miles, for their 32 and 33-foot vehicles; and $1,500 every 20-23 thousand miles, for their 28-foot vehicles. WSP assumed the costs provided for tire replacements on 28-foot vehicles also apply to 27, 26, and 25.3-foot vehicles.

3.3.4.1.5 Operations and Maintenance Costs

Components of O&M costs include vehicle maintenance, vehicle tools, training and PPEs, vehicle fuel costs, and the costs to maintain and operate charging and fueling infrastructure. Annual O&M cost assumptions for battery electric vehicles are outlined in Table 3-17, represented in a cost per mile.

The analysis applies unit O&M cost per mile by vehicle type with total costs based on assumed average annual vehicle mileage. The model accounts for changes to service levels based on range restrictions for electric vehicles to estimate O&M costs, by applying unit costs to total mileage as driven by number of vehicles and mileage per vehicle.

[20] If the bus purchases or leases will not include a warranty, a battery replacement cost may be estimated at approximately, $7 per pound, and assumed to weigh approximately 500 pounds, based on similar transit agencies. The model can be easily updated to assume this.

Table 3-17: Battery Electric Maintenance Costs by Vehicle Age ($2019 per mile)

Vehicle Age	25.3’	26’	27’	32’	33’	35’	36’
Year 1	0.27	0.31	0.31	0.32	0.34	0.34	0.34
Year 2	0.24	0.27	0.27	0.28	0.30	0.30	0.30
Year 3	0.24	0.27	0.27	0.29	0.30	0.30	0.30
Year 4	0.28	0.32	0.32	0.33	0.35	0.35	0.35
Year 5	0.33	0.38	0.38	0.40	0.42	0.42	0.42
Year 6	0.37	0.42	0.42	0.44	0.46	0.46	0.46
Year 7	0.41	0.47	0.47	0.49	0.52	0.52	0.52
Year 8	0.47	0.53	0.53	0.56	0.59	0.59	0.59
Year 9	0.54	0.61	0.61	0.65	0.68	0.68	0.68
Year 10	0.63	0.71	0.71	0.75	0.79	0.79	0.79
Year 11	0.74	0.84	0.84	0.88	0.93	0.93	0.93
Year 12	0.88	0.99	0.99	1.05	1.10	1.10	1.10
Year 13	0.41	0.46	0.46	0.48	0.51	0.51	0.51
Year 14	0.45	0.50	0.50	0.53	0.56	0.56	0.56

Source: WSP

3.3.4.1.6 Energy Costs

Electricity prices for battery electric vehicles are based on current rates with Southern California Edison (SCE) and reflect charge rates and demand for energy consumption that vary by hour and month.

Total annual energy costs are estimated for each operator and facility and are highly driven by charging strategy with respect to location of on route chargers if any, facilities, vehicle routes, and fleet size purchase. These charging strategies are subject to change as the team works to refine each agency’s optimal charging strategy, and as charging rates change. This analysis does not assume any major behavioral changes based on coach operators.

Table 3-18 presents Southern California Edison Rates and Table 3-19 presents the hours during which each rate would be applicable.

Table 3-18: Rates per kWh

Rates (per kWh)		
Time of Use Period	Summer (June-September)	Winter (October-May)
On-Peak	$0.41	
Mid-Peak	$0.20	$0.24
Off-Peak	$0.10	$0.10
Super Off-Peak		$0.06

Source: Southern California Edison

Table 3-19: Time Periods

Time Periods (weekdays excluding holidays)				
	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	16:00-21:00	N/A	N/A	N/A
Mid-Peak	N/A	16:00-21:00	16:00-21:00	16:00-21:00
Off-Peak	All other hours	21:00-08:00	All other hours	21:00-08:00
Super Off-Peak	N/A	08:00-16:00	N/A	08:00-16:00

Source: Southern California Edison

The rates in Table 3-18 and Table 3-19 above were applied to the hourly times during which the operators are expected to be charging. The energy use assumed for each operator, in a moderate charging scenario, is presented in Table 3-20. The model is capable of running additional scenarios to cost the low charging and high charging scenario as well.

Table 3-20: Hourly Energy use (kWh) – Moderate Scenario

Facility ID	Facility	Operator	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
1000001	Joshua Tree Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	-
1000002	29 Palms Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	50
1000003	Crestline Future Site	MT	-	-	-	-	-	-	-	-	-	-	-	78
1000009	Big Bear Lake	MT	-	-	-	-	-	-	-	-	-	15	50	-
1000004	West Valley	Omnitrans	5,300	4,788	3,633	2,415	1,203	350	80	-	128	80	-	-
1000005	East Valley	Omnitrans	11,488	9,843	7,523	4,808	2,040	688	373	168	130	433	735	553
1000006	VVTA HQ - Hesperia Yard	VVTA	3,988	3,810	2,668	1,845	1,335	688	480	155	305	405	308	423
1000007	Barstow Future Yard	VVTA	945	660	600	600	525	173	110	220	295	300	215	-
1000008	Needles Garage	Needles	-	-	-	-	-	-	-	-	-	-	-	-

Source: WSP

Table 3-20: Hourly Energy use (kWh) – Moderate Scenario (continued)

Facility ID	Facility	Operator	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1000001	Joshua Tree Yard	MBTA	88	-	133	-	-	-	320	58	-	-	13	140
1000002	29 Palms Yard	MBTA	-	10	208	-	-	5	130	-	10	43	80	65
1000003	Crestline	MT	15	-	-	-	-	75	15	143	180	28	83	3
1000009	Big Bear Lake	MT	-	-	65	-	-	78	-	95	150	3	-	-
1000004	West Valley	Omnitrans	-	-	-	20	75	-	148	808	1,950	3,615	5,313	5,918
1000005	East Valley	Omnitrans	258	308	533	508	273	48	195	2,493	5,723	8,355	11,143	12,978
1000006	VVTA HQ - Hesperia Yard	VVTA	183	55	-	-	265	815	1,475	1,800	1,630	3,563	4,720	4,075
1000007	Barstow Future Yard	VVTA	-	-	-	-	-	23	150	265	958	1,470	1,370	1,080
1000008	Needles Garage	Needles	-	-	-	-	-	-	8	103	-	-	-	-

Source: WSP

Table 3-21 and Table 3-22 outline the two MBTA facilities resulting costs, based on the hourly SCE rates and the hourly charging strategy, as well as the total resulting annual cost per bus.

Table 3-21: Total Annual Cost Per Bus - MBTA, Twentynine Palms Yard

Months	Days per month	11:00	13:00	14:00	17:00	18:00	20:00	21:00	22:00	23:00
January	31	100.64	20.13	417.66	36.58	951.20	73.17	310.97	256.01	208.01
February	28	90.90	18.18	377.24	33.04	859.15	66.09	280.88	231.24	187.88
March	31	100.64	20.13	417.66	36.58	951.20	73.17	310.97	256.01	208.01
April	30	97.40	19.48	404.19	35.40	920.52	70.81	300.94	247.75	201.30
May	31	100.64	20.13	417.66	36.58	951.20	73.17	310.97	256.01	208.01
June	30	147.81	29.56	613.41	61.34	1,594.75	122.67	521.36	236.50	192.15
July	31	152.74	30.55	633.86	63.38	1,647.91	126.76	538.74	244.38	198.56
August	31	152.74	30.55	633.86	63.38	1,647.91	126.76	538.74	244.38	198.56
September	30	147.81	29.56	613.41	61.34	1,594.75	122.67	521.36	236.50	192.15
October	31	100.64	20.13	417.66	36.58	951.20	73.17	310.97	256.01	208.01
November	30	97.40	19.48	404.19	35.40	920.52	70.81	300.94	247.75	201.30
December	31	100.64	20.13	417.66	36.58	951.20	73.17	310.97	256.01	208.01
Total	365	1,390	278	5,768	536	13,942	1,072	4,558	2,969	2,412
									Total Annual Cost	**$32,925**
									Buses at Garage	**6**
									Total Annual Cost Per Bus	**$5,487**

Source: WSP

Table 3-22: Total Annual Cost Per Bus - MBTA, Joshua Tree Yard

Months	Days per month	12:00	14:00	18:00	19:00	22:00	23:00
January	31	176	267	2,341	421	40	448
February	28	159	241	2,115	380	36	405
March	31	176	267	2,341	421	40	448
April	30	170	258	2,266	407	39	434
May	31	176	267	2,341	421	40	448
June	30	259	392	3,926	705	37	414
July	31	267	405	4,056	729	38	428
August	31	267	405	4,056	729	38	428
September	30	259	392	3,926	705	37	414
October	31	176	267	2,341	421	40	448
November	30	170	258	2,266	407	39	434
December	31	176	267	2,341	421	40	448
Total	365	2,432	3,683	34,318	6,166	464	5,195
						Total Annual Cost	**$5,529**
						Buses at Garage	**18**
						Total Annual Cost Per Bus	**$2,903**

Source: WSP

3.3.4.1.7 Environmental Costs

Environmental costs are considered non-cash expenses and include monetized values for tailpipe emissions and upstream emissions of CO2, criteria pollutants, and noise. The analysis does not assume tailpipe emissions for battery electric vehicles and includes estimates of tailpipe emissions for CNG gas vehicles, for comparative purposes. Tailpipe emissions include estimates of CO_2, NO_X, CO, PM_{10}, PM $_{2.5}$. At this time, the non-cash component of the analysis continues to be refined and will be included in the next iteration of the analysis. Emissions data was taken from the U.S. Department of Energy's Greet Fleet Calculator tool.

Upstream emissions consist of emissions resulting from the production of CNG, and production of electricity for BEBs based on the mix of utility power sources.

3.3.4.1.8 General - Inflation

The model accounts for inflation using the Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U)[21].

Table 3-23: Consumer Price Index

CPI-U	2019	2020	2021	2022	2023
Riverside & San Bernardino	2.87%	3.24%	2.96%	3.10%	3.03%

Source: WSP

3.3.4.2 Scenario Analysis

3.3.4.2.1 Cost Overview

Background

Analysis was conducted to compare an electrification scenario for MBTA with a "business as usual" scenario which assumes that all future procurements maintain the current MBTA's practice of procuring CNG vehicles (referred to as Scenario 1 Baseline CNG). Given CARB's mandate of conversion by 2040, the business as usual scenario is a theoretical scenario for comparative benefit-cost assessment purposes.

The analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs, plus a non-cash cost of environmental benefits and costs, which WSP staff monetizes to account for a holistic comparative between cost and benefit.

Table 3-24 delineates the overall results of the MBTA analysis, assessing the full battery electric vehicle conversion and the baseline scenario. Values presented throughout this document are subject to change as updated costs are uncovered.

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[21] Source, California Department of Finance: http://www.dof.ca.gov/Forecasting/Economics/Eco_Forecasts_Us_Ca/documents/US%20CA%20Inflation%20Forecast%20GB%202020 20-21.xlsx

Table 3-24: Morongo Basin Transit Authority – Overall Cost Summary

2020-2050 Fleet Replacement Cost Comparison ($2020 in millions)		SCENARIO 1: Baseline CNG	SCENARIO 2: Build – BEB
Capital	Vehicle Purchase Price	10.69	14.88
	Modifications & Contingency	0.86	1.17
	Charging/Fueling Infrastructure	0.36	1.91
	Total Capital Costs	11.91	17.96
Operating	Vehicle Maintenance	10.56	7.37
	Overhaul	0.36	0.45
	Tire Replacement Cost	0.65	0.55
	Vehicle Tools Training and PPEs[22]	-	-
	Other and Miscellaneous Costs	-	-
	Vehicle Fuel Costs	6.47	3.29
	Electric Vehicle Utility Costs	-	0.58
	Charging/Fueling Infrastructure	0.00	0.00
	Battery/Fuel Cell Replacement[23]	-	-
	Total Operating Costs	18.04	12.24
Disposal	Battery Disposal	-	-
	Bus Disposal (Salvage Value)	(0.24)	(0.33)
	Total Disposal Costs	(0.24)	(0.33)
	Total Cash Costs	29.71	29.87
	Total Cash Cost per Mile	2.70	2.72
Environmental	Emissions - Tailpipe	0.34	0.18
	Emissions - Refining/Utility	10.94	5.78
	Noise	0.58	0.51
	Total Environmental Costs	11.86	6.47
	Total Cash and Non-Cash Costs	41.57	36.34
	Total Cash and Non-Cash Costs per Mile	3.78	3.30
	Total Mileage (millions)	11	11

Source: WSP

[22] Morongo Bay Transit Authority's does not incur vehicle tools, training and PPE costs, as they are included in the price of the bus.
23 Battery replacements on the existing CNG fleets are assumed to be part of existing maintenance costs. If the bus purchases or leases will not include a warranty, the analysis can be easily updated to assume this.

3.3.4.2.2 Cost Conclusions

Overall, the lifecycle cost analysis shows that despite higher initial costs, the full lifecycle *cash cost* of a transition to battery electric vehicles will be slightly higher in comparison to continued reliance on CNG gas vehicles. While operating costs savings are anticipated for a battery electric vehicle conversion, the high capital costs of battery electric vehicles, batteries and charging infrastructure may offset the savings. As operating costs are highly dependent on factors that are not well-established, as further discussed in previous sections. This is particularly the case for annual vehicle maintenance costs, while existing capital cost premiums are currently well-known.

A subsequent analysis will assess year by year cost savings associated with operations, which specifically will highlight how long it will take for the savings from operations to offset the higher up-front capital costs.

Discussion of General Inputs

Inputs to the lifecycle cost model include:

- Fleet modernization schedules – vehicles acquired each year by fuel type.
- Vehicle costs including initial purchase, maintenance, mid-life overhaul and disposal
- Battery purchase, replacement and disposal or salvage
- Battery charging infrastructure purchase, installation and maintenance
- Energy costs, natural gas and electricity
- Environmental costs for vehicle tailpipe emissions of CO_2 and criteria pollutants
- Environmental costs for vehicle noise

The model examines one complete replacement of the fleet, beginning in the year 2020 and ending with final vehicle acquisition in 2033. The model tracks the total cost of ownership (initial capital cost, annual operating cost and final disposal cost) of each new vehicle for its full asset life.

The values provided are not a comparison between an all CNG vehicle and a battery electric fleet, but rather a comparison between continuing current practices and gradually phasing in battery electric vehicle procurement.

In addition to vehicle costs, the model also includes the costs of purchasing, installing and maintaining charging infrastructure for battery electric vehicles.

All model inputs are provided in current year (2019/2020) dollars. The model applies inflation factors to escalate costs to year of expenditure dollars. The Riverside-San Bernardino-Ontario metropolitan area historical CPI-U, presented in Table 3-23, was used for most costs, except the following cases where a different specific index was used:

- CNG gas prices were escalated at a rate of 3 percent.
- Electricity costs were escalated using EIA transportation electricity annual forecasted price growth rate forecasts by year, presented in Table 3-25.

Table 3-25: Annual Energy Outlook – US Energy Information Administration[24]

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	0.00%	14.75%	5.14%	6.08%	5.24%

Source: US Energy Information Adminsitration

Year of expenditure costs were then discounted to present value 2020 dollars using a discount rate of 2.37 percent. The resulting present values of all costs are summed to yield the full lifecycle cost comparison.

Vehicle Procurement Schedule by Facility; Scenario 2: Battery Electric Vehicle Conversion

The battery electric vehicle scenario assumes the vehicle procurements to be consistent with the tables that follow. These procurements could either continue the MBTA current practice of procuring only CNG vehicles, switch to procuring only battery electric vehicles or procure a mix over the years of transition. The two primary factors that would need to be considered for each year of procurement are the availability of charging infrastructure and the range and performance of available electric vehicles.

In early years, the construction of charging infrastructure would be the primary constraint, which is why battery electric vehicles are not assumed to be procured until 2025 for both Palms and Joshua Tree. Existing vehicles which will reach the end of their useful life prior to the build out of this infrastructure are assumed to be replaced with CNG vehicles.

[24] US Energy Information Administration, Annual Energy Outlook 2018 - Reference: 3-AEO2018.101.ref2018-d121317a

Table 3-26: Scenario 2 – Build Case for Battery Electric Vehicle Fleet Replacement Schedule Breakdown - Joshua Tree

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Battery electric 25.3’						5					5										
Battery electric 26’							1				1	1									
Battery electric 27’																					
Battery electric 32’																					
Battery electric 33’										2	1										
Battery electric 36’												3									
CNG 25.3’																					
CNG 26’		1		1																	
CNG 27’																					
CNG 32’																					
CNG 33’			2	1																	
CNG 36’		3																			
Total		4	2	2		5	1			2	7	4									

Source: WSP

Table 3-27: Scenario 2 - BEB Fleet Replacement Schedule Breakdown – Twentynine Palms

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Battery electric 25.3’						1					1										
Battery electric 33’												4									
Battery electric 35’								1													
CNG 25.3’																					
CNG 33’					4																
CNG 35’	1																				
Total	1				4	1		1			1	4									

Source: WSP

Vehicle Procurement Schedule by Facility – Baseline CNG

Table 3-28: Fleet Replacement Schedule Breakdown Joshua Tree

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
CNG 25.3’						5					5										
CNG 26’		1		1			1				1	1									
CNG 27’										1	3										
CNG 32’			1	3																	
CNG 33’			2	1						2	1										
CNG 36’		3										3									
Total	**0**	**4**	**3**	**5**	**0**	**5**	**1**	**0**	**0**	**3**	**10**	**4**									

Source: MBTA

Table 3-29: Fleet Replacement Schedule Breakdown Twentynine Palms

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
CNG 25.3’						1					1										
CNG 33’					4							4									
CNG 35’	1							2													
Total	**1**	**0**	**0**	**0**	**4**	**1**	**0**	**2**	**0**	**0**	**1**	**4**									

Source: MBTA

3.3.4.3 Uncertainties

The analysis provided in this documentation should be considered a conservative assessment of battery electric vehicle costs, as the industry in North America is still developing as demand increases and the market stabilizes. Production costs may decrease as production increases to meet future demand through benefits of economy of scale. However, cost reductions may be offset by reductions in tax breaks, grant programs, discounts and incentives that are available for the acquisition of battery electric vehicles and associated charging infrastructure.

The costs for batteries are also anticipated to decline with continued development of more efficient technology and lower production costs resulting from economies of scale. Some potential future cost reductions, however, may be offset (or more than offset) through increases in the cost of acquiring the primary battery components, specifically lithium or other alternative rare earth minerals. In addition, the energy density of batteries is increasing, so the decline in cost per kWh could be offset by a choice to buy higher-capacity, longer range batteries for vehicles purchased in later years and for replacement of original batteries on vehicles purchased in the early years.

The cost of fuel and electricity also have a strong correlation on the benefits of battery electric vehicles over CNG vehicles. Any major changes to the price would have a direct impact on operating costs for the agency. While utility prices are historically less volatile than CNG prices, there exists less downward price potential as utility prices tend to be set by large scale capital investments and distribution costs, as opposed to market inventory levels and feedstock supply costs, which are the primary drivers of CNG prices and volatility.

3.3.5 Recommendations

3.3.5.1 Joshua Tree Fleet Technology

Without FCEB cutaways currently available on the market, this report recommends a full battery-electric conversion. The capabilities of current BEB technology would support the immediate conversion of six blocks. This leaves one block that will require an alternative strategy for successful BEB integration.

There are several strategies that may be used to support BEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances
- Phasing BEB integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

3.3.5.2 Twentynine Palms Fleet Technology

Without FCEB cutaways currently available on the market, this report recommends a full battery-electric conversion. The capabilities of current BEB technology would support the immediate conversion of four blocks. This leaves three blocks that will require an alternative strategy for successful BEB integration.

There are several strategies that may be used to support BEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances
- Phasing BEB integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities that must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

3.3.5.3 Fleet Phasing and Implementation

WSP recommends that the entire electrical yard infrastructure for the site's BEB charging requirements, including a transformer and switchgear sized for the ultimate fleet, be installed with the initial phase at both the Joshua Tree and Twentynine Palms sites to avoid having to disrupt ongoing charging operations or install duplicate infrastructure in subsequent phases.

3.3.5.3.1 Joshua Tree Phasing

Phase 1

The recommended first phase of charger installation the for the Joshua Tree site is to install all the in-ground conduit to route electrical service to seven charging cabinets with 14 plug-in dispensers mounted at the edge of the parking spaces on the eastern boundary of the facility. These chargers and dispensers can be installed without any trenching modification to the existing paved parking areas (see Figure 3-15).

Phase 2

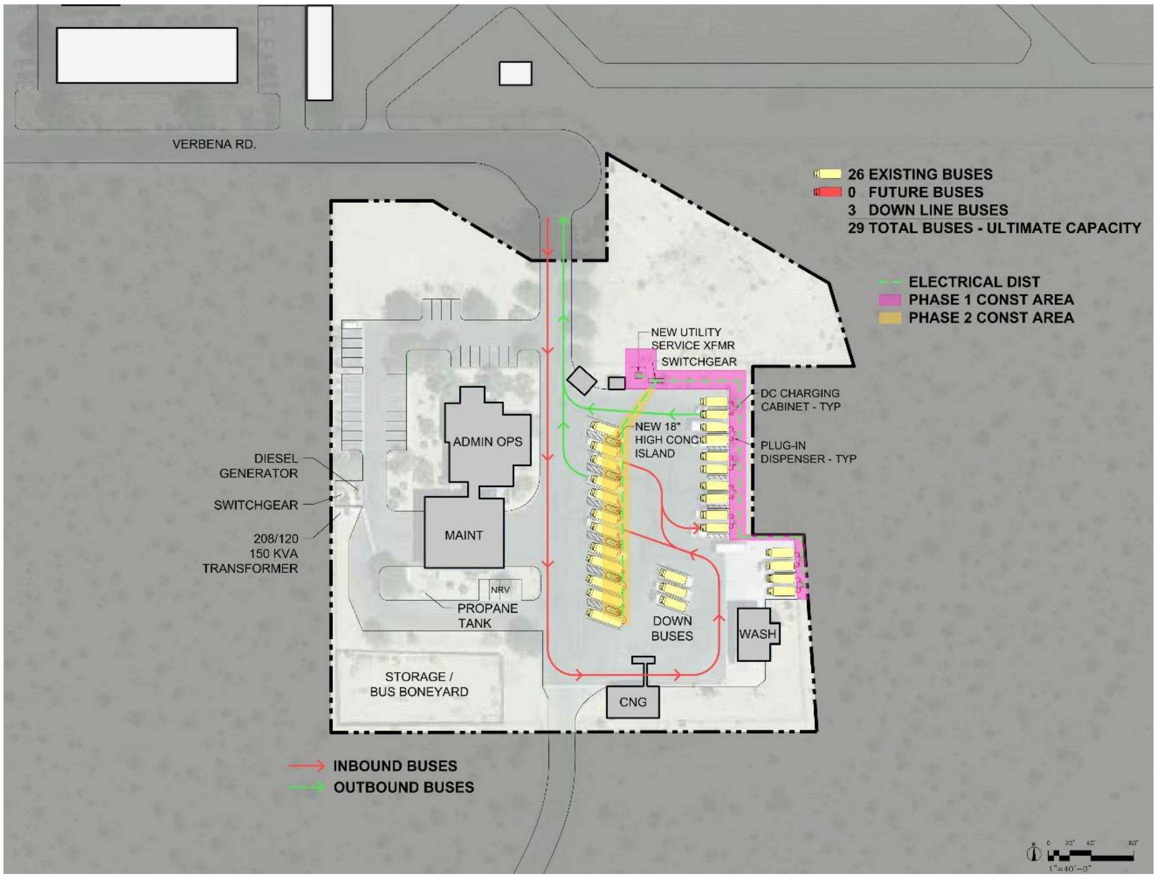
Phase 2 at Joshua Tree should complete all yard trenching to distribute to electrical service to the central yard parking and construct all the islands to house the charging cabinets and dispensers. Charging cabinets and dispensers can then be added to the islands as needed with the phase-in of BEBs (see Figure 3-15).

Hydrogen fueled vehicles are recommended for implementation during the final phase to allow time for FCEB cutaway-style buses to enter the market in greater numbers. As of 2020, hydrogen fuel cell cutaway buses have not been sufficiently tested to confirm the ability to replace MBTA's existing long-range routes. As more manufacturers provide cutaway FCEB options on the market, the containerized hydrogen fueling solution can be rapidly deployed with minimal site impacts. Note that as shown on the concept layout, the hydrogen fueling yard and dispenser infrastructure and equipment can be added at any time with minimal impact to ongoing operations and the hydrogen yard is not dependent on the BEB infrastructure phasing.

3.3.5.4 Facilites Preliminary Designs

3.3.5.4.1 Joshua Tree Yard Phasing

Figure 3-15: Joshua Tree Yard Proposed Full ZEB Build-out and Phasing



Source: WSP

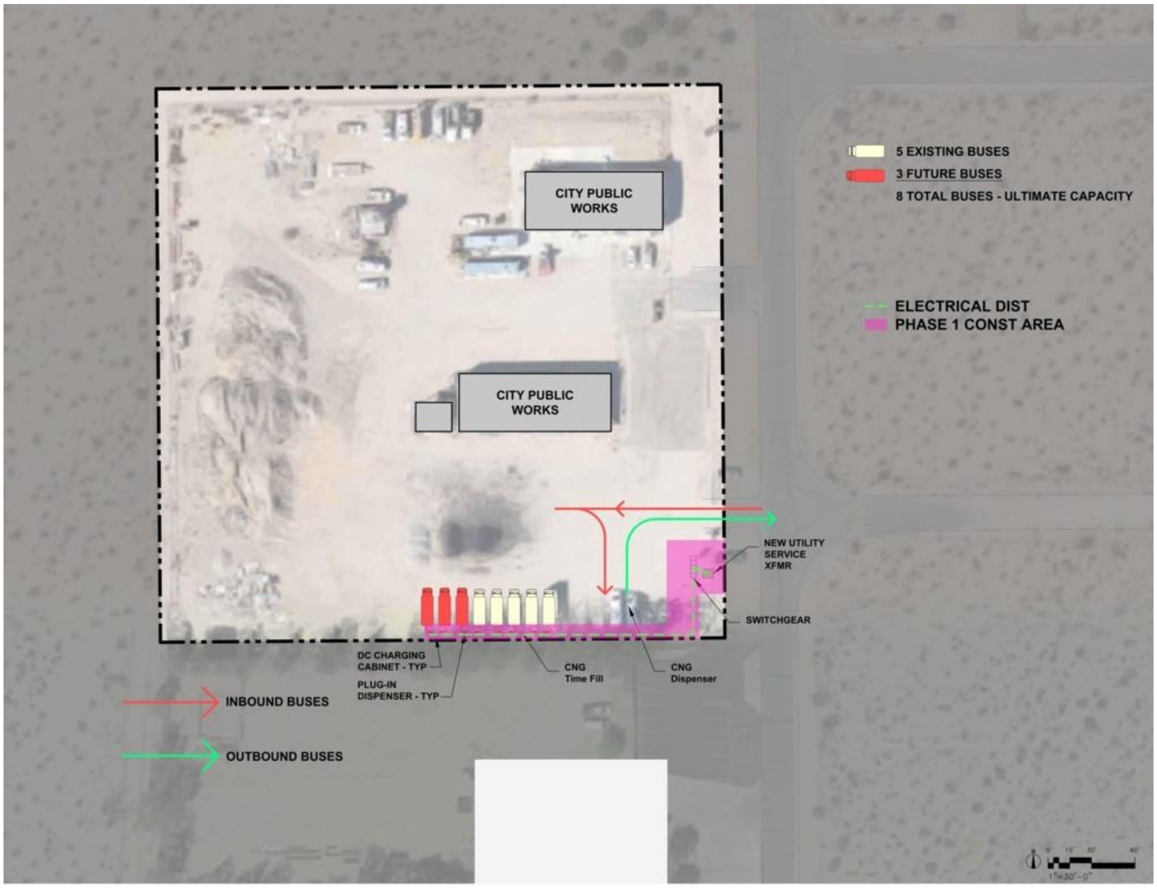
3.3.5.4.2 Twentynine Palms Phasing

Based on the size of the Twentynine Palms site and the lower number of vehicles to be charged, WSP recommends completing the entire BEB charging installation in a single phase at the Twentynine Palms site (see Figure 3-16).

3.3.5.4.3 Yucca Valley Transit Center Phasing

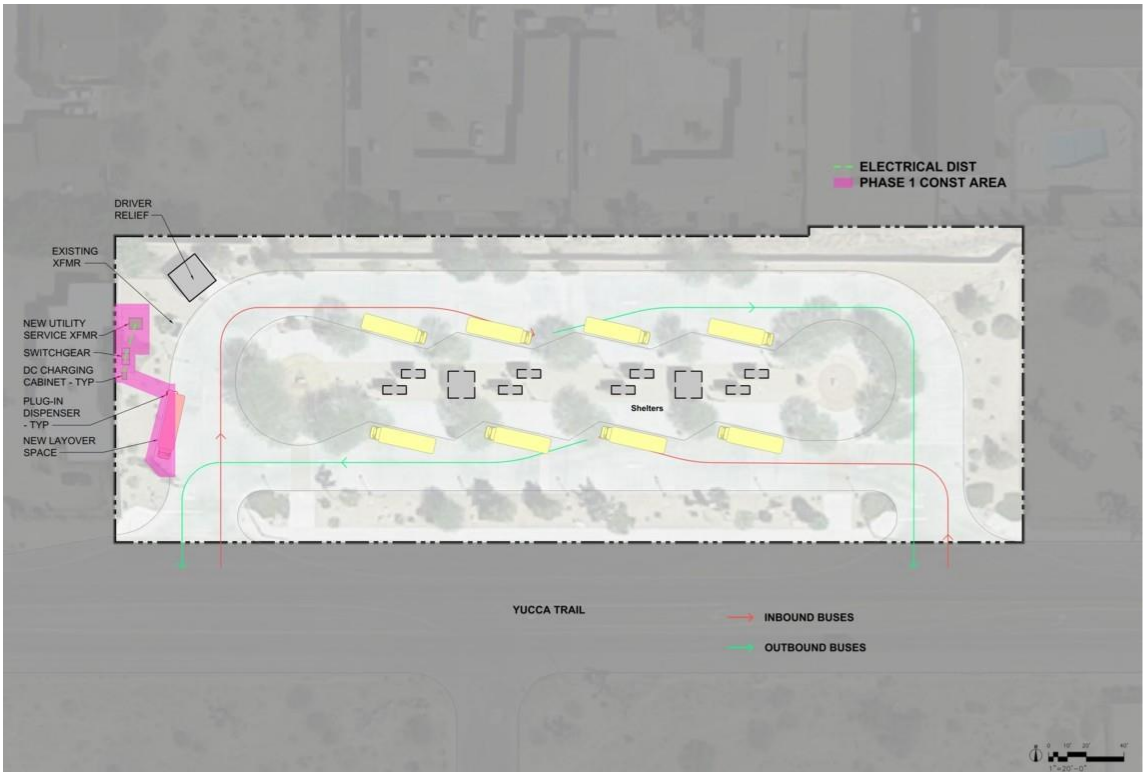
Based on the size of the Twentynine Palms site and the lower number of vehicles to be charged, WSP recommends completing the entire BEB charging installation in a single phase at the Yucca Valley Transit Center (see Figure 3-17).

Figure 3-16: Twentynine Palms Yard Proposed Full ZEB Build-Out and Phasing



Source: WSP

Figure 3-17: Yucca Valley Transit Center Proposed ZEB Build-Out and Phasing



Source: WSP

4 MOUNTAIN AREA REGIONAL TRANSIT AUTHORITY

4.1 Introduction

MT was formed as a joint power authority (JPA) between the City of Big Bear Lake and the County of San Bernardino, providing service between the City of San Bernardino and the San Bernardino mountain communities. MT's ridership peaks between December and March, when tourists are drawn to the robust ski industry in the San Bernardino Mountains during snowy winter months.

4.2 Existing Conditions

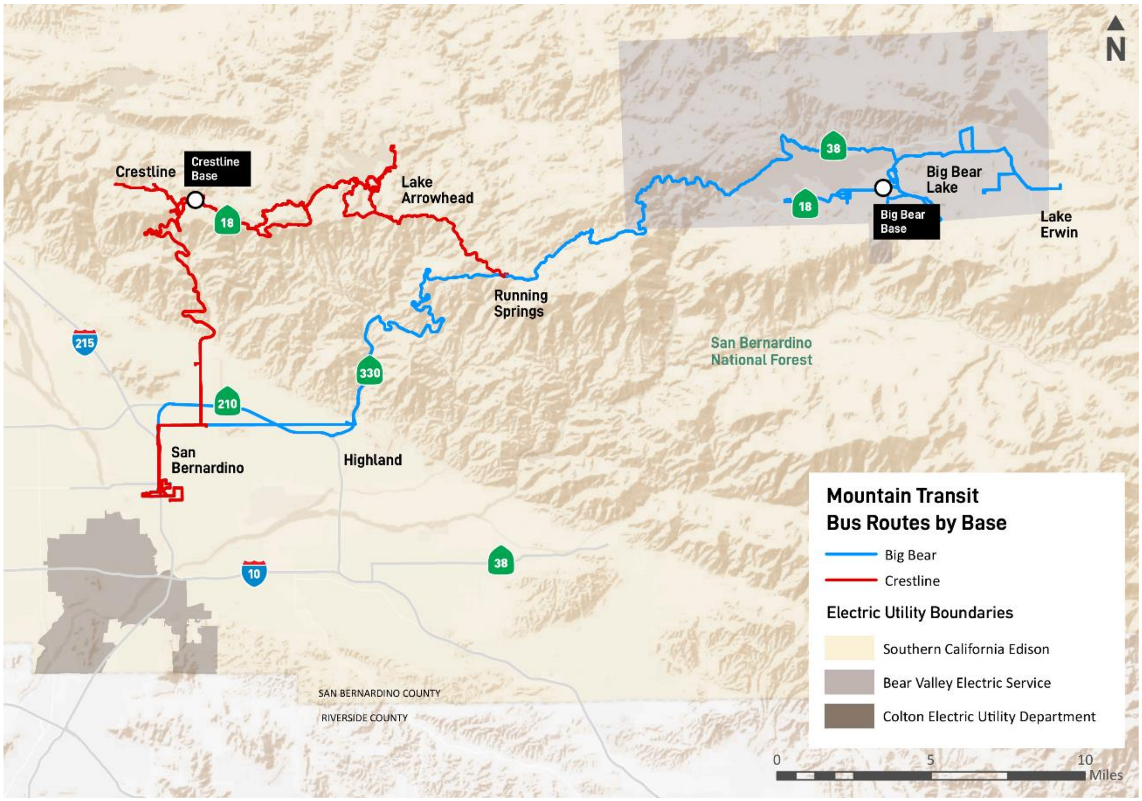
4.2.1 Service Area and Environmental Factors

MT provides two primary transit services — fixed-route bus service and dial-a-ride. It operates local shuttle services in and between Big Bear Lake, Lake Arrowhead, and the surrounding mountain communities, and intercity connection services between these communities and the City of San Bernardino. Through the latter service, MT provides connections to Omnitrans, Metrolink, and private commercial bus service. In addition to its primary destination cities, Big Bear Lake, Crestline, Lake Arrowhead and San Bernardino, MT provides service in the following mountain communities: Big Bear City, Erwin Lake, Highland, Moonridge, and Running Springs.

Figure 4-1 shows the extent of MT's service, with routes color-coded by the two facility locations, Big Bear and Crestline. Additionally, the map indicates the boundaries of the two pertinent electric utilities: SCE, which serves much of the service area including the Crestline facility, and Bear Valley Electric Service, which serves the routes in and around Big Bear Lake, including the Big Bear facility.

MT faces two considerable obstacles, weather and terrain, in providing its service. These obstacles will undoubtedly also influence MT's electrification process. Because MT operates in both the mountain communities and the City of San Bernardino, its fleet must be able to handle a wide variety of weather conditions. While much of San Bernardino County experiences a hot, arid desert climate, the area around Big Bear Lake sees significant snowfall during the winter months. Winter average low temperatures in Big Bear Lake are between 21 and 22 degrees, while in the City of San Bernardino average lows in those same months are between 41 and 43 degrees. On a given winter day, a bus could begin its service day in the City of San Bernardino with a mid-day high temperature of 68 degrees (average high for January) and conclude its day in Big Bear Lake with a low temperature of 21 degrees (average low for January). The summer months offer a similar juxtaposition, high temperatures in the City of Big Bear Lake average 81 degrees in July, compared with 96 degrees in the City of San Bernardino.

Figure 4-1: MT Routes by Base and Electric Utility Boundaries



Source: WSP

There is also a stark contrast in terrain and elevation between the mountain communities and the City of San Bernardino. Big Bear Lake's elevation is 6,750 feet while the City of San Bernardino is at approximately 1,000 feet, meaning MT must both operate at high altitude *and* climb to that high altitude from the valley floor. Snow typically begins at 5,000 feet but can reach as low as 3,000 feet during storms. To combat these environmental challenges, all MT buses are equipped with auto-chains for their tires and during heavy snow conditions, all buses must transition to conventional heavy duty chains. If chains were to be used for ZEBs, these chains would need to be a consideration when modeling battery consumption and have to be an acceptable after-market equipment use that does not void the manufacturer warranty. Therefore, MT must ensure compliance with the OEM, including warranty protection for chains and possible "cold-weather climate" packages, which include additional battery capacity or diesel-generated heat for HVAC battery drain.

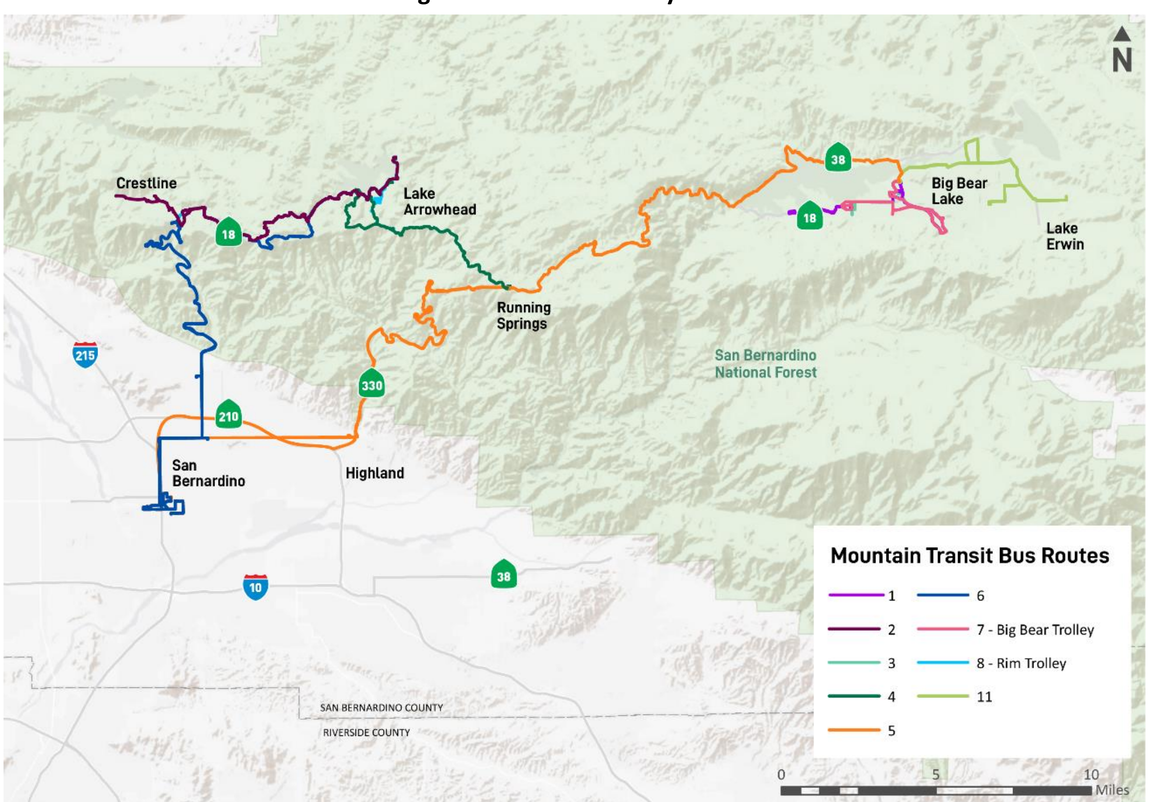
Additionally, many of the roads between the mountain villages - especially in the Rim of the World (RIM is a common term for the Lake Arrowhead and Crestline areas) and even some portions of the roads traveling up the mountain - are very narrow with steep, short grades, and have many curves. These roads present difficulty for buses in all seasons, but especially during the winter months, when snow can lead to slipping and traffic delays. State Routes 18 and 330 provide off-the-mountain (OTM) access to Lake Arrowhead and Big Bear Lake, respectively. Both roads feature grades of up to seven percent, which presents a challenge, snow notwithstanding. The steep grades of the roads that climb the mountain also present an unusual challenge for a transit system. The RIM OTM is a shorter and not as steep grade as the Big Bear OTM; however, the narrow roads do not permit a bus larger than 27.5-feet in length to operate on this route. The Big

Bear OTM can handle a larger bus; however, the route length (50 miles one-way) and steeper grades require that these buses utilize a diesel engine. In the past, MT did use gasoline engines for the Big Bear OTM, but the engines frequently broke down and MT had to transition to diesel engines. Electric motors, which have higher torque and better acceleration from low speeds and on hills, should provide benefits to MT in meeting these challenges; however, the terrain, length of the grade climbing thousands of feet, coupled with the low temperatures, will reduce the range of BEBs, reducing the length of blocks that can be completed. In addition, the narrow and mountainous roadways demand service reliability, meaning that greater scrutiny should be observed in calculating the range of vehicles operating on these challenging bus routes. FCEBs can largely meet range concerns, yet the concern lies in the fact that there is no close proximity to hydrogen infrastructure and delivery on the mountain during severe weather. An additional benefit of FCEBs is the output of heat, thereby assisting range and passenger comfort during winter months.

4.2.2 Schedule and Operations

MT operates service on ten fixed routes, shown in Figure 4-2. Five routes are local shuttles in the Big Bear Valley, three are local shuttles in the RIM area, and the final two provide intercity OTM service between the two service areas and the City of San Bernardino. Of the ten routes, two are seasonal services in both Big Bear Lake in the winter and a trolley/weekend service in the RIM area from May to November. Odd-numbered routes correspond to Big Bear Valley service, and even-numbered routes correspond to the RIM/Lake Arrowhead area. All Big Bear routes originate from the Fox Farm Transfer station.

Figure 4-2: MT Service by Route



Source: WSP

The five local shuttles in Big Bear Lake are:

- 1 – Boulder Bay to Interlaken Center, serving the Village and Bear Mountain
- 3 – Mountain Meadows to Bear Mountain and Interlaken Center
- 7 – Trolley service on weekends, holidays and peak tourist periods from the Village in Big Bear Lake to Snow Summit ski resort
- 9 – Winter service during weekends, holidays and peak tourist periods, from the Backward Look Lot to the two Ski Resorts
- 11 – Erwin Lake to Interlaken Center, serving Big Bear Lake, Big Bear City, and Sugarloaf

The Trolley fare is $5 for unlimited service for the entire weekend. Standard fare for the remaining routes is $1.50 cash; seniors, veterans, and disabled riders can board for $0.75. Day passes and punch tickets are also available for purchase with cash or credit card.

The three local shuttles in the RIM area are:

- 2 – Valley of Enchantment to Lake Arrowhead, serving Crestline
- 4 – Lake Arrowhead to Running Springs
- 8 – Trolley service from Crestline, to Lake Arrowhead to Santa's Village, on weekends, holidays and peak tourist periods, from May to November

The Trolley fare is $5 for unlimited service for the entire weekend. Fares on the remaining routes vary based on distance traveled between the four shuttle service subareas: Top Town/Crestline, Twin Peaks/Rimforest, Lake Arrowhead, and Running Springs. The range is between $1.00 for travel within a subarea to $4.00 for end-to-end travel crossing several subareas. Day passes and punch tickets are available but at a higher rate than the Big Bear routes.

The two OTM routes are:

- 5 – Big Bear Valley San Bernardino, servicing Running Springs and Highland
- 6 – Lake Arrowhead to San Bernardino, servicing Crestline

Fares for both OTM routes are based on fare zones. For Route 5, this ranges from $2.50 for one zone to $10 for the full route from Big Bear Lake to the City of San Bernardino. For Route 6, the full route from Lake Arrowhead to the City of San Bernardino is $7.50; service to and between Crestline and Rimforest are less, depending on the number of zones traveled.

As described in Table 4-1, Routes 1, 3 and 11 in Big Bear Lake run daily; Route 9 is a winter route. OTM service runs one fewer trip on the weekends. For routes 2 and 4 that service Lake Arrowhead, all routes operate on full schedule Monday to Friday. On Saturdays, Routes 2 and 4 operate a full schedule, while Route 6 operates a limited schedule. Only Route 2 operates on Sunday on a limited schedule.

Additionally, MT operates a weekend trolley service in Big Bear Lake and a summer seasonal weekend trolley service (mid-May to mid-October) from Lake Arrowhead to Lake Gregory. Both routes offer unlimited rides for the weekend for a flat fare of $5, or $2.50 for seniors, veterans, and disabled riders. The Big Bear Trolley runs hourly on Saturdays from 9:30 AM to 9:30 PM and on Sundays from 11:30 AM to 2:30 PM. On holiday weekends, MT uses a Saturday schedule on Sunday and a Sunday schedule on Monday. The RIM area trolley runs roughly every hour and 40 minutes from 1:40 PM to 8:40 PM.

Table 4-1: Mountain Area Regional Transit Authority Summary of Service

Route	Length (mi.)*	Days	Seasonality	Number of Trips	Span	Headways
1	13.1- 18.6	Daily	Year-round	14	5:30 AM to 7:30 PM	Hourly
2	12.5–20.1	Monday–Saturday Sunday	Year-round	9 5	5:26 AM to 6:20 PM 10:15 AM to 5:35 PM	90 minutes 90 minutes
3	19.5	Daily	Year-round	7	10:00 AM to 5:00 PM	Hourly
4	13.9 – 16.2	Monday–Saturday	Year-round	5	10:30 AM to 5:15 PM	90 minutes
5	59.9	Monday–Friday Saturday–Sunday	Year-round	3 2	6:30 AM to 7:20 PM 6:30 AM to 7:20 PM	4.5 and 5 hours 9.5 hours
6	38.1	Monday–Friday Saturday	Year-round	4 2	5:15 AM to 8:20 PM 8:30 AM to 5:25 PM	3:15, 6:10, 3:00 6:10
9	8	Christmas-New Years, Sat., Sun., Holidays	Mid-Nov.- Mid-March	16 12 9 11	5:30 AM to 1:30 PM 5:10 AM to 11:10 AM 2:55 PM to 7:15 PM 1:55 PM to 9:55 PM	30 minutes
11	22.5–26.5	Daily	Year-round	14	5:30 AM to 7:30 PM	Hourly
BBL Trolley	10.8	Sat., Sun., Holidays Daily	Mid-November – Mid-March Christmas-New Years Day	13 4	9:30 AM to 9:44 PM 11:30 AM to 2:59 PM	Hourly
Rim Trolley	30.7	Sat., Sun., Holidays	Mid-May - Mid-October	17	1:40 PM to 10:28 PM	100 minutes

Source: Mountain Transit, 2019

4.2.3 Upcoming Capital Programs and Service Changes

MT is in the process of redeveloping their existing Crestline site and establishing a new replacement site for their Big Bear facility. It is anticipated that both these new facilities will be fully equipped to support a full BEB fleet when they are opened, with all electrical equipment, electrical capacity and BEB chargers, dispensers and other components installed during the initial construction.

At the existing Crestline facility, MT intends to demolish all existing structures, and build a new three-bay maintenance facility and small administrative building along the north edge of the property. MT has also acquired a parcel across the street from the Crestline facility, the new site will function as temporary bus storage and dispatching/staging while the existing Crestline site is under construction. However, at this time, MT does not intend to use this site for ZE-related bus operations.

MT is in negotiations to purchase a three-acre parcel in Big Bear Lake to construct a new administrative and maintenance facility, bus wash, and customer service center. MT anticipates that the property purchase will be completed by the end of the FY 2019-20. The site is anticipated to be under construction in 2021 with normal operations in 2022. Upon occupying the new facility, MT will cease use or dispose of the existing facility.

Ultimately, MT's two new facilities (remodeled Crestline and new Big Bear Lake facilities) will include enhancements and expansions of electrical equipment, additional electrical capacity, and the installation of BEB chargers, dispensers, and other components to support an all-ZEB fleet.

No known service changes are available at this time, however, once the Redlands Passenger Rail (Arrow) service opens in 2022, providing OTM connection as a rail link is a potential future pilot route. Further study will occur in the next iteration of the SRTP in 2022.

4.2.4 Facilities

This section provides a summary understanding of each of MT's existing site and facility conditions. As of 2019, MT's fleet runs on gasoline or diesel fuel, which is sourced from the local sheriff's station in both Big Bear Lake and Crestline.

4.2.4.1 Crestline

MT's Crestline facility is located at 621 Forest Shade Road, Crestline, California, on approximately 0.4 acre of land. Table 4-2 describes MT's facilities, equipment, and fleet. See Figure 4-4 for a site circulation diagram, indicating how buses enter and exit the property. The current facility is extremely limited in extra space to install either ground-mounted, overhead electrical charging equipment, or hydrogen storage infrastructure. As previously mentioned, MT intends to demolish all existing structures, and build a new three-bay maintenance facility and small administrative building along the north edge of the property.

Table 4-2: MT Crestline Inventory

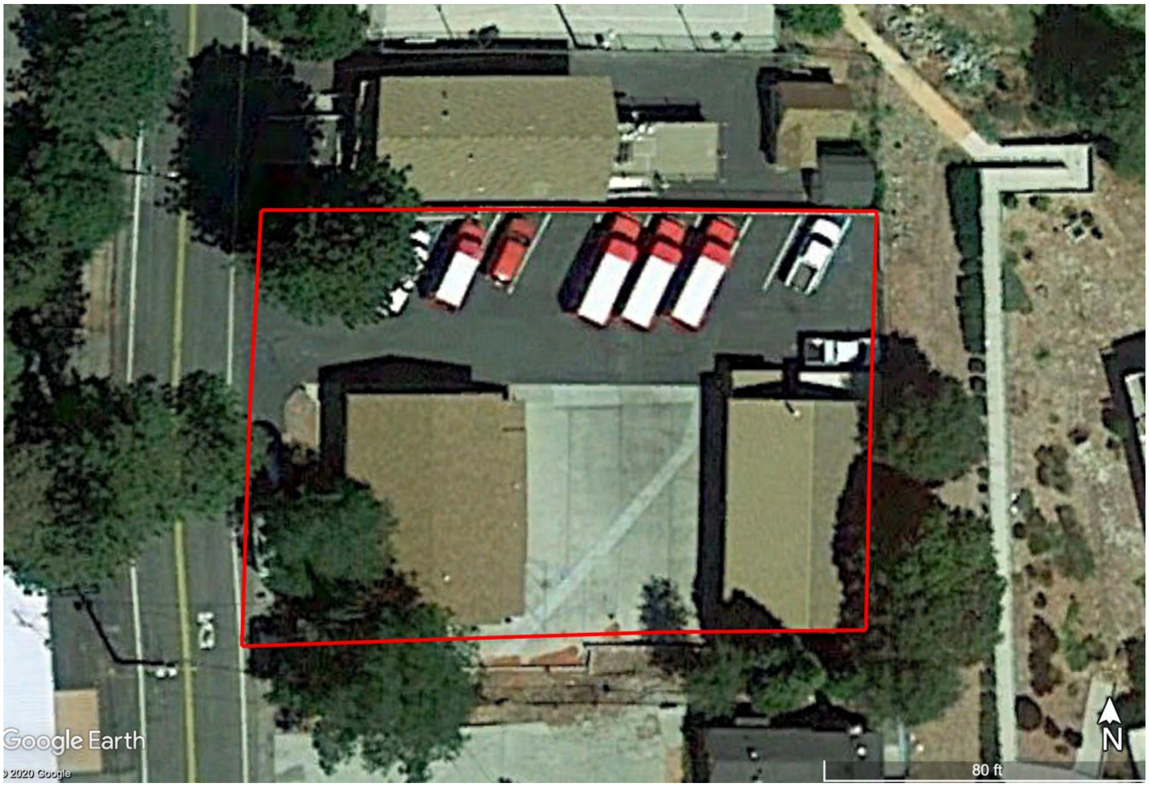
Fleet Overview	
Cutaway Bus[25]	11
Trolley Bus[26]	1
30-foot Bus	-
35-foot Bus	-
40-foot Bus	-
45-foot Bus	-
60-foot Articulated Bus	-
Total	**12**
Facilities	
Total Maintenance Bays	2
Paint Booths	-
CNG Fueling Positions	-
CNG Compressor Yards	-
Diesel Fueling Positions	-
Unleaded Fueling Positions	-
NRV Bays	-
Body shops	-
Bus Wash Lanes	-

Source: WSP

[25] 3 buses are minivans (22 feet) and the rest are traditional Cutaway buses between 25 feet and 27.5 feet in length.

[26] MT operates out of Crestline one trolley bus during summer.

Figure 4-3: Crestline Base – Existing Conditions



Source: WSP

Figure 4-4: Crestline Site Circulation

Source: WSP

SCE provides electrical service to the existing site. The service is fed from an overhead power distribution line to the main 200 Amp 240/120V panel board. There is a manual transfer switch next to the main panel board to attach the portable generator to serve the portion of the load during the power outage. At the time of the site visit, the electric service was down, and the facility had significant damage due to fire caused by the portable generator.

4.2.4.2 Big Bear Lake (Future)

The Big Bear Lake (future) facility is located approximately ¼-mile north of the existing Big Bear Lake facility. Electrical service will be provided by the Bear Valley Electric Service Utility.

As previously mentioned, MT is in the process of developing a new site to replace the existing Big Bear Lake facility. The planned ZEB modifications shown in this document are based on the concept for the new Big Bear Lake Base (Big Bear Lake Future).

Table 4-3 describes the existing site's facilities, equipment, and fleet. Figure 4-5 shows the existing Big Bear Lake facility while Figure 4-6 shows the future site.

Table 4-3: MT Big Bear Inventory

Fleet Overview	
Cutaway Bus[27]	13
Trolley Bus[28]	1
30-foot Bus	-
35-foot Bus	-
40-foot Bus	-
45-foot Bus	-
60-foot Articulated Bus	-
Total	**14**
Facilities	
Total Maintenance Bays	2
Paint Booths	-
CNG Fueling Positions	-
CNG Compressor Yards	-
Diesel Fueling Positions	-
Unleaded Fueling Positions	-
NRV Bays	-
Body shops	-
Bus Wash Lanes	-

Source: WSP

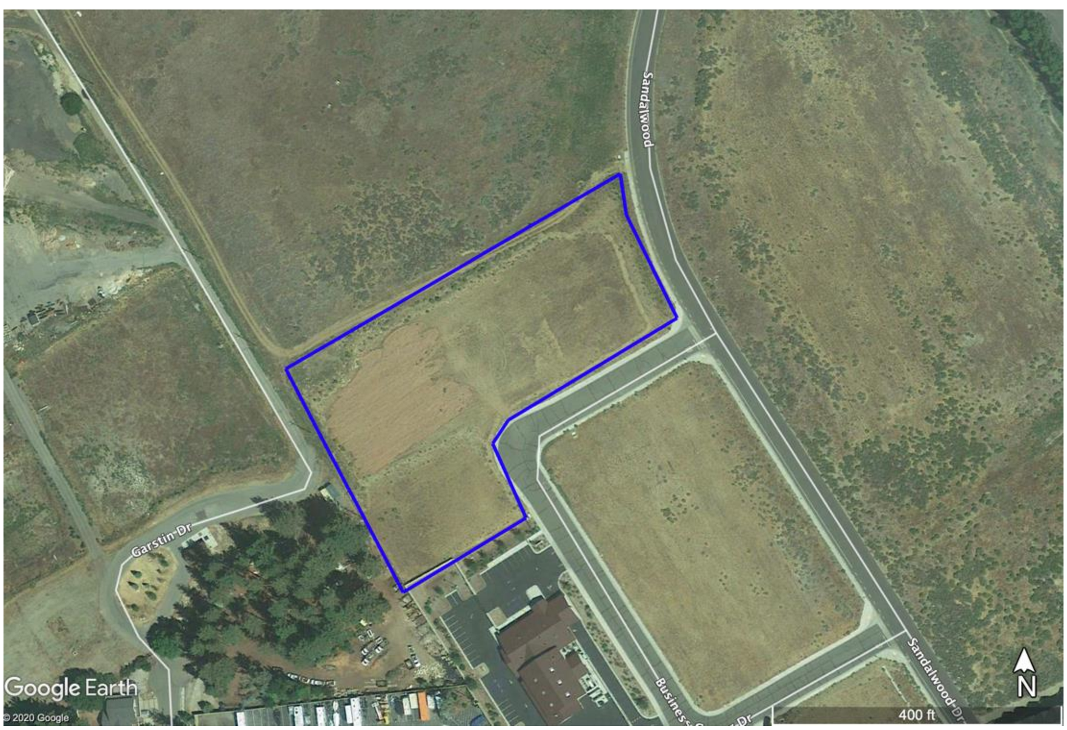
[27] 2 buses are minivans (16.5 feet) and the rest are cutaway buses between 27 and 37.5 feet in length.

[28] MT operates one trolley bus on weekends and holidays, year round.

Figure 4-5: Big Bear Lake - Existing Conditions

Source: Google Earth

Figure 4-6: Big Bear Lake Future Site – Existing Conditions



Source: Google Earth

The Bear Valley Electric Service Utility powers the Big Bear Lake facility. The 12 KV-208/120V pad-mounted transformer is located at the front side of the property to serve both the MT facility and Phil's Automotive Service Center facilities. The transformer also feeds a switchboard via underground distribution, the switchboard has an unidentified amp capacity main breaker located in the electric room, which distributes power through the entire site. The breaker size was not properly identified because it is covered by a switchboard plate.

The facility does not have any backup power means in the case of a power outage. According to MT staff, the facility has occasionally experienced long power outages especially during the winter, and in some cases, the outages lasted approximately eight hours. The illustrations and images below provide details regarding on-site power distribution.

4.3 ZEB Implementation

4.3.1 Technology

Past and ongoing ZEB analysis for MT's operations has determined that BEB adoption is the ZEB technology that best meets the needs of MT for their purchasing and transition requirements pursuant to the ICT regulation. FCEBs, at this time, are not feasible due to no current manufacturers offering a cutaway.

MT's future BEBs are expected to have specifications that are compatible with the SAE J1772 charging standard (e.g., "plug-in charging"). It is recommended that MT specify charging ports on the front and rear of BEBs to allow for their existing site circulation and parking patterns to continue without modifications as both head-in and back-in parking are used in existing MT parking operations. Acquiring buses with the dual port locations will allow for vehicles to operate from all sites with no restrictions based on charger layout.

Any buses which will perform OTM service are recommended to be procured with overhead charging rails to utilize potential opportunity charging that is being considered at the San Bernardino Transit Center (SBTC) for range extending. An alternative "no charging rails" solution would need to identify a non-publicly accessible/isolated layover space for 30+ minute layover space where a BEB could be connected to a plug-in charger. Note that current plug-in chargers are limited to 150-200 kW due to National Electric Code requirements for handheld wiring. Roof-mounted charging rails would allow a MT BEB to access higher power charging (200-600 kW) at the SBTC.

Currently, there are no manufacturers in the U.S. market that offer a FCEB cutaway, deeming hydrogen power infeasible, under existing conditions. While a hydrogen-powered cutaway may be developed in the future, MT must plan and design for facilities and buses that are currently on the market to ensure they can comply with CARB's ICT regulation. However, as technology further develops, MT will remain open to technologies outside of BEB and will update plans, studies, and strategies, accordingly.

For specific blocks that are not capable of being served efficiently by existing BEB technology (primarily, the OTM routes), FCEBs could be a viable option, if cutaways are eventually introduced to the market. In that case, it is recommended that hydrogen fuel cell vehicles be utilized and fueled either via future commercial/public hydrogen fueling stations located near the SBTC. As no fueling operations currently exist on MT's sites, and given the makeup of the mountain communities (a small, full-time population base, along with peaks of tourism and few employment centers), MT does not anticipate other employers/fleets building a hydrogen station in the communities, and therefore, it is not recommended to introduce on-site hydrogen fueling.

The impacts of these recommendations for each site follow.

4.3.2 Analysis/Findings

4.3.2.1 Crestline

Based on the recommended ground mounted DC plug in charging solution, the Crestline facility is capable of parking 12 buses with 12 plug in charging positons in a 1:2 charger to bus dispenser ratio.

The following BEB equipment and locations are proposed:

- Four charging cabinets in the eastern portion of the facility adjacent to the bus parking with seven plug-in dispenser charging positions along the northern facility wall in the existing parking layout.
- Three charging cabinets along the western property line with five plug-in dispenser charging positions along the western property line. Buses will be connected to the dispenser via a charging point located on the front of the bus.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One medium voltage utility service transformer in a new utility yard in the open space west of the existing parking spaces and east of the site entrance.
- One switchgear in a new utility yard in the open space west of the existing parking spaces and east of the site entrance.
- MT does not currently perform any on-site fueling, and no space is available within the existing Crestline site. Hydrogen fueling options are restricted due to lack of available space and safety clearance, as the property is immediately adjacent to the Boys and Girls Club to the west and a flood mitigation channel to the north (Figure 5-3). Finally, MT has not expressed a demand for hydrogen infrastructure feasibility.

Conceptual layouts for the proposed ZEB solutions for MT's facilities are present in Section 4.3.5.3 of this document.

4.3.2.1.1 Modeling Results

Base-Only Charging – Crestline

The Crestline facility operate six vehicle blocks. The smallest block distance traveled is 125 miles and the longest is 198 miles. As discussed in Section 2.1.2, a 118 kWh (94 kWh operating) battery was used to model the cutaway transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 118 kWh battery. Eighty-three percent of vehicle blocks could be completed at the optimistic efficiency, 67 percent could be completed at the base efficiency, and 0 percent could be completed at the conservative efficiency.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies, six vehicle blocks would need to be served by vehicles with an advertised battery capacity between 137 and 250 kWh that also operate at the same kWh/mi efficiency as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 4-4 provides the summary of block completion percentage for MT at the Crestline Site, and Table 4-5 provides a list of the current vehicle blocks that would not be able to complete 100 percent of service with the 118-kWh battery at the conservative efficiency. Table 4-5 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 4-4: MT Crestline Site Base-Only Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	83% (5)	67% (4)	0% (0)
150	120	100% (6)	67% (4)	67% (4)
200	160	100% (6)	100% (6)	83% (5)
250	200	100% (6)	100% (6)	100% (6)

Source: WSP

Table 4-5: Summary of MT's Future Site Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
2>8	118	8.8	126	79	105	132
2>3	118	7.4	135	85	113	142
2>1004	118	6.1	138	87	116	145
2>4	118	6.5	138	87	116	145
2>9	118	14.3	188	118	157	196
2>1	118	14.0	199	125	166	208

Source: WSP

Base and On-Route Charging – Crestline

The Crestline facility will operate six vehicle blocks. The smallest block distance traveled is 125 miles and the longest is 198 miles. As discussed in Section 2.1.2, a 118 kWh (94 kWh operating) battery was used to model the cutaway transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with the 118 kWh battery. Eighty-three percent of vehicle blocks could be achieved at the optimistic efficiency, 86 percent could be achieved at the base efficiency, and 0 percent could be achieved at the conservative efficiency.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies, one vehicle block would need to be served by vehicles with an advertised battery capacity up to 259 kWh that also operate at the same kWh/mi efficiency as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 4-6 provides the summary of block completion percentage for MT at the Crestline Site, and Table 4-7 provide a list of the current vehicle blocks that would not be able to complete 100 percent of service with the 118-kWh battery at the conservative efficiency. Table 4-7 also details the needed advertised battery capacity to achieve the existing service on the block at all efficiencies.

Table 4-6: MT– Crestline Site and On-Route Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	83% (5)	67% (4)	0% (0)
150	120	100% (6)	67% (4)	67% (4)
200	160	100% (6)	100% (6)	83% (5)
250	200	100% (6)	100% (6)	100% (6)

Source: WSP

Table 4-7: Summary of MT's Crestline Site and On-Route Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
2>8	118	8.8	126	79	105	132
2>3	118	7.4	135	85	113	142
2>9	118	14.3	188	118	157	196
2>1	118	14.0	199	125	166	208

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

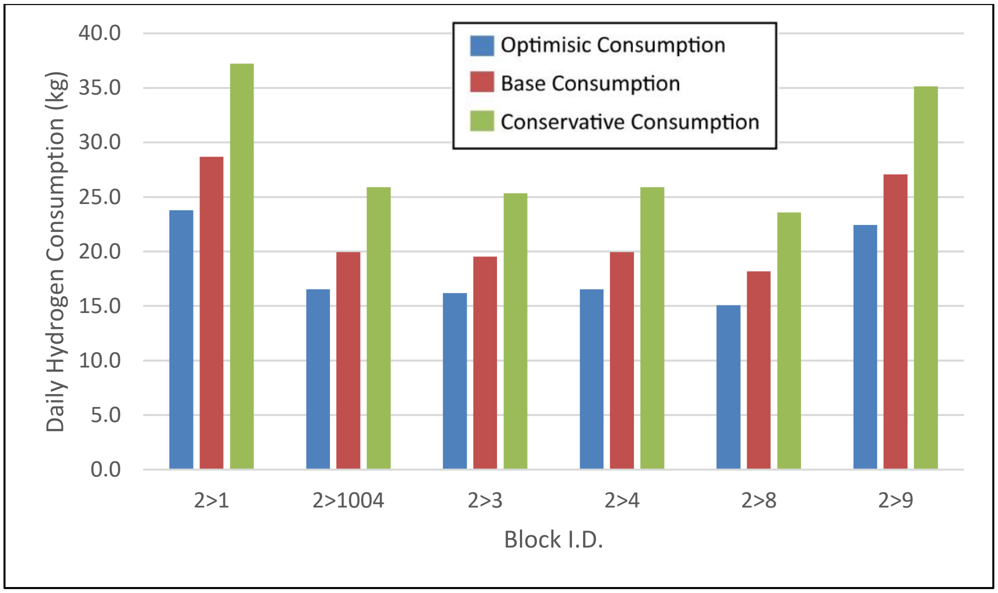
Without cutaway FCEB vehicles currently available on the market, the Crestline facility does not qualify for FCEB adoption at this time.

Hydrogen Requirements

An analysis of anticipated fuel consumption for full-fleet FCEB conversions was conducted to support future planning efforts following the release of FCEB cutaways. This information may be used when considering future vehicle procurements and on-site hydrogen storage and production needs.

Individual service blocks in the Crestline fleet would require between 15 kg and 37 kg of hydrogen for daily operations with an average consumption of 23 kg (Figure 4-7). In total, the fleet would require between 111 kg and 173 kg of hydrogen a day (Table 4-8). This quantity could be reasonably be provided through on-site production via SMR or electrolysis as well as contracted delivery.

Figure 4-7: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of the Crestline Yard



Source: WSP

Table 4-8: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of the Crestline Yard

Block ID	Block Distance	Vehicle Type	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
2>1	198.6	Cutaway	40	23.8	28.7	37.2
2>1004	138.1	Cutaway	40	16.5	20.0	25.9
2>3	135.2	Cutaway	40	16.2	19.5	25.3
2>4	138.1	Cutaway	40	16.5	20.0	25.9
2>8	125.9	Cutaway	40	15.1	18.2	23.6
2>9	187.5	Cutaway	40	22.4	27.1	35.1
Total				**110.5**	**133.4**	**173.1**

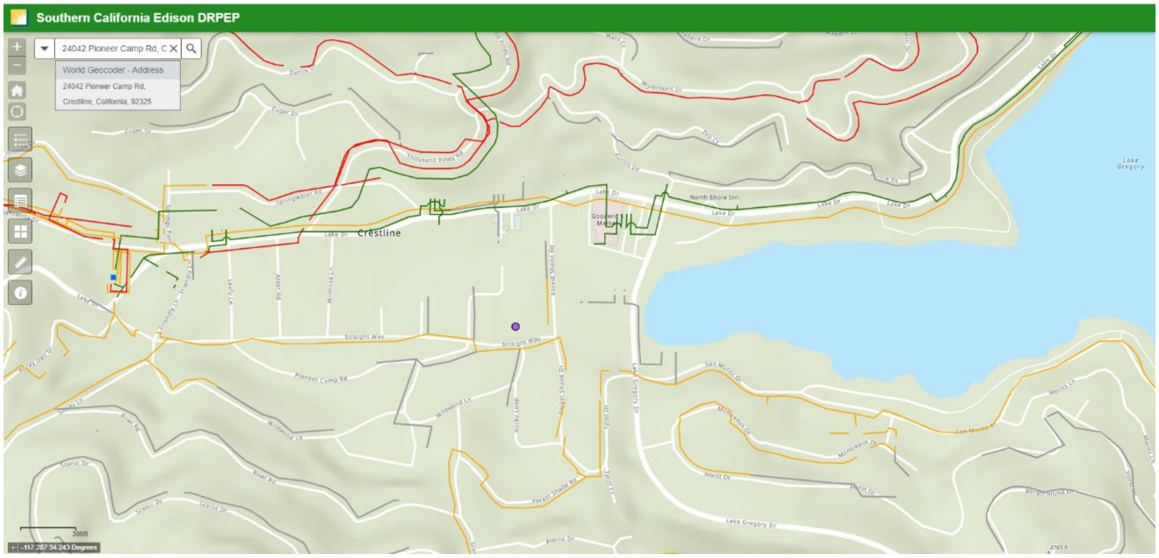
Source: WSP

4.3.2.1.2 Site Energy Analysis

The Crestline facility will be home to twelve buses maximum. Based on the recommended two 150 kW ground-mounted DC plug-in charging solution, there will be six plug-in charging positions in a 1:4 charger to bus dispenser ratio. This will require new SCE service for 300 kW.

According to SCE, the existing facility is served from the "Moritz" circuit (Figure 4-8), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. Therefore, at full build out, the Crestline facility would require ~2% of the circuit's power. It should be feasible for SCE to provide this service.

Figure 4-8: SCE Distribution Map Crestline Facility



Source: SCE

Using the current block scheme, the BEBs will require 460 - 780 kWh every day to support the six buses. The SCE EV-TOU rates don't include any "demand charges", so there is no incentive to "flatten the curve" of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9PM. Therefore, MT should invest in good charge management software that avoids incurring big costs from charging during peak times.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformers in a new utility yard in the open space north of the existing parking yard and east of the site entrance.
- One 480V switchboard in the new utility yard.
- Underground or aboveground conduits to ground mounted chargers around the outside of the site.

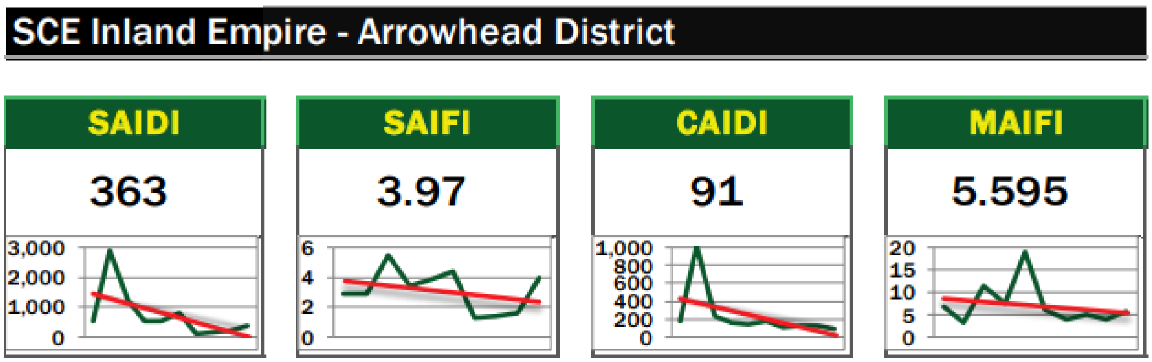
The EVSE could also be 60 kW chargers instead of 150 kW chargers. This would be a 1:2 charging ratio and would charge the vehicles slower and with less room for growth. But the capital cost may be cheaper. It is an option MT could consider though during a detailed design phase. The peak power would be closer to 240 kW.

This would also change the size of transformers required. If there is an unanticipated future growth requiring larger chargers, these could feasibly be added to an initial deployment of 60kW chargers, but steps should be taken during the detail design process to accommodate for transformer and conduit sizing to ensure minimal impact to any future re-work.

The effects of resiliency should also be considered though. If there is an outage, a faster charge time may be extremely beneficial to maintaining service in the event of an over-night outage.

From a resiliency perspective, this site is vulnerable to electric power disruption. In addition, this area of California is prone to wildfires and is completely located within the fire risk zone. As mentioned in Section 1.5.1.3, Crestline is located in SCE's Arrowhead district. This district has some of the worst reliability metrics in the state of California. All SCE distribution equipment is located aboveground on poles in this area, which is more vulnerable to wind and fire than underground utilities. See Section 1.5.1.3 for more details about reliability of SCE's electric grid. WSP recommends that Mountain Transit consider a back-up generator at this site. Figure 4-9 shows the reliability figure for the Crestline facility. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

Figure 4-9: Crestline Base (SCE Arrowhead District) Energy Reliability Figures



Source: SCE

The 2015 SAIDI score of 363 minutes indicates that each customer was without power for an average of 363 minutes throughout the year. The SAIFI score of 3.97 indicates that most customers had nearly 4 average outages per year. The CAIDI score of 91 minutes indicates that if Crestline loses power, it can expect to get power restored within 91 minutes on average. (3.97 outages * 91 minutes per outage = 363 total outage minutes) Finally, the Crestline site should also expect 5.595 momentary outages, which will reset all chargers, unless they are provided with uninterrupted power supplies, which adds cost.

4.3.2.2 Big Bear Lake (Future Site)

Based on the recommended ground-mounted DC plug-in charging solution, the Big Bear Lake (future) facility will be capable of parking 18 buses with 18 plug-in charging positions in a 1:2 charger to bus dispenser ratio. Smaller cutaway type vehicles will pull into spaces and charge in the front of the vehicle while larger buses will back into their parking stalls and be charged via a rear plug-in port.

The following BEB equipment and locations are proposed:

- Nine charging cabinets with 18 plug-in dispenser-charging positions along the western property line.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One medium voltage utility service transformer in the northwest corner of the site.
- One switchgear located in the northwest corner of the site.

MT does not currently perform any on-site fueling, and WSP does not recommend adding on-site fueling to the ongoing operations due to the difficulty of transporting hydrogen to the site at high altitude. If hydrogen fuel vehicles were desired by MT, WSP recommends installing a modular hydrogen compression and dispensing system coupled with a modular hydrogen generating, from water, electrolyser. The on-site generation of hydrogen would eliminate the need for commercial transportation up the mountain. However due to the high cost of the initial hydrogen equipment, the power used to create the hydrogen with the electrolyser, and the significant maintenance of the hydrogen equipment and an operational history of no on-site fueling, while viable WSP does not recommend a hydrogen solution for MT.

Conceptual layouts for the proposed ZEB solutions for MT's facilities are present in Section 4.3.5.3.

4.3.2.2.1 Modeling Results

Base-Only Charging – Big Bear Lake (Future)

Currently, the Big bear Lake facility operates five vehicle blocks. The smallest vehicle block distance traveled is 96 miles and the longest is 273 miles. As discussed in Section 2.1.2, a 118 kWh (94 kWh operating) battery was used to model the cutaway transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with the 118 kWh battery. Eighty percent of vehicle blocks could be completed at the optimistic and base efficiency, and 60 percent could be completed at the conservative efficiency.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies for base-only charging, two vehicle blocks would need to be served by vehicles with an advertised battery capacity of around 250 kWh that also operate at the same kWh/mi as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 4-9 provides the summary of block completion at the Big Bear Lake facility, and Table 4-10 provides a list of the current vehicle blocks that would not be able to complete the service with the battery capacity modeled. Table 4-10 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 4-9: MT - Big Bear Lake Base-Only Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	80% (4)	80% (4)	60% (3)
150	120	80% (4)	80% (4)	80% (4)
200	160	100% (5)	80% (4)	80% (4)
250	200	100% (5)	100% (5)	80% (4)
300	240	100% (5)	100% (5)	100% (5)

Source: WSP

Table 4-10: Summary of MT's Big Bear Lake Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
2>11	118	7.1	115	72	96	120
2>12	118	14.6	273	172	229	286

Source: WSP

Hydrogen Fuel Cell Electric Bus

Without cutaway FCEB vehicles currently available on the market, the Big Bear future facility does not qualify for FCEB adoption at this time.

Service Performance

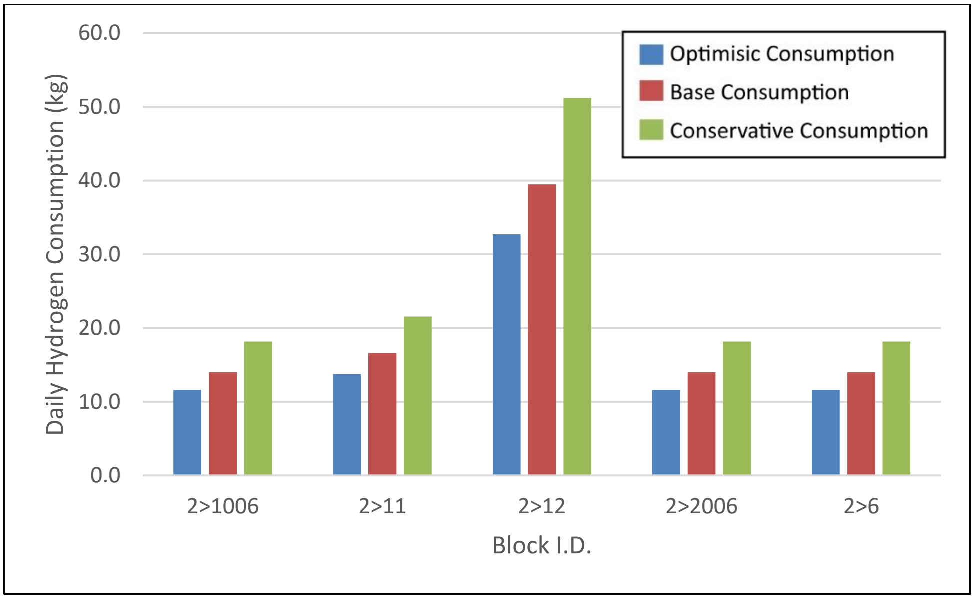
Without cutaway FCEB vehicles currently available on the market, the Big Bear future facility does not qualify for FCEB adoption at this time.

Hydrogen Requirements

An analysis of anticipated fuel consumption for full-fleet FCEB conversions was conducted to support future planning efforts following the release of FCEB cutaways. This information may be used when considering future vehicle procurements and on-site hydrogen storage and production needs.

Four of the five service blocks operating out of Big Bear Lake run less than 115 miles per day resulting in extremely low hydrogen fuel requirements ranging between 11.6 kg and 22 kg. Out of this facility, block 2>12 has a significantly longer block distance at 273 miles, requiring a daily hydrogen need ranging between 33 kg and 51 kg per day (Figure 4-10). In total, if fully converted to FCEB, the Big Bear Lake fleet would require between 81 kg and 127 kg of hydrogen a day (Table 4-11). This quantity could be reasonably be provided through on-site production via SMR or electrolysis as well as contracted delivery.

Figure 4-10: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Big Bear Lake



Source: WSP

Table 4-11: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Big Bear Lake

Block ID	Block Distance	Vehicle Type	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
2>1006	96.9	Cutaway	40	11.6	14.0	18.2
2>11	114.9	Cutaway	40	13.7	16.6	21.5
2>12	273.3	Cutaway	40	32.7	39.5	51.2
2>2006	96.9	Cutaway	40	11.6	14.0	18.2
2>6	96.9	Cutaway	40	11.6	14.0	18.2
2>1006	96.9	Cutaway	40	11.6	14.0	18.2
Total				**81.2**	**98.1**	**127.2**

Source: WSP

4.3.2.2.2 Site Energy Analysis

The future Big Bear Lake facility will be home to eighteen buses maximum. Based on the recommended three 60 kW ground-mounted DC plug-in charging solution, there will be eight plug-in charging positions in a 1:2 charger to bus dispenser ratio. This will require new Bear Valley Electric Service for 420 kW of additional load.

Exact circuit information from the Big Bear Lake site is unknown since it is not under the same SCE Distribution system. This site is serviced from Bear Valley Electric Service. The WSP team spoke with BVES on January 28th and got details on what they can support electrically. Currently, this facility is only slated for three chargers, though there may be a new facility built nearby. In either case, BVES has said they could support up to 1MW of new load growth in the area without any impact to the distribution grid. The site will need an upgraded transformer, but that is site specific, not utility specific, and most installations will require new medium voltage SW/Transformers on site anyways.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformers in a new utility yard in the open space north of the existing parking yard and east of the site entrance.
- One 480V switchboard in the new utility yard.
- Underground or aboveground conduits to ground mounted chargers around the outside of the site.

The EVSE could also be 150 kW chargers instead of 60 kW chargers. This would also be a 1:2 charging ratio and would charge he vehicles substantially faster and would allow for growth of the fleet as well, however it would be more expensive. It is an option MT could consider though during a detailed design phase. The peak power would be just over 1MW, which would mean BVES would need to consider their ability to support these loads much more closely. Additionally, a mix of 150 kW or 60 kW chargers could be considered for this site as well.

4.3.3 ZEB Procurement Schedule

In accordance with the ICT regulation, MT will prioritize ZEB purchases and progressively increase the percentage of ZEB purchases over time. Based on initial analysis, the last conventional bus is expected to be purchased in 2028. All new buses purchases are anticipated to be ZEB starting in 2029.

Early retirement should not be an issue pursuant to the ICT regulation based on MT's assumed procurement schedule. However, if it becomes one, MT will deploy various strategies to ensure that buses fulfill their "useful life". One potential strategy is to place newly acquired buses on MT's longest (distance) blocks of service. This will ensure that these buses meet their distance-based useful life requirement more rapidly.

MT's existing fleet consists of 24 cutaway buses and vans. Assuming a 1:1 replacement ratio, each existing bus will eventually be replaced with an equivalent-length BEB cutaway bus. However, the number of ZEBs required may increase with time based on service requirements.

Table 4-12 presents a summary of MT's anticipated bus procurements through 2040. Years 2026 and 2029 are highlighted because these indicate when MT's new purchases should be 25 percent and 100 percent ZEBs, respectively.

Table 4-12: Summary of MT's Future Bus Purchases (through 2040)

Year	Total Buses	Zero-Emission Buses				Conventional (Gasoline or Diesel) Buses			
		Number	PCT.	Bus Type	Fuel Type	Number	PCT.	Bus Type	Fuel Type
2020	3	0	0%	-	-	3	100%	Cutaway	Gasoline
2021	6	0	0%	-	-	6	100%	Cutaway	Gasoline
2022	1	0	0%	-	-	1	100%	Cutaway	Gasoline
2023	4	0	0%	-	-	4	100%	Cutaway	Gasoline
2024	11	0	0%	-	-	11	100%	Cutaway	Gasoline/Diesel
2025	2	0	0%	-	-	2	100%	Cutaway	Gasoline
2026	4	1	25%	Cutaway	BEB	3	75%	Cutaway	Gasoline
2027	0	0	0%	-	-	0	0%	-	-
2028	5	2	40%	Cutaway	BEB	3	60%	Cutaway	Gasoline
2029	8	8	100%	Cutaway	BEB	0	0%	-	-
2030	5	5	100%	Cutaway	BEB	0	0%	-	-
2031	4	4	100%	Cutaway	BEB	0	0%	-	-
2032	2	2	100%	Cutaway	BEB	0	0%	-	-
2033	1	1	100%	Cutaway	BEB	0	0%	-	-
2034	9	9	100%	Cutaway	BEB	0	0%	-	-
2035	4	4	100%	Cutaway	BEB	0	0%	-	-
2036	7	7	100%	Cutaway	BEB	0	0%	-	-
2037	3	3	100%	Cutaway	BEB	0	0%	-	-
2038	1	1	100%	Cutaway	BEB	0	0%	-	-
2039	7	7	100%	Cutaway	BEB	0	0%	-	-
2040	4	4	100%	Cutaway	BEB	0	0%	-	-

Note: The first replacement for each bus type is based on MT's existing procurement schedule, each subsequent replacement is based on FTA's UBL.
Source: WSP, March 2020

4.3.4 Mountain Transit Cost Analysis

This analysis should be considered a conservative assessment of battery and fuel cell electric bus costs, as the industry in North America is in the preliminary stages of product development. Production costs are anticipated to decrease as production increases to meet future demand.

