Attachment A

Pasadena Zero Emission Rollout Plan

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List of Acronyms

AC	Alternating Current
AQMD	South Coast Air Quality Management District
BEB	Battery Electric Bus
BTM	Behind-the-Meter
CAISO	California Independent System Operator
CalACT	California Association for Coordinated Transportation
CARB	California Independent System Operator
CCS	California Association for Coordinated Transportation
CEC	California Energy Commission
CH4	Methane
CLEEN	California Lending for Energy and Environmental Needs
CMAQ	Congestion Mitigation and Air Quality
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO2	Carbon Dioxide
CPUC	California Public Utilities Commission
DAC	Disadvantaged Community
DC	Direct Current
DCFC	Direct Current Fast Charge
DER	Distributed Energy Resource
DGS	California Department of General Services
DOE	U.S. Department of Energy
EBCM	Electric Bus Corridor Model
EMFAC	Emission Factor Model
EnergIIZE	Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles
EV	Electric Vehicle
EVITP	Electric Vehicle Infrastructure Training Program
EVSE	Electric Vehicle Supply Equipment
FCEB	Fuel Cell Electric Bus

ft	Feet
FTA	Federal Transit Administration
FTM	In Front-of-the-Meter
GGRF	Greenhouse Gas Reduction Fund
GHG	Greenhouse Gas
GIS	Geographic Information System
GREET	Greenhouse Gases, Regulated Emissions, and Energy use in Technologies Model
GVWR	Gross Vehicle Weight Rating
GWh	Gigawatt-hour
HDRSAM	Heavy-Duty Refueling Station Analysis Model
HVAC	Heating, Ventilation, and Air Conditioning
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
IAAS	Infrastructure-as-a-Service
IBank	Infrastructure and Economic Development Bank
ICT	Innovative Clean Transit
ISRF	Infrastructure State Revolving Fund
IIJA	Infrastructure Investment and Jobs Act
ITC	Investment Tax Credit
JPL	Jet Propulsion Laboratory
Kg	Kilogram
kV	Kilovolt
KVA	Kilovolt-ampere
kW	Kilowatt
kWh	Kilowatt-hour
L2	AC Charging at 240V and at least 6 kW
LACTOA	Los Angeles County Transit Operators Association
LADOT	Los Angeles Department of Transportation
LADWP	Los Angeles Department of Water and Power
lbs	Pounds
LCFS	Low Carbon Fuel Standard
LCTOP	Low Carbon Transit Operations Program
Low-No	Low or No Emissions Program
MDT	Microgrid Design Toolkit
Metro	Los Angeles Metro
MW	Megawatt
MWh	Megawatt-hour
N20	Nitrous Oxide
NFPA	National Fire Protection Association
NOx	Nitrogen Oxide
NREL	National Renewable Energy Laboratory
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration
PEM	Proton Exchange Membrane
PM	Particulate Matter
PM10	Particulate Matter - 10 micrometers and smaller

PM2.5	Particulate Matter - 2.5 micrometers and smaller
PPA	Power Purchasing Agreement
PSPS	Public Safety Power Shutoffs
PWP	Pasadena Water and Power
PV	Photovoltaic
RAISE	Rebuilding American Infrastructure with Sustainability and Equity
RFID	Radio Frequency Identification
RFP	Request For Proposal
RNG	Renewable Natural Gas
SaaS	Software-as-a-Service
SAE	Society of Automotive Engineers
SARTA	Stark Area Regional Transit Authority
SCE	Southern California Edison
SCPPA	Southern California Public Power Authority
SCRTTC	Southern California Regional Transit Training Consortium
SMR	Steam Methane Reforming
SOC	State of Charge
SOx	Sulfur Oxides
STURAA	Surface Transportation and Uniform Relocation Assistance Act of 1987
TAP	Transit Access Pass
TIRCP	Transit and Intercity Rail Capital Program
TOU	Time-of-Use
WCCoE	West Coast Center of Excellence in Zero Emission Technology
ZEB	Zero-emission Bus