4.3.4.1 Battery Electric Buses – General Assumptions

The WSP team is actively engaged with Electric vehicle manufacturers to understand trends in the industry and VVTA, the only county operator currently operating BEBs, to inform assumptions vehicle operations. The values presented throughout this document are subject to change and based on the best available information at the time of this analysis.

Compared to conventional diesel and gasoline fueled vehicles, electric vehicles incur different capital and operating costs that vary based on the type of vehicles and operating environments.

For example, the cost of installation and maintenance of charging infrastructure will differ in both magnitude and the types of resources required in comparison to the replacement and maintenance of a diesel fueling facility. Other examples include battery replacement schedules, mid-life overhaul, and disposal value.

Electric buses and garages may offer the opportunity to lower some operations and maintenance costs while increase others, and similar to conventional fueled vehicles, are highly dependent on the size and complexity of the vehicle fleet being supported. Additionally, an electrification strategy would entail replacing unleaded gasoline and diesel with electric power, which would incur very different energy pricing structures and exposure to energy price volatility. Table 4-13 outlines the major cost categories associated with vehicle electrification. Estimated costs in each of these categories were developed for electrification scenarios, as well as a "business as usual" baseline which assumes no change in the current types of vehicles in the fleet.

The total cost of each operator's transition will be contingent upon their specific fleet size, vehicle acquisition plan, facility sizes, charging strategy, and construction schedule, among other details.

Table 4-13: Cost Components attributed to Electric Vehicle Operations

Capital	Vehicle and Equipment Purchase
	Training, Capital Spares & Contingency
	Charging Infrastructure
	Mid-Life Fleet Overhaul
	Battery Replacement
Operating	Vehicle Maintenance
	Vehicle Tools, Training and Equipment
	Vehicle Energy Costs
	Charger Maintenance
	Fueling/Charging Labor
Disposal	Battery Disposal/Salvage
	Bus Salvage

Source: WSP

4.3.4.1.1 Battery Electric Vehicle Costs

Battery electric vehicle procurement costs continue to evolve as new vehicle models are developed and production increased to meet demand. Anticipated cost reductions through economies of scale may be somewhat offset by discounted prices that may be offered by some manufacturers to establish market share, specifically new entrants to the market. Furthermore, battery technology and production continue to evolve offering further potential reductions to production costs but also potential exposure to volatility in the pricing structures for critical battery production inputs. Additional considerations also need to be considered for specific agency requirements and features, delivery schedule requirements, and battery size requirements to meet operating conditions. Assumptions regarding procurement costs for battery electric vehicles as compared to MT's unleaded vehicles and their one diesel bus are provided in the table below:

Table 4-14: Vehicle Cost Assumptions

Vehicle Type	Vehicle Cost Estimates (2019 $s)
Battery Electric 16.5 ft	$173,315
Battery Electric 22 ft	$194,795
Battery Electric 25 ft	$317,761
Battery Electric 27 ft	$237,036
Battery Electric 27.5 ft	$242,528
Battery Electric 30 ft	$302,554
Battery Electric 32.5 ft	$270,345
Battery Electric 37 ft	$904,490
Unleaded 16.5 ft	$53,316
Unleaded 22 ft	$80,459
Unleaded 25 ft	$117,036
Unleaded 27 ft	$117,036
Unleaded 27.5 ft	$105,150
Unleaded 30 ft	$136,706
Unleaded 32.5 ft	$137,619
Diesel 37 Ft	$230,000

Source: WSP

Conventional gasoline fuel vehicle acquisition costs ranged from $53,316-$137,619 for cutaway vehicles ranging in size between 16.5 feet to 32.5 feet and are based on information provided by current cutaway vehicle manufacturers. Assumptions from the California Air Resources Board (CARB) on vehicle purchase prices determined that the incremental cost of zero-emissions cutaway vehicles is approximately $120,000 as compared to unleaded gasoline cutaway vehicles. The larger 37-foot bus cost of $904,490 is based on information provided by transit bus manufacturers.

4.3.4.1.2 Charging Infrastructure Costs

Charging infrastructure cost estimates include equipment, design and installation costs which primarily consist of materials and labor. The cost estimates also include general contractors and subcontractor's markups which are comprised of field overhead, home office overhead, and subcontractor earnings. The estimates also include a pricing contingency markup, to allow for unexpected design and installation Issues.

Plug-in chargers are assumed to cost $70,701, based on a recent VVTA contract.[29] Additionally, the cost to install chargers, including labor and permits, is assumed to be $8,500 per charger. On-route opportunity chargers are assumed to cost $330,000 for both the charger and installation, based on the experience of Foothill Transit. With the recommended ground-mounted plug-in charging strategy, the Crestline Facility would be capable of parking 12 buses with 12 plug-in charging positions (6 chargers), and the Big Bear Lake base is capable of accommodating 18 buses

[29] VVTA New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6, 2018.

with 18 plug-in positions (9 chargers), in a 1:2 charger to bus dispenser ratio. The financial analysis assumes that chargers would be purchased in the year that buses are ordered, when the cost of purchasing the charger would be incurred, and the cost of installing the charger would be incurred in the year of vehicle delivery, which is assumed to be one year after the bus order. As such, the exact year and number of chargers purchased correleates with the fleet procurment plan, presented in Section 4.3.4.2.2.

The analysis did not include on-site stationary battery energy storage for resiliency. If Mountain Transit elects to include a generator for resiliency of their battery electric buses, a generator at Crestline is estimated to cost $421,500 based on a full load of 300 kW, and a generator at Big Bear Lake is estimated to cost $843,000 based on a full load of 600 kW.

4.3.4.1.3 Mid-life Overhaul and Battery Replacement

At the year seven mid-point of each vehicle's operational life, a full vehicle overhaul, is assumed on all buses with a length of 30-feet and greater. This includes the 30, 32.5, and 37 feet vehicles.[30]

The analysis assumes that MT's battery electric vehicles will include battery warranties, and as such, battery replacement costs are not assumed to be incurred by MT.[31] Battery replacements on the existing unleaded and diesel fleets are assumed to be minimal and part of existing maintenance costs.

4.3.4.1.4 Tire Replacement Cost

The analysis assumes that MT's vehicles undergo regular tire replacements, which have a significant contribution to costs. Specifically, MT incurred approximately $80,219 in tire replacement costs for 24 vehicles, from the months of August 2018 to June 2019, a time period during which MT operated an average vehicle mileage of 28,984. This translates into an annual cost of $0.115 per mile, which is significantly higher than industry standards and peer agencies; however, given the terrain, the grades and severe weather conditions, tires are replaced more frequently.

4.3.4.1.5 Operations and Maintenance Costs

Components of O&M costs include vehicle maintenance, vehicle tools, training and PPEs, vehicle fuel costs, and the costs to maintain and operate charging and fueling infrastructure. Annual O&M cost assumptions for electric vehicles are outlined in Table 4-15, represented in a cost per mile.

The analysis applies unit O&M cost per mile by vehicle type with total costs based on assumed average annual vehicle mileage. The model accounts for changes to service levels based on range restrictions for electric vehicles to estimate O&M costs, by applying unit costs to total mileage as driven by number of vehicles and mileage per vehicle.

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[30] During an interview among Mountain Transit staff, MK Consulting, and WSP on March 4, 2020, Mountain Transit staff indicated that the agency performs overhaul activities on their vehicles and may be able to provide costs. At the time that this iteration of the financial analysis was documented, WSP had not received the overhaul costs. As such, WSP's assumptions regarding overhaul frequency and costs are based on peer agencies and industry data. However, the model can be easily updated with data and assumptions more specific to Mountain Transit should this become available.

[31] If the vehicle purchases or leases will not include a warranty, a battery replacement cost may be estimated at approximately, $7 per pound, and assumed to weigh approximately 500 pounds, based on similar transit agencies. The model can be easily updated to assume this.

Table 4-15: Electric Vehicle Maintenance Costs by Vehicle Age (2019 Dollars per mile)

Vehicle Age	16.5	22	25	27	27.5	30	32.5
Year 1	0.24	0.25	0.27	0.31	0.31	0.32	0.34
Year 2	0.21	0.22	0.24	0.27	0.27	0.28	0.30
Year 3	0.21	0.22	0.24	0.27	0.27	0.29	0.30
Year 4	0.24	0.26	0.28	0.32	0.32	0.33	0.35
Year 5	0.29	0.31	0.33	0.38	0.38	0.40	0.42
Year 6						0.44	0.46
Year 7						0.49	0.52

Source: WSP

4.3.4.1.6 Energy Costs

Electricity prices for battery electric vehicles are based on current rates with Southern California Edison (SCE) and reflect charge rates and demand for energy consumption that vary by hour and month.

Total annual energy costs are estimated for each operator and facility and are highly driven by charging strategy with respect to location of on route chargers if any, facilities, vehicle routes, and fleet size purchase. These charging strategies are subject to change as the team works to refine each agency's optimal charging strategy, and as charging rates change. This analysis does not assume any major behavioral changes based on coach operators.

Table 4-16 presents Southern California Edison Rates and Table 4-17 presents the hours during which each rate from Table 4-17 would be applicable.

Table 4-16: Rates per kWh

Rates (per kWh)		
Time of Use Period	Summer (June-September)	Winter (October-May)
On-Peak	$0.41	
Mid-Peak	$0.20	$0.24
Off-Peak	$0.10	$0.10
Super Off-Peak		$0.06

Source: WSP

Table 4-17: Time Periods

Time Periods (weekdays excluding holidays)				
	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	16:00-21:00	N/A	N/A	N/A
Mid-Peak	N/A	16:00-21:00	16:00-21:00	16:00-21:00
Off-Peak	All other hours	21:00-08:00	All other hours	21:00-08:00
Super Off-Peak	N/A	08:00-16:00	N/A	08:00-16:00

Source: WSP

The rates in Table 4-16 and Table 4-17 above were applied to the hourly times during which the operators are expected to be charging. The energy use assumed for each operator, in a moderate charging scenario, is presented in Table 4-18. The model is capable of running additional scenarios to cost the low charging and high charging scenario as well.

As displayed in Table 4-18 and Table 4-20, the Mountain Transit Crestline facility is expected to charge during 9 hours of the day, while the Big Bear Lake buses will charge for 7 hours of the day.

Table 4-18: Hourly Energy use (kWh) – Moderate Scenario

Facility ID	Facility	Operator	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
1000001	Joshua Tree Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	-
1000002	29 Palms Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	50
1000003	Crestline	MT	-	-	-	-	-	-	-	-	-	-	-	78
1000009	Big Bear Lake	MT	-	-	-	-	-	-	-	-	-	15	50	-
1000004	West Valley	Omnitrans	5,300	4,788	3,633	2,415	1,203	350	80	-	128	80	-	-
1000005	East Valley	Omnitrans	11,488	9,843	7,523	4,808	2,040	688	373	168	130	433	735	553
1000006	VVTA HQ - Hesperia Yard	VVTA	3,988	3,810	2,668	1,845	1,335	688	480	155	305	405	308	423
1000007	Barstow Future Yard	VVTA	945	660	600	600	525	173	110	220	295	300	215	-
1000008	Needles Garage	Needles	-	-	-	-	-	-	-	-	-	-	-	-

Source: WSP

Table 4-18: Hourly Energy use (kWh) – Moderate Scenario (continued)

Facility ID	Facility	Operator	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1000001	Joshua Tree HQ	MBTA	88	-	133	-	-	-	320	58	-	-	13	140
1000002	29 Palms Yard	MBTA	-	10	208	-	-	5	130	-	10	43	80	65
1000003	Crestline	MT	15	-	-	-	-	75	15	143	180	28	83	3
1000009	Big Bear Lake	MT	-	-	65	-	-	78	-	95	150	3	-	-
1000004	West Valley	Omnitrans	-	-	-	20	75	-	148	808	1,950	3,615	5,313	5,918
1000005	East Valley	Omnitrans	258	308	533	508	273	48	195	2,493	5,723	8,355	11,143	12,978
1000006	VVTA HQ - Hesperia Yard	VVTA	183	55	-	-	265	815	1,475	1,800	1,630	3,563	4,720	4,075
1000007	Barstow Future Yard	VVTA	-	-	-	-	-	23	150	265	958	1,470	1,370	1,080
1000008	Needles Garage	Needles	-	-	-	-	-	-	8	103	-	-	-	-

Source: WSP

Table 4-19 and Table 4-20 lay the Crestline and Big Bear Valley resulting costs, based on the hourly SCE rates and the hourly charging strategy, as well as the total resulting annual cost per bus.

Table 4-19: Total Annual Cost Per Bus - Mountain Transit, Crestline

Months	Days per month	11:00	12:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
January	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22	264.01	8.00
February	28	140.90	27.27	495.66	99.13	941.76	1,189.59	181.74	238.46	7.23
March	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22	264.01	8.00
April	30	150.96	29.22	531.07	106.21	1,009.03	1,274.56	194.72	255.49	7.74
May	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22	264.01	8.00
June	30	229.11	44.34	920.05	184.01	1,748.09	2,208.11	337.35	243.89	7.39
July	31	236.74	45.82	950.72	190.14	1,806.36	2,281.72	348.60	252.02	7.64
August	31	236.74	45.82	950.72	190.14	1,806.36	2,281.72	348.60	252.02	7.64
September	30	229.11	44.34	920.05	184.01	1,748.09	2,208.11	337.35	243.89	7.39
October	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22	264.01	8.00
November	30	150.96	29.22	531.07	106.21	1,009.03	1,274.56	194.72	255.49	7.74
December	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22	264.01	8.00
Total	365	2,154	417	8,043	1,609	15,282	19,304	2,949	3,061	93
									Total Annual Cost	**$52,912**
									Buses at Garage	**10**
									Total Annual Cost Per Bus	**$5,291**

Source: WSP

Table 4-20: Total Annual Cost Per Bus - Mountain Transit, Big Bear Valley

Months	Days per month	9:00	10:00	14:00	17:00	19:00	20:00	21:00
January	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22
February	28	140.90	27.27	495.66	99.13	941.76	1,189.59	181.74
March	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22
April	30	150.96	29.22	531.07	106.21	1,009.03	1,274.56	194.72
May	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22
June	30	229.11	44.34	920.05	184.01	1,748.09	2,208.11	337.35
July	31	236.74	45.82	950.72	190.14	1,806.36	2,281.72	348.60
August	31	236.74	45.82	950.72	190.14	1,806.36	2,281.72	348.60
September	30	229.11	44.34	920.05	184.01	1,748.09	2,208.11	337.35
October	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22
November	30	150.96	29.22	531.07	106.21	1,009.03	1,274.56	194.72
December	31	155.99	30.19	548.77	109.75	1,042.66	1,317.05	201.22
Total	365	2,154	417	8,043	1,609	15,282	19,304	2,949
							Total Annual Cost	**$52,912**
							Buses at Garage	**10**
							Total Annual Cost Per Bus	**$5,291**

Source: WSP

4.3.4.1.7 Environmental Costs

Environmental costs are considered non-cash expenses and include monetized values for tailpipe emissions and upstream emissions of CO2, criteria pollutants, and noise. The analysis does not assume tailpipe emissions for battery electric vehicles and includes estimates of tailpipe emissions for unleaded gas cutaway vehicles, for comparative purposes. Tailpipe emissions include estimates of CO_2, NO_X, CO, PM_{10}, $PM_{2.5}$. Emissions data was taken from the U.S. Department of Energy's Greet Fleet Calculator tool.

Upstream emissions consist of emissions resulting from petroleum refining for the production of unleaded gasoline and diesel, and production of electricity for battery electric vehicles are based on the mix of utility power sources.

4.3.4.1.8 General - Inflation

The model accounts for inflation using the Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U).[32]

Table 4-21: Consumer Price Index

CPI-U	2019	2020	2021	2022	2023
Riverside & San Bernardino	2.87%	3.24%	2.96%	3.10%	3.03%

Source: WSP

4.3.4.2 Scenario Analysis

4.3.4.2.1 Cost Overview

Background

Analysis was conducted to compare an electrification scenario for MT with a "business as usual" scenario which assumes that all future procurements maintain the current Mountain Transit practice of procuring unleaded gasoline and diesel vehicles (referred to as Scenario 1 Baseline unleaded).

The electrification scenario assumes that MT will not replace the two 37-foot diesel freightliners with battery electric buses, given the challenging route conditions of high miles per route or block and steep grades, and the lower acquisition costs for the diesel bus in comparison to a 37.5' BEB. Instead, the analysis assumes that MT will replace these vehicles with another diesel freightliner when they reach the end of their useful lives in 2024 and that by 2032, the replacement diesels will be replaced with an electric buses. Given CARB's mandate of conversion by 2040, the business as usual scenario is a theoretical scenario for comparative benefit-cost assessment purposes.

The analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs, plus a non-cash cost of environmental benefits and costs, which WSP staff monetizes to account for a holistic comparative between cost and benefit.

[32] Source, California Department of Finance: http://www.dof.ca.gov/Forecasting/Economics/Eco_Forecasts_Us_Ca/documents/US%20CA%20Inflation%20Forecast%20GB%202020-21.xlsx

Table 4-22 delineates the overall results of the MT analysis, assessing the full electric vehicle conversion and the baseline scenario. Values presented throughout this document are subject to change as updated costs are uncovered.

Table 4-22: Mountain Transit – Overall Cost Summary

2020-2050 Fleet Replacement Cost Comparison (2020 dollars in millions)		SCENARIO 1: Baseline Unleaded and Diesel Vehicles	SCENARIO 2: Build – Electric Vehicles
Capital	Vehicle Purchase Price	6.48	9.61
	Modifications & Contingency	5.16	5.60
	Charging/Fueling Infrastructure	0.03	0.99
	Total Capital Costs	*11.67*	*16.20*
Operating	Vehicle Maintenance	9.60	8.47
	Overhaul	0.64	1.24
	Tire Replacement Cost	1.45	1.58
	Vehicle Tools Training and PPEs	0.00	0.00
	Other and Miscellaneous Costs	1.21	1.32
	Vehicle Fuel Costs	7.34	4.43
	Electric Vehicle Utility Costs	-	0.47
	Charging/Fueling Infrastructure	0.04	0.08
	Battery/Fuel Cell Replacement	0.18	0.09
	Total Operating Costs	*20.46*	*17.68*
Disposal	Battery Disposal[33]	-	-
	Bus Disposal (Salvage Value)	(0.15)	(0.08)
	Total Disposal Costs	*(0.15)*	*(0.08)*
	Total Cash Costs	31.98	33.80
	Total Cash Cost per Mile	2.67	2.41
Environmental	Emissions - Tailpipe	0.37	0.21
	Emissions - Refining/Utility	0.12	0.13
	Noise	0.60	0.61
	Total Environmental Costs	*1.09*	*0.95*
	Total Cash and Non-Cash Costs	33.07	34.75
	Total Cash and Non-Cash Costs per Mile	2.76	2.48
	Total Mileage (million miles)	**12**	**14**

Source: WSP

[33] The analysis assumes that Mountain Transit's battery electric buses will include battery warranties, and as such, battery replacement costs are not assumed to be incurred by Mountain Transit. Battery replacements on the existing unleaded and diesel fleets are assumed to be part of existing maintenance costs. If the bus purchases or leases will not include a warranty, the analysis can be easily updated to assume this.

4.3.4.2.2 Cost Conclusions

Overall, the lifecycle cost analysis shows that despite higher initial costs, the full lifecycle cost of a transition to battery electric vehicles will be slightly higher in comparison to continued reliance on unleaded gasoline and diesel vehicles. While operating costs savings are anticipated for a conversion to electric vehicles, the high capital costs of electric vehicles, batteries and charging infrastructure may offset the savings. As operating costs are highly dependent on factors that are not well-established, as further discussed in pervious sections. This is particularly the case for annual vehicle maintenance costs, while existing capital cost premiums are currently well-known.

Discussion of General Inputs

Inputs to the lifecycle cost model include:

- Fleet modernization schedules – vehicles acquired each year by fuel type.
- Vehicle costs including initial purchase, maintenance, mid-life overhaul and disposal
- Battery purchase, replacement and disposal or salvage
- Battery charging infrastructure purchase, installation and maintenance
- Energy costs, gasoline, diesel, and electricity
- Environmental costs for vehicle tailpipe emissions of CO_2 and criteria pollutants
- Environmental costs for vehicle noise

The model examines one complete replacement of the fleet, beginning in the year 2020 and ending with final vehicle acquisition in 2024. The model tracks the total cost of ownership (initial capital cost, annual operating cost and final disposal cost) of each new vehicle for its full asset life.

The values provided are not a comparison between an all unleaded gasoline or diesel vehicle and a electric vehicle fleet, but rather a comparison between continuing current practices and gradually phasing in battery electric vehicle procurement.

In addition to vehicle costs, the model also includes the costs of purchasing, installing and maintaining charging infrastructure for battery electric vehicles.

All model inputs are provided in current year (2019/2020) dollars. The model applies inflation factors to escalate costs to year of expenditure dollars. The Riverside-San Bernardino-Ontario metropolitan area historical CPI-U, presented in Table 4-22, was used for most costs, except the following cases where a different specific index was used:

- Unleaded gasoline prices used the 2019 average of unleaded gasoline prices in California as a basis, and then were escalated were escalated at the same rate as national average gasoline prices as forecasted by EIA. Short term resulting forecast is presented in Table 4-23.

Table 4-23: Unleaded gasoline price forecast

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	3.46	3.96	4.25	4.51	4.72

Source: WSP

- Electricity costs were escalated using EIA transportation electricity annual forecasted price growth rate forecasts by year

Table 4-24: Annual Energy Outlook – US Energy Information Administration[34]

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	0.00%	14.75%	5.14%	6.08%	5.24%

Source: WSP

Year of expenditure costs were then discounted to present value 2020 dollars using a discount rate of 2.37 percent. The resulting present values of all costs are summed to yield the full lifecycle cost comparison.

Vehicle Procurement Schedule by Facility; Scenario 2: Electric Vehicle Conversion

The battery electric vehicle scenario assumes the vehicle procurements to be consistent with the tables that follow. These procurements could either continue the MT current practice of procuring only unleaded cutaway vehicles, switch to procuring only electric vehicles (battery or fuel cell), or procure a mix over the years of transition. The two primary factors that would need to be considered for each year of procurement are the availability of charging infrastructure and the range and performance of available electric vehicles, as well as the vehicles ability to perform and provide durability, which is required in a four season, rural, mountainous environment.

In early years, the construction of charging infrastructure would be the primary constraint, which is why battery electric vehicles are not assumed to be procured until 2023 for RIM and 2022 for Big Bear Lake. Existing vehicles which will reach the end of their useful life prior to the build out of this infrastructure are assumed to be replaced with unleaded gasoline vehicles.

[34] US Energy Information Administration, Annual Energy Outlook 2018 - Reference: 3-AEO2018.101.ref2018-d121317a

Table 4-25: Scenario 2 - Electric Vehicle Fleet Replacement Schedule Breakdown - Big Bear Lake

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
16.5’ EV													1			
22’ EV														1		
25’ EV										1						
27’ EV										1						
27.5’ EV										1						
30’ EV											1					
32.5’ EV									2	1	2					
37’ DSL															1	
37’ EV																
16.5’ UNL	1				1				1							
22’ UNL				1					1							
25’ UNL					1											
27’ UNL					1											
27.5’ UNL					1											
30’ UNL				1												
32.5’ UNL		2	1	2												
37’ DSL					2											
Total	**1**	**2**	**1**	**4**	**6**	**0**	**0**	**0**	**4**	**4**	**3**	**0**	**1**	**1**	**1**	**0**

Source: WSP

Table 4-26: Scenario 2 - Electric Vehicle Fleet Replacement Schedule Breakdown – RIM

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
16.5’ EV													1			
22’ EV											2					
25’ EV										1						
27.5’ EV							1			3		4				
16.5’ UNL	1				1				1							
22’ UNL	1					2										
25’ UNL					1											
27.5’ UNL		4			3		3									
Total	**2**	**4**	**0**	**0**	**5**	**2**	**4**	**0**	**1**	**4**	**2**	**4**	**1**	**0**	**0**	**0**

Source: WSP

Vehicle Procurement Schedule by Facility – Baseline Unleaded Gasoline/Diesel

Table 4-27: Scenario 1 - Baseline Fleet Replacement Schedule Breakdown - Big Bear Lake

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
16.5’ UNL	1				1				1				1			
22’ UNL				1					1					1		
25’ UNL					1					1						
27’ UNL					1					1						
27.5’ UNL					1					1						
30’ UNL				1							1					
32.5’ UNL		2	1	2					2	1	2					
37’ DSL					2										1	
Total	**1**	**2**	**1**	**4**	**6**	**0**	**0**	**0**	**4**	**4**	**3**	**0**	**1**	**1**	**1**	**1**

Source: WSP

Table 4-28: Scenario 1 - Baseline Fleet Replacement Schedule Breakdown - RIM

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
16.5' UNL	1				1				1				1			
22' UNL	1					2					2					
25' UNL					1					1						
27.5' UNL		4			3		4			3		4				
Total	**2**	**4**	**0**	**0**	**5**	**2**	**4**	**0**	**1**	**4**	**2**	**4**	**1**	**0**	**0**	**0**

Source: WSP

4.3.4.3 Uncertainties

The analysis provided in this documentation should be considered a conservative assessment of battery and fuel cell electric vehicle costs, as the industry in North America is still developing as demand increases and the market stabilizes. Production costs may decrease as production increases to meet future demand through benefits of economy of scale. However, cost reductions may be offset by reductions in tax breaks, grant programs, discounts and incentives that are available for the acquisition of battery electric vehicles and associated charging infrastructure. There may be additional costs associated with the management and reporting of these programs.

The costs for batteries are also anticipated to decline with continued development of more efficient technology and lower production costs resulting from economies of scale. Some potential future cost reductions, however, may be offset (or more than offset) through increases in the cost of acquiring the primary battery components, specifically lithium or other alternative rare earth minerals. In addition, the energy density of batteries is increasing, so the decline in cost per kWh could be offset by a choice to buy higher-capacity, longer range batteries for vehicles purchased in later years and for replacement of original batteries on vehicles purchased in the early years.

The cost of fuel and electricity also have a strong correlation on the benefits of battery electric vehicles over gasoline or diesel vehicles. Any major changes to the price would have a direct impact on operating costs for the agency. While utility prices are historically less volatile than gasoline and diesel prices, there exists less downward price potential as utility prices tend to be set by large scale capital investments and distribution costs, as opposed to market inventory levels and feedstock supply costs, which are the primary drivers of gasoline and diesel prices and volatility.

4.3.5 Recommendations

4.3.5.1 MT Fleet Technology

Without FCEB cutaways currently available on the market, this report recommends a full battery-electric conversion. The capabilities of current BEB technology would support the immediate conversion of zero blocks. This leaves six blocks that will require an alternative strategy for successful BEB integration.

There are strategies that may be used to support BEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Phasing BEB integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities that must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

4.3.5.2 Fleet Phasing and Implementation

WSP recommends that the entire electrical yard infrastructure for the site's BEB charging requirements including a transformer and switchgear sized for the ultimate fleet be installed with the initial phase at the Crestline and Big Bear Lake future sites to avoid having to disrupt ongoing charging operations or install duplicate infrastructure in subsequent phases.

4.3.5.2.1 Crestline Phasing

WSP recommends completing the entire charger and infrastructure installation at the Crestline site in a single phase as the site layout precludes dividing the project in a manner to gain advantages on costing or construction, see Figure 4-12.

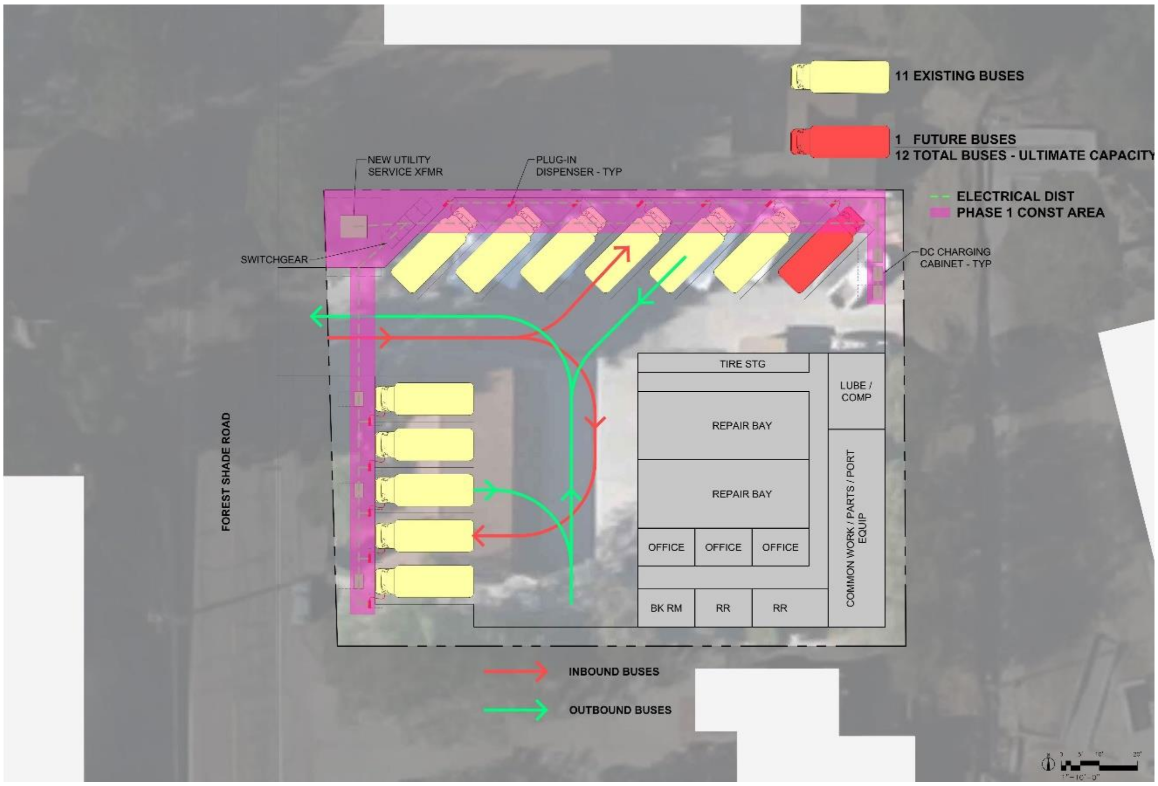
The plan for the Crestline site is to install all of the electrical distribution in above-ground conduit along the northern existing site wall to route electrical service to all four charging cabinets with eight plug-in dispensers mounted at the edge of the parking spaces on the northern boundary of the facility. These chargers and dispensers can be installed without trenching the existing facility. However, this may change with the redesign of the property.

4.3.5.2.2 Big Bear Lake Phasing

The Big Bear Lake future facility will be completed in one phase, as this is a new construction, greenfield site. It is recommended that conduit, circuitgear, and adqueate power supply be taken into consideration prior to construction. Thus, installation chargers may be phased in gradually as the operator adopts BEBs, yet infrastructure will already be established.

4.3.5.3 Facility Preliminary Design

Figure 4-11: Crestline Proposed Full ZEB Build-out and Phasing



Source: WSP

Figure 4-12: Big Bear Lake Proposed Full ZEB Build-out and Phasing

Source: WSP

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5 CITY OF NEEDLES

5.1 Introduction

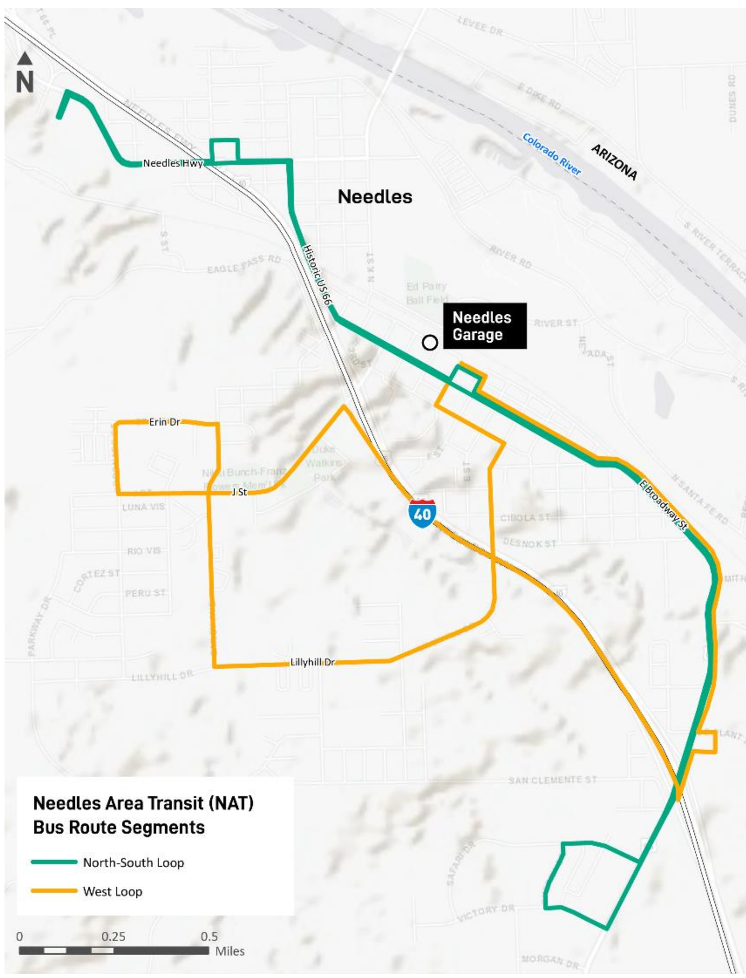
NAT is an operation run by the City of Needles. It is the smallest of the five transit operators within San Bernardino County.

5.2 Existing Conditions

5.2.1 Service Area and Environmental Factors

NAT serves the City of Needles, which rests along the Colorado River and the Arizona and Nevada borders at the eastern edge of San Bernardino County (Figure 5-1). Its population according to the 2010 United States Census was 4,984.[35]

Figure 5-1: NAT Service by Route Segment



Source: WSP

[35] 2013-2017 American Community Survey, 5-Year Estimates, United States Census, 2019.

Relative to the other communities that the countywide transit operators serve, Needles is quite geographically isolated from the remainder of the county. The nearest city within San Bernardino County is Barstow, over 140 miles away across the Mojave Desert and two mountain ranges; the nearest large city is Las Vegas, 110 miles away. Bullhead City, Arizona, is the nearest large commercial center, roughly 20 miles due north of Needles.

Needles experiences a desert climate, experiencing average high temperatures of 108 degrees in July. Average temperatures are lowest in December and January, 43 and 44 degrees, respectively. The city receives very little precipitation, with annual rainfall amounting to 4.65 inches.[36]

5.2.2 Schedule and Operations

NAT operates deviated fixed-route service on a single route within the city, which runs weekdays 7:00 am to 6:55 pm and Saturdays 10:00 am to 4:55 pm. Fares are $1.35 for fixed-route service and $2.00 for deviated service, with a $0.10 fare discount for seniors and disabled passengers. NAT also operates a dial-a-ride service for seniors and disabled passengers, and medical transportation to Mohave Valley/Bullhead City on Tuesdays and Thursdays and a Shopper Shuttle on Wednesdays (with advanced reservation). The route is shown in Figure 5-1.

The single fixed route is a combination of two loops, each with a 25-minute duration. The east-west loop begins on the hour and serves several civic destinations and the Colorado River Medical Center. The north-south loop begins on each half-hour and travels along historic route 66, serving the Needles town center.

5.2.3 Upcoming Capital Programs and Service Changes

No known capital projects or service changes are currently underway or in planning within the City of Needles.

5.2.4 Facilities: Needles Area Transit Garage

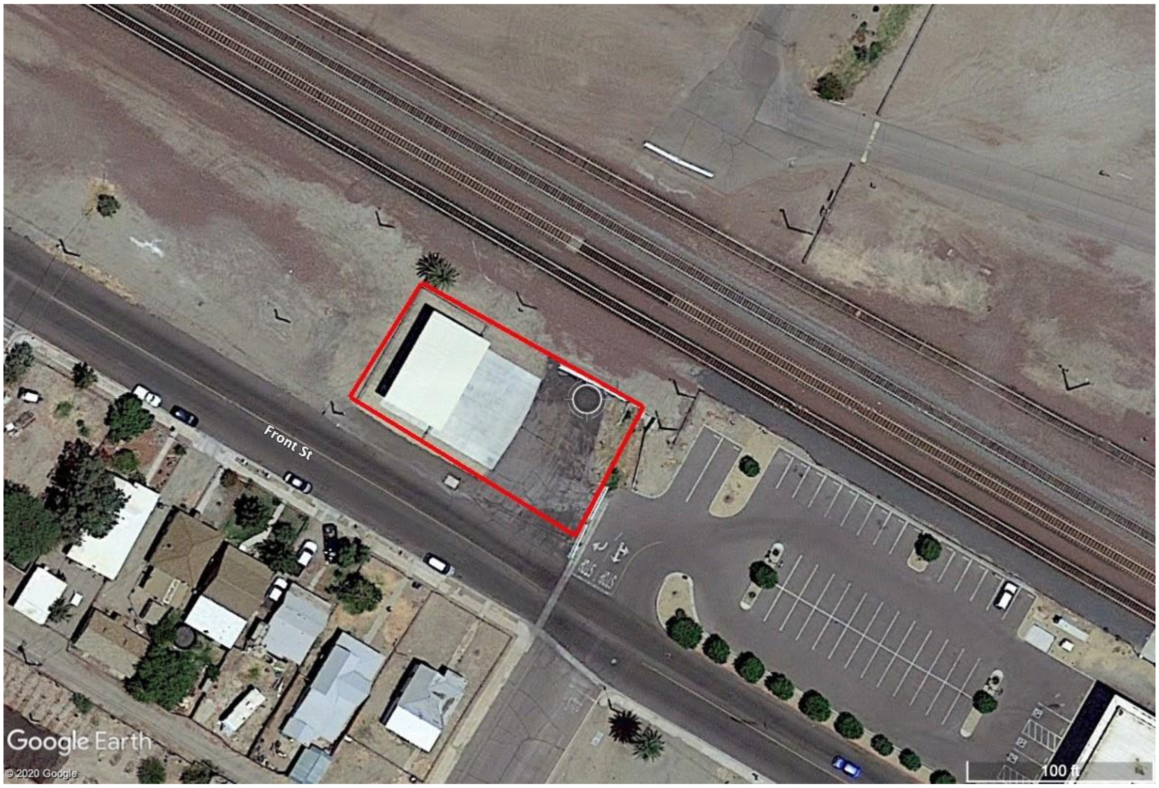
NAT is the City of Needles' fixed route service, which currently operates a fleet of three revenue service buses. This section provides an understanding of NAT's existing site and facility conditions. Operations is housed out of a centralized garage immediately adjacent to the layover location at the El Garces Intermodal Transportation Facility. NAT currently uses an all-diesel fleet. A more detailed catalog of the existing site condition is available in the report titled "Zero Emission Bus (ZEB) Analysis Facilities Inventory Report" issued January 15, 2020.

The NAT garage is located at 1101 Front Street in Needles, California, on approximately 0.4 acre of land (Figure 5-3). Table 5-1 describes the site facilities, equipment, and fleet.

The NAT garage is powered via underground distribution service lateral by the Needles Public Utility Authority. It is directly connected to an overhead low voltage distribution via light pole adjacent to the facility and is feeding a 200 A meter service. The facility does not have any means of backup power.

[36] U.S. Climate data; Needles, CA, 2019 https://www.usclimatedata.com/climate/needles/california/united-states/usca0753

Figure 5-2: NAT Garage - Existing Conditions



Source: WSP

Figure 5-3: NAT Garage Site Circulation

Source: WSP

Table 5-1: NAT Garage Inventory

Fleet Overview	
Cutaway Bus[37]	3
30-foot Bus	-
35-foot Bus	-
40-foot Bus	-
45-foot Bus	-
60-foot Articulated Bus	-
Total	**3**
Facilities	
Total Maintenance Bays	-
Paint Booths	-
CNG Fueling Positions	-
CNG Compressor Yards	-
Diesel Fueling Positions	-
Unleaded Fueling Positions	-
NRV Bays	-
Body shops	-
Bus Wash Lanes	-

Source: WSP

5.3 ZEB Implementation

5.3.1 Technology

Based on NAT's existing service needs and site configuration, WSP recommends implementing ground-mounted plug-in chargers both internal and external to the existing storage facility to support the incoming future BEBs. The proposed full facility ZEB master plan layout is based on utilizing a 150kW DC charging cabinet used in a 1:2 charging ratio (one DC charging cabinet energizes two separate plug-in cord dispensers). This charger to dispenser ratio would meet the requirements to charge NAT's fleet during the vehicles' servicing and dwell time on the site while minimizing the peak electrical demand for the City of Needles.

WSP recommends specifying charging ports on the rear of any BEBs ordered to allow for their existing site circulation and parking patterns to continue without modifications.

For the specific routes which the route modeling exercise has identified as not capable of being served efficiently by existing BEB technology, it is recommended that hydrogen fuel cell vehicles be utilized and fueled either via future commercial/public hydrogen fueling stations located in the Needles service area. As no fueling operations currently exist on NAT's site nor does the existing site have enough open area to add even a small modular hydrogen fueling system WSP does not recommended to introduce on-site hydrogen fueling.

[37] Cutaway bus lengths for NAT are 25 feet.

The impacts of these recommendations for each site follow.

5.3.2 Analysis/Findings: Needles Area Transit Garage

Based on the recommended ground-mounted DC plug-in BEB charging solution NAT's site is capable of parking a total of four buses with two total plug-in charging positions in a 1:2 charger to bus dispenser ratio.

Ground-mounted plug-in charging is proposed to be located in the following positions:

- Two charging cabinets along the western facility exterior and site boundary with three plug-in dispenser charging positions along the western facility interior wall and one plug-in dispenser charging position on the northeastern existing facility exterior for exterior yard charging.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One MV utility service transformer along the northwestern facility exterior and site boundary
- One switchgear service along the western facility exterior and site boundary

NAT does not currently perform any on-site fueling and no space is currently available within the NAT site.

Conceptual layouts for the proposed ZEB solutions for NAT's facility are present in Section 5.3.5.2 of this document.

5.3.2.1 Modeling Results

Base-Only Charging – Needles Garage

Currently, NAT operates one vehicle block with a cutaway bus. The block is scheduled to travel 165 miles on weekdays. As discussed in Section 2.1.2, a 118 kWh (94 kWh operating) battery was used to model the cutaway transit vehicles for base-only charging.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with the 118 kWh battery. Although 100 percent of service could be completed at the optimistic efficiency, an advertised battery capacity between 150 and 200 kWh would be needed to complete the single block at all efficiencies.

Table 5-2 provides the summary of block completion for NAT at the Needles Garage, and Table 5-3 details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 5-2: NAT Garage Base-Only Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	**94**	100% (1)	0% (0)	0% (0)
150	120	100% (1)	100% (1)	0% (0)
200	160	100% (1)	100% (1)	100% (1)

Source: WSP

Table 5-3: Summary of NAT Garage Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
5>1	118	12.0	166	104	139	173

Source: WSP

Base and On-Route Charging – Needles Area Transit Garage

Currently, Needles operates one vehicle block with three cutaway buses. The block is scheduled to travel 165 miles on weekdays. As discussed in Section 2.1.2, a 118 kWh (94 kWh operating) battery was used to model the cutaway transit vehicles for base and on-route charging.

The analysis found it would be possible to complete all vehicle blocks with base and on-route charging with the 118 kWh battery. The single block will complete all trips at all efficiencies.

Table 5-4 provides the summary of block completion for base and on-route charging for NAT at the Needles Garage.

Table 5-4: NAT Garage and On-Route Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
118	94	100% (1)	100% (1)	100% (1)

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

Without cutaway FCEB vehicles currently available on the market, Needles Garage does not qualify for FCEB adoption at this time.

Hydrogen Requirements

An analysis of anticipated fuel consumption for full-fleet FCEB conversions was conducted to support future planning efforts following the release of FCEB cutaways. This information may be used when considering future vehicle procurements and on-site hydrogen storage and production needs.

With only a single service block operating a moderate daily mileage, hydrogen consumption and Needles Garage resembles more a of small light-duty fleet than a bus fleet, requiring between 20 kg and 31 kg of hydrogen per day (Table 5-5). This quantity could be supplied with very infrequent deliveries and potentially future commercial fueling stations.

Table 5-5: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of NAT Garage

Block ID	Block Distance	Vehicle Type	Representative Vehicle	Optimistic H2 Consumption (kg)	Base H2 Consumption (kg)	Conservative H2 Consumption (kg)
5>1	165.5	Cutaway	40'	19.8	23.9	31.0

Source: WSP

5.3.2.1.2 Site Energy Analysis

Needles only has one facility that services one bus with a possible future growth to four buses. Only one 150 kW charger with a 1:4 charger to plug ratio will be needed. NAT will need to coordinate with the City of Needles municipal utility, however this is such a minimal impact to the grid that there are no significant concerns at this time. Since Needles municipal utility is so small, there is limited data available about power reliability in the area.

5.3.3 Procurement Schedule

In accordance with the ICT regulation, the City of Needles will prioritize ZEB purchases and progressively increase the percentage of ZEB purchases over time. Based on initial analysis, the last conventional bus is expected to be purchased in 2023. All new buses purchases are anticipated to be ZEB starting in 2028 – one year before the requirement.

Early retirement should not be an issue pursuant to the ICT regulation based on Needles' assumed procurement schedule. However, if it becomes one, the city will deploy several strategies to ensure that buses fulfill their "useful life." One potential strategy is to place newly acquired buses on NAT's longest (distance) blocks of service. This will ensure that these buses meet their distance-based useful life requirement more rapidly.

NAT's existing fleet consists of three 25-foot cutaway buses. Assuming a 1:1 replacement ratio, each existing bus will eventually be replaced with a 25-foot BEB cutaway bus. However, the number of ZEBs required may increase based on service requirements.

Table 5-6 presents a summary of NAT's anticipated bus procurements through 2040. Years 2026 and 2029 are highlighted because these indicate when NAT's new purchases should be 25 percent and 100 percent ZEBs, respectively.

Table 5-6: Summary of NAT's Future Bus Purchases (through 2040)

		Zero-Emission Buses				Conventional (CNG) Buses			
Year	Total Buses	Number	Pct.	Bus Type	Fuel Type	Number	Pct.	Bus Type	Fuel Type
2020	0	0	0%	-	-	0	0%	-	-
2021	0	0	0%	-	-	0	0%	-	-
2022	0	0	0%	-	-	0	0%	-	-
2023	1	0	0%	-	-	1	100%	Cutaway	Diesel
2024	0	0	0%	-	-	0	0%	-	-
2025	0	0	0%	-	-	0	0%	-	-
2026	0	0	0%	-	BEB	0	0%	-	-
2027	0	0	0%	-	BEB	0	0%	-	-
2028	1	1	100%	Cutaway	BEB	0	0%	-	-
2029	0	0	0%	-	BEB	0	0%	-	-
2030	0	0	0%	-	BEB	0	0%	-	-
2031	0	0	0%	-	BEB	0	0%	-	-
2032	0	0	0%	-	BEB	0	0%	-	-
2033	1	1	100%	Cutaway	BEB	0	0%	-	-
2034	0	0	0%	-	BEB	0	0%	-	-
2035	0	0	0%	-	BEB	0	0%	-	-
2036	0	0	0%	-	BEB	0	0%	-	-
2037	0	0	0%	-	BEB	0	0%	-	-
2038	1	1	100%	Cutaway	BEB	0	0%	-	-
2039	0	0	0%	-	BEB	0	0%	-	-
2040	0	0	0%	-	BEB	0	0%	-	-

Note: All new purchases were assumed to have a useful life of five years per FTA Circular 9030.1D, Ch. VI, paragraph 4.a. NAT typically has two buses in service with a third classified as a spare. The spare, per this schedule, is kept for 10 years before replacement with the second oldest fleet vehicle. For example, in 2033, NAT will purchase a new BEB. Its 2028 bus will still be used in service and its 2023 bus will be used as a spare (2018 vehicle will be retired).

Source: WSP, February 2020

5.3.4 City of Needles Cost Analysis

This analysis should be considered a conservative assessment of battery vehicle costs, as the industry in North America is in the preliminary stages of product development. Production costs are anticipated to decrease through economies of scale as production increases to meet future demand.

5.3.4.1 Battery Electric Vehicles – General Assumptions

The WSP team is actively engaged with Electric vehicle manufacturers to understand trends in the industry and VVTA, the only county operator currently operating BEBs, to inform assumptions vehicle operations. The values presented throughout this document are subject to change and based on the best available information at the time of this analysis.

Compared to conventional gasoline fueled vehicles, electric vehicles incur different capital and operating costs that vary based on the type of vehicles and operating environments. For example, the cost of installation and maintenance of charging infrastructure will differ in both magnitude and the types of resources required in comparison to the replacement and maintenance of a conventional fueling facility. Other examples include battery replacement schedules, mid-life overhaul, and disposal value.

Electric buses and garages may offer the opportunity to lower some operations and maintenance costs while increase others and similar to conventional fueled vehicles are highly dependent on the size and complexity of the vehicle fleet being supported. Additionally, an electrification strategy would entail replacing unleaded gasoline with electric power, which would incur different energy pricing structures and different exposure to energy price volatility. Table 5-7 outlines the major cost categories associated with vehicle electrification. Estimated costs in each of these categories were developed for electrification scenarios, as well as a "business as usual" baseline which assumes no change in the current types of vehicles in the fleet.

The total cost of each operator's transition will be contingent upon their specific fleet size, fleet acquisition plan, facility sizes, charging strategy, and construction schedule, among other details.

Table 5-7: Cost Components Attributed to Electric Vehicle Operations

Capital	Vehicle and Equipment Purchase
	Training, Capital Spares & Contingency
	Charging Infrastructure
	Mid-Life Fleet Overhaul
	Battery Replacement
Operating	Vehicle Maintenance
	Vehicle Tools, Training and Equipment
	Vehicle Energy Costs
	Charger Maintenance
	Fueling/Charging Labor
Disposal	Battery Disposal/Salvage
	Vehicle Salvage

Source: WSP

5.3.4.1.1 Battery Electric Vehicle Costs

Battery electric vehicle procurement costs continue to evolve as new vehicle models are developed and production increased to meet demand. Anticipated cost reductions through economies of scale may be somewhat offset by discounted prices that may be offered by some manufacturers to establish market share, specifically new entrants to the market. Furthermore, battery technology and production continue to evolve offering further potential reductions to production costs but also potential exposure to volatility in the pricing structures for critical battery production inputs. Additional considerations also need to be considered for specific agency requirements and features, delivery schedule requirements, and battery size requirements to meet operating conditions.

Assumptions regarding procurement costs for battery electric vehicles as compared to NAT's unleaded gasoline fleet are provided in Table 5-8.

Table 5-8: Vehicle Cost Assumptions

Vehicle Type	Vehicle Cost Estimates (2019 Dollars)
Battery electric 20 ft	$164,108
Battery electric 21.5 ft	$169,079
Battery electric 25 ft	$298,069
Unleaded 20 ft	$44,108
Unleaded 21.5 ft	$49,079
Unleaded 25 ft	$178,069

Source: WSP

Conventional gasoline vehicle acquisition costs ranged from $44,108-$178,069 for cutaway buses ranging in size from 20 feet to 25 feet and is based on information provided by current cutaway bus manufacturers. The incremental costs for battery electric vehicles are based on cost assumptions from the California Air Resources Board (CARB), which determined that the incremental cost of zero-emissions cutaway vehicles is approximately $120,000 as compared to unleaded gasoline cutaway vehicles.

5.3.4.1.2 Charging Infrastructure Costs

Charging infrastructure cost estimates include equipment, design and installation costs which primarily consist of materials and labor. The cost estimates also include general contractors and subcontractor's markups which are comprised of field overhead, home office overhead, and subcontractor earnings. The estimates also include a pricing contingency markup, to allow for unexpected design and installation Issues.

Plug-in chargers are assumed to cost $70,701, based on a recent VVTA contract.[38] Additionally, the cost to install chargers, including labor and permits, is assumed to be $8,500[39] per charger. With the recommended ground-mounted plug-in charging strategy, the Needles Garage would be capable of parking 4 buses with 12 plug-in charging positions (2 chargers), in a 1:2 charger to bus dispenser ratio. The financial analysis assumes that chargers would be purchased in the year that buses are ordered, when the cost of purchasing the charger would be incurred, and the cost of installing the charger would be incurred in the year of vehicle delivery, which is assumed to be one year after the bus order. As such, the exact year and number of chargers purchased correlates with the fleet procurement plan, presented in Section 5.3.4.2.2.

The analysis did not include on-site stationary battery energy storage for resiliency. If Needles Area Transit elects to include a generator for resiliency of their battery electric buses, a generator is estimated to cost $210,750 based on a full load of 150 Kw.

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[38] VVTA New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6, 2018.

[39] VVTA New Flyer Chargers for 40 ft BEB buses, Purchase Order 1197 dated November 6, 2018.

5.3.4.1.3 Mid-life Overhaul and Battery Replacement

No overhaul was assumed for battery electric vehicles. Although no overhaul was assumed for battery electric vehicles, the BEB scenario still assumes some overhaul costs, given that the first replacement cycle will entail replacing existing unleaded gasoline vehicles with similar gasoline models until the infrastructure to accommodate electric vehicles is in place in 2024. Unleaded gasoline vehicles were assumed to undergo overhead costs every two years, as WSP understands that many of the vehicles have had their useful lives extended significantly.[40]

The analysis assumes that NAT's battery electric vehicles will include battery warranties, and as such, battery replacement costs are not assumed to be incurred by NAT.[41] Battery replacements on the unleaded fleets are fairly minimal and assumed to be part of existing maintenance costs.

5.3.4.1.4 Tire Replacement Cost

The analysis assumes that NAT vehicles undergo regular tire replacements of $0.006 per mile, based on Omnitran's experience.

5.3.4.1.5 Other Miscellaneous Costs

CARB staff assumes some additional "other and miscellaneous" costs are associated with zero-emission cutaway deployment, equal to approximately 2.5 percent of the vehicle price.[42] We have not assumed these costs apply to unleaded gasoline vehicles, which are informed by actual operating experience.

5.3.4.1.6 Operations and Maintenance Costs

Components of O&M costs include vehicle maintenance, vehicle tools, training and PPEs, vehicle fuel costs, and the costs to maintain and operate charging and fueling infrastructure. Annual O&M cost assumptions for electric vehicles are outlined in Table 5-9, represented in dollars per mile.

Table 5-9: Electric Vehicle Maintenance Costs by Vehicle Age (2019 Dollars per mile)

Vehicle Age	20'	21.5'	25'
Year 1	0.25	0.25	0.27
Year 2	0.22	0.22	0.24
Year 3	0.22	0.22	0.24
Year 4	0.26	0.26	0.28
Year 5	0.31	0.31	0.33
Year 6	0.34	0.34	0.37

Source: WSP

[40] If two years is too aggressive, the analysis can be easily updated to extend the overhaul time periods and thereby reduce these costs.

[41] If the bus purchases or leases will not include a warranty, a battery replacement cost may be estimated at approximately, $7 per pound, and assumed to weigh approximately 500 pounds, based on similar transit agencies. The model can be easily updated to assume this.

[42] California Air Resources Board (CARB) (2018). https://ww3.arb.ca.gov/regact/2018/ict2018/appi.pdf

The analysis applies unit O&M cost per mile by bus type with total costs based on assumed average annual vehicle mileage. The model accounts for changes to service levels based on range restrictions for electric vehicles to estimate O&M costs, by applying unit costs to total mileage as driven by number of vehicles and mileage per vehicle.

5.3.4.1.7 Energy Costs

Electricity prices for battery electric vehicles are based on current rates with Southern California Edison (SCE) and reflect charge rates and demand for energy consumption that vary by hour and month.

Total annual energy costs are estimated for each operator and facility and are highly driven by charging strategy with respect to location of on route chargers if any, facilities, vehicle routes, and fleet size purchase. These charging strategies are subject to change as the team works to refine each agency's optimal charging strategy, and as charging rates change. This analysis does not assume any major behavioral changes based on coach operators.

Table 5-10 presents Southern California Edison Rates and Table 5-11 present the hours during which each rate from Table 5-10 would be applicable.

Table 5-10: Rates per kWh

Rates (per kWh)		
Time of Use Period	Summer (June-September)	Winter (October-May)
On-Peak	$0.41	
Mid-Peak	$0.20	$0.24
Off-Peak	$0.10	$0.10
Super Off-Peak		$0.06

Source: WSP

Table 5-11: Time Periods

Time Periods (weekdays excluding holidays)				
	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	16:00-21:00	N/A	N/A	N/A
Mid-Peak	N/A	16:00-21:00	16:00-21:00	16:00-21:00
Off-Peak	All other hours	21:00-08:00	All other hours	21:00-08:00
Super Off-Peak	N/A	08:00-16:00	N/A	08:00-16:00

Source: WSP

The rates in Table 5-10 and Table 5-11 above were applied to the hourly times during which the operators are expected to be charging. The energy use assumed for each operator, in a moderate charging scenario, is presented in Table 5-12. The model is capable of running additional scenarios to cost the low charging and high charging scenario as well.

Table 5-12: Hourly Energy use (kWh) – Moderate Scenario

Facility ID	Facility	Operator	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
1000001	Joshua Tree Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	-
1000002	29 Palms Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	50
1000003	Crestline	MT	-	-	-	-	-	-	-	-	-	-	-	78
1000009	Big Bear Lake	MT	-	-	-	-	-	-	-	-	-	15	50	-
1000004	West Valley	Omnitrans	5,300	4,788	3,633	2,415	1,203	350	80	-	128	80	-	-
1000005	East Valley	Omnitrans	11,488	9,843	7,523	4,808	2,040	688	373	168	130	433	735	553
1000006	VVTA HQ - Hesperia Yard	VVTA	3,988	3,810	2,668	1,845	1,335	688	480	155	305	405	308	423
1000007	Barstow Future Yard	VVTA	945	660	600	600	525	173	110	220	295	300	215	-
1000008	Needles Garage	Needles	-	-	-	-	-	-	-	-	-	-	-	-

Source: WSP

Table 5-12: Hourly Energy use (kWh) – Moderate Scenario (continued)

Facility ID	Facility	Operator	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1000001	Joshua Tree Yard	MBTA	88	-	133	-	-	-	320	58	-	-	13	140
1000002	29 Palms Yard	MBTA	-	10	208	-	-	5	130	-	10	43	80	65
1000003	Crestline	MT	15	-	-	-	-	75	15	143	180	28	83	3
1000009	Big Bear Lake	MT	-	-	65	-	-	78	-	95	150	3	-	-
1000004	West Valley	Omnitrans	-	-	-	20	75	-	148	808	1,950	3,615	5,313	5,918
1000005	East Valley	Omnitrans	258	308	533	508	273	48	195	2,493	5,723	8,355	11,143	12,978
1000006	VVTA HQ - Hesperia Yard	VVTA	183	55	-	-	265	815	1,475	1,800	1,630	3,563	4,720	4,075
1000007	Barstow Future Yard	VVTA	-	-	-	-	-	23	150	265	958	1,470	1,370	1,080
1000008	Needles Garage	Needles	-	-	-	-	-	-	8	103	-	-	-	-

Source: WSP

As displayed in Table 5-12, Needles is expected to charge during the hours of 18:00 (consuming 8 kWh) and 19:00 (consuming 103 kWh. This would mean that in January, for instance, they would be charged $0.24 per hour. During 6 pm in January, 8 kWh x $0.24 x 31 days in January = 54.88. Table 5-13 lays out the resulting costs of the hourly SCE rates and the hourly charging strategy, by each hour of the month, and the total resulting annual cost per bus.

Table 5-13: Total Annual Cost Per Bus – Needles

Needles Garage	Days per month	18:00	19:00
January	*31.00*	54.88	749.99
February	*28.00*	49.57	677.41
March	*31.00*	54.88	749.99
April	*30.00*	53.11	725.79
May	*31.00*	54.88	749.99
June	*30.00*	92.00	1,257.40
July	*31.00*	95.07	1,299.31
August	*31.00*	95.07	1,299.31
September	*30.00*	92.00	1,257.40
October	*31.00*	54.88	749.99
November	*30.00*	53.11	725.79
December	*31.00*	54.88	749.99
	365	**804**	**10,992**
	Total Annual Cost	**$11,797**	
	Buses at Garage	**4**	
	Total Annual Cost Per Bus	**$2,949**	

Source: WSP

5.3.4.1.8 Environmental Costs

Environmental costs are considered non-cash expenses and include monetized values for tailpipe emissions and upstream emissions of CO2, criteria pollutants, and noise. The analysis does not assume tailpipe emissions for electric vehicles and includes estimates of tailpipe emissions for unleaded gasoline vehicles, for comparative purposes. Tailpipe emissions include estimates of CO2, NOX, CO, PM10, PM 2.5. Emissions data was taken from the U.S. Department of Energy's Greet Fleet Calculator tool.

Upstream emissions consist of emissions resulting from the production of unleaded gasoline, and production of electricity for BEBs based on the mix of utility power sources.

5.3.4.1.9 General - Inflation

The model accounts for inflation using the Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U).[43]

Table 5-14: Consumer Price Index

CPI-U	2019	2020	2021	2022	2023
Riverside & San Bernardino	2.87%	3.24%	2.96%	3.10%	3.03%

Source: WSP

5.3.4.2 Scenario Analysis

5.3.4.2.1 Cost Overview

Background

Analysis was conducted to compare an electrification scenario for NAT with a "business as usual" scenario which assumes that all future procurements maintain the current practice of procuring unleaded vehicles (referred to as Scenario 1 Baseline Unleaded). Given CARB's mandate of full conversion to zero emissions by 2040, the business as usual scenario is a theoretical scenario for comparative benefit-cost assessment purposes.

The analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs, plus a non-cash cost of environmental benefits and costs, which WSP staff monetizes to account for a holistic comparative between cost and benefit.

Table 5-15 delineates the overall results of the NAT analysis, assessing the full Electric Vehicle conversion and the baseline scenario. Estimates presented throughout this document are preliminary and subject to change.

[43] Source, California Department of Finance: http://www.dof.ca.gov/Forecasting/Economics/Eco_Forecasts_Us_Ca/documents/US%20CA%20Inflation%20Forecast%20GB%2020 20-21.xlsx

Table 5-15: Needles – Overall Cost Summary

2020-2050 Fleet Replacement Cost Comparison (2020 dollars in thousands)		SCENARIO 1: Baseline Unleaded	SCENARIO 2: Build – Battery Electric
Capital	Vehicle Purchase Price	761	1,143
	Modifications & Contingency	94	141
	Charging/Fueling Infrastructure	-	125
	Total Capital Costs	*855*	*1,409*
Operating	Vehicle Maintenance	279	258
	Overhaul	243	127
	Tire Replacement Cost	6	5
	Vehicle Tools Training and PPEs[44]	-	-
	Other and Miscellaneous Costs	-	12
	Vehicle Fuel Costs	614	136
	Electric Vehicle Utility Costs	-	52
	Charging/Fueling Infrastructure	-	7
	Battery/Fuel Cell Replacement[45]	-	-
	Total Operating Costs	*1,142*	*597*
Disposal	Battery Disposal	-	-
	Bus Disposal (Salvage Value)	(10)	(10)
	Total Disposal Costs	*(10)*	*(10)*
	Total Cash Costs	1,987	1,996
	Total Cash Cost per Mile	2.01	2.02
Environmental	Emissions - Tailpipe	31	8
	Emissions - Refining/Utility	10	10
	Noise	52	43
	Total Environmental Costs	93	61
	Total Cash and Non-Cash Costs	2,080	2,057
	Total Cash and Non-Cash Costs per Mile	2.10	2.08
Total Mileage (thousand miles)		990	990

Source: WSP

[44] Needles Area Transit does not incur vehicle tools, training and PPE cost and assumed as they are included in the price of the bus.

[45] The analysis assumes that Needles Area Transit's battery electric vehicles will include battery warranties, and as such, battery replacement costs are not assumed to be incurred by Needles Area Transit. Battery replacements on the unleaded fleets are assumed to be part of existing maintenance costs.

5.3.4.2.2 Cost Conclusions

Overall, the lifecycle cost analysis shows that despite higher initial costs, the full lifecycle cash cost of a transition to battery electric vehicles will be comparable to continued reliance on unleaded gasoline vehicles. Operating costs are highly dependent on factors that are not well-established, as further discussed in previous sections. This is particularly the case for annual vehicle maintenance costs, while existing capital cost premiums are currently well-known.

A subsequent analysis will assess year by year cost savings associated with operations, which will highlight how long it will take for the savings from operations to offset the higher up-front capital costs.

Discussion of General Inputs

Inputs to the lifecycle cost model include:

- Fleet modernization schedules – vehicles acquired each year by fuel type.
- Vehicle costs including initial purchase, maintenance, mid-life overhaul and disposal
- Battery purchase, replacement and disposal or salvage
- Battery charging infrastructure purchase, installation and maintenance
- Energy costs, gasoline and electricity
- Environmental costs for vehicle tailpipe emissions of CO_2 and criteria pollutants
- Environmental costs for vehicle noise

The model examines one complete replacement of the fleet, beginning in the year 2020 and ending with final vehicle acquisition in 2031. The model tracks the total cost of ownership (initial capital cost, annual operating cost and final disposal cost) of each new vehicle for its full asset life.

The values provided are not a comparison between an all unleaded vehicle and an electric vehicle fleet, but rather a comparison between continuing current practices and gradually phasing in battery electric vehicle procurement.

In addition to vehicle costs, the model also includes the costs of purchasing, installing and maintaining charging infrastructure for battery electric vehicles.

All model inputs are provided in current year (2019/2020) dollars. The model applies inflation factors to escalate costs to year of expenditure dollars. The Riverside-San Bernardino-Ontario metropolitan area historical CPI-U, presented in Table 5-14, was used for most costs, except the following cases where a different specific index was used:

- Unleaded gasoline prices used the 2019 average of unleaded gasoline prices in California as a basis, and then were escalated were escalated at the same rate as national average gasoline prices as forecasted by EIA. Short term resulting forecast is presented in Table 5-16.

Table 5-16: Unleaded Gasoline Price Forecast (2019 $s per gallon)

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	3.46	3.96	4.25	4.51	4.72

Source: WSP

- Electricity costs were escalated using EIA transportation electricity annual forecasted price growth rate forecasts by year, presented in Table 5-17.

Table 5-17: Annual Energy Outlook – US Energy Information Administration[46]

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	0.00%	14.75%	5.14%	6.08%	5.24%

Source: WSP

Year of expenditure costs were then discounted to present value 2020 dollars using a discount rate of 2.37 percent. The resulting present values of all costs are summed to yield the full lifecycle cost comparison.

Vehicle Procurement Schedule by Facility; Scenario 2: Battery Electric Vehicle Conversion

The battery electric vehicle scenario assumes the vehicle procurements to be consistent with the tables that follow. These procurements could either continue NAT's current practice of procuring only unleaded vehicles, switch to procuring only battery electric vehicles or procure a mix over the years of transition. The two primary factors that would need to be considered for each year of procurement are the availability of charging infrastructure and the range and performance of available electric vehicles.

In early years, the construction of charging infrastructure would be the primary constraint, which is why battery electric vehicles are not assumed to be procured until 2024 for Needles Garage. Existing vehicles which will reach the end of their useful life prior to the build out of this infrastructure are assumed to be replaced with unleaded vehicles.

[46] US Energy Information Administration, Annual Energy Outlook 2018 - Reference: 3-AEO2018.101.ref2018-d121317a

Table 5-18: Build Case - Electric Vehicle Fleet Replacement Schedule Breakdown - Needles Garage

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
BEB 25'									1					1					1		
UNL 25’				1																	
Total	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0

Source: WSP

Vehicle Procurement Schedule by Facility – Unleaded Gasoline

Table 5-19: Baseline - Unleaded Fleet Replacement Schedule Breakdown - Needles Garage

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
UNL 25’				1					1					1					1		
Total	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0

Source: City of Needles

5.3.4.3 Uncertainties

The analysis provided should be considered a conservative assessment of battery electric vehicle costs, as the industry in North America is still developing as demand increases and the market stabilizes. Production costs may decrease as production increases to meet future demand through benefits of economy of scale. However, cost reductions may be offset by reductions in tax breaks, grant programs, discounts and incentives that are available for the acquisition of battery electric vehicles and associated charging infrastructure.

The costs for batteries could decline with continued development of more efficient technology and lower production costs resulting from economies of scale. Some potential future cost reductions, however, may be offset (or more than offset) through increases in the cost of acquiring the primary battery components, specifically lithium or other alternative rare earth minerals. In addition, the energy density of batteries is increasing, so the decline in cost per kWh could be offset by a choice to buy higher-capacity, longer range batteries for vehicles purchased in later years and for replacement of original batteries on buses purchased in the early years.

The cost of fuel and electricity also have a strong impact on the potential comparison of battery electric vehicles and unleaded gasoline vehicles. Any major fluctuations in energy prices would have a direct impact on operating costs for the agency. While utility prices are historically less volatile than unleaded gasoline prices, there exists less downward price potential as utility prices tend to be set by large scale capital investments and distribution costs, as opposed to market inventory levels and feedstock supply costs, which are the primary drivers of unleaded gasoline prices and volatility.

5.3.5 Recommendations

5.3.5.1 City of Needles Fleet Technology

Without FCEB cutaways currently available on the market, this report recommends a full battery-electric conversion. The capabilities of current BEB technology would support the immediate conversion of the service block operating out of Needles Garage when using on-route charging, this is the recommended strategy for zero-emission conversion at this facility.

There are several strategies that may be used to support BEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances
- Phasing BEB integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

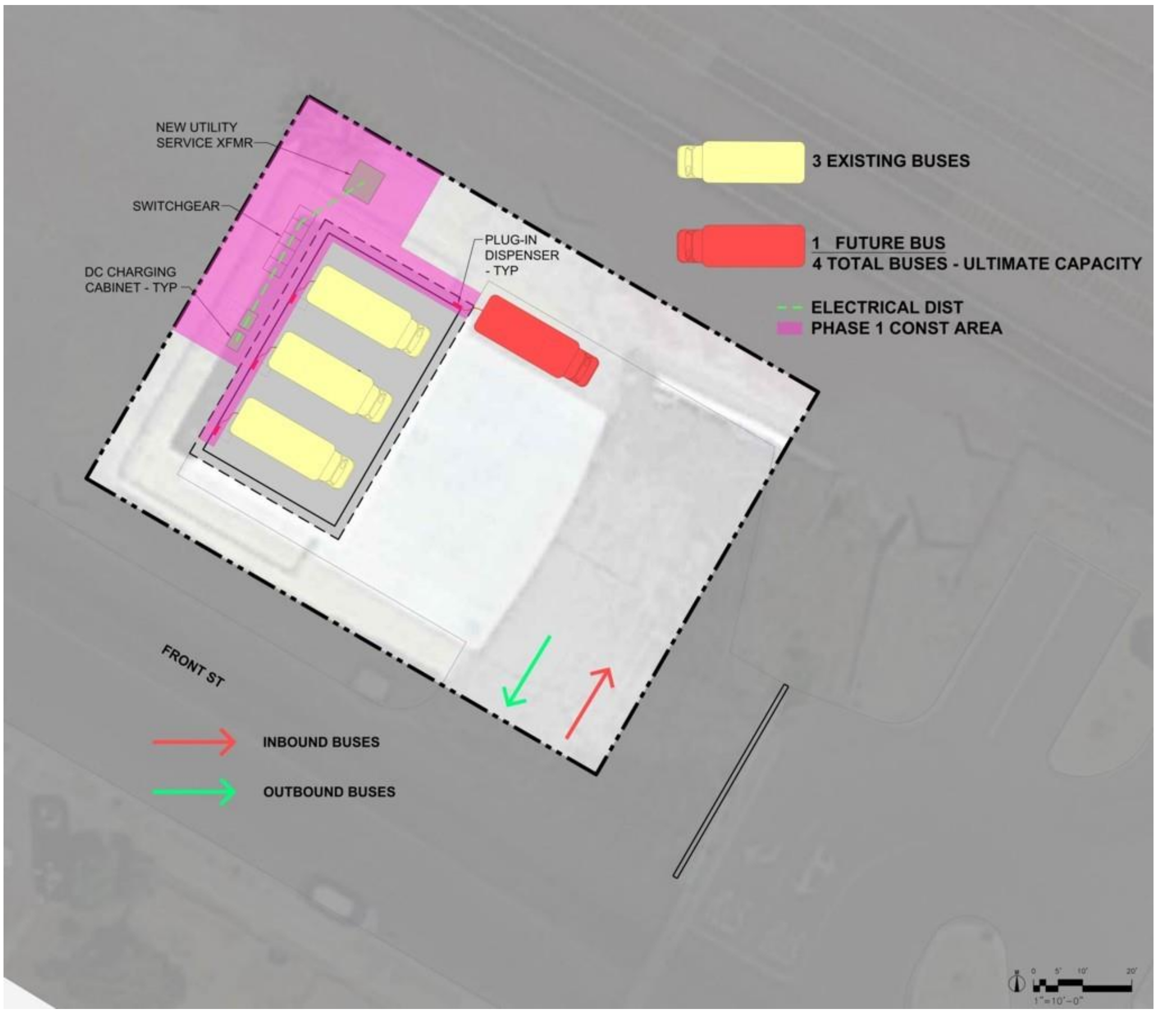
While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities that must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

5.3.5.2 Fleet Phasing and Implementation

The WSP team recommends completing the entire charger and infrastructure installation at the NAT Garage site in a single phase as the site size and layout precludes dividing the project in a manner to gain advantages on costing or construction (see Figure 5-4).

The plan for the NAT garage site is to install all of the in-ground conduit to route electrical service to both of the two charging cabinets with four plug-in dispensers mounted at the edge of the parking spaces in the existing building and on its exterior wall. These chargers and dispensers can be installed with aboveground electrical distribution routed along a cable way from the new electrical yard to the western exterior wall to meet the charging cabinets. From the charging cabinets, the electrical distribution can then penetrate the wall to the interior dispensers, as well as run outside for the exterior charger.

Figure 5-4: NAT Garage Proposed Full ZEB Build-Out and Phasing



Source: WSP

6 OMNITRANS

6.1 Introduction

Omnitrans is the largest and highest-ridership transit operator in San Bernardino County. It was established in 1976 through a joint power agreement, which now includes 15 cities and unincorporated parts of the county. The operator is governed by a Board of Directors, comprising the mayor or a councilmember from each member-city and four county supervisors.

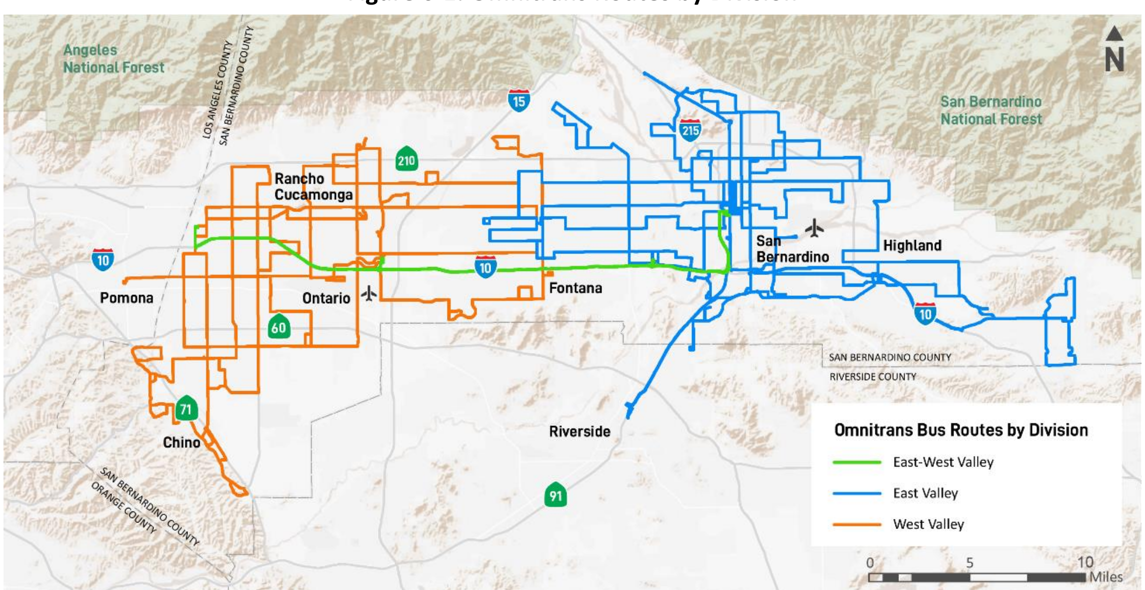
6.2 Existing Conditions

6.2.1 Service Area and Environmental Factors

Omnitrans serves the urbanized area referred to as the San Bernardino Valley, south of the San Bernardino Mountains, which has a population of approximately 1.7 million and includes the cities of Chino, Chino Hills, Colton, Fontana, Grand Terrace, Highland, Loma Linda, Montclair, Ontario, Redlands, Rialto, San Bernardino, Upland, Rancho Cucamonga, Yucaipa, and portions of unincorporated areas of the County of San Bernardino. The service area includes Ontario and San Bernardino airports, several Metrolink and Amtrak stations, as well as connections to several other regional bus transit authorities: Foothill Transit, Riverside Transit Authority, MT, VVTA, Pass Transit (Beaumont and Banning), and a connection with Sunline (Palm Springs area) will begin in May 2020.

Omnitrans' service is organized into two facilities: East Valley, which serves the cities of Colton, Fontana, Grand Terrace, Highland, Loma Linda, Redlands, Rialto, San Bernardino, Yucaipa and unincorporated areas of the county; and West Valley, which serves the cities of Chino, Chino Hills, Fontana, Montclair, Ontario, Rancho Cucamonga, Upland, and unincorporated areas of the county. Figure 6-1 shows the distribution of these routes between the divisions (Route 290 operates between both). There also are two smaller facilities that Omnitrans uses primarily for paratransit vehicles.

Figure 6-1: Omnitrans Routes by Division



Source: WSP

The City of San Bernardino metropolitan area is typical of Southern California in terms of environmental conditions. With a hot-summer Mediterranean climate, average high temperatures peak in August at 96 degrees; December is the coldest average month with a 41-degree average low. During the fall, the city is particularly affected by the Santa Ana winds, bringing higher temperatures and increased risk of wildfires.

6.2.2 Schedule and Operations[47]

Omnitrans operates 34 bus routes across four types of service: standard intercity routes, BRT, freeway express, and local shuttles. Routes in Omnitrans' system connect at several transit centers, which are off-street facilities, and transfer centers, which are on-street stops with multiple routes. The transit centers Omnitrans uses include: Chaffey College Transit Center, Chino Transit Center, Fontana Transit Center (Metrolink), Montclair Transit Center (Metrolink), Pomona Transit Center (South Pomona Metrolink), Riverside Metrolink, San Bernardino Transit Center (Metrolink), and Yucaipa Transit Center. Omnitrans does not own or operate any transit center or transfer center with the exception of the San Bernardino Transit Center. Finally, implementation of the proposed ConnectForward service charges anticipated in September 2020 are elaborated upon in Section 6.2.3.1.

Shown here by community, Omnitrans operates the following 34 routes:

- Bloomington: 19, 29
- Chino: 81, 83, 84, 85, 88, OmniGo 365
- Chino Hills: 88, OmniGo 365
- Colton: 1, 15, 19, 22, 215, 290
- Fontana: 10, 14, 15, 19, 20, 29, 61, 66, 67, 82
- Grand Terrace: OmniGo 325
- Highland: 3 & 4, 15
- Loma Linda: sbX Green Line, 2, 8, 19, OmniGo 325
- Mentone: 8
- Montclair: 66, 85, 88, 290
- Ontario: 61, 80, 81, 82, 83, 86, 290
- Pomona: 61
- Rancho Cucamonga: 61, 66, 67, 80, 81, 82, 85
- Redlands: 8, 15, 19, 208
- Rialto: 10, 14, 15, 19, 22
- San Bernardino: sbX Green Line, 1, 2, 3 & 4, 5, 7, 8, 10, 11, 14, 15, 208, 215, 290
- Upland: 66, 83, 84, 85
- Yucaipa: 8, 19, 208, OmniGo 308/309/310

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[47] Existing service as of date of pubication: April 24, 2020

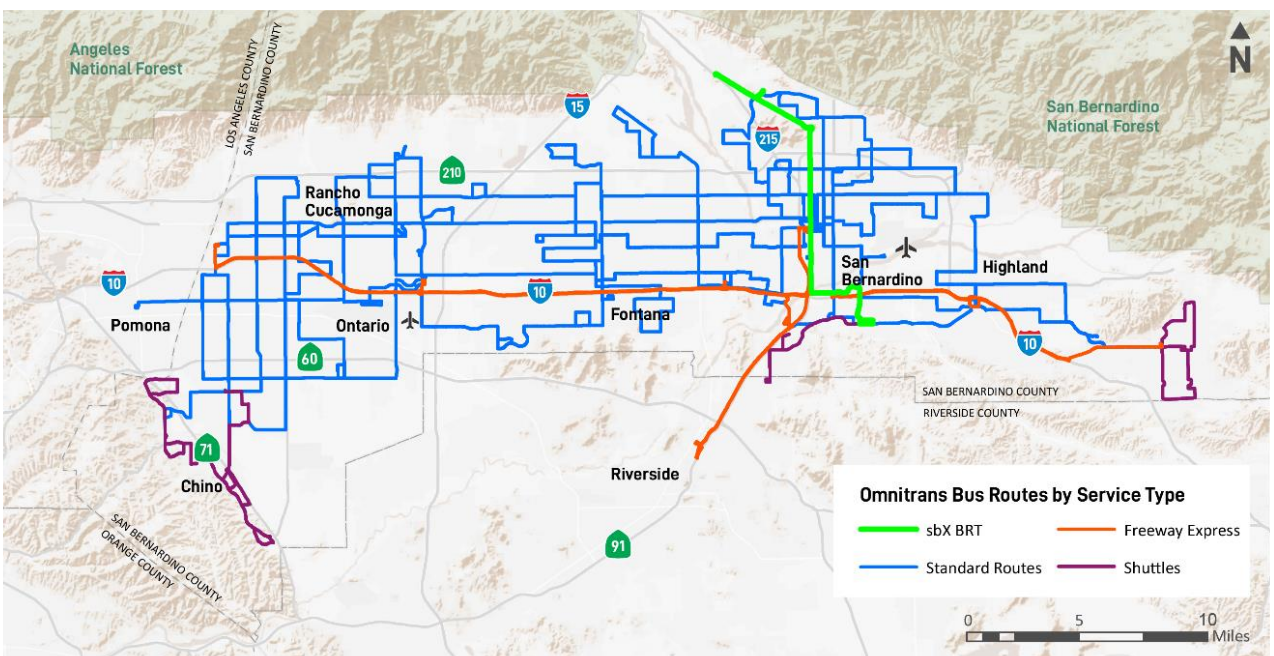
The vast majority of Omnitrans' routes operate daily. Table 6-1 details each route's length, days of operation, service span, and frequencies by weekday, Saturday, and Sunday. Most routes operate with limited service on Saturday, and service is further limited on Sundays. All but two standard routes operate on Saturday; a select few do not operate on Sunday.

The map in Figure 6-2 shows Omnitrans' routes by service type, while Table 6-1 shows each route's service details All single- and double-digit routes are standard intercity routes. These routes range from seven to 30 thirty miles in route length. The 200-level routes are freeway express routes, serving Interstate 10 and Interstate 215 corridors with limited stops; these routes are also generally longer than the intercity routes. Lastly, the 300-level routes are OmniGo shuttles, which use smaller vehicles to travel short, circular routes in the communities of Yucaipa, Grand Terrace, and Chino Hills.

Omnitrans' only current BRT service is the sbX Green Line, which travels along the E Street Corridor between Cal State University San Bernardino and Loma Linda University and Medical Center. Five of the sbX Green Line's 16 miles are in dedicated bus lanes. Omnitrans has a planned future system of 10 BRT routes; SBCTA is currently leading the final design of the West Valley Connector bus rapid transit line, expected to start operation in 2024, and will provide service in the cities of Montclair, Ontario, Pomona, and Rancho Cucamonga. See Section 3.2.3 for additional details.

Omnitrans uses a generally standardized fare structure for each route, with seven different classifications of passengers. A full fare is $2.00, senior/disabled/Medicare fares are $0.90, veteran fares are $0.90, youth fares that are 18 and younger are $2.00 (discounts for weekly and monthly passes), uniformed military and emergency personnel are free, children (46 inches tall and under, with a paying rider) are free, and GoSmart fares are free.

Figure 6-2: Omnitrans Routes by Service Type



Source: WSP

Table 6-1: Omnitrans Summary of Service

Route	Length (mi.)*	Days	Weekday Span	Headways (min.)		
				M-F	Sat	Sun
sbX	16.5	Monday–Saturday	5:00 AM to 11:01 PM	10	20	n/a
1	17.0	Daily	4:30 AM to 10:39 PM	15	30	30
2	17.2	Daily	4:29 AM to 10:55 PM	60	55	30
3 & 4	19.7	Daily	4:22 AM 11:32 PM	15	20	20
5	15.5	Daily	4:39 AM to 10:42 PM	30	60	60
7	8.9	Daily	5:50 AM to 9:57 PM	30	60	60
8	19.2	Daily	4:53 AM to 10:39 PM	30/60	60	60
10	15.2	Daily	5:03 AM to 8:32 PM	30/60	60	60
11	14.6	Daily	5:20 AM to 10:18 PM	30/60	60	60
14	13.8	Daily	3:30 AM to 11:07 PM	15	15	15
15	30.8	Daily	5:09 AM to 10:42 PM	30	60	60
19	29.6	Daily	4:49 AM to 10:36 PM	30	60	60
20	7.1	Daily	4:25 AM to 9:12 PM	60	60	60
22	14.1	Daily	5:00 AM to 9:53 PM	30	60	60
29	9.3	Monday–Saturday	6:45 AM to 6:35 PM	60	60	n/a
61	23.8	Daily	4:04 AM to 11:24 PM	15	15	15
66	18.2	Daily	4:10 AM to 11:16 PM	15/30	30	30
67	17.0	Monday–Friday	5:53 AM to 8:48 PM	60	n/a	n/a
80	11.5	Daily	5:02 AM to 8:42 PM	60	60	60
81	21.0	Monday–Saturday	4:25 AM to 10:29 PM	30/60	60	n/a
82	31.0	Daily	4:25 AM to 10:12 PM	60	65	65
83	14.3	Daily	5:54 AM to 9:57 PM	60	60	60
84	11.4	Daily	6:03 AM to 8:56 PM	60	60	60
85	20.7	Daily	4:20 AM to 10:51 PM	30	60	60
86	14.1	Monday–Friday	4:57 AM to 9:46 PM	60	n/a	n/a
88	12.1	Daily	4:33 AM to 10:12 PM	60	60	60
208	29.9	Monday–Friday	4:28 AM to 8:16 AM 5:00 PM to 8:15 PM	30/48	n/a	n/a
215	24.2	Daily	5:05 AM to 9:49 PM	20/30	60	60
290	56.5	Monday–Friday	4:18 AM to 8:46 PM	40/ 120	n/a	n/a
308	7.1	Daily	5:59 AM to 8:40 PM	30/60	30	60
309	7.1	Daily	5:56 AM to 7:10 PM	30	30	60
310	6.3	Monday–Friday	5:45 AM to 7:39 PM	30/60	n/a	n/a
325	7.9	Daily	5:12 AM to 8:36 PM	70	70	70
365	23.5	Daily	5:00 AM to 8:52 PM	60	60	60

Source: Omnitrans Bus Book

An additional program, "GoSmart," exists for enrolled college students to utilize the entire Omnitrans system for free. GoSmart is a partnership between Omnitrans and several area colleges, including California State University San Bernardino, Chaffey College, Crafton Hills College, and San Bernardino Valley College. Additionally, Omnitrans accepts Metrolink tickets for one free transfer on an Omnitrans bus departing from a Metrolink station.

6.2.3 Upcoming Capital Programs and Service Changes

The West Valley Corridor Study, an independent analysis of ZEB technology along the proposed corridor, is summarized below with the complete study highlighted in Appendix A. Additionally, upcoming operator service changes proposed in the ConnectForward Service Plan are discussed in further detail below.

Omnitrans has a new solar canopy project currently in the design stages to add solar power generation via photovoltaic panels mounted on canopies over parking and on building roofs. Additionally, battery backup storage is proposed to be added to the sites. Note that to date WSP has not received layouts on these future projects.

Omnitrans is in the environmental review stages of a major capital investment project, the West Valley Corridor BRT line. As part of the scope of this study, a ZEB analysis based on the future corridor study was performed to assess the needs and demands of integrated this future BRT line with ZEB service, see the section below and Appendix A for reference.

In February 2020, Omnitrans awarded a purchase order to New Flyer of America, Inc. for the provision of four 40-foot BEBs (expected delivery in 2021). To support these vehicles, Omnitrans is actively engaged with the utility, Southern California Edison (SCE). SCE's Charge Ready Program will provide the agency with support on the planning, design, installation, and funding of BEB-supporting infrastructure at Omnitrans' East Valley and West Valley facilities.

6.2.3.1 ConnectForward Service Plan

Omnitrans is proposing implementating the ConnectForward service plan in September 2020 to prepare the agency for future regional transit needs and ensure long-term financial sustainability. It proposes an 11% service reduction by route realignment, route elimination, the creation of new routes. The changes are designed to maximize efficiency while minimizing customer impact. The vast majority of eliminated routes will be incorporated into the existing and proposed new routes.

Changes

A summary of the changes is found in Table 6-2.

- Frequency Changes in the form of reduced services or headways are applied to Route 2, 3, 4, 8, 14, 22, 61, 66, 290, OmniGo Yucaipa Route 309, and OmniGo Yucaipa Route 310
- OmniGo Chino Hills Route 365 is eliminated, but will be replaced with MicroTransit program, keeping the modified school tripper service near Chino Hills High School bell times.
- Routes 5, 7, 20, 80, 86, OmniGo Grand Terrace Route 325, and OmniGo Yucaipa Route 308 are eliminated but the majority of the routes will be incorporated into the other routes
- Route 1, Route 29, Route 81, Route 82, Route 83, and Route 84 will have route realignments.
- New routes to be added are:

  - Route 6: Combining the northern portion of Route 5 and southern portion of Route 7 with every 30 minutes peak service
  - Route 87: Combining the northern part of Route 80 and the southern part of Route 86 with every 60 minutes peak service. It also extends south of Riverside to Ontario Ranch Road with an end-of line near the San Bernardino and Riverside County line.
  - Route 305: Combining the southern part of Route 5, which adds the coverage of the OmniGo Grand Terrace 325 service area. This route uses a smaller 16-passenger vehicle with every 60 minutes peak service.
  - Route 383: Combining the northern part of Routes 83 and 84 with every 60 minutes peak service. This route uses a smaller 16-passenger vehicle.
  - MicroTransit Chino Hills: New on-demand service in Chino Hills that is reservation-based, shared ride service, similar to Uber or Lyft. It will serve all customers, including those with disabilities, weekdays only, 6 a.m.-6 p.m. Proposed fares are $5 per trip, with a day pass, for fixed route service.
- Route 12 and 29 and weekend service on route 84 and 88 will be run with smaller vehicles.
- Changes on the ADA services in the form of service reduction in Chino Hills, South Ontario, and Grand Terrace due to proposed fixed route changes, service reduction on weekend in Yucaipa, reduction of the advance reservation window to reduce the number of no-shows, and proposed elimination of beyond-the-boundary service.

Table 6-2: Proposed Changes for the ConnectForward Plan

Route	Length (mi.)*	Existing Headways (min.)			Proposed Changes		
		M-F	Sat	Sun	M-F	Sat	Sun
sbX	16.5	10	20	n/a			
1	17	15	30	30	Route re-alignment		
2	17.2	60	55	30	70 min headway	70 min headway	70 min headway
3 & 4	19.7	15	20	20	15 min headway	25 min headway	25 min headway
5	15.5	30	60	60	Eliminated		
6	New Route						
7	8.9	30	60	60	Eliminated		
8	19.2	30/60	60	60	Reduce weekday service from the VA Ambulatory Clinic to Downtown Redlands from 30 minutes to 60 minutes, keeping service between Downtown San Bernardino and the VA Ambulatory Clinic at 30 minutes.	60 min headway	60 min headway
10	15.2	30/60	60	60			
11	14.6	30/60	60	60			
14	13.8	15	15	15	15 min headway	20 min headway	20 min headway
15	30.8	30	60	60			
19	29.6	30	60	60			
20	7.1	60	60	60	Eliminated		
22	14.1	30	60	60	Reduce weekday service north of Foothill on Riverside from 30 minutes to 60 minutes, keeping service between Arrowhead Regional Medical Center and Foothill (mostly along Riverside) at 30 minutes.	60 min headway	60 min headway
29	9.3	60	60	n/a	Route re-alignment and run with smaller vehicles		
61	23.8	15	15	15	15 min headway	20 min headway	20 min headway
66	18.2	15/30	30	30	20 min headway	30 min headway	30 min headway

<table>
<tr><th rowspan="2">Route</th><th rowspan="2">Length (mi.)*</th><th colspan="3">Existing Headways (min.)</th><th colspan="3">Proposed Changes</th></tr>
<tr><th>M-F</th><th>Sat</th><th>Sun</th><th>M-F</th><th>Sat</th><th>Sun</th></tr>
<tr><td>67</td><td>17</td><td>60</td><td>n/a</td><td>n/a</td><td></td><td></td><td></td></tr>
<tr><td>80</td><td>11.5</td><td>60</td><td>60</td><td>60</td><td colspan="3">Eliminated</td></tr>
<tr><td>81</td><td>21</td><td>30/60</td><td>60</td><td>n/a</td><td colspan="3">Route re-alignment</td></tr>
<tr><td>82</td><td>31</td><td>60</td><td>65</td><td>65</td><td colspan="3">Route re-alignment</td></tr>
<tr><td>83</td><td>14.3</td><td>60</td><td>60</td><td>60</td><td colspan="3">Route re-alignment</td></tr>
<tr><td>84</td><td>11.4</td><td>60</td><td>60</td><td>60</td><td colspan="3">Route re-alignment and run with smaller vehicles on weekend</td></tr>
<tr><td>85</td><td>20.7</td><td>30</td><td>60</td><td>60</td><td></td><td></td><td></td></tr>
<tr><td>86</td><td>14.1</td><td>60</td><td>n/a</td><td>n/a</td><td colspan="3">Eliminated</td></tr>
<tr><td>87</td><td colspan="7">New Route</td></tr>
<tr><td>88</td><td>12.1</td><td>60</td><td>60</td><td>60</td><td></td><td>Run with smaller vehicles</td><td>Run with smaller vehicles</td></tr>
<tr><td rowspan="2">208</td><td>29.9</td><td>30/48</td><td>n/a</td><td>n/a</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>215</td><td>24.2</td><td>20/30</td><td>60</td><td>60</td><td></td><td></td><td></td></tr>
<tr><td>290</td><td>56.5</td><td>40/ 120</td><td>n/a</td><td>n/a</td><td>Eliminate Mid-day service between 10:00 a.m. and 2:00 p.m.</td><td>n/a</td><td>n/a</td></tr>
<tr><td>305</td><td colspan="7">New Route</td></tr>
<tr><td>308</td><td>7.1</td><td>30/60</td><td>30</td><td>60</td><td colspan="3">Eliminated</td></tr>
<tr><td>309</td><td>7.1</td><td>30</td><td>30</td><td>60</td><td>60 min headway</td><td>n/a</td><td>n/a</td></tr>
<tr><td>310</td><td>6.3</td><td>30/60</td><td>n/a</td><td>n/a</td><td>60 min headway</td><td>n/a</td><td>n/a</td></tr>
<tr><td>325</td><td>7.9</td><td>70</td><td>70</td><td>70</td><td colspan="3">Eliminated</td></tr>
<tr><td>365</td><td>23.5</td><td>60</td><td>60</td><td>60</td><td colspan="3">Eliminated and replaced with MicroTransit program; keeping modified school tripper service near Chino Hills High School bell times.</td></tr>
<tr><td>383</td><td colspan="7">New Route</td></tr>
<tr><td>MicroTransit Chino Hills</td><td colspan="7">New Route</td></tr>
</table>

Source: Omnitrans and https://omnitrans.org/connectforward/ (accessed on April 20, 2020)

6.2.3.2 West Valley Connector ZEB Feasibility Study

The West Valley Connector (WVC) ZEB Feasibility Study[48] presents the inputs, approach, and analysis used to evaluate the preliminary feasibility of deploying ZEBs to serve SBCTA and Omnitrans' planned Phase I of a future BRT project connecting the cities of Pomona, Montclair, Ontario, and Rancho Cucamonga. The purpose of the analysis is to determine the feasibility of operating 40-foot BEBs and FCEBs on the WVC BRT route and to identify the best-fit technology. To support this analysis, a model was developed to determine: (1) energy requirements of ZEBs, and (2) ZEB performance under various charging/fueling and operating scenarios. Since the WVC along Holt Boulevard, Milliken Ave., and Foothill Boulevard are still in the planning phase, uncertainty exists in terms of service and operations. Several operating plan and scheduling assumptions were applied to demonstrate likely service conditions. The analysis concludes with a recommendation to implement BEBs along the route using a combination of base charging and on-route charging as the most practical strategy for meeting the planned service requirements of the corridor, in addition to further exploration and research into hydrogen fuel cell feasibility. Specifically, this memorandum recommends positioning two on-route chargers at Pomona Transit Center and nine chargers with 18 dispensers at the maintenance and storage facility to provide overnight charging. The findings of this initial analysis will be woven into the overall SBCTA Master Plan for ZEB adoption and implementation.

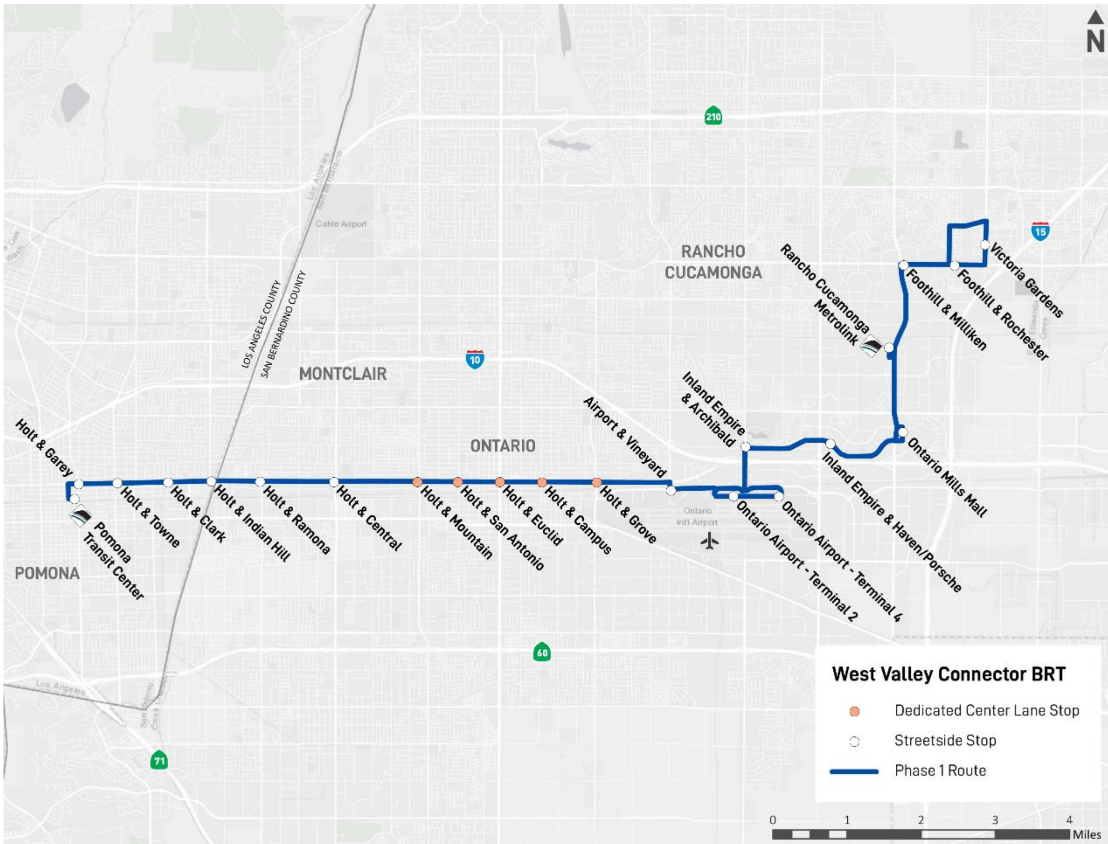
SBCTA and Omnitrans will build and operate Phase 1 of the BRT route along a 19-mile corridor along Holt Avenue, connecting to Ontario International Airport (ONT), Ontario Mills Mall, the Rancho Cucamonga Metrolink station, and ending at Victoria Gardens open-air mall. The WVC "Phase 1" is an arterial BRT line that would connect several cities: Pomona, Montclair, Ontario, and (Figure 6-3). The WVC Phase 1 will be the second BRT corridor in San Bernardino County, following the sbX Green Line, which connects the cities of San Bernardino and Loma Linda.

The Holt Avenue corridor is currently served by Omnitrans' Route 61 bus line, while Route 66 operates on Foothill Boulevard, the Historic U.S. Route 66. Together, these are two of the highest ridership routes in Omnitrans' service area. Finally, multimodal connectivity is an additional overarching theme of this project. The route commences at the Pomona Transit Center, which connects the WVC to the Pomona Metrolink station as well as Foothill Transit's services. As the route traverses eastward, connectivity at ONT is serviced at both airline terminal buildings. The route continues to the Rancho Cucamonga Metrolink station and ends near the I-15/Route 66 interchange at Victoria Gardens, a major commercial hub for the area. WVC lays a foundational bridge of intercounty transportation and provides links to rail, air, and transit centers along its path.

As part of the 2010 SANBAG Countywide Transportation Plan, the WVC has already been determined as a baseline scenario for transit expansion in San Bernardino County. In alignment with existing sustainability measures, the further development of BRT and GHG reductions are imperative for overall county goals of further transit investment.

[48] Please refer to Appendix A for the complete West Valley Connector ZEB Feasibility Report.

Figure 6-3: West Valley Connector BRT Project Map



Source: WSP

Omnitrans currently operates an entirely CNG fleet and has committed to transitioning to a 100 percent zero-emission fleet by 2040. Determining ZEB technologies in transit (hydrogen fuel cell and BEB) decided to analyze the operational and cost feasibility of integrating these technologies, namely BEB, into their existing CNG and hybrid fleet.

By examining and modeling both BEB and hydrogen fuel cell technologies, the recommendations made are based on the highest operational feasibility, with minimal associated capital costs. Implementing the WVC BRT as a zero-emissions route from the onset would bolster SBCTA's sustainability and long-term planning initiatives, while also serving as a case study for adoption of ZEBs across Omnitrans' entire fleetBEB.[49]

6.2.4 Facilities

This section provides a summary understanding of each of Omnitrans' existing site and facility conditions. Omnitrans operates in the San Bernardino Valley of the greater Los Angeles area, with the West Valley Division located in Montclair and the East Valley Division located in San Bernardino proper. Additionally, the SBTC has transfer points with neighboring transit agencies, such as VVTA, MT, RTA, and Pass Transit.

[49] Full recommendations and additional analysis are provided below in Appendix A.

Currently, the entire Omnitrans fleet operates on CNG. A more detailed catalog of the existing site condition is available in the report titled "Zero Emission Bus (ZEB) Analysis Facilities Inventory Report" issued January 15, 2020.

6.2.4.1 West Valley

Omnitrans' West Valley facility is located at 4748 E Arrow Hwy, Montclair, California, on approximately 5.5 acres of land (Figure 6-5). The facility has an assumed maximum bus capacity of 74 buses. Table 6-3 describes the site's facilities, equipment, and fleet.

Currently, 71 CNG-powered buses are stored, maintained, fueled, and serviced at the division. The facility includes the following separate structures and major site areas: A one-story maintenance building, one-story transportation building, stand-alone wash building, stand-alone fuel building, an employee parking lot on Arrow Highway, and a CNG compressor yard with support equipment.

Table 6-3: Omnitrans West Valley Inventory

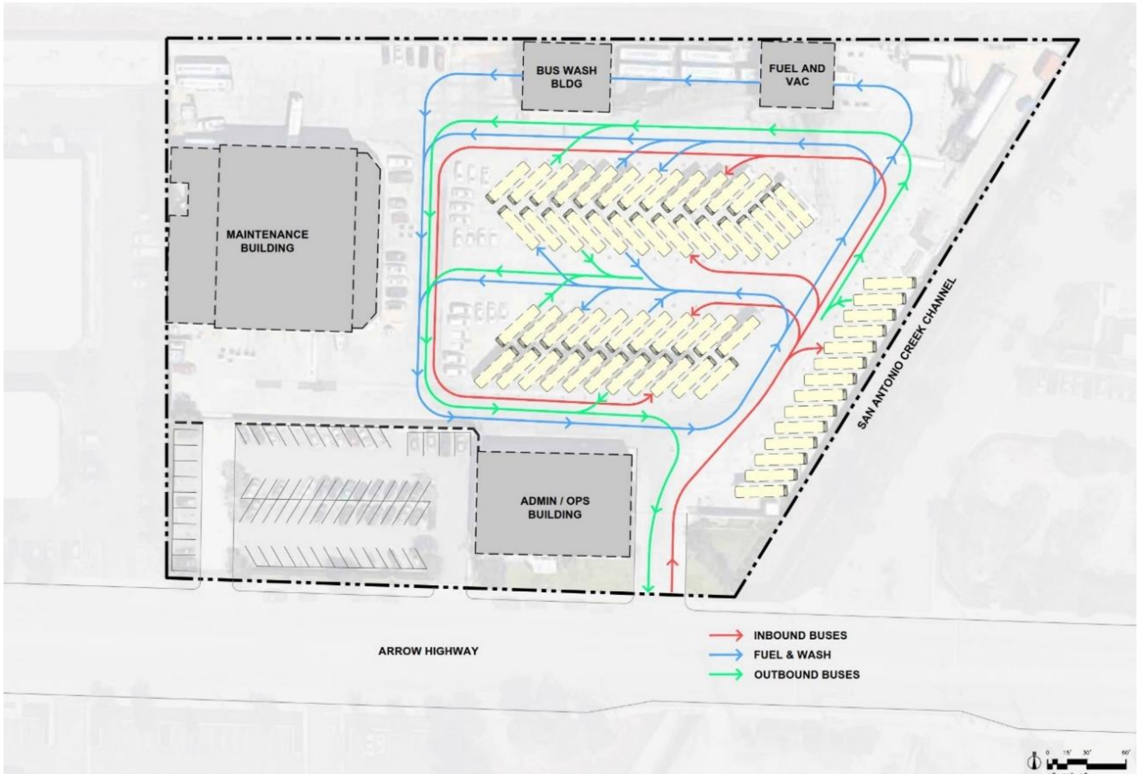
Fleet Overview	
Cutaway Bus	-
30-foot Bus	-
35-foot Bus	-
40-foot Bus	71
45-foot Bus	-
60-foot Articulated Bus	-
Total	**71**
Facilities	
Total Maintenance Bays	8
Paint Booths	-
CNG Fueling Positions	2
CNG Compressor Yards	1
Diesel Fueling Positions	-
Unleaded Fueling Positions	1
NRV Bays	-
Body shops	-
Bus Wash Lanes	2 (1 drive-thru/1 chassis wash)

Source: WSP

Figure 6-4: West Facility - Existing Conditions

Source: WSP

Figure 6-5: Omnitrans West Facility Site Circulation



Source: WSP

SCE supplies the 1000 kVA (12 kV–480 Y/277) pad mounted transformer with a 12-kV underground connection. The low voltage side of the transformer is feeding the switchboard with a (1600AF/1000AT) Amp main breaker. It shall be noted that the West valley facility has been backed up with a 500kW and 150kW generators and that there is a designated 100A service for the EV charging station. According to the provided "Collective Load Detail," the West Valley has a peak of 814kW, which is almost full-service capacity per NEC requirements.

According to Omnitrans, a new overhead transformer and a 600-amp service meter along with two power cabinets and four facility charge boxes will be installed in the north west corner of the facility for the first four BEBs (expected delivery in 2021). This is part of the SCE Charge-Ready Transport program.

6.2.4.2 East Valley

Omnitrans’ East Valley facility is located at 1700 W. 5th Street, San Bernardino, California, on approximately 12.7 acres of land (Figure 6-6). The facility has an assumed maximum bus capacity of 120 buses. Table 7-3 describes the site’s facilities, equipment, and fleet.

Currently, 115 CNG-powered buses are stored, fueled, and serviced at the facility. The East Valley facility includes the following separate structures and major site areas: A two-story maintenance building, two-story transportation building, stand-alone wash building, stand-alone fuel building, an employee parking lot, and a CNG compressor yard with support equipment. Employee parking is on site in the employee parking lot along 5th Street or the satellite employee parking, which is off Medical Center Drive.

Buses enter from Medical Center Drive and park facing west of the facility before undergoing service. Individual buses are then taken by Omnitrans nightly service staff to the fuel lanes for fare retrieval and fueling before pulling forward to the bus wash lanes. After fuel and wash, buses are circulated back into the bus parking tracks and re-parked facing east in nose-to-tail tracks. The interiors of the buses are cleaned during the fueling process. Once re-parked after nightly service, buses remain parked in-place until morning pull out unless a maintenance issue has been identified.

Table 6-4: Omnitrans East Valley Inventory

Fleet Overview	
Cutaway Bus	-
30-foot Bus	-
35-foot Bus	-
40-foot Bus	100
45-foot Bus	-
60-foot Articulated Bus	15
Total	**115**
Facilities	
Total Maintenance Bays	24
Paint Booths	1
CNG Fueling Positions	3
CNG Compressor Yards	1
Diesel Fueling Positions	1
Unleaded Fueling Positions	1
NRV Bays	2
Body shops	1
Bus Wash Lanes	2 (1 drive-thru/1 chassis wash)

Source: WSP

Figure 6-6: East Valley– Existing Conditions

Source: WSP

Figure 6-7: Omnitrans East Valley Site Circulation

Source: WSP

SCE powers the Omnitrans East Valley facility, which is fed via 12 kV underground power distribution. The Omnitrans East Valley Facility's power distribution has been retrofitted to meet the upgraded demands of the CNG Fuel Station Project. As a result of this retrofit, the 12 kV switchgear, the 2500 kVA (12 kV-480/277 V) utilities transformer, spare transformer pad, the new power distribution panels (Panel 1 & 3), harmonic filter, automatic transfer switch, and 1000 kW generator was installed. Consequently, the old 1000 kVA transformer and the old power meter had been abandoned ; thus, the old power distribution panel (MSA) which distributes power to four preexisting buildings (Maintenance Facility, Admin Building, Wash Facility Building, and Vacuum and Fueling Building) had to be fed from the new power distribution panel (Panel #1) via an 800 A designated circuit breaker. It shall be noted that the aforementioned buildings are backed up by an old 200 kW and a 350 kW standby generator. The CNG fuel station (Panel #3) is fed from the new power distribution panel (Panel #1) with a 2000 A designated circuit breaker and backed up by a 1000 kW generator.

A new transformer and a 600 amp service meter along with two power cabinets and five facility charge boxes will be installed along the east side of the property along Medical Center Drive for the first four BEBs. This is part of the SCE Charge-Ready Transport Program.

6.2.4.3 San Bernardino Transit Center

The SBTC is located at 599 W. Rialto Ave, San Bernardino, California, on approximately 5.1 acres of land.

Figure 6-8: San Bernardino Transit Center - Existing Conditions

Source: WSP

SCE powers the SBTC, which is fed via 12 kV underground power distribution. SCE supplied the 150 kVA (12 kV – 480 V Y/277) pad-mounted transformer. The LV side of the transformer is feeding the switchboard with a (600 AF/120 AT) A main breaker.

The SBTC has 120A nominal service size. According to the provided "Collective Load Detail," the SBTC has a peak of 67kW that is at about 93 percent full-service capacity per NEC requirements; thus, there is approximately 10A remaining which is available for future use.

6.3 ZEB Implementation

6.3.1 Technology

Omnitrans' future BEBs are expected to have specifications that are compatible with the Society of Automotive Engineers' (SAE) J1772 (plug-in) and SAE J3105 (pantograph) charging standards. By supporting both standards, Omnitrans' buses will have flexibility in charging in multiple layouts. The plug-in standard will allow buses to charge at the base (overnight) and while being serviced, and the pantograph standard will allow buses to charge at the base and at potential on-route charging stations. The roof-mounted charging rails that are associated with the pantograph standard will allow a BEB to access high-power charging (200-600 kW).

Based on Omnitrans' existing service needs and site configurations, it is recommended that an overhead-mounted (pantograph and/or plug-in) charging strategy be implemented to support BEBs at both West Valley and East Valley facilities. The dispensers will be supported by an overhead frame that will cover the surface of the bus parking tracks. This overhead strategy is due to space constraints at both facilities. The overhead frame can also support photovoltaic panels and electrical equipment and components (conduit, etc.).

The proposed facility 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). This charger to dispenser ratio maximizes space utility, reduces costs, and meets the requirements to charge the fleet during servicing and dwell time on the site while minimizing the peak electrical demand. However, Omnitrans is currently exploring other strategies that may require less power and space, such as a 1:3 charging orientation.

Inductive (wireless) charging for BEBs is also a future consideration, however, this technology is still very expensive, and has yet to be deployed on a large scale to prove its viability for fleet operations. Based on current site circulation and configurations, all plug-in ports shall be at the rear of the bus.

For the specific routes which route-modeling has identified as not capable of being served by existing BEB technology, it is recommended that FCEBs be considered. If FCEBs are integrated into the fleet, they should be fueled at a future commercial or public hydrogen fueling station located in either Ontario or Chino. Based on the recommended BEB strategy, onsite storage or generation is infeasible due to space constraints, however, if plans are revised, onsite solutions may be deemed feasible.

On-site liquid storage (delivered by truck) is a consideration dependent upon space constraints. Alternatively, an on-site electrolyzer that generates hydrogen from water, could be used to eliminate the need to deliver hydrogen to the site. Note that while possible to self- generate, the available space at both Omnitrans' sites do not allow for a large enough electrolyzer to generate more hydrogen than could be used to fill four to six FCEBs, daily (assumption of 37 kilograms per bus at 350 bar).

The impacts of these recommendations for each site follow.

6.3.2 Analysis/Findings

6.3.2.1 West Valley

It is recommended that the West Valley facility adopt an overhead platform-mounted retractor cord DC plug-in or overhead pantograph charging solution. With this approach, the West Valley facility is capable of parking 74 buses (max capacity of the facility) with 74 charging positions in a 1:2 charger to bus dispenser ratio. Ground-mounted charging cabinets and dispensers are not recommended for West Valley as they would create a significant reduction in bus parking capacity due to parking losses to accommodate ground-mounted charging equipment.

The following BEB equipment and locations are proposed:

- 37 ground-mounted DC charging cabinets located at both ends of the proposed overhead support structures. Distribution to 74 retractor cord plug-in dispenser (or pantograph) charging positions mounted from overhead support structures in a new 45-degree track parking layout.
- Dispensers are located for connecting to the rear of the bus to reduce the length of support structure at the rear of the parking tracks in order to maintain bus turning clearances.
- The overhead support structure columns are to be placed every three to four tracks. These columns will also provide the mounting space for retractor cord controls to be installed to control each overhead dispenser's charging cable position for a plug-in option, or to support overhead mounted pantographs.

The plug-in charging dispensers (or pantographs) and charging cabinets will be served by the following electrical infrastructure:

- Three medium voltage utility service transformers in a new utility yard in the open space south of the existing parking yard and east of the site entrance.
- Three sets of switchgear will be located near the proposed overhead support structures to reduce long-distance medium voltage conduit runs.

If FCEBs are to be integrated in the future (using the proposed configuration), it is recommended that offsite commercially available hydrogen fueling stations be utilized. Required clearances around liquid hydrogen storage exceed what the current site configuration is able to accommodate, making onsite hydrogen fueling infeasible at this time.

Conceptual layouts for the proposed ZEB solutions for Omnitrans' facilities are present in Section 6.3.5.4 of this document.

6.3.2.1.1 Modeling Results

Base-Only Charging – West Valley

Currently, the West Valley facility operates 48 vehicle blocks with 40-foot transit vehicles. The smallest block distance traveled is 27 miles and the longest is 280 miles. As discussed in Section 2.1.2, a 660-kWh (524-kWh operating) battery was used to model the transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 660 kWh battery. Only 25 percent of vehicle blocks could be completed at the optimistic efficiency, 10 percent at the base efficiency, and 8 percent at the conservative efficiency.

For the fleet to maintain a 1:1 ratio with the transition to BEB with base-only charging, Omnitrans would need battery capacities that exceed over 1,000 kWh at the same efficiency as the 660 kWh vehicles (~3.4 kWh/mi.), but this capacity is not currently available.

Table 6-5 provides the summary of block completion percentage for Omnitrans at the West Valley Division, and Table 6-6 provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service with the 660 kWh battery at the conservative efficiency. Table 6-6 also details the needed advertised battery capacity to achieve 100 percent of service on the block at all efficiencies.

Table 6-5: Omnitrans – West Valley Base-Only Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
660	**524**	**25% (12)**	**10% (5)**	**8% (4)**
700	560	38% (18)	13% (6)	8% (4)
750	600	56% (27)	13% (6)	8% (4)
800	640	77% (37)	15% (7)	10% (5)
850	680	94% (45)	19% (9)	13% (6)
900	720	96% (46)	29% (14)	13% (6)
950	760	100% (48)	40% (19)	13% (6)
1000	800	100% (48)	56% (27)	15% (7)

Source: WSP

Table 6-6: Summary of Omnitrans West Valley Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>61-14	660	9.4	139	465	620	775
3>61-13	660	11.0	149	502	670	837
3>66-8	660	12.9	173	583	778	972
3>61-11	660	12.8	186	622	830	1037
3>80-5	660	15.4	186	626	834	1043
3>61-12	660	14.3	196	660	880	1099
3>61-5	660	14.3	196	660	880	1099
3>61-7	660	14.3	196	660	880	1099
3>85-7	660	14.5	197	661	881	1101
3>85-3	660	16.0	200	674	899	1124
3>85-2	660	15.5	201	676	902	1127
3>86-1	660	15.9	202	680	907	1134
3>66-1	660	14.4	207	697	929	1161
3>66-4	660	14.4	207	697	929	1161
3>88-1	660	17.9	209	706	942	1177
3>85-1	660	16.0	218	729	972	1215
3>80-3	660	16.1	218	733	977	1221
3>365-1	660	16.7	220	740	987	1234
3>80-4	660	17.8	221	742	989	1236
3>86-2	660	17.4	221	744	992	1240

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>83-1	660	15.7	222	745	993	1242
3>83-2	660	15.7	222	745	994	1242
3>365-2	660	15.7	223	749	999	1248
3>85-6	660	16.8	224	754	1005	1257
3>88-2	660	18.7	225	756	1008	1260
3>80-2	660	16.9	227	765	1020	1275
3>82-3	660	16.9	229	770	1026	1283
3>83-3	660	16.5	231	778	1037	1296
3>61-10	660	15.8	232	780	1039	1299
3>61-2	660	16.2	232	780	1039	1299
3>61-3	660	16.1	234	784	1046	1307
3>83-4	660	16.5	235	790	1053	1316
3>85-5	660	18.0	236	793	1057	1321
3>66-6	660	16.8	241	810	1080	1350
3>66-2	660	16.6	242	813	1084	1355
3>66-9	660	16.6	242	813	1084	1355
3>66-3	660	17.6	242	816	1088	1360
3>61-4	660	17.5	243	817	1089	1362
3>61-9	660	17.2	243	817	1089	1362
3>66-10	660	16.8	243	817	1090	1362
3>85-4	660	18.7	252	848	1131	1414
3>80-1	660	18.4	260	875	1167	1458
3>61-1	660	19.1	280	942	1256	1570
3>61-6	660	19.3	280	942	1256	1570

Source: WSP

Base and On-Route Charging – West Valley

Currently, the West Valley Facility operates 48 vehicle blocks with 40-foot transit vehicles. The smallest block distance traveled is 27 miles and the longest is 280 miles. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) battery was used to model the transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with the 660 kWh battery. Only 65 percent of vehicle blocks could be achieved at the optimistic efficiency, 52 percent at the base efficiency, and 23 percent at the conservative efficiency.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies, 37 vehicle blocks would need to be served by vehicles with an advertised battery capacity over 660 kWh that also operate at the same kWh/mi efficiency as the other 40-foot vehicles modeled (3.4 kWh/mi.).

Table 6-7 provides the summary of block completion percentage for Omnitrans at the West valley Yard, and Table 6-8 provides a list of the current vehicle blocks that would not be able to complete 100 percent of service with the 660 kWh battery at the conservative efficiency. Table 6-8 also details the needed advertised battery capacity to achieve 100 percent of service on the blocks at all efficiencies.

Table 6-7: Omnitrans – West Valley Base and On-Route Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**52% (25)**	**21% (10)**	**6% (3)**
660	**524**	**65% (31)**	**52% (25)**	**23% (11)**
700	560	67% (32)	52% (25)	25% (12)
750	600	88% (42)	54% (26)	31% (15)
800	640	98% (47)	56% (27)	35% (17)
850	680	98% (47)	60% (29)	42% (20)
900	720	100% (48)	65% (31)	52% (25)
950	760	100% (48)	69% (33)	52% (25)
1000	800	100% (48)	88% (42)	56% (27)

Source: WSP

Table 6-8: Summary of Omnitrans West Valley Base and On-Route Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>61-4	660	17.5	243	272	469	679
3>61-9	660	17.2	243	269	479	719
3>61-2	660	16.2	232	261	488	729
3>66-1	660	14.4	207	277	509	741
3>61-3	660	16.1	234	248	496	757
3>66-4	660	14.4	207	307	539	771
3>61-10	660	15.8	232	358	588	829
3>66-3	660	17.6	242	357	589	834
3>61-6	660	19.3	280	276	558	850
3>66-2	660	16.6	242	336	588	855
3>66-6	660	16.8	241	337	598	868
3>66-9	660	16.6	242	357	602	873
3>61-1	660	19.1	280	316	598	880
3>66-10	660	16.8	243	366	620	892
3>85-2	660	15.5	201	516	742	967
3>85-3	660	16.0	200	534	759	984
3>85-7	660	14.5	197	591	811	1031

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>80-5	660	15.4	186	626	834	1043
3>85-1	660	16.0	218	609	852	1095
3>85-6	660	16.8	224	614	865	1117
3>86-1	660	15.9	202	680	907	1134
3>88-1	660	17.9	209	706	942	1177
3>80-3	660	16.1	218	733	977	1221
3>365-1	660	16.7	220	740	987	1234
3>80-4	660	17.8	221	742	989	1236
3>86-2	660	17.4	221	744	992	1240
3>83-1	660	15.7	222	745	993	1242
3>83-2	660	15.7	222	745	994	1242
3>365-2	660	15.7	223	749	999	1248
3>85-5	660	18.0	236	723	987	1251
3>88-2	660	18.7	225	756	1008	1260
3>85-4	660	18.7	252	708	991	1274
3>80-2	660	16.9	227	765	1020	1275
3>82-3	660	16.9	229	770	1026	1283
3>83-3	660	16.5	231	778	1037	1296
3>83-4	660	16.5	235	790	1053	1316
3>80-1	660	18.4	260	875	1167	1458

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

Service performance at West Valley was evaluated using three degrees of efficiency (described in the Methodology Section) to determine the percentage of each service block that could be completed when operating current FCEB technology. The total percentage of blocks that meet service requirements using FCEB vehicles is presented to demonstrate the viability of the technology. Any block operating vehicle classes not currently available as FCEBs were immediately disqualified for FCEB Using the results of this analysis, anticipated hydrogen fuel consumption was calculated for three alternative scenarios: 1) full-fleet FCEB conversion, 2) conversion of only the qualifying blocks (those that met range requirements, and 3) and conversion of only FCEB qualifying blocks that cannot be served by BEBs.

Under optimistic vehicle efficiency estimations, there was a 100 percent service block completion when operating current FCEB technologies. Under base efficiency estimations, only four service blocks failed to meet range requirements, resulting in a 92 percent of the service blocks meeting performance goals (Table 6-9). When measured under the most conservative efficiency estimation, FCEB fleet performance declined dramatically, with only 19 percent of the fleet qualifying for FCEB conversion (Table 6-10). Of these failed blocks, however, the average percent of the service blocks completed was 84 percent, indicating that with minor technological advances or mid-day refueling, an FCEB conversion may be viable.

Table 6-9: West Valley Non-Qualifying Service Blocks Under Base Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
3>61-1	280.4	87.96%
3>61-6	280.4	87.96%
3>80-1	260.1	94.80%
3>85-4	252.0	97.87%

Source: WSP

Table 6-10: West Valley Non-Qualifying Service Blocks Under Conservative Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
3>365-1	222.8	95.03%
3>365-2	27.7	98.05%
3>61-1	232.3	73.47%
3>61-10	185.7	82.46%
3>61-12	149.3	86.77%
3>61-2	232.3	84.43%
3>61-3	233.7	86.77%
3>61-4	242.6	86.77%
3>61-5	196.0	72.21%
3>61-6	280.4	79.13%
3>61-7	196.0	82.01%
3>61-9	242.6	74.26%
3>66-1	207.5	82.13%
3>66-10	243.3	74.35%
3>66-2	241.9	82.01%
3>66-3	241.7	82.13%
3>66-4	207.5	82.13%
3>66-6	241.1	88.72%
3>66-9	241.9	85.01%
3>80-1	260.1	89.68%
3>80-2	227.3	97.49%
3>80-3	218.3	91.12%
3>80-4	220.9	91.07%
3>82-3	229.2	97.04%
3>83-1	221.5	91.07%
3>83-2	221.7	58.72%

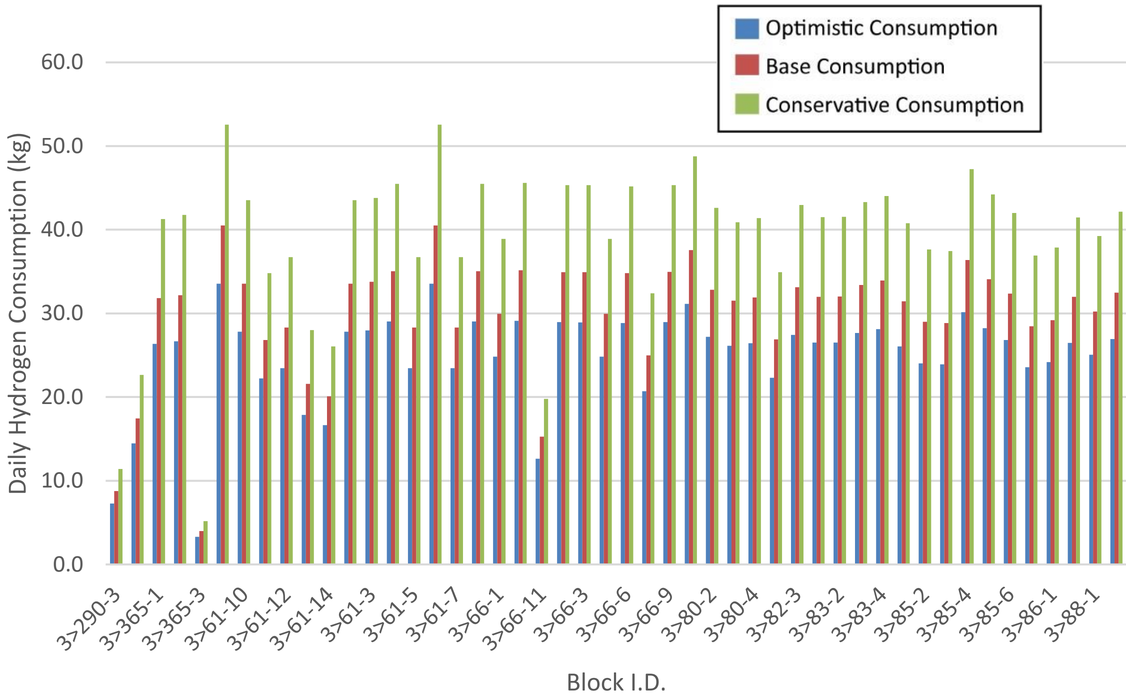
Block I.D.	Daily Mileage	Percent Block Distance Complete
3>83-3	231.1	58.72%
3>83-4	234.9	86.44%
3>85-1	217.6	90.05%
3>85-2	200.9	94.64%
3>85-3	199.8	44.78%
3>85-4	252.0	84.91%
3>85-5	235.9	76.67%
3>85-6	224.0	89.28%
3>85-7	197.0	91.38%
3>86-1	202.1	91.38%
3>86-2	221.3	95.67%
3>88-1	209.4	86.25%
3>88-2	225.0	87.51%

Source: WSP

Hydrogen Requirements

A full-fleet FCEB conversion at West Valley would require between 1,197 kg and 1,847 kg per day, with individual blocks requiring an average of 31 kg of fuel per day (Figure 6-9). To support this hydrogen need, bi-daily delivery would likely be necessary, unless supplemented with on-site production. When considering only the service blocks that meet performance criteria when using current FCEB technologies, the fuel requirement under optimistic estimations remains the same and shifts only slightly under the base estimation to 1,289 kg per day. As a result of the steep drop-off of qualifying blocks under the conservative estimation, fuel requirements under this scenario drops to only 215 kg. Under the final conversion scenario, which considers only FCEB qualifying blocks to supplement the BEB fleet, between 22 kg and 25 kg of fuel would be required (Table 6-11, Table 6-12). Since this represents only a single service block, this scenario is not justified.

Figure 6-9: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of West Valley



Source: WSP

Table 6-11: West Valley Hydrogen Consumption for Three FCEB Fleet Conversion Scenarios

Efficiency	Full Fleet H2 (kg)	Qualifying Fleet H2 (kg)	BEB Supplemental Fleet H2 (kg)
Optimistic	1197	1197	22
Base	1444	1289	27
Conservative	1874	215	35

Source: WSP

Table 6-12: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of West Valley

Block ID	Block Distance	Vehicle Type	Representative Vehicle	Optimistic H2 Consumption (kg)	Base H2 Consumption (kg)	Conservative H2 Consumption (kg)
3>290-3	60.8	40'	40'	7.3	8.8	11.4
3>290-4	120.8	40'	40'	14.5	17.5	22.6
3>365-1	220.3	40'	40'	26.4	31.8	41.3
3>365-2	222.8	40'	40'	26.7	32.2	41.8
3>365-3	27.7	40'	40'	3.3	4.0	5.2
3>61-1	280.4	40'	40'	33.6	40.5	52.5
3>61-10	232.3	40'	40'	27.8	33.6	43.5
3>61-11	185.7	40'	40'	22.2	26.8	34.8
3>61-12	196.0	40'	40'	23.5	28.3	36.7

Block ID	Block Distance	Vehicle Type	Representative Vehicle	Optimistic H2 Consumption (kg)	Base H2 Consumption (kg)	Conservative H2 Consumption (kg)
3>61-13	149.3	40'	40'	17.9	21.6	28.0
3>61-14	139.0	40'	40'	16.6	20.1	26.1
3>61-2	232.3	40'	40'	27.8	33.6	43.5
3>61-3	233.7	40'	40'	28.0	33.8	43.8
3>61-4	242.6	40'	40'	29.0	35.0	45.5
3>61-5	196.0	40'	40'	23.5	28.3	36.7
3>61-6	280.4	40'	40'	33.6	40.5	52.5
3>61-7	196.0	40'	40'	23.5	28.3	36.7
3>61-9	242.6	40'	40'	29.0	35.0	45.5
3>66-1	207.5	40'	40'	24.8	30.0	38.9
3>66-10	243.3	40'	40'	29.1	35.1	45.6
3>66-11	105.6	40'	40'	12.6	15.3	19.8
3>66-2	241.9	40'	40'	28.9	34.9	45.3
3>66-3	241.7	40'	40'	28.9	34.9	45.3
3>66-4	207.5	40'	40'	24.8	30.0	38.9
3>66-6	241.1	40'	40'	28.9	34.8	45.2
3>66-8	172.9	40'	40'	20.7	25.0	32.4
3>66-9	241.9	40'	40'	29.0	34.9	45.3
3>80-1	260.1	40'	40'	31.1	37.6	48.8
3>80-2	227.3	40'	40'	27.2	32.8	42.6
3>80-3	218.3	40'	40'	26.1	31.5	40.9
3>80-4	220.9	40'	40'	26.4	31.9	41.4
3>80-5	186.3	40'	40'	22.3	26.9	34.9
3>82-3	229.2	40'	40'	27.4	33.1	43.0
3>83-1	221.5	40'	40'	26.5	32.0	41.5
3>83-2	221.7	40'	40'	26.5	32.0	41.5
3>83-3	231.1	40'	40'	27.7	33.4	43.3
3>83-4	234.9	40'	40'	28.1	33.9	44.0
3>85-1	217.6	40'	40'	26.0	31.4	40.8
3>85-2	200.9	40'	40'	24.0	29.0	37.7
3>85-3	199.8	40'	40'	23.9	28.9	37.5
3>85-4	252.0	40'	40'	30.2	36.4	47.2
3>85-5	235.9	40'	40'	28.2	34.1	44.2
3>85-6	224.0	40'	40'	26.8	32.4	42.0
3>85-7	197.0	40'	40'	23.6	28.5	36.9
3>86-1	202.1	40'	40'	24.2	29.2	37.9

Block ID	Block Distance	Vehicle Type	Representative Vehicle	Optimistic H2 Consumption (kg)	Base H2 Consumption (kg)	Conservative H2 Consumption (kg)
3>86-2	221.3	40'	40'	26.5	32.0	41.5
3>88-1	209.4	40'	40'	25.1	30.2	39.2
3>88-2	225.0	40'	40'	26.9	32.5	42.2
Total				**1196.6**	**1444.3**	**1874.0**

Source: WSP

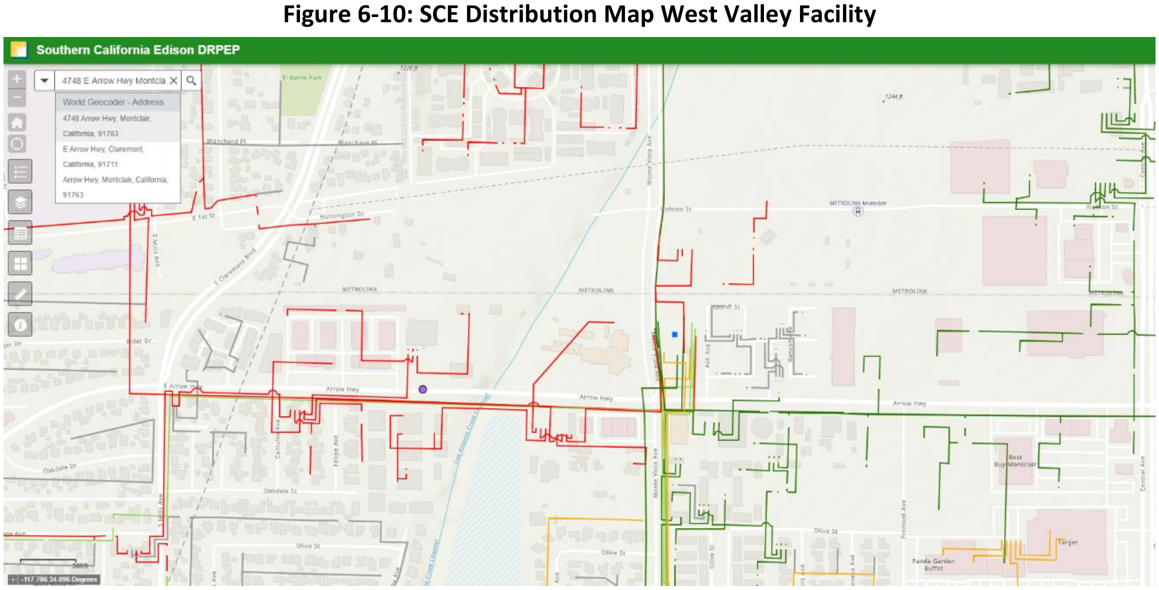
6.3.2.1.2 Site Energy Analysis

The West Valley facility is home to 74 buses. Based on the recommended 37 ground-mounted 150 kW DC plug-in charging solution, the West Valley division is capable of parking 74 buses with plug-in charging positions in a 1:2 charger to bus dispenser ratio. This will require new SCE service for 5,500 kW, assuming that 37 chargers are installed.

According to SCE, the existing facility is served from the “Kingsley” circuit (Figure 6-10), which delivers power at 12kV. A rule of thumb is that a 12kV circuit can hold around 8.3MW of power. Therefore, at full build out, the West Valley facility would require ~66 percent of the circuit’s power, and the circuit already has a full load at peak draw. SCE requires a method of serviceMOS application and study for all new connections that take up more than 10% of the load on the circuit. Omnitrans should consider putting in the MOS as soon as possible, since the MOS study takes 18 months, before detailed design and construction can even begin. In short, it is feasible to get this level of power service from SCE, but it will take time.

After full build out, the BEBs will require 27,000 - 45,000 kWh every day to support the 63 buses. The SCE EV-TOU rates don’t include any “demand charges”, so there is no incentive to “flatten the curve” of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9 pm. Therefore, Omnitrans should invest in good charge management software that avoids incurring big costs from charging during peak times.

Figure 6-10: SCE Distribution Map West Valley Facility



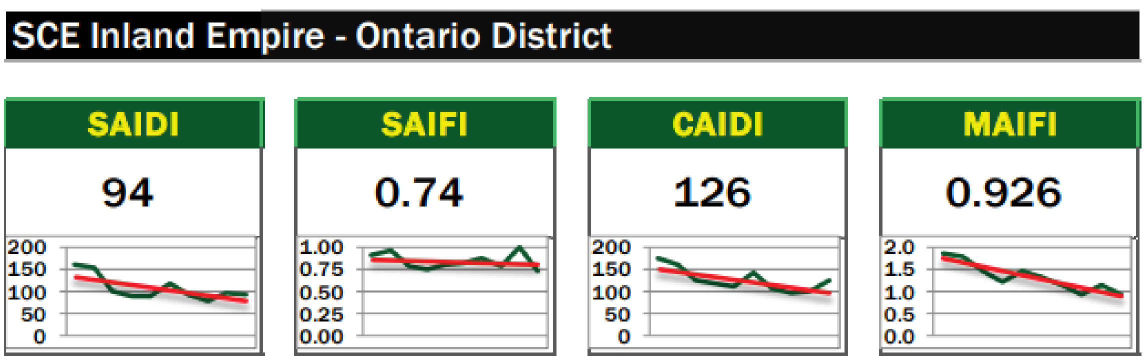
Source: SCE

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- Two 3,000 kVA medium voltage utility service transformers in a new utility yard in the open space south of the existing parking yard and east of the site entrance.
- Two sets of 480V switchboards in a new utility yard in the open space south of the existing parking yard and east of the site entrance.
- Underground conduits to ground mounted chargers.

From a resiliency perspective, this site is good for electrification. The site is located as part of SCE's Ontario district, which is one of the most reliable districts in SCE's territory. In addition, there is no fire risk to the Kingsley circuit that serves this site, while some of the other circuits have been deemed a risk by CPUC. See Section 1.5.1.3 for more details about reliability of SCE's electric grid and Section 1.5.1.3.3 for more details about Fire Risks. Therefore, there is no need to invest heavily in redundancy based on the risk factors. Figure 6-11 shows the reliability figure for West Valley. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

Figure 6-11: West Valley (SCE Ontario District) Energy Reliability Figures



Source: SCE

6.3.2.2 East Valley

It is recommended that the East Valley facility adopt an overhead platform-mounted retractor cord DC plug-in or overhead pantograph charging solution. With this approach, the East Valley facility is capable of parking 120 buses (max capacity of the division) with 120 charging positions in a 1:2 charger to bus dispenser ratio. Ground-mounted charging cabinets and dispensers are not recommended for East Valley as they would create a significant reduction in bus parking capacity due to parking losses to accommodate ground-mounted charging equipment.

The following BEB equipment and locations are proposed:

- 60 ground-mounted charging cabinets located in a centralized island in the middle of the parking racks. Distribution to 120 retractor cord plug-in dispenser or overhead pantograph charging positions mounted from an overhead support structure in the existing track parking.
- Dispensers are located for connecting to the rear of the bus to reduce the length of support structure at the rear of the parking tracks in order to maintain bus turning clearances.

Additionally, the eastern-most front row of tracks will have the dispensers staggered back slightly to allow for less support structure and easier maneuvers out of the track parking area.

- Overhead support structure columns will be placed every four tracks. These columns will also provide the mounting space for retractor cord controls to be installed to control each overhead dispenser's charging cable position.

The plug-in (or pantograph) charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- Four medium voltage utility service transformers in a new utility yard in the open space along the northern site wall and west of the existing bus wash.
- Four sets of switchgear in a central utility yard in the open space at a central island in the parking tracks.

If FCEBs are to be integrated in the future (using the proposed configuration), it is recommended that offsite commercially available hydrogen fueling stations be utilized. Required clearances around liquid hydrogen storage exceed what the current site configuration is able to accommodate, making onsite hydrogen fueling infeasible at this time.

Conceptual layouts for the proposed ZEB solutions for Omnitrans' facilities are present in Section 6.3.5.4 of this document.

6.3.2.2.1 Modeling Results

Base-Only Charging – East Valley

Currently, the East Valley facility operates a total of 115 vehicle blocks with 100 vehicle blocks operated with 40-foot vehicles and 15 vehicle blocks operated with 60-foot vehicles. The smallest vehicle block distance traveled is 46 miles and the longest is 424 miles. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) battery was used to model both the 40- and 60-foot vehicles.

The analysis found it would not be possible to complete all vehicle blocks for the 40- and 60-foot vehicle blocks with base-only charging with a 660 kWh battery. Only 48 percent of 40-foot vehicle blocks could be achieved at the optimistic efficiency, 23 percent could be achieved at the base efficiency, and 10 percent could be achieved at the conservative efficiency. For 60-foot vehicle blocks, 40 percent of vehicle blocks could be achieved at the optimistic efficiency, 20 percent could be achieved at the base efficiency, 13 percent could be achieved at the conservative efficiency.

For the fleet to maintain a 1:1 ratio with the transition to BEB with base-only charging Omnitrans would need battery capacities that exceed over 1,000 kWh for both 40- and 60-foot vehicles that operate at the same efficiency as the 660 kWh vehicles (~3.4 kWh/mi. for 40-foot vehicles and ~5.10 kWh/mi. for 60-foot vehicles), but this technology is not currently available.

Table 6-13 provides the summary of block completion for Omnitrans at the East Valley Division for 40-foot vehicles, and Table 6-14 provides the summary of block completion for 60-foot vehicles. Table 6-15 provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service with the battery capacity modeled. Table 6-15 also details the needed advertised battery capacity to achieve 100 percent of existing service on the blocks at all efficiencies.

Table 6-13: Omnitrans – East Valley Base-Only Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
660	**524**	**48% (48)**	**23% (23)**	**10% (10)**
700	560	56% (56)	25% (25)	17% (17)
750	600	73% (73)	31% (31)	18% (18)
800	640	85% (85)	34% (34)	21% (21)
850	680	90% (90)	43% (43)	23% (23)
900	720	97% (97)	51% (51)	27% (27)
950	760	97% (97)	60% (60)	32% (32)
1000	800	97% (97)	73% (73)	34% (34)

Source: WSP

Table 6-14: Omnitrans – East Valley Base-Only Charging 60-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
660	**524**	**40% (6)**	**20% (3)**	**13% (2)**
700	560	40% (6)	27% (4)	13% (2)
750	600	40% (6)	27% (4)	20% (3)
800	640	40% (6)	40% (6)	20% (3)
850	680	40% (6)	40% (6)	20% (3)
900	720	40% (6)	40% (6)	27% (4)
950	760	40% (6)	40% (6)	27% (4)
1000	800	53% (8)	40% (6)	40% (6)

Source: WSP

Table 6-15: Summary of Omnitrans East Valley Base-Only Charging Incomplete Blocks

Block ID	Vehicle Size (feet)	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>290-2	40	660	4.6	125	397	529	662
3>43587	40	660	8.5	120	403	537	671
3>43589	40	660	8.9	120	403	537	671
3>43594	40	660	8.5	121	405	541	676
3>43596	40	660	8.5	121	405	541	676
3>215-5	40	660	5.5	127	406	541	677
3>43562	40	660	10.3	122	410	547	683
3>43593	40	660	9.1	125	421	562	702
3>202-1	60	660	5.6	95	446	595	743

Block ID	Vehicle Size (feet)	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>43595	40	660	9.5	135	454	606	757
3>43561	40	660	11.9	141	476	635	793
3>43530	40	660	12.2	141	476	635	793
3>215-4	40	660	7.2	151	483	644	805
3>43474	40	660	12.4	144	485	647	809
3>202-15	60	660	7.1	110	515	687	858
3>14-3	40	660	13.8	155	521	695	869
3>14-5	40	660	13.5	155	521	695	869
3>14-2	40	660	14.3	160	538	717	896
3>14-4	40	660	13.9	160	538	717	896
3>29-1	40	660	12.5	161	540	720	900
3>43557	40	660	13.3	161	542	723	903
3>43528	40	660	13.6	161	542	723	904
3>43471	40	660	14.0	163	546	728	911
3>43560	40	660	12.5	171	567	756	945
3>14-7	40	660	15.8	175	588	783	979
3>202-13	60	660	8.4	126	593	791	988
3>202-14	60	660	8.2	126	593	791	988
3>22-3	40	660	14.2	177	595	793	992
3>43466	40	660	14.9	181	607	809	1011
3>43467	40	660	15.0	181	607	809	1011
3>43468	40	660	15.0	181	607	809	1011
3>43529	40	660	15.3	180	608	811	1014
3>43525	40	660	14.7	182	611	815	1018
3>43526	40	660	15.1	182	611	815	1018
3>66-5	40	660	13.7	186	626	834	1043
3>66-7	40	660	13.5	186	626	834	1043
3>43742	40	660	13.2	187	628	837	1047
3>43473	40	660	16.1	190	638	851	1064
3>85-9	40	660	14.1	194	652	869	1086
3>85-8	40	660	14.1	195	652	869	1086
3>14-6	40	660	16.8	194	652	870	1087
3>43741	40	660	14.0	196	660	880	1099
3>43592	40	660	14.5	199	668	891	1114
3>14-1	40	660	17.5	198	669	892	1115
3>43472	40	660	16.9	199	669	892	1115

Block ID	Vehicle Size (feet)	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>22-4	40	660	16.0	201	676	902	1127
3>43527	40	660	16.4	201	677	903	1128
3>43559	40	660	16.0	203	681	908	1134
3>43469	40	660	17.2	208	699	932	1165
3>43470	40	660	17.3	208	699	932	1165
3>43802	40	660	16.8	209	702	935	1169
3>43801	40	660	16.7	209	703	937	1171
3>22-2	40	660	17.0	211	710	947	1184
3>20-1	40	660	17.6	212	712	949	1187
3>325-1	40	660	16.1	213	715	954	1192
3>19-8	40	660	14.1	214	716	954	1193
3>43556	40	660	17.3	216	725	967	1209
3>43499	40	660	18.0	216	726	967	1209
3>43558	40	660	17.1	216	726	969	1211
3>43498	40	660	17.9	217	730	973	1217
3>43531	40	660	17.9	219	737	983	1229
3>15-3	40	660	14.8	219	738	985	1231
3>15-5	40	660	14.6	219	738	985	1231
3>15-6	40	660	14.7	219	738	985	1231
3>22-1	40	660	17.3	220	741	988	1235
3>43497	40	660	18.9	220	742	989	1236
3>308-1	40	660	14.9	224	748	998	1247
3>19-9	40	660	16.4	224	752	1003	1254
3>82-4	40	660	16.3	225	756	1008	1260
3>15-4	40	660	14.5	225	756	1008	1260
3>43678	40	660	15.7	226	759	1011	1264
3>43800	40	660	17.9	226	760	1014	1267
3>15-2	40	660	15.2	230	775	1034	1292
3>19-3	40	660	16.2	231	776	1035	1293
3>19-6	40	660	16.1	231	776	1035	1293
3>19-7	40	660	16.2	231	776	1035	1293
3>19-1	40	660	16.3	232	777	1036	1295
3>19-5	40	660	16.3	232	777	1036	1295
3>82-1	40	660	16.9	234	784	1045	1307
3>15-8	40	660	16.3	240	810	1080	1350
3>43586	40	660	18.0	243	818	1090	1363

Block ID	Vehicle Size (feet)	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>309-1	40	660	15.6	248	829	1106	1382
3>61-8	40	660	17.3	247	832	1109	1386
3>43679	40	660	17.8	251	847	1129	1412
3>82-2	40	660	18.5	255	855	1140	1426
3>19-4	40	660	18.0	256	857	1143	1428
3>19-2	40	660	18.0	256	858	1144	1430
3>43681	40	660	16.8	258	863	1151	1438
3>43680	40	660	17.6	257	863	1151	1439
3>15-1	40	660	16.4	259	869	1158	1448
3>15-7	40	660	16.8	263	885	1180	1475
3>202-5	60	660	13.5	204	958	1277	1597
3>202-6	60	660	13.3	205	963	1284	1605
3>215-1	40	660	13.8	324	1032	1376	1719
3>215-2	40	660	13.9	324	1032	1376	1719
3>202-10	60	660	14.5	221	1035	1380	1725
3>202-2	60	660	14.4	221	1035	1380	1725
3>202-11	60	660	16.0	236	1106	1474	1843
3>202-4	60	660	15.5	237	1111	1481	1851
3>202-12	60	660	16.7	252	1183	1577	1971
3>202-3	60	660	16.5	252	1183	1578	1972
3>202-7	60	660	17.0	252	1183	1578	1972
3>290-1	40	660	15.5	424	1353	1804	2255

Source: WSP

Base and On-Route Charging – East Valley

Currently, the East Valley facility operates a total of 115 vehicle blocks with 100 vehicle blocks operated with 40-foot vehicles and 15 vehicle blocks operated with 60-foot vehicles. The smallest vehicle block distance traveled is 46 miles and the longest is 424 miles. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) battery was used to model both the 40- and 60-foot vehicles.

The analysis found it would not be possible to complete all vehicle blocks for the 40- and 60-foot vehicle blocks with base and on-route charging with a 660 kWh battery, but the block completion is much higher with on-route charging with 89 percent of 40-foot vehicle blocks able to be achieved at the optimistic efficiency, 80 percent at the base efficiency, and 61 percent at the conservative efficiency. For 60-foot vehicle blocks, 100 percent of vehicle blocks could be achieved at the optimistic efficiency, 73 percent at the base efficiency, and 33 percent at the conservative efficiency.

For the fleet to maintain a 1:1 ratio with the transition to BEB with base-only charging Omnitrans would need battery capacities that exceed over 1,000 kWh for both 40- and 60-foot vehicles that operate at the same efficiency as the 660 kWh vehicles (~3.4 kWh/mi.). Although this technology is not available, the use of on-route charging will greatly reduce the need for a mass increase in fleet size.

Table 6-16 provides the summary of block completion for Omnitrans at the East Valley Division for 40-foot vehicles, and Table 6-17 provides the summary of block completion for 60-foot vehicles. A 440 kWh battery is also shown to show that 44–77 percent of blocks could be completed with a smaller battery size, compared to the larger and more expensive 660 kWh battery. Table 6-18 provides a list of the current vehicle blocks that would not be able to complete the service with the battery capacity modeled. Table 6-18 also details the needed advertised battery capacity to achieve 100 percent of service on the block at all efficiencies.

Table 6-16: Omnitrans – East Valley Site and On-Route Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**77% (77)**	**61% (61)**	**44% (44)**
660	**524**	89% (89)	80% (80)	61% (61)
700	560	93% (93)	83% (83)	64% (64)
750	600	96% (96)	87% (87)	68% (68)
800	640	99% (99)	89% (89)	70% (70)
850	680	99% (99)	89% (89)	72% (72)
900	720	100% (100)	94% (94)	77% (77)
950	760	100% (100)	97% (97)	81% (81)
1000	800	100% (100)	98% (98)	84% (84)

Source: WSP

Table 6-17: Omnitrans – East Valley Site and On-Route Charging 60-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**87% (10)**	**33% (5)**	**20% (3)**
660	**524**	**100% (15)**	**73% (11)**	**33% (5)**
700	560	100% (15)	80% (12)	40% (6)
750	600	100% (15)	93% (14)	40% (6)
800	640	100% (15)	93% (14)	40% (6)
850	680	100% (15)	100% (15)	40% (6)
900	720	100% (15)	100% (15)	53% (8)
950	760	100% (15)	100% (15)	73% (11)
1000	800	100% (15)	100% (15)	73% (11)

Source: WSP

Table 6-18: Summary of Omnitrans Site and On-Route Charging Incomplete Blocks

Block ID	Vehicle Size (feet)	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>43801	40	660	16.7	209	229	455	682
3>66-5	40	660	13.7	186	301	494	688
3>66-7	40	660	13.5	186	301	494	688
3>43592	40	660	14.5	199	321	528	735
3>43498	40	660	17.9	217	365	388	767
3>43800	40	660	17.9	226	260	514	767
3>43497	40	660	18.9	220	352	549	783
3>15-3	40	660	14.8	219	341	546	788
3>43474	40	660	12.4	144	485	647	809
3>202-14	60	660	8.2	126	495	655	815
3>43499	40	660	18.0	216	376	580	822
3>15-4	40	660	14.5	225	377	597	841
3>15-8	40	660	16.3	240	377	604	857
3>15-5	40	660	14.6	219	405	646	888
3>15-6	40	660	14.7	219	405	646	888
3>61-8	40	660	17.3	247	367	629	891
3>15-1	40	660	16.4	259	403	647	892
3>29-1	40	660	12.5	161	540	720	900
3>43471	40	660	14.0	163	546	728	911
3>43586	40	660	18.0	243	390	640	913
3>15-2	40	660	15.2	230	443	687	931
3>85-9	40	660	14.1	194	532	749	966
3>202-10	60	660	14.5	221	345	633	978
3>85-8	40	660	14.1	195	559	769	979
3>22-3	40	660	14.2	177	595	793	992
3>202-6	60	660	13.3	205	436	687	1008
3>43466	40	660	14.9	181	607	809	1011
3>43467	40	660	15.0	181	607	809	1011
3>43468	40	660	15.0	181	607	809	1011
3>202-5	60	660	13.5	204	434	705	1024
3>202-2	60	660	14.4	221	435	683	1028
3>202-12	60	660	16.7	252	420	649	1036
3>43473	40	660	16.1	190	638	851	1064
3>15-7	40	660	16.8	263	491	778	1065

Block ID	Vehicle Size (feet)	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
3>43472	40	660	16.9	199	669	892	1115
3>22-4	40	660	16.0	201	676	902	1127
3>43469	40	660	17.2	208	699	932	1165
3>43470	40	660	17.3	208	699	932	1165
3>22-2	40	660	17.0	211	710	947	1184
3>202-7	60	660	17.0	252	473	830	1187
3>325-1	40	660	16.1	213	715	954	1192
3>202-11	60	660	16.0	236	458	827	1195
3>22-1	40	660	17.3	220	741	988	1235
3>82-4	40	660	16.3	225	756	1008	1260
3>202-3	60	660	16.5	252	573	930	1287
3>82-1	40	660	16.9	234	784	1045	1307
3>202-4	60	660	15.5	237	576	946	1316
3>82-2	40	660	18.5	255	855	1140	1426
3>290-1	40	660	15.5	424	788	1234	1680

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

Service performance at East Valley was evaluated using three degrees of efficiency (described in the Methodology Section) to determine the percentage of each service block that could be completed when operating current FCEB technology. The total percentage of blocks that meet service requirements using FCEB vehicles is presented to demonstrate the viability of the technology. Any block operating vehicle classes not currently available as FCEBs were immediately disqualified for FCEB Using the results of this analysis, anticipated hydrogen fuel consumption was calculated for three alternative scenarios: 1) full-fleet FCEB conversion; 2) conversion of only the qualifying blocks (those that met range requirements); and 3) and conversion of only FCEB qualifying blocks that cannot be served by BEBs.

Under optimistic vehicle efficiency estimations, only three blocks failed to meet range requirements, providing a 97% fleet completion when operating current FCEB technologies (Table 6-19). Under base efficiency estimations, 13 of the 115 service blocks failed to meet range requirements with 88.7% of the fleet meeting performance requirements (Table 6-20). When measured under the most conservative efficiency estimation, FCEB fleet performance declined dramatically, with only 47% of the fleet qualifying for FCEB conversion (Table 6-21). As an emerging technology, WSP recommends using conservative estimations as a basis for all fleet transition plans. Based on the results of this analysis and the steep drop-off of qualifying blocks between the base and conservative efficiencies, it may be inferred that with minor improvements to FCEB technology and range, significant improvement to fleetwide performance would be realized.

Table 6-19: East Valley Service Non-Qualifying Service Blocks Under Optimistic Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
3>215-1	323.7	91.97%
3>215-2	323.7	91.97%
3>290-1	424.4	70.14%

Source: WSP

Table 6-20: East Valley Service Non-Qualifying Service Blocks Under Base Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
3>15-1	258.7	95.33%
3>15-7	263.2	93.69%
3>19-2	256.0	96.35%
3>19-4	255.6	96.47%
3>215-1	323.7	76.19%
3>215-2	323.7	76.19%
3>290-1	424.4	58.11%
3>309-1	247.9	99.48%
3>43679	251.2	98.17%
3>43680	256.7	96.07%
3>43681	257.7	95.71%
3>61-8	247.2	99.75%
3>82-2	254.9	96.76%

Source: WSP

Table 6-21: East Valley Non-Qualifying Service Blocks Under Conservative Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
3>14-1	200.0	95.03%
3>14-6	193.8	98.05%
3>15-1	258.7	73.47%
3>15-2	230.5	82.46%
3>15-3	219.0	86.77%
3>15-4	225.1	84.43%
3>15-5	219.0	86.77%
3>15-6	219.0	86.77%
3>15-7	263.2	72.21%
3>15-8	240.2	79.13%
3>19-1	231.8	82.01%
3>19-2	256.0	74.26%

Block I.D.	Daily Mileage	Percent Block Distance Complete
3>19-3	231.4	82.13%
3>19-4	255.6	74.35%
3>19-5	231.8	82.01%
3>19-6	231.4	82.13%
3>19-7	231.4	82.13%
3>19-8	214.2	88.72%
3>19-9	223.6	85.01%
3>20-1	211.9	89.68%
3>202-11	235.6	97.49%
3>202-12	252.0	91.12%
3>202-3	252.2	91.07%
3>202-4	236.7	97.04%
3>202-7	252.2	91.07%
3>215-1	323.7	58.72%
3>215-2	323.7	58.72%
3>22-1	219.9	86.44%
3>22-2	211.1	90.05%
3>22-4	200.8	94.64%
3>290-1	424.4	44.78%
3>308-1	223.8	84.91%
3>309-1	247.9	76.67%
3>325-1	212.9	89.28%
3>43469	208.0	91.38%
3>43470	208.0	91.38%
3>43472	198.7	95.67%
3>43497	220.4	86.25%
3>43498	217.2	87.51%
3>43499	215.8	88.07%
3>43527	201.3	94.41%
3>43531	218.7	86.91%
3>43556	215.6	88.18%
3>43558	216.4	87.84%
3>43559	202.9	93.68%
3>43586	243.0	78.23%
3>43592	198.7	95.67%
3>43678	225.5	84.28%
3>43679	251.2	75.66%

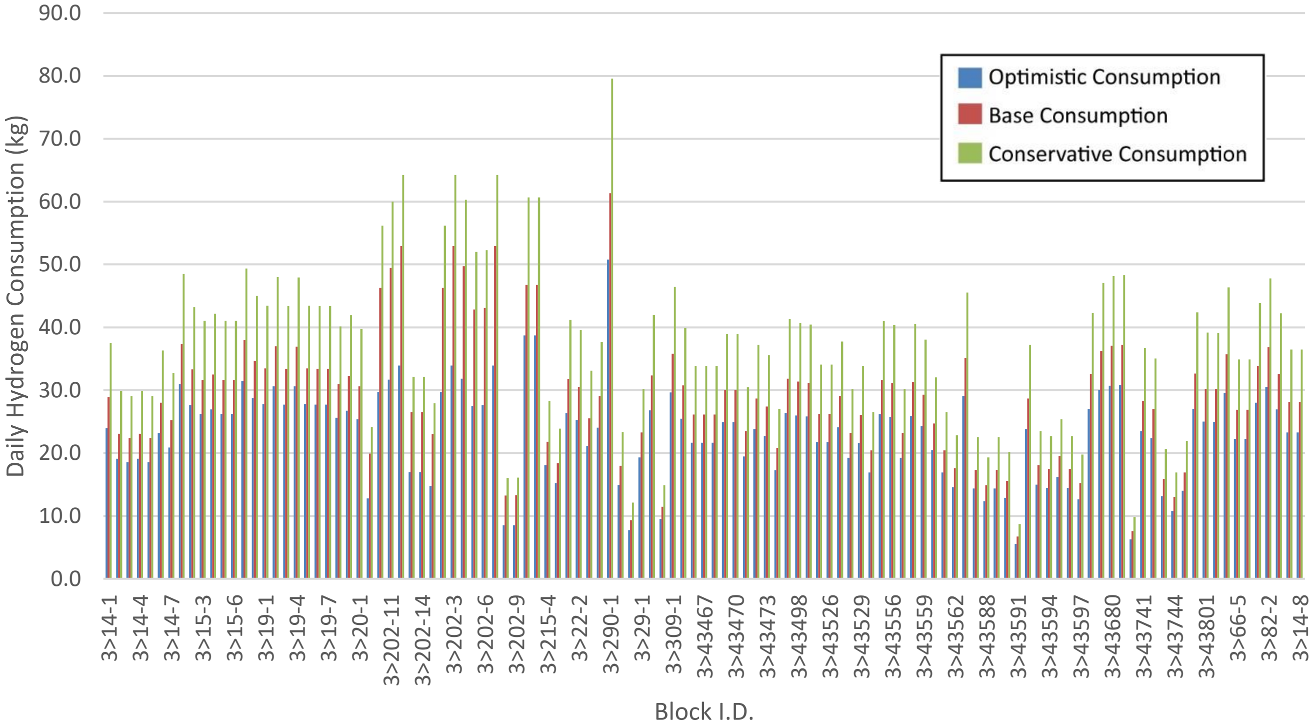
Block I.D.	Daily Mileage	Percent Block Distance Complete
3>43680	256.7	74.04%
3>43681	257.7	73.76%
3>43741	196.0	96.98%
3>43800	226.1	84.06%
3>43801	209.0	90.96%
3>43802	208.7	91.08%
3>61-8	247.2	76.88%
3>82-1	234.0	81.22%
3>82-2	254.9	74.57%
3>82-4	225.2	84.39%
3>85-8	194.5	97.72%
3>14-8	194.5	97.74%

Source: WSP

Hydrogen Requirements

As the largest fleet operated within San Bernardino County, a full-fleet FCEB conversion would require very large quantities of hydrogen fuel, ranging between 2,647 kg and 4,263 kg per day, with each block requiring an average of 30 kg daily (Figure 6-12). Sourcing hydrogen at these quantities could pose a significant challenge, with a typical delivery load containing 4,000 kg. A likely solution would require hosting two 15,000-gallon storage containers on-site with a bi-daily shipment of fuel via two delivery trucks. On-site production at this scale would resemble industrial production, requiring significant considerations to maintenance and staffing. However, some on-site hydrogen production could be used to buffer delivery requirements. If East Valley converted only the service blocks that fell within range requirements when using current FCEB technology, hydrogen consumption is considerably more reasonable, ranging between 1,528 kg and 2,647 kg per day. Using a single 15,000-gallon storage container, daily or bi-daily deliveries would be required to maintain service. Under the third scenario, converting only qualifying FCEB service blocks that cannot be served by BEBs, daily hydrogen consumption is extremely reasonable, ranging between 341 kg and 577 kg of hydrogen per day to service 15 service blocks (Table 6-22, Table 6-23). Providing this quantity of hydrogen could be achieved through delivered sources or on-site hydrogen production via SMR or electrolysis.

Figure 6-12: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of East Valley



Source: WSP

Table 6-22: East Valley Hydrogen Consumption for Three FCEB Fleet Conversion Scenarios

Efficiency	Full Fleet Hydrogen (kg)	Qualifying Fleet Hydrogen (kg)	BEB Supplemental Fleet Hydrogen (kg)
Optimistic	2647	2647	341
Base	3322	2799	458
Conservative	4263	1528	577

Source: WSP

Table 6-23: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of East Valley

Block ID	Block Distance	Vehicle Type (feet)	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
3>14-1	200.0	40	40	35.1	42.4	55.0
3>14-2	159.6	40	40	22.9	35.7	43.3
3>14-3	155.0	40	40	38.7	46.7	60.6
3>14-4	159.6	40	40	61.6	74.4	96.5
3>14-5	155.0	40	40	25.8	31.1	40.3
3>14-6	193.8	40	40	36.2	43.7	56.7

Block ID	Block Distance	Vehicle Type (feet)	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
3>14-7	174.6	40	40	15.6	18.9	24.5
3>15-1	258.7	40	40	46.0	55.5	72.0
3>15-2	230.5	40	40	16.1	19.4	25.1
3>15-3	219.0	40	40	22.9	35.7	43.3
3>15-4	225.1	40	40	21.2	25.6	33.2
3>15-5	219.0	40	40	16.2	19.6	25.4
3>15-6	219.0	40	40	36.1	43.6	56.6
3>15-7	263.2	40	40	30.3	36.6	47.5
3>15-8	240.2	40	40	42.8	51.7	67.1
3>19-1	231.8	40	40	24.5	29.6	38.4
3>19-2	256.0	40	40	14.3	17.3	22.4
3>19-3	231.4	40	40	38.3	59.7	72.5
3>19-4	255.6	40	40	26.1	31.5	40.9
3>19-5	231.8	40	40	26.7	32.3	41.8
3>19-6	231.4	40	40	29.4	35.5	46.0
3>19-7	231.4	40	40	23.1	27.9	36.2
3>19-8	214.2	40	40	23.2	28.0	36.3
3>19-9	223.6	40	40	23.5	28.3	36.7
3>20-1	211.9	40	40	31.8	38.3	49.7
3>202-1	94.8	60	60	20.1	24.2	31.4
3>202-10	220.5	60	60	31.6	38.1	49.5
3>202-11	235.6	60	60	25.7	31.0	40.2
3>202-12	252.0	60	60	26.8	32.4	42.0
3>202-13	126.2	60	60	22.6	35.2	42.8
3>202-14	126.2	60	60	25.4	30.7	39.8
3>202-15	109.6	60	60	37.0	44.6	57.9
3>202-2	220.5	60	60	34.1	41.1	53.4
3>202-3	252.2	60	60	35.5	42.8	55.6
3>202-4	236.7	60	60	35.7	43.1	55.9
3>202-5	204.1	60	60	15.9	19.2	24.9
3>202-6	205.2	60	60	13.1	15.8	20.5
3>202-7	252.2	60	60	20.1	24.2	31.5
3>202-8	63.0	60	60	22.6	35.2	42.8
3>202-9	63.2	60	60	13.5	16.3	21.1
3>215-1	323.7	40	40	9.9	12.0	15.5

Block ID	Block Distance	Vehicle Type (feet)	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
3>215-2	323.7	40	40	10.8	13.0	16.9
3>215-4	151.0	40	40	3.7	4.5	5.8
3>215-5	127.3	40	40	44.5	53.7	69.6
3>22-1	219.9	40	40	44.5	53.7	69.6
3>22-2	211.1	40	40	10.2	12.3	15.9
3>22-3	176.7	40	40	7.3	8.8	11.4
3>22-4	200.8	40	40	35.1	42.4	55.0
3>290-1	424.4	40	40	22.9	35.7	43.3
3>290-2	124.6	40	40	38.7	46.7	60.6
3>290-5	64.6	40	40	61.6	74.4	96.5
3>29-1	161.2	40	40	25.8	31.1	40.3
3>308-1	223.8	40	40	36.2	43.7	56.7
3>308-2	79.4	40	40	15.6	18.9	24.5
3>309-1	247.9	40	40	46.0	55.5	72.0
3>325-1	212.9	40	40	16.1	19.4	25.1
3>43466	180.8	40	40	22.9	35.7	43.3
3>43467	180.8	40	40	21.2	25.6	33.2
3>43468	180.8	40	40	16.2	19.6	25.4
3>43469	208.0	40	40	36.1	43.6	56.6
3>43470	208.0	40	40	30.3	36.6	47.5
3>43471	162.6	40	40	42.8	51.7	67.1
3>43472	198.7	40	40	24.5	29.6	38.4
3>43473	189.8	40	40	14.3	17.3	22.4
3>43474	144.2	40	40	38.3	59.7	72.5
3>43497	220.4	40	40	26.1	31.5	40.9
3>43498	217.2	40	40	26.7	32.3	41.8
3>43499	215.8	40	40	29.4	35.5	46.0
3>43525	181.7	40	40	23.1	27.9	36.2
3>43526	181.7	40	40	23.2	28.0	36.3
3>43527	201.3	40	40	23.5	28.3	36.7
3>43528	160.9	40	40	31.8	38.3	49.7
3>43529	180.5	40	40	20.1	24.2	31.4
3>43530	141.3	40	40	31.6	38.1	49.5
3>43531	218.7	40	40	25.7	31.0	40.2
3>43556	215.6	40	40	26.8	32.4	42.0

Block ID	Block Distance	Vehicle Type (feet)	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
3>43557	160.9	40	40	22.6	35.2	42.8
3>43558	216.4	40	40	25.4	30.7	39.8
3>43559	202.9	40	40	37.0	44.6	57.9
3>43560	171.0	40	40	34.1	41.1	53.4
3>43561	141.3	40	40	35.5	42.8	55.6
3>43562	121.7	40	40	35.7	43.1	55.9
3>43586	243.0	40	40	15.9	19.2	24.9
3>43587	120.0	40	40	13.1	15.8	20.5
3>43588	103.0	40	40	20.1	24.2	31.5
3>43589	120.0	40	40	22.6	35.2	42.8
3>43590	107.7	40	40	13.5	16.3	21.1
3>43591	46.5	40	40	9.9	12.0	15.5
3>43592	198.7	40	40	10.8	13.0	16.9
3>43593	125.3	40	40	3.7	4.5	5.8
3>43594	120.8	40	40	44.5	53.7	69.6
3>43595	135.3	40	40	44.5	53.7	69.6
3>43596	120.8	40	40	10.2	12.3	15.9
3>43597	105.5	40	40	7.3	8.8	11.4
3>43678	225.5	40	40	35.1	42.4	55.0
3>43679	251.2	40	40	22.9	35.7	43.3
3>43680	256.7	40	40	38.7	46.7	60.6
3>43681	257.7	40	40	61.6	74.4	96.5
3>43740	52.5	40	40	25.8	31.1	40.3
3>43741	196.0	40	40	36.2	43.7	56.7
3>43742	186.9	40	40	15.6	18.9	24.5
3>43743	110.0	40	40	46.0	55.5	72.0
3>43744	90.3	40	40	16.1	19.4	25.1
3>43748	117.0	40	40	22.9	35.7	43.3
3>43800	226.1	40	40	21.2	25.6	33.2
3>43801	209.0	40	40	16.2	19.6	25.4
3>43802	208.7	40	40	36.1	43.6	56.6
3>61-8	247.2	40	40	30.3	36.6	47.5
3>66-5	186.2	40	40	42.8	51.7	67.1
3>66-7	186.2	40	40	24.5	29.6	38.4
3>82-1	234.0	40	40	14.3	17.3	22.4

Block ID	Block Distance	Vehicle Type (feet)	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
3>82-2	254.9	40	40	38.3	59.7	72.5
3>82-4	225.2	40	40	26.1	31.5	40.9
3>85-8	194.5	40	40	26.7	32.3	41.8
3>14-8	194.5	40	40	29.4	35.5	46.0
Total				**81.2**	**98.1**	**127.2**

Source: WSP

6.3.2.2.2 Site Energy Analysis

The East Valley facility is home to up to 120 buses. WSP has recommended that overhead platform mounted chargers with retractable DC plug-in cords be implemented for BEBs. Therefore, 60 chargers will be needed for a 1:2 charger to bus dispenser ratio. This will require new SCE service for 9,000 kW, assuming that 150 kW chargers are installed.