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Figures

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Section I

Section I: Project Introduction and Technology Overview

Project Description

The City of Pasadena provides both fixed-route (Pasadena Transit) and demand response (Pasadena Dial-A-Ride) public transit to the Pasadena region. In addition to providing transit service to the City of Pasadena, the Department of Transportation also serves San Marino and the unincorporated Los Angeles County areas adjacent to Pasadena, including Altadena, the Kinneloa area, Chapman Woods, and portions of the City San Gabriel. To combat climate change and improve air quality, the City of Pasadena aims to transition to a zero-emission bus (ZEB) fleet. Additionally, the Innovative Clean Transit (ICT) regulation issued by the California Air Resources Board (CARB) mandates that all transit agencies in California transition to ZEBs. The City of Pasadena intends to prepare a Transit Fleet Electrification Plan to examine the economic and technological feasibility of this transition. This report examines the City of Pasadena's needs and is intended to provide elected officials and policymakers with information needed to help make decisions regarding the rollout of a fully zero-emission transit fleet. The ICT Regulation allows transit agencies to form Joint Groups. Under this approach, the members of the Joint Group can collectively comply with the ICT Regulation, rather than individually. **The City of Pasadena is not part of a Joint Group.**

This report is structured in three sections: Section I provides an overview of the City of Pasadena Public Transportation Services and delves into a detailed discussion of current ZEB technology, including charging infrastructure, charging/fueling cost considerations, resiliency, financing resources, and more. Section II examines the feasibility of transitioning to a fully ZEB transit fleet for the City of Pasadena. The feasibility study provides a techno-economic analysis of transitioning to a battery electric bus (BEB) fleet and a hydrogen fuel cell electric bus (FCEB) fleet, Pasadena Department of Transportation's transit operations, the energy needs of the fleet, a plan for phasing in ZEBs, utility analysis, an overview of infrastructure and resiliency equipment that will serve the fleet, financial analysis, and a funding strategy. Section III explores the sustainability and environmental impact of transitioning to a zero-emission transit fleet.

Pasadena Department of Transportation - Public Transportation Services Overview

The City of Pasadena provides essential local public transportation services to the City of Pasadena and the surrounding area, connecting people to the community and the regional transit network. The regional transit agencies that operate in Pasadena include the Los Angeles County Metropolitan Transportation Authority (Metro), Foothill Transit, the Los Angeles Department of Transportation (LADOT) Commuter Express, and Access Services.

The City of Pasadena was incorporated in 1886. The City of Pasadena operates the city's public transportation services, including fixed-route services under the name of Pasadena Transit and demand response transportation services under the name of Pasadena Dial-A-Ride for individuals who are least 60 years old or who have a disability. Pasadena Transit began in 1994, and service has since evolved from one downtown circulator to a network of routes that operate throughout the City. Pasadena Dial-A-Ride started providing service in 1984. Between these two services, the City of Pasadena had an annual ridership of approximately 1.6 million boardings in 2019. In 2017, the City of Pasadena was awarded the Outstanding Transportation Agency award by the California Association for Coordinated Transportation (CalACT) (Pasadena Transit website, 2019).

In 2004, the City of Pasadena was an early adopter of alternative fuel transit vehicles with the integration of several hybrid electric buses (E-Buses) into its fixed-route fleet. By 2014, Pasadena Transit had fully transitioned their fixed-route fleet from diesel to compressed natural gas (CNG) and in 2021 the City converted their CNG fuel to renewable natural gas (RNG).

Pasadena Transit

Pasadena Transit is a fixed-route transit service. Fixed-route service is defined as service where buses travel established routes at scheduled times. Pasadena Transit currently has 29 buses to operate six routes that provide essential transit connections in Pasadena and portions of Altadena seven days a week. In 2014, the fixed-route fleet completed its transition from diesel to CNG, and in 2021 all buses began running on RNG. Pasadena Transit is also investigating expanding transit service.

Pasadena Dial-A-Ride

Pasadena Dial-A-Ride is a shared demand response curb-to-curb transportation service for individuals who are at least 60 years old or who have a disability and live in Pasadena or the unincorporated Los Angeles County areas adjacent to Pasadena, including Altadena, the Kinneloa area, Chapman Woods, and portions of the City San Gabriel. Due to the curb-to-curb nature of this service, these vehicles are also able to traverse residential streets, have limitations in service areas due to street width or other conditions, and do not adhere to a fixed schedule. Pasadena Dial-A-Ride operates seven days a week.