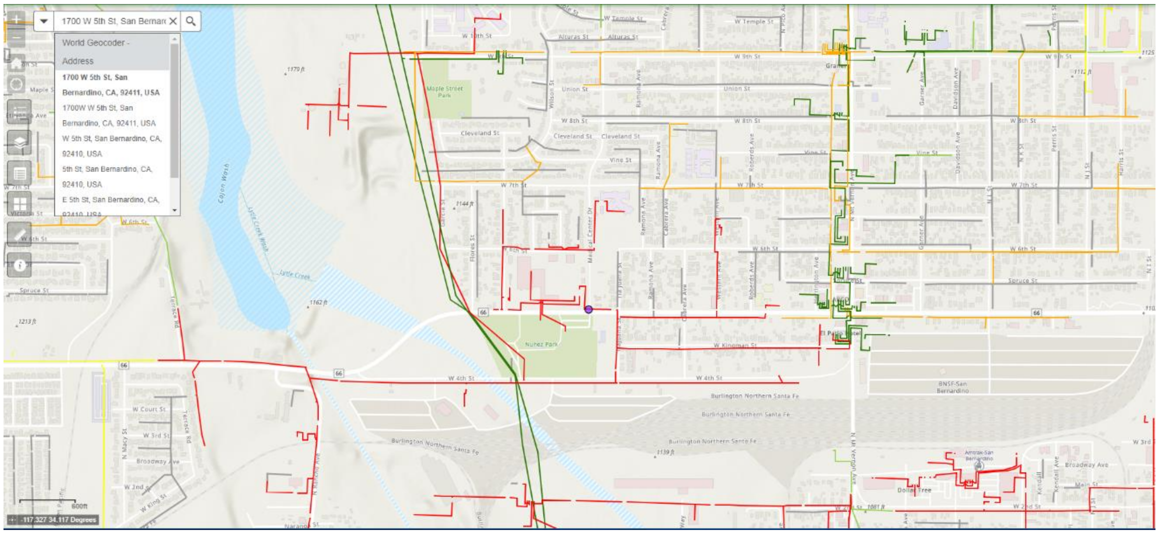
According to SCE, the existing facility is served from the “Herz” circuit (Figure 6-13), which delivers power at 12kV. This circuit already has substantial load on it. A rule of thumb is that a 12kV circuit can hold around 8.3MW of power. Therefore, there is not enough power on the circuit for full build out. This does not mean that it is impossible to build, but SCE will require a method of service (MOS) application and study right away. The SCE MOS studies take 18 months, before detailed design and construction can even begin. It is likely that a new circuit will need to be brought into this site so that it is fed by two 12 kV circuits.

After full build out, the BEBs will require 61,000 - 102,000 kWh every day to support the 120 buses. The SCE EV-TOU rates don’t include any “demand charges”, so there is no incentive to “flatten the curve” of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9 pm. Therefore, Omnitrans should invest in good charge management software that avoids incurring big costs from charging during peak times.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- Four medium voltage utility service transformers at 2,500 kVA each in a new utility yard in the open space along the northern site wall and west of the existing bus wash.
- Four sets of 480V switchboards in the new utility yard.
- Overhead conduits
- Redundant circuits or back up power, see resiliency discussion below.

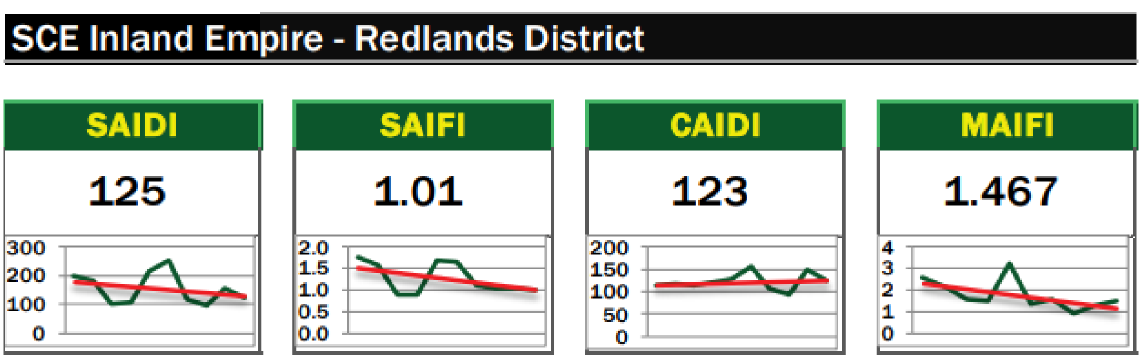
Figure 6-13: SCE Distribution Map East Valley Facility



Source: SCE

From a resiliency perspective, this site is not as reliable as the West Valley facility. The site is located in SCE's Redlands district. This district is a good performer, but has about 25% more issues than the West Valley facility district. In addition, the specific circuit that serves the facility is partially in the fire risk zone. See Section 1.5.1.3 for more details about reliability of SCE's electric grid and Section 1.5.1.3.3 for more details about Fire Risks. WSP recommends that Omnitrans inquire about a new feeder to this site to help improve reliability and redundancy. Figure 6-14 shows the reliability figure for East Valley. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

Figure 6-14: East Valley (SCE Redlands District) Energy Reliability Figures



Source: SCE

6.3.2.3 San Bernardino Transit Center

To allow for rapid charging of BEBs requiring range extensions, an overhead inverted pantograph charger is recommended for the San Bernardino Transit Center to provide on route charging of vehicles as they dwell on the site. One of the primary reasons this technology was selected over underground inductive charging is that it is currently much more ubiquitous throughout the industry. This provides the opportunity to support other agencies providing connections to SBTC. Overhead pantograph charging is recommended as existing systems can provide charging at rates up to 450+ kW and the height of the overhead charging connection maintains distance from and reduces access by the public to the charging connection. However, it is of note that any on route charging capability must be compatible with both standard 40’ low floor buses as well as cutaway BEBs. Any use of plug-in charging at the transit center, not recommended by WSP, should be done isolated from public accessible areas to limit public interaction with a ground level charging system and cord plugged into the bus.

An on route charging position is proposed for the following location:

- Minimum of one overhead inverted pantograph mast mounted to the paving adjacent to the existing bus berth nearest to the southeast corner of the transit center building. This location is ideal as it is near the existing electrical yard and service

The overhead inverted pantograph charging system will be served by the following electrical infrastructure:

- One MV utility service transformer in a new utility yard adjacent to the south of the existing electrical yard and northeast of the proposed pantograph charger
- One switchgear in a new utility yard adjacent to the south of the existing electrical yard and northeast of the proposed pantograph charger

No hydrogen fueling is recommended for this site as no existing fueling operations or infrastructure are in place and public access would be difficult to control.

Conceptual layouts for the proposed ZEB solutions for Omnitrans’ facilities are present in Section 6.3.5.4 of this document.

6.3.2.3.1 Site Energy Analysis

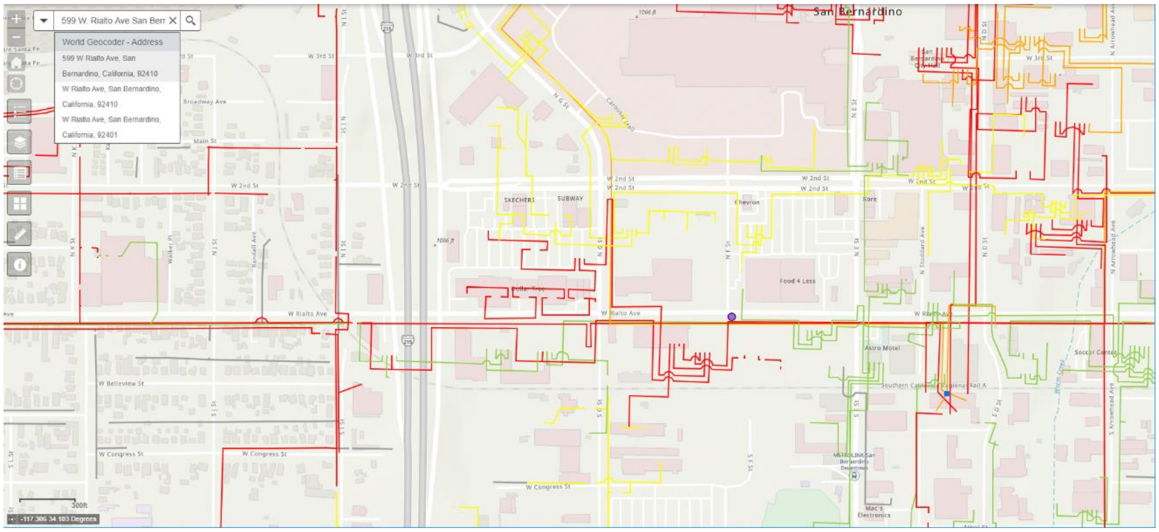
At San Bernardino Transit Center, the WSP team recommends one 450 kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450 kW.

According to SCE, the existing facility is served from the “Herz” circuit (Figure 6-15), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. It should be feasible to get this level of power service from SCE, even without an MOS. SCE already indicated that a switch is available to provide this service in the nearby vicinity.

The pantograph will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformer.
- One 480V switchboard.
- Underground conduits to ground mounted charger.

Figure 6-15: SCE Distribution Map San Bernardino Transit Center



Source: SCE

From a resiliency perspective, the San Bernardino Transit Center is located in the Redlands District for SCE. Redlands has slightly worse than average reliability over the past few years, but is not a terrible performer. Figure 6-14 shows the reliability figure for Redlands District.

The Herz circuit is partially located within the CPUC high risk fire circuit. However, SCE indicated that the “Shops” circuit is also located on the same street and it is possible to use that instead. This provides some redundancy for MBTA since the East Valley facility will probably be on the Herz circuit. It would be best not to lose both sites at the same time, if they are both on the Herz circuit.

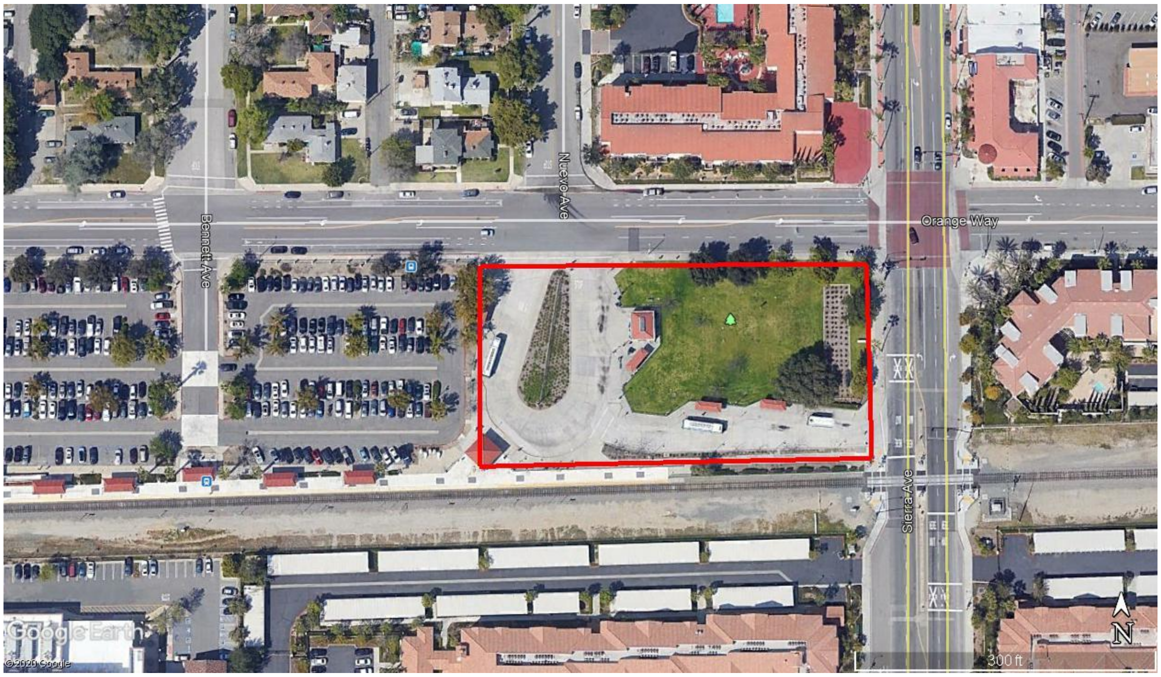
In addition, WSP recommends that Omnitrans consider a mobile diesel generator that can be moved in place in emergencies. According to WSP’s BOLT modeling, on route chargers are critical to increasing the percentage of service that can be electrified and will be crucial to day to day operations.

6.3.2.4 On Route Charging Site Energy Analysis

6.3.2.4.1 Fontana Metrolink Plaza

Fontana Metrolink Plaza is located at 16777 Orange Way, Fontana, CA 92335 (Figure 6-16).

Figure 6-16: Fontana Metrolink Plaza - Existing Conditions



Source: Google Maps, March 2020

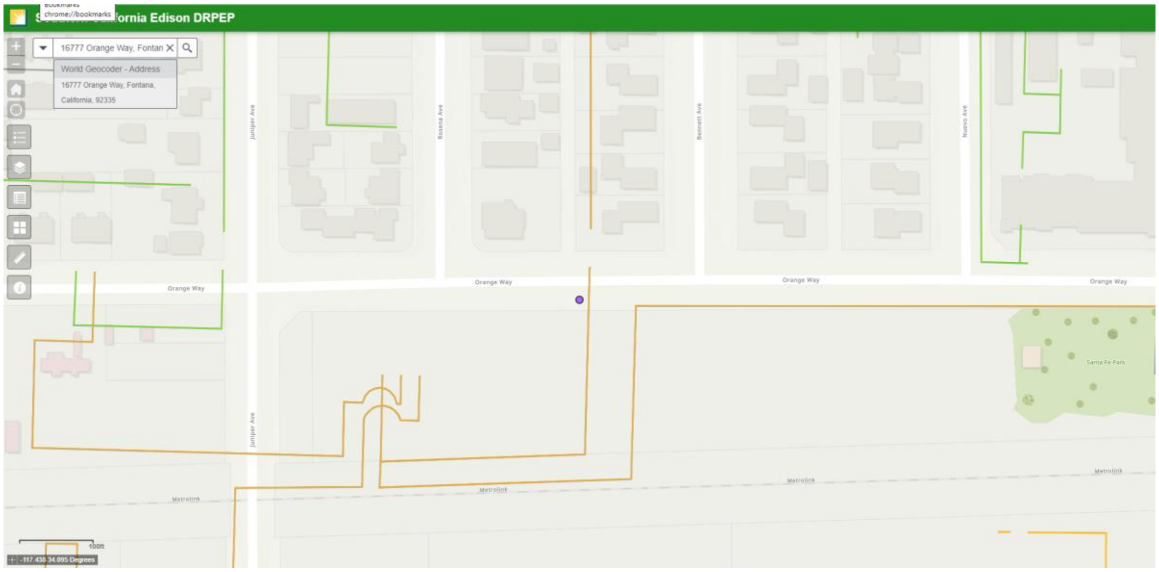
At Fontana Metrolink Plaza, the WSP team recommends one 450 kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450 kW.

According to SCE, the existing facility is served from the “Coleen” circuit (Figure 6-17), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. It should be feasible to get this level of power service from SCE, even without an MOS. SCE already indicated that a switch is available to provide this service in the nearby vicinity.

The plug-in charging dispensers and charging cabinet will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformer.
- One 480V switchboard in the new utility yard.
- Underground conduits to Pantograph Charger

Figure 6-17: SCE Distribution Map Fontana MetroLink Plaza

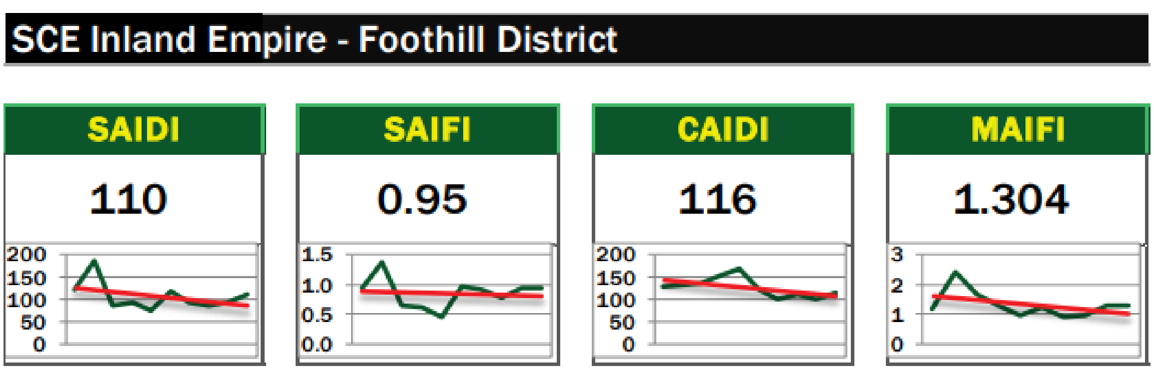


Source: SCE

From a resiliency perspective, the Fontana MetroLink Plaza is located in the Foothills District for SCE. This district is generally slightly above average. It can expect ~1 outage and restoration within two hours. Omnitrans should consider a diesel generator at this site, but it may not be necessary. Sometimes, a mobile generator can be used to service several of the sites that are on different circuits, in different districts. However, according to WSP's BOLT modeling, on route chargers are critical to increasing the % of service that can be electrified and will be crucial to day to day operations.

Figure 6-18 shows the reliability metrics for Fontana Metrolink Plaza. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

Figure 6-18: Fontana Metrolink Plaza (SCE Foothill District) Energy Reliability Figures



Source: SCE

6.3.2.4.2 Pomona Transit Center

The Pomona Transit Center is located at 100 W Commercial St, Pomona, CA, 91768; Lat/Long: 34.059369, -117.751232 (Figure 6-19).

Figure 6-19: Pomona Transit Center – Existing Condition

Source: Google Earth

At Pomona Center, the WSP team recommends one 450kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450kW.

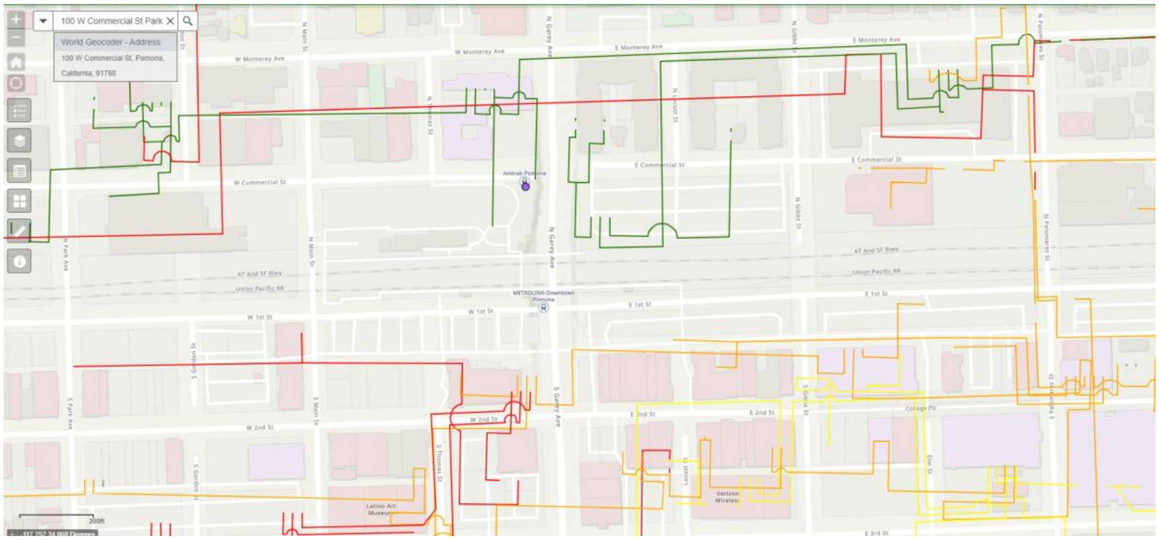
According to SCE, the existing facility is served from the "Parcell" circuit, which delivers power rated at 12kV. A rule of thumb is that a 12kV circuit can hold around 8.3MW of power. The Parcell circuit can hit a peak of 400A, which is roughly the limit for 12kV circuits from SCE, in August, thus straining the system. It is likely that an MOS will be required in order to provide reliable power to this site.

In addition, this site already has en-route charging from Foothill Transit. It is possible that the existing service line could be modified to add this load, but this would require coordination between both transit agencies and SCE.

The pantograph will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformer.
- One 480V switchboard.
- Underground conduits to a ground mounted charger.

Figure 6-20: SCE Distribution Map Pomona Transit Center



Source: SCE

From a resiliency perspective, the Pomona Transit Center is located in the Foothills District for SCE. This district is generally slightly above average (Figure 6-22). It can expect ~1 outage and restoration within two hours. Since this site will be shared with Foothills Transit, which will have its own on route chargers, coordination between the agencies and SCE for reliability to this site will be very important.

In addition, the WSP team recommends that Omnitrans consider a mobile diesel generator that can be moved in place in emergencies. According to modeling analysis, on route chargers are critical to increasing the percentage of service that can be electrified and will be crucial to day to day operations (Figure 2-9). It is possible that some of this backup burden could be shared with Foothills Transit since they will have demand for reliable on route charging at this site as well.

6.3.2.4.3 Yucaipa Transit Center

Yucaipa Transit Center is located at Yucaipa, CA 92399 (Figure 6-21).

Figure 6-21: Yucaipa Transit Center - Existing Conditions

Source: Google Earth, March 2020

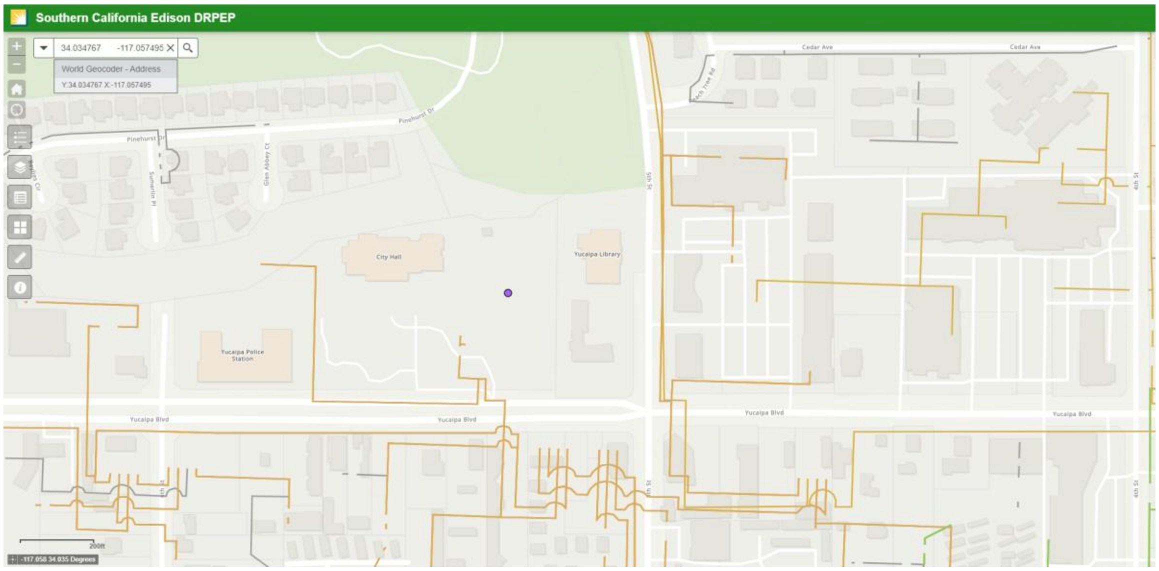
At Yucaipa Transit Center, the WSP team recommends one 450 kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450 kW.

According to SCE, the existing facility is served from the "Stonewood" circuit (Figure 6-22), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. It should be feasible to get this level of power service from SCE, even without an MOS. SCE already indicated that a switch is available to provide this service in the nearby vicinity.

The overhead pantograph and charging cabinet will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformers.
- One 480V switchboard in the new utility yard.
- Underground conduits to ground mounted charger.

Figure 6-22: SCE Distribution Map Yucaipa Transit Center



Source: SCE

From a resiliency perspective, the Yucaipa Transit Center is located in the Redlands District for SCE. Redlands has slightly worse than average reliability over the past few years, but is not a terrible performer. Figure 6-14 shows the reliability figure for Redlands District.

This site and the Stonewood circuit are located within the CPUC high risk fire circuit. See Appendix B for a map of the Stonewood circuit and fire risk areas. WSP recommends that MBTA consider a mobile diesel generator that can be moved in place in emergencies. If the circuit is affected by fire, but it is still safe at the site, a diesel generator can keep buses moving. According to WSP's BOLT modeling, on route chargers are critical to increasing the % of service that can be electrified and will be crucial to day to day operations.

6.3.3 Procurement Schedule

In accordance with the ICT regulation, Omnitrans will prioritize ZEB purchases and progressively increase the percentage of ZEB purchases over time. Based on initial analysis, the last CNG bus is expected to be purchased in 2028. All new buses purchases are anticipated to be ZEB starting in 2029, in accordance with the ICT regulation.

Early retirement should not be an issue pursuant to the ICT regulation based on Omnitrans' assumed procurement schedule. However, if it becomes an issue, Omnitrans will deploy a number of strategies to ensure that buses fulfill their "useful life". One potential strategy is to place newly acquired buses on Omnitrans' longest (distance) blocks of service. This will ensure that these buses meet their distance-based useful life requirement more rapidly.

Omnitrans' existing fleet consists of 186 buses. Assuming a 1:1 replacement ratio, each existing bus will eventually be replaced with an equivalent BEB or FCEB. However, the number of ZEBs required may increase with time based on service requirements.

Table 6-24 presents a summary of Omnitrans' anticipated bus procurements through 2040. Years 2023, 2026 and 2029 are highlighted because these indicate when Omnitrans' new purchases should be 25 percent, 50 percent, and 100 percent ZEBs, respectively.

Table 6-24: Summary of Omnitrans' Future Bus Purchases (through 2040)

Year	Total Buses	Zero-Emission Buses				Conventional (CNG) Buses			
		Number	PCT.	Bus Type	Fuel Type	Number	PCT.	Bus Type	Fuel Type
2020*	**4**	4	100%	40'	BEB	0	0%	-	-
2021	**0**	0	0%	-	-	0	0%	-	-
2022	**0**	0	0%	-	-	0	0%	-	-
2023	**0**	0	0%	-	-	0	0%	-	-
2024	**0**	0	0%	-	-	0	0%	-	-
2025	**31**	8	26%	40'	BEB	23	74%	40'	CNG
2026	**34**	17	50%	40'/60'	BEB	17	50%	40'/60'	CNG
2027	**0**	0	0%	-	-	0	0%	-	-
2028	**16**	8	50%	40'	BEBs/FCEBs	8	50%	40'	CNG
2029	**15**	15	100%	40'	BEBs/FCEBs	0	0%	-	-
2030	**13**	13	100%	40'	BEBs/FCEBs	0	0%	-	-
2031	**0**	0	0%	-	BEBs/FCEBs	0	0%	-	-
2032	**29**	29	100%	40'/60'	BEBs/FCEBs	0	0%	-	-
2033	**23**	23	100%	40'	BEBs/FCEBs	0	0%	-	-
2034	**0**	0	0%	-	BEBs/FCEBs	0	0%	-	-
2035	**0**	0	0%	-	BEBs/FCEBs	0	0%	-	-
2036	**0**	0	0%	-	BEBs/FCEBs	0	0%	-	-
2037	**8**	8	100%	40'	BEBs/FCEBs	0	0%	-	-
2038	**17**	17	100%	40'/60'	BEBs/FCEBs	0	0%	-	-
2039	**23**	23	100%	40'	BEBs/FCEBs	0	0%	-	-
2040	**33**	33	100%	40'/60'	BEBs/FCEBs	0	0%	-	-

Note: CNG buses assumed to be replaced after 14 years in service and BEBs assumed to be replaced after 12 years in service.
In February 2020, Omnitrans procured their first four BEBs

Source: WSP, February 2020

6.3.4 Omnitrans Cost Analysis

This analysis should be considered a conservative assessment of battery and fuel cell electric bus costs, as the industry in North America is still small and in preliminary stages. Production costs may decrease through economies of scale as production increases to meet future demand.

6.3.4.1 Battery Electric Buses – General Assumptions

The WSP team is actively engaged with Electric vehicle manufacturers to understand trends in the industry and VVTA, the only county operator currently operating BEBs, to inform assumptions vehicle operations. The values presented throughout this document are subject to change and based on the best available information at the time of this analysis.

Compared to conventional diesel, gasoline and natural gas vehicles, electric vehicles incur different capital and operating costs that vary both on the type of vehicles operated and operating environments. For example, the cost of installation and maintenance of charging infrastructure will differ in both magnitude and the types of resources required in comparison to the replacement and maintenance of a diesel fueling facility. Other examples include battery replacement schedules, mid-life overhaul, and disposal value.

Electric buses and garages may offer the opportunity to lower some operations and maintenance costs while increase others and similar to conventional fueled vehicles are highly dependent on the size and complexity of the vehicle fleet being supported. Additionally, an electrification strategy would entail replacing Compressed Natural Gas (CNG) with electric power, which would incur very different energy pricing structures and exposure to energy price volatility. Table 6-25 outlines the major cost categories associated with bus electrification. Estimated costs in each of these categories were developed for electrification scenarios, as well as a "business as usual" baseline which assumes no change in the current types of vehicles in the fleet.

The total cost of each operator's transition will be contingent upon their specific fleet size, bus acquisition plan, facility sizes, charging strategy, construction schedule, among other details.

Table 6-25: Cost Components Attributed to Electric Vehicle Operations

Capital	Vehicle and Equipment Purchase
	Training, Capital Spares & Contingency
	Charging Infrastructure
	Mid-Life Fleet Overhaul
	Battery Replacement
Operating	Vehicle Maintenance, software subscriptions and support costs
	Vehicle Tools, Training and Equipment
	Vehicle Energy Costs
	Charger Maintenance, software subscriptions and support costs
	Fueling/Charging Labor
Disposal	Battery Disposal/Salvage
	Bus Salvage

Source: WSP

6.3.4.1.1 Battery Electric Bus Vehicle Costs

Battery electric vehicle procurement costs continue to evolve as new vehicle models are developed and production increased to meet demand. Anticipated cost reductions through economies of scale may be somewhat offset by discounted prices that may be offered by some manufacturers to establish market share, specifically new entrants to the market. Furthermore, battery technology and production continue to evolve offering further potential reductions to production costs but also potential exposure to volatility in the pricing structures for critical battery production inputs. Additional considerations also need to be considered for specific agency requirements and features, delivery schedule requirements, and battery size requirements to meet operating conditions. Assumptions regarding cost per battery electric buses as compared to Omnitrans' CNG buses are outlined in Table 6-26 below:

Table 6-26: Vehicle Cost Assumptions

Bus Type	Bus Cost Estimates[50] (2019 Dollars)
BEB 40 ft	$950,556
BEB 60 ft	$1,782,312
CNG 40 ft	$678,976
CNG 60 ft	$1,273,080

Source: WSP

An estimated standard cost per bus (before options) of $950,556 and $1,782,312 were assumed for a 40-foot and 60-foot battery electric bus based on the most recent Omnitrans fleet acquisition plan. For CNG 40-foot and 60-foot buses, $678,976 and $1,273,080 were assumed based on the most recent fleet acquisition plan.

6.3.4.1.2 Charging Infrastructure Costs

Charging infrastructure cost estimates include equipment, design and installation costs which primarily consist of materials and labor. The cost estimates also include general contractors and subcontractor's markups which are comprised of field overhead, home office overhead, and subcontractor earnings. The estimates also include a pricing contingency markup, to allow for unexpected design and installation Issues.

Plug-in chargers are assumed to cost $70,701, based on a recent VVTA contract.[51] Additionally, the cost to install chargers, including labor and permits, is assumed to be $8,500 per charger. On route opportunity chargers are assumed to cost $330,000 for both the charger and installation, based on the experience of Foothill Transit. With the recommended ground-mounted plug-in charging strategy, the East Valley would be capable of parking 74 buses with 74 plug-in charging positions (37 chargers), and the East Valley capable of accommodating 120 buses with 120 plug-in positions (60 chargers), in a 1:2 charger to bus dispenser ratio. The financial analysis assumes that plug-in chargers would be purchased in the year that buses are ordered, when the cost of purchasing the charger would be incurred, and the cost of installing the plug-in charger would be incurred in the year of vehicle delivery, which is assumed to be one year after the bus order. As such, the exact year and number of plug-in chargers purchased correlates with the fleet procurement plan, presented in Section 6.3.4.3.2. En-route chargers include one at Fontanta Metrolink Plaza, Pomona Transit Center, Yucaipa Transit Center, and one at the San Bernardino Transit Center.

No resiliency is recommended for the West Valley facility, as SCE reliability at the site is very high, see Energy report for more details. For the East Valley Facility, due to size and fire risk to the existing feed, WSP recommended a second feed from Southern California Edison. The cost of a second feed would vary depending on distance to nearest substation and other SCE factors.Mid-life Overhaul and Battery Replacement

[50] Updated Omnitrans ZEB Procurement Plan provided by Connie Raya on March 31, 2020 via email.

[51] VVTA New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6, 2018.

6.3.4.1.3 Mid-life Overhaul and Battery Replacement

Mid-life overhauls are assumed to be performed at approximately the sixth or seventh year of the vehicles' life, at a cost of $70,000. The overhaul cost was applied to both CNG and BEB buses at the same frequency going forward.

Omnitrans purchased a 12-year warranty for its electric bus batteries. As such, this financial analysis does not analyze battery replacement costs for BEB buses but instead, accounts for the warranty in the additional options and charges.

6.3.4.1.4 Tire Replacement Cost

Omnitrans does not directly replace bus tires, but rather leases tires from Firestone at a cost of $0.006 per mile.

6.3.4.1.5 Operations and Maintenance Costs

Components of O&M costs include vehicle maintenance, vehicle tools, training and PPEs, vehicle fuel costs, and the costs to maintain and operate charging/fueling infrastructure. Annual O&M Cost assumptions for BEB's are outlined in Table 6-27, represented in cost per mile. Omnitrans does not yet have experience with battery electric buses, and as such these figures represent assumed forecast values based on experience to date with other agencies.

Table 6-27: BEB Maintenance Costs by Bus Age (2019 Dollars per mile)

Bus Age	BEB 40 ft	BEB 60 ft
Year 1	0.34	0.43
Year 2	0.30	0.38
Year 3	0.30	0.38
Year 4	0.35	0.44
Year 5	0.42	0.53
Year 6	0.46	0.59
Year 7	0.52	0.66
Year 8	0.59	0.75
Year 9	0.68	0.86
Year 10	0.79	1.00
Year 11	0.93	1.18
Year 12	1.10	1.40

Source: WSP

Table 6-28: CNG Maintenance Costs by Bus Age (2019 Dollars per mile)

Bus Age	CNG 40 ft	CNG 60 ft
Year 1	0.19	0.32
Year 2	0.19	0.32
Year 3	0.24	0.41
Year 4	0.29	0.49
Year 5	0.49	0.83
Year 6	0.43	0.73
Year 7	0.49	0.82
Year 8	0.54	0.91
Year 9	0.50	0.85
Year 10	0.55	0.94
Year 11	0.60	1.02
Year 12	0.63	1.06
Year 13	0.65	1.11
Year 14	0.68	1.15

Source: WSP

This analysis applies unit O&M cost per mile by bus type. Ultimately, total costs are driven by unit costs and bus mileage. The financial model accounts for changes to service levels to estimate O&M costs, by applying unit costs to total mileage as driven by number of buses and mileage per bus.

Omnitrans provided CNG 40-foot and CNG 60-foot bus operations and maintenance cost. However, the data was inconsistent or incomplete for all bus ages 1 – 14. Available data for CNG 40-foot buses includes operations at years 1, 2, 4, 5, 6, 8, 9, 11, and 17. These data points were interpolated to obtain the missing costs in bus ages 3, 7, 10, 12, 13 and 14. A maximum age of 14 years was assumed for the O&M cost projections based on CNG vehicles' expected life of 14 years.

For CNG 60-foot assumptions, only a single data point was provided for the bus at after 8 years of operations. The difference between CNG 40-foot bus and CNG 60-foot buses at 8 years was 70 percent. As such, the CNG 40-foot maintenance cost was escalated by 70 percent to obtain costs for all ages of CNG 60-foot buses.

6.3.4.1.6 Energy Costs

Electricity prices for battery electric vehicles are based on current rates with Southern California Edison (SCE) and reflect charge rates and demand for energy consumption that vary by hour and month.

Total annual energy costs are estimated for each operator and facility and are highly driven by charging strategy with respect to location of on route chargers if any, facilities, vehicle routes, and fleet size purchase. These charging strategies are subject to change as the team works to refine each agency's optimal charging strategy, and as charging rates change. This analysis does not assume any major behavioral changes based on coach operators.

Table 6-29 presents Southern California Edison Rates and Table 6-30 presents the hours during which each rate would be applicable.

Table 6-29: Rates per kWh

Rates (per kWh)		
Time of Use Period	Summer (June-September)	Winter (October-May)
On-Peak	$0.41	
Mid-Peak	$0.20	$0.24
Off-Peak	$0.10	$0.10
Super Off-Peak		$0.06

Source: Southern California Edison

Table 6-30: Time Periods

Time Periods (weekdays excluding holidays)				
	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	16:00-21:00	N/A	N/A	N/A
Mid-Peak	N/A	16:00-21:00	16:00-21:00	16:00-21:00
Off-Peak	All other hours	21:00-08:00	All other hours	21:00-08:00
Super Off-Peak	N/A	08:00-16:00	N/A	08:00-16:00

Source: Southern California Edison

The rates in Table 6-29 and Table 6-30 above were applied to the hourly times during which the operators are expected to be charging. The energy use assumed for each operator, in a moderate charging scenario, is presented in Table 6-31. The model is capable of running additional scenarios to cost the low charging and high charging scenario as well. Table 6-32 and Table 6-33 outline the two Omnitrans facilities' resulting costs, based on the hourly SCE rates and the hourly charging strategy, as well as the total resulting annual cost per bus.

Table 6-31: Hourly Energy use (kWh) – Moderate Scenario

Facility ID	Facility	Operator	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
1000001	Joshua Tree Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	-
1000002	29 Palms Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	50
1000003	Crestline	MT	-	-	-	-	-	-	-	-	-	-	-	78
1000009	Big Bear Lake	MT	-	-	-	-	-	-	-	-	-	15	50	-
1000004	West Valley	Omnitrans	5,300	4,788	3,633	2,415	1,203	350	80	-	128	80	-	-
1000005	East Valley	Omnitrans	11,488	9,843	7,523	4,808	2,040	688	373	168	130	433	735	553
1000006	VVTA HQ - Hesperia Yard	VVTA	3,988	3,810	2,668	1,845	1,335	688	480	155	305	405	308	423
1000007	Barstow Future Yard	VVTA	945	660	600	600	525	173	110	220	295	300	215	-
1000008	Needles Garage	Needles	-	-	-	-	-	-	-	-	-	-	-	-

Source: WSP

Table 6-31: Hourly Energy use (kWh) – Moderate Scenario (continued)

Facility ID	Facility	Operator	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1000001	Joshua Tree Yard	MBTA	88	-	133	-	-	-	320	58	-	-	13	140
1000002	29 Palms Yard	MBTA	-	10	208	-	-	5	130	-	10	43	80	65
1000003	Crestline	MT	15	-	-	-	-	75	15	143	180	28	83	3
1000009	Big Bear Lake	MT	-	-	65	-	-	78	-	95	150	3	-	-
1000004	West Valley	Omnitrans	-	-	-	20	75	-	148	808	1,950	3,615	5,313	5,918
1000005	East Valley	Omnitrans	258	308	533	508	273	48	195	2,493	5,723	8,355	11,143	12,978
1000006	VVTA HQ - Hesperia Yard	VVTA	183	55	-	-	265	815	1,475	1,800	1,630	3,563	4,720	4,075
1000007	Barstow Future Yard	VVTA	-	-	-	-	-	23	150	265	958	1,470	1,370	1,080
1000008	Needles Garage	Needles	-	-	-	-	-	-	8	103	-	-	-	-

Source: WSP

Table 6-32: Total Annual Cost Per Bus - Omnitrans, West Valley

Months	Days per month	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
January	31.00	16,961	15,321	11,624	7,728	3,848	1,120	256	-	408	161	-	-	-	-	-	40	549	-	1,079	5,908	14,268	26,451	17,001	18,937
February	28.00	15,319	13,838	10,500	6,980	3,476	1,012	231	-	369	145	-	-	-	-	-	36	496	-	975	5,337	12,887	23,891	15,355	17,104
March	31.00	16,961	15,321	11,624	7,728	3,848	1,120	256	-	408	161	-	-	-	-	-	40	549	-	1,079	5,908	14,268	26,451	17,001	18,937
April	30.00	16,414	14,826	11,249	7,479	3,724	1,084	248	-	395	156	-	-	-	-	-	39	531	-	1,044	5,718	13,808	25,597	16,452	18,326
May	31.00	16,961	15,321	11,624	7,728	3,848	1,120	256	-	408	161	-	-	-	-	-	40	549	-	1,079	5,908	14,268	26,451	17,001	18,937
June	30.00	15,668	14,153	10,738	7,139	3,555	1,035	236	-	377	236	-	-	-	-	-	59	920	-	1,809	9,906	23,921	44,346	15,705	17,493
July	31.00	16,190	14,625	11,096	7,377	3,673	1,069	244	-	389	244	-	-	-	-	-	61	951	-	1,870	10,236	24,719	45,824	16,228	18,076
August	31.00	16,190	14,625	11,096	7,377	3,673	1,069	244	-	389	244	-	-	-	-	-	61	951	-	1,870	10,236	24,719	45,824	16,228	18,076
September	30.00	15,668	14,153	10,738	7,139	3,555	1,035	236	-	377	236	-	-	-	-	-	59	920	-	1,809	9,906	23,921	44,346	15,705	17,493
October	31.00	16,961	15,321	11,624	7,728	3,848	1,120	256	-	408	161	-	-	-	-	-	40	549	-	1,079	5,908	14,268	26,451	17,001	18,937
November	30.00	16,414	14,826	11,249	7,479	3,724	1,084	248	-	395	156	-	-	-	-	-	39	531	-	1,044	5,718	13,808	25,597	16,452	18,326
December	31.00	16,961	15,321	11,624	7,728	3,848	1,120	256	-	408	161	-	-	-	-	-	40	549	-	1,079	5,908	14,268	26,451	17,001	18,937
Total	365	196,666	177,649	134,790	89,613	44,621	12,987	2,969	-	4,731	2,224	-	-	-	-	-	556	8,043	-	15,818	86,598	209,123	387,681	197,130	219,579
																								Total Annual Cost	1,790,778
																								Buses at Garage	60
																								Total Annual Cost Per Bus	29,846

Source: WSP

Table 6-33: Total Annual Cost Per Bus - Omnitrans, East Valley

Months	Days per month	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
January	31.00	36,761	31,497	24,073	15,385	6,528	2,200	1,192	536	416	871	1,479	1,112	518	619	1,072	1,022	1,994	348	1,427	18,237	41,871	61,133	35,657	41,530
February	28.00	33,204	28,449	21,743	13,896	5,896	1,987	1,077	484	376	786	1,336	1,004	468	559	968	923	1,801	314	1,289	16,473	37,819	55,217	32,207	37,511
March	31.00	36,761	31,497	24,073	15,385	6,528	2,200	1,192	536	416	871	1,479	1,112	518	619	1,072	1,022	1,994	348	1,427	18,237	41,871	61,133	35,657	41,530
April	30.00	35,576	30,481	23,296	14,888	6,318	2,129	1,154	519	403	842	1,432	1,076	502	599	1,037	989	1,930	336	1,381	17,649	40,520	59,161	34,507	40,190
May	31.00	36,761	31,497	24,073	15,385	6,528	2,200	1,192	536	416	871	1,479	1,112	518	619	1,072	1,022	1,994	348	1,427	18,237	41,871	61,133	35,657	41,530
June	30.00	33,959	29,096	22,238	14,212	6,031	2,032	1,101	495	384	1,279	2,173	1,633	761	909	1,574	1,500	3,343	583	2,392	30,576	70,200	102,493	32,939	38,364
July	31.00	35,091	30,066	22,979	14,686	6,232	2,100	1,138	512	397	1,321	2,245	1,688	787	939	1,627	1,550	3,454	602	2,472	31,595	72,540	105,910	34,037	39,643
August	31.00	35,091	30,066	22,979	14,686	6,232	2,100	1,138	512	397	1,321	2,245	1,688	787	939	1,627	1,550	3,454	602	2,472	31,595	72,540	105,910	34,037	39,643
September	30.00	33,959	29,096	22,238	14,212	6,031	2,032	1,101	495	384	1,279	2,173	1,633	761	909	1,574	1,500	3,343	583	2,392	30,576	70,200	102,493	32,939	38,364
October	31.00	36,761	31,497	24,073	15,385	6,528	2,200	1,192	536	416	871	1,479	1,112	518	619	1,072	1,022	1,994	348	1,427	18,237	41,871	61,133	35,657	41,530
November	30.00	35,576	30,481	23,296	14,888	6,318	2,129	1,154	519	403	842	1,432	1,076	502	599	1,037	989	1,930	336	1,381	17,649	40,520	59,161	34,507	40,190
December	31.00	36,761	31,497	24,073	15,385	6,528	2,200	1,192	536	416	871	1,479	1,112	518	619	1,072	1,022	1,994	348	1,427	18,237	41,871	61,133	35,657	41,530
Total	365	426,264	365,223	279,136	178,391	75,698	25,511	13,822	6,215	4,824	12,023	20,433	15,359	7,158	8,548	14,803	14,108	29,224	5,094	20,912	267,301	613,694	896,010	413,462	481,553
																								Total Annual Cost	4,194,769
																								Buses at Garage	126
																								Total Annual Cost Per Bus	33,292

Source: WSP

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6.3.4.1.7 Environmental Costs

Environmental costs include non-cash components of the cost analysis, such as monetized values for tailpipe emissions and upstream emissions of CO2, criteria pollutants, and noise. The financial analysis includes an estimate of tailpipe emissions for CNG buses, for comparative purposes. Upstream emissions consist of emissions resulting from refinement of waste products for CNG buses and production of electricity for battery electric buses. Tailpipe emissions include estimates of CO_2, NO_X, CO, PM_{10}, $PM_{2.5}$. Emissions data was taken from the U.S. Department of Energy's Greet Fleet Calculator tool.

6.3.4.1.8 General - Inflation

The financial model accounts for inflation using the Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U). Table 6-34 is the CPI-U values from 2019 – 2023 provided by California Department of Finance[52]

Table 6-34: Riverside - San Bernardino-Ontario Metropolitan Area Historical Consumer Price Index for all Urban Consumers (CPI-U)

CPI-U	2019	2020	2021	2022	2023
Riverside & San Bernardino	2.87%	3.24%	2.96%	3.10%	3.03%

Source: WSP

6.3.4.2 Fuel Cell Electric Bus – General Assumptions

The WSP team is in continued conversation with local hydrogen suppliers to ensure the most up-to-date cost estimates. The values presented throughout this document are subject to change with any further revisions in pricing.

The cost of implementing FCEB consists of the initial cost of buses procurement; one-time charges for capital investment and construction; annual fees for leases, operation and maintenance; and the cost of procuring the hydrogen fuel. The cost for bus procurement is based on the current fleet inventory of each agency. Capital annual costs depend on whether the transit agencies decide to produce their hydrogen on-site or deliver the hydrogen from contracted services. The fuel consumption rate at each facility and the associated costs of delivery and on-site production can serve as a metric for determining which hydrogen source best meets SBCTA's needs.

6.3.4.2.1 Fuel Cell Vehicle Costs

Similar to battery electric buses, procurement costs are constantly changing with technological developments. Assumptions for this specific analysis regarding cost per fuel cell buses are outlined in Table 6-35.

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52 http://www.dof.ca.gov/Forecasting/Economics/Eco_Forecasts_Us_Ca/index.html

Table 6-35: FCEB Bus Costs

Bus Length	Bus Cost
40 ft	$1,014,978[53]
60 ft	$1,463,934[54]

Source: WSP

6.3.4.2.2 Mid-life Overhaul and Fuel Cell Replacement

At the mid-point of each vehicle's operational life, assumed to be in year 6, a full vehicle overhaul would be needed, including a fuel cell replacement cost of $22,500.

6.3.4.2.3 Capital Investment and Construction

Depending on how the transit agencies source their hydrogen, the upfront capital required for hydrogen is quite intensive with on-site hydrogen production capital being higher than external delivery.

The financial analysis assumes external sourcing and liquid delivery rather than on-site production. Associated costs are outlined in the below table. As such, Omnitrans will incur a one-time charge of $2,133,641 for an external liquid hydrogen delivery system.

The price for gas feedstock and liquid hydrogen delivery was based on data from Ballard and 2017 Clean Energy proposal for OCTA hydrogen delivery system, adjusted to 2019 dollars. The equipment costs do not include the costs for permit application, civil work contract and site preparation, warranty, sales tax, freight, and contingency.

[53] California Department of General Services has contracts that can be used by transit agencies to procure a 40' New Flyer fuel cell buses at $1,014,978

[54] California Department of General Services has contracts that can be used by transit agencies to procure a 60' New Flyer fuel cell buses at $1,463,934

Table 6-36: One-Time Charges for All Equipment Options

Equipment Cost	Internal					External	
	Reformer[55]				Electrolysis[56]	Gas[57]	Liquid[58]
	180kg	270kg	540kg	700kg			
Vaporizer				$ 4,000,000		$ -	$ -
Compressor	$ 254,000	$ 254,000	$ 508,000		$ 8,300,000	$ 1,000,000	$ 1,318,649
Storage	$ 67,000	$ 67,000	$ 204,000				$ 567,754
Dispenser	$ 200,000	$ 200,000	$ 200,000				$ 156,272
Electrolyser (900 kg)	$ -	$ -	$ -	$ -		$ -	$ -
SMR	$ 1,314,778	$ 1,799,000	$ 3,599,721	$ 3,500,000	$ -	$ -	$ -
Other[59]							$ 90,964
Equipment Cost Total	**$ 1,835,778**	**$ 2,320,000**	**$ 4,511,721**	**$ 7,500,000**	**$ 8,300,000**	**$ 1,000,000**	**$ 2,133,641**
Construction Cost	**$ 600,000**	**$ 600,000**	**$ 600,000**		**$ -**	**$ -**	**$ -**
One-Time Charges Total	**$ 2,435,778**	**$ 2,920,000**	**$ 5,111,721**	**$ 7,500,00**	**$ 8,300,000**	**$ 1,000,000**	**$ 2,133,641**

Source: WSP

6.3.4.2.4 Hydrogen Fuel Energy Cost and Annual Delivery Fees

The cost for liquid hydrogen and delivery are estimated as $9.50/kg.

Table 6-37: Fuel Charge

Fuel Cost (including delivery)/kg	Internal[60]		External[61]	
	Reformer	Electrolysis	Gas	Liquid
Fuel Cost (including delivery)/kg	$ 6.00	$ 7.00	$ 12.00	$ 9.50

Source: WSP

Over time, externally sourced hydrogen fuel delivery will increase in cost primarily due to the annual fees that transit agencies pay for contracted services to provide the hydrogen. Annual fees include tube trailer or liquid tank lease, vaporizer lease, and other handling costs. The underlying cost of hydrogen fuel assumed in this analysis is based on current conditions of demand and supply. Future market conditions may result in downward pricing pressures on both hydrogen fuel costs and delivery costs, specifically if there were to be a significant increase in demand and resulting production, potentially providing some economies of scale. Alternatively, an increase in

[55] 180 – 540kg/day SMR cost estimation is based on HyGear HyGEN cost.700kg/day SMR cost is based on Ballard FCEB White Paper 2018.

[56] Based on the price of SunLine transit.

[57] Based on Ballard FCEB White Paper 2018.

[58] 2017 Clean Energy proposal for OCTA hydrogen delivery system, adjusted to 2019 dollar

[59] ESD Buttons, Fuel Support Panel, Switchgear, Air Compressor and Dryer, Fire Detection Upgrades, Fleetwatch Integration

[60] Based on the price of SunLine transit.

[61] Based on Ballard FCEB White Paper 2018

demand may not necessarily result in an increase in supply, resulting in price increases. Calculating the range of risks and uncertainties would require additional sensitivity tests, including the corresponding underlying pricing assumptions for other fuels to align with general energy market prices.

6.3.4.3 Scenario Analysis

6.3.4.3.1 Cost Overview

Background

An analysis was conducted to compare two potential electrification scenarios for Omnitrans (battery electric bus and fuel cell electric bus) with a "business as usual" scenario which assumes that all future procurements maintain the current Omnitrans practice of procuring CNG buses (referred to as Scenario 1 Baseline CNG). Given CARB's mandate of conversion by 2040, this is a theoretical scenario for comparative benefit-cost assessment purposes.

Table 6-38 delineates the overall results of the Omnitrans financial analysis, assessing the full BEB conversion, the FCEB conversion, and the baseline CNG scenario. Values presented throughout this document are subject to change as updated costs are uncovered.

The financial analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs, plus a non-cash cost of environmental benefits and costs, which WSP staff monetizes to account for a holistic comparative cost and benefit.

Table 6-38: Omnitrans – Overall Cost Summary

2020-2050 Fleet Replacement Cost Comparison (2020 $ million)		SCENARIO 1: Baseline CNG	SCENARIO 2: Build - BEB	SCENARIO 3: Build – FCEB
Capital	Vehicle Purchase Price	165.51	219.90	222.66
	Modifications & Contingency	12.08	16.05	16.25
	Charging/Fueling Infrastructure	0.02	8.52	3.80
	Total Capital Costs	*177.61*	244.47	*242.71*
Operating	Vehicle Maintenance	75.50	76.09	95.63
	Overhaul	5.88	7.30	5.80
	Tire Replacement Cost	0.49	0.79	0.79
	Vehicle Tools Training and PPEs[62]	-	-	-
	Other and Miscellaneous Costs	-	-	-
	Vehicle Fuel Costs	124.58	28.84	38.72
	Electric Vehicle Utility Costs	-	69.15	11.85
	Charging/Fueling Infrastructure	0.00	0.01	0.00
	Battery/Fuel Cell Replacement	0.01	0.00[63]	0.02
	Total Operating Costs	*206.46*	182.18	*152.81*
Disposal	Battery Disposal	-	-	-
	Bus Disposal	(0.49)	(0.49)	(0.49)
	Total Disposal Costs	*(0.49)*	*(0.49)*	*(0.49)*
Total Cash Costs		**383.58**	**426.16**	**395.03**
Total Cash Cost per Mile		**2.54**	**3.16**	**2.93**
Environmental	Emissions - Tailpipe	4.92	1.06	1.23
	Emissions - Refining/Utility	143.97	35.51	34.85
	Noise	7.60	5.59	5.59
	Total Environmental Costs	*156.49*	*42.16*	*41.67*
Total Cash and Non-Cash Costs		**540.07**	**468.32**	**436.70**
Total Cash and Non-Cash Costs per Mile		**3.58**	**3.47**	**3.23**
Total Mileage (million miles)		***151***	***135***	***135***

Source: WSP

[62] Omintrans has 1 trainer, whose salary is included in the vehicle purchase price.

[63] Omnitrans will purchase batteries with a 12 year warranty, as such, no battery replacement cost is assumed. The cost of the warranty is included in capital costs under "Modifications & Contingency."

6.3.4.3.2 Cost Conclusions

Overall, the cost-benefit analysis shows higher initial costs, lower operations and maintenance costs, and a slightly higher full lifecycle cash cost of a transition to battery electric buses and fuel cell electric bus.

While operating costs savings are anticipated for a BEB conversion, the high capital costs of BEB's, batteries and their charging infrastructure may offset the savings. The operating cost benefits are highly dependent on factors that are not well-established. This is particularly the case for annual vehicle maintenance costs, while the initial capital cost premium is based on current actual experience.

Discussion of General Inputs

Inputs to the cost-benefit model include:

- Fleet modernization schedules – buses acquired each year by fuel type.
- Vehicle costs including initial purchase, maintenance, mid-life overhaul and disposal
- Battery purchase, replacement and disposal or salvage
- Battery charging infrastructure purchase, installation and maintenance
- Energy costs, gas, liquid hydrogen, and electricity
- Environmental costs for vehicle tailpipe emissions of CO_2 and criteria pollutants
- Environmental costs for vehicle noise

The model examines one complete replacement of the fleet, beginning in the year 2020 and ending with buses acquired in 2039. The model tracks the total cost of ownership (initial capital cost, annual operating cost and final disposal cost) of each new bus for its full bus life.

It should be noted this this is not a comparison between an all CNG, all BEB, or all FCEB scenario, but rather a comparison between continuing current practices and gradually phasing in battery electric bus procurement versus fuel cell electric bus procurement.

In addition to vehicle costs, the model also includes the costs of purchasing, installing and maintaining charging infrastructure for battery electric buses.

All model inputs are provided in current year (2019/2020) dollars. The model applies inflation factors to escalate costs to year of expenditure dollars. The Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U), presented in Table 6-44 was used for most costs, except the following cases where a different specific index was used:

- CNG gas prices were escalated at a rate of 3 percent.
- Electricity costs were escalated using EIA transportation electricity annual forecasted price growth rate forecasts by year

Table 6-39: Annual Energy Outlook – US Energy Information Administration[64]

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	0.00%	14.75%	5.14%	6.08%	5.24%

Source: WSP

These year of expenditure costs were then discounted to present value using a discount rate of 2.37 percent. The resulting present values of all costs are summed to yield the full lifecycle cost comparison.

Vehicle Procurement Schedule by Facility

The battery electric and fuel cell electric scenarios assume the bus procurements to be consistent with the tables that follow. These procurements could either continue the Omnitrans current practice of procuring only CNG buses, or switch to procuring only electric buses (battery or fuel cell) or procure a mix through the years. The two primary factors that would need to be considered for each year of procurement are the availability of charging infrastructure and the range and performance of available electric buses.

In early years, the availability of charging infrastructure would be the strictest constraint, which is why the BEB and FCEB scenarios do not assume any bus procurements until 2024.

[64] US Energy Information Administration, Annual Energy Outlook 2018 - Reference: 3-AEO2018.101.ref2018-d121317a

Table 6-40: BEB Vehicle Procurement Schedule by Facility Location

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ CNG East Valley						23	3		4												
40’ CNG West Valley							7		4												
40’ BEB East Valley	2					4	5		4	8	7		26					4	5		
40’ BEB West Valley	2					4	5		4	7	6		2	23				4	5	19	
60’ CNG East Valley							7														
60’ BEB East Valley							7						1						7		
Total	4	0	0	0	0	31	34	0	16	15	13	0	29	23	0	0	0	8	17	19	**0**

Source: WSP

Table 6-41: FCEB Vehicle Procurement Schedule by Facility Location

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ CNG East Valley						23	3		4												
40’ CNG West Valley							7		4												
40’ FCEB East Valley	2					4	5		4	8	7		26					4	5		2
40’ FCEB West Valley	2					4	5		4	7	6		2	23				4	5	19	
60’ CNG East Valley							7														
60’ FCEB East Valley							7						1						7		
Total	4	0	0	0	0	31	34	0	16	15	13	0	29	23	0	0	0	8	17	19	**2**

Source: WSP

Table 6-42: Baseline Vehicle Procurement Schedule by Facility Location

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ CNG East Valley	2					27	8		8	8	7		26						5		
40’ CNG West Valley	2					4	12		8	7	6		2	23				4	5	19	
60’ CNG East Valley							14						1						7		
Total	4	0	0	0	0	30	34	0	16	15	13	0	29	23	0	0	0	8	17	23	33

Source: WSP

6.3.4.4 Uncertainties

Analysis provided in this documentation should be considered a conservative assessment of battery and fuel cell electric bus costs, as the industry in North America is still small and in preliminary stages of development. Production costs may decrease as production increases to meet future demand. However, cost reductions may be offset by reductions in tax breaks, grant programs, discounts and incentives that are available for the acquisition of battery electric buses and associated charging infrastructure.

The costs for batteries and fuel cells could decline with continued development of more efficient technology and lower production costs resulting from economies of scale. Some potential future cost reductions, however, may be offset (or more than offset) through increases in the cost of acquiring the primary battery components, specifically lithium or other alternative materials. In addition, the energy density of batteries is increasing, so the decline in cost per kWh could be offset by a choice to buy higher-capacity, longer range batteries for buses purchased in later years and for replacement of original batteries on buses purchased in the early years.

The cost of CNG fuel and electricity also have a strong impact on the benefits of battery electric buses. Any major changes to the price would have a direct impact on operating costs for the agency. While utility prices are historically less volatile than CNG prices, there is less downward price potential as utility prices tend to be set by large scale capital investments and distribution costs, as opposed to market inventory levels and feedstock supply costs, which are the primary drivers of diesel prices and volatility.

6.3.5 Recommendations

6.3.5.1 West Valley Fleet Technology Considerations

When selecting the best-fit technology for the needs of West Valley, several factors should be considered, including: service performance, up-front capital expenses, operations and maintenance costs (including current and future fuel costs), required staffing to maintain equipment, and the feasibility of site-specific infrastructure. Considerations for each of the modeled scenarios is outlined below).

BEB Base-Only Benefits and Limitations

- Prioritizing the transition of service blocks that require the least infrastructure, may provide the time necessary for the technologies to advance.
- In the situation that technology does not improve, an increase in infrastructure and/or fleet will be required to meet existing service levels.
- Without any supporting on-site energy production, this strategy may create a vulnerability to shifting utility rates and resulting operations costs.
- Relying solely on a single point of power may also reduce resiliency and present new challenges for participating in emergency response services.

BEB Base and On-Route Charging Benefits and Limitations

- When incorporating strategic placement of on-route charging, the limitations to vehicle range can be eliminated.

- Distributing charging opportunities through the day and service area has the potential to sequester peak energy demand costs.
- On-route charging infrastructure can be cost-intensive, potentially requiring land easements.
- To accommodate on-route charging opportunities, there could be additional costs due to extended layovers. On-route charging could also result in potential impacts to standardized headways and reduce the ability to dynamically modify and improve route performance.

FCEB Benefits and Limitations

- FCEBs demonstrate a similar range capability as vehicle technologies traditionally used by transit operators.
- FCEBs have a quick refueling turnaround and return to service, providing the opportunity to use mid-day refueling to reduce range limitations.
- The up-front cost of FCEB vehicles currently exceeds that of BEBs.
- On-site storage of hydrogen can be restricted by available space and the necessary infrastructure for meeting safety codes.
- On-site production of hydrogen requires experienced staff to maintain equipment.

Hydrogen that is delivered from an external source may be subject to the volatility of market supply and demand.

Strategies

When considering performance, all three technology scenarios modeled in this report fell short of meeting existing service levels at West Valley (Table 6-43). Because of this, the best solution for West Valley will likely include a combination of multiple strategies. Results of this analysis can help inform this decision by highlighting the most efficient and cost-effective strategy that aligns with ICT regulations and the specific needs of the transit operator. Potential pathways for realizing a successful zero-emission transition are outlined below:

Table 6-43: Percent of Service Blocks Completed for Each Technology Scenario Modeled for West Valley

Vehicle Efficiency	BEB Base Charging	BEB On-Route Charging	FCEB
Optimistic	25%	65%	100%
Base	10%	52%	92%
Conservative	8%	23%	19%

Source: WSP

There are several strategies that may be used to support ZEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances

- Phasing zero-emission integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities that must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

6.3.5.2 East Valley Fleet Technology Considerations

When selecting the best-fit technology for the needs of East Valley, several factors should be considered, including: service performance, up-front capital expenses, operations and maintenance costs (including current and future fuel costs), required staffing to maintain equipment, and the feasibility of site-specific infrastructure. Considerations for each of the modeled scenarios is outlined below.

BEB Base-Only Benefits and Limitations

- Prioritizing the transition of service blocks that require the least infrastructure, may provide the time necessary for the technologies to advance.
- In the situation that technology does not improve, an increase in infrastructure and/or fleet will be required to meet existing service levels.
- Without any supporting on-site energy production, this strategy may create a vulnerability to shifting utility rates and resulting operations costs.
- Relying solely on a single point of power may also reduce resiliency and present new challenges for participating in emergency response services.

BEB Base and On-Route Charging Benefits and Limitations

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- Distributing charging opportunities through the day and service area has the potential to sequester peak energy demand costs.
- On-route charging infrastructure can be cost-intensive, potentially requiring land easements.
- To accommodate on-route charging opportunities, there could be additional costs due to extended layovers. On-route charging could also result in potential impacts to standardized headways and reduce the ability to dynamically modify and improve route performance.

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- On-site storage of hydrogen can be restricted by available space and the necessary infrastructure for meeting safety codes.
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Table 6-44: Percent of Service Blocks Completed for Each Technology Scenario Modeled for East Valley

Vehicle Efficiency	BEB Base Charging	BEB On-Route Charging	FCEB
Optimistic	43%	80%	97%
Base	22%	66%	89%
Conservative	10%	54%	47%

Source: WSP

There are several strategies that may be used to support ZEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances
- Phasing ZE integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities that must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

6.3.5.3 Fleet Phasing and Implementation

WSP recommends that the entire electrical yard infrastructure for the site's BEB charging requirements including a the initial transformer and switchgear and additional pads and conduit for the future transformer and switchgear for the ultimate fleet be installed with the initial phase at both the West Valley and East Valley sites to avoid having to disrupt ongoing charging operations or install duplicate infrastructure in subsequent phases.

6.3.5.3.1 West Valley Phasing

Phase 1

The recommended first phase of charger installation the for the West Valley facility is to install all of the in-ground conduit to route electrical service from the new electrical yard to seven charging cabinets with 14 overhead plug-in (or pantograph) dispensers mounted to the new overhead support structure on the eastern boundary of the facility.

Phase 2

The recommended first phase of charger installation the for the West Valley facility is to install all of the in-ground conduit to route electrical service from the new electrical yard to seven charging cabinets with 14 overhead plug-in (or pantograph) dispensers mounted to the new overhead support structure on the eastern boundary of the facility.

Phase 3

Phase 3 at West Valley will complete yard trenching to distribute to electrical service to the southern yard parking grouping and the remainder of the overhead support structure and remaining dispensers.

6.3.5.3.2 East Valley Phasing

Phase 1

The first phase of construction will include the installation of all in-ground conduit to route electrical service from the new electrical service yard to the proposed overhead structure and charging cabinet island. A portion of the support structure should be installed over the northern half of the exiting parking tracks and the charging cabinet platform should be installed on the southern central edge of the new support structure to support the initial 30 charging cabinets. The conduit routing power from the electrical yard to the support structure should be sized for the ultimate distribution demand to meet the needs of the subsequent phase without further trenching. 60 overhead retractor cable plug-in (or pantograph) charging dispensers will be hung from the new support structure to serve each of the covered parking spaces and controls for the retractor cable (plug-in charging) in each spot will be located on the nearest support structure column.

Phase 2

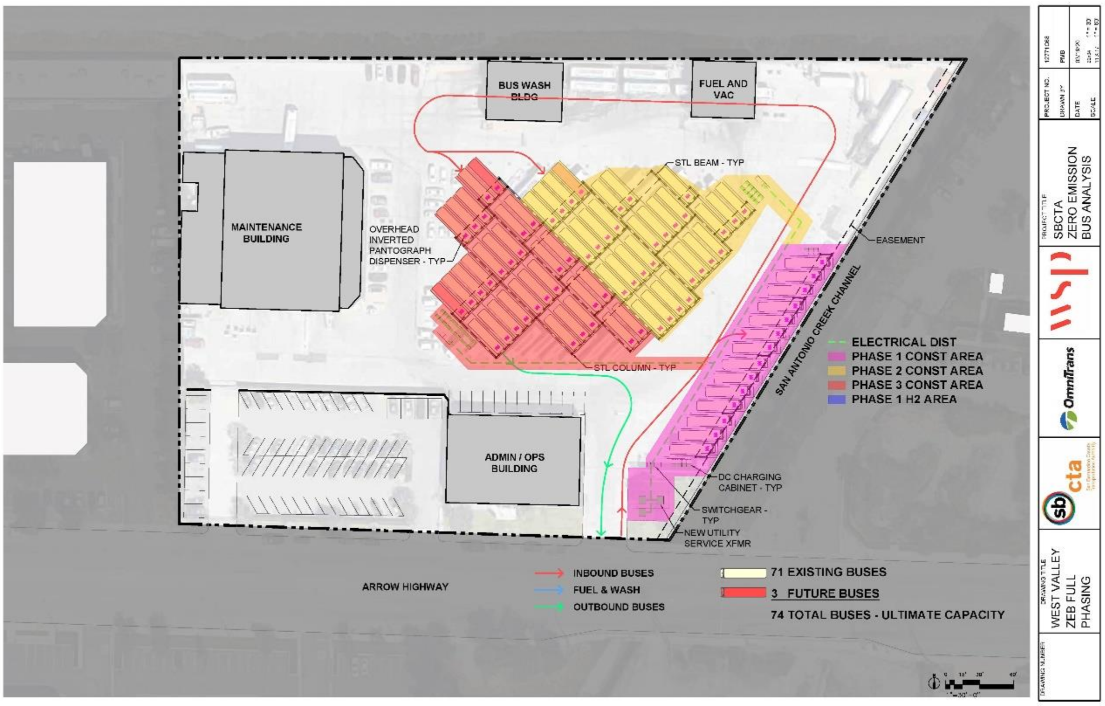
Phase 2 at East Valley will consist of construction of the southern half of the support structure and charging cabinet in a mirrored design of the northern portion completed in Phase 1. The additional transformer and switchgear will be installed on the pads and conduit constructed in the electrical yard during Phase 1 and routed via the overhead support structure, so that no new trenching will be required. The new support structure housing an additional 60 retractor cable plug-in (or pantograph) charging dispensers and overhead platform with 30 additional charging cabinets will be installed to provide the entire facility with charging capabilities.

6.3.5.3.3 San Bernardino Transit Center Phasing

The entire overhead inverted pantograph charging system and the associated new electrical service yard should be completed in a single phase. Ideally this location would be completed in the same timeframe as the early phases of Omnitrans and MT's ZEB projects to allow for the routes needing range extension to have access to the on route charging at their onset.

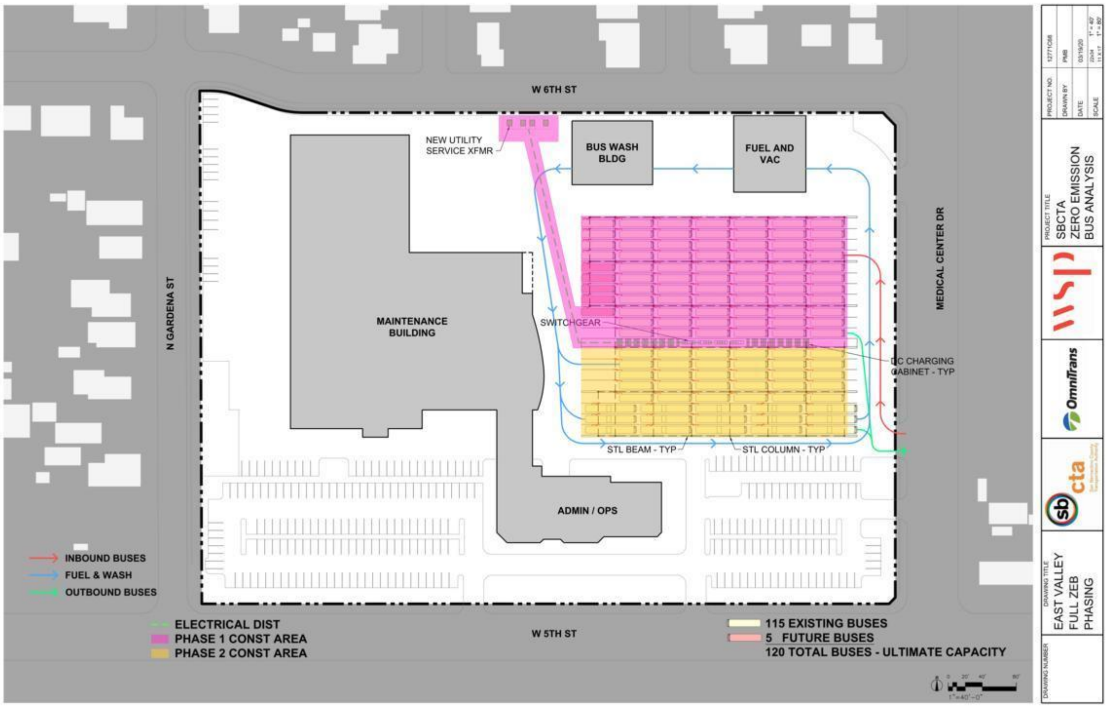
6.3.5.4 Facility Preliminary Design

Figure 6-23: West Valley Proposed Full ZEB Build-Out and Phasing Plan



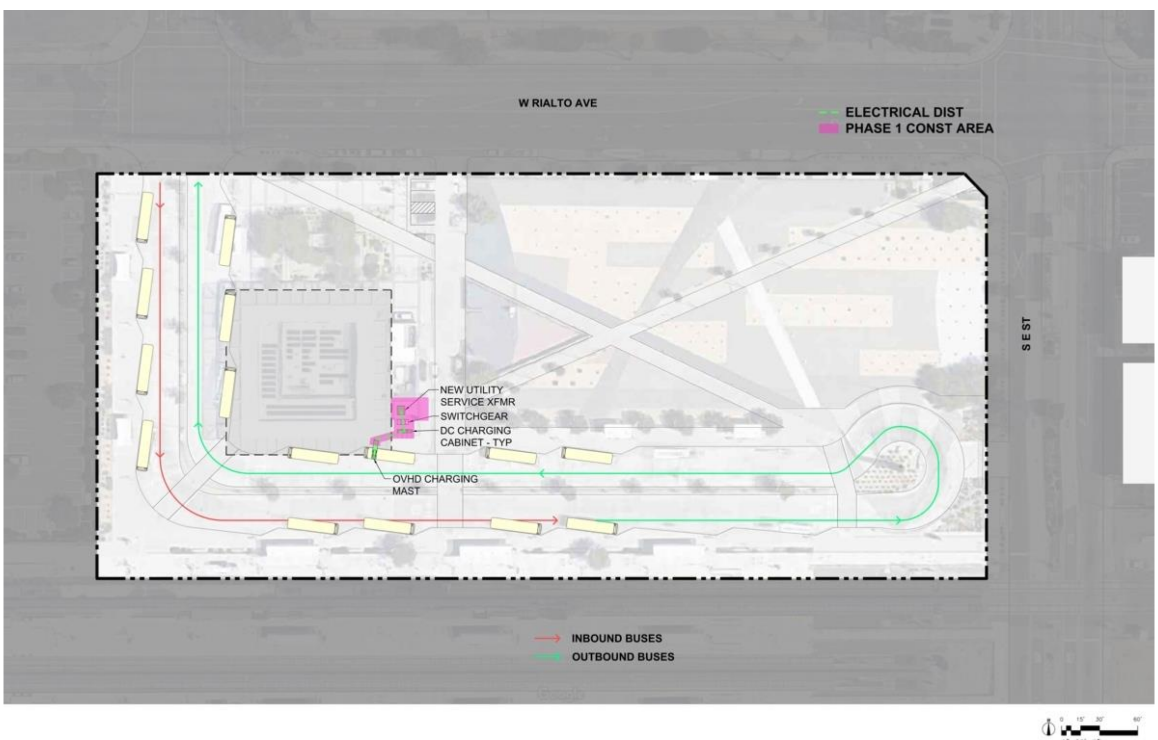
Source: WSP

Figure 6-24: East Valley Proposed Full ZEB Build-out and Phasing Plan



Source: WSP

Figure 6-25: San Bernardino Transit Center Proposed ZEB Build-out and Phasing Plan



Source: WSP

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7 VICTOR VALLEY TRANSIT AUTHORITY

7.1 Introduction

VVTA is a joint-powers agreement between San Bernardino County, the Town of Apple Valley, and the cities of Adelanto, Barstow, Hesperia, and Victorville. Each municipality seats a member on the authority's board, who are joined by two county supervisors.

Established in 1989, the authority took its present shape in 2015, when VVTA merged the previously independent Barstow Area Transit (BAT). Under the terms of the merger, VVTA added two BAT board members to its combined board, one from the City of Victor Valley and one a county supervisor.

7.2 Existing Conditions

7.2.1 Service Area and Environmental Factors

VVTA serves the four major cities and their surrounding areas in the high desert Victor Valley area: Adelanto, Apple Valley, Hesperia, and Victorville. According to the 2010 United States Census, the city of Victorville is the largest of these cities, with approximately 121,000 residents; the Town of Apple Valley has a population of 69,000; the City of Adelanto has a population of 32,000; and the City of Hesperia has a population of 93,000. All four cities share at least one border with one of the other three cities.

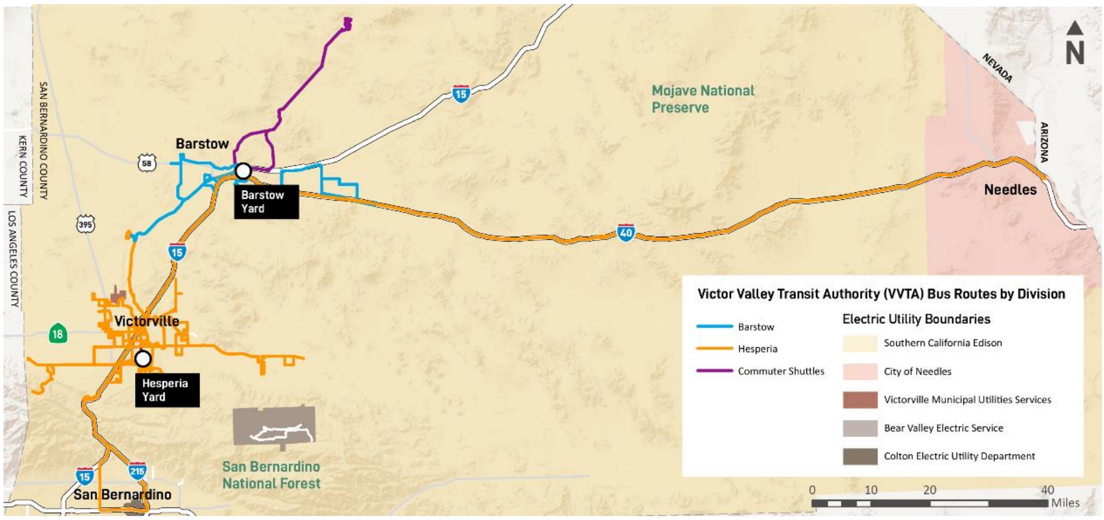
VVTA also operates transit service to and within the City of Barstow, a relatively isolated city of approximately 22,000, 30-miles northeast of Victorville and halfway between Los Angeles and Las Vegas when traveling on the I-15 Freeway.

VVTA's service area is large. The full extent of the service area, with the electric utility boundaries that serve it, is shown in Figure 7-1. While its legacy Victor Valley routes all serve cities that share borders, those cities are not densely developed, and the developed portions of the cities are separated, in some cases, by more than 20 miles. Barstow is relatively compact in its development, but it is isolated and smaller than the Victor Valley cities. Additionally, the VVTA operates a limited service route to the City of Needles approximately 175 miles east of Victorville.

Although the service area is large, only two electric utilities service most of the area: SCE and, in the eastern-most portion only, City of Needles Electric Utility. Colton Electric Utility Department does serve one route that connects VVTA to the City of San Bernardino, but that would likely be avoided as an on-route charging site unless it presents an opportunity for interlining with Omnitrans.

VVTA predominantly operates its services in the Mojave Desert, where summer high temperatures often reach 100 degrees while winter low temperatures often drop below freezing. The area sees very little rainfall and snowfall. The service area itself is largely flat, but it sits in the high desert with elevations of approximately 3,000 feet in Victor Valley and 2,200 feet in Barstow. These elevation changes will reduce the range of electric buses serving these routes.

Figure 7-1: VVTA Routes by Division and Electric Utility Boundaries



Source: WSP

The limited service to Needles presents several additional challenges: elevation changes frequently across the mountainous desert terrain, ultimately ending in Needles at 475 feet, and there is nearly no development between the cities of Barstow and Needles.

7.2.2 Schedule and Operations

VVTA operates 30 regular routes, eight commuter routes, and one special route across its service area. Figure 7-2 shows VVTA's route by divisions. VVTA's regular routes are:

VVTA's regular routes are:

- Adelanto: Routes 31, 32, and 33
- Apple Valley: Routes 23, 40, 41, 42, 43, and 47
- Barstow: Routes 1, 2, 3, 6, 28, and 29
- Hesperia/Oak Hills: Routes 24A, 24B, 66, and 68
- Victorville: Routes 15, 21P, 21W, 22, 50, 50X, 51, 52, 53, 54, and 55

All eight commuter routes serve Fort Irwin National Training Center (NTC), a major training area for the United States military in the Mojave Desert approximately 36 miles northeast of Barstow. Not all commuter routes are round-trips - trips inbound to NTC in the AM are designated "A" and return trips in the PM are designated "B." The routes originate from the following locations:

- Victorville: Routes 101A and 101B (Bear Valley Road)
- Hesperia: Routes 102, 103, 105 (L Street) and 107
- Helendale: Route 105
- Barstow: Route 106 (Williams park-and-ride)

Figure 7-2: VVTA Service by Route

Source: WSP

Lastly, VVTA offers the intercity Route 200, the "Needles Link." Route 200 operates Friday-only service, with one trip from Needles at 6:15 AM via Barstow to Victorville at 10:30 AM and a return trip departing Victorville at 2:45 PM and arriving Needles at 7:15 PM. A roundtrip of more than 350 miles, the route stops only at Needles G Street, the Barstow Library, the Victorville Transfer Point, and the Victorville Court House. VVTA began offering this service in 2016 to provide alternate transportation to the courts in Barstow and Victorville in the wake of state funding cuts to courts in Needles and Barstow. Needles residents can reserve a seat on Route 200 with curb-to-curb pick-up in advance.

VVTA operates with two facilities: Barstow (all Barstow routes, the Needles Link, and commuter shuttles 101A, 104B, and 105B) and Hesperia (all other routes, mostly serving the Victor Valley). A summary of all routes by service area are shown in Table 7-1.

VVTA's longest route is Route 200 to Needles at 513 miles for a roundtrip. Even leaving aside this outlier, its other routes generally range from 92 to 352 miles roundtrip for the Barstow routes and 84 to 393 miles roundtrip in the Hesperia/Victor Valley routes.

Table 7-1: VVTA Summary of Service

Service Area	Routes	Days	No. of Trips	Span	Headways
Hesperia Division					
Adelanto	31, 32, 33	Daily (Weekends limited)	6–24	6:00 AM – 9:01 PM	30 to 60 min.
Apple Valley	23, 40, 41, 42, 43, 47	Daily (Weekends limited)	7–25	6:00 AM – 8:55 PM	30 min. to 2 hr.
Hesperia	24, 66, 68	Daily (Weekends limited)	15	6:08 AM to 9:18 PM	Hourly
Needles	200	Friday only	1	6:15 AM to 7:15 PM	One roundtrip
Victorville	15, 21, 22, 50, 51, 52, 53, 54, 55	Daily (Weekends limited)	6–24	6:00 AM to 9:52 PM	30 min. to 2.5 hr.
Commuter Routes	104A, 105A, 106A, 107A, 101B, 102B, 103B, 107	Monday to Friday	1	4:15 – 7:35 AM 3:45 – 8:10 PM	One route/day, arrive/depart Fort Irwin hourly (AM) or 30 – 75 min. (PM)
Barstow Division					
Barstow	1, 2, 3, 6, 28, 29	Daily (Weekends limited)	5–14	6:00 AM to 8:35 PM	Hourly 28, 29: 3 hrs.
Commuter Routes	101A, 104B, 105B	Monday to Friday	1	4:15 – 7:35 AM 3:45 – 8:10 PM	One route per day, arrive/depart Fort Irwin hourly (AM) or 30 – 75 min. (PM)

Source: VVTA

VVTA uses six different fare structures. Its most common is local fares, which are $1.50 for a regular rider, $1.25 for a student, and $0.75 for veterans, seniors, disabled passengers, and those passengers with Medicare, and free for children (5 and under). For routes that travel in unincorporated parts of the county, a $1 county fare addition ($0.50 for discounted) is required. This applies to routes 21–24, 28, and 29. For those routes that permit deviation, fares are $2.00 ($1.00 for discounted groups). Lastly, single trips on NTC shuttles and on the Needles Link are $13.00; a single fare on the Needles Link portion from Barstow to Victorville is $6.50. Discounted groups receive 50 percent off.

7.2.3 Upcoming Capital Programs and Service Changes

In November 2019, VVTA replaced seven of its CNG vehicles were replaced with BEBs (five 35-footers and two 40-footers). These buses are equipped with 466 kWh of battery capacity and are fueled by electrical power via ChargePoint CP-250 chargers (62.5 kW) at the Hesperia Yard.

The future Barstow yard is currently under construction with expected completion in 2020. The facility is designed to accept ChargePoint Power Blocks, DC charging cabinets of 156kW+ not commercially available at the time of this report publication but anticipated to be available in the near future, in the future to accommodate BEB charging. The charging equipment and electrical infrastructure will be installed in space between the existing CNG fueling site and the new bus parking yard.

Additionally, VVTA is in the midst of grant applications to fund on-site hydrogen storage and compression at both the Future Barstow Yard and the Victor Valley Transportation Center on D Street in downtown Victorville. The hydrogen tanks and compressors would accommodate delivered liquid hydrogen gas and would thus allow for future scaling of on-site electrolysis or steam reformation. Finally, VVTA is pursuing an energy storage and demand response program at its Hesperia Yard to tackle peak demand charges and integrating charge management efficiencies.

7.2.4 Facilities

This section provides a summary understanding of each of VVTA's existing site and facility conditions. VVTA has its operational headquarters in Hesperia, immediately adjacent to Victorville. Additionally, this site houses a bus yard and a maintenance facility. A second yard and maintenance facility are currently under construction in Barstow, with existing service being operated from a contractor site lot. VVTA is currently a CNG and diesel-fueled fleet, however, seven BEBs are scheduled for service testing beginning in November 2019. In addition, VVTA has a solar canopy atop its facility in Hesperia as well as charging infrastructure. A more detailed catalog of the existing site condition is available in the report titled "Zero Emission Bus (ZEB) Analysis Facilities Inventory Report" issued January 15, 2020.

7.2.4.1 Hesperia Yard

Victor Valley's Hesperia Yard facility is located at 17150 Smoke Tree Street, Hesperia, California, on approximately 10 acres of land (Figure 7-4). Table 7-2 describes the site's facilities, equipment, and fleet.

Currently, 49 CNG-powered buses and seven BEBs are stored, maintained, fueled, and serviced at the yard. Hesperia Yard includes the following separate structures and major site areas: a two-story maintenance building, two-story transportation building, stand-alone wash building, stand-alone fuel building, employee parking lots, photovoltaic canopy-coverings in the bus parking and employee parking areas, and a CNG compressor with support equipment. Employee parking is on site in the employee parking lots along Smoke Tree Street.

Table 7-2: VVTA Hesperia Yard Inventory

Fleet Overview	
Cutaway Bus[65]	8
30-foot Bus	-
35-foot Bus	7
40-foot Bus	36[66]
45-foot Bus	5
60-foot Articulated Bus	-
Total	**56**
Facilities	
Total Maintenance Bays	9
Paint Booths	-
CNG Fueling Positions	4
CNG Compressor Yards	1
Diesel Fueling Positions	1
Unleaded Fueling Positions	1
NRV Bays	-
Body shops	-
Bus Wash Lanes	2

Source: WSP

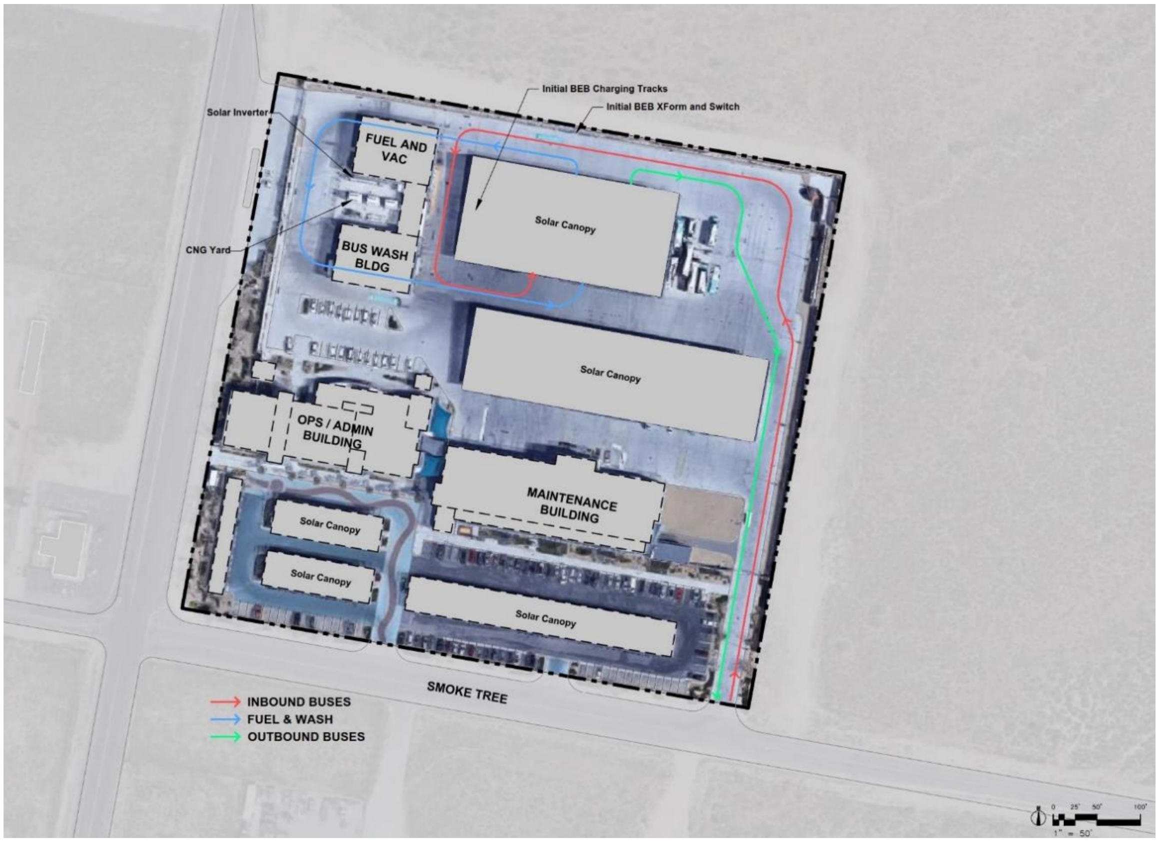
[65] Cutaway buses for VVTA range in length from 25-33 feet.

[66] 7 of which are BEB

Figure 7-3: Hesperia Yard – Existing Conditions

Source: WSP

Figure 7-4: Hesperia Yard Site Circulation



Source: WSP

SCE powers the VVTA headquarters, which is fed via multiple 12kV underground power distribution feeds.

SCE supplies the 500kVA (12kV-480/277V) utility transformer which feeds the main switchboard. This switchboard contains an 800A main breaker with seven 100A branch breakers designated for the seven recently installed ChargePoint Express 250 EV bus charging stations which are located on the north side of the existing facility, with an input rating of 480V AC, 3-phase, 81A. Consequently, the total continuous power consumption equates to 693A for the seven charging ports.

There is an additional 2000A service, which distributes power to the entire facility. It includes four preexisting buildings (OPS/Admin building, Vacuum and Fueling building, Maintenance Facility, and Bus wash building). In addition, there are is also solar photovoltaic co-generation, that has been integrated into the existing system by feeding power to the MCC CNG power distribution panel to offset some of the power consumption. It shall be noted that the aforementioned buildings are backed up by a 500kVA standby generator.

However, following discussions with VVTA staff, in order to install future additional ChargePoint chargers in the existing facility, VVTA must invest in upgrading the existing 800A service for future electric loads.

7.2.4.2 Barstow Future Yard

The future Barstow Yard (Figure 7-5) is currently in the early stages of construction at 100 Sandstone Court, Barstow, California with an expected completion date in 2020. The site is on approximately 5 acres of land for the Barstow Yard and 1.7 acres for the on-site CNG fueling station. The current Barstow Yard is a small operation and joint venture with the City of Barstow and Transdev. Further study of this site was not performed for this study due to the imminent opening of the Barstow Future Yard in 2020. Table 7-3 describes the future site's facilities and equipment.

Table 7-3: Barstow Yard Future Inventory

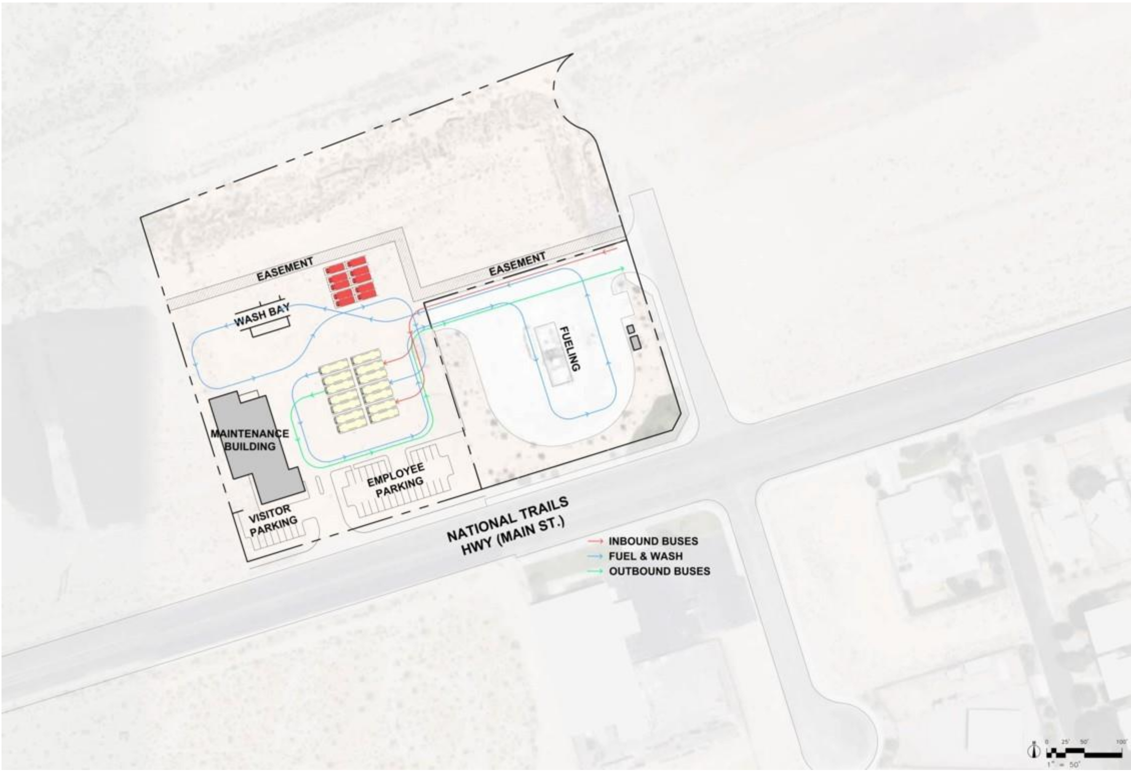
Future Facilities	
Total Maintenance Bays	3
Paint Booths	-
CNG Fueling Positions	5 (existing)
CNG Compressor Yards	1 (existing)
Diesel Fueling Positions	-
Unleaded Fueling Positions	-
NRV Bays	-
Body shops	-
Bus Wash Lanes	1

Source: WSP

Figure 7-5: Barstow Future Yard - Existing Conditions

Source: WSP

Figure 7-6: Barstow Future Yard Site Circulation



Source: WSP

The future Barstow Yard is currently under construction. There is an SCE-owned MV distribution line running parallel to the facility on the other side of the road. Also, there is an underground power distribution pathway from the intersection of Main Street and Sandstone Court that feeds the existing pad mounted transformer located within the existing CNG fuel station. Per the construction documents submitted to the city of Barstow, it is indicated that two services are to be installed with nominal ratings of 600 A and 1600 A.

7.3 ZEB Implementation

7.3.1 Technology

Past and ongoing ZEB analysis for VVTA's operations has determined that an adoption of both BEBs and (predominantly) FCEBs is the ZEB technology that best meets the needs of VVTA for their purchasing and transition requirements pursuant to the ICT regulation.

VVTA's future BEBs are expected to have specifications that are compatible with the Society of Automotive Engineers' (SAE) J1772 charging standard (e.g., "plug-in charging"). It is recommended that VVTA specify charging ports on the rear of BEBs to allow for their existing site circulation and parking patterns to continue without additional modifications. Battery sizing (kilowatts) will be determined based on service needs requirements and what is available and feasible based on costs and weight. Charger rating (kilowatt-hour) will be based on service needs, battery acceptance, and costs.

The majority of VVTA's service blocks extend beyond the current range capabilities of BEBs, for this reason, it is recommended that BEBs only serve blocks that operate less than 150 miles in a service period. For the remaining service blocks, FCEBs are recommended as the primary ZE technology. Serval methods of hydrogen fuel sourcing are available to VVTA, including delivery and on-site production. A phased investment in hydrogen infrastructure is recommended for VVTA, beginning with on-site liquid hydrogen storage delivered by a local supplier and graduating into on-site production via electrolysis. The impacts of these recommendations for each site follow.

7.3.2 Analysis/Findings

7.3.2.1 Hesperia Yard

Based on Hesperia Yard's existing service needs, the daily hydrogen requirement is more than 1,600 kg. To support this, at least one 15,000-gallon (~4,500kg) liquid hydrogen storage tank is recommended, requiring a minimum footprint of 40 feet by 50 feet plus safety offsets.

Currently, the site design at Hesperia Yard does not support the spatial requirements for hydrogen infrastructure. According to the NFPA 55, all air intakes (heating, ventilating, or air-conditioning equipment (HVAC), compressors, other) must be located at least 75-feet from liquid hydrogen storage containers. This cannot currently be achieved at the Hesperia site without displacing large amounts of vehicle parking or reconfiguring all the on-site buildings. It is recommended that VVTA identify a nearby site to host hydrogen fueling to avoid significant infrastructural modifications on-site. Under this assumption, the following FCEB equipment is proposed for the off-site fueling location:

- One 15,000-gallon liquid hydrogen storage tank
- One liquid pumping system
- One no-fog vaporization system
- Boil-off gas compressor
- Three hydrogen dispensers located on a dispenser island fueling pad
- Electric capabilities of 480 VAC, 3 phases, 60HZ, 300-350 KW
- H2 & flame detection
- Emergency shut-off buttons
- Additional pump and dispenser for redundancy (optional)

Conceptual layouts for the proposed ZEB solutions for VVTA's facilities are present in 7.3.5.4 of this document.

7.3.2.1.1 Modeling Results

Base-Only Charging – Hesperia Yard

Currently, the Hesperia Yard operates 47 vehicle blocks with 40-foot transit vehicles. The smallest block distance traveled is 31 miles and the longest is 514 miles. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) was used to model the transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 660 kWh battery. Only 49 percent of vehicle blocks could be completed at the optimistic efficiency, 28 percent could be completed at the base efficiency, and 17 could be completed percent at the conservative efficiency.

For the fleet to maintain a 1:1 ratio with the transition to BEB with base-only charging VVTA would need battery capacities that exceed over 1,000 kWh for 40-foot vehicles that operate at the same efficiency as the 660 kWh vehicles (~3.4 kWh/mi.), but this technology is not available.

Table 7-4 provides the summary of block completion percentage for VVTA at the Hesperia Yard, and Table 7-5 provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service with the 660-kWh battery at the conservative efficiency. Table 7-5 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 7-4: VVTA – Hesperia Base-Only Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**23% (11)**	**13% (6)**	**4% (2)**
660	**524**	**49% (23)**	**28% (13)**	**17% (8)**
700	560	51% (24)	28% (13)	19% (9)
750	600	60% (28)	38% (18)	26% (12)
800	640	62% (29)	40% (19)	26% (12)
850	680	68% (32)	40% (19)	26% (12)
900	720	72% (34)	47% (22)	34% (16)
950	760	72% (34)	51% (24)	38% (18)
1000	800	81% (38)	60% (28)	40% (19)

Source: WSP

Table 7-5: Summary of VVTA Hesperia Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
4>157466	660	11.1	119	400	533	667
4>157455	660	6.8	131	436	582	727
4>157486	660	10.6	133	445	593	741
4>157457	660	13.1	134	450	600	749
4>157479	660	15.0	224	406	644	882
4>157476	660	3.8	168	535	713	891
4>157488	660	3.8	168	535	713	891
4>157480	660	3.8	168	535	713	891
4>157458	660	3.8	170	542	722	903
4>157449	660	3.8	170	542	722	903
4>157459	660	9.6	177	595	793	992
4>157472	660	15.6	193	649	865	1081
4>157473	660	15.6	194	650	867	1083

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
4>157474	660	15.7	196	658	877	1097
4>157465	660	15.8	205	687	916	1145
4>157481	660	14.9	212	715	954	1192
4>157478	660	15.4	215	723	964	1205
4>157452	660	15.3	215	724	966	1207
4>157468	660	15.7	218	733	977	1221
4>157469	660	15.6	223	752	1003	1254
4>157483	660	9.5	285	619	937	1255
4>157470	660	15.7	246	826	1101	1376
4>157489	660	6.0	262	834	1112	1390
4>157475	660	15.2	265	846	1128	1409
4>157463	660	15.8	253	851	1134	1418
4>157477	660	15.2	264	890	1187	1484
4>157467	660	15.6	284	957	1276	1595
4>157448	660	15.8	293	985	1313	1641
4>157484	660	15.4	296	995	1327	1658
4>157485	660	11.9	298	997	1330	1662
4>157462	660	16.0	302	1013	1351	1688
4>157453	660	16.0	302	1015	1353	1691
4>157482	660	15.5	309	1039	1385	1732
4>157450	660	15.8	324	1088	1451	1814
4>157494	660	8.2	371	1184	1579	1973
4>157495	660	8.2	371	1184	1579	1973
4>157464	660	16.5	358	1204	1606	2007
4>157456	660	16.3	384	1289	1719	2149
4>157451	660	16.7	515	1731	2308	2886

Source: WSP

Base and On-Route Charging – Hesperia Yard

Currently, the Hesperia Yard operates 47 vehicle blocks with 40-foot transit vehicles. The smallest block distance traveled is 31 miles and the longest is 514 miles. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) battery was used to model the transit vehicles.

The analysis found it would not be possible to complete all vehicle blocks with the 660 kWh battery. Sixty-four percent of vehicle blocks could be completed at the optimistic efficiency, 45 percent could be completed at the base, and 34 percent could be completed at conservative efficiencies. VVTA would be able purchase a smaller battery size for at least 28 percent of the fleet.

For a complete 1:1 ratio of existing fleet to BEB at all efficiencies, one vehicle block would need to be served by vehicles with an advertised battery capacity between 119 and 200 kWh that also operate at the same kWh/mi efficiency as the other cutaway vehicles modeled (0.67 kWh/mi.).

Table 7-6 provides the summary of block completion percentage for VVTA at the Hesperia Yard, and Table 7-7 provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service with the 660-kWh battery at the conservative efficiency. Table 7-7 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 7-6: VVTA – Hesperia Yard Base and On-Route Charging Cutaway Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**45% (21)**	**32% (15)**	**28% (13)**
660	**524**	**64% (30)**	**45% (21)**	**34% (16)**
700	560	66% (31)	45% (21)	34% (16)
750	600	68% (32)	55% (26)	43% (20)
800	640	70% (33)	55% (26)	43% (20)
850	680	77% (36)	55% (26)	43% (20)
900	720	81% (38)	64% (30)	51% (24)
950	760	81% (38)	66% (31)	55% (26)
1000	800	85% (40)	68% (32)	55% (26)

Source: WSP

Table 7-7: Summary of VVTA Hesperia Yard Base and On-Route Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
4>157455	660	6.8	131	436	582	727
4>157483	660	9.5	285	385	551	734
4>157478	660	15.4	215	288	509	741
4>157452	660	15.3	215	288	511	744
4>157479	660	15.0	224	406	644	882
4>157476	660	3.8	168	535	713	891
4>157488	660	3.8	168	535	713	891
4>157480	660	3.8	168	535	713	891
4>157458	660	3.8	170	542	722	903
4>157449	660	3.8	170	542	722	903
4>157474	660	15.7	196	658	877	1097

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
4>157465	660	15.8	205	687	916	1145
4>157481	660	14.9	212	715	954	1192
4>157485	660	11.9	298	612	885	1209
4>157462	660	16.0	302	567	896	1225
4>157453	660	16.0	302	568	898	1227
4>157469	660	15.6	223	752	1003	1254
4>157470	660	15.7	246	826	1101	1376
4>157489	660	6.0	262	834	1112	1390
4>157475	660	15.2	265	846	1128	1409
4>157463	660	15.8	253	851	1134	1418
4>157477	660	15.2	264	890	1187	1484
4>157448	660	15.8	293	985	1313	1641
4>157484	660	15.4	296	995	1327	1658
4>157482	660	15.5	309	1039	1385	1732
4>157450	660	15.8	324	1088	1451	1814
4>157495	660	8.2	371	1108	1494	1880
4>157494	660	8.2	371	1134	1529	1923
4>157464	660	16.5	358	1204	1606	2007
4>157456	660	16.3	384	1289	1719	2149
4>157451	660	16.7	515	1731	2308	2886
4>157455	660	6.8	131	436	582	727
4>157483	660	9.5	285	385	551	734
4>157478	660	15.4	215	288	509	741
4>157452	660	15.3	215	288	511	744
4>157479	660	15.0	224	406	644	882
4>157476	660	3.8	168	535	713	891

Source: WSP

Hydrogen Fuel Cell Electric Bus

Some agencies around the nation are beginning to recognize the potential for commercialization of the zero-emission technologies they are integrating within their fleets. Following suit with SunLine Transit Agency's public alternative fueling station, VVTA is strategizing approaches to increase economic opportunity within the agency by producing their own hydrogen in excess and selling it to local consumers. Two sites are currently being considered for scaling VVTA's hydrogen production and positioning a local hydrogen retail station.

The first location is a 10-acre parcel set directly adjacent to the Barstow site. If developed, this site would serve as the only public hydrogen fueling station in the community. The location of the

Barstow site also sits near the junction of I-15 and I-40, five minutes from a conventional truck fueling station. As commercial freight vehicles begin to make the transition to alternative fuels, this site could prove to be a promising location for drawing early adopters.

VVTA is also considering positioning a retail hydrogen station at an inactive transit center located in Hesperia. This site is located near various retail sites as well as a Burlington Northern Santa Fe railroad line, again offering the opportunity to market to intermodal freight vehicles using alternative fuels. The site in consideration currently provides CNG fueling, indicating that many of the necessary upgrades to accommodate “lighter-than-air” fuels will already be in place.

Providing adequate hydrogen to supply a full-fleet conversion at VVTA along with public fueling stations will be substantial, requiring multiple electrolyzers and/or SMR units. At each site, careful consideration to renewable power generation and renewable natural gas should be given to ensure long-term payback on capital infrastructure in addition to establishing complete energy independence.

Service Performance

Service performance at Hesperia Yard was evaluated using three degrees of efficiency (described in the Methodology Section) to determine the percentage of each service block distance that could be complete when operating current FCEB technology. The total percentage of blocks that meet service requirements using FCEB vehicles is presented to demonstrate the viability of the technology. Any block operating vehicle classes not currently available as FCEBs were immediately disqualified for FCEB consideration (Table 7-8). Using the results of this analysis, anticipated hydrogen fuel consumption was calculated for three alternative scenarios: 1) full-fleet FCEB conversion, 2) conversion of only the qualifying blocks (those that met range requirements), and 3) FCEB conversion for all service blocks with more than 150 miles of daily range.

In total, FCEB service performance at Hesperia Yard fell short of meeting service requirements under all three efficiency estimations. Under optimistic efficiencies, 79 percent of the fleet were able to complete the entire service block distance using the modeled FCEBs (Table 7-9). For the service blocks that failed under optimistic efficiencies, the average percent of the block distance completed was 86 percent. When considering base efficiencies 62 percent of the service blocks were able to meet the full range requirements, with failed blocks reaching an average of 80 percent of the required block distance (Table 7-10). At the conservative efficiency, only 38 percent of service blocks met range requirements when using FCEBS. The failed blocks under conservative estimations reached an average of 72 percent of the service block distance (Table 7-11).

As Hesperia Yard moves forward with FCEB adoption, they should closely consider vehicle phasing to prioritize the service blocks the met range requirements at all levels of efficiency estimation. For the remaining blocks, consideration to service changes, including mid-day refueling and driver relief, may be necessary unless significant advances in FCEB technology are realized. Under the conservative estimations, two blocks had less than a 50 percent completion of the daily mileage, indicating that more than one mid-day refueling may be required, or the block distance may need to be adjusted to accommodate FCEB technology.

Table 7-8: Hesperia Non-Qualifying Blocks Because of Unavailable Technology

Block I.D.	Bus Type
4>157449	Coach
4>157458	Coach
4>157467	Coach
4>157480	Coach
4>157488	Coach

Source: WSP

Table 7-9: Hesperia Yard Non-Qualifying Service Blocks Under Optimistic Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157450	323.5	92.00%
4>157451	514.8	57.83%
4>157453	302.4	98.45%
4>157456	384.0	77.52%
4>157462	301.8	98.63%
4>157464	357.8	83.19%
4>157482	308.7	96.41%
4>157485	298.1	99.84%
4>157494	371.4	80.14%
4>157495	371.5	80.13%

Source: WSP

Table 7-10: Hesperia Yard Non-Qualifying Service Blocks Under Base Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157448	293.4	84.05%
4>157450	323.5	76.22%
4>157451	514.8	47.91%
4>157453	302.4	81.56%
4>157456	384.0	64.22%
4>157462	301.8	81.71%
4>157463	253.3	97.35%
4>157464	357.8	68.92%
4>157467	284.4	97.98%
4>157475	265.3	92.95%
4>157477	263.9	93.46%
4>157482	308.7	79.88%
4>157483	284.7	86.63%

Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157484	296.5	83.18%
4>157485	298.1	82.72%
4>157489	261.6	94.27%
4>157494	371.4	66.39%
4>157495	371.5	66.39%

Source: WSP

Table 7-11: Hesperia Yard Non-Qualifying Service Blocks Under Conservative Efficiency

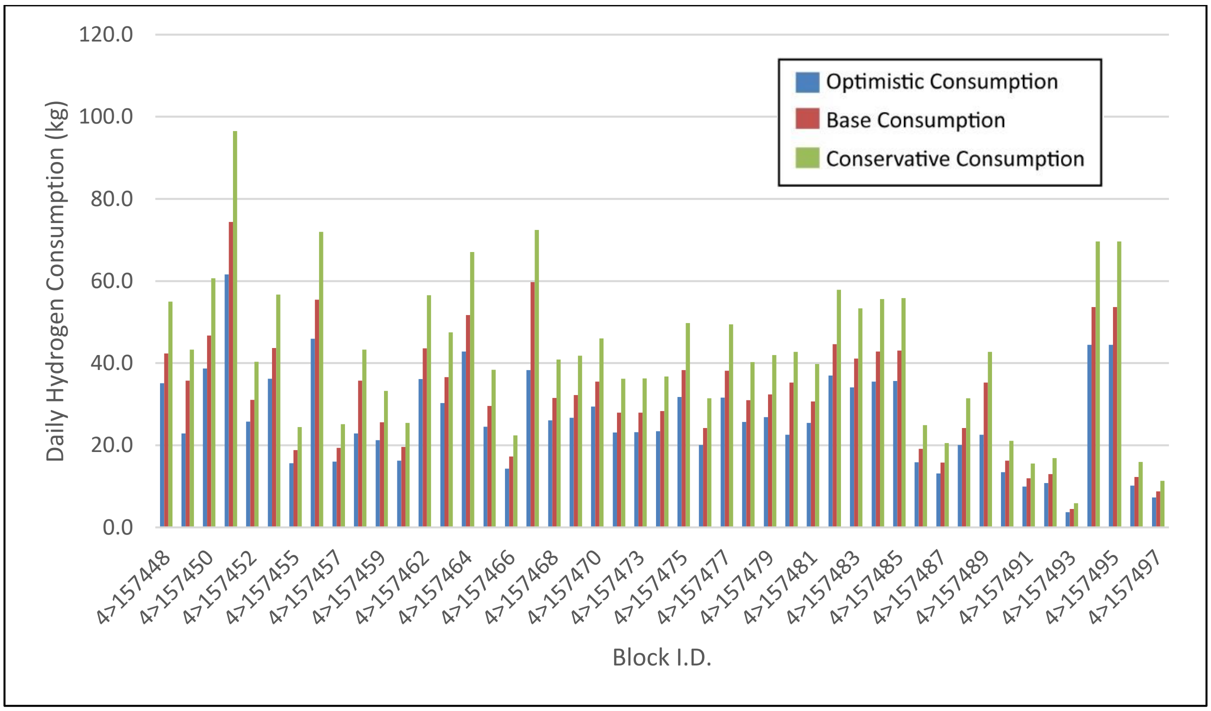
Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157448	293.4	64.77%
4>157450	323.5	58.74%
4>157451	514.8	36.92%
4>157452	215.2	88.34%
4>157453	302.4	62.86%
4>157456	384.0	49.50%
4>157462	301.8	62.98%
4>157463	253.3	75.03%
4>157464	357.8	53.12%
4>157465	204.7	92.83%
4>157467	284.4	80.75%
4>157468	218.1	87.16%
4>157469	223.3	85.13%
4>157470	245.6	77.39%
4>157472	193.3	98.31%
4>157473	193.7	98.14%
4>157474	196.0	96.98%
4>157475	265.3	71.64%
4>157477	263.9	72.03%
4>157478	214.7	88.52%
4>157479	224.1	84.82%
4>157481	212.3	89.51%
4>157482	308.7	61.56%
4>157483	284.7	66.77%
4>157484	296.5	64.11%
4>157485	298.1	63.75%
4>157489	261.6	72.65%
4>157494	371.4	51.17%
4>157495	371.5	51.17%

Source: WSP

Hydrogen Requirements

A full-fleet FCEB conversion at Hesperia Yard would require between 1,239 kg and 1,982 kg of hydrogen per day, with each bus requiring an average of 34 kg (Figure 7-7, Table 7-13). To support this hydrogen need, bi-daily delivery would likely be necessary, unless supplemented with on-site hydrogen production. When considering only the service blocks that meet performance criteria when using current FCEB technologies, the fuel requirements were reduced dramatically, ranging between 210 kg and 686 kg of hydrogen per day. Most relevant to VVTA's planning is the third level of analysis which examined hydrogen requirements based on the planned fleet mix. Under thus assumption, the fleet will require between 1,057 kg and 1,698 kg of hydrogen (Table 7-13). If using liquid hydrogen storage, this fuel need would require delivery and refilling every two to four days (optimistic to conservative estimation). On-site production for this quantity of hydrogen would likely require at least two electrolyser or SMR systems.

Figure 7-7: Daily Hydrog en Fuel Consumption for Each Service Block Operating Out of Hesperia Yard



Source: WSP

Table 7-12: Hesperia Yard Hydrogen Consumption for Three FCEB Fleet Conversion Scenarios

Efficiency	Full Fleet Hydrogen (kg)	Qualifying Fleet Hydrogen (kg)	BEB Supplemental Fleet Hydrogen (kg)
Optimistic	1239	686	1057
Base	1541	494	1321
Conservative	1982	210	1698

Source: WSP

Table 7-13: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Hesperia Yard

Block ID	Block Distance	Vehicle Type	Representative Vehicle	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
4>157448	293.4	40'	40'	35.1	42.4	55.0
4>157449	170.0	Coach	60'	22.9	35.7	43.3
4>157450	323.5	40'	40'	38.7	46.7	60.6
4>157451	514.8	40'	40'	61.6	74.4	96.5
4>157452	215.2	40'	40'	25.8	31.1	40.3
4>157453	302.4	40'	40'	36.2	43.7	56.7
4>157455	130.5	40'	40'	15.6	18.9	24.5
4>157456	384.0	40'	40'	46.0	55.5	72.0
4>157457	134.1	40'	40'	16.1	19.4	25.1
4>157458	170.0	Coach	60'	22.9	35.7	43.3
4>157459	177.2	40'	40'	21.2	25.6	33.2
4>157461	135.6	40'	40'	16.2	19.6	25.4
4>157462	301.8	40'	40'	36.1	43.6	56.6
4>157463	253.3	40'	40'	30.3	36.6	47.5
4>157464	357.8	40'	40'	42.8	51.7	67.1
4>157465	204.7	40'	40'	24.5	29.6	38.4
4>157466	119.4	40'	40'	14.3	17.3	22.4
4>157467	284.4	Coach	60'	38.3	59.7	72.5
4>157468	218.1	40'	40'	26.1	31.5	40.9
4>157469	223.3	40'	40'	26.7	32.3	41.8
4>157470	245.6	40'	40'	29.4	35.5	46.0
4>157472	193.3	40'	40'	23.1	27.9	36.2
4>157473	193.7	40'	40'	23.2	28.0	36.3
4>157474	196.0	40'	40'	23.5	28.3	36.7
4>157475	265.3	40'	40'	31.8	38.3	49.7
4>157476	167.8	40'	40'	20.1	24.2	31.4
4>157477	263.9	40'	40'	31.6	38.1	49.5
4>157478	214.7	40'	40'	25.7	31.0	40.2
4>157479	224.1	40'	40'	26.8	32.4	42.0
4>157480	167.8	Coach	60'	22.6	35.2	42.8
4>157481	212.3	40'	40'	25.4	30.7	39.8
4>157482	308.7	40'	40'	37.0	44.6	57.9
4>157483	284.7	40'	40'	34.1	41.1	53.4
4>157484	296.5	40'	40'	35.5	42.8	55.6

Block ID	Block Distance	Vehicle Type	Representative Vehicle	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
4>157485	298.1	40'	40'	35.7	43.1	55.9
4>157486	132.7	40'	40'	15.9	19.2	24.9
4>157487	109.4	40'	40'	13.1	15.8	20.5
4>157488	167.8	Coach	60'	20.1	24.2	31.5
4>157489	261.6	40'	40'	22.6	35.2	42.8
4>157490	112.5	40'	40'	13.5	16.3	21.1
4>157491	82.8	40'	40'	9.9	12.0	15.5
4>157492	90.0	40'	40'	10.8	13.0	16.9
4>157493	31.2	40'	40'	3.7	4.5	5.8
4>157494	371.4	40'	40'	44.5	53.7	69.6
4>157495	371.5	40'	40'	44.5	53.7	69.6
4>157496	84.9	40'	40'	10.2	12.3	15.9
4>157497	60.6	40'	40'	7.3	8.8	11.4
Total				**1238.5**	**1540.5**	**1981.9**

Source: WSP

7.3.2.1.2 Site Energy Analysis

BEBs

The Hesperia facility is home to up to 56 buses, however, only 12 are planned to be BEBs. Therefore, six chargers will be needed for a 1:2 charger to bus dispenser ratio. This will require new SCE service for 900 kW, assuming that 150 kW chargers are installed.

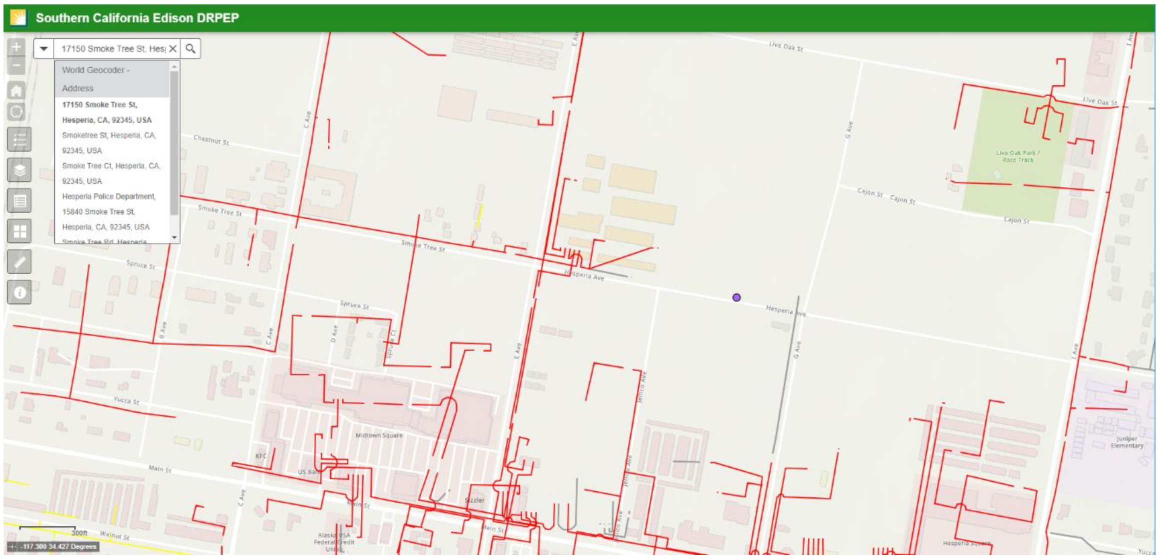
According to SCE, the existing facility is served from the “Fargo” circuit (Figure 7-8), which delivers power at 12kV. A rule of thumb is that a 12kV circuit can hold around 8.3MW of power. SCE will probably require a method of service (MOS) application and study right away. The SCE MOS studies take 18 months, before detailed design and construction can even begin.

The SCE EV-TOU rates don’t include any “demand charges”, so there is no incentive to “flatten the curve” of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9PM. Therefore, VVTA should invest in good charge management software that avoids incurring big costs from charging during peak times.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One medium voltage utility service transformer
- One switchboard

Figure 7-8: SCE Distribution Map Hesperia Yard

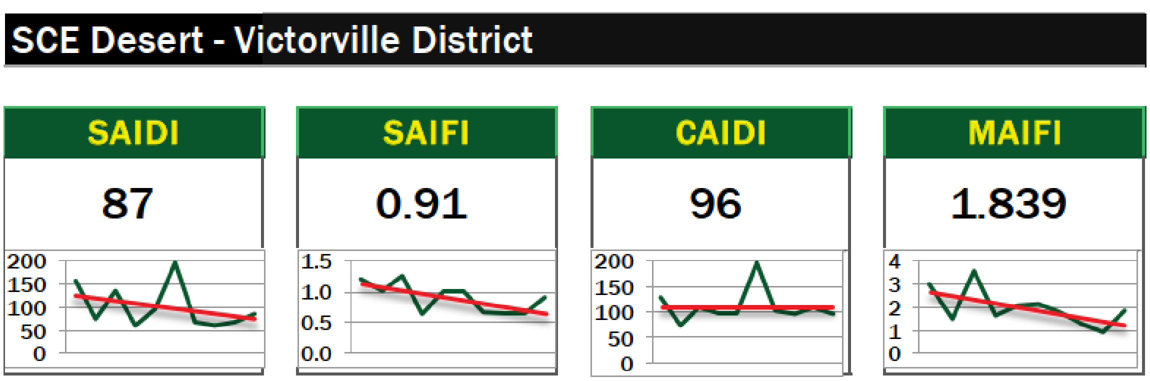


Source: SCE

From a resiliency perspective, this site is in one of the most reliable districts in SCE territory, the Victorville district. Figure 7-9 shows the reliability metrics for Hesperia Yard. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

The 2015 SAIDI score of 87 minutes indicates that each customer was without power for only an average of 87 minutes throughout the year. The SAIFI score of 0.91 indicates that most customers had less than 1 average outage per year, and the power was restored in around an hour and a half. (0.91 outages * 96 minutes per outage = 87 total outage minutes) Finally, the Hesperia site should also expect 1.8 momentary outages, which will reset all chargers.

Figure 7-9: Hesperia Yard (SCE Victorville District) Energy Reliability Figures



Source: SCE

Fuel Cell Electric Buses

Total hydrogen use per day is expected to be 1,060 -1,700 kg. This is expected to use 848 kWh - 4,250 kWh per day. The worst case new service from SCE is around 1MW for all pumps, compression, and storage of liquid hydrogen. As detailed above, SCE will require an MOS for any service request above 10 percent of the circuit, or 830kW. Depending on the exact equipment selection, it may be possible for VVTA to avoid the MOS process.

7.3.2.2 Barstow Future Yard

Based on the planned FCEB fleet at the future Barstow Yard, approximately 400 kg of hydrogen will be required to serve the site. This is a reasonable quantity for on-site production via electrolysis and steam-methane reformation, however, it is recommended that VVTA begin hydrogen phasing with liquid hydrogen delivered to the site by tank truck and stored on-site. Hydrogen fueling is recommended to be located adjacent to the existing CNG and liquefied natural gas (LNG) fueling currently present on the site. The following infrastructural upgrades are recommended at the future Barstow Yard:

- One liquid hydrogen storage tank (tank size may be negotiated with the supplier, VVTA may likely benefit from using a larger storage tank to reduce delivery costs and prevent losses during filling)
- One liquid pumping system
- One no-fog vaporization system
- Two hydrogen dispensers located on a dispenser island fueling pad
- Electric capabilities of 480 VAC, 3 phases, 60HZ, 300-350 KW
- H2 & flame detection
- Emergency shut-off buttons
- *Optional additional pump and dispenser for redundancy
- Optional fire barrier between CNG and hydrogen storage to reduce footprint

VVTA has plans on procuring an additional five BEBs. If using the recommended ground-mounted DC plug-in charging solution, the Barstow Yard will be capable of parking five buses with five plug-in charging positions in a 1:2 charger to bus dispenser ratio.

The following BEB equipment and locations are suggested:

- Three charging cabinets on the southern side of the southern grouping of bus parking spaces with five plug-in dispenser-charging positions distributed every two tracks in the parking spaces.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One medium voltage utility service transformer in a new utility yard in the open space east of the employee parking lot and west of the CNG fueling circulation area.
- One switchgear in a new utility yard in the open space east of the employee parking lot and west of the CNG fueling circulation area.

Conceptual layouts for the proposed ZEB solutions for VVTA's facilities are present in Section 7.3.5.4.

7.3.2.2.1 Modeling Results

Base-Only Charging – Barstow Future Yard

The Barstow Future Yard will operate a total of 14 vehicle blocks with 90 miles as the smallest distance and 399 as the longest. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) was used to model the 40-foot vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 660 kWh battery. Only 57 percent of 40-foot vehicle blocks could be achieved at the optimistic efficiency, 50 percent could be achieved at the base efficiency, and 21 percent could be achieved at the conservative efficiency.

For the fleet to maintain a 1:1 ratio with the transition to BEB with base-only charging, VVTA would need battery capacities that exceed 1,000 kWh for 40-foot vehicles that operate at the same efficiency as the 660 kWh vehicles (~3.4 kWh/mi.), but this technology is not currently available.

Table 7-14 provides the summary of block completion for VVTA's Barstow future facility. Table 7-15 provides a list of the current vehicle blocks that would not be able to achieve 100 percent of service with the battery capacity modeled. Table 7-15 also details the needed advertised battery capacity to achieve 100 percent of service on the vehicle block at all efficiencies.

Table 7-14: VVTA – Barstow Future Yard Base-Only Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**50% (7)**	**14% (2)**	**0% (0)**
660	**524**	**57% (8)**	**50% (7)**	**21% (3)**
700	560	71% (10)	50% (7)	43% (6)
750	600	86% (12)	50% (7)	50% (7)
800	640	86% (12)	57% (8)	50% (7)
850	680	86% (12)	57% (8)	50% (7)
900	720	86% (12)	57% (8)	50% (7)
950	760	86% (12)	57% (8)	50% (7)
1000	800	86% (12)	71% (10)	57% (8)

Source: WSP

Table 7-15: Summary of VVTA Barstow Future Yard Base-Only Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
4>157444	660	14.3	122	411	548	685
4>157447	660	3.2	130	413	551	689
4>157446	660	3.2	131	418	557	696
4>157441	660	14.4	127	426	568	710
4>157437	660	14.4	173	583	777	971
4>157440	660	14.3	213	718	958	1197
4>157438	660	14.3	215	722	963	1204
4>157454	660	15.2	399	1341	1788	2235
4>157471	660	13.4	397	1036	1479	1921
4>157442	660	15.0	321	1081	1441	1801
4>157439	660	14.9	351	1182	1576	1970

Source: WSP

Base and On-Route Charging – Barstow Future Yard

The Barstow Future Yard will operate a total of 14 vehicle blocks with 90 miles as the smallest distance and 399 as the longest distance traveled. As discussed in Section 2.1.2, a 660 kWh (524 kWh operating) battery was used to model the 40-foot vehicles.

The analysis found it would not be possible to complete all vehicle blocks with base-only charging with a 660 kWh battery. Only 64 percent of 40-foot vehicle blocks could be achieved at the optimistic efficiency, 50 percent could be achieved at the base efficiency, and 21 percent could be achieved at the conservative efficiency.

For the fleet to maintain a 1:1 ratio with the transition to BEB with base-only charging, VVTA would need battery capacities that exceed over 1,000 kWh for both 40-foot vehicles that operate at the same efficiency as the 660 kWh vehicles (~3.4 kWh/mi.), but this technology is not currently available.

Table 7-16 provides the summary of block completion for VVTA's Barstow future facility. Table 7-17 provides a list of the current vehicle blocks that would not be able to complete the service with the battery capacity modeled. Table 7-17 also details the needed advertised battery capacity to complete the existing service on the block at all efficiencies.

Table 7-16: VVTA – Barstow Future Yard Base and On-Route Charging 40-foot Vehicle Block Completion Percentage

Advertised Battery Capacity (kWh)	80% Battery Capacity Safety Level (kWh)	Optimistic Efficiency (+25%)	Base Efficiency	Conservative Efficiency (-25%)
440	**352**	**50% (7)**	**14% (2)**	**0% (0)**
660	**524**	**64% (9)**	**50% (7)**	**21% (3)**
700	560	64% (9)	50% (7)	21% (3)
750	600	64% (9)	50% (7)	21% (3)
800	640	71% (10)	50% (7)	43% (6)
850	680	86% (12)	50% (7)	50% (7)
900	720	86% (12)	57% (8)	50% (7)
950	760	86% (12)	57% (8)	50% (7)
1000	800	86% (12)	57% (8)	50% (7)

Source: WSP

Table 7-17: Summary of VVTA Barstow Future Yard Base and On-Route Charging Incomplete Blocks

Block ID	Advertised Battery Size (kWh)	Duration	Miles	Optimistic Efficiency kWh Needed	Base kWh Needed	Conservative Efficiency kWh Needed
4>157444	660	14.3	209	411	548	685
4>157447	660	3.2	186	413	551	689
4>157446	660	3.2	186	418	557	696
4>157441	660	14.4	199	426	568	710
4>157437	660	14.4	95	583	777	971
4>157440	660	14.3	226	718	958	1197
4>157438	660	14.3	219	722	963	1204
4>157454	660	15.2	144	571	1018	1465
4>157471	660	13.4	225	676	1119	1561
4>157442	660	15.0	240	1081	1441	1801
4>157439	660	14.9	110	1182	1576	1970

Source: WSP

Hydrogen Fuel Cell Electric Bus

Service Performance

Service performance at Barstow Future Yard was evaluated using three degrees of efficiency (described in the Methodology Section) to determine the percentage of each service block distance that could be complete when operating current FCEB technology. The total percentage of blocks that meet service requirements using FCEB vehicles is presented to demonstrate the viability of the technology. Using the results of this analysis, anticipated hydrogen fuel consumption was calculated for three alternative scenarios: 1) full-fleet FCEB conversion, 2) conversion of only the qualifying blocks (those that met range requirements), and 3) only the service blocks that extend beyond the 150 mile daily range.

FCEB performance at Barstow Yard fell short of meeting service requirements under all three efficiency estimations. Under optimistic and base efficiencies, 71 percent of the service blocks completed the range requirements (Table 7-18). Of the blocks that failed, the average percent of block distance complete was 82 percent at the optimistic efficiency and 68 percent at the base efficiency (Table 7-19). Under the conservative efficiency, 57 percent of the service blocks met all service requirements, with the failed blocks reaching an average of 67 percent of the total block distance (Table 7-20).

Table 7-18: Barstow Future Yard Non-Qualifying Service Blocks Under Optimistic Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157439	350.6	84.90%
4>157442	320.7	92.82%
4>157454	399.5	74.52%
4>157471	397.3	74.92%

Source: WSP

Table 7-19: Barstow Future Yard Non-Qualifying Service Blocks Under Base Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157439	350.6	70.34%
4>157442	320.7	76.90%
4>157454	399.5	61.74%
4>157471	397.3	62.07%

Source: WSP

Table 7-20: Barstow Future Yard Non-Qualifying Service Blocks Under Conservative Efficiency

Block I.D.	Daily Mileage	Percent Block Distance Complete
4>157438	214.6	88.59%
4>157439	350.6	54.21%
4>157440	213.3	89.12%
4>157442	320.7	59.27%
4>157454	399.5	47.58%
4>157471	397.3	47.84%

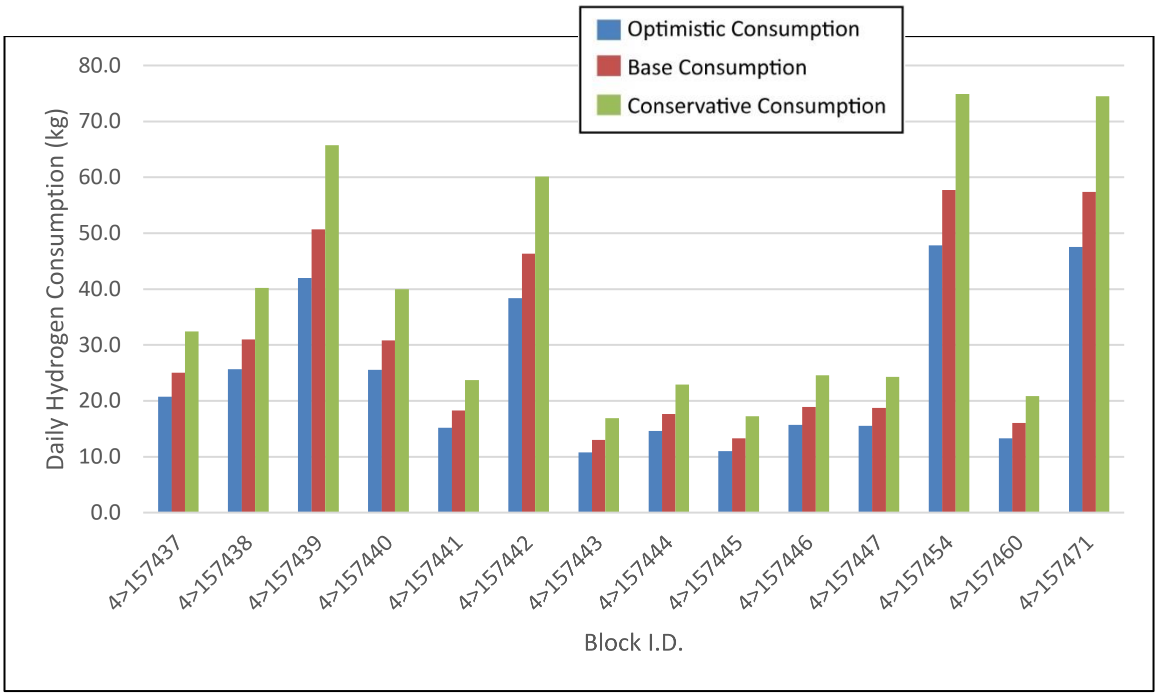
Source: WSP

Like Hesperia Yard, phasing of FCEBs should begin with the blocks the met range requirements at all levels of efficiency estimation, providing time for the technology to mature. Gaps in FCEB performance may be addressed through service changes such as mid-day refueling. Under the conservative estimations, two blocks had less than a 50 percent completion of the daily mileage, indicating that multiple mid-day refueling events may be required, alternatively the block distance may need to be adjusted to accommodate FCEB technology.

Hydrogen Requirements

A full-fleet FCEB conversion at Barstow Future Yard would require between 344 kg and 538 kg of hydrogen per day, with an average daily fuel consumption of 31 kg per service block (Figure 7-10). When considering only the service blocks that meet performance criteria when using current FCEB technologies, the fuel requirements were reduced to 168 kg, 203 kg, and 183 kg for optimistic, base, and conservative efficiencies, respectively. The daily hydrogen requirements based on the planned fleet mix can be expected to range between 248 kg and 388 kg (Table 7-21). This quantity of hydrogen could be supported through periodic deliveries, SMR, or Electrolysis.

Figure 7-10: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Barstow Future Yard



Source: WSP

Table 7-21: Daily Hydrogen Fuel Consumption for Each Service Block Operating Out of Barstow Future Yard

Block ID	Block Distance	Vehicle Type (feet)	Representative Vehicle (feet)	Optimistic Hydrogen Consumption (kg)	Base Hydrogen Consumption (kg)	Conservative Hydrogen Consumption (kg)
4>157437	173.1	40	40	20.7	25.0	32.4
4>157438	214.6	40	40	25.7	31.0	40.2
4>157439	350.6	40	40	42.0	50.7	65.7
4>157440	213.3	40	40	25.5	30.8	40.0
4>157441	126.6	40	40	15.2	18.3	23.7
4>157442	320.7	40	40	38.4	46.3	60.1
4>157443	90.2	40	40	10.8	13.0	16.9
4>157444	122.3	40	40	14.6	17.7	22.9
4>157445	92.0	40	40	11.0	13.3	17.2
4>157446	131.0	40	40	15.7	18.9	24.6
4>157447	129.6	40	40	15.5	18.7	24.3
4>157454	399.5	40	40	47.8	57.7	74.9
4>157460	111.2	40	40	13.3	16.1	20.8
4>157471	397.3	40	40	47.6	57.4	74.5
Total				**343.7**	**414.9**	**538.3**

Source: WSP

Table 7-22: Barstow Future Yard Hydrogen Consumption for Three FCEB Fleet Conversion Scenarios

Efficiency	Full Fleet Hydrogen (kg)	Qualifying Fleet Hydrogen (kg)	BEB Supplemental Fleet Hydrogen (kg)
Optimistic	344	168	248
Base	415	203	299
Conservative	538	183	388

Source: WSP

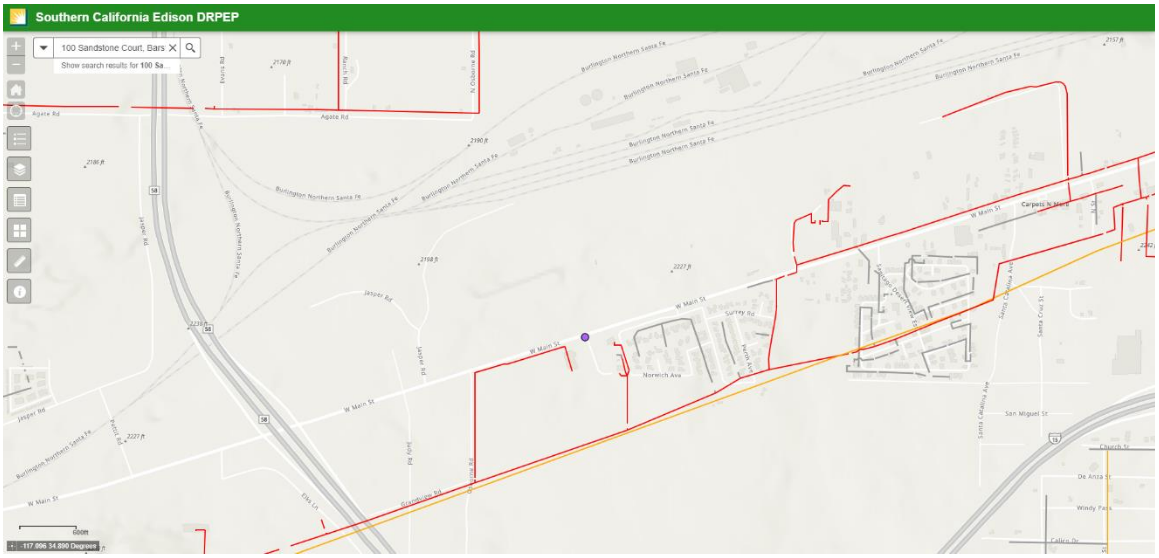
7.3.2.2.2 Site Energy Analysis

BEBs

The future Barstow facility is potentially home to up to 24 buses. If VVTA is considering BEBs, then 12 chargers will be needed for a 1:2 charger to bus dispenser ratio. This will require new SCE service for 1,800 kW, assuming that 150 kW chargers are installed.

According to SCE, the existing facility is served from the "Fargo" circuit (Figure 7-11), which delivers power at 12kV. A rule of thumb is that a 12kV circuit can hold around 8.3MW of power. SCE will probably require a method of service (MOS) application and study right away. The SCE MOS studies take 18 months, before detailed design and construction can even begin.

Figure 7-11: SCE Distribution Map Barstow Future Yard



Source: SCE

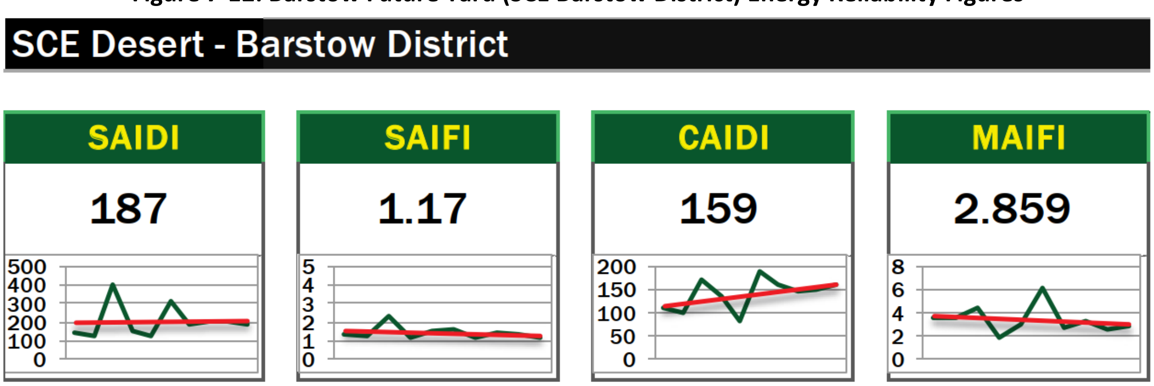
The SCE EV-TOU rates don't include any "demand charges", so there is no incentive to "flatten the curve" of the charging vehicles. However, there are big jumps in price during the peak hours of 4-9 pm. Therefore, VVTA should invest in good charge management software that avoids incurring big costs from charging during peak times.

The plug-in charging dispensers and charging cabinets will be served by the following electrical infrastructure:

- One 2,500 kVA medium voltage utility service transformer
- One switchboard

From a resiliency perspective, this site is in a below average district, the Barstow district. Depending on the level of resilience required for transit service, back up power may be procured. Figure 7-12 shows the reliability metrics for Barstow Future Yard. The left side of each chart is 2006, and the end of each chart is 2015, when this comprehensive overview was completed. Despite some blips in years, performance improved generally over time. The red line is the overall trend line. The most recent reliability data published by SCE is 2018 currently.

Figure 7-12: Barstow Future Yard (SCE Barstow District) Energy Reliability Figures



Source: SCE

The 2015 SAIDI score of 187 minutes indicates that each customer was without power for over 3 hours throughout the year. The SAIFI score of 1.17 indicates that most customers had 1 or 2 outages per year. (1.17 outages * 159 minutes per outage = 187 total outage minutes) Finally, the Hesperia site should also expect 2.8 momentary outages, which will reset all chargers.

Fuel Cell Electric Buses

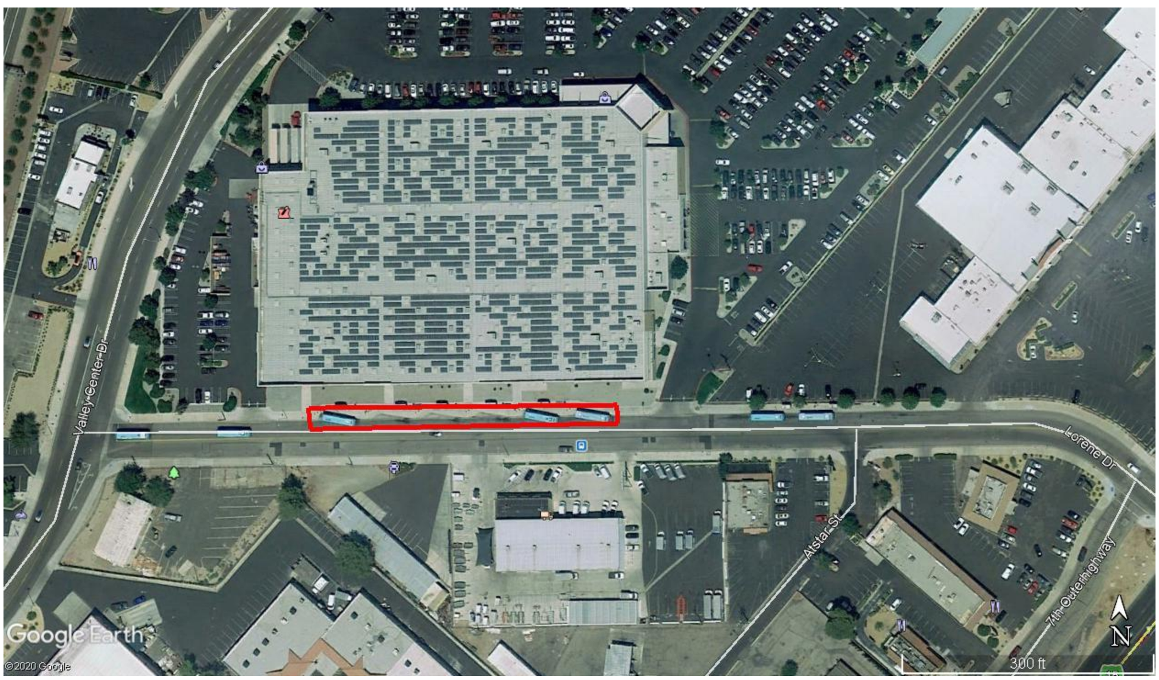
Total hydrogen use per day is expected to be 250 -400 kg. This is expected to use 200 kWh - 1,000 kWh per day. The worst case new service from SCE is around 250 kW for all pumps, compression, and storage of liquid hydrogen. As detailed above, VVTA should be able to get new service without going through the MOS process.

7.3.2.3 On Route Charging Site Energy Analysis

7.3.2.3.1 Lorene Drive & 7th Street Station

At Lorene Drive & 7th Street Station (Figure 7-13), WSP recommends one 450 kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450 kW.

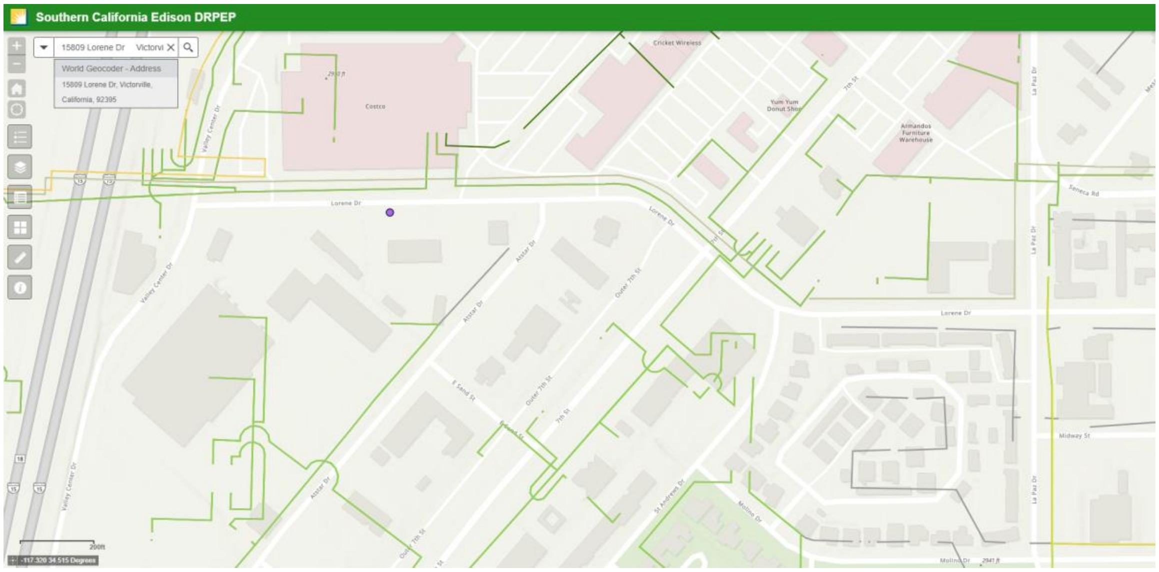
Figure 7-13: Lorene Drive & 7th St Station - Existing Conditions



Source: Google Earth, March 2020

According to SCE, the existing facility is served from the "Talpa" circuit (Figure 7-14), which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. It should be feasible to get this level of power service from SCE, even without an MOS, SCE already indicated that a switch is available to provide this service in the nearby vicinity.

Figure 7-14: SCE Distribution Map Lorene & 7th Street Station



Source: SCE

The plug-in charging dispensers and charging cabinet will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformer.
- One 480V switchboard in the new utility yard.
- Underground conduits to pantograph charger.

7.3.2.3.2 G Street at Broadway

At G Street at Broadway (Figure 7-15), WSP recommends one 450 kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450 kW.

At G Street at Broadway, WSP recommends one 450 kW ground-mounted DC overhead pantograph charging solution. This will require new SCE service for 450 kW.

According to SCE, the existing facility is served from the “Riley” circuit, which delivers power rated at 12 kV. A rule of thumb is that a 12 kV circuit can hold around 8.3 MW of power. It should be feasible to get this level of power service from SCE, even without an MOS. SCE already indicated that a switch is available to provide this service in the nearby vicinity.

The plug-in charging dispensers and charging cabinet will be served by the following electrical infrastructure:

- One 500 kVA medium voltage utility service transformer.
- One 480V switchboard in the new utility yard.
- Underground conduits to pantograph charger

Figure 7-15: G Street at Broadway - Existing Conditions

Source: Google Earth, March 2020

7.3.3 Procurement Schedule

In accordance with the ICT regulation, VVTA will prioritize ZEB purchases and progressively increase the percentage of ZEB purchases over time. Based on initial analysis, the last conventional bus is expected to be purchased in 2028. All new buses purchases are anticipated to be ZEB starting in 2029.

Early retirement should not be an issue pursuant to the ICT regulation based on VVTA's assumed procurement schedule. However, if it becomes one, VVTA will deploy several strategies to ensure that buses fulfill their "useful life". One potential strategy is to place newly acquired ZEBs on shorter (achievable) blocks and gradually move them to longer routes as technology advances and capabilities/limits are determined.

VVTA's existing fleet consists of 71 buses. Assuming a 1:1 replacement ratio, each existing bus will eventually be replaced with an equivalent length FCEB bus. VVTA owns and operates seven BEBs at the Hesperia Yard with plans to acquire an additional five BEBs for the Barstow Yard. The current strategy is to use BEBs to serve blocks with less than 150 miles and utilize FCEBs for longer distance blocks. The number of ZEBs required may increase with time based on service requirements.

Table 7-23 presents a summary of VVTA's anticipated bus procurements through 2040. Years 2026 and 2029 are highlighted because these indicate when VVTA's new purchases should be 25 percent and 100 percent ZEBs, respectively.

Table 7-23: Summary of VVTA's Future Bus Purchases (through 2040)

Year	Total Buses	Zero-Emission Buses				Conventional (CNG) Buses			
		Number	Pct.	Bus Type	Fuel Type	Number	Pct.	Bus Type	Fuel Type
2020	**0**	0	0%	-	-	0	0%	-	-
2021	**5**	5	100%	Standard	BEB	0	0%	-	-
2022	**7**	0	0%	-	-	7	100%	Standard	CNG
2023	**0**	0	0%	-	-	0	0%	-	-
2024	**0**	0	0%	-	-	0	0%	-	-
2025	**5**	0	0%	-	-	5	100%	Standard	CNG
2026	**0**	0	0%	-	-	0	0%	-	-
2027	**0**	0	0%	-	-	0	0%	-	-
2028	**10**	3	30%	Standard	FCEB	7	70%	Standard	CNG
2029	**1**	1	100%	Standard	FCEB	0	0%	-	-
2030	**10**	10	100%	Standard/ Coach	FCEB	0	0%	-	-
2031	**7**	7	100%	Standard	FCEB	0	0%	-	-
2032	**16**	16	100%	Standard	FCEB	0	0%	-	-
2033	**0**	0	0%	-	-	0	0%	-	-
2034	**7**	7	100%	Standard	FCEB	0	0%	-	-
2035	**0**	0	0%	-	-	0	0%	-	-
2036	**0**	0	0%	-	-	0	0%	-	-
2037	**5**	5	100%	Standard	BEB/FCEB	0	0%	-	-
2038	**0**	0	0%	-	-	0	0%	-	-
2039	**0**	0	0%	-	-	0	0%	-	-
2040	**10**	10	100%	Standard	FCEB	0	0%	-	-

Note: All new purchases were assumed to have a useful life based on VVTA's existing procurement cycle, however, this may vary and be adjusted based on warranties and changes in technology.
-In 2037, VVTA will need to replace their BEBs that were purchased in 2021, based on VVTA's needs, these will be replaced with BEBs or FCEBs
-VVTA's existing fixed-route cutaway fleet is excluded from their planned procurement schedule (pursuant to the ICT regulation) because these vehicles are expected to be replaced with vehicles that have less than a 14,000 GVWR.

Source: WSP

7.3.4 Victor Valley Transit Authority Cost Analysis

This analysis should be considered a conservative assessment of battery and fuel cell electric bus costs, as the industry in North America is in the preliminary stages of product development. Production costs are anticipated to decrease as production increases to meet future demand.

7.3.4.1 Battery Electric Buses – General Assumptions

The WSP team is actively engaged with Electric vehicle manufacturers to understand trends in the industry and VVTA, the only SBCTA agency currently operating BEBs, to inform assumptions vehicle operations. The values presented throughout this document are subject to change and based on the best available information at the time of this analysis.

Compared to conventional natural gas vehicles, electric vehicles incur different capital and operating costs that vary both on the type of vehicles operated and operating environments. For example, the cost of installation and maintenance of charging infrastructure will differ in both magnitude and the types of resources required in comparison to the replacement and maintenance of a natural gas fueling facility or sourcing natural gas externally. Other examples include battery replacement schedules, mid-life overhaul, and disposal value.

Electric buses and garages may also have lower operations and maintenance costs. Additionally, an electrification strategy would entail replacing natural gas with electric power, which would incur very different energy pricing structures and exposure to energy price volatility. Table 7-24 outlines the major cost categories associated with bus electrification. Estimated costs in each of these categories were developed for electrification scenarios, as well as a "business as usual" baseline which assumes no change in the current types of vehicles in the fleet.

The total cost of each operator's transition will be contingent upon their specific fleet size, bus acquisition plan, facility sizes, charging strategy, construction schedule, among other details.

Table 7-24: Cost Components Attributed to Electric Bus Operations

Capital	Vehicle and Equipment Purchase
	Training, Capital Spares & Contingency
	Charging Infrastructure
	Mid-Life Fleet Overhaul
	Battery Replacement and degradation reducing range
Operating	Vehicle Maintenance and software subscription and support costs
	Vehicle Tools, Training and Equipment
	Vehicle Energy Costs
	Charger Maintenance and software subscription and support charges
	Fueling/Charging Labor
Disposal	Battery Disposal/Salvage
	Bus Salvage

Source: WSP

7.3.4.1.1 Battery Electric Bus Vehicle Costs

Battery electric vehicle procurement costs continue to evolve as new vehicle models are developed and production increased to meet demand. Anticipated cost reductions through economies of scale may be somewhat offset by discounted prices that may be offered by some manufacturers to establish market share, specifically new entrants to the market. Furthermore, battery technology and production continue to evolve offering further potential reductions to production costs but also potential exposure to volatility in the pricing structures for critical battery production inputs. Additional considerations also need to be considered for specific agency requirements and features, delivery schedule requirements, and battery size requirements to meet operating conditions. Assumptions regarding cost per battery electric buses as compared to VVTA's CNG buses are outlined in the table below. CNG prices are used to estimate costs in in the "business as usual" scenario.

Table 7-25: Vehicle Cost Assumptions

Bus Type	Bus Cost Estimates
BEB 40 ft	$903,680[67]
BEB 32 ft	$246,246
BEB 24 ft	$191,811
CNG 45 ft	$775,000
CNG 40 ft	$500,000
CNG 35 ft	$490,000
CNG 33 ft	$400,000

Source: WSP

An estimated standard cost per bus (with options totaling about $3,100) of $903,680 for VVTA was assumed for a 40-foot battery electric bus based on recent purchasing contracts, VVTA's New Flyer Purchase of 40-foot battery electric buses, under Purchase Order 1197, dated November 6, 2018. Additionally, $246,246 for 32-foot battery electric buses, and $191,800 for 24-foot battery electric buses were based on information provided by manufacturers of smaller vehicle types.

7.3.4.1.2 Charging Infrastructure Costs

Charging infrastructure cost estimates include equipment, design and installation costs which primarily consist of materials and labor. The cost estimates also include general contractors and subcontractor's markups which are comprised of field overhead, home office overhead, and subcontractor earnings. The estimates also include a pricing contingency markup, to allow for unexpected design and installation Issues.

Plug-in chargers are assumed to cost $70,701, based on a recent VVTA contract.[68] Additionally, the costs to install chargers and account for labor and permits is assumed to cost $8,500 per charger installation. On route opportunity chargers are assumed to cost $330,000 for both the charger and installation, based on the experience of Foothill Transit. With the recommended ground-mounted plug-in charging strategy, the Barstow Yard would be capable of parking 15 buses with 15 plug-in charging positions (8 chargers). As a charging strategy has not been recommended by WSP at Hesperia Yard, the model assumed tha the existing capacity of 63 would apply, (32 chargers), in a 1:2 charger to bus dispenser ratio. The financial analysis assumes that plug-in chargers would be purchased in the year that buses are ordered, when the cost of purchasing the charger would be incurred, and the cost of installing the plug-in charger would be incurred in the year of vehicle delivery, which is assumed to be one year after the bus order. As such, the exact year and number of plug-in chargers purchased correleates with the fleet

[67] Victor Valley New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6 2018.

[68] Victor Valley New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6 2018.

procurement plan. En-route chargers include one at G Street and Broadway, and one at Lorene Drive at 7th street station.

The analysis did not include on-site stationary battery energy storage for resiliency. If Victor Valley Transit Authority elects to include a generator for resiliency of their battery electric buses, a generator at Hesperia Yard is estimated to cost $1,300,000 based on a full load of 900 kW. Barstow and other transit centers owned by VVTA could use a single mobile generator that is sized for approximately 450kW and estimated to cost $650,000

7.3.4.1.3 Mid-life Overhaul and Battery Replacement

At the year seven mid-point of each vehicle's operational life, a full vehicle overhaul, is assumed on all buses except for the 24 foot cutaway buses[69].

The analysis assumes that VVTA's battery electric buses will include battery warranties, and as such, battery replacement costs are not assumed to be incurred by VVTA[70]. Given that VVTA does incur the costs of replacing batteries on their existing fleet, the baseline scenario analysis includes an assumption that they would continue to do so.

7.3.4.1.4 Operations and Maintenance Costs

Components of O&M costs include vehicle maintenance, vehicle tools, training and PPEs, vehicle fuel costs, and the costs to maintain and operate charging and fueling infrastructure. Annual O&M cost assumptions for BEB's are outlined in Table 7-26, represented in a cost per mile.

The analysis applies unit O&M cost per mile by bus type with total costs based on assumed average annual bus mileage. The model accounts for changes to service levels based on range restrictions for BEB's to estimate O&M costs, by applying unit costs to total mileage as driven by number of buses and mileage per bus.

Table 7-26: BEB and CNG Maintenance Costs by Bus Age (2019 Dollars per mile)

Bus Age	BEB 40 ft	CNG 40 ft
Year 1	0.34	0.78
Year 2	0.30	0.85
Year 3	0.30	0.92
Year 4	0.35	0.99
Year 5	0.42	1.07
Year 6	0.46	1.10
Year 7	0.52	1.14
Year 8	0.59	1.17
Year 9	0.68	1.20

[69] During an interview with VVTA staff and WSP staff on March 4 2020, VVTA staff indicated that they do perform overhaul activities on their buses, but did not have a record of costs. As such, WSP's assumptions regarding overhaul frequency and costs are based on peer agencies and industry data.

[70] If the bus purchases or leases will not include a warranty, a battery replacement cost may be estimated at approximately, $7 per pound, and assumed to weigh approximately 500 pounds, based on similar transit agencies. The model can be easily updated to assume this.

Bus Age	BEB 40 ft	CNG 40 ft
Year 10	0.79	1.24
Year 11	0.93	1.38
Year 12	1.10	1.52
Year 13	0.51	1.67
Year 14	0.56	1.83

Source: WSP

7.3.4.1.5 Energy Costs

Electricity prices for battery electric vehicles are based on current rates with Southern California Edison (SCE) and reflect charge rates and demand for energy consumption that vary by hour and month.

Total annual energy costs are estimated for each operator and facility and are highly driven by charging strategy with respect to location of en-route chargers if any, facilities, vehicle routes, and fleet size purchase. These charging strategies are subject to change as the team works to refine each agency's optimal charging strategy, and as charging rates change. This analysis does not assume any major behavioral changes based on coach operators.

Table 7-27 presents Southern California Edison Rates and Table 7-28 presents the hours during which each rate would be applicable.

Table 7-27: Rates per kWh

Rates (per kWh)		
Time of Use Period	Summer (June-September)	Winter (October-May)
On-Peak	$0.41	
Mid-Peak	$0.20	$0.24
Off-Peak	$0.10	$0.10
Super Off-Peak		$0.06

Source: Southern California Edison

Table 7-28: Time Periods

Time Periods (weekdays excluding holidays)				
	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	16:00-21:00	N/A	N/A	N/A
Mid-Peak	N/A	16:00-21:00	16:00-21:00	16:00-21:00
Off-Peak	All other hours	21:00-08:00	All other hours	21:00-08:00
Super Off-Peak	N/A	08:00-16:00	N/A	08:00-16:00

Source: Southern California Edison

The rates in Table 7-27 and Table 7-28 above were applied to the hourly times during which the operators are expected to be charging. The energy use assumed for each operator, in a moderate charging scenario, is presented in Table 7-29. The model is capable of running additional scenarios to cost the low charging and high charging scenario as well. Table 7-30 and Table 7-31 outline the two Victor Valley facililities' resulting costs, based on the hourly SCE rates and the hourly charging strategy, as well as the total resulting annual cost per bus.

Table 7-29: Hourly Energy use (kWh) – Moderate Scenario

Facility ID	Facility	Operator	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
1000001	Joshua Tree Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	-
1000002	29 Palms Yard	MBTA	-	-	-	-	-	-	-	-	-	-	-	50
1000003	Crestline	MT	-	-	-	-	-	-	-	-	-	-	-	78
1000009	Big Bear Lake	MT	-	-	-	-	-	-	-	-	-	15	50	-
1000004	West Valley	Omnitrans	5,300	4,788	3,633	2,415	1,203	350	80	-	128	80	-	-
1000005	East Valley	Omnitrans	11,488	9,843	7,523	4,808	2,040	688	373	168	130	433	735	553
1000006	VVTA HQ - Hesperia Yard	VVTA	3,988	3,810	2,668	1,845	1,335	688	480	155	305	405	308	423
1000007	Barstow Future Yard	VVTA	945	660	600	600	525	173	110	220	295	300	215	-
1000008	Needles Garage	Needles	-	-	-	-	-	-	-	-	-	-	-	-

Source: WSP

Table 7-29: Hourly Energy use (kWh) – Moderate Scenario (continued)

Facility ID	Facility	Operator	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1000001	Joshua Tree Yard	MBTA	88	-	133	-	-	-	320	58	-	-	13	140
1000002	29 Palms Yard	MBTA	-	10	208	-	-	5	130	-	10	43	80	65
1000003	Crestline	MT	15	-	-	-	-	75	15	143	180	28	83	3
1000009	Big Bear Lake	MT	-	-	65	-	-	78	-	95	150	3	-	-
1000004	West Valley	Omnitrans	-	-	-	20	75	-	148	808	1,950	3,615	5,313	5,918
1000005	East Valley	Omnitrans	258	308	533	508	273	48	195	2,493	5,723	8,355	11,143	12,978
1000006	VVTA HQ - Hesperia Yard	VVTA	183	55	-	-	265	815	1,475	1,800	1,630	3,563	4,720	4,075
1000007	Barstow Future Yard	VVTA	-	-	-	-	-	23	150	265	958	1,470	1,370	1,080
1000008	Needles Garage	Needles	-	-	-	-	-	-	8	103	-	-	-	-

Source: WSP

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Table 7-30: Total Annual Cost Per Bus - Victor Valley, Hesperia Yard

Months	Days per month	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
January	31.00	12,761	12,192	8,536	5,904	4,272	2,200	1,536	496	976	815	619	850	369	111	-	-	1,939	5,963	10,792	13,170	11,927	26,067	15,105	13,041
February	28.00	11,526	11,013	7,710	5,333	3,859	1,987	1,387	448	882	736	559	768	333	101	-	-	1,751	5,386	9,748	11,896	10,772	23,544	13,643	11,779
March	31.00	12,761	12,192	8,536	5,904	4,272	2,200	1,536	496	976	815	619	850	369	111	-	-	1,939	5,963	10,792	13,170	11,927	26,067	15,105	13,041
April	30.00	12,349	11,799	8,261	5,714	4,134	2,129	1,487	480	945	789	599	823	357	108	-	-	1,876	5,771	10,444	12,746	11,542	25,226	14,617	12,620
May	31.00	12,761	12,192	8,536	5,904	4,272	2,200	1,536	496	976	815	619	850	369	111	-	-	1,939	5,963	10,792	13,170	11,927	26,067	15,105	13,041
June	30.00	11,788	11,263	7,886	5,454	3,947	2,032	1,419	458	902	1,197	909	1,249	541	164	-	-	3,251	9,998	18,094	22,081	19,996	43,702	13,953	12,047
July	31.00	12,181	11,639	8,149	5,636	4,078	2,100	1,466	473	932	1,237	939	1,291	559	169	-	-	3,359	10,331	18,697	22,817	20,662	45,159	14,418	12,448
August	31.00	12,181	11,639	8,149	5,636	4,078	2,100	1,466	473	932	1,237	939	1,291	559	169	-	-	3,359	10,331	18,697	22,817	20,662	45,159	14,418	12,448
September	30.00	11,788	11,263	7,886	5,454	3,947	2,032	1,419	458	902	1,197	909	1,249	541	164	-	-	3,251	9,998	18,094	22,081	19,996	43,702	13,953	12,047
October	31.00	12,761	12,192	8,536	5,904	4,272	2,200	1,536	496	976	815	619	850	369	111	-	-	1,939	5,963	10,792	13,170	11,927	26,067	15,105	13,041
November	30.00	12,349	11,799	8,261	5,714	4,134	2,129	1,487	480	945	789	599	823	357	108	-	-	1,876	5,771	10,444	12,746	11,542	25,226	14,617	12,620
December	31.00	12,761	12,192	8,536	5,904	4,272	2,200	1,536	496	976	815	619	850	369	111	-	-	1,939	5,963	10,792	13,170	11,927	26,067	15,105	13,041
Total	365	147,963	141,377	98,982	68,462	49,538	25,511	17,811	5,752	11,318	11,259	8,548	11,745	5,091	1,539	-	-	28,419	87,402	158,182	193,036	174,805	382,051	175,144	151,210
																								Total Annual Cost	1,955,146
																								Buses at Garage	56
																								Total Annual Cost Per Bus	34,913

Source: WSP

Table 7-31: Total Annual Cost Per Bus - Victor Valley, Barstow Yard

Months	Days per month	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
January	31.00	3,024	2,112	1,920	1,920	1,680	552	352	704	944	604	433	-	-	-	-	-	-	165	1,098	1,939	7,006	10,756	4,384	3,456
February	28.00	2,731	1,908	1,734	1,734	1,517	499	318	636	853	545	391	-	-	-	-	-	-	149	991	1,751	6,328	9,715	3,960	3,122
March	31.00	3,024	2,112	1,920	1,920	1,680	552	352	704	944	604	433	-	-	-	-	-	-	165	1,098	1,939	7,006	10,756	4,384	3,456
April	30.00	2,927	2,044	1,858	1,858	1,626	534	341	681	914	584	419	-	-	-	-	-	-	159	1,062	1,876	6,780	10,409	4,243	3,345
May	31.00	3,024	2,112	1,920	1,920	1,680	552	352	704	944	604	433	-	-	-	-	-	-	165	1,098	1,939	7,006	10,756	4,384	3,456
June	30.00	2,794	1,951	1,774	1,774	1,552	510	325	650	872	887	636	-	-	-	-	-	-	276	1,840	3,251	11,746	18,033	4,050	3,193
July	31.00	2,887	2,016	1,833	1,833	1,604	527	336	672	901	916	657	-	-	-	-	-	-	285	1,901	3,359	12,137	18,634	4,185	3,299
August	31.00	2,887	2,016	1,833	1,833	1,604	527	336	672	901	916	657	-	-	-	-	-	-	285	1,901	3,359	12,137	18,634	4,185	3,299
September	30.00	2,794	1,951	1,774	1,774	1,552	510	325	650	872	887	636	-	-	-	-	-	-	276	1,840	3,251	11,746	18,033	4,050	3,193
October	31.00	3,024	2,112	1,920	1,920	1,680	552	352	704	944	604	433	-	-	-	-	-	-	165	1,098	1,939	7,006	10,756	4,384	3,456
November	30.00	2,927	2,044	1,858	1,858	1,626	534	341	681	914	584	419	-	-	-	-	-	-	159	1,062	1,876	6,780	10,409	4,243	3,345
December	31.00	3,024	2,112	1,920	1,920	1,680	552	352	704	944	604	433	-	-	-	-	-	-	165	1,098	1,939	7,006	10,756	4,384	3,456
Total	365	35,066	24,490	22,264	22,264	19,481	6,401	4,082	8,163	10,946	8,340	5,977	-	-	-	-	-	-	2,413	16,086	28,419	102,685	157,646	50,836	40,075
																								Total Annual Cost	565,636
																								Buses at Garage	15
																								Total Annual Cost Per Bus	37,709

Source: WSP

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7.3.4.1.6 Environmental Costs

Environmental costs are considered non-cash expenses and include monetized values for tailpipe emissions and upstream emissions of CO2, criteria pollutants, and noise. The analysis does not assume tailpipe emissions for BEB's and includes estimates of tailpipe emissions for compressed natural gas buses, for comparative purposes. Tailpipe emissions include estimates of CO_2, NO_X, CO, PM_{10}, $PM_{2.5}$. Emissions data was taken from the Department of Energy's Greet Fleet Calculator.

Upstream emissions consist of emissions resulting from the extraction, processing and production of CNG, and production of electricity for battery electric buses based on the mix of utility power sources.

7.3.4.1.7 General - Inflation

The financial model accounts for inflation using the Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U). Table 5 presents the CPI-U values from 2019 – 2023 provided by California Department of Finance[71]

Table 7-32: Riverside - San Bernardino-Ontario Metropolitan Area Historical Consumer Price Index for all Urban Consumers (CPI-U)

CPI-U	2019	2020	2021	2022	2023
Riverside & San Bernardino	2.87%	3.24%	2.96%	3.10%	3.03%

Source: WSP

7.3.4.2 Fuel Cell Electric Bus – General Assumptions

The WSP team is in continued conversation with local hydrogen suppliers to ensure the most up-to-date cost estimates. The values presented throughout this document are preliminary and subject to change with any further revisions in pricing.

The cost of implementing FCEB consists of the initial cost of buses procurement; one-time charges for capital investment and construction; annual fees for leases, operation and maintenance; and the cost of procuring the hydrogen fuel. The cost for bus procurement is based on the current fleet inventory of each agency. Capital annual costs depend on whether the transit agencies decide to produce their hydrogen on-site or deliver the hydrogen from contracted services. The fuel consumption rate at each facility and the associated costs of delivery and on-site production can serve as a metric for determining which hydrogen source best meets SBCTA's needs.

7.3.4.2.1 Fuel Cell Vehicle Costs

Similar to battery electric buses, procurement costs are constantly changing with technological developments. Assumptions for this specific analysis regarding cost per fuel cell buses are outlined in Table 7-33.

[71] http://www.dof.ca.gov/Forecasting/Economics/Eco_Forecasts_Us_Ca/index.html

Table 7-33: FCEB Bus Costs

Bus Length	Bus Cost
40 ft	$1,014,978[72]
60 ft	$1,463,934[73]
Cutaways	$200,000

Source: WSP

7.3.4.2.2 Mid-life Overhaul and Fuel Cell Replacement

At the year six mid-point of each vehicle's operational life, a full vehicle overhaul of $200,000 would be needed, in addition to a fuel cell overhaul cost of $22,500.

7.3.4.2.3 Operations and Maintenance Costs

FCEB operations and maintenance costs were assumed to be approximately 15 percent higher than CNG annual operations and maintenance costs, per CARB guidance.

Table 7-34: FCEB and CNG Maintenance Costs by Bus Age (2019 Dollars per mile)

Bus Age	FCEB 40 ft	CNG 40 ft
Year 1	0.90	0.78
Year 2	0.97	0.85
Year 3	1.06	0.92
Year 4	1.14	0.99
Year 5	1.23	1.07
Year 6	1.27	1.10
Year 7	1.31	1.14
Year 8	1.34	1.17
Year 9	1.38	1.20
Year 10	1.43	1.24
Year 11	1.58	1.38
Year 12	1.75	1.52
Year 13	1.92	1.67
Year 14	2.11	1.83

Source: WSP

[72] California Department of General Services has contracts that can be used by transit agencies to procure a 40' New Flyer fuel cell buses at $1,014,978

[73] California Department of General Services has contracts that can be used by transit agencies to procure a 60' New Flyer fuel cell buses at $1,463,934

7.3.4.2.4 Capital Investment and Construction

Depending on how the transit agencies source their hydrogen, the upfront capital required for hydrogen is quite intensive with on-site hydrogen production capital being higher than external delivery.

VVTA is considering external sourcing and liquid delivery rather than on-site production, which will be reflected in the cost assumptions. Associated costs are outlined in the below table.

The price for gas and liquid hydrogen delivery of $9.50 was based on data from Ballard and 2017 Clean Energy proposal for OCTA hydrogen delivery system, adjusted to 2019 dollars. The equipment costs do not include the costs for permit application, civil work contract and site preparation, warranty, sales tax, freight, and contingency.

Table 7-35: Hesperia Yard – Infrastructure Liquid Delivery (2019 $s)

VVTA Recommendations		
Phase 1 (25 bus system)	1 dispenser, 1 pump, vaporization	$3,000,000
	Construction	$1,500,000
	9,000 gallon tank purchase price	$500,000
	9,000 gallon tank rental	$5,000/month
Phase 2 (add 25 bus capacity)	1 dispenser, 1 pump, vaporization	$800,000
	Additional dispenser	$200,000
	Construction	$300,000
	15,000 gallon tank purchase price	$700,000
	15,000 gallon tank rental	$8,000/month

Source: WSP

Table 7-36: Barstow – Infrastructure Liquid Delivery

Barstow Infrastructure Liquid Delivery (15 bus system)	
1 dispenser, 1 pump, vaporization	$1,700,000
Construction	$1,200,000
9,000 gallon tank purchase price	$500,000
9,000 gallon tank rental	$5,000/month

Source: WSP

7.3.4.2.5 Hydrogen Fuel Energy Cost and Annual Delivery Fees

As VVTA plans to source liquid hydrogen externally and have it delivered, their fuel cost per kg is expected to be $9.50, based on data from Ballard and 2017 Clean Energy proposal for OCTA hydrogen delivery system, adjusted to 2019 dollars.

Table 7-37: Fuel Charge (2019 $s)

Hesperia Fuel Costs Liquid Delivery	
Liquid Delivery Costs (per kg)	$9.50
Hydrogen Requirement (kg per day)	1,698
Total Cost Per Day	$16,131

Source: WSP

Over time, externally sourced hydrogen fuel delivery will increase in cost primarily due to the annual fees that transit agencies pay for contracted services to provide the hydrogen. Annual fees include tube trailer or liquid tank lease, vaporizer lease, and other handling costs. The underlying cost of hydrogen fuel assumed in this analysis is based on current conditions of demand and supply. Future market conditions may result in downward pricing pressures on both hydrogen fuel costs and delivery costs, specifically if there were to be a significant increase in demand and resulting production, potentially providing some economies of scale. Alternatively, an increase in demand may not necessarily result in an increase in supply, resulting in price increases. Calculating the range of risks and uncertainties would require additional sensitivity tests, including the corresponding underlying pricing assumptions for other fuels to align with general energy market prices.

7.3.4.3 Scenario Analysis

7.3.4.3.1 Cost Overview

Background

An analysis was conducted to compare two potential electrification scenarios for VVTA (battery electric bus and fuel cell electric bus) with a "business as usual" scenario which assumes that all future procurements maintain the current VVTA practice of procuring CNG buses (referred to as Scenario 1 Baseline CNG). Please note the baseline scenario also includes VVTA's current fleet of 7 battery electric buses. Given CARB's mandate of conversion by 2040, this is a theoretical scenario for comparative benefit-cost assessment purposes.

Table 7-38 delineates the overall results of the VVTA financial analysis, assessing the full BEB conversion, the FCEB conversion, and the baseline CNG scenario. Again, the values presented throughout this document are preliminary and subject to change.

The financial analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs, plus a non-cash cost of environmental benefits and costs, which WSP staff monetizes to account for a holistic comparative cost and benefit.

Table 7-38: VVTA – Overall Cost Summary

2020-2050 Fleet Replacement Cost Comparison (2020 $ million)		SCENARIO 1: Baseline CNG	SCENARIO 2: Build – BEB	SCENARIO 3: Build - FCEB
Capital	Vehicle Purchase Price	43.88	69.85	74.86
	Modifications & Contingency	8.67	10.62	10.26
	Charging/Fueling Infrastructure	0.62	3.53	6.05
	Total Capital Costs	*53.17*	*84.00*	*91.17*
Operating	Vehicle Maintenance	63.40	43.83	68.64
	Overhaul	23.16	20.21	29.35
	Tire Replacement Cost	0.31	0.31	0.31
	Vehicle Tools Training and PPEs	-	-	-
	Other and Miscellaneous Costs	-	-	-
	Vehicle Fuel Costs	23.47	5.46	12.30
	Electric Vehicle Utility Costs	-	30.06	0.35
	Charging/Fueling Infrastructure	0.01	0.35	4.57
	Battery/Fuel Cell Replacement	0.01	0.00	0.02
	Total Operating Costs	*110.36*	*100.22*	*115.54*
Disposal	Battery Disposal	-	-	-
	Bus Disposal	(0.28)	(0.54)	(0.28)
	Total Disposal Costs	*(0.28)*	*(0.54)*	*(0.28)*
Total Cash Costs		**163.25**	**183.68**	**206.43**
Total Cash Cost per Mile		**3.14**	**3.53**	**3.97**
Environmental	Emissions - Tailpipe	1.52	0.37	0.44
	Emissions - Refining/Utility	49.64	12.37	12.08
	Noise	2.62	2.13	2.13
	Total Environmental Costs	*53.78*	*14.87*	*14.65*
Total Cash and Non-Cash Costs		**217.03**	**198.55**	**221.08**
Total Cash and Non-Cash Costs per Mile		**4.17**	**3.82**	**4.25**
Total Mileage (million miles)		***52***	***52***	***52***

Source: WSP

7.3.4.3.2 Cost Conclusions

Overall, the lifecycle cost analysis shows that despite higher initial costs, the full lifecycle *cash cost* of a transition to battery electric vehicles will be slightly higher in comparison to continued reliance on CNG vehicles, while a conversion to a fuel cell electric bus may be a more costly option. While operating costs savings are anticipated for a BEB conversion, the high capital costs of BEB's, batteries and their charging infrastructure may offset the savings. As operating costs benefits are highly dependent on factors that are not well-established, as further discussed in Section 7.3.4.4 Uncertainties. This is particularly the case for annual vehicle maintenance costs, while the existing capital cost premiums are based on current actual experience.

Discussion of General Inputs

Inputs to the lifecycle model include:

- Fleet modernization schedules – buses acquired each year by fuel type.
- Vehicle costs including initial purchase, maintenance, mid-life overhaul and disposal
- Battery purchase, replacement and disposal or salvage
- Battery charging infrastructure purchase, installation and maintenance
- Energy costs, gas, liquid hydrogen, and electricity
- Environmental costs for vehicle tailpipe emissions of CO_2 and criteria pollutants
- Environmental costs for vehicle noise

The model examines one complete replacement of the fleet, beginning in the year 2020 and ending with final vehicle acquisition in 2033. The model tracks the total cost of ownership (initial capital cost, annual operating cost and final disposal cost) of each new vehicle for its full asset life.

The values provided are not a comparison between an all CNG fleet and a BEB fleet, but rather a comparison between continuing current practices and gradually phasing in battery electric bus procurement versus fuel cell electric bus procurement.

In addition to vehicle costs, the model also includes the costs of purchasing, installing and maintaining charging infrastructure for battery electric buses and hydrogen fueling systems.

All model inputs are provided in current year (2019/2020) dollars. The model applies inflation factors to escalate costs to year of expenditure dollars. The Riverside-San Bernardino-Ontario metropolitan area historical Consumer Price Index for all Urban Consumers (CPI-U), presented in Table 7-39 was used for most costs, except the following cases where a different specific index was used:

- CNG gas prices were escalated at a rate of 3 percent.
- Electricity costs were escalated using EIA transportation electricity annual forecasted price growth rate forecasts by year

Table 7-39: Annual Energy Outlook – US Energy Information Administration[74]

	2019	2020	2021	2022	2023
CPI-U: Riverside / San Bernardino	0.00%	14.75%	5.14%	6.08%	5.24%

Source: WSP

These year of expenditure costs were then discounted to present value using a discount rate of 2.37 percent. The resulting present values of all costs are summed to yield the full lifecycle cost comparison.

Table 7-40 below outlines the replacement schedule provided by VVTA, which does not disaggregate buses by division (between Hesperia or Barstow) or by bus length. As such, the assumptions regarding the bus lengths and bus divisions which the finance team made in order to analyze costs are laid out under each scenario.

Table 7-40: General Fleet Replacement Plan

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
BEB	5																			
CNG		7			5			7												
FCEB								3	1	10	7	16		7			5			10
Total	**5**	**7**	**-**	**-**	**5**	**-**	**-**	**10**	**1**	**10**	**7**	**16**	**-**	**7**	**-**	**-**	**5**	**-**	**-**	**10**

Source: WSP

Vehicle Procurement Schedule by Facility - Scenario 2 Battery Electric Bus Conversion

The battery electric and fuel cell electric scenarios assume the bus procurements to be consistent with the tables that follow. These procurements could either continue the VVTA current practice of procuring only CNG buses, or switch to procuring only electric buses (battery or fuel cell) or procure a mix through the years. The two primary factors that would need to be considered for each year of procurement are the availability of charging infrastructure and the range and performance of available electric buses.

In early years, the availability of charging infrastructure would be the strictest constraint. However, VVTA is currently able to accommodate some battery electric buses, and is expected to have the infrastructure to accept additional battery electric buses by the end of 2020. The tables below were adapted from the replacement schedule provided by VVTA, which did not disaggregate buses by facility (between Hesperia or Barstow) or by bus length. Assumptions were made in order to analyze the BEB and FCEB scenario by facility and in a manner that would account for the difference in costs of lengths of various bus lengths.

[74] US Energy Information Administration, Annual Energy Outlook 2018 - Reference: 3-AEO2018.101.ref2018-d121317a

Table 7-41: BEB Fleet Replacement Plan – Hesperia Yard

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ BEB[75]	2							4	1	4	2	6		2			2			3
35’ BEB	2							3		4	3	4		2			2			4
40’ CNG		3			2															
35’ CNG		2			2															
FCEB[76]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**4**	**5**	**-**	**-**	**4**	**-**	**-**	**7**	**1**	**8**	**5**	**10**	**-**	**4**	**-**	**-**	**4**	**-**	**-**	**7**

Source: WSP

Table 7-42: BEB Fleet Replacement Plan – Barstow Yard

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ BEB	1							1	0	1	1	3		1			1			1
35’ BEB								2		1	1	3		2						1
40’ CNG		1																		
35’ CNG		1			1															
FCEB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**1**	**2**	**-**	**-**	**1**	**-**	**-**	**3**	**0**	**2**	**2**	**6**	**-**	**3**	**-**	**-**	**1**	**-**	**-**	**2**

Source: WSP

[75] Per VVTA staff, all future bus purchases will be either 35’ or 40’.

[76] For the Battery electric bus scenario, no FCEB purchase are assumed. All planned FCEB purchases as per the fleet plan are assumed to instead be battery electric bus purchases.

Vehicle Procurement Schedule by Facility Scenario 3 – Fuel Cell Electric Bus Conversion

Table 7-43: FCEB Fleet Replacement Plan – Hesperia Yard

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ BEB[77]	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35’ BEB[78]	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40’ CNG		3			2															
35’ CNG		2			2															
40’ FCEB								4	1	4	2	6		2			2			3
35’ FCEB								3		4	3	4		2			2			4
Total	**4**	**5**	**-**	**-**	**4**	**-**	**-**	**7**	**1**	**8**	**5**	**10**	**-**	**4**	**-**	**-**	**4**	**-**	**-**	**7**

Source: WSP

Table 7-44: FCEB Fleet Replacement Plan – Barstow Yard

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ BEB	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35’ BEB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40’ CNG		1																		
35’ CNG		1			1															
40’ FCEB								1		1	1	3		1			1			1
35’ FCEB								2		1	1	3		2						1
Total	**1**	**2**	**-**	**-**	**1**	**-**	**-**	**3**	**-**	**2**	**2**	**6**	**-**	**3**	**-**	**-**	**1**	**-**	**-**	**2**

Source: WSP

77 Per VVTA staff, all future bus purchases will be either 35’ or 40’.

78 For the FCEB scenario, no BEB purchases are assumed.

Vehicle Procurement Schedule by Facility – Baseline CNG

Table 7-45: CNG Fleet Replacement Plan – Hesperia Yard

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ CNG	2	3			2			4	1	4	2	6		2			2			4
35’ CNG	2	2			2			3		4	3	4		2			2			4
Total	**4**	**5**	**-**	**-**	**4**	**-**	**-**	**7**	**1**	**8**	**5**	**10**	**-**	**4**	**-**	**-**	**4**	**-**	**-**	**8**

Source: WSP

Table 7-46: CNG Fleet Replacement Plan – Barstow Yard

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
40’ CNG	1	1						1		1	1	3		1			1			1
35’ CNG		1			1			2		1	1	3		2						1
Total	**1**	**2**	**-**	**-**	**1**	**-**	**-**	**3**	**-**	**2**	**2**	**6**	**-**	**3**	**-**	**-**	**1**	**-**	**-**	**2**

Source: WSP

7.3.4.4 Uncertainties

Analysis provided in this documentation should be considered a conservative assessment of battery and fuel cell electric bus costs, as the industry in North America is small and in preliminary stages of development. Production costs may decrease as production increases to meet future demand. However, cost reductions may be offset by reductions in tax breaks, grant programs, discounts and incentives that are available for the acquisition of battery electric buses and associated charging infrastructure.

The costs for batteries and fuel cells could decline with continued development of more efficient technology and lower production costs resulting from economies of scale. Some potential future cost reductions, however, may be offset (or more than offset) through increases in the cost of acquiring the primary battery components, specifically lithium or other alternative materials. In addition, the energy density of batteries is increasing, so the decline in cost per kWh could be offset by a choice to buy higher-capacity, longer range batteries for buses purchased in later years and for replacement of original batteries on buses purchased in the early years.

The cost of CNG fuel and electricity can be very influential on the benefits of battery electric buses over CNG buses. Any major changes to the price would have a direct impact on operating costs for the agency. While utility prices are historically less volatile than CNG prices, there is less downward price potential as utility prices tend to be set by large scale capital investments and distribution costs, as opposed to market inventory levels and feedstock supply costs, which are the primary drivers of CNG prices and volatility.

7.3.5 Recommendations

7.3.5.1 Hesperia Yard Fleet Technology Considerations

When selecting the best-fit technology for the needs of Hesperia Yard, several factors should be considered, including: service performance, up-front capital expenses, operations and maintenance costs (including current and future fuel costs), required staffing to maintain equipment, and the feasibility of site-specific infrastructure. Considerations for each of the modeled scenarios is outlined below.

BEB Base-Only Benefits and Limitations:

- Prioritizing the transition of service blocks that require the least infrastructure, may provide the time necessary for the technologies to advance.
- In the situation that technology does not improve, an increase in infrastructure and/or fleet will be required to meet existing service levels.
- Without any supporting on-site energy production, this strategy may create a vulnerability to shifting utility rates and resulting operations costs.
- Relying solely on a single point of power may also reduce resiliency and present new challenges for participating in emergency response services.

BEB Base and On-Route Charging Benefits and Limitations:

- When incorporating strategic placement of on-route charging, the limitations to vehicle range can be eliminated.

- Distributing charging opportunities through the day and service area has the potential to sequester peak energy demand costs.
- On-route charging infrastructure can be cost-intensive, potentially requiring land easements.
- To accommodate on-route charging opportunities, there could be additional costs due to extended layovers. On-route charging could also result in potential impacts to standardized headways and reduce the ability to dynamically modify and improve route performance.

FCEB Benefits and Limitations:

- FCEBs demonstrate a similar range capability as vehicle technologies traditionally used by transit operators.
- FCEBs have a quick refueling turnaround and return to service, providing the opportunity to use mid-day refueling to reduce range limitations.
- The up-front cost of FCEB vehicles currently exceeds that of BEBs.
- On-site storage of hydrogen can be restricted by available space and the necessary infrastructure for meeting safety codes.
- On-site production of hydrogen requires experienced staff to maintain equipment.

Hydrogen that is delivered from an external source may be subject to the volatility of market supply and demand.

7.3.5.1.1 Strategies

When considering performance, all three technology scenarios modeled in this report fell short of meeting existing service levels at Hesperia Yard (Table 7-47). Because of this, the best solution for Hesperia Yard will likely include a combination of multiple strategies. Results of this analysis can help inform this decision by highlighting the most efficient and cost-effective strategy that aligns with ICT regulations and the specific needs of the transit operator. Potential pathways for realizing a successful ZE transition are outlined below:

Table 7-47: Percent of Service Blocks Completed for Each Technology Scenario Modeled for Hesperia Yard

Vehicle Efficiency	BEB Base Charging	BEB On-Route Charging	FCEB
Optimistic	34%	57%	79%
Base	21%	40%	62%
Conservative	13%	32%	38%

Source: WSP

There are several strategies that may be used to support ZEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances

- Phasing ZE integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

7.3.5.2 Barstow Future Yard Fleet Technology Considerations

When selecting the best-fit technology for the needs of Barstow Future Yard, several factors should be considered, including: service performance, up-front capital expenses, operations and maintenance costs (including current and future fuel costs), required staffing to maintain equipment, and the feasibility of site-specific infrastructure. Considerations for each of the modeled scenarios is outlined below.

BEB Base-Only Benefits and Limitations:

- Prioritizing the transition of service blocks that require the least infrastructure, may provide the time necessary for the technologies to advance.
- In the situation that technology does not improve, an increase in infrastructure and/or fleet will be required to meet existing service levels.
- Without any supporting on-site energy production, this strategy may create a vulnerability to shifting utility rates and resulting operations costs.
- Relying solely on a single point of power may also reduce resiliency and present new challenges for participating in emergency response services.

BEB Base and On-Route Charging Benefits and Limitations:

- When incorporating strategic placement of on-route charging, the limitations to vehicle range can be eliminated.
- Distributing charging opportunities through the day and service area has the potential to sequester peak energy demand costs.
- On-route charging infrastructure can be cost-intensive, potentially requiring land easements.
- To accommodate on-route charging opportunities, there could be additional costs due to extended layovers. On-route charging could also result in potential impacts to standardized headways and reduce the ability to dynamically modify and improve route performance.

FCEB Benefits and Limitations:

- FCEBs demonstrate a similar range capability as vehicle technologies traditionally used by transit operators.
- FCEBs have a quick refueling turnaround and return to service, providing the opportunity to use mid-day refueling to reduce range limitations.
- The up-front cost of FCEB vehicles currently exceeds that of BEBs.

- On-site storage of hydrogen can be restricted by available space and the necessary infrastructure for meeting safety codes.
- On-site production of hydrogen requires experienced staff to maintain equipment.

Hydrogen that is delivered from an external source may be subject to the volatility of market supply and demand.

7.3.5.2.1 Strategies

When considering performance, all three technology scenarios modeled in this report fell short of meeting existing service levels at Barstow Future Yard (Table 7-48). Because of this, the best solution for Barstow Future Yard will likely include a combination of multiple strategies. Results of this analysis can help inform this decision by highlighting the most efficient and cost-effective strategy that aligns with ICT regulations and the specific needs of the transit operator. Potential pathways for realizing a successful ZE transition are outlined below:

Table 7-48: Percent of Service Blocks Completed for Each Technology Scenario Modeled for Barstow Future Yard

Vehicle Efficiency	BEB Base Charging	BEB On-Route Charging	FCEB
Optimistic	57%	64%	79%
Base	43%	43%	62%
Conservative	14%	14%	38%

Source: WSP

There are several strategies that may be used to support ZEBs in maintaining existing service levels. Among these strategies are the following:

- Providing additional on-route chargers
- Modifying vehicle schedules to reduce average block distances
- Phasing ZE integration slowly to allow the technology to evolve, this may involve filing an exemption in accordance with the ICT regulation

While the data revealed throughout this study will largely inform the final recommendations, there are nuances unique to each operator and their respective facilities that must be considered. Because of the potential large capital costs or impact to service, it is essential that local operators have an opportunity to review the alternatives and provide feedback on possible strategies.

7.3.5.3 Fleet Phasing and Implementation

Adhering to the construction schedule and milestones will be critical because the facilities' construction must be completed before buses are delivered, otherwise, the buses will not be able to operate. To accomplish this, construction for FCEB and BEB-supporting infrastructure is expected to be done in phases to minimize disruption of operations. No enhancements are expected at Hesperia Yard since buses are expected to be fueled offsite (not feasible onsite), however, Barstow Yard is anticipated to be constructed in two phases.

Additional electrical capacity may be required to meet the service needs of buses at the future Barstow Yard. Construction and enhancements to bring this additional electrical capacity is anticipated to take three to five years based on electrical utilities' (conservative) protocol. This timeframe would include method of service studies, design, and construction. It is recommended that electrical infrastructure such as transformers and switchgears be installed with the initial phase at Barstow Yard to avoid the disruption of ongoing operations.

The following provides details on recommended phasing for Barstow Yard.

7.3.5.3.1 Future Barstow Yard Phasing

Phase 1

WSP recommends completing all infrastructural upgrades (concrete pads, fire barriers, etc.) on the site during the initial construction to avoid having to interrupt services once they begin at the future Barstow Yard. The first step in Phase 1 will include the introduction of BEB infrastructure including three charging cabinets to serve five island-mounted plug-in dispensers in the southern parking spaces.

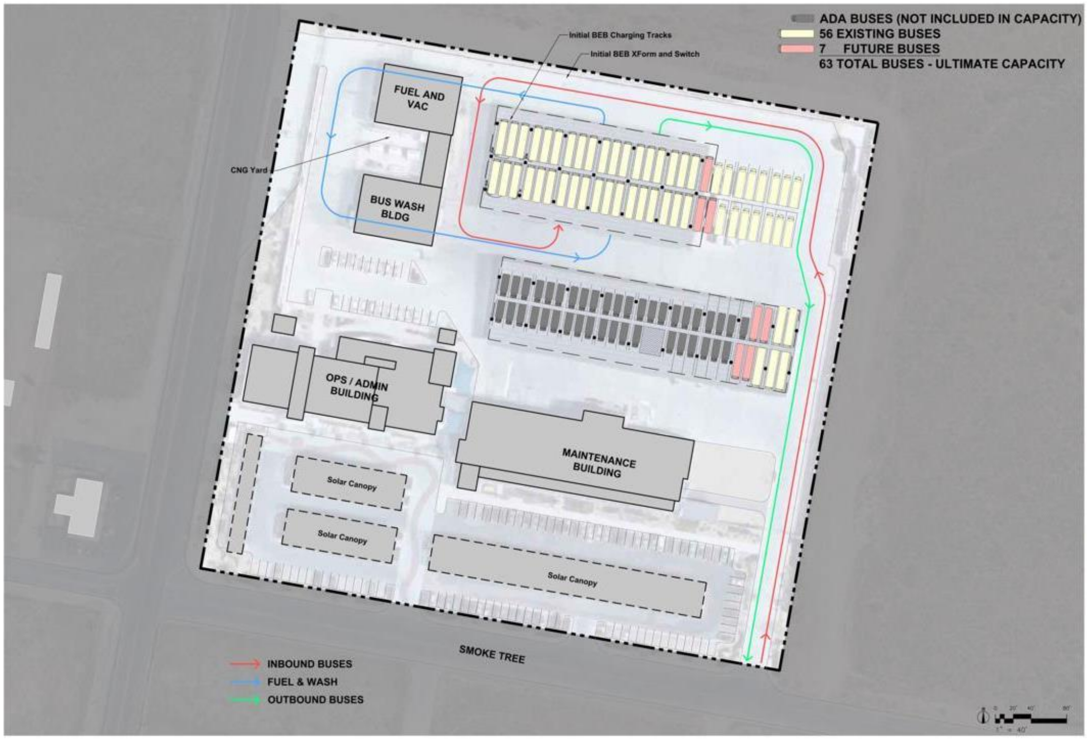
Following BEB upgrades, VVTA may begin the first phase of hydrogen implementation. This will include installation of foundational hydrogen fueling station equipment with a single dispenser and right-sized tank. During the transition from CNG to hydrogen, VVTA may elect to place a fire barrier between the CNG and liquid hydrogen storage to reduce safety offsets from 75 feet to zero feet in accordance with NFPA 55.

Phase 2

Phase 2 at theBarstow Yard would include an upgrade of the liquid hydrogen storage tank and an optional additional dispenser at the fueling yard. If Barstow elects to move forward with on-site hydrogen production, suitable technology available on the market would include a 445 kg electrolyser or a 540 kg SMR unit.

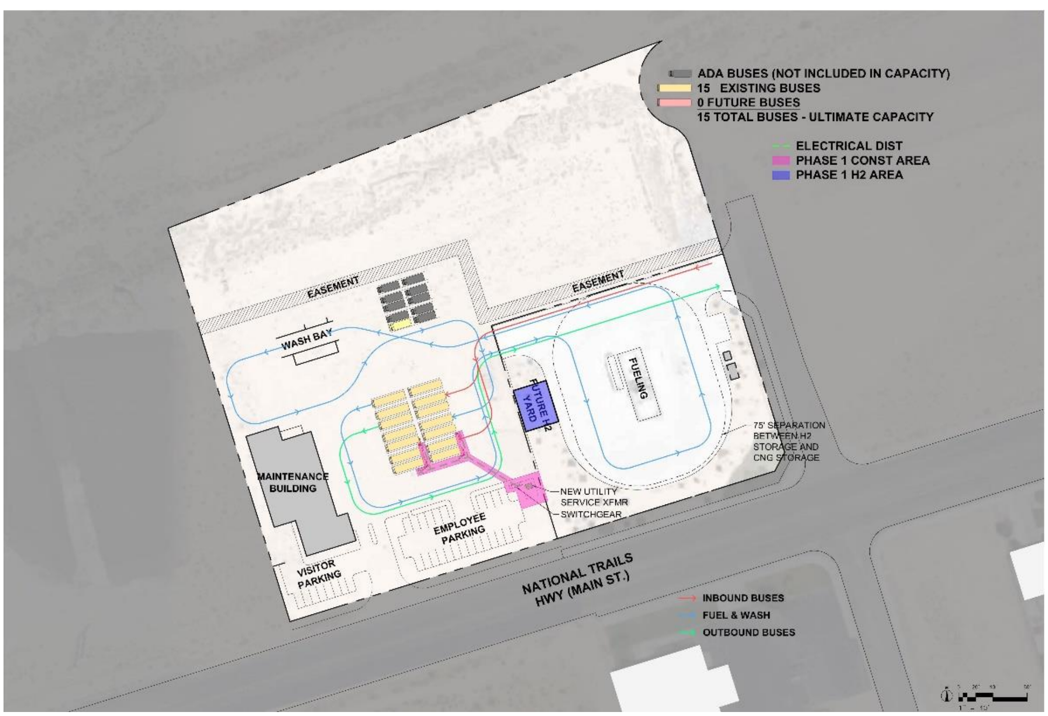
7.3.5.4 Facility Preliminary Design

Figure 7-16: Hesperia Yard Proposed Full ZEB Build-out and Phasing Plan



Source: WSP

Figure 7-17: Future Barstow Yard Proposed Full ZEB Build-out and Phasing Plan



Source: WSP

8 DISADVANTAGED COMMUNITIES

This section identifies and assesses disadvantaged communities (DACs) in the Inland Empire region and potential impacts that could result from implementation of the proposed project.

8.1 Background

Equity is measured on an environmental justice (EJ) framework, established to promote the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income. At the national level, EJ has been established into law with Executive Order 12898, Federal Actions and Executive Order 13166. In addition, Title VI of the Civil Rights Act, in the same grounds as the executive orders above, provides that no person in the United States shall be excluded from participation in, be denied the benefits of, or be subject to discrimination under any program or activity receiving federal financial assistance. At the state level, Caltrans guidance ensures that the goals of Title VI are carried out by transportation agencies implementing public participation programs in California, regardless of the availability of federal funding.

When making decisions for transportation investments, SBCTA and local transit agencies are addressing equity in a proactive approach. This analysis will help to consider DACs and whether the proposed improvements are equitable for these communities. This analysis focuses on how the air pollution benefits of ZE technology could advance social equity by focusing on serving communities most vulnerable to air pollution, and negative health and social conditions.

DACs refer to the areas throughout California that suffer the most from a combination of economic, health, and environmental burdens. The California Environmental Protection Agency (CalEPA) and California's Senate Bill 535 define a "disadvantaged" community as a community that is located in one of the top 25 percent highest scoring census tracts identified by the results of the California Communities Environmental Health Screening Tool Version 3 (CalEnviroScreen 3.0).

CalEnviroScreen uses environmental, health, and socioeconomic data to produce a numerical score representing a community's pollution burden and socioeconomic vulnerability. The score is calculated for each census tract in California; census tracts with higher scores, experience a higher pollution burden compared to census tracts with low scores. The CalEnviroScreen score is determined from a weighted scoring system of a variety of pollution and socioeconomic indicators. There are 20 indicators that are grouped into four components: pollution exposure, environmental effects, sensitive populations, and socioeconomic factors. The first two components capture pollution burden and the last two capture population characteristics.

By using CalEnviroScreen, agencies in San Bernardino County can prioritize the deployment of ZEB fleets in communities that are disadvantaged. Deploying ZEBs on routes that traverse through the highest concentration of DACs would provide environmental benefits to the communities that would benefit the most. Each agency could use this data to determine: 1) which facilities are constructed first (local benefits) and 2) which routes should be the first to adopt ZEBs.

8.2 Methodology

To determine if a facility is in a DAC area and if its routes traverse DACs, data from CalEnviroScreen 3.0 and agency-specific geospatial data (locations of facilities and routes) was analyzed in ArcGIS.

Locations of facilities were intersected with CalEnviroScreen's database to determine if a facility is located in a census tract deemed disadvantaged. For route analysis, first, the number of census tracts that each route traverses (by agency) was determined. Then, the number of DACs that these same routes traverse was calculated to determine the percentage of DACs that each route traverses. These results were then analyzed, duplicates were removed, and aggregated by facility.

8.3 Findings

Of all agencies, only Omnitrans and VVTA's facilities are located in DACs. However, Omnitrans, VVTA, *and* MT operate service in DACs.

MT's Crestline and Big Bear facilities are not in DACs, however, they both serve several DACs. The Crestline facility traverses 24 census tracts with 14 (58 percent) being disadvantaged. The Big Bear facility traverses 34 tracks with 17 being disadvantaged (50 percent)

Both Omnitrans' East Valley and West Valley facilities are located in DACs. The East Valley's routes serve the greatest number of DACs in the San Bernardino County transit service area. The routes service 163 census tracts with 103 being identified as disadvantaged (63 percent). The West Valley facility's routes traverse 129 tracts with 78 of them being disadvantaged (60 percent).

VVTA's Hesperia and Barstow facilities are both in DACs. The Hesperia facility serves 95 census tracts with 37 (39 percent) being DAC. The Barstow facility serves 12 communities with five (42 percent) being DAC.

Needles and MBTA's facilities are not in DACs and neither agency serves a DAC, as defined by CalEnviroScreen.

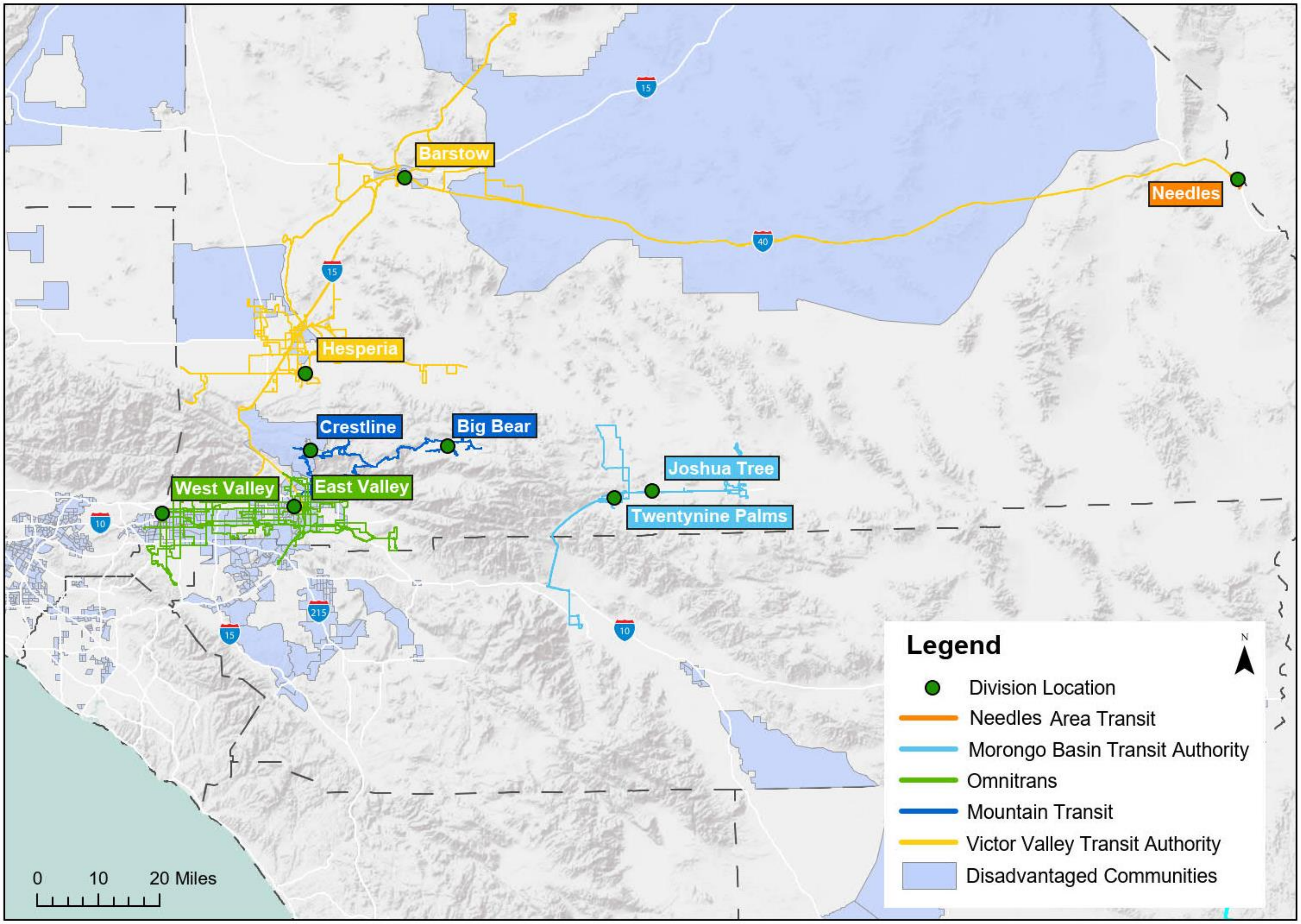
Table 8-1 summarizes each facility's DAC status and the number of DACs served and Figure 8-1 and Figure 8-1 presents where and the number of DACs relative to all agencies, respectively. Figures 8-3 through 8-5 illustrated Omnitrans, VVTA, MT's disadvantaged communities, respectively.

Table 8-1: Disadvantaged Communities Summary

Agency	Facility Location	Located in DAC	Number of Census Tracts	Number of DACs	Percent DACs
Needles	Needles	No	2	0	0%
MBTA	Joshua Tree	No	19	0	0%
MBTA	Twentynine Palms	No	25	0	0%
Omnitrans	West Valley	Yes	129	78	60%
Omnitrans	East Valley	Yes	163	103	63%
MT	Crestline	No	24	14	58%
MT	Big Bear	No	34	17	50%
VVTA	Hesperia	Yes	95	37	39%
VVTA	Barstow	Yes	12	5	42%

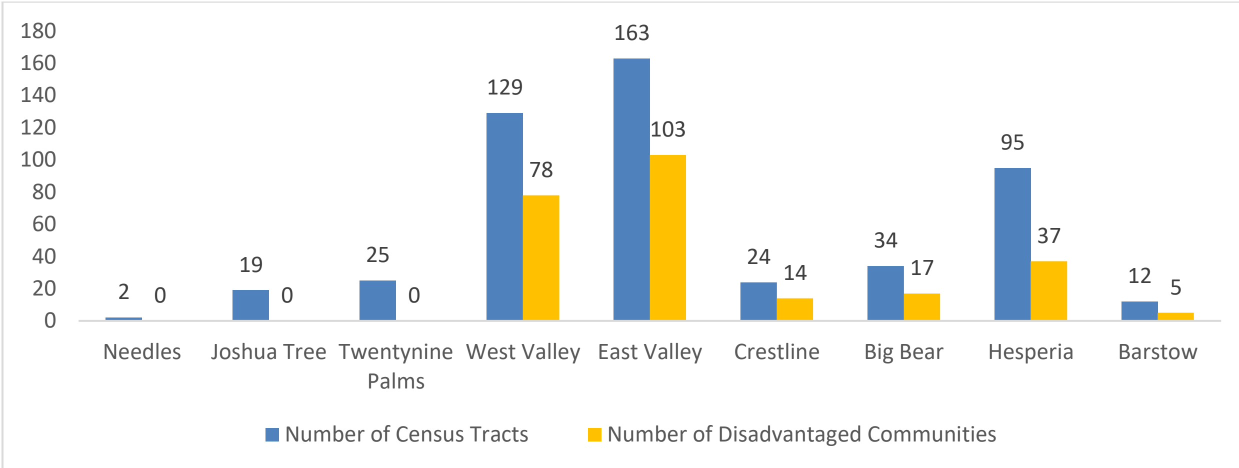
Source: WSP

Figure 8-1: Disadvantaged Communities and Countywide Service Area Bus Routes



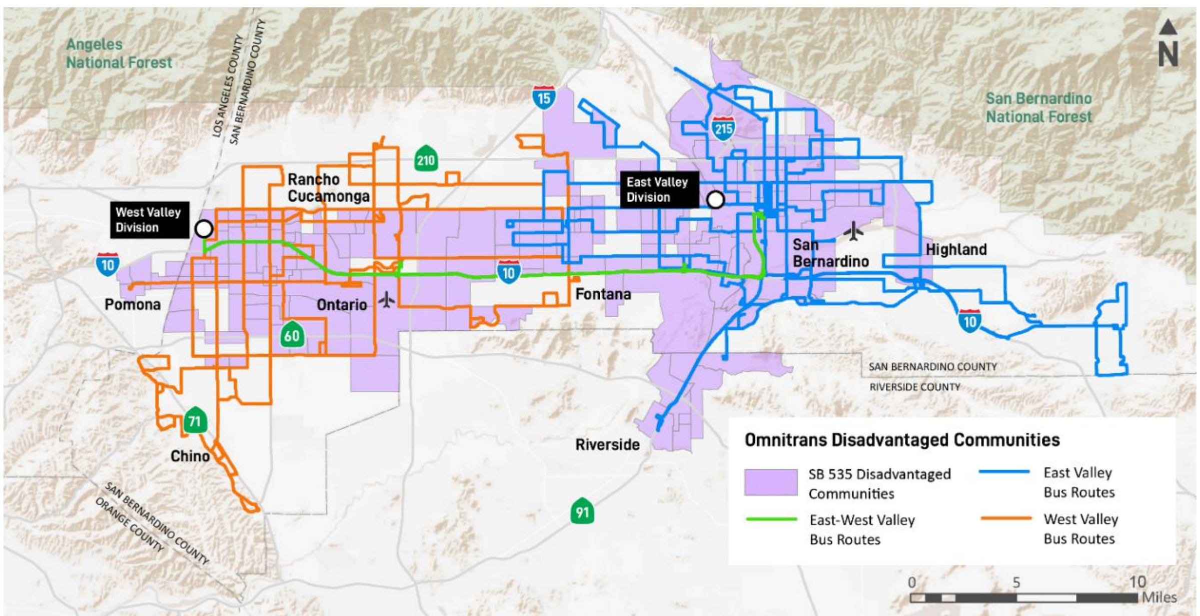
Source: WSP

Figure 8-2: Number of DAC Along Bus Routes Deployed by Transit Authority



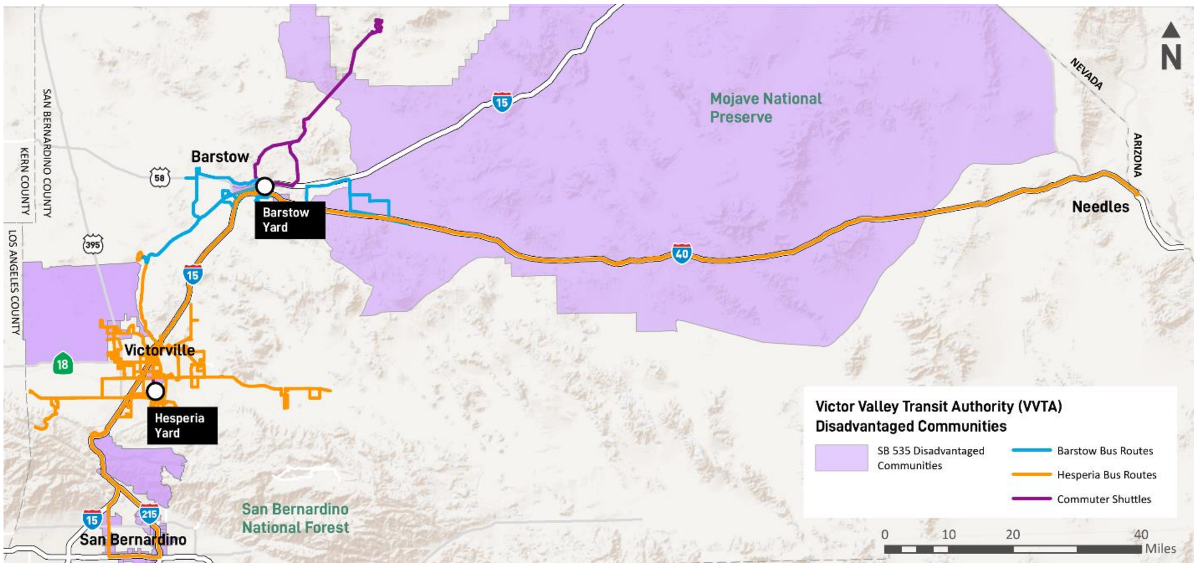
Source: WSP

Figure 8-3: Omnitrans' Disadvantaged Communities



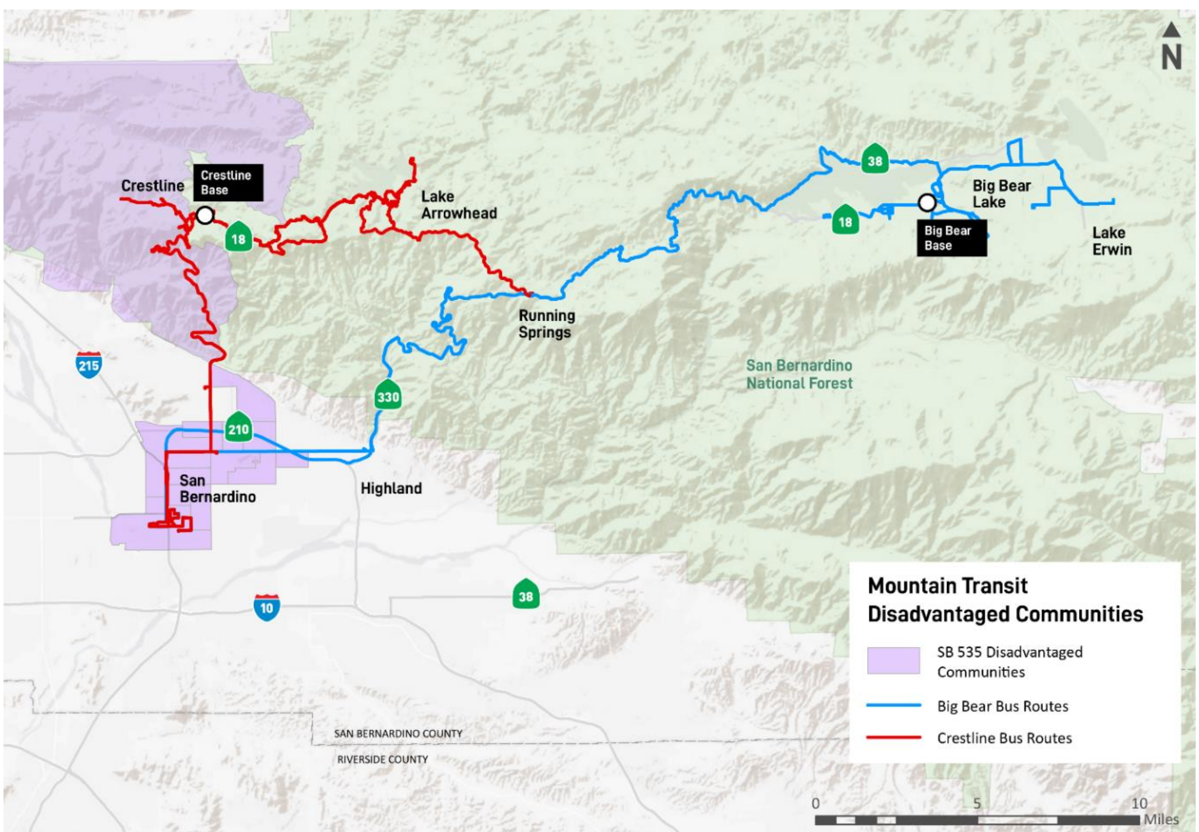
Source: WSP

Figure 8-4: VVTA's Disadvantaged Communities



Source: WSP

Figure 8-5: MT's Disadvantaged Communities



Source: WSP

8.4 Application of DAC Analysis

Since all agencies' facilities are anticipated to be constructed at the same time (i.e., Omnitrans' East and West Valley facilities will be constructed in parallel), no communities will yield the benefits of ZEB integration before another. The determination of which routes receive ZEBs first will have to be further analyzed. It is likely that range will be the determining factor in route prioritization, however, each agency will have to factor in DACs into the prioritization strategy for equity and funding purposes..

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9 NEXT STEPS & RESILIENCY PLANNING

As mentioned, the process to transition to ZEBs should and will be iterative to minimize risk, but also to accommodate new developments in a rapidly-evolving market. San Bernardino County agencies will use the information outlined in both the Rollout Plan and Master Plan to identify and further refine the following:

Determine the BEB and/or FCEB Fleet Mix

Both the Rollout Plan and Master Plan addresses each agency's specific needs and policy choices to determine which technologies (BEB or FCEB) is most feasible. VVTA has made it clear that it is very interested in FCEBs, for example, due to concerns about range and length of its service blocks and its own experience with ZEB implementation to date. The recommendations contained herein address what the WSP team believes is the most feasible and cost-effective means of implementing the mix of ZEB types at each agency. However, all agencies will have to re-address these issues and determine whether these recommendations regarding feasibility based on costs, service requirements, and availability have changed as each agency implements its transition toward ZEBs.

Address Incomplete Service Blocks

The WSP team's analysis has found that many blocks cannot be completed when considering BEBs and FCEBs, meaning, agencies will have to determine if they're going to file exemptions, purchase additional buses, restructure service to suit technological limitations, or invest in opportunity charging. These choices are rooted in each agency's own policies and plans outside of ZEB considerations. Because the smaller agencies are not required to submit their rollout plans until July 1, 2023, they have the opportunity to monitor technology advancements over the next three years to determine if newly available technologies can meet longer range needs; of course, the ability to file an exemption remains.

Engage Utilities and Energy Providers

The adoption of ZEBs is not possible without a partnership with energy providers. For that reason, it is pertinent that agencies begin discussions with their energy providers to ensure that the ZEB-supporting infrastructure, delivery of buses, and potential energy enhancements are in alignment. If this is not planned properly, an agency may receive BEBs (for instance) with delays in electrical enhancements – which can negatively impact service and costs. Each agency should ensure that the utility can assist with determining how much power is available and a path forward to providing the required power. It is also important to engage early and often to take advantage of incentives and funding partnerships, such as Southern California Edison's Charge Ready Program.

Overall, additional considerations and research, such as engaging the electrical distribution utilities, must be coordinated to aid the transition to zero emissions buses. Both BEBs and FCEBs are feasible at the sites evaluated. In general, most of the transit operator sites are served by 12 kV service and new service can be added up to ~830 kW in a fairly straightforward manner. Above ~830 kW, SCE will trigger a MOS application, which takes significant time and money.

Omnitrans facility appear to be the most difficult to get new service and may require substantial distribution upgrades which could lead to a five-plus year timeframe for deployment. Omnitrans may want to consider significant FCEB investment if the electrical infrastructure costs are too high.

VVTA has expressed an interest in pursuing mostly FCEB, this keeps electric service size low, unless electrolyzers are chosen for the hydrogen production technology.

The WSP team paid close attention to the reliability and resilience of the electrical service at each site. This information will help the five operators within San Bernardino County make the best decisions about paying for additional resilience.

While this report does not make detailed recommendations for on-site/alternative energy options, we recommend that SBCTA examine each transit operator during the next phases in more detail.

Energy Used by Electric Buses

The following data comes from the modeling work completed by the team. Not all of the calculations reflect the final full build out state of each facility.

Table 9-1: BEB Energy Consumption

Facility	Blocks	Miles	Energy Consumed (Low Estimate)		Energy Consumed (Mid Estimate)		Energy Consumed (High Estimate)	
			kWh	kWh/mile	kWh	kWh/mile	kWh	kWh/mile
Joshua Tree Yard	7	1,119	562	0.50	749	0.67	937	0.84
29 Palms Yard	7	897	451	0.50	601	0.67	751	0.84
Crestline	6	923	464	0.50	619	0.67	773	0.84
Big Bear Lake	5	679	341	0.50	455	0.67	569	0.84
West Valley	48	9,998	26,862	2.69	35,816	3.58	44,769	4.48
East Valley	115	21,785	61,189	2.81	81,585	3.75	101,982	4.68
VVTA HQ - Hesperia Yard	47	10,323	27,411	2.66	36,548	3.54	45,685	4.43
Barstow Future Yard	14	2,872	7,646	2.66	10,195	3.55	12,743	4.44
Needles Garage	1	166	83	0.50	111	0.67	139	0.84
	250	**48,760**	**125,009**	2.56	**166,679**	3.42	**208,348**	4.27

Source: WSP

Overall BEB Feasibility Per Site and Next Steps to Reach Full Electrification

Since most sites are with SCE, close coordination with them, especially as solutions or technology changes, will be imperative to ensure as fast as possible of a turnaround for getting electrical service required.

Table 9-2: Facility Feasibility

Facility Name	Peak Power Required	MOS required?	Notes/Next Steps
Joshua Tree Yard	1050 kW	Yes	It may be possible to keep loads low enough to avoid the MOS.
29 Palms Yard	300 kW	No	SCE has indicated that the transformer providing power to this site is close to capacity, but with minor changes this load can be accommodated, close coordination with SCE recommended. This may be a prime site for a Charge Ready project.
Crestline	300 kW	No	Resiliency of the power grid may be a substantial consideration for this site even though the Grid availability exists. Steps should be taken to minimize the effects of power failures on service.
Big Bear Lake	600 kW	No	The utility for this site is BVES instead of SCE. BVES has said they can accommodate up to 1 MW of power for this facility without any substantial grid changes
Needles Area Transit	150 kW	No	Very low load required, but close coordination with the City of Needles municipal utility for electric load should be done during detail design
West Valley	5.5 MW	Yes	Close coordination with SCE will be critical for this site. Getting an MOS started as soon as possible is strongly recommended.
East Valley	9 MW	Yes	Close coordination with SCE will be critical for this site. Getting an MOS started as soon as possible is strongly recommended. This site will likely require a second 12 kV circuit as well.
Hesperia Yard	1.9 MW	Yes	This site load includes 12 BEB (900 kW) and the rest FCEB (1 MW). Close coordination with SCE will be critical for this site. Getting an MOS started as soon as possible is strongly recommended
Barstow Yard	250 kW	No	This assumes 100% FCEB with on-site storage of liquid hydrogen.

Source: WSP

Table 9-3: On Route Charger Feasibility

On Route Charger Name	Peak Power Required	MOS required	Notes/Next Steps
Yucca Valley Transit Ctr	150 kW	No	Design to include parking away from public foot traffic to avoid tampering with charger
29 Palms New Transit Ctr	150 kW	No	Design to include parking away from public foot traffic to avoid tampering with charger
Fontana Metrolink Plaza	450 kW	No	Consider adding resiliency measures such as on-site diesel gen backup
Pomona Transit Center	450 kW	Yes	Shared site with Foothill Transit, coordination with SCE and Foothill for resiliency and load balancing is strongly encouraged
Yucaipa Transit Center	450 kW	No	Consider adding resiliency measures such as on-site diesel gen backup
San Bernardino Transit Ctr	450 kW	No	Consider adding resiliency measures such as on-site diesel gen backup
Lorene Drive & 7th Street Station	450 kW	No	Consider adding resiliency measures such as on-site diesel gen backup
G Street at Broadway	450 kW	No	Consider adding resiliency measures such as on-site diesel gen backup

Source: WSP

Utility Resiliency Recommendations

See below chart of resilience recommendations per site.

Table 9-4: Utility Resiliency Recommendations

Operator	Agency	Site	Resilience Option
MBTA	1	Joshua Tree Yard	Generator
MBTA	1	29 Palms Yard	Generator
MBTA	1	Yucca Valley Transit Ctr*	Generator
MBTA	1	29 Palms New Transit Ctr	Generator
MT	2	Crestline*	Generator
MT	2	Big Bear Lake	Generator
Needles	5	Needles Garage	Generator
Omnitrans	3	West Valley	None
Omnitrans	3	East Valley*	Redundant Circuit
Omnitrans	3	Fontana Metrolink Plaza	Mobile Generator
Omnitrans	3	Pomona Transit Center	Mobile Generator
Omnitrans	3	Yucaipa Transit Center*	Mobile Generator
Omnitrans	3	San Bernardino Transit Ctr	Mobile Generator
VVTA	4	VVTA HQ - Hesperia Yard	Generator
VVTA	4	Barstow Future Yard	Mobile Generator
VVTA	4	Lorene Drive & 7th Street Station	Mobile Generator
VVTA/NAT	4	G Street at Broadway	Mobile Generator

* Indicates that the circuit is in a high fire risk area. See Appendix C for these circuit maps.
Source: WSP

Costs Refinements

Construction, capital, operating, and maintenance costs vary based on a number of factors. It will be important to get an understanding of the up-front costs and lifecycle costs and savings of investing in ZEBs. The WSP team has developed such cost estimates and each agency will need to revisit these estimates to determine if pricing has changed, such as changes in their purchasing schedules.

Consider Collaboration Opportunities

Whether purchasing things via CalACT or strategizing on a joint agreement for opportunity charging, agencies can continue to maximize their outcomes by engaging with other regional and local agencies. It important for all agencies to continue to participate in groups such as the Zero Emission Bus Resource Alliance (ZEBRA) working group, California Transit Association and the state's chapter of the Association for Commuter Transportation, the American Public Transportation Association (APTA)'s Bus Technology Committee, and other industry working groups.

Explore Pilot Projects

Investing or committing to either FCEBs or BEBs is a difficult decision. Since these technologies are still rapidly evolving, it is pertinent for agencies to understand how they will actually operate (outside of modeling or forecasts). Agencies should begin to explore opportunities to partner with

OEMs or peer agencies to procure or temporarily use pilot buses to validate assumptions or inform future purchases.

Ensure ICT Regulation Compliance and Subsequent Implementation

Only one of the five operating agencies with the County (Omnitrans) is required to submit a Rollout Plan by July 1, 2020. The others are required to submit a plan by July 1, 2023. It is recommended that they do so in order to monitor technology trends, market availability of new buses such as cutaways with ZE propulsion expected to come into the bus market, fuel and electricity pricing trends and the impact of contemplated service changes on these agencies' ZEB Rollout Plans. Should the agencies elect to file a Countywide Rollout Plan, they have the option of doing so by transmitting such an intention to CARB by no later than July 1, 2022. At that time, they can also notify CARB that Omnitrans' Rollout Plan will be amended such that it will join the Countywide Plan.

Moreover, as with any major capital plan and infrastructure program, it is important to note that as steps to implement the Rollout Plan and Master Plan, this analysis is only the beginning. Much more will be required as each agency procures buses and engages firms to design and build the required infrastructure, and to ensure these steps remain the most cost-effective options with respect to their impacts on service operation and maintenance. Finally, while the team listed a variety of funding sources, each agency must tailor its grant funding applications based on its own needs and resources.

While the Rollout Plan and Master Plan documents have limitations, these studies represent more than a snapshot in time. Rather, they are "future-proofed" as much as possible based on the team's knowledge of technology and cost trends to date. Moreover, they are intended to be guides on how best to implement a ZEB transition. Thus, it remains up to each agency to decide how best to use these recommendations.

APPENDIX A: WEST VALLEY CONNECTOR ZERO EMISSION BUS FEASIBILITY REPORT

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West Valley Connector
Zero Emission Bus
Feasibility Report

Prepared for:

San Bernardino County Transportation Authority

Prepared by:

wsp

444 South Flower Street
Suite 800
Los Angeles, California 90071

April 25, 2020

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Acronyms and Abbreviations

BEB	battery-electric bus
BRT	bus rapid transit
CNG	compressed natural gas
ENC	El Dorado National-California
EV	electric vehicle
FCEB	fuel cell electric bus
GHG	greenhouse gases
kW	kilowatt
kWh	kilowatt hour
LH2	liquified hydrogen
MSF	maintenance and storage facility – Ontario, CA
MW	megawatt
NREL	National Renewable Energy Lab
OCTA	Orange County Transit Authority
OEM	original equipment manufacturer
ONT	Ontario International Airport
RNG	renewable natural gas
SBCTA	San Bernardino County Transportation Authority
SCE	Southern California Edison
SMR	steam methane reformation
SOC	state of charge
UCI	University of California - Irvine
WVC	West Valley Connector
ZE	zero emission(s)
ZEB	zero emission bus

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1 INTRODUCTION

1.1 Overview

This memorandum presents the inputs, approach, and analysis used to evaluate the preliminary feasibility of deploying zero-emission buses (ZEBs) to serve San Bernardino County Transportation Authority and Omnitrans' planned Phase I of the West Valley Connector (WVC), a bus rapid transit (BRT) project connecting the cities of Pomona, Montclair, Ontario, and Rancho Cucamonga. The purpose of the analysis is to determine the feasibility of operating 40-foot battery-electric buses (BEBs) and/or hydrogen fuel cell buses (FCEBs) on the WVC BRT route and to identify the best-fit technology. To support this analysis, a model was developed to determine: (1) energy requirements of ZEBs and (2) ZEB performance under various charging/fueling and operating scenarios. Since the WVC along Holt Boulevard, Milliken Ave., and Foothill Boulevard are still in the planning phase, uncertainty exists in terms of service and operations. Several operating plan and scheduling assumptions were applied to demonstrate likely service conditions. The analysis concludes with a recommendation to implement BEBs along the route using a combination of base charging and on-route charging as the most practical strategy for meeting the planned service requirements of the corridor, in addition to further exploration and research into hydrogen fuel cell feasibility. Specifically, this memorandum recommends positioning two on-route chargers at Pomona Transit Center and nine chargers with 18 dispensers at the maintenance and storage facility to provide overnight charging. The findings of this initial analysis will be woven into the overall SBCTA Master Plan for ZEB adoption and implementation.

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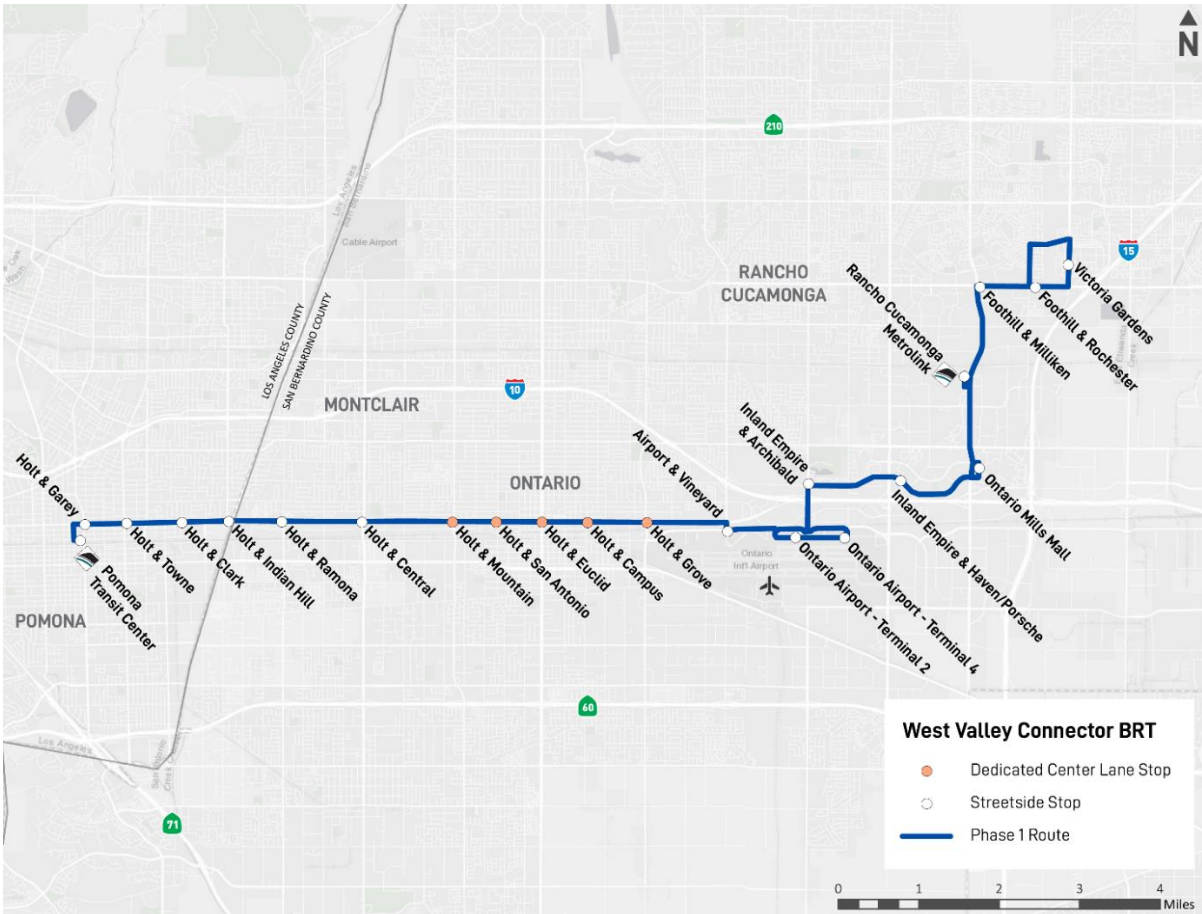
2 PROJECT BACKGROUND

SBCTA and Omnitrans will build and operate Phase 1 of the BRT route along a 19-mile corridor along Holt Avenue, connecting to Ontario International Airport (ONT), Ontario Mills Mall, the Rancho Cucamonga Metrolink station, and ending at Victoria Gardens open-air mall. The WVC "Phase 1" is an arterial BRT line that would connect several cities: Pomona, Montclair, Ontario, and Rancho Cucamonga (Figure 2-1). The WVC Phase 1 will be the second BRT corridor in San Bernardino County, following the sbX Green Line, which connects the cities of San Bernardino and Loma Linda.

The Holt Avenue corridor is currently served by Omnitrans' Route 61 bus line, while Route 66 operates on Foothill Boulevard, the Historic U.S. Route 66. Together, these are two of the highest ridership routes in Omnitrans' service area. Finally, multimodal connectivity is an additional overarching theme of this project. The route commences at the Pomona Transit Center, which connects the WVC to the Pomona Metrolink station as well as Foothill Transit's services. As the route traverses eastward, connectivity at ONT is serviced at both airline terminal buildings. The route continues to the Rancho Cucamonga Metrolink station and ends near the I-15/Route 66 interchange at Victoria Gardens, a major commercial hub for the area. WVC lays a foundational bridge of intercounty transportation and provides links to rail, air, and transit centers along its path.

Figure 2-1. West Valley Connector, Phase I BRT Project Map



Source: WSP

2.1 Service Description

The WVC Phase 1 BRT is expected to launch in early 2024 and is estimated to attract 4,610 daily riders in its opening year.[1] The proposed BRT is a 19-mile route that will operate on three arterial segments: East Holt Avenue between the Pomona Transit Center in downtown Pomona and ONT; Inland Empire Boulevard between Archibald Avenue and Ontario Mills Mall; Milliken Avenue connection to the Rancho Cucamonga Metrolink Station; and Foothill Boulevard (Route 66) to Victoria Gardens. The route provides 22 station pairs, spaced between 0.3-1.7 miles apart. A 3.5-mile dedicated bus lane section along Holt Avenue will include five center-running stations (see Figure 1). Station improvements will include digital timetable displays, shelter canopy with enhanced lighting, and bench seating. The Phase 1 plans to operate from 6:00 am to 8:00 pm. 10-minute peak headways will occur during the hours of 6:00 am to 9:00 am and 3:00 pm - 6:00 pm for a total of six hours, with 15-minute off-peak headways occurring during the hours of 9:00 am - 3:00 pm and 6:00 pm - 8:00 pm, for a total of eight hours. Thus, the planned schedule will establish reliable and frequent service.

The end-to-end trip duration is estimated at approximately 63 minutes (126 minutes round-trip), with riders benefitting from the reduced number of stops, transit signal priority and more

[1] "West Valley Connector Corridor – STOPS Model Travel Forecast Results" *Cambridge Systematics.* August 2018.

frequent service (which will reduce dwell time on individual buses and crowding) to provide a faster trip. Additionally, sbX bus branding will allow for greater visibility and public promotion. Buses servicing this route are expected to be lightly maintained and stored at a maintenance and storage facility (MSF) with a proposed location approximately five miles from the head of the route. Based on the geographic location of the bus base, the expectation has been established for 20-minute pull-in and pull-out deadheads. Based on service requirements, mock schedules were developed to determine the minimum number of buses required for service. From the mock schedule, it was determined that a minimum of 14 buses are required for operation. Note: Since the West Valley Connector is a specialized service with dedicated buses, it is suggested that the spare ratio exceeds the minimum 20%. Hence, 18 total buses are recommended to serve the WVC fleet.

Table 2-1.WVC Phase I BRT Stops (Eastbound)

Stop Order	Stop
1	Pomona Transit Center
2	Holt & Garey
3	Holt & Towne
4	Holt & Clark
5	Holt & Indian Hill
6	Holt & Ramona
7	Holt & Central
8	Holt & Mountain
9	Holt & San Antonio
10	Holt & Euclid
11	Holt & Campus
12	Holt & Grove
13	Airport & Vineyard
14	Ontario Airport - Terminal 2
15	Ontario Airport - Terminal 4
16	Inland Empire & Archibald
17	Inland Empire & Haven/Porsche
18	Ontario Mills Mall
19	Rancho Metrolink
20	Foothill & Milliken
21	Foothill & Rochester
22	Victoria Gardens

Source: WSP

2.2 Zero Emission Bus Adoption

As part of the 2010 SANBAG (now SBCTA) Countywide Transportation Plan, the WVC has already been determined as a baseline scenario for transit expansion in San Bernardino County. In alignment with existing sustainability measures, the further development of BRT and greenhouse gas (GHG) reductions are imperative for overall county goals of further transit investment. Omnitrans currently operates an entirely CNG fleet and has committed to transitioning to a 100% zero-emission fleet by 2040.

By examining and modeling both BEB and hydrogen fuel cell technologies, recommendations will be made to determine the highest operational feasibility, while minimizing associated capital costs. Implementing the WVC BRT as a ZE route from the onset would bolster SBCTA's sustainability and long-term planning initiatives, while also serving as a case study for adoption of ZEBs across Omnitrans' entire fleet.

2.2.1 Battery-Electric Bus

BEBs provide many environmental benefits to the community and region, as well as potential life-cycle cost savings to the operating agency. BEBs operate via an electric drive train with power stored in large Lithium-ion batteries. Though Lithium-ion is the most energy dense battery technology available, BEBs currently lack the range capabilities of CNG buses. For this reason, it is essential to analyze and understand how BEBs will perform under existing operating conditions before procuring buses and charging infrastructure. Depending on the length of vehicle runs, the conditions under which the buses operate, and other issues, various strategies may need to be considered to extend the operating range of some or all the BEB vehicles in operation, including, but not limited to, on-route charging at one or multiple locations, higher-powered chargers for overnight or on-route charging, increased fleet size, and changes to route alignments or schedules.

The performance of a BEB is typically measured by the range of the vehicle. This can be expressed in miles or hours of operation but can be highly variable depending on a myriad of factors. These include regional climate and weather conditions, geographical topography, road sinuosity, ridership, battery health, operator driving style, and traveling speeds. It is not uncommon for BEBs to achieve less than sixty percent of the range stated by the manufacturer. This uncertainty requires acute attention to ongoing measured BEB performance reported by agencies operating in similar conditions as SBCTA.

Multiple charging options are available to service BEB fleets including plug-in base charging, overhead conductive fast charging, and inductive beneath-grade fast charging. As with BEBs, this technology is rapidly evolving to support agencies in meeting their service needs. The most common and straightforward charging technology used to support BEB fleets is plug-in base charging. This method of charging requires a manual connection of the charger to the bus for extended charging times, typically overnight. Plug-in charging is available in AC or DC options, depending on the manufacture, however DC charging is typically recommended as it is more ubiquitous throughout the industry, preventing agencies from getting locked-in with a single OEM.

Fast charging options are generally categorized as conductive or inductive. Conductive charging typically takes the form of overhead pantograph chargers. Pantograph chargers have a high-energy output of up to 500 kW allowing rapid charging within 5-15 minutes. These chargers are typically placed at layover points and connect to the vehicle semi-autonomously, allowing the operator to remain in the driver's seat throughout the charging window. Currently, overhead pantograph chargers are the most developed on-route charging option throughout the industry.

The alternative method of on-route charging is inductive charging. Inductive charging provides wireless charging through an electromagnetic field, much like the wireless charging of a cell phone when placed on a charging pad. Energy is transferred between a transmitter "pad" located beneath the pavement slab and a receiver on the underside of the bus. For buses, inductive charging has two potential applications: stationary or dynamic.

For stationary inductive charging applications, a bus pulls into a designated charging position aided by visual and audio for alignment. Once positioned, the charging begins as controlled by charge management software. With dynamic charging, colloquially referred to as "charging lanes", buses can charge while in motion by driving over charging coils embedded within the pavement. This method of charging allows a bus to continue in-service and reduces the need and costs associated with charging overnight at the base. The concept of dynamic charging for transit buses is compelling, considering buses typically do not deviate from their respective routes. The United Kingdom, South Korea, Israel, and Sweden are the examples of countries that already did pilot projects to adapt the technology.

Figure 2-2. Conceptual Charging Lane

Source: http://redgreenandblue.org/

Electreon is an Israeli firm that specializes in smart infrastructure for public transit and is currently focusing on the development of dynamic inductive charging in Israel and Sweden. In February 2019, it was announced that Electreon is planning to launch a one-kilometer electric road between Tel Aviv University and the city's train station. However, because the technology is still relatively nascent and in its testing phase, there is not much data available on the costs, transmission power, considerations, and best practices. The most recent Electreon pilot testing in Sweden in March 2020 resulted in 45 kW transferred to a 40-ton electric truck on a 50-meters long pilot section. The results of the model provided in this report indicate that at least 500kW of power is necessary on-route to meet the WVC service needs, suggesting that inductive technology cannot provide the needed power to serve the route. Therefore, at this time, due to the limited number of pilots and assumed construction and implementation costs for BEB, dynamic inductive charging is not a viable solution for the WVC corridor. However, as more data and pilots are deemed successful, the technology should be considered as an alternative, especially because WVC has a dedicated right-of-way.

The service evaluations used throughout this analysis help determine the optimal mix of battery sizes and charging infrastructure, location and sizes of on-route chargers, and changes to bus schedules, which can significantly impact operational and capital investments. Before an agency commits to BEBs, it is important to model and analyze performance capabilities tailored to the agency's unique operating and service conditions.

2.2.2 Hydrogen Fuel Cell Electric Bus

Hydrogen is the most abundant element available and contains nearly four times the energy density as Lithium-ion batteries. FCEBs also have the capability to operate under relatively similar conditions as CNG buses with rapid refueling times (~15 minutes), albeit with a more limited fuel range. Though range anxiety is not quite as palpable as with BEBs, fueling concerns do arise, particularly regarding access to fuel stations and sourcing. As a relatively nascent technology, traditional fossil fuel manufacturers are beginning to recognize the shift toward renewables and are investing in scaling up this method of fuel technology.

Hydrogen is primarily produced two-fold, via steam-methane reformation (SMR) and electrolysis. The former, reformation, is the primary source of hydrogen in the United States, with more than 95% of the world's hydrogen derived from this method of production[2]. SMR uses high pressure steam to separate hydrogen atoms from a methane source, such as CNG. Along with pure hydrogen, a bi-product of SMR is carbon dioxide, making this technology less favorable among communities focused on climate resiliency. In some instances, renewable natural gas (RNG) is used to increase the sustainability of the production process by capturing existing methane from sources such as landfills and wastewater treatment plants. This more sustainable option was used at SunLine Transit in the Coachella Valley. Through low carbon fuel standard credits, the agency was able to achieve a similar cost for RNG as traditionally sourced natural gas.

An alternative method of hydrogen production is electrolysis. Electrolysers work in a similar manner as hydrogen fuel cells, albeit in reverse, using a direct electric current to separate hydrogen molecules from water. A benefit of this method is that electrolysis can result in zero GHG emissions during production, when renewable energy sources are used. However, hydrogen production via electrolysis is highly energy intensive, requiring upwards of 50 kWh per kg produced. As such, the current energy grid fuel mix is not suitable for large-scale electrolysis due to the sheer amount of emissions produced[3]. For long-term planning, integration with solar or wind technology can make electrolysis much less resource-intensive in terms of production and long-term scalability.

The only tailpipe emission released from FCEBs is water vapor. Despite the upstream costs and emissions of producing hydrogen from CNG as well as delivering and storing it for use in FCEBs, the total GHG emissions are cut in half from internal combustion engines fueled by petroleum. However, the methane emissions produced should not be negated by this form of production. The main deterrent of FCEB deployment is the lack of existing supply chain, large capital investment, and energy intensive production.

Transit operators have two general options for sourcing hydrogen: (1) delivered from a local supplier with on-site storage, or (2) produced and stored on-site. In rare occasions, a commercial fueling station may be within reasonable proximity to service routes, however, this method is not recommended as fuel prices are often more expensive and volatile.

When first gaining familiarity with the technology, it is often recommended that agencies have the hydrogen delivered via a local supplier (Linde and Air Liquide are within proximity to the WVC depot). Delivery may be in the form of compressed gas or cryogenically liquified hydrogen. With typical gas tube trailers capable of carrying only 300 kg of hydrogen, this storage method is recommended only for servicing very small fleets to avoid high delivery costs. Liquified hydrogen (LH2) is the preferred option for scalability, as LH2 trucks can haul upwards of 4,000 kg. Agencies have the option to lease or purchase their hydrogen storage tank. When leasing hydrogen storage

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[2] U.S. Department of Energy, Fuel Cell Technologies Office. 2020. https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

[3] "Hydrogen Production: Electrolysis" *U.S. Office of Energy Efficiency & Renewable Energy.*

tanks, the supplier is responsible for all equipment maintenance and safety adherence. This reduces the need to train local staff and can also reduce the risk of an accident.

In addition to storage, FCEB operations require the agency install hydrogen filling stations. A major benefit of hydrogen infrastructure is that it is built to be scalable. A station can simply and cost-effectively increase its capacity from 10 to 100 or more buses by upgrading the compression and storage equipment and adding dispensers. Operating a combination of low-emission CNG buses with zero-emission fuel cell electric buses out of a single transit depot is a model that is both economical and scalable to hundreds of buses.

For Omnitrans, the most significant limiting factor to the deployment of FCEBs is likely the equipment footprint and safety code compliance. With typical on-site liquid storage requiring a minimum of 40-feet by 50-feet of area, and regulatory safety offsets limiting the proximity to CNG storage, off-site storage may be necessary. This is described in greater detail in the SBCTA ZEB Analysis Master Plan.

Finally, when planning for *any* zero-emission bus technology, contingency planning is essential. With longer range and faster refueling times, FCEBs are a more resilient option than BEBs in the event of extended power outages or mass emergency evacuations. Always, planning for redundancy should be made to avoid service interruptions. Transit agencies report that most hydrogen station issues involve compressor failures. To avoid station downtime, agencies can consider acquiring additional compressors, storage containers (for on-site production), and dispensers. If sourcing hydrogen from off-site, a quick response time from station providers is important to maintain bus service. Agencies recommend negotiating the service contract with station providers to cover response time for repairs.[4]

Given the extensive challenges that are currently of concern regarding FCEBs, opportunities arise as more firms reach a scalable period of production. Further investment and technological advances will come in the following decade, when hydrogen will solidify itself as a viable, truly clean alternative to both BEBs and CNG-fueled transit systems.

2.2.3 Methodology

To support ZE fleet planning for the WVC Phase 1 BRT, WSP developed a dynamic, formula-based model used to perform simulations of BEBs and FCEBs operating along the route. The model sought to identify the best-fit technology for the route's service requirements based on estimations of overall capital and operating costs through the development of mock schedules, simulations of vehicle performance, and calculations of fuel and power consumption. Throughout the analysis, a wide array of sources are used to formulate assumptions including, existing analyses of the WVC Phase 1 BRT corridor, Altoona and OEM reports, and published literature. This analysis is designed to serve as an initial feasibility study, providing guidance on technologies that should be considered in future analyses, and therefore does not consider several variables required for refined ZE planning such as climate, route grade and sinuosity, and passenger load. It is important to note that ZE technology is rapidly evolving, and the assumptions used throughout this analysis may quickly shift as the technologies improve.

The vehicles modeled throughout this analysis are to serve as representative vehicles of the technologies considered. It is not the intent of this analysis to provide OEM vehicle model

[4] "Fuel Cell Buses in U.S. Transit Fleets" *Eudy, Leslie and Post, Matthew; National Renewable Labs, September 2018*

recommendations, but rather demonstrate how common technological configurations can perform along the WVC. The vehicles used in this analysis were selected based on available performance data from Altoona testing and academic reports.

The following section outlines the methodologies and assumptions used in each stage of the WVC Phase 1 BRT simulation and analysis.

2.3 BEB Service and Performance Requirements

An essential element for accurately assessing the performance of ZEBs on a transit route, is understanding how the vehicle's capabilities align with the service requirements of the route. Route schedules form the foundation of the analysis by providing a framework for determining the minimum fleet size and round-trips necessary to meet service goals. Since the WVC Phase 1 BRT is still in the planning stages, a service schedule has not been finalized. For this reason, WSP designed tentative schedules for BEB and FCEB operations based on our understanding of service requirements and layover locations (Appendix A: BEB On-Route Mock ScheduleAppendix B: BEB Base-Only Charging ScheduleAppendix C: FCEB Schedule).

To assess the costs associated with powering/fueling the vehicles, several inputs were analyzed to determine the total anticipated energy and power consumption required for typical weekday operations. The BEB energy analyses required consideration to the fleet profile (quantity and battery capacity), charger power specifications, and charger locations to determine the amount of kWh (energy) and megawatts (MW) (demand) required on a typical weekday.

The energy consumption and demand modeling were created with consideration to local utility rates to estimate total annual costs for powering the fleet. The utility that would serve the proposed bus base and on-route charging location is SCE. Based on anticipated voltage and peak demand to service the WVC fleet, the best-fit tariff for Omnitrans is the Time of Use (TOU)-EV-9 rate, with primary service voltage between 2kV and 50kV (Table 2-2 and Table 2-3). A benefit to this tariff is that there is no demand charge, making high-power on-route chargers more economical. This also allows Omnitrans greater flexibility in designing charge management strategies. In this analysis, BEB energy consumption, pull-in times, and pull-out times were used in alignment with these utility rates to identify estimated utility costs for the WVC fleet with and without the use of charge management strategies. A detailed comparison of utility costs with and without charge management is further described in Section 0.

Table 2-2. Southern California Edison Utility Rate

Time of Use Period	Rates (per kWh)	
	Summer (June-September)	Winter (October-May)
On-Peak	$0.40891	-
Mid-Peak	$0.20129	$0.23603
Off-Peak	$0.09854	$0.10323
Super Off-Peak	-	$0.06493

Source: SCE

Table 2-3. Southern California Edison Time of Use Detail

Time of Use Period	Weekdays		Weekends and Holidays	
	Summer	Winter	Summer	Winter
On-Peak	4 p.m. – 9 p.m.	N/A	N/A	N/A
Mid-Peak	N/A	4 p.m. – 9 p.m.	4 p.m. – 9 p.m.	4 p.m. – 9 p.m.
Off-Peak	All other hours	9 p.m. – 8 a.m.	All other hours	9 p.m. – 8 a.m.
Super Off-Peak	N/A	8 a.m. – 4 p.m.	N/A	8 a.m. – 4 p.m.

Source: WSP

2.3.1 Quantity of Buses

BEB fleet requirements can vary widely depending on the service and route characteristics on which they operate. With a lower range than alternative propulsion buses, it is often necessary to increase BEB fleet sizes to meet service needs (Table 2-4).

Earlier analyses of the WVC Phase 1 BRT assumes that operations will require 18 buses (including spares). In this analysis, a mock schedule was drafted to validate these anticipated fleet requirements under the planned service profile and modeled scenarios. When using on-route charging strategies, the fleet assumption of 18 buses is maintained, however if using base-only charging, the fleet size is significantly increased to 24 BEBs to account for frequent pull-ins for recharging.

Table 2-4. BEB Range Compared to Other Alternative Fuel Buses

	Diesel hybrid	CNG	New Flyer FCEB (61.6 kg capacity)	New Flyer BEB (466 kWh) *	BYD BEB (587 kWh) *
Range (miles)	565	480	242	180	220

Source: WSP

NOTES: *New Flyer and BYD ranges were based on model (not OEM assumptions). The model included a safety buffer of 20%. These conservative assumptions virtually shrunk the battery capacity.
CNG = compressed natural gas; kWh = kilowatt hours, FCEB = Fuel Cell Electric Bus

2.3.2 Chargers

Recharging is the equivalent of refueling for BEB buses. The two types of charging typically used are base charging and on-route charging. Base charging is suitable for larger battery capacities and slower charge rates, typically overnight, whereas on-route charging is configured at layover locations (usually trip endpoints) and is more suitable for smaller battery capacities and faster charge rates, typically during service hours. WSP modeled multiple charging scenarios using a combination of base charging and on-route charging options to determine the best-fit scenario for SBCTA. The chargers selected for modeling in this analysis represent common industry preference and are well suited for scalability (Table 2-5).

There are multiple considerations to be had with charging configurations. For instance, a single 150 kW charging cabinet can have a single dispenser (for one bus), or it can have two dispensers, reducing the peak demand for each bus to 75 kW. Using a single charging cabinet with multiple dispensers has the benefit of reducing overall capital costs for electrical upgrades as well as charging equipment. For this reason, 150 kW chargers with two dispensers are assumed for base charging in this analysis.

The WVC fleet requires significant energy inputs on-route to complete service requirements without increasing the fleet size. To provide the fleet with adequate power within the 15-minute allotted layover period, 500 kW overhead pantograph chargers were assumed throughout the analysis.

It should be noted that the flow of power from a charger to the bus is variable depending on the buses SOC (and varies by OEM). This variation is expressed as charge-curves or charge-rates (c-curves/rates). For example, a bus with a 50% SOC that is plugged into a 150 kW charger may receive 150 kW when the battery capacity reaches between 50%-60%, 125 kW between 60%-75%, and 100 kW between 75%-85%. Typically, a battery may only receive a charger's rated power for a very short period, resulting in longer charge times, and more detailed planning and analysis. This model and analysis did not account for c-rates, as they vary between battery, charger, and SOC, however, in subsequent analyses, when schedules are confirmed, c-rates should be considered. Although assuming a constant power flow can *underestimate* the time it takes to charge and *overestimate* the power required at the bus base or on-route, conservative adjustments to the battery were applied to account for this variation.

Table 2-5. Representative Charging Technology Modeled

OEM	Location	Type	Power (kW)
Eaton	On-route	Overhead Pantograph	500
Proterra	Bus Base	Plug-In	150

Source: WSP

2.3.3 Charging Locations

An essential factor in determining the performance and range of BEBs is identifying where and how often they charge. As with the fueling function for CNG buses, the primary charging location for BEBs is the bus garage, or bus base. However, depending on energy need, on-route chargers may be required at one or both route end points. Depending on the frequency and length of layovers, multiple chargers may be required at each end-point to prevent bus bunching. The following discusses deployment of chargers at both the base and on-route charging locations.

Base Charging

To determine the energy needs at the bus base, one must understand the fleet size, bus schedule, and the time buses are pulling into and out of the bus base throughout the day. This information is vital to calculate energy needs for each bus block and at which time each bus would need to engage and disengage from the base chargers. To establish a baseline understanding of potential needs at the bus base, WSP developed a tentative service schedule based on the anticipated service requirements for the WVC Phase 1 BRT. The estimates provided were based on the service requirement of 14 and 19 buses (determined in the tentative schedule) with use of a 1:2 charger to bus strategy using 150 kW chargers.

The energy requirement analysis in this study began by identifying the pull-in and pull-out times of each of the buses operating along the route. Calculations were then made to estimate the BEBs' state of charge at the time of pull-in. Using this information, the amount of time required to fully charge the buses was determined, providing the window of charge time required for each bus block. This serves as the foundation for the demand and consumption needs at the base. This analysis provides a better understanding of the impact of on-route charging on the overall energy demand and consumption at the bus base, as well as a more refined estimate of the number of base chargers required to support operations.

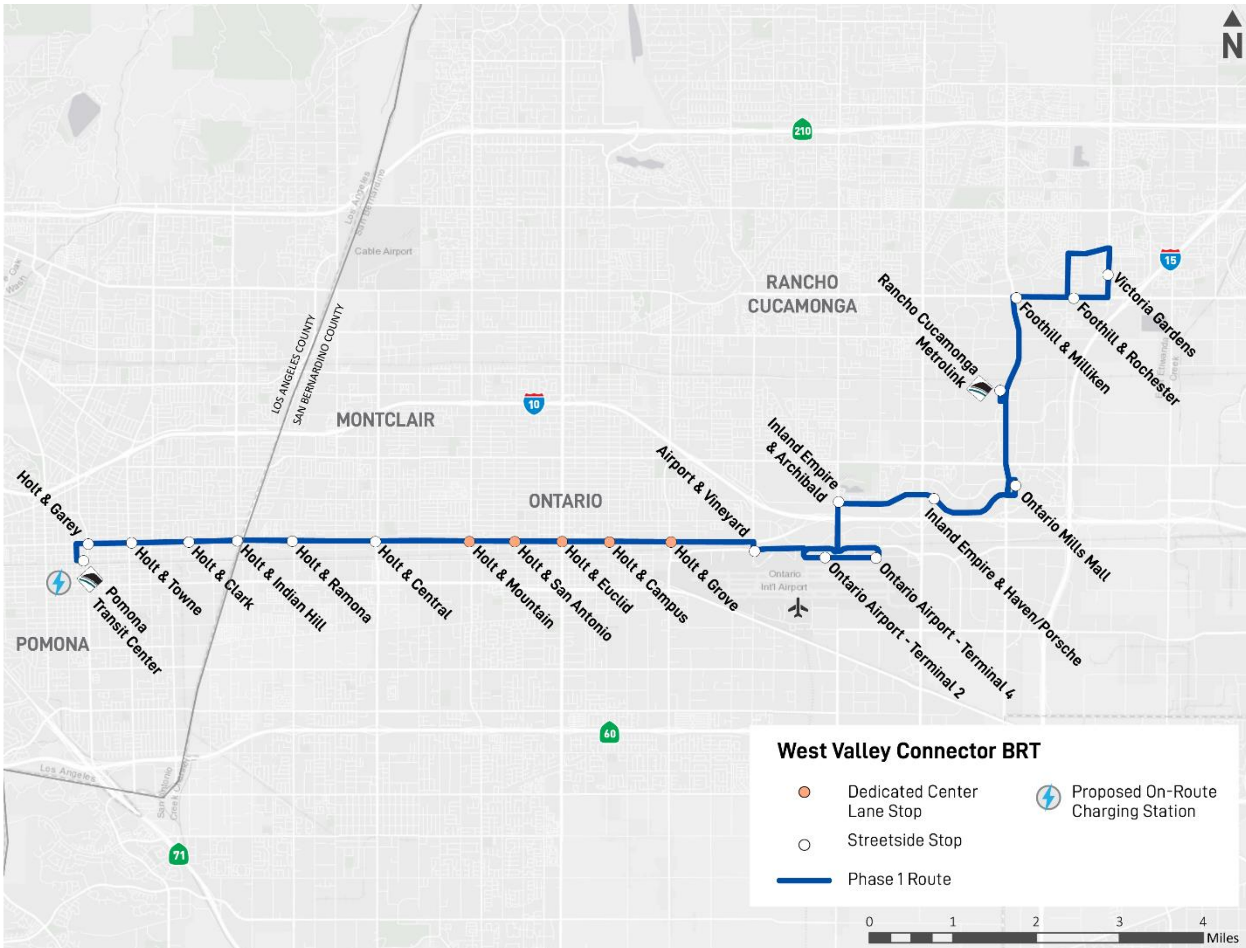
On-Route Charging

On-route charging, or "opportunity charging", is a strategy that enables buses to charge while in service, typically at layover points. On-route charging serves many purposes, including extending the range of a bus, reducing peak demand and consumption at the base, and minimizing disruption of service due to battery limitations. Potential on-route charging locations along the WVC Phase 1 BRT route are identified in Figure 2-3; however, not all were evaluated in this model because not all were necessary to meet service requirements.

The on-route charging scenarios used in this model assumes charging would take place during each round trip using a 500 kW pantograph charger at Pomona Transit Center. With chargers located at the head of the route, the option to charge buses immediately following the pull-out deadhead (prior to the start of service) is available. The model analyzed BEB performance with and without pre-service on-route charging to identify viable strategies for meeting WVC service requirements. Initially, a 10-minute charging window was assumed to allow a conservative 5-minute buffer for charger engagement and disengagement and allow any necessary travel time from the stop to the charging location. From this baseline, charge time was incrementally added until all service parameters were met with a single on-route charging location. Using the tentative schedule, it was determined that at least two chargers would be necessary at the on-route charging location to avoid conflicts with multiple buses occupying the facility and requiring charging simultaneously.

To determine the energy requirements (daily consumption and peak demand) at the on-route charging locations, the total number of layovers occurring at each location on a typical weekday was multiplied by the amount of energy provided from the 500 kW charger in the required charging period (11.5 minutes) to meet service parameters (approximately 96kWh per charge). To advance the conservative approach to energy calculations, WSP assumed that each charger delivered its advertised power at a constant flow for the full 11.5 minutes. In reality, batteries have limits and charge curves/rates change over time (i.e., a 500 kW charger does not provide 500 kW at a constant rate), in addition, the full on-route charge time is only required for the longest service block lengths, thus most service blocks can reach the required SOC in less than the modeled charging window. Refined on-route charge times should be validated by SBCTA through a BEB pilot prior to any procurements to determine if more or less time will be required for on-route charging, and to provide insight into opportunities for reducing the daily number of charging events on each vehicle.

Figure 2-3. Possible On-Route Charging Locations



Source: WSP

2.4 FCEB Service and Performance Requirements

Service and performance of FCEBs operating along the WVC Phase 1 BRT route began with an assessment of FCEB specs and a determination of anticipated vehicle range. The representative vehicle used in this analysis is the 40-foot New Flyer Xcelsior Charge H2 (XHE40). This vehicle was selected based on available Altoona test reports and documented vehicle performance provided by the National Renewable Energy Lab (NREL)[5]. The efficiencies used for performance evaluations were sourced from the 2018 Altoona vehicle demonstration reports[6]. Efficiencies for FCEBs are reported in miles per pound of hydrogen, thus optimistic efficiencies will have a higher value in contrast to BEB efficiencies which are reported as energy used per mile.

[5] National Renewable Energy Laboratory (U.S.), United States. Department of Energy. Office of Scientific and Technical Information, and United States. Office of the Assistant Secretary of Energy Efficiency and Renewable Energy. Fuel Cell Buses in.

[6] New Flyer XHE40 Atloona Report http://apps.altoonabustest.psu.edu/buses/reports/501.pdf?1547230960

Using the Altoona efficiencies and vehicle fuel tank capacity, the anticipated vehicle range was determined (Table 2-6). Though Altoona testing serves as an objective measure of vehicle performance through pilot tests conducted along various route-types, it does not fully capture the many variables that affect vehicle range, such as route grade and HVAC use. Furthermore, the calculated range using these efficiencies have not yet been demonstrated within any agencies that are reporting FCEB performance. For example, the Stark Area Regional Transit Authority (SARTA) reported a measured range of 215 miles in contrast to the forecasted range of 250 miles, AC Transit reported an average range of 266 miles, and OCTA typically assigns FCEBs only to blocks with less than 225 miles as a result of range issues.[7] [8] [9*]. For this reason, the most conservative efficiency measures for each vehicle model (expressed as arterial route efficiencies in Altoona reports), with an anticipated range of 190 miles was used throughout this analysis for performance and fuel consumption estimations. The arterial route efficiencies also best represent the characteristics of the WVC route.

Table 2-6. Representative FCEB Efficiencies and Range

	Optimistic	Base	Conservative
Efficiencies (mi/lb)	3.79	3.14	2.42
Range (miles)	298	247	190

Source: Altoona

2.5 FCEB Fuel Requirements

2.5.1 FCEB Vehicle and Fuel Tank Capacity

Prior to determining the best-fit hydrogen technology for servicing an FCEB fleet, estimations of daily fleet hydrogen requirements are necessary. The critical factors for determining fuel consumption for FCEBs is the fuel tank capacity, vehicle efficiency, and number of buses necessary to complete service requirements. Typically, approximately 5% of the tank is unusable due to issues with pressurization during refueling. For this reason, a 5% adjustment was made to the advertised fuel tank capacity. The fuel tank for the 40-foot New Flyer XHE40 has an advertised capacity of 37.5 kg with a usable tank capacity of 36 kg. This sets the foundation for determining FCEB operational cost estimates.

2.5.2 Quantity of Buses and Service Impacts

To determine the quantity of buses necessary to meet service requirements, a mock schedule was developed with the goal of minimizing the total number of buses in service (Appendix B: BEB Base-Only Charging Schedule). Although the range of FCEBs is greater than the range of BEBs, FCEB operation along the WVC corridor requires more return trips to the depot and greater vehicle miles traveled. The reason for this is because the conservative vehicle range (190 miles) is just short of the maximum block distance determined in the schedule (282 miles), requiring the

[7] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/134491/zero-emission-bus-evaluation-results-sarta-fta-report-no-0140_0.pdf

[8] https://www.nrel.gov/docs/fy19osti/72208.pdf

[9] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/132691/zero-emission-bus-evaluation-results-orange-county-transportation-authority-fuel-cell-electric-bus.pdf

* Note: Each of the agencies noted operate 40-foot FCEBs as opposed to 60-Foot FCEBs, however, these represent the most current and accurate FCEB demonstration to date.

vehicles to return to the base to refuel throughout the service period. To avoid a surge of buses returning to the base in succession, effectively requiring a significant increase in fleet size, the schedule was designed to stagger bus returns throughout the day. Using this approach, a total of 16 buses are necessary for meeting service goals.

2.5.3 Fuel Source

One of the most essential considerations for determining FCEB fuel cost, is establishing how the hydrogen fuel is produced and sourced. Currently, the most common method of hydrogen production is steam reformation because of its lower cost, however, many hydrogen production companies are making the shift to electrolysis as this method is more efficient and produces less harmful emissions. To source the fuel, SBCTA may elect to either have the hydrogen delivered and stored at the base or produced on site. Either option requires the installation of on-site hydrogen storage (Figure 2-4). It is not uncommon for surrounding communities to express trepidations and resistance to installation of new hydrogen production equipment and storage due to the risk of hydrogen seepage and combustion. For instance, the Omnitrans' East Valley bus division has experienced extensive resistance from neighborhood interest groups regarding on-site fueling. Early and frequent community engagement around the West Valley location would be advised if hydrogen storage is to be considered there.

Hydrogen delivery requires the agency to arrange an agreement with a local hydrogen production company to deliver the required quantity of fuel on a periodic basis. The frequency of hydrogen delivery depends upon the size of the storage tank located at the base and the fuel requirements of the fleet. Because hydrogen storage comes with some associated risks, safety upgrades and an environmental analysis will be required. Currently, hydrogen production is limited with only a few hydrogen stations currently in operation, this increases SBCTA's vulnerability to the volatile market prices of hydrogen in 2018, the average retail price of hydrogen ranges between $9/kg to $16/kg.[10]

Alternatively, SBCTA may elect to invest in on-site hydrogen production. On-site hydrogen production requires investment in expensive upfront capital costs but could decrease the price of hydrogen fuel to around $7/kg ($3.18). The costs associated with production include the energy required to power the equipment (~50 kWh/kg for electrolysis and ~5 kWh/kg for SMR), the source water (electrolysis), and the natural gas inputs (SMR). The figures used for determining the total cost of on-site hydrogen production are based on local case studies, published research, and discussions with local suppliers. For instance, Sunline Transit Agency adopted an electrolyser in 2018 which totaled $8.3 million. This price was all-encompassing, including a modular PEM electrolyser capable of producing 900 kg/day, two fuel pumps, as well as storage and safety equipment. A 900 kg electrolyser is quite large by today's standards, however, if operators continue to scale up their hydrogen fleets, increased production will be necessary. For instance, to provide for the 2,663 fleet miles traveled for FCEBs on the WVC, between 319 kg and 499 kg of hydrogen will be needed per day. With only a few additions to the FCEB fleet, a 900 kg daily supply could quickly be exhausted.

[10] https://www.nrel.gov/docs/fy19osti/72208.pdf

Figure 2-4. 4,500kg hydrogen tank located at Orange County Transit Authority (OCTA) designed to serve 50 FCEB buses.

Source: OCTA

2.6 Factors Not Considered in Analysis

Due to the conceptual nature of this project, unknown inputs and assumptions will need to be confirmed before proceeding with utility negotiations, facility and fleet procurement, and service and operational changes. Listed below are considerations that should be integrated into the model once information is confirmed:

- **Charge curves**: The capacity and OEM of the BEB battery affects the rate of charge coming from charging equipment. The variance in power output is often demonstrated through the ratio of charging rate to charging time, also referred to as a charge curve. Because of the complexity and variability (between OEMs) associated with c-curve analysis, this simulation does not account for charge curves and uses the advertised power (nameplate) of the charger at a constant rate. Future analysis should include charge curves to more accurately predict energy requirements.

- **On-route charging constraints:** Information related to service and physical constraints are not considered, such as space requirements and availability at on-route charging locations and the total bus parking capacity. Field work and detailed service information need to be determined before the number of possible on-route charging bays, chargers, etc. can be confirmed.

- **Space requirements at base:** BEBs and FCEBs require significant space be dedicated for hosting infrastructure. If SBCTA elects to have hydrogen shipped in, they will need to identify a location that meets safety requirements for storing and dispensing hydrogen. If on-site production is selected, adequate space for an electrolyser or SMR unit will be necessary in addition to the previously mentioned infrastructure. For BEB operations, consideration to utility infrastructure and supporting maintenance alongside charging must be taken into account. Details on spatial requirements for the West Valley and East Valley facilities can be found in the SBCTA ZEB Analysis Master Plan.
- **Cost of supporting infrastructure and labor:** There is a wide range of line items that contribute to the overall costs to integrate BEBs and FCEBs into a fleet. Though this analysis considered the big line items such as charging and hydrogen production equipment, it does not include infrastructural costs specific to the site. Prior to BEB procurement, it is recommended that SBCTA conduct a full facility review to determine the extent to which electrical infrastructure must be installed or upgraded. FCEB procurement should include thorough negotiations surrounding equipment maintenance and fuel delivery.

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3 RESULTS AND ANALYSIS

To provide SBCTA with comprehensive recommendations for West Valley Connector BRT operations, this analysis simulated a series of operational scenarios to identify viable zero-emission implementation strategies in alignment with route service goals. The analysis evaluated the performance of BEBs as well as FCEBs, offering SBCTA with objective measures to determine the best-fit technology for service needs.

3.1 BEB Service and Performance

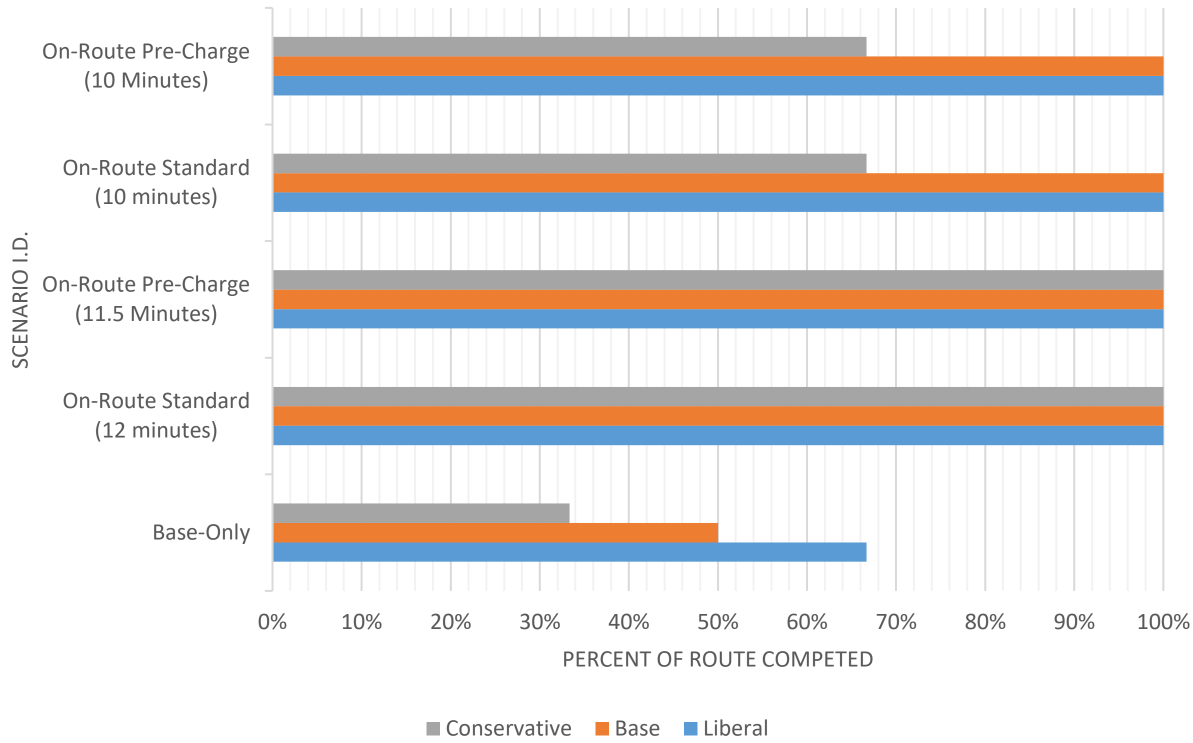
The analysis began with a determination of the battery technology necessary to meet the 14-hour service requirement without returning to the base or using on-route charging (assuming the bus leaves the base with a 100% SOC). Based on the assumed travel times, a maximum of six roundtrips would be required to complete a full day's service. To meet this range on a single charge, a BEB would need to be equipped with a 1,021 kWh battery (the largest BEB battery currently in operation is 660 kWh). Since this capacity far exceeds battery technology currently available on the market, integration of BEBs into this line will require consideration to alternative operations strategies which may include, on-route charging, reduced bus run lengths, or other changes to charging infrastructure or route operations.

The following section examines the viability of two BEB operational scenarios under the conservative assumptions outlined earlier in this document to determine best-fit strategies for the unique requirements of the WVC BRT. The scenarios modeled begin with the most streamlined and cost-effective operations strategies and increase in complexity (beginning with options that most resemble CNG service) until operational requirements were met.

Each of the scenarios were evaluated to determine the total number of round-trips that could be met under various charging configurations using the three levels of sensitivity for efficiency estimations, as described in Section 2.3.

Figure 3-1 displays the percent of the 14-hour service period that the bus could complete under each of the modeled scenarios. In this analysis, both on-route charging strategies (standard and pre-charge) required additional charge time to meet the service goals for all three efficiency sensitivities (+/- 30%). When charging BEBs at the head of the route, prior to the start of service, 11.5 minutes of charge time is required to meet all service parameters. The charge time increases to 12 minutes, if charging does not take place until after the first round-trip when the BEBs arrive back at Pomona Regional Transit Center Station. A detailed summary of each scenario is outlined below.

Figure 3-1. Block Completion

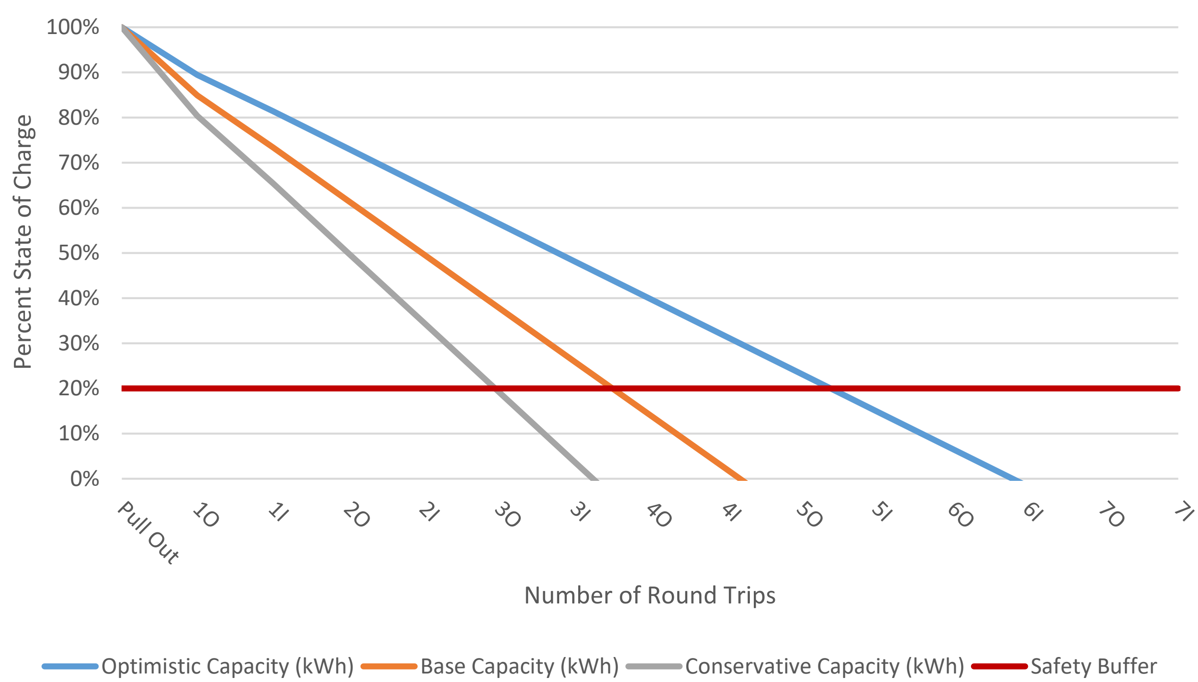


Source: WSP

3.1.1 Scenario Base Only: Proterra E2 Catalyst (440 kWh)

With an advertised range of 161 miles, it was expected that the Proterra E2 Catalyst would not be able to meet the 300-mile block distance determined in the mock schedule. Under the most optimistic efficiency estimations, this scenario is able to complete 4 out of the 7 roundtrips required. Using base and conservative estimations, this scenario could only complete 3 and 2 round-trips, respectively (Figure 3-2). As a representative vehicle of typical 40' BEB capabilities, this scenario demonstrates that either on-route charging or an increase in fleet size will be required when operating 40' BEBs along the WVC.

Figure 3-2. Total Number of Round Trips Possible Under Scenario 40' Base

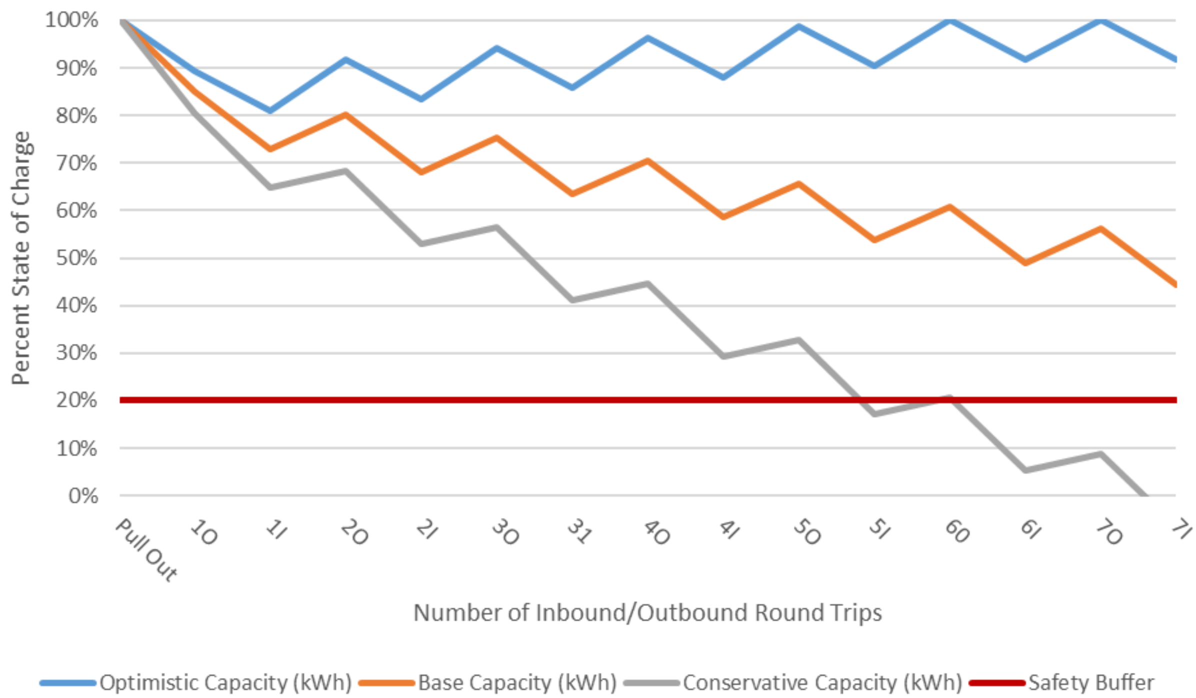


Source: WSP

3.1.2 Scenario On-Route Standard (10 minutes and 12 minutes): Proterra E2 Catalyst (440 kWh)

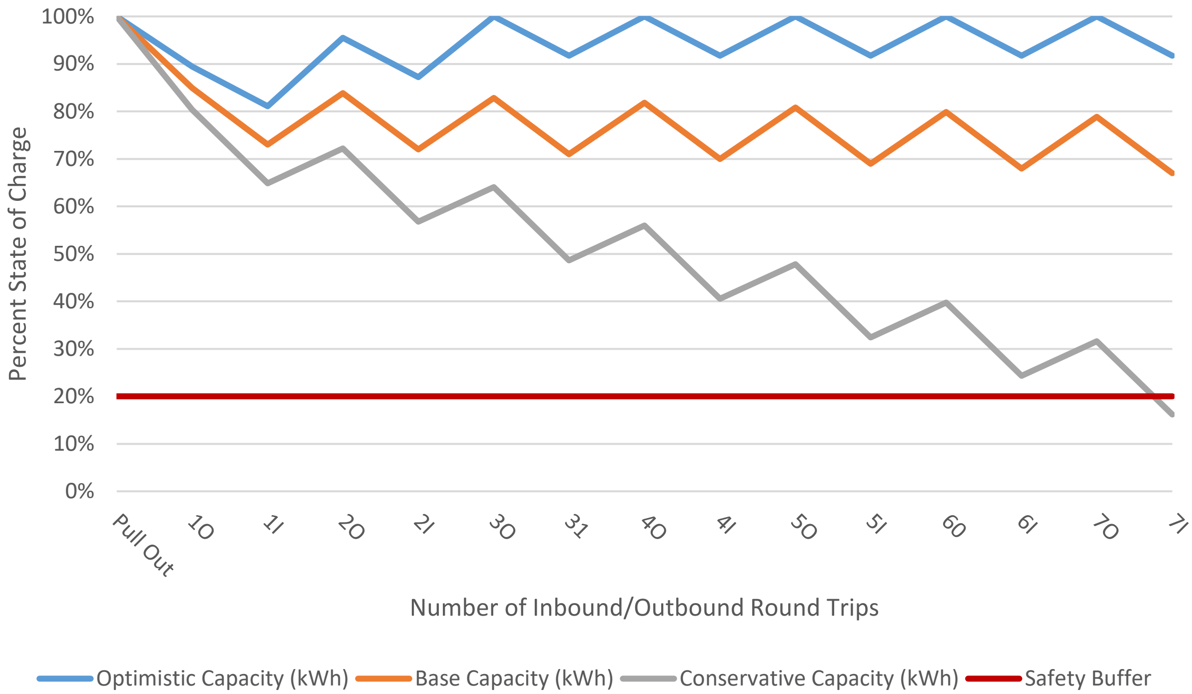
When charging for only 10-minutes at Pomona Regional Transit Center, this scenario was able to meet service goals only for optimistic and base efficiency estimations. Under conservative estimations, the BEBs were only able to complete 67% of the service requirements (Figure 3-3). To ensure service standards were met, additional minutes were added to the on-route charge time until service requirements were met for all three efficiency estimations. The total required on-route charge time under this scenario was 12 minutes (Figure 3-4).

Figure 3-3. Service performance of a 40-foot BEB when using a 500 kW on route charger at Pomona Regional Transit Center for 10-minute charge durations



Source: WSP

Figure 3-4. Service performance of a 40-foot BEB when using a 500 kW on route charger at Pomona Regional Transit Center for 12-minute charge durations



Source: WSP

3.1.3 Scenario On-Route Pre-Charge (10 minutes and 11.5 minutes): Proterra E2 Catalyst (440 kWh)

In an effort to reduce the charging time required during layovers, this analysis evaluated performance of the representative BEB fleet with the addition of one charging opportunity at the head of the route. When charging for only 10 minutes, the performance of this operating scenario closely resembled the standard on-route charging scenario, falling short of service requirements by two round trips under conservative estimations (Figure 3-5). In order to meet service goals with only one on-route charging location, 11.5-minute charge times would be required when using pre-charge strategies (Figure 3-6). If schedule recovery becomes a challenge for the WVC corridor, an additional charging opportunity at the head of the route is recommended to reduce individual charging times throughout the service period.

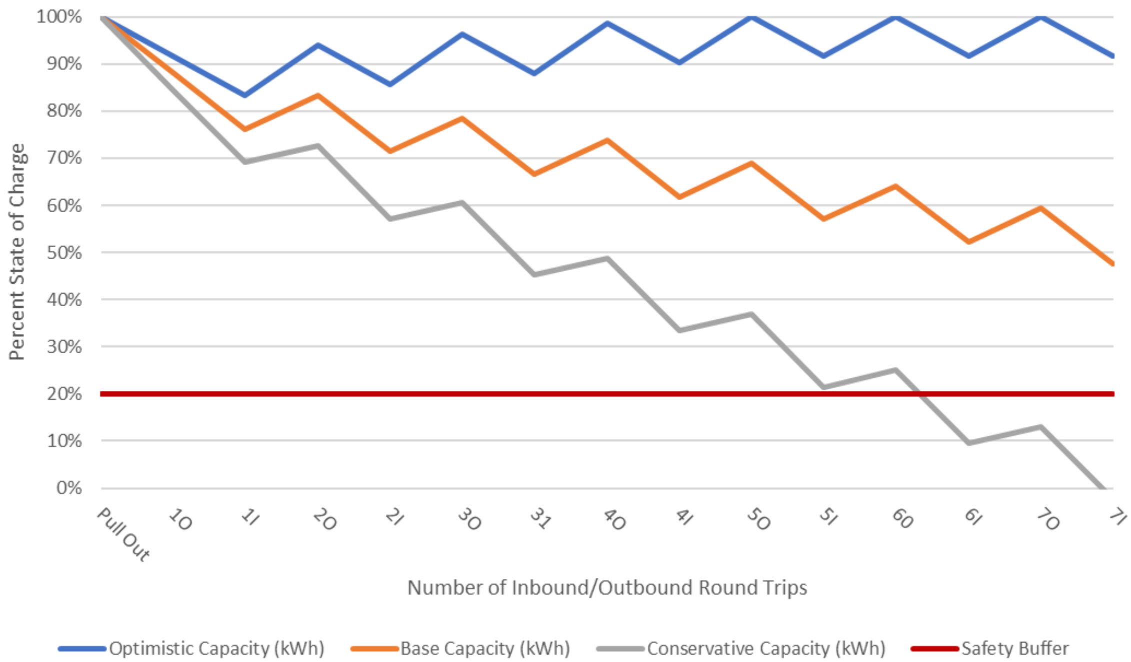
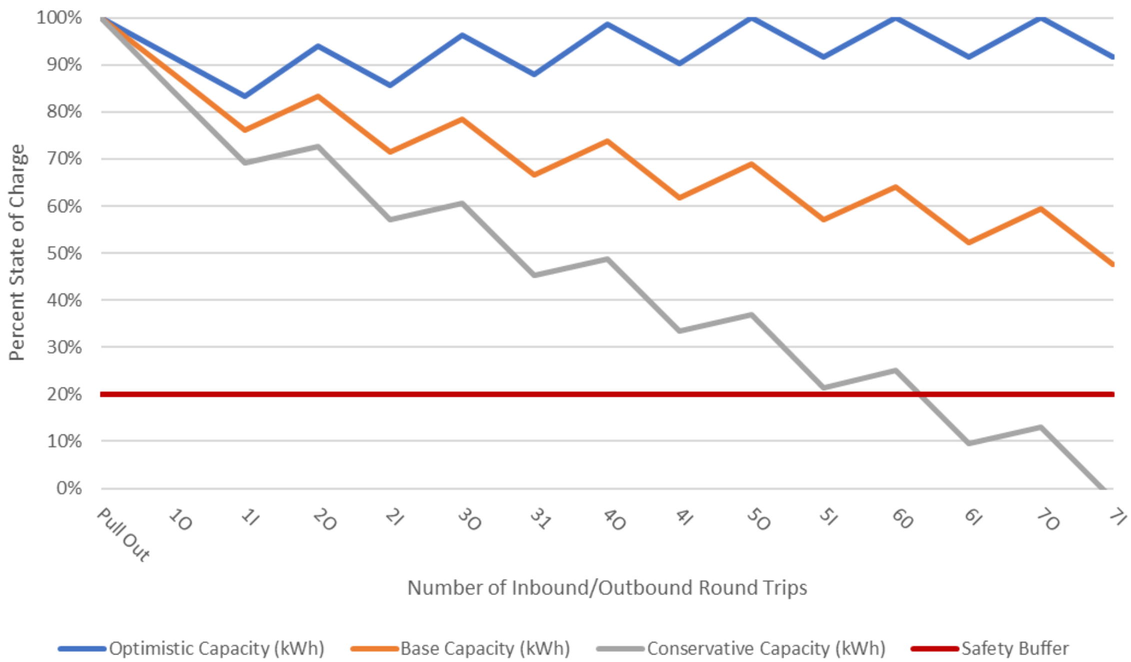
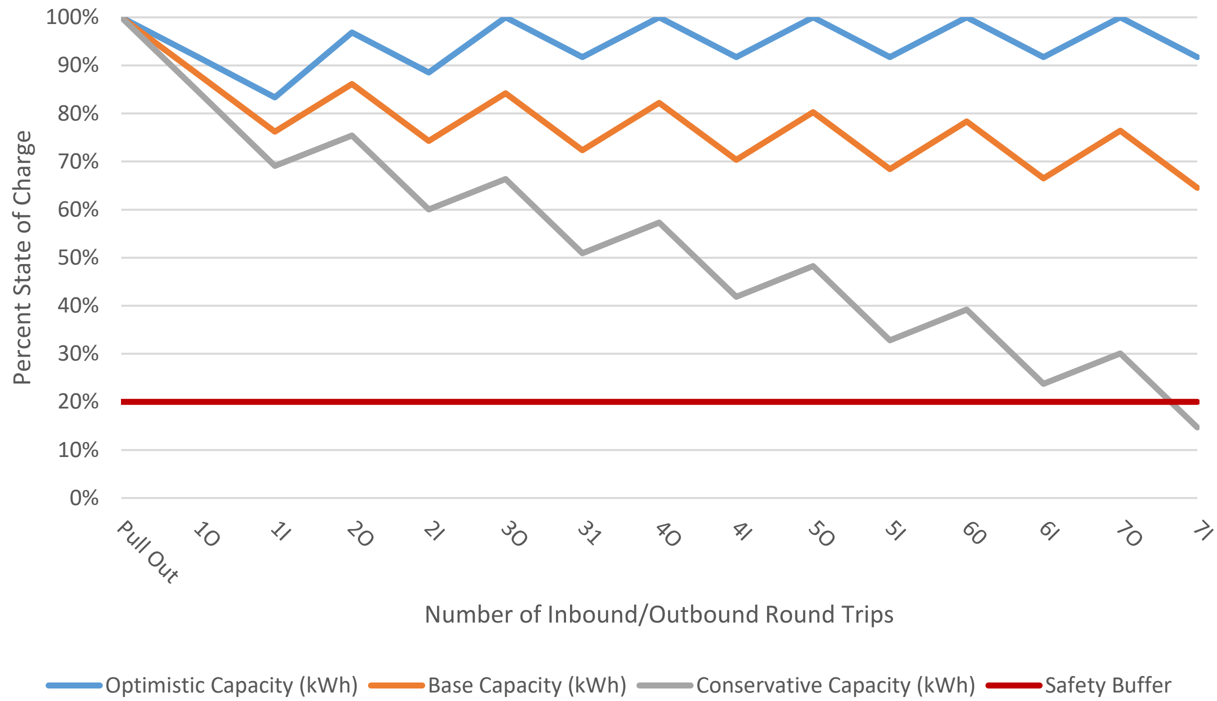


Figure 3-5. Service performance of a 40-foot BEB when using a 500 kW on-route charger at Pomona Transit Center for 10-minute charge times with an additional charging opportunity at the head of the route



Source: WSP

Figure 3-6. Service performance of a 40-foot BEB when using a 500 kW on-route charger at Pomona Transit Center for 11.5-minute charge times with an additional charging opportunity at the head of the route



Source: WSP

3.2 BEB Energy and Power Requirements

Energy required at the bus base was analyzed for each of the modeled scenarios to identify expected demand and consumption when using different charging configurations (base-only and on-route). As noted in Section 3.1, in order to meet service requirements without the use of on-route charging, a significant increase of fleet size would be necessary to support the frequent return trips to the base for recharging. The energy requirements for this operating strategy were modeled using the mock schedule developed for this analysis. For the on-route charging scenarios, a detailed review of energy requirements for based on the best performing scenario (on-route charging with pre-charge) was developed based on the mock schedule and the currently available technologies used throughout the model.

All charging scenarios were evaluated against the Southern California Edison (TOU)-EV-9 rate structure, with and without the use of charge management, to demonstrate the value of staggering bus charging to avoid peak period pricing. Beyond reducing utility costs, the use of charge management may also reduce the required utility infrastructure at the base. A summary of the estimated energy consumption under conservative efficiency estimations for typical weekday operations at the bus base and on-route charging site (Pomona Transit Center) is summarized in Table 3-1.

Table 3-1. Summary of Daily Energy Consumption for Base-Only Charging and On-Route Charging Options

Scenario	Buses in Service	Daily Miles	Energy Consumed at the Base (kWh) (Conservative Efficiency)	Energy Consumed On-Route (kWh) (Conservative Efficiency)
Base Charging Only	19	2,736	11,750	NA
On-Route (with pre-charge)	14	2,507	4,462	5,845

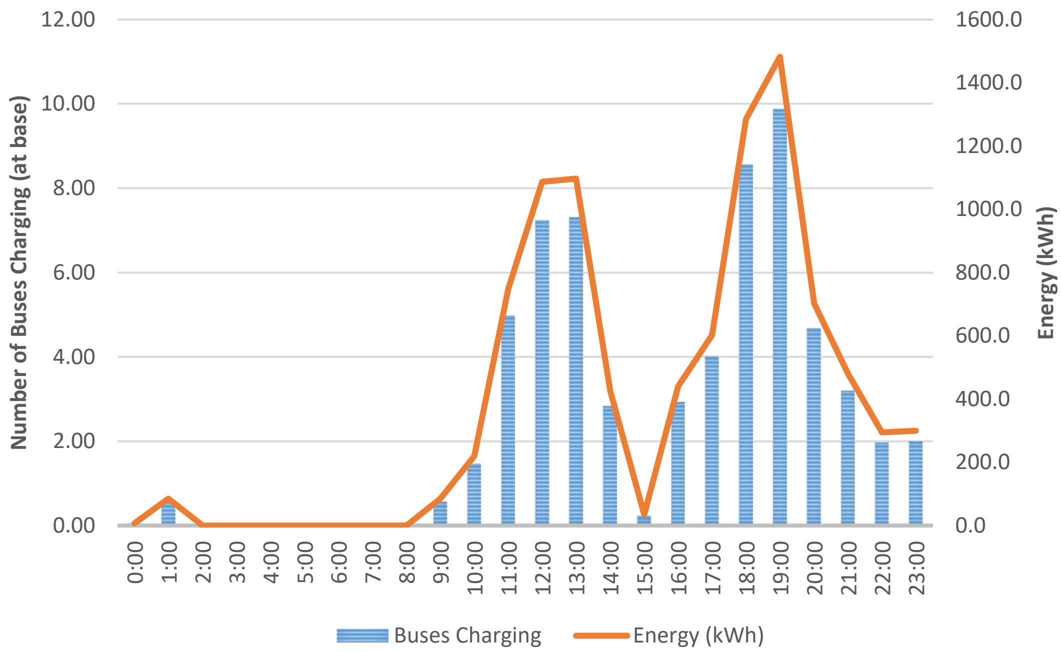
Source: WSP

3.2.1 Scenario Base Charging Only: 19 BEBs - 3.55 kWh/mile efficiency

For the base charging only scenarios to have been feasible, SBCTA would need to either operate BEBs with a battery size of 1,021 kWh (the largest battery currently available is around 660 kWh) or increase the WVC service fleet by 5 BEBs (compared to on-route strategies). Without a large enough battery currently available to meet service requirements, increasing fleet numbers and pull-ins are the only viable option under this scenario.

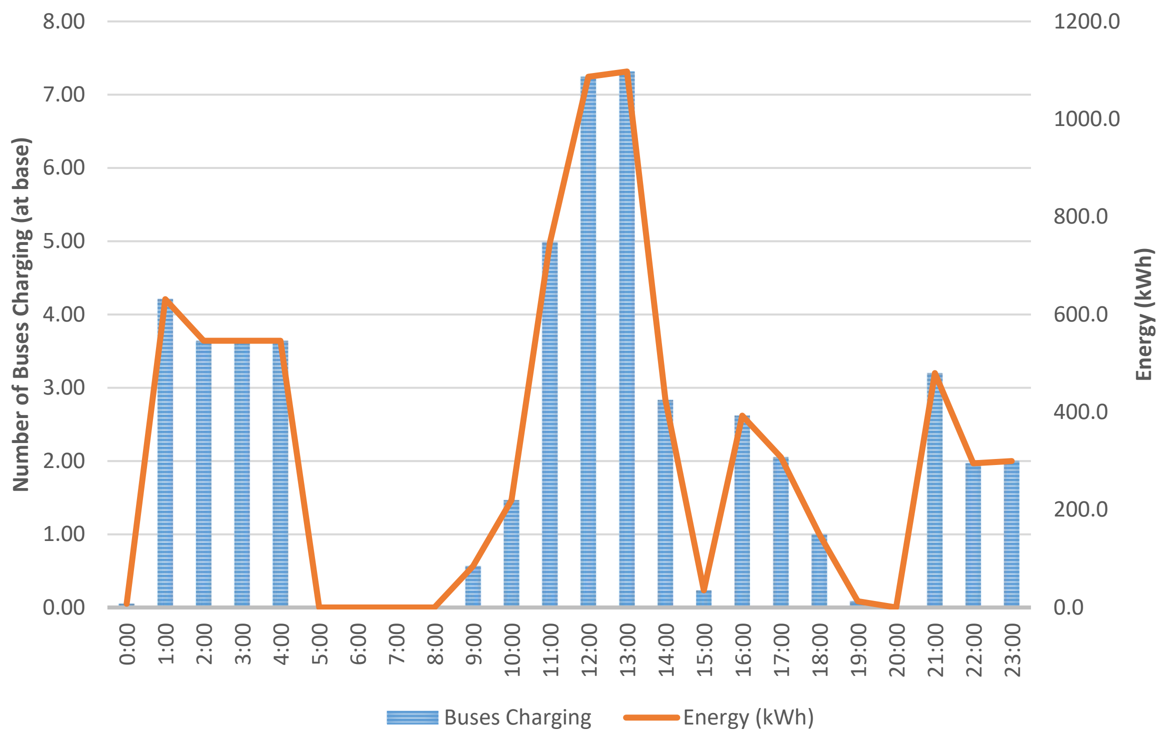
The operation of BEBs without on-route charging on the WVC requires frequent pull-ins for SOC recovery. In the mock schedule developed for this scenario, a total of 39 deadheads were required to meet service parameters. These added deadheads resulted in the addition of 229 miles to the overall fleet mileage compared to the on-route scenario. The BEB battery capacities at all pull-in times throughout the day were used to calculate the energy consumption and associated costs at the base under two charging scenarios: (1) Buses charge immediately upon arriving to the base; and (2) Bus charging is staggered using charge management to reduce utility costs associated with peak pricing periods (Figure 3-7 and Figure 3-8 respectively). This comparison is made to demonstrate the value of Omnitrans continuing to maintain their charge management strategies even as the fleet size increases. Under this scenario, the total daily energy consumption is 11,750 kWh, the peak demand for the minimum chargers required when using 1:2 charging strategies is 7.12 MW.

Figure 3-7. Hour-by-Hour Summary of Number of Buses Charging and Energy Consumption for the Base-Charging Only Scenario without the Use of Charge Management



Source: WSP

Figure 3-8. Hour-by-Hour Summary of Number of Buses Charging and Energy Consumption for the Base-Charging Only Scenario with the Use of Charge Management

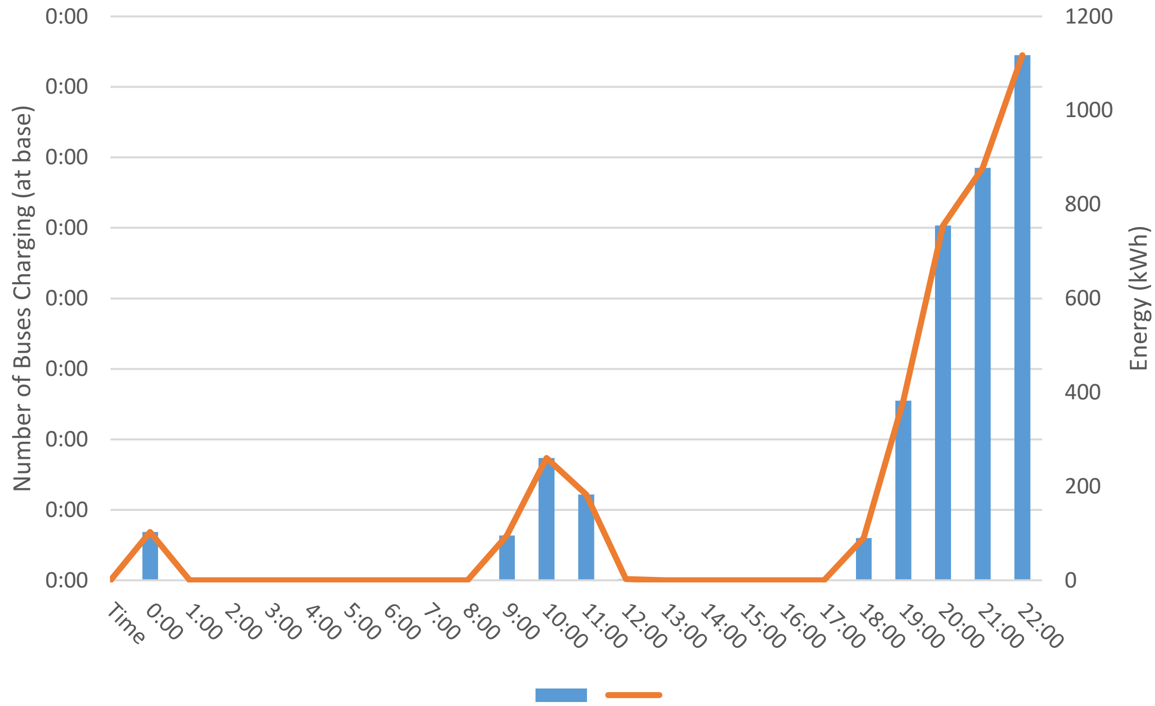


Source: WSP

3.2.2 Scenario On-Route Charging Pre-Charge (11.5 minutes): 19 BEBs - 3.55 kWh/mile efficiency

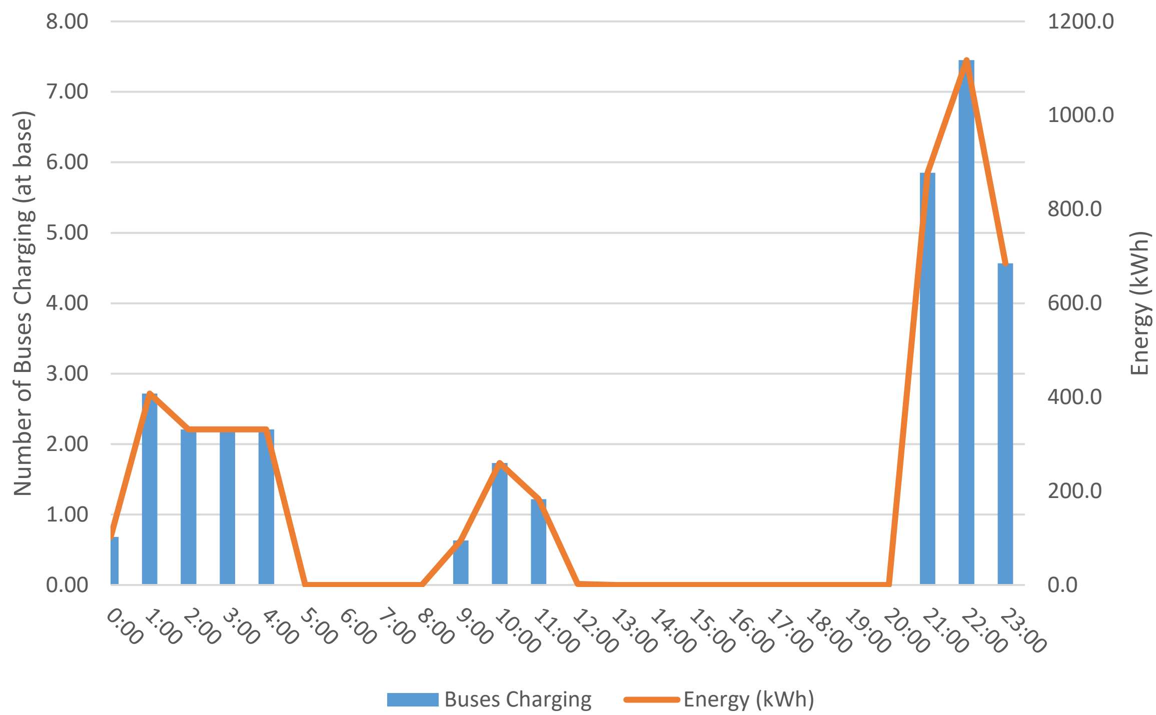
To provide for service needs of the WVC Corridor, the model assumes two on-route chargers located at Pomona Transit Center to serve all 14 buses during each round-trip. Though on-route charging supports the bus's operations throughout the day, the use of base charging is assumed during midday pull-ins (during off-peak hours) and overnight to balance peak demand and meet service needs. For this reason, the on-route charging utility calculations include consumption at the on-route charging location as well as the base. Again, energy consumption at the base is demonstrated with and without charge management strategies to emphasize the value of continuing to avoid peak-period pricing**.** The energy requirements at the on-route charging site assume each of the 14 buses receive an 11.5-minutes charge with a 500 kW charger during each round trip. When both chargers operate simultaneously, the peak demand is 1 MW.

Figure 3-9. Hour-by-Hour Summary of Number of Buses Charging and Energy Consumption for the On-Route Charging Scenario without the Use of Charge Management



Source: WSP

Figure 3-10. Hour-by-Hour Summary of Number of Buses Charging and Energy Consumption for the On-Route Charging Scenario with the Use of Charge Management



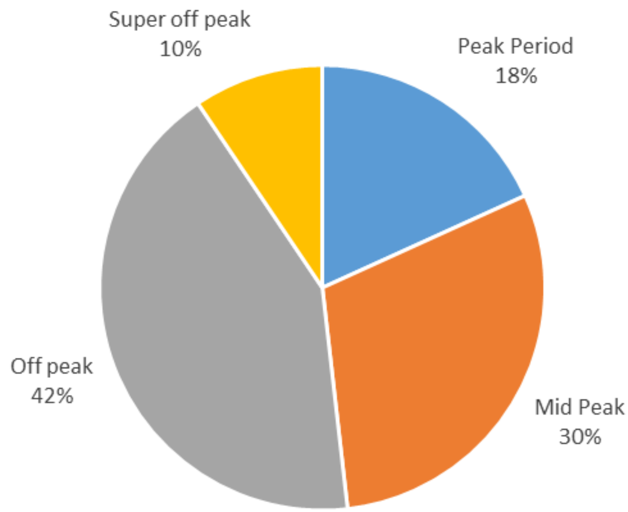
Source: WSP

If future service changes require a larger fleet, more chargers may be added to Pomona Transit Center or another suitable location along the route, which would result in higher consumption rates. Though peak period utility rates cannot be avoided at on-route charging locations, these savings can be realized with charge management strategies at the base. Figure 3-11

Figure 3-11. SCE Time of Use Rate Distribution without Charge Management

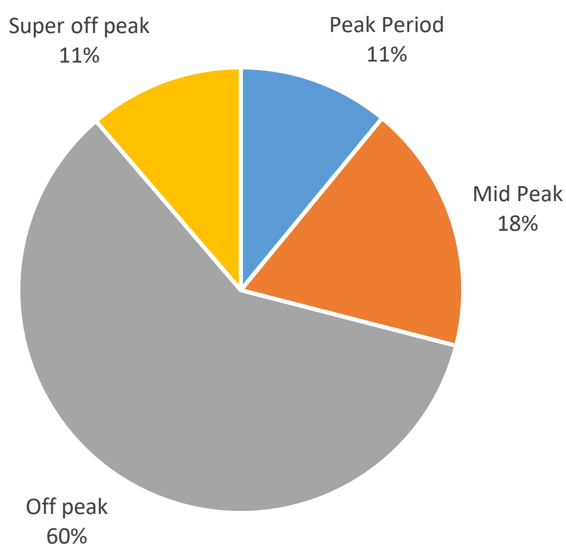
and Figure 3-12 compare the time of use rate distribution with and without charge management at the base. With simple bus staggering strategies, peak period rates can be reduced by 7% and mid peak period rates can be reduced by 12%.

Figure 3-11. SCE Time of Use Rate Distribution without Charge Management



Source: WSP

Figure 3-12. SCE Time of Use Rates Distribution with Charge Management



Source: WSP

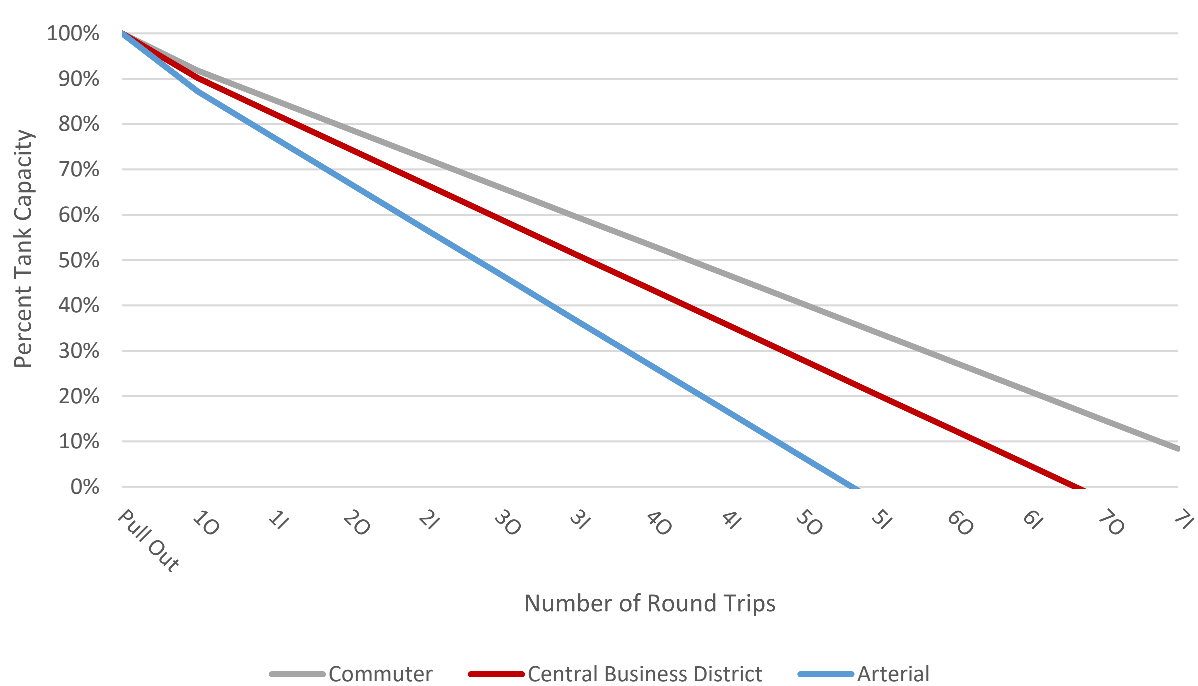
3.3 FCEB Service and Performance

The FCEB evaluation used the calculations of the anticipated range of the 40-foot New Flyer XHE40 (described in Section 2.5.12.4) as a baseline for measuring route performance. Using the mock schedule developed in this analysis, it was determined that with 14 FCEBs operating along the route, a maximum of six roundtrips and a 240-mile block distance is required to meet service parameters. The challenge that arose in the FCEB simulation was that the estimated conservative vehicle range of 190 miles required several of the buses to return to the base to recharge throughout the service period. To avoid pulling each bus in at the same time and significantly increasing the fleet size, the bus pull-ins were staggered to reduce fleet requirements. Using this strategy, several of the buses would complete only a couple of roundtrips before returning to the base, to ensure they could arrive back at the terminus for the next series of pull-ins. As a result, the total number of deadheads was inflated dramatically compared to the on-route BEB schedule. For comparison, the on-route BEB schedule required 17 deadheads and the FCEB schedule required 32 deadheads, resulting in an additional 78 miles traveled in a service period. The following section displays the performance of FCEBs based on the efficiency estimations provided in the Altoona reports with a 5% adjustment to tank capacity. As noted earlier, the FCEB analysis is based on the most conservative (arterial) efficiencies as these most align with the WVC route characteristics as well as documented FCEB performance data.

3.3.1 Scenario 40' FCEB: New Flyer XHE40, 37.5 kg tank

With an estimated range between 190 miles and 298 miles, the New Flyer XHE40 performed well during the route simulation. As demonstrated in the calculations, this vehicle falls short of the necessary roundtrips by only 2 round-trips under the most conservative efficiency estimations. This vehicle performs very well under the efficiency estimations under base and optimistic efficiency estimations where it was capable of meeting or exceeding the 6 required round-trips (Figure 3-13). Since the results of this simulation come very close to meeting service requirements, it is recommended that SBCTA run a pilot of this FCEB to gain refined performance data.

Figure 3-13. Total Number of Round Trips Possible Under Scenario: 40' FCEB



Source: WSP

3.4 FCEB Fuel Requirements

The FCEB hydrogen fuel estimations were determined using the required FCEB fleet size, vehicle miles traveled (according to the mock schedule) and fuel tank capacity for both of the modeled vehicles. Each of these inputs is discussed in greater detail below.

The amount of hydrogen required to power an FCEB fleet during a typical weekday service was determined by dividing the anticipated fleet miles traveled per day (based on the mock schedule) by the estimated vehicle efficiencies. With 61 total daily round-trips and 32 deadhead trips, the total distance traveled by the fleet in a day is 2,663 miles. Using the efficiency estimations outlined in Table 9, the estimated daily fuel consumption was determined for each of the vehicles at all 3 levels of efficiency (Table 3-2). These figures support annual fuel calculations costs in addition to providing context for the amount of fuel required for delivery or on-site production. Based on these figures, the hydrogen requirements for the WVC fleet could reasonably be supported by on-site production via electrolysis or SMR.

Table 3-2. Daily and Annual Hydrogen Fuel Consumption (kG) of FCEB Fleet, Assuming 365 days of

	Optimistic Efficiency (kg)	Base Efficiency (kg)	Conservative Efficiency (kg)
Daily	319	385	499
Annual	116,330	140,411	182,186

Source: WSP

4 PRELIMINARY COST ESTIMATES

4.1 Vehicles and Infrastructure Cost Overview

The costs of ZEBs and associated infrastructure varies widely depending on an array of factors. To begin, most ZEBs manufactured today often encompass some degree of customization to meet the needs of the agency. Customizable features may include battery sizes and/or the number of battery packs (the most expensive single feature on the bus), the number of doors, or an inclusion of an auxiliary heater, to name a few. Also, as an emergent technology, there is a bit of a push and pull with the shifting of price points; traditional economic influences such as inflation may be counterbalanced with a decline in technology costs. In the same sense, savings from economies of scale may be limited by manufacturer constraints. Regarding the cost of charging infrastructure and hydrogen stations, many of these same principals apply with added considerations to electrical capacity and land use. In recognition of these factors, it is apparent that estimating capital costs of ZEBs is a complex and involved process that requires thorough evaluation of the agency's needs and involved conversations with the OEMs. As a result of the shifting nature of ZEB costs and the multitude of considerations that influence infrastructural costs, side-by-side comparisons of BEBs and FCEBs do not represent the full picture for fleet conversions. To provide SBCTA and Omnitrans with a general idea of infrastructural considerations and significant line-items, cost figures for both BEBs and FCEBs were compiled using OEM quotes, recent procurements, and industry reports, which are included below.

4.2 BEB 40' Vehicle and Infrastructure Cost Summary

To estimate the total capital costs for a full BEB transition (buses only) of the WVC Phase 1 BRT route, each unit cost was multiplied by the number of buses and chargers used in the simulations throughout this report. The original WVC fleet assumptions included 18 total buses for route service and spares. Using the mock schedule in this analysis, it appears that this fleet size can be achieved with on-route charging strategies, including the minimum 25% spare ratio. If base-only charging was selected as the preferred operations strategy the fleet size would need to be increased to 24 BEBs including spares. In the utility calculations, estimations of required base and on-route chargers were also made. It should be noted that if using the 1:2 charger to bus configuration, the minimum number of chargers required would be half of the service fleet size. To provide scalability and a level of redundancy, however, this analysis recommends installing a quantity of chargers equal to half of the full fleet (including spares).

The cost values associated with the 40-foot buses and 150 kW chargers represent 2018 purchase prices of New Flyer BEBs by Victor Valley Transit Authority (VVTA), another operator within San Bernardino County, to provide local values. Again, as a rapidly evolving market, it is likely that these prices will shift in the near future. Based on the provided figures, Omnitrans may expect capital costs of $903.7K for the individual 40-foot BEBs. It is becoming standard practice in the industry for BEB manufacturers to offer a 12-year battery warranty in the contract agreement. For this reason, this warranty is assumed in the estimated purchase price and battery replacements are not factored in. In the event that Omnitrans does not negotiate a battery warranty in the original purchase contract, an additional $80,767 should be added to the individual bus costs to account for midlife overhauls. The total upfront capital cost for BEBs under the on-route charging scenario, with the assumption of 18 total buses, is showcased as $16.3

million. If using base-only charging strategies, the total capital costs for a 24-bus fleet is $21.6 million (Table 4-1). Thus, the total capital costs for the vehicles may be reduced by more than $5 million when using on-route charging strategies.

Charger costs may also vary depending on the technology used (DC or AC) and installation costs. In this analysis, plug-in chargers are assumed to cost $70,701, based on a recent VVTA contract. [11] Additionally, the cost to install the chargers, with consideration to labor and permits, is assumed to cost $8,500 per charger installation. On-route chargers have a significantly higher upfront capital investment of $349,000 with installation costs of $150,000, based on experience at Foothill Transit which also operates on-route chargers at the Pomona Transit Center[12]. In total, when operating with on-route charging strategies (9 base chargers and 2 on-route chargers), the total cost of chargers is estimated at $1,710,809 (Table 4-2). If Omnitrans elected to move forward with base-only charging, twelve chargers would be required, totaling $950,412 (Table 4-3).

Table 4-1. 40' BEB Vehicle Option Unit Cost and Total Costs for On-Route Charging Strategies and Base-Only Charging Strategies

Charging Configuration	Length (feet)	Base Buy	Total Units	Total Cost
On-Route	40	$903,680	18	$16,266,240
Base Only	40	$903,680	24	$21,688,320

Source: WSP

Table 4-2. Charger Unit Cost and Total Costs for Charger Configurations to Support On-Route Charging Strategies

Charger Type	Power (kW)	Price per Unit	Install Cost	Total Units	Total Cost
Base DC (2018)	150	$70,701	$8,500	9	$712,809
On-Route DC (2016)	500	$349,000	$150,000	2	$988,000

Source: WSP

Table 4-3. Charger Unit Cost and Total Costs for Charger Configurations to Support Base-Only Charging Strategies

Charger Type	Power (kW)	Price per Unit	Install Cost	Total Units	Total Cost
Base DC (2018)	150	$70,701	$8,500	12	$950,412

Source: WSP

4.3 BEB 40' Operations and Maintenance Costs

Operations and maintenance (O&M) costs were calculated for each year of the bus' anticipated 12-year lifespan. The elements considered in the estimation of O&M costs include vehicle maintenance, vehicle tools, training and personal protective equipment, and the costs to maintain and operate charging/fueling infrastructure. This analysis applies unit O&M costs per mile by bus type. Ultimately, total costs are driven by unit costs and bus mileage. The financial model accounts

[11] Victor Valley New Flyer Purchase of 40 ft BEB buses, Purchase Order 1197 dated November 6 2018.

[12] National Renewable Energy Lab (U.S). Foothill Transit Battery Electric Bus Demonstration Report. 2016. https://www.nrel.gov/docs/fy16osti/65274.pdf

for changes to service levels to estimate O&M costs, by applying unit costs to total mileage as driven by number of buses and mileage per bus.

The lifetime O&M costs were calculated for the BEB on-route charging scenario as well as the BEB base-charging only scenario. The unit cost remains the same between the 2 scenarios, however, as the annual mileage under the base-only charging scenario is greater than the on-route charging scenario, a lifetime total cost difference of more than $500K exists (Table 4-4 and Table 4-5).

Table 4-4. Estimated Lifetime Operations and Maintenance Costs under the BEB On-Route Charging Scenario

Bus Age	Cost Per Mile	Annual Mileage	Total Costs
Year 1	$0.34	915,055	$311,119
Year 2	$0.30	915,055	$274,517
Year 3	$0.30	915,055	$274,517
Year 4	$0.35	915,055	$320,269
Year 5	$0.42	915,055	$384,323
Year 6	$0.46	915,055	$420,925
Year 7	$0.52	915,055	$475,829
Year 8	$0.59	915,055	$539,882
Year 9	$0.68	915,055	$622,237
Year 10	$0.79	915,055	$722,893
Year 11	$0.93	915,055	$851,001
Year 12	$1.10	915,055	$1,006,561
		Total	**$6,204,073**

Source: WSP

Table 4-5. Estimated Lifetime Operations and Maintenance Costs under the BEB Base Only Charging Scenario

Bus Age	Cost Per Mile	Annual Mileage	Total Costs
Year 1	$0.34	998,567	$339,513
Year 2	$0.30	998,567	$299,570
Year 3	$0.30	998,567	$299,570
Year 4	$0.35	998,567	$349,498
Year 5	$0.42	998,567	$419,398
Year 6	$0.46	998,567	$459,341
Year 7	$0.52	998,567	$519,255
Year 8	$0.59	998,567	$589,155
Year 9	$0.68	998,567	$679,026
Year 10	$0.79	998,567	$788,868
Year 11	$0.93	998,567	$928,667
Year 12	$1.10	998,567	$1,098,424
			$6,770,284

Source: WSP

BEB 40' Utility Costs

This analysis also provides estimates associated with energy and peak demand costs. The rates used in these calculations were sourced from Southern California Edison Utility and represent (TOU)-EV-9 rates. Utility providers encourage off-peak charging by elevating utility costs during peak hours when there is a significant draw on the overall grid capacity (e.g. during hot summer months). For this reason, EV rates are conducive to charging during non-peak hours, which discourages base charging from 4:00-9:00 PM. This is in line with Omnitrans' current energy management strategies and should carry forward as the fleet size expands. Though weekend and holiday utility rates are calculated into the total cost estimates, the fleet energy requirements are based on 365 days of typical weekday operations to remain consistent with the assumptions used throughout this analysis.

Annual utility cost estimates are provided for each of the scenarios modeled and their respective operating schedules. Without the use of charge management, total annual utility costs are $598K and $507K for base charging only and on-route charging scenarios respectively, yielding a total cost differential of $90K per year (Table 4-6). Conversely, when charge management strategies are maintained by the agency, the annual utility costs for the base-only charging strategy is $424K, and the annual cost with on-route charging is $434K (Source: WSP

Table 4-7). Though the base-only strategy is serving more buses throughout the day with increased deadheads, the total energy costs for the on-route charging scenario when using charge management is higher as a result of additional service fees and unavoidable peak period costs at the on-route location. Again, the dramatic shift in operating costs with and without the use of charge management are presented to highlight the benefit of Omnitrans' current energy management strategies.

Table 4-6. Annual Energy and Demand Costs for Two 40' Operating Scenarios. (Without Demand Management)

Without Charge Management	Base Charging Only	On-Route Charging
Buses in Service	19	14
Daily Energy Use (kWh)	11750	10309
Base Energy Costs	$594,869	$240,115
Base Demand Fees	NA	NA
Base Service Fee	$2,775	$2,775
On Route Energy	NA	$261,352
On Route Demand Fees	NA	NA
On-Route Service Fee	NA	$2,775
Total	**$597,644**	**$507,016**

Source: WSP

Table 4-7. Annual Energy and Demand Costs for Two 40' Operating Scenarios. (With Demand Management)

With Charge Management	Base Charging Only	On-Route Charging
Base Energy	$420,759	$169,837
Base Demand	NA	NA
Base Service Fee	$2,775	$2,775
On Route Energy	-	$261,352
On Route Demand	-	NA
On-Route Service Fee	-	$2,775
Total	**$423,534**	**$433,963**

Source: WSP

4.4 BEB 40' Total Cost Breakdown

Since it has already been established that charge management is the preferred option, overall cost comparisons for base-charging only strategies and on-route charging strategies are provided assuming charge management is employed. With all cost components in place, it becomes clear that BEB operations with the use of on-route charging is significantly more cost advantageous than increasing the fleet size to provide base-only charging with a total savings exceeding $4 million. Beyond the savings highlighted in the sections above, this option also reduces associated operator wages. Each of the factors considered in the sections above are consolidated in Table 4-8 which demonstrate total costs for operating BEBs under the base-charging only and on-route charging scenarios.

Table 4-8. Total 40' BEB Operating Costs for On-Route Scenarios, Including Capital and Utility Costs

Without Demand Management		Base Charging Only	On-Route Charging
Capital Costs	Battery-Electric Buses	$21,688,320	$16,266,240
	Base Chargers	$950,412	$712,809
	On-Route Chargers	NA	$998,000
Capital Costs Subtotal		*$22,638,732*	*$17,977,049*
Bus Base Utility Costs	Bus Base Energy Charges	$420,759	$169,837
	Bus Base Demand Charges	NA	NA
	Bus Base Service Charge	$2,775	$2,775
On-Route Charging Utility Costs	On-Route Energy Charges	NA	$261,352
	On-Route Demand Charges	NA	NA
	On-Route Service Charge	NA	$2,775
Utility Charges Subtotal		*$423,534*	*$436,738*
Vehicle Maintenance		*$6,204,073*	*$6,770,284*
Total		**$29,266,339**	**$25,184,071**

Source: WSP

4.5 FCEB 40' Vehicle Cost Summary

Similar to BEBs, procurement costs of FCEBs are constantly changing with technological developments. The vehicle prices used in this analysis are the current rates provided in the California Department of General Services contracts for 40-foot New Flyer fuel cell buses[13]. Based on operational feasibility and range limitations, the total base number of units required for purchase is 20 buses, including 4 spares. In addition to the upfront costs, FCEBs typically require a fuel cell replacement after 6 years, which costs approximately $22,500, according to representatives at Ballard Power Systems Inc. The total capital costs for required FCEBs and fuel cell replacements is $20.7 million (Table 4-9).

Table 4-9. 60' FCEB Vehicle Unit and Total Costs for 18 and 17 Buses (Based on Operational Feasibility)

OEM	Length (feet)	Base buy	Fuel Cell Replacement	Total units	Total Cost
New Flyer	40	$1,014,978	$22,500	24	$20,749,560

Source: WSP

4.6 FCEB 40' Operations and Maintenance Costs

O&M costs for FCEBs were calculated in a similar manner as BEBs, albeit adjusted to the needs of the fuel cell technology. The elements considered in this estimation include vehicle maintenance, vehicle tools, training and personal protective equipment, and the costs to maintain and operate charging/fueling infrastructure. This analysis applies unit O&M costs per mile by bus type. Ultimately, total costs are driven by unit costs and bus mileage. The financial model accounts for

[13] Source: Cal eProcure Contract, California Department of General Services, December 2019

changes to service levels to estimate O&M costs, by applying unit costs to total mileage as driven by number of buses and mileage per bus.

Over the anticipated 12-year life of the bus, an FCEB fleet operating along the WVC can expect to incur $9.2 million in O&M costs (Table 4-10).

Table 4-10. Estimated Lifetime Operations and Maintenance Costs under the FCEB Scenario

Bus Age	Cost Per Mile	Annual Mileage	Total Costs
Year 1	$0.48	971,995	$466,558
Year 2	$0.42	971,995	$408,238
Year 3	$0.42	971,995	$408,238
Year 4	$0.49	971,995	$476,278
Year 5	$0.58	971,995	$563,757
Year 6	$0.65	971,995	$631,797
Year 7	$0.73	971,995	$709,556
Year 8	$0.83	971,995	$806,756
Year 9	$0.95	971,995	$923,395
Year 10	$1.11	971,995	$1,078,914
Year 11	$1.30	971,995	$1,263,594
Year 12	$1.54	971,995	$1,496,872
		Total	**$9,233,953**

4.7 FCEB 40' Infrastructure & Fuel Costs Summary

Compared to BEBs, the upfront capital required for hydrogen production or sourcing is quite intensive. The 900kg electrolyser, two fuel dispensers, compression and storage tanks, as well as safety equipment amounted to a total of $8.3 million (Table 4-13). Though quite a significant investment, externally sourcing hydrogen fuel comes at a much greater cost over time due to supply chain concerns incurred by transportation and transmission charges. Firms such as Clean Energy and Air Liquide promise to install the necessary capital infrastructure, maintain said infrastructure, and charge the agency a fee for all services of hydrogen delivery. However, contracted services for hydrogen can escalate to upwards of $30 per kg[14] whereas electrolysis allows for production at a cost of $7 per kg (Table 4-11).[15] However, rates as low as $9.08 per kg have been reported by hydrogen provider Clean Energy.

The results of the model along with hydrogen technology feasibility considerations were used to identify viable strategies for sourcing hydrogen fuel. The primary factor taken into account was the daily hydrogen requirements. Using the most conservative estimation, any hydrogen equipment considered to service the WVC fleet would need to output a minimum of 499 kg per day. This quantity could reasonably be provided via liquid delivery, SMR, or electrolysis. If sourcing

[14] Source: "Fuel Cell Buses in U.S. Transit Fleets" *Eudy, Leslie and Post, Matthew; National Renewable Labs, September 2018*

[15] Source: SunLine Transit, September 2019.

via liquid delivery, the hydrogen could be stored in a vertical 9,000-gallon or 15,000-gallon tank. This cost analysis assumed a 15,000-gallon tank to extend delivery intervals to every eight days. Liquid tanks have the option of being purchased outright or leased monthly. Though purchasing a tank requires in-house maintenance, this value was used in the cost analysis to provide lifetime capital cost estimations. If Omnitrans elects to lease a tank, they can expect to pay approximately $8,000 per month for a 15,000-gallon tank.

If Omnitrans opted for on-site hydrogen production, SMR and electrolysis are both viable options. Based on the fleet's daily hydrogen need, a 540 kg SMR unit would be suitable to maintain daily operations. On-site production at this scale has the potential to require less of a footprint than liquid delivery, potentially alleviating space constraints, however, detailed site evaluations should be conducted if Omnitrans elects to move forward with either technology. These can be made available in containerized systems which can easily be scaled up if the fleet expands. Under the conservative estimations, the hydrogen requirement slightly exceeds the capacity of a 445 kg electrolyser, which is significantly less expensive than a 900 kg electrolyser (~$3.8 million vs. $8.3 million). To maintain conservative estimations and to provide future-readiness, however, the 900 kg electrolyser was assumed in the calculations.

Hydrogen fuel costs for each of the sources described above were sourced from research literature and conversations with local suppliers. The fuel costs used in this analysis do not reflect local utility rates or the use of on-site energy production but offer a general sense of anticipated delivery and production costs. Table 4-11 highlights the cost per kg of each method of hydrogen sourcing described above. Using these values, the total annual hydrogen cost based on the 3 levels of efficiency used throughout this analysis are demonstrated in Table 4-12.

Table 4-11. Estimated Hydrogen Fuel Costs Per kg for Three Methods of Sourcing

Method	Cost
Delivery Cost (per kg)	$9.50[16]
Electrolysis Cost (per kg)	$7.00[17]
SMR Cost (per kg)	$6.00[18]

Source: WSP

Table 4-12. Annual Hydrogen Requirements and Costs for Three Methods of Sourcing Using Three Efficiency Estimations

Method	Optimistic	Base	Conservative
Annual Hydrogen Requirements (kg)	116,330	140,411	182,186
Delivery Cost	$1,105,133	$1,333,903	$1,730,767
Electrolysis Cost	$814,309	$982,876	$1,275,302
SMR Cost	$697,979	$842,465	$1,093,116

Source: WSP

For instance, SunLine Transit in the Coachella Valley recently installed a hydrogen electrolyser production plant. The electrolyser, 2 fuel dispensers, compression and storage tanks, as well as

[16] CleanEnergy OCTA 2017 data adjusted to 2019

[17] Reported by SunLine Transit Agency in September 2019

[18] Ballard FCEB white Paper. 2018

safety equipment amounted to a total of $8.3 million (Table 4-13). Though quite a significant investment, externally sourcing hydrogen fuel comes at a much greater cost due to supply chain concerns incurred by transportation and transmission charges. Firms such as Clean Energy and Air Liquide promise to install the necessary capital infrastructure, maintain said infrastructure, and charge the agency a fee for all services of hydrogen delivery. However, contracted services for hydrogen can escalate to upwards of $30 per kg whereas electrolysis allows for production at a cost of $7 per kg. However, rates as low as $9.08 per kg have been reported by hydrogen provider Clean Energy.

The results of the model along with hydrogen technology feasibility considerations were used to identify viable strategies for sourcing hydrogen fuel. The primary factor taken into account was the daily hydrogen requirements. Using the most conservative estimation, any hydrogen equipment considered to service the WVC fleet would need to output a minimum of 499 kg per day. This quantity could reasonably be provided via liquid delivery, SMR, or electrolysis. If sourcing via liquid delivery, the hydrogen could be stored in a vertical 9,000- gallon or 15,000--gallon tank. This cost analysis assumed a 15,000-gallon tank to extend delivery intervals to every eight8 days. Liquid tanks have the option of being purchased outright or leased monthly. Though purchasing a tank requires in-house maintenance, this value was used in the cost analysis to provide lifetime capital cost estimations. If Omnitrans elects to lease a tank, they can expect to pay approximately $8,000 per month for a 15,000-gallon tank.

If Omnitrans opted for on-site hydrogen production, SMR and electrolysis are both viable options. Based on the fleet's daily hydrogen need, a 540 kg SMR unit would be suitable to maintain daily operations. These can be made available in containerized systems which can easily be scaled up if the fleet expands. Under the conservative estimations, the hydrogen requirement slightly exceeds the capacity of a 445 kg electrolyser, which is significantly less expensive than a 900 kg electrolyser (~$3.8 million vs. $8.3 million). To maintain conservative estimations and to provide future-readiness, however, the 900 kg electrolyser was assumed in the calculations.

Hydrogen fuel costs for each of the sources described above were sourced from research literature and conversations with local suppliers. The fuel costs used in this analysis do not reflect local utility rates or the use of on-site energy production but offer a general sense of anticipated delivery and production costs.

The cost analysis for hydrogen infrastructure includes the total cost of equipment, including dispensers, compression, and storage. Additional storage is added to SMR and electrolysis methods to provide redundancy in case of production system failure. Also included in the analysis, are associated construction costs according to equipment suppliers and reported costs from SunLine Transit's electrolyser installation. In total, the infrastructural costs are $5.3 million, $8.3 million, and $5.2 million for SMR, electrolysis, and liquid delivery (Table 4-13). Though liquid delivery offers lower up-front capital costs, over the life of the bus, on-site production would prove to be more cost effective, especially if renewable energy production was used to power the equipment.

Table 4-13. 40' FCEB Capital Costs per Source Method

Capital Costs	Internal		External
Equipment	**SMR 540 kg**	**Electrolysis 900 kg**	**Liquid Delivery**
SMR	$3,599,721	NA	NA
Electrolyser	NA	$4,446,000	NA
Liquid Storage Tank (15,000 gallon)	NA	NA	$700,000
Dispenser	$200,000	$200,000	$200,000
Compression, Fueling, Storage	$712,000	$1,650,000	$2,800,000
Additional Storage	$204,000	$204,000	NA
Construction	$600,000	$1,800,000	$1,500,000
Total	**$5,315,721**	**$8,300,000**	**$5,200,000**

Source: WSP

4.8 FCEB 40' Total Cost Breakdown

An aggregated breakdown of fuel costs, capital infrastructure, and bus fleet purchase is provided for the first year of operation as well as forecasted out over twelve years for each fuel source (Table 4-14 and Table 4-15). The purpose of this data is to compare the lifetime costs (12 years) to operate FCEBs using each of the considered fuel sources. The first-year costs including fleet acquisitions, infrastructure, and fuel costs are $27.6 million, $30.7 million and $28.1 million for SMR, electrolysis, and liquid delivery, respectively. Making SMR the least-cost option followed by liquid delivery. With fuel costs extended over a 12-year period, the lifetime cost of the fleet is $48.4 million, $53.6 million, and $56.0 million. While the capital investment of electrolysis is vast, the return on investment yields a net positive compared to leasing equipment. However, if leasing on-site storage, maintenance costs are included in the leasehold agreement, therefore major overhauls are covered by the fuel supplier. A significant investment must be made regardless of adoption strategy, further funding mechanisms must be explored, with careful consideration made prior to committing to either investment.

Table 4-14. FCEB 40' Vehicle, Fuel, and Infrastructure Costs in the First Year of Operation

	Internal		External
	SMR 540 kg	**Electrolysis 900 kg**	**Liquid Delivery**
FCEB Buses	$20,749,560	$20,749,560	$20,749,560
Infrastructure Costs	$5,315,721	$8,300,000	$5,200,000
Fuel Costs	$1,093,116	$1,275,302	$1,730,767
Operations and Maintenance Costs	$466,558	$466,558	$466,558
Total	**$27,624,954**	**$30,791,419**	**$28,146,884**

Source: WSP

Table 4-15. FCEB 40’ Vehicle, Fuel, and Infrastructure Costs over a 12-Year Period

	Internal		External
	SMR 540 kg	**Electrolysis 900 kg**	**Liquid Delivery**
FCEB Buses	$20,749,560	$20,749,560	$20,749,560
Infrastructure Costs	$5,315,721	$8,300,000	$5,200,000
Fuel Costs	$13,117,390	$15,303,621	$20,769,200
Operations and Maintenance Costs	$9,233,953	$9,233,953	$9,233,953
Total	**$48,416,623**	**$53,587,134**	**$55,952,713**

Source: WSP

4.9 FCEB Versus BEB Total Cost Comparison

The following data is a very high-level comparison of total costs for both BEB and FCEB technologies. The least cost approach to BEB operations is through the deployment of 2 on-route chargers, with a total capital and first-year utility cost totaling $18.9 million. The least cost option for FCEB operations is the use of an on-site SMR unit, totaling $27.9 million. Based on initial observations, FCEB technology requires significantly higher capital costs, upwards of $9 million in additional funding versus a 40’ BEB fleet purchase, including utility costs and charging infrastructure (Table 4-16). Several limitations of this analysis include labor costs and additional grid/transformer upgrades needed to facilitate the integration of BEBs at a new maintenance and storage facility. Furthermore, this does not consider future technological advances, reduced costs, or scalability of hydrogen fuel supply. Integration with existing on-route chargers at the Pomona Regional Transit Center allows for interagency collaboration and is not quantifiable in terms of cost in this analysis. Yet, this is a significant resource available to Omnitrans and utilization of said existing infrastructure must be notated as an additional asset available for BEB adoption.

Table 4-16. 40’ BEB vs. 40’ FCEB Comparison[1]

Technology	BEB Base Only	BEB On-Route	FCEB SMR	FCEB Electrolysis	FCEB Delivery
Capital Costs	$22,638,732	$17,977,049	$26,065,281	$29,049,560	$25,949,560
Annual Fuel Costs	$423,534	$436,738	$1,093,116	$1,275,302	$1,730,767
Average Annual Maintenance Costs	$564,190	$517,006	$769,496	$769,496	$769,496
Total	**$23,626,456**	**$18,930,793**	**$27,927,893**	**$31,094,358**	**$28,449,823**

Source: WSP

[1]Analysis performed by WSP with supplied data

5 FINDINGS AND RECOMMENDATIONS

In this document, the WSP team evaluated multiple scenarios to identify viable strategies for successful integration of ZEBs for the WVC BRT. This section provides findings and next steps for ZEB implementation. These were based on highly conservative estimations of anticipated operations scheduling to represent performance under worst-case scenarios. For a broader range of feasible strategies, more refined modeling can be achieved once a detailed schedule and operations information are confirmed.

5.1 BEB Findings

1. If operating BEBs, a combination of base and on-route charging is required to meet the service requirements of the WVC. At best, a bus would only be able to complete approximately 67% of its service requirements under the most optimistic estimations without on-route charging.

2. To prevent bus bunching and service delays, 2 500 kW on-route chargers will be required at Pomona Transit Center. Meeting service requirements for the longest-running block requires charging the buses for 11.5 minutes during each layover. This is 1.5 minutes more than recommended charge times within a 15-minute layover period; however, the additional charge may not be necessary with technological advances when the line opens in 2024. To prevent bus bunching, it is suggested that two 500-kW chargers be available to service buses during 15-minute layovers.

3. Foothill Transit currently operates 2 on-route chargers at Pomona Regional Transit Center. Cross-agency discussions should be conducted to identify joint venture opportunities.

4. The use of charge management tools significantly reduces costs associated with BEB operations and may allow Omnitrans to reduce the number of chargers at the base as they scale up the fleet.

5.2 FCEB Findings

1. FCEBs have a longer range than BEBs, although since the range does not currently meet the requirements for WVC blocks, more frequent return trips to the base are required for refueling. To reduce the total number of deadheads required for refueling, Omnitrans could increase the fleet size, however this would result in higher upfront capital costs and on-going operational costs.

2. Hydrogen fuel is in limited supply, therefore SBCTA/Omnitrans should begin preliminary fuel negotiations immediately if it is determined to move forward with FCEB procurements. Interagency collaboration, joint-ventures, and countywide operator coordination allow for shared resources and intensive capital projects, such as hydrogen gas production. A shared hydrogen program with VVTA may also be considered to reduce costs.

3. When comparing external fuel and internal fuel production, benefits and drawbacks exist for each modality. Both options will require Omnitrans to install storage equipment at the base. Ultimately, equipment may either be purchased or leased. If leased, outside contractors may perform all maintenance and troubleshooting on the equipment, albeit with ongoing associated costs, including delivery fees. Omnitrans may also elect to invest in an on-site SMR unit or electrolyser for hydrogen production. Though this option requires significant upfront capital costs, a return on investment may be seen in as early as 5 years. This option also eliminates the need to continually identify viable sources of fuel in the case that demand exceeds production. Additionally, grant funding is available to produce renewable hydrogen gas, as in the case of the electrolyser at SunLine Transit. Consideration of the rapidly shifting cost of fuel must be considered in long-term planning.

5.3 Next Steps

5.3.1 Recommendations and Considerations

1. Technology: Based on current technological costs and performance outlined in this report, WSP recommends pursuing a BEB fleet with on-route charging for the first phase of WVC procurements. The upfront capital costs for 40-foot BEBs is currently more than $100,000 less than 40-foot FCEBs on the market; and the volatility of hydrogen prices make planning for long-term operations unpredictable. 40-foot BEBs allow for faster implementation, lower capital costs, and operational flexibility with other routes in the Omnitrans network. **Specifically, the WSP team recommends procuring a total of 18 40- foot BEBs with a battery capacity of at least 440 kWh**. As a rapidly evolving zero-emission technology, however, FCEBs should continue to be considered for future zero-emission procurements. Ultimately, operating a mix of ZEB technologies may serve Omnitrans operationally as well as provide for greater resilience in the face of extended power outages or emergency evacuations.

2. On-Route Charging: Based on the results of the simulation, **2 on-route 500kW chargers located at Pomona Transit Center are recommended for WVC service. To maintain service, each bus should charge at the head of the route (prior to beginning service) and during each layover for a duration of 11.5 minutes. If the initial on-route charging opportunity is omitted, then the longest service blocks will require an on-route charge time of 12 minutes to complete the service requirements.** To reduce schedule delays, it is recommended that on-route chargers are placed in an area with adequate space for the operator to adjust the position of the bus in order to properly align with the overhead charger. Available real estate at Pomona Transit Center must be assessed at the property owner to ensure off-street parking and bus layover is feasible for on-route charger integration. Additionally, though overhead pantograph chargers are most commonly used throughout the nation, alternative technologies such as beneath-ground inductive charging should be considered as the technology develops.

3. Base Charging: **A minimum of 9 150 kW base chargers are recommended with 2 of the chargers providing future-readiness and redundancy. The WSP team**

recommends using 2:1 bus to charger configurations to reduce peak demand and infrastructure costs. It is recommended that Omnitrans invest in demand charge management technologies to manage costs associated with peak energy use and demand.

4. Utilities: Omnitrans should work closely with SCE to negotiate utility rates and infrastructure upgrades in alignment with the agency's needs. In the SCE analysis performed in this simulation, it was determined that the **electric vehicle (EV) rates are most cost effective when BEBs are being charged outside the window of 4PM-9PM**.

5. Modeling: Future modeling efforts should include inputs that are not considered in this analysis, as outlined in Section 2.2.3, to provide more refined and accurate results.

6. Hydrogen Feasibility: Further consideration, research, and dialogue should be employed when exploring hydrogen fuel integration. Discussion and research with potential OEMs, fuel suppliers, and joint-venture opportunities with neighboring transit agencies must be coordinated to facilitate further development in this emergent technology.

7. Future Proofing: Where possible, Omnitrans should consider the possibility of zero emission fleet infrastructure upgrades and designs. For instance, installing adequate conduit throughout the maintenance facility, as well as spatial planning for hydrogen production, are upfront modifications that eliminate the need for future modifications to facilities.

8. Resiliency: To ensure Omnitrans' future ZEB fleet is prepared for extreme weather, disasters, and extended outages, considerations for contingency power, fuel provision, and evacuation services should be considered in future analyses.

9. Route Piloting: Prior to moving forward with acquisitions of sizable ZEB purchase orders, a demonstration pilot should be conducted on the WVC route being considered. This may be achieved through small ZEB orders or temporary vehicle leases with the manufacturer. In the case of hydrogen, a pilot partnership with a fuel contractor may be explored to provide fueling needs. Piloting can help determine actual ZEB inefficiencies, opportunities, as well as operational challenges such as bus bunching and arterial congestion challenges present along the corridor.

Optimization Considerations

- Demand and consumption: There are many strategies available to help sequester demand and consumption costs. Where possible, it is recommended that the operator stagger and extend charging events to reduce peak demand. In the schedule provided in this analysis staggered charging is considered, although it is recommended that the operator also consider demand charge management (DCM) software to automate efficient energy distribution.

- Solar, battery storage, and charge management: Considerations for solar canopies at the proposed maintenance and storage facility, demand charge management, and battery storage should be included in future analyses for resiliency and demand cost management.

- Optimization of on-route charging: based on the analysis (assuming 11.5-minute charges), many trips can be completed with less time. The amount of time charged, the type of charger (and its C-rate), and the SOC of the bus in question should all be considered and optimized in future iterations of this analysis.

- Spatial constraints: This analysis assumes adequate spatial availability at each on-route charging location. Omnitrans will need to conduct field work and be open to leasing nearby parcels or initiating partnerships with local jurisdictions, such as Foothill Transit, to ensure enough bays and power are available for BEBs.

- Continued evaluation: Although this analysis provides recommendations on vehicle selection based on simulated performance, WSP recommends continued communication and collaboration with outside agencies operating ZEBs for anecdotal information that may support future purchasing decisions.

APPENDIX A: BEB ON-ROUTE MOCK SCHEDULE

	Pull-Out	Layover	Outbound Trip	Layover	Inbound Trip	Pull-In	
	0:20	0:15	1:03	0:00	1:03	0:20	
Bus	Leave Garage (Deadhead)	Arrive Terminus 1	Leave Terminus 1	Arrive Terminus 2	Leave Terminus 2	Arrive Terminus.1	Arrive Garage (Deadhead)
1	5:25 AM	5:45 AM	6:00 AM	7:03 AM	7:03 AM	8:06 AM	
2	5:35 AM	5:55 AM	6:10 AM	7:13 AM	7:13 AM	8:16 AM	
3	5:45 AM	6:05 AM	6:20 AM	7:23 AM	7:23 AM	8:26 AM	
4	5:55 AM	6:15 AM	6:30 AM	7:33 AM	7:33 AM	8:36 AM	
5	6:05 AM	6:25 AM	6:40 AM	7:43 AM	7:43 AM	8:46 AM	
6	6:15 AM	6:35 AM	6:50 AM	7:53 AM	7:53 AM	8:56 AM	
7	6:25 AM	6:45 AM	7:00 AM	8:03 AM	8:03 AM	9:06 AM	9:26 AM
8	6:35 AM	6:55 AM	7:10 AM	8:13 AM	8:13 AM	9:16 AM	
9	6:45 AM	7:05 AM	7:20 AM	8:23 AM	8:23 AM	9:26 AM	
10	6:55 AM	7:15 AM	7:30 AM	8:33 AM	8:33 AM	9:36 AM	9:56 AM
11	7:05 AM	7:25 AM	7:40 AM	8:43 AM	8:43 AM	9:46 AM	
12	7:15 AM	7:35 AM	7:50 AM	8:53 AM	8:53 AM	9:56 AM	
13	7:25 AM	7:45 AM	8:00 AM	9:03 AM	9:03 AM	10:06 AM	10:26 AM
14	7:35 AM	7:55 AM	8:10 AM	9:13 AM	9:13 AM	10:16 AM	
1		8:06 AM	8:21 AM	9:24 AM	9:24 AM	10:27 AM	
2		8:16 AM	8:31 AM	9:34 AM	9:34 AM	10:37 AM	
3		8:26 AM	8:41 AM	9:44 AM	9:44 AM	10:47 AM	11:07 AM
4		8:36 AM	8:51 AM	9:54 AM	9:54 AM	10:57 AM	
5		8:46 AM	9:01 AM	10:04 AM	10:04 AM	11:07 AM	
6		8:56 AM	9:16 AM	10:19 AM	10:19 AM	11:22 AM	
8		9:16 AM	9:31 AM	10:34 AM	10:34 AM	11:37 AM	
9		9:26 AM	9:46 AM	10:49 AM	10:49 AM	11:52 AM	
11		9:46 AM	10:01 AM	11:04 AM	11:04 AM	12:07 PM	
12		9:56 AM	10:16 AM	11:19 AM	11:19 AM	12:22 PM	
14		10:16 AM	10:31 AM	11:34 AM	11:34 AM	12:37 PM	
1		10:27 AM	10:46 AM	11:49 AM	11:49 AM	12:52 PM	
2		10:37 AM	11:01 AM	12:04 PM	12:04 PM	1:07 PM	
4		10:57 AM	11:16 AM	12:19 PM	12:19 PM	1:22 PM	
5		11:07 AM	11:31 AM	12:34 PM	12:34 PM	1:37 PM	
6		11:22 AM	11:46 AM	12:49 PM	12:49 PM	1:52 PM	
8		11:37 AM	12:01 PM	1:04 PM	1:04 PM	2:07 PM	
9		11:52 AM	12:16 PM	1:19 PM	1:19 PM	2:22 PM	
11		12:07 PM	12:31 PM	1:34 PM	1:34 PM	2:37 PM	
12		12:22 PM	12:46 PM	1:49 PM	1:49 PM	2:52 PM	
14		12:37 PM	1:01 PM	2:04 PM	2:04 PM	3:07 PM	
1		12:52 PM	1:16 PM	2:19 PM	2:19 PM	3:22 PM	
2		1:07 PM	1:31 PM	2:34 PM	2:34 PM	3:37 PM	
4		1:22 PM	1:46 PM	2:49 PM	2:49 PM	3:52 PM	

	Pull-Out	Layover	Outbound Trip	Layover	Inbound Trip	Pull-In	
	0:20	0:15	1:03	0:00	1:03	0:20	
Bus	Leave Garage (Deadhead)	Arrive Terminus 1	Leave Terminus 1	Arrive Terminus 2	Leave Terminus 2	Arrive Terminus.1	Arrive Garage (Deadhead)
5		1:37 PM	2:01 PM	3:04 PM	3:04 PM	4:07 PM	
6		1:52 PM	2:16 PM	3:19 PM	3:19 PM	4:22 PM	
8		2:07 PM	2:31 PM	3:34 PM	3:34 PM	4:37 PM	
9		2:22 PM	2:46 PM	3:49 PM	3:49 PM	4:52 PM	
11		2:37 PM	3:01 PM	4:04 PM	4:04 PM	5:07 PM	
12		2:52 PM	3:11 PM	4:14 PM	4:14 PM	5:17 PM	
7	3:01 PM	3:21 PM	3:21 PM	4:24 PM	4:24 PM	5:27 PM	
14		3:07 PM	3:31 PM	4:34 PM	4:34 PM	5:37 PM	
1		3:22 PM	3:41 PM	4:44 PM	4:44 PM	5:47 PM	
10	3:31 PM	3:51 PM	3:51 PM	4:54 PM	4:54 PM	5:57 PM	
2		3:37 PM	4:01 PM	5:04 PM	5:04 PM	6:07 PM	6:27 PM
4		3:52 PM	4:11 PM	5:14 PM	5:14 PM	6:17 PM	6:37 PM
13	4:01 PM	4:21 PM	4:21 PM	5:24 PM	5:24 PM	6:27 PM	6:47 PM
5		4:07 PM	4:31 PM	5:34 PM	5:34 PM	6:37 PM	6:57 PM
6		4:22 PM	4:41 PM	5:44 PM	5:44 PM	6:47 PM	7:07 PM
3	4:31 PM	4:51 PM	4:51 PM	5:54 PM	5:54 PM	6:57 PM	7:17 PM
8		4:37 PM	5:01 PM	6:04 PM	6:04 PM	7:07 PM	7:27 PM
9		4:52 PM	5:11 PM	6:14 PM	6:14 PM	7:17 PM	7:37 PM
11		5:07 PM	5:21 PM	6:24 PM	6:24 PM	7:27 PM	7:47 PM
12		5:17 PM	5:31 PM	6:34 PM	6:34 PM	7:37 PM	7:57 PM
7		5:27 PM	5:41 PM	6:44 PM	6:44 PM	7:47 PM	8:07 PM
14		5:37 PM	5:51 PM	6:54 PM	6:54 PM	7:57 PM	8:17 PM
1		5:47 PM	6:01 PM	7:04 PM	7:04 PM	8:07 PM	8:27 PM

Source: WSP

APPENDIX B: BEB BASE-ONLY CHARGING SCHEDULE

	Pull-Out	Layover	Outbound Trip	Layover	Inbound Trip	Pull-In	
	0:20	0:15	1:03	0:00	1:03	0:20	
Bus	Leave Garage (Deadhead)	Arrive Terminus 1	Leave Terminus 1	Arrive Terminus 2	Leave Terminus 2	Arrive Terminus 1	Arrive Garage (Deadhead)
1	5:25 AM	5:45 AM	6:00 AM	7:03 AM	7:03 AM	8:06 AM	
2	5:35 AM	5:55 AM	6:10 AM	7:13 AM	7:13 AM	8:16 AM	
3	5:45 AM	6:05 AM	6:20 AM	7:23 AM	7:23 AM	8:26 AM	
4	5:55 AM	6:15 AM	6:30 AM	7:33 AM	7:33 AM	8:36 AM	
5	6:05 AM	6:25 AM	6:40 AM	7:43 AM	7:43 AM	8:46 AM	
6	6:15 AM	6:35 AM	6:50 AM	7:53 AM	7:53 AM	8:56 AM	
7	6:25 AM	6:45 AM	7:00 AM	8:03 AM	8:03 AM	9:06 AM	9:26 AM
8	6:35 AM	6:55 AM	7:10 AM	8:13 AM	8:13 AM	9:16 AM	
9	6:45 AM	7:05 AM	7:20 AM	8:23 AM	8:23 AM	9:26 AM	
10	6:55 AM	7:15 AM	7:30 AM	8:33 AM	8:33 AM	9:36 AM	9:56 AM
11	7:05 AM	7:25 AM	7:40 AM	8:43 AM	8:43 AM	9:46 AM	
12	7:15 AM	7:35 AM	7:50 AM	8:53 AM	8:53 AM	9:56 AM	
13	7:25 AM	7:45 AM	8:00 AM	9:03 AM	9:03 AM	10:06 AM	10:26 AM
14	7:50 AM	8:10 AM	8:10 AM	9:13 AM	9:13 AM	10:16 AM	
1		8:06 AM	8:20 AM	9:23 AM	9:23 AM	10:26 AM	10:46 AM
2		8:16 AM	8:30 AM	9:33 AM	9:33 AM	10:36 AM	10:56 AM
3		8:26 AM	8:40 AM	9:43 AM	9:43 AM	10:46 AM	11:06 AM
4		8:36 AM	8:50 AM	9:53 AM	9:53 AM	10:56 AM	11:16 AM
5		8:46 AM	9:00 AM	10:03 AM	10:03 AM	11:06 AM	11:26 AM
6		8:56 AM	9:15 AM	10:18 AM	10:18 AM	11:21 AM	11:41 AM
8		9:16 AM	9:30 AM	10:33 AM	10:33 AM	11:36 AM	11:56 AM
9		9:26 AM	9:45 AM	10:48 AM	10:48 AM	11:51 AM	12:11 PM
11		9:46 AM	10:00 AM	11:03 AM	11:03 AM	12:06 PM	12:26 PM
12		9:56 AM	10:15 AM	11:18 AM	11:18 AM	12:21 PM	12:41 PM
14		10:16 AM	10:30 AM	11:33 AM	11:33 AM	12:36 PM	12:56 PM
7	10:10 AM	10:45 AM	10:45 AM	11:48 AM	11:48 AM	12:51 PM	
10	10:40 AM	11:00 AM	11:00 AM	12:03 PM	12:03 PM	1:06 PM	
19	10:55 AM	11:15 AM	11:15 AM	12:18 PM	12:18 PM	1:21 PM	
13	11:10 AM	11:30 AM	11:30 AM	12:33 PM	12:33 PM	1:36 PM	
15	11:25 AM	11:45 AM	11:45 AM	12:48 PM	12:48 PM	1:51 PM	
16	11:40 AM	12:00 PM	12:00 PM	1:03 PM	1:03 PM	2:06 PM	
17	11:55 AM	12:15 PM	12:15 PM	1:18 PM	1:18 PM	2:21 PM	
18	12:10 PM	12:30 PM	12:30 PM	1:33 PM	1:33 PM	2:36 PM	
1	12:25 PM	12:45 PM	12:45 PM	1:48 PM	1:48 PM	2:51 PM	
2	12:25 PM	12:45 PM	1:00 PM	2:03 PM	2:03 PM	3:06 PM	
7		12:51 PM	1:15 PM	2:18 PM	2:18 PM	3:21 PM	3:41 PM
10		1:06 PM	1:30 PM	2:33 PM	2:33 PM	3:36 PM	3:56 PM
19		1:21 PM	1:45 PM	2:48 PM	2:48 PM	3:51 PM	4:11 PM
13		1:36 PM	2:00 PM	3:03 PM	3:03 PM	4:06 PM	4:26 PM
15		1:51 PM	2:15 PM	3:18 PM	3:18 PM	4:21 PM	4:41 PM

	Pull-Out	Layover	Outbound Trip	Layover	Inbound Trip	Pull-In	
	0:20	0:15	1:03	0:00	1:03	0:20	
Bus	Leave Garage (Deadhead)	Arrive Terminus 1	Leave Terminus 1	Arrive Terminus 2	Leave Terminus 2	Arrive Terminus 1	Arrive Garage (Deadhead)
16		2:06 PM	2:30 PM	3:33 PM	3:33 PM	4:36 PM	4:56 PM
17		2:21 PM	2:45 PM	3:48 PM	3:48 PM	4:51 PM	5:11 PM
18		2:36 PM	3:00 PM	4:03 PM	4:03 PM	5:06 PM	5:26 PM
1		2:51 PM	3:10 PM	4:13 PM	4:13 PM	5:16 PM	5:36 PM
2		3:20 PM	3:20 PM	4:23 PM	4:23 PM	5:26 PM	5:46 PM
3	3:10 PM	3:30 PM	3:30 PM	4:33 PM	4:33 PM	5:36 PM	
4	3:20 PM	3:40 PM	3:40 PM	4:43 PM	4:43 PM	5:46 PM	6:06 PM
5	3:30 PM	3:50 PM	3:50 PM	4:53 PM	4:53 PM	5:56 PM	6:16 PM
6	3:40 PM	4:00 PM	4:00 PM	5:03 PM	5:03 PM	6:06 PM	6:26 PM
8	3:50 PM	4:10 PM	4:10 PM	5:13 PM	5:13 PM	6:16 PM	6:36 PM
9	4:00 PM	4:20 PM	4:20 PM	5:23 PM	5:23 PM	6:26 PM	6:46 PM
12	4:10 PM	4:30 PM	4:30 PM	5:33 PM	5:33 PM	6:36 PM	6:56 PM
14	4:20 PM	4:40 PM	4:40 PM	5:43 PM	5:43 PM	6:46 PM	7:06 PM
7	4:30 PM	4:50 PM	4:50 PM	5:53 PM	5:53 PM	6:56 PM	7:16 PM
10	4:40 PM	5:00 PM	5:00 PM	6:03 PM	6:03 PM	7:06 PM	7:26 PM
11	4:50 PM	5:10 PM	5:10 PM	6:13 PM	6:13 PM	7:16 PM	7:36 PM
19	5:00 PM	5:20 PM	5:20 PM	6:23 PM	6:23 PM	7:26 PM	7:46 PM
13	5:10 PM	5:30 PM	5:30 PM	6:33 PM	6:33 PM	7:36 PM	7:56 PM
3		5:40 PM	5:40 PM	6:43 PM	6:43 PM	7:46 PM	8:06 PM
4		5:46 PM	5:50 PM	6:53 PM	6:53 PM	7:56 PM	8:16 PM
5		5:56 PM	6:00 PM	7:03 PM	7:03 PM	8:06 PM	8:26 PM

Source: WSP

APPENDIX C: FCEB SCHEDULE

	Pull-Out	Layover		Outbound Trip	Layover	Inbound Trip	Pull-In
	0:20	0:15		1:03	0:00	1:03	0:20
Bus	Leave Garage (Deadhead)	Arrive Terminus 1	Leave Terminus 1	Arrive Terminus 2	Leave Terminus 2	Arrive Terminus 1	Arrive Garage (Deadhead)
1	5:25 AM	5:45 AM	6:00 AM	7:03 AM	7:03 AM	8:06 AM	
2	5:35 AM	5:55 AM	6:10 AM	7:13 AM	7:13 AM	8:16 AM	
3	5:45 AM	6:05 AM	6:20 AM	7:23 AM	7:23 AM	8:26 AM	
4	5:55 AM	6:15 AM	6:30 AM	7:33 AM	7:33 AM	8:36 AM	
5	6:05 AM	6:25 AM	6:40 AM	7:43 AM	7:43 AM	8:46 AM	
6	6:15 AM	6:35 AM	6:50 AM	7:53 AM	7:53 AM	8:56 AM	
7	6:25 AM	6:45 AM	7:00 AM	8:03 AM	8:03 AM	9:06 AM	9:26 AM
8	6:35 AM	6:55 AM	7:10 AM	8:13 AM	8:13 AM	9:16 AM	
9	6:45 AM	7:05 AM	7:20 AM	8:23 AM	8:23 AM	9:26 AM	
10	6:55 AM	7:15 AM	7:30 AM	8:33 AM	8:33 AM	9:36 AM	9:56 AM
11	7:05 AM	7:25 AM	7:40 AM	8:43 AM	8:43 AM	9:46 AM	
12	7:15 AM	7:35 AM	7:50 AM	8:53 AM	8:53 AM	9:56 AM	
13	7:25 AM	7:45 AM	8:00 AM	9:03 AM	9:03 AM	10:06 AM	10:26 AM
14	7:35 AM	7:55 AM	8:10 AM	9:13 AM	9:13 AM	10:16 AM	
1		8:06 AM	8:20 AM	9:23 AM	9:23 AM	10:26 AM	
2		8:16 AM	8:30 AM	9:33 AM	9:33 AM	10:36 AM	
3		8:26 AM	8:40 AM	9:43 AM	9:43 AM	10:46 AM	11:06 AM
4		8:36 AM	8:50 AM	9:53 AM	9:53 AM	10:56 AM	
5		8:46 AM	9:00 AM	10:03 AM	10:03 AM	11:06 AM	
6		8:56 AM	9:15 AM	10:18 AM	10:18 AM	11:21 AM	11:41 AM
8		9:16 AM	9:30 AM	10:33 AM	10:33 AM	11:36 AM	
9		9:26 AM	9:45 AM	10:48 AM	10:48 AM	11:51 AM	
11		9:46 AM	10:00 AM	11:03 AM	11:03 AM	12:06 PM	12:26 PM
12		9:56 AM	10:15 AM	11:18 AM	11:18 AM	12:21 PM	
14		10:16 AM	10:30 AM	11:33 AM	11:33 AM	12:36 PM	
1		10:26 AM	10:45 AM	11:48 AM	11:48 AM	12:51 PM	1:11 PM
2		10:36 AM	11:00 AM	12:03 PM	12:03 PM	1:06 PM	
4		10:56 AM	11:15 AM	12:18 PM	12:18 PM	1:21 PM	
5		11:06 AM	11:30 AM	12:33 PM	12:33 PM	1:36 PM	1:56 PM
7	11:25 AM	11:45 AM	11:45 AM	12:48 PM	12:48 PM	1:51 PM	
8		11:36 AM	12:00 PM	1:03 PM	1:03 PM	2:06 PM	2:26 PM
9		11:51 AM	12:15 PM	1:18 PM	1:18 PM	2:21 PM	
10	12:10 PM	12:30 PM	12:30 PM	1:33 PM	1:33 PM	2:36 PM	
12		12:21 PM	12:45 PM	1:48 PM	1:48 PM	2:51 PM	3:11 PM
14		12:36 PM	1:00 PM	2:03 PM	2:03 PM	3:06 PM	
13	12:55 PM	1:15 PM	1:15 PM	2:18 PM	2:18 PM	3:21 PM	

	Pull-Out 0:20	Layover 0:15		Outbound Trip 1:03	Layover 0:00	Inbound Trip 1:03	Pull-In 0:20
Bus	**Leave Garage (Deadhead)**	**Arrive Terminus 1**	**Leave Terminus 1**	**Arrive Terminus 2**	**Leave Terminus 2**	**Arrive Terminus 1**	**Arrive Garage (Deadhead)**
2		1:06 PM	1:30 PM	2:33 PM	2:33 PM	3:36 PM	3:56 PM
4		1:21 PM	1:45 PM	2:48 PM	2:48 PM	3:51 PM	4:11 PM
3	1:25 PM	2:00 PM	2:00 PM	3:03 PM	3:03 PM	4:06 PM	
7		1:51 PM	2:15 PM	3:18 PM	3:18 PM	4:21 PM	4:41 PM
6	2:10 PM	2:30 PM	2:30 PM	3:33 PM	3:33 PM	4:36 PM	
9		2:21 PM	2:45 PM	3:48 PM	3:48 PM	4:51 PM	5:11 PM
10		2:36 PM	3:00 PM	4:03 PM	4:03 PM	5:06 PM	
11	2:50 PM	3:10 PM	3:10 PM	4:13 PM	4:13 PM	5:16 PM	
14		3:06 PM	3:20 PM	4:23 PM	4:23 PM	5:26 PM	5:46 PM
1	3:10 PM	3:30 PM	3:30 PM	4:33 PM	4:33 PM	5:36 PM	5:56 PM
13		3:21 PM	3:40 PM	4:43 PM	4:43 PM	5:46 PM	6:06 PM
5	3:30 PM	3:50 PM	3:50 PM	4:53 PM	4:53 PM	5:56 PM	6:16 PM
8	3:40 PM	4:00 PM	4:00 PM	5:03 PM	5:03 PM	6:06 PM	6:26 PM
12	3:50 PM	4:10 PM	4:10 PM	5:13 PM	5:13 PM	6:16 PM	6:36 PM
3		4:06 PM	4:20 PM	5:23 PM	5:23 PM	6:26 PM	6:46 PM
15	3:55 PM	4:15 PM	4:30 PM	5:33 PM	5:33 PM	6:36 PM	6:56 PM
2	4:05 PM	4:25 PM	4:40 PM	5:43 PM	5:43 PM	6:46 PM	7:06 PM
6		4:36 PM	4:50 PM	5:53 PM	5:53 PM	6:56 PM	7:16 PM
4	4:40 PM	5:00 PM	5:00 PM	6:03 PM	6:03 PM	7:06 PM	7:26 PM
16	4:50 PM	5:10 PM	5:10 PM	6:13 PM	6:13 PM	7:16 PM	7:36 PM
10		5:06 PM	5:20 PM	6:23 PM	6:23 PM	7:26 PM	7:46 PM
11		5:16 PM	5:30 PM	6:33 PM	6:33 PM	7:36 PM	7:56 PM
7	5:20 PM	5:40 PM	5:40 PM	6:43 PM	6:43 PM	7:46 PM	8:06 PM
1		5:36 PM	5:50 PM	6:53 PM	6:53 PM	7:56 PM	8:16 PM
13		5:46 PM	6:00 PM	7:03 PM	7:03 PM	8:06 PM	8:26 PM

APPENDIX B: SCE CHARGING EQUIPMENT

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Charge Ready
Approved Product List

Southern California Edison Company's ("SCE") Charge Ready Programs are funded by SCE utility ratepayers and administered by SCE under the auspices of the California Public Utilities Commission. SCE does not make any recommendations or representations regarding any suppliers or products approved for use under any of the transportation electrification programs administered by SCE. SCE makes no representations regarding any suppliers' or products' quality, workmanship or safety and is not liable for the quality or safety of such products.

Customers must purchase equipment from an approved vendor and select an approved network provider to participate in Charge Ready Programs. Approved vendors and approved network providers are listed below.

EVSE Manufacturer	Eligible Programs	Approved EVSE Model Numbers	Charger Type	Maximum Power Output (kW)	Notes	Charge Ready Pilot Rebate Category	Charge Ready Transport Rebate Category
ABB							
ABB	Charge Ready Transport	**HVC 150C**	DC	150 kW	Power Cabinet. Must acquire dispensers.	N/A	51 - 150 kW
ABB	Charge Ready Transport	**Terra 24 DC Wallbox**	DC	24 kW	1x CCS1 connector 1x CHAdeMO connector or 1x CCS1 connector	N/A	19.3 - 50 kW
ABB	Charge Ready Transport	**Terra 53**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
ABB	Charge Ready Transport	**Terra 54**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
ABB	Charge Ready Transport	**Terra 54 HV**	DC	50 kW	1x CCS1 connector	N/A	19.3 - 50 kW
Blink							
Blink	Charge Ready Transport	**IQW2-80U-M1-R2-N-25 (Advanced)**	AC	19.2 kW	Single Port	N/A	0 - 19.2 kW
Blink	Charge Ready Transport	**IQW2-80U-W1-N1-N-25 (Smart)**	AC	19.2 kW	Single Port	N/A	0 - 19.2 kW
BTCPower							
BTCPower	Charge Ready Pilot Charge Ready Transport	**EVP-1001-30-#**	AC	7.2 kW	Single Port. Must acquire Gateway	L2B	0 - 19.2 kW
BTCPower	Charge Ready Pilot Charge Ready Transport	**EVP-2001-30-#**	AC	7.2 kW	Single Port. Must acquire Gateway	L2B	0 - 19.2 kW
BTCPower	Charge Ready Pilot Charge Ready Transport	**EVP-2002-30-#**	AC	7.2 kW	Dual Port. Must acquire Gateway.	L2B	0 - 19.2 kW
BTCPower	Charge Ready Pilot Charge Ready Transport	**EVP-2001-40-#**	AC	7.2 kW	Single Port. Must acquire Gateway	L2B	0 - 19.2 kW
BTCPower	Charge Ready Pilot Charge Ready Transport	**EVP-2002-40-#**	AC	7.2 kW	Dual Port. Must acquire Gateway.	L2B	0 - 19.2 kW
BTCPower	Charge Ready Transport	**EVP-2001-70-#**	AC	16.8 kW	Single Port	N/A	0 - 19.2 kW
BTCPower	Charge Ready Transport	**EVP-FC-50-001**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
BTCPower	Charge Ready Transport	**EVP-FC-50-002**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
BTCPower	Charge Ready Transport	**L3#-25-###-CS**	DC	25 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
BTCPower	Charge Ready Transport	**L3#-50-###-CS**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
BTCPower	Charge Ready Transport	**EVPC-100**	DC	100 kW	Power Cabinet. Must acquire dispensers.	N/A	Dependent on chosen configuration
BTCPower	Charge Ready Transport	**EVPC-150**	DC	150 kW	Power Cabinet. Must acquire dispensers.	N/A	Dependent on chosen configuration
BTCPower	Charge Ready Transport	**EVPC-200**	DC	200 kW	Power Cabinet. Must acquire dispensers.	N/A	Dependent on chosen configuration
ChargePoint							
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CPF25**	AC	7.2 kW	Single Port. Must acquire Gateway.	L2B	0 - 19.2 kW

ChargePoint	Charge Ready Pilot Charge Ready Transport	**CPF25-DUAL**	AC	7.2 kW	Dual Port. Must acquire Gateway.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4011**	AC	7.2 kW	Single Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4011-GW1**	AC	7.2 kW	Single Port. Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4013**	AC	7.2 kW	Single Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4013-GW1**	AC	7.2 kW	Single Port. Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4021**	AC	7.2 kW	Dual Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4021-GW1**	AC	7.2 kW	Dual Port. Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4023**	AC	7.2 kW	Dual Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4023-GW1**	AC	7.2 kW	Dual Port. Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4023-GW1-PMGMT40**	AC	7.2 kW	Dual Port power share. Gateway EVSE	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4023-PMGMT40**	AC	7.2 kW	Dual Port power share. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4025**	AC	7.2 kW	Dual Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4025-GW1**	AC	7.2 kW	Dual Port. Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4025-GW1-PMGMT40**	AC	7.2 kW	Dual Port power share. Gateway EVSE	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4025-PMGMT40**	AC	7.2 kW	Dual Port power share. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4027**	AC	7.2 kW	Dual Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4027-GW1**	AC	7.2 kW	Dual Port. Gateway EVSE.	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4027-GW1-PMGMT40**	AC	7.2 kW	Dual Port power share. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Pilot Charge Ready Transport	**CT4027-PMGMT40**	AC	7.2 kW	Dual Port power share. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
ChargePoint	Charge Ready Transport	**CPF50**	AC	12 kW	Single Port. Must aquire Gateway	N/A	0 - 19.2 kW
ChargePoint	Charge Ready Transport	**CPF50-DUAL**	AC	12 kW	Dual Port.Must aquire Gateway	N/A	0 - 19.2 kW
ChargePoint	Charge Ready Transport	**CPE250C-500-CCS1-CHD**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
ChargePoint	Charge Ready Transport	**CPE250C-625-CCS1-CHD**	DC	62.5 kW	1x CCS1 connector 1x CHAdeMO connector Can be combined with second unit for output up to 125 kW	N/A	51 - 150 kW
Clipper Creek							
Clipper Creek	Charge Ready Pilot	**ACS-15**	AC	1.4 kW	Single Port	L1	N/A
Clipper Creek	Charge Ready Pilot	**ACS-20**	AC	1.9 kW	Single Port	L1	N/A
Clipper Creek	Charge Ready Pilot Charge Ready Transport	**LCS-25**	AC	4.8 kW	Single port. Must acquire Gateway	L2B	0 - 19.2 kW
Clipper Creek	Charge Ready Pilot Charge Ready Transport	**HCS-40**	AC	7.7 kW	Single port. Must acquire Gateway	L2B	0 - 19.2 kW

Clipper Creek	Charge Ready Pilot Charge Ready Transport	**HCS-50**	AC	9.6 kW	Single port. Must acquire Gateway	L2B	0 - 19.2 kW
Clipper Creek	Charge Ready Transport	**HCS-60**	AC	11.5 kW	Single port. Must acquire Gateway	L2B	0 - 19.2 kW
Clipper Creek	Charge Ready Transport	**HCS-80**	AC	15.4 kW	Single port. Must acquire Gateway	N/A	0 - 19.2 kW
Clipper Creek	Charge Ready Transport	**CS-100**	AC	19.2 kW	Single port. Must acquire Gateway	N/A	0 - 19.2 kW
Delta							
Delta	Charge Ready Pilot Charge Ready Transport	**AWU70215BEMV**	AC	7.2 kW	Single Port	L2A	0 - 19.2 kW
Delta	Charge Ready Pilot Charge Ready Transport	**EVMU3017MWS**	AC	7.2 kW	Single Port. Must acquire Gateway.	L2B	0 - 19.2 kW
Delta	Charge Ready Pilot Charge Ready Transport	**EVMU4017MWS**	AC	9.6 kW	Single Port. Must acquire Gateway.	L2B	0 - 19.2 kW
Delta	Charge Ready Transport	**DC Wallbox**	DC	25 kW	1x CCS1 connector 1x CHAdeMO connector. Must acquire Gateway.	N/A	19.3 - 50 kW
EFACEC							
EFACEC	Charge Ready Pilot Charge Ready Transport	**Public Charger**	AC	7.2 kW	Dual Port	L2A	0 - 19.2 kW
EFACEC	Charge Ready Pilot Charge Ready Transport	**Public Charger**	AC	7.2 kW	Single Port	L2A	0 - 19.2 kW
EFACEC	Charge Ready Transport	**QC20**	DC	25 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
EFACEC	Charge Ready Transport	**QC45**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
EFACEC	Charge Ready Transport	**HV160**	DC	160 kW	Must use non-liquid cooled cables.	N/A	151+ kW
EFACEC	Charge Ready Transport	**HV175**	DC	161 kW	Must use non-liquid cooled cables.	N/A	151+ kW
Enel X							
Enel X	Charge Ready Pilot Charge Ready Transport	**JuiceBox Pro 32C**	AC	7.7 kW	Single Port	L2A	0 - 19.2 kW
Enel X	Charge Ready Pilot Charge Ready Transport	**JuiceBox Pro 40C**	AC	9.6 kW	Single Port	L2A	0 - 19.2 kW
EVBox							
EVBox	Charge Ready Pilot Charge Ready Transport	**B2320-45###**	AC	7.4 kW	Single Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
EVBox	Charge Ready Pilot Charge Ready Transport	**B2320-65###**	AC	7.4 kW	Single Port. Gateway EVSE.	L2B	0 - 19.2 kW
EVBox	Charge Ready Pilot Charge Ready Transport	**B2323-45###**	AC	7.4 kW	Dual Port. Must acquire Gateway EVSE.	L2B	0 - 19.2 kW
EVBox	Charge Ready Pilot Charge Ready Transport	**B2323-65###**	AC	7.4 kW	Dual Port. Gateway EVSE.	L2B	0 - 19.2 kW
EVBox	Charge Ready Pilot Charge Ready Transport	**EVB-BDH#**	AC	7.4 kW	Dual Port	L2A	0 - 19.2 kW
EVBox	Charge Ready Pilot Charge Ready Transport	**EVB-BSH#**	AC	7.4 kW	Single Port	L2A	0 - 19.2 kW
EverCharge							
EverCharge	Charge Ready Pilot Charge Ready Transport	**EC001**	AC	7.2kW	Single Port	L2a	0 - 19.2 kW
EVoCharge							
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO30-#11-00#**	AC	7.7 kW	Single Port	L2A	0 - 19.2 kW

EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO30-#12-00#**	AC	7.7 kW	Dual Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO30-#21-00#**	AC	7.7 kW	Single Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO30-#22-00#**	AC	7.7 kW	Dual Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO32-#11-00#**	AC	7.7 kW	Single Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO32-#12-00#**	AC	7.7 kW	Dual Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO32-#21-00#**	AC	7.7 kW	Single Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO32-#22-00#**	AC	7.7 kW	Dual Port	L2A	0 - 19.2 kW
EVoCharge	Charge Ready Pilot Charge Ready Transport	**EVO72-310-001A**	AC	7.2 kW	Single Port	L2A	0 - 19.2 kW
EVSE LLC							
EVSE LLC	Charge Ready Pilot Charge Ready Transport	**3703**	AC	7.2 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
EVSE LLC	Charge Ready Pilot Charge Ready Transport	**3704 REV G**	AC	7.2 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
EVSE LLC	Charge Ready Pilot Charge Ready Transport	**3704-002 REV G**	AC	7.2 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
EVSE LLC	Charge Ready Pilot Charge Ready Transport	**3722**	AC	7.7 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
KIGT Inc.							
KIGT Inc.	Charge Ready Pilot Charge Ready Transport	**B24030DC5**	AC	6.6 kW	Dual Port	L2A	0 - 19.2 kW
KIGT Inc.	Charge Ready Pilot Charge Ready Transport	**B24030SC5#**	AC	6.6 kW	Single Port	L2A	0 - 19.2 kW
KIGT Inc.	Charge Ready Pilot Charge Ready Transport	**B24030SH3**	AC	6.6 kW	Single Port	L2A	0 - 19.2 kW
Konnectronix							
Konnectronix	Charge Ready Pilot	**P00-400-XXX#**	AC	1.9 kW	Single Port	L1	N/A
Konnectronix	Charge Ready Pilot	**P00-415-XXX#**	AC	1.9 kW	Single Port	L1	N/A
Konnectronix	Charge Ready Pilot Charge Ready Transport	**P00-450-XXX#**	AC	4.8 kW	Single Port	L2B	0 - 19.2 kW
Konnectronix	Charge Ready Pilot Charge Ready Transport	**P00-465-XXX#**	AC	4.8 kW	Single Port	L2B	0 - 19.2 kW
SemaConnect							
SemaConnect	Charge Ready Pilot Charge Ready Transport	**520 Series**	AC	7.2 kW	Single Port	L2A	0 - 19.2 kW
SemaConnect	Charge Ready Pilot Charge Ready Transport	**620 Series**	AC	7.2 kW	Single Port	L2A	0 - 19.2 kW
Siemens							
Siemens	Charge Ready Pilot Charge Ready Transport	**VCSG30GCPUW**	AC	7.2 kW	Single Port. Must acquire Gateway.	L2B	0 - 19.2 kW
Tellus Power							
Tellus Power	Charge Ready Pilot Charge Ready Transport	**UP160J-#MP-###**	AC	7.2 kW	Dual Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
Tellus Power	Charge Ready Pilot Charge Ready Transport	**UP80J-#MP-###**	AC	7.2 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
Tritium							

Tritium	Charge Ready Transport	**Veefil RT 50**	DC	50 kW	1x CCS1 connector 1x CHAdeMO connector	N/A	19.3 - 50 kW
Webasto (formerly AeroVironment)							
Webasto	Charge Ready Pilot	**24931-020**	AC	1.9 kW	Single Port	L1	N/A
Webasto	Charge Ready Pilot Charge Ready Transport	**19356-32A-###**	AC	7.7 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
Webasto	Charge Ready Pilot Charge Ready Transport	**Turbo DX 32A**	AC	7.7 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW
Webasto	Charge Ready Pilot Charge Ready Transport	**Turbo DX 16A**	AC	3.8 kW	Single Port. Must acquire Gateway EVSE	L2B	0 - 19.2 kW

Notes

Approval of selected equipment is contingent on selecting an approved vendor and approved network provider from the provided list

EVSE manufacturer listed may not be an approved vendor. Please refer to the provided list

in the model number can be a number, letter, or blank

Definitions:

L1 – Level 1 charging station (120 volts), without network capability

L2 "A" – Level 2 charging station (up to 240 volts), with standalone network capability integrated into the station (e.g., cellular)

L2 "B" – Level 2 charging station (up to 240 volts), with network capability provided by an external device (such as a kiosk or gateway) usually shared among multiple stations

Connector - the physical plug inserted into the vehicle receptacle.

Port - a charging connection to the vehicle which is capable of independently charging a vehicle concurrently with any other port.

Station - the complete set of equipment that comprises the EV supply equipment on a local branch circuit.

Plaza - a collection of charging stations at a single location and utility connection.

Charge Ready Transport Rebate Category	Eligible Rebate Amount
0 kW - 19.2 kW	50% of the cost of EVSE, up to $1,500 per port
19.3 kW - 50 kW	50% of the cost of EVSE, up to $11,500 per port
51 kW - 150 kW	50% of the cost of EVSE, up to $20,500 per port
151+ kW	50% of the cost of EVSE, up to $35,000 per port

***Cost of installation not included in rebate for Charge Ready Transport**

Charge Ready Pilot Rebate Category	Base Cost Amount per Port
L1	Up to $1396
L2A	Up to $2390
L2B	Up to $2095

Approved Vendors	Contact Information
ABB	steve.bloch@us.abb.com
Amply	simon@amplypower.com
Blackdog Electrical Systems Inc.	chris@blackdogelectricalsystems.com
Blink	AHillman@BlinkCharging.com
BTCPower	larryh@btcpower.com
ChargePoint	garrett.everhart@chargepoint.com
Enel X	Karen.hsu@enel.com
EV Connect, Inc.	david@evconnect.com
EVBox	robert.golden@ev-box.com
EverCharge	charging@evercharge.net
Evgo	lars.peters@evgo.com
EVoCharge	sales@evocharge.com
EVSE LLC	dspacht@controlmod.com
Greenlots	jmason@greenlots.com
KIGT Inc.	paul@kigt.co
Kitu Systems, Inc.	jpak@kitu.io
Konnectronix	Jhipchen@Konnectronix.com
Liberty PlugIns	forest@libertyplugins.com
National Car Charging	jburness@nationalcarcharging.com
OpConnect	dturner@opconnect.com
PLEMCo	evse@plem.co
PowerFlex Systems	George@powerflex.com
Siemens	Thulin.anders@siemens.com
Tellus Power	Rania@telluspower.com

Approved Network Providers	Contact Information
Kitu Systems, Inc.	jpak@kitu.io
Greenlots	jmason@greenlots.com
ChargePoint	cody.thornton@chargepoint.com
Enel X	Karen.hsu@enel.com
EV Connect, Inc.	david@evconnect.com
Gridscape Solutions	sales@grid-scape.com
PowerFlex Systems	George@powerflex.com
Tellus Power	Rania@telluspower.com
EVgo	lars.peters@evgo.com
EvGateway	Laura@EvGateway.com
EverCharge	charging@evercharge.net
KIGT Inc.	paul@kigt.co
Liberty Plugins	forest@libertyplugins.com
OpConnect	dturner@opconnect.com
The Mobility House	gregor.hintler@mobilityhouse.com
Siemens	Thulin.anders@siemens.com
SemaConnect	eric.werner@semaconnect.com
Blink	AHillman@BlinkCharging.com
Noodoe Inc.	arkshih@noodoe.com

The Mobility House	gregor.hintler@mobilityhouse.com
Tritium	stok@tritium.com.au
Webasto	Charlie.Botsford@webasto.com
Sustainable Electric Solutions	asims@sustainsp.com
SemaConnect	eric.werner@semaconnect.com
Control Mod	dspacht@controlmod.com
Verdek	info@verdek.com
Axxera, Inc. (EvGateway)	Laura@EvGateway.com
Bottom Line Utility Solutions, Inc.	Will@blusinc.com
GreenWealth Energy Solutions, Inc.	andrew.lee@green-wealth.com
Zero Impact Soltuions	spiro@zi.solutions
Clean Fuel Connection	inquiry@cleanfuelconnection.com
Optima Energy, Inc.	Young@opnrg.com
Noodoe Inc.	arkshih@noodoe.com

Charge Ready

Approved Off-Road Vendors

Southern California Edison Company's ("SCE") Charge Ready Programs are funded by SCE utility ratepayers and administered by SCE under the auspices of the California Public Utilities Commission. SCE does not make any recommendations or representations regarding any suppliers or products approved for use under any of the transportation electrification programs administered by SCE. SCE makes no representations regarding any suppliers' or products' quality, workmanship or safety and is not liable for the quality or safety of such products.

Customers must purchase equipment from an approved vendor to participate in Charge Ready Programs. Approved vendors are listed below. Final model selection subject to SCE approval.

Approved Vendors	Contact Information	Notes
XL Lifts	aimee@xlliftsinc.com	Selected model subject to final approval by SCE
Ecotec	Jim.keyser@ecotecbatchcharger.com	Models approved are :Access 5,10,13,20/24,36,48,80/C
ESL Power Systems	cvalero@eslpwr.com	Sells TRU chargers. eTRUconnect is only approved model.
Power Designer SIBEX	Mrigor@Powerdesingers.com	Selected model subject to final approval by SCE

APPENDIX C: CIRCUIT MAPS OF FIRE RISK SITES

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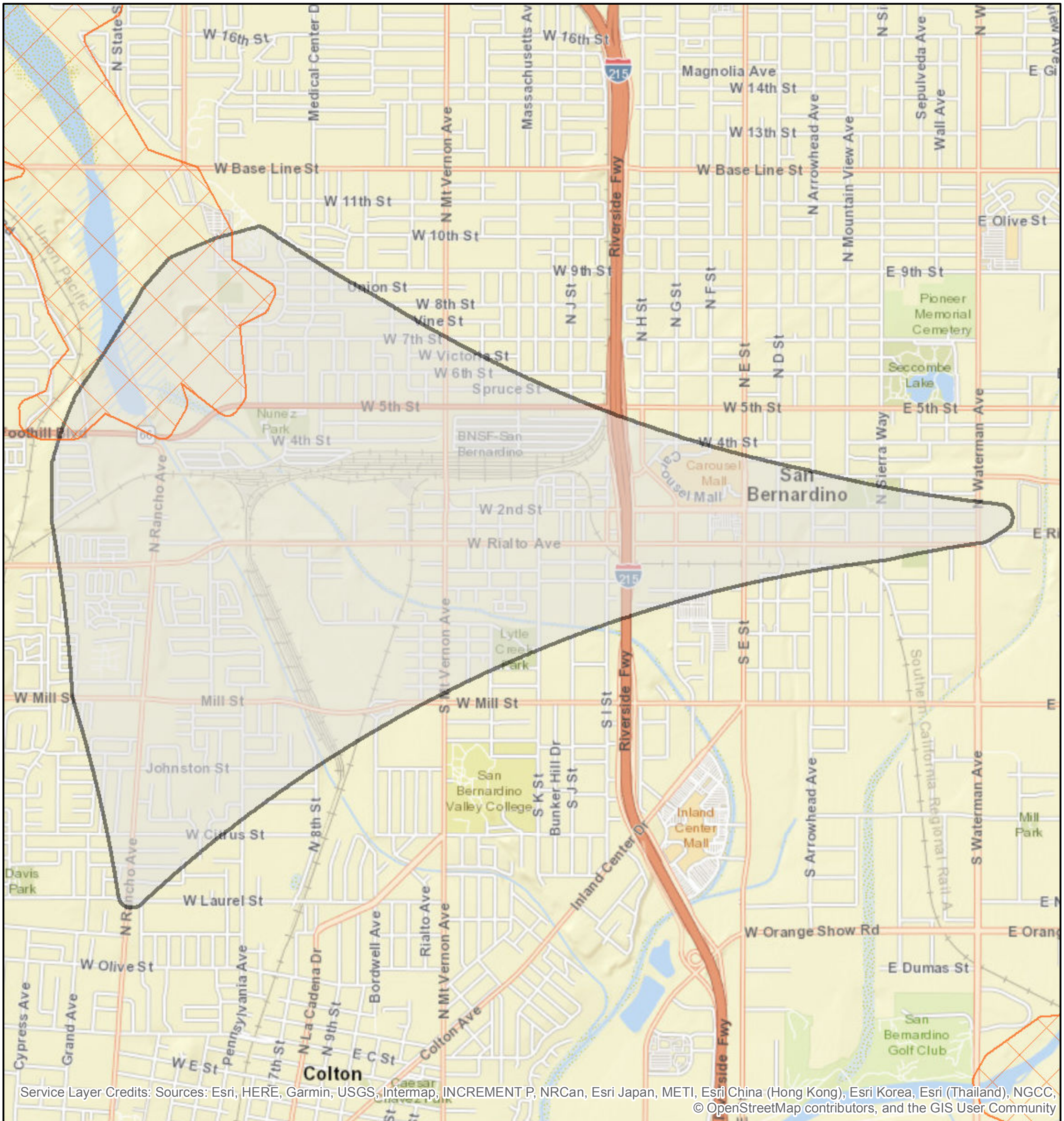
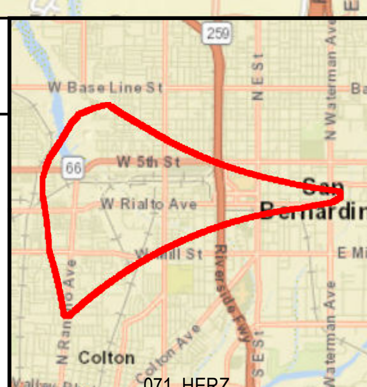
San Bernardino County



HERZ

Circuit Map

San Bernardino County



0 0.125 0.25 0.5 Miles

1 in = 1 miles

High Fire Risk Area

Outage Boundary

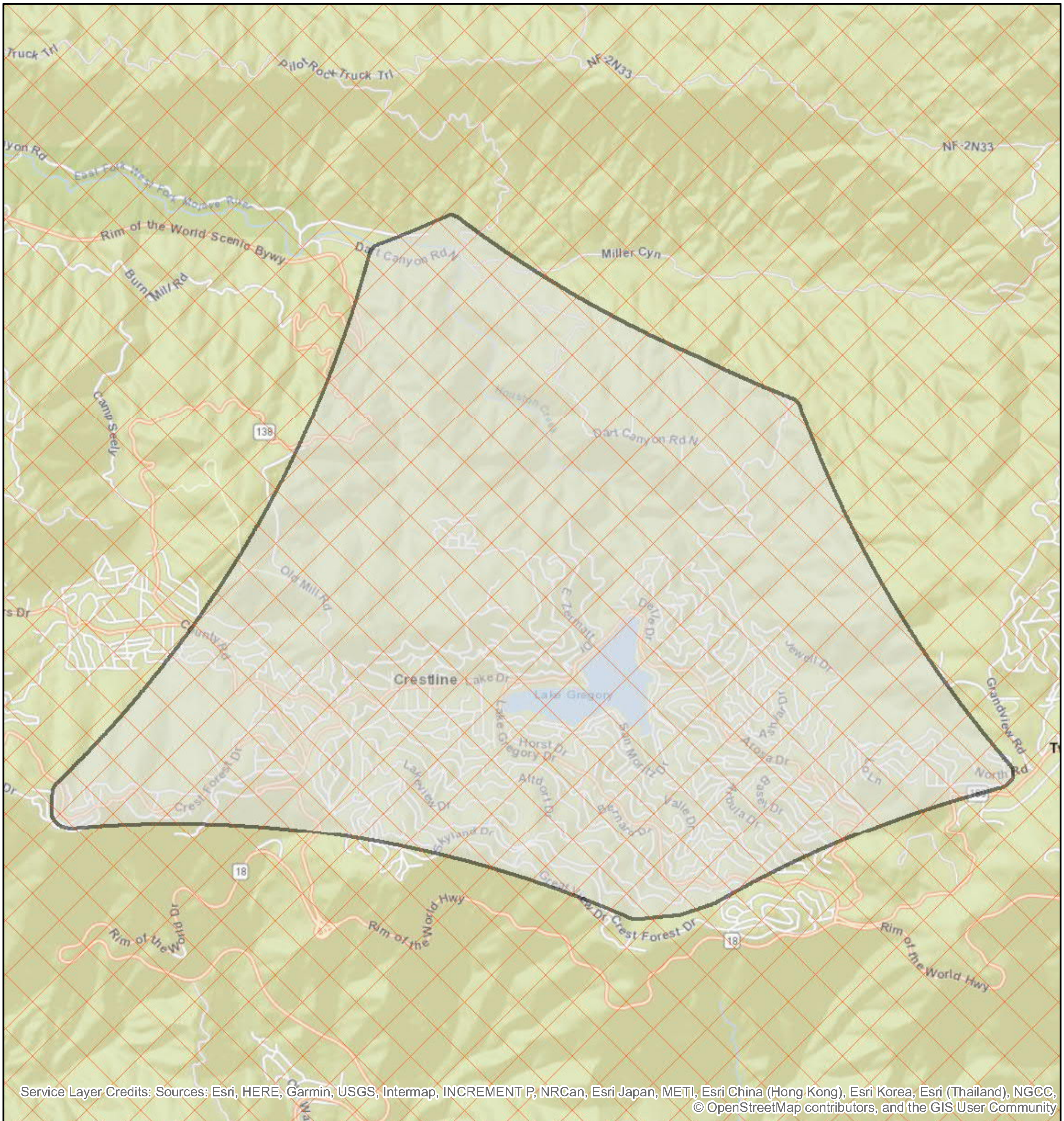
SCE has identified this area as containing distribution circuit(s) that provide electrical service to customers located in High Fire Risk Areas and may be subject to Public Safety Power Shutoffs (PSPS). Some circuits, as indicated on the map, may originate from, terminate in, or otherwise traverse High Fire Risk Areas, and the entire circuit may be subject to a PSPS event outage. While SCE's goal is to minimize the outage to affected areas during a PSPS event, various system design, operational, and environmental factors will affect how and when power is restored to these circuits or portions thereof.

The map was prepared on 4/23/2019 is subject to change at any time. All boundaries are approximate.

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

DOC: PSPS_Map

San Bernardino County



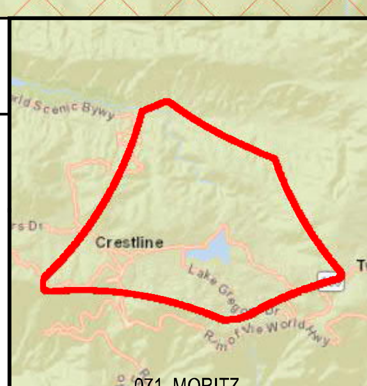
MORITZ

Circuit Map

San Bernardino County

High Fire Risk Area

Outage Boundary



0 0.15 0.3 0.6 Miles

1 in = 1 miles

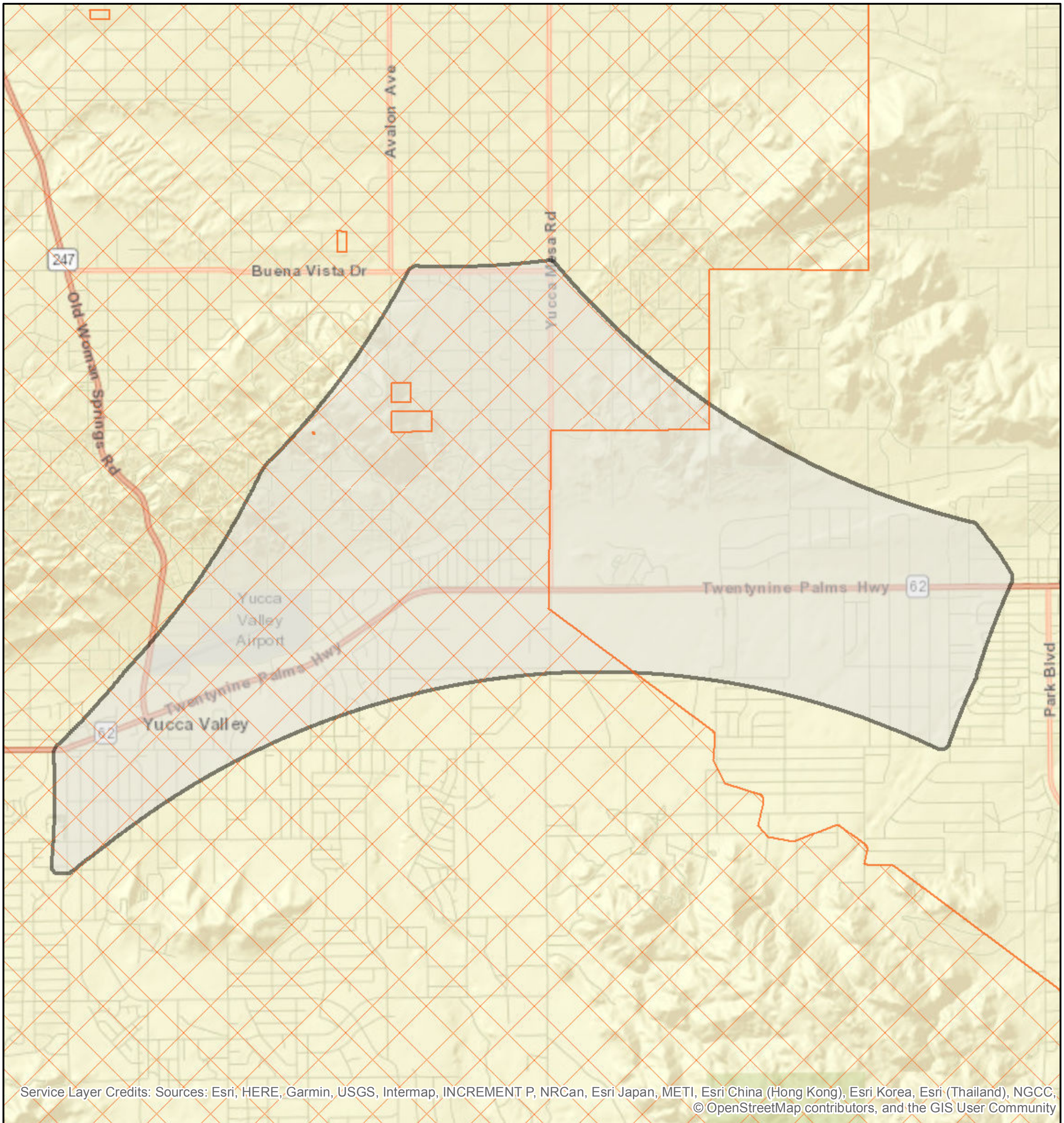
SCE has identified this area as containing distribution circuit(s) that provide electrical service to customers located in High Fire Risk Areas and may be subject to Public Safety Power Shutoffs (PSPS). Some circuits, as indicated on the map, may originate from, terminate in, or otherwise traverse High Fire Risk Areas, and the entire circuit may be subject to a PSPS event outage. While SCE's goal is to minimize the outage to affected areas during a PSPS event, various system design, operational, and environmental factors will affect how and when power is restored to these circuits or portions thereof.

The map was prepared on 4/23/2019 is subject to change at any time. All boundaries are approximate.

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

DOC:: PSPS_Map

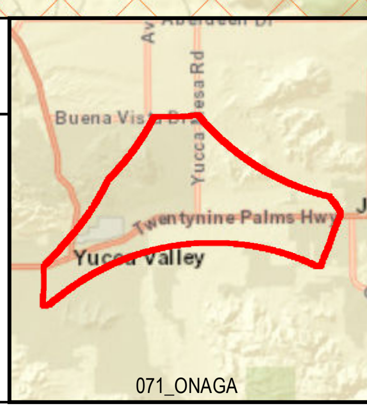
San Bernardino County



ONAGA

Circuit Map

San Bernardino County



0 0.225 0.45 0.9 Miles

1 in = 1 miles

High Fire Risk Area

Outage Boundary

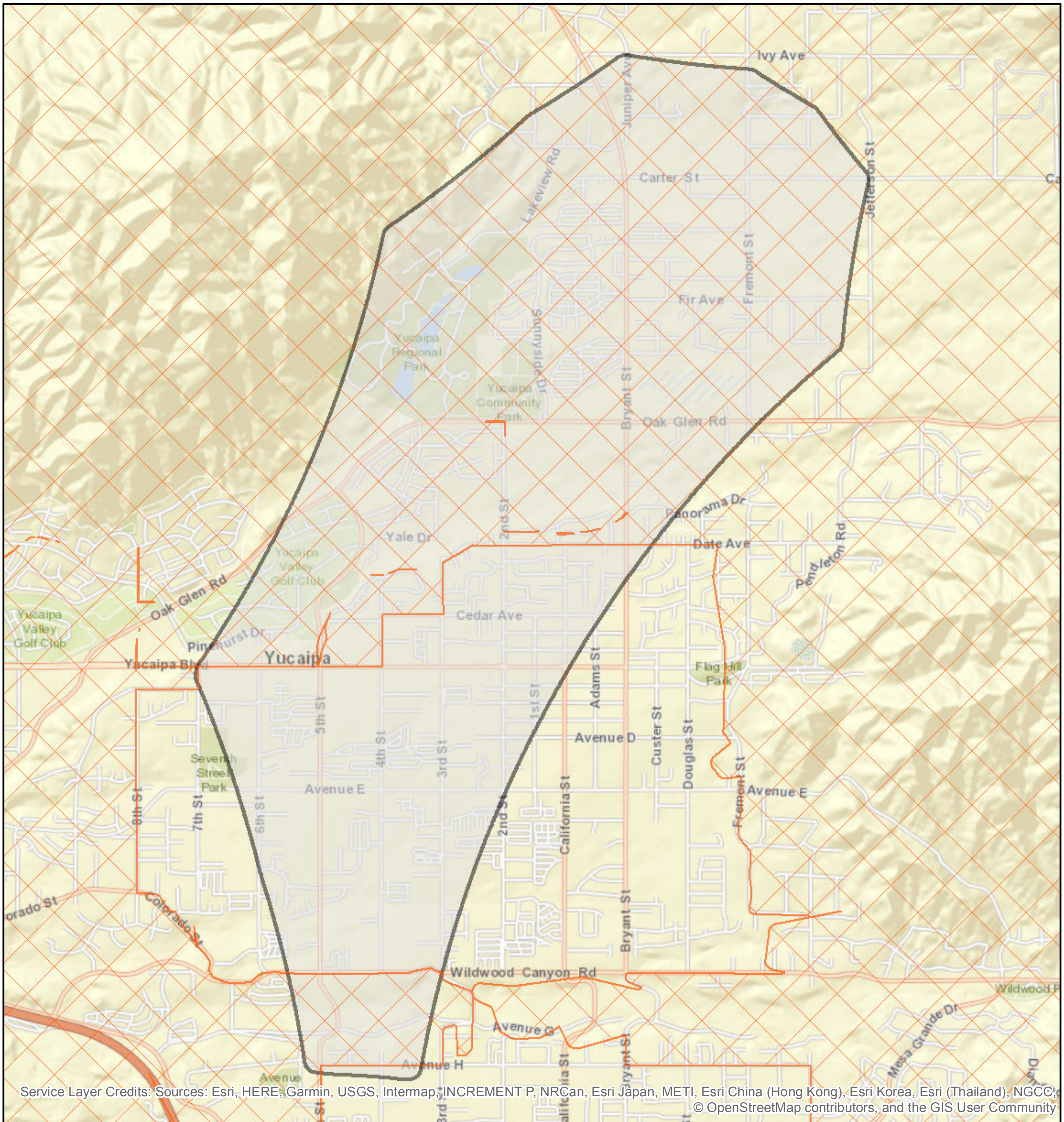
SCE has identified this area as containing distribution circuit(s) that provide electrical service to customers located in High Fire Risk Areas and may be subject to Public Safety Power Shutoffs (PSPS). Some circuits, as indicated on the map, may originate from, terminate in, or otherwise traverse High Fire Risk Areas, and the entire circuit may be subject to a PSPS event outage. While SCE's goal is to minimize the outage to affected areas during a PSPS event, various system design, operational, and environmental factors will affect how and when power is restored to these circuits or portions thereof.

The map was prepared on 4/23/2019 is subject to change at any time. All boundaries are approximate.

SOUTHERN CALIFORNIA EDISON

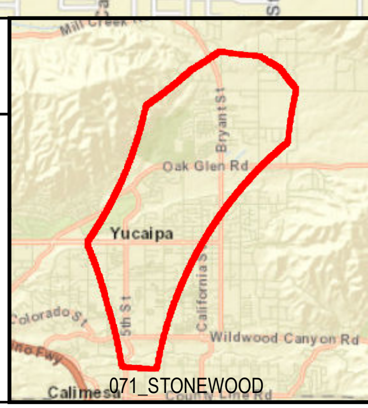
An EDISON INTERNATIONAL Company

DOC:: PSPS_Map



STONEWOOD
Circuit Map

San Bernardino County



0 0.15 0.3 0.6 Miles
1 in = 1 miles

High Fire Risk Area

Outage Boundary

SCE has identified this area as containing distribution circuit(s) that provide electrical service to customers located in High Fire Risk Areas and may be subject to Public Safety Power Shutoffs (PSPS). Some circuits, as indicated on the map, may originate from, terminate in, or otherwise traverse High Fire Risk Areas, and the entire circuit may be subject to a PSPS event outage. While SCE's goal is to minimize the outage to affected areas during a PSPS event, various system design, operational, and environmental factors will affect how and when power is restored to these circuits or portions thereof.

The map was prepared on 4/23/2019 is subject to change at any time. All boundaries are approximate.

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

DOC:: PSPS_Map

APPENDIX D: SBTA OPERATOR CHARGER TYPES

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Operator	Agency	Site	SCE MOS Study Required	Address	City	Lat	Long	Charger Type	Max Possible Buses (based on Facility)	Power per charger (kW)	Quantity (Facilities)	Required (kW) Facilities	SCE District	SCE Circuit Name	Circuit Voltage (kV)	Peak Load of Circuit (Amps)	3ph Power (kW) of circuit	Substation Name	Maximum Allowable Load on Circuit	Peak New Total (MAX Facilities)
MBTA	1	Joshua Tree HQ	Yes	62405 Verbena Road	Joshua Tree, CA 92252	34.1376482	-116.3033566	depot	26	150	7	1050	Yucca Valley	Monument	12	171.15	3557.18	Joshua Tree	8304	4607.18
MBTA	1	29 Palms Yard	No	6994 Bullion Ave.	Twentynine Palms, CA 92277	34.1265084	-116.0635993	depot	8	150	2	300	Yucca Valley	Smoke Tree	12	52.54	1091.99	Twentynine Palms	8304	1391.99
MBTA	1	Yucca Valley Transit Ctr	No	57430 Yucca Trail	Yucca Valley, CA 92284	34.1206129	-116.4107475	en-route		150	1	150	Yucca Valley	Onaga	12	459.14	9542.77	Yucca	8304	9692.77
MBTA	1	29 Palms New Transit Ctr	No	73455 Twentynine Palms Highway	Twentynine Palms, CA 92277	34.1352134	-116.0597682	en-route		150	1	150	Yucca Valley	Old Dale	4.8	163.19	1356.70	Twentynine Palms	3321.6	1506.70
MT	2	Crestline Future Site	No	24042 Pioneer Camp Road	Crestline, CA 92325	34.2417512	-117.2786108	depot	8	150	2	300	Arrowhead	Moritz	12	245.33	5098.94	Huston	8304	5398.94
MT	2	Big Bear Lake	N/A	41939 Fox Farm Road	Big Bear Lake, CA 92315	34.2473577	-116.8870011	depot	14	150	4	600	N/A	N/A	N/A	N/A	N/A	N/A	1000	N/A
Needles	5	Needles Garage	N/A	1101 Front Street	Needles, CA 92363	34.8410478	-114.6076333	depot	4	150	1	150	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OmniTrans	3	West Valley	MOS	4748 E Arrow Hwy	Montclair, CA 91763	34.0931337	-117.701661	depot	74	150	37	5550	Ontario	Kingsley	12	421.39	8758.17	San Antonio	8304	14308.17
OmniTrans	3	East Valley	MOS	1700 W. 5th Street	San Bernardino, CA 92411	34.1088245	-117.3245705	depot	120	150	60	9000	Redlands	Herz	12	480.00	9976.32	Cardiff	8304	18976.32
OmniTrans	3	Fontana Metrolink Plaza	No	16777 Orange Way	Fontana, CA 92335	34.095493	-117.436824	en-route		450	1	450	Foothill	Colleen	12	486.34	10108.09	Randall	8304	10558.09
OmniTrans	3	Yucaipa Transit Center	MOS	N/A	Yucaipa, CA 92399	34.034767	-117.057495	en-route		450	1	450	Redlands	Stonewood	12	N/A	N/A	Yucaipa	8304	N/A
OmniTrans	3	San Bernardino Transit Ctr	No	599 W. Rialto Ave	San Bernardino, CA 92411	34.1008609	-117.2963743	en-route		450	1	450	Redlands	Shops	12	182.50	3793.08	Cardiff	8304	4243.08
VVTA	4	VVTA HQ - Hesperia Yard	MOS	17150 Smoke Tree Street	Hesperia, CA 92345	34.4247483	-117.2902023	depot	12	150	6	900	Victorville	Fargo	12	315.24	6551.95	Hesperia	8304	7451.95
VVTA	4	Barstow Future Yard	No	100 Sandstone Court	Barstow, CA 92311	34.8864211	-117.0796274	depot	24	150	12	1800	Barstow	Judy	12	220.22	4577.05	Ordway	8304	6377.05
VVTA	4	Lorene Drive & 7th Street Station	MOS	15809 Lorene Dr	Victorville, CA 92395	34.514367	-117.318694	en-route		450	1	450	Victorville	Talpa	12	362.67	7537.73	Savage	8304	7987.73
VVTA/NAT	4	G Street at Broadway	N/A	198 G Street	Needles, CA 92363	34.840012	-114.606745	en-route		450	1	450	Yucca Valley	Riley	12	213.33	4433.85	Cardiff	8304	4883.85