ZEB Overview

Benefits of ZEBs

In Southern California, most transit agencies use a fleet of buses powered by CNG. These buses have an internal combustion engine that burns CNG to create torque and propel the bus. The current CNG buses have proven to be a reliable technology capable of handling most transit bus duty cycles, but they do have several drawbacks, including noise pollution and tailpipe emissions. The combustion of CNG produces carbon dioxide (CO2)—a greenhouse gas (GHG) that contributes directly to climate change—and other pollutants. One of the most potent pollutants is nitrogen oxide (NOx). NOx, when combined with heat and sunlight, produces ozone, which is harmful to the respiratory system and human health. NOx emissions are regulated by the State of California.

ZEBs are buses that produce no tailpipe emissions, and therefore do not produce any GHGs or criteria emissions during bus operations. In practical terms, a ZEB cannot use an internal combustion engine and must use an electrified drivetrain. There are currently two ZEB technologies in existence: the BEB, which uses electricity from a battery to power the bus, and the FCEB, which uses hydrogen to produce electricity that propels the bus. These two technologies do not produce any tailpipe GHG or NOx emissions, which helps to improve air quality. The electricity to charge the bus and the hydrogen production process do produce GHG emissions, but since the drivetrain of a ZEB is twice as efficient as that of an internal combustion engine, ZEBs produce less GHG emissions than CNG buses. ZEBs also generate less noise than CNG buses.

The ICT Regulation

The ICT regulation issued by CARB mandates that all transit agencies in California transition to ZEBs. Fleets must be 100% zero-emission by 2040, and the regulation provides a timeline for phasing in ZEB procurements. Under the ICT regulation, the City of Pasadena qualifies as a small transit agency—they are located in the South Coast Air Basin and operates fewer than 65 buses in annual maximum service. Small transit agencies must submit a ZEB Rollout Plan to the Executive Officer of CARB by July 1, 2023, with the following items:

a. A goal of full transition to ZEBs by 2040 with careful planning that avoids early retirement of conventional internal combustion engine buses.
b. Identification of the types of ZEB technologies a transit agency is planning to deploy, such as BEB or FCEB.
c. A schedule for construction of facilities and infrastructure modifications or upgrades, including charging, fueling, and maintenance facilities, to deploy and maintain ZEBs. This schedule must specify the general location of each facility, type of infrastructure, service capacity of infrastructure, and a timeline for construction.
d. A schedule for zero-emission and conventional internal combustion engine bus purchases and lease options. This schedule for bus purchases must identify the bus types, fuel types, and number of buses.
e. A schedule for conversion of conventional internal combustion engine buses to ZEBs, if any. This schedule for bus conversion must identify number of buses, bus types, and the propulsion systems being removed and converted.
f. A description of how a transit agency plans to deploy ZEBs in Disadvantaged Communities (DACs) as listed in the latest version of CalEnviroScreen (https://oehha.ca.gov/calenviroscreen).
g. A training plan and schedule for ZEB operators and maintenance and repair staff.
h. Identification of potential funding sources.

The ICT timeline for phasing in ZEB procurements for a small transit agency is as follows:

- By 2026: 25% of new bus purchases must be zero-emission.
- By 2029: 100% of new bus purchases must be zero-emission.

The ICT Regulation allows multiple transit agencies to form a Joint Group. Joint Groups allows the members of the group to jointly comply with the ICT Regulation rather than individually. **The City of Pasadena is not part of a Joint Group.**

U.S. Federal Requirements

Altoona Bus Testing

The Surface Transportation and Uniform Relocation Assistance Act of 1987 (STURAA) created the Standardized Bus Testing program. The Standardized Bus Testing program, which is frequently referred to as Altoona Bus Testing, is a federal program that tests the maintainability, reliability, safety, performance, structural integrity and durability, fuel and/or energy economy, noise, and emissions from buses. Altoona Bus Testing is intended to serve as quality control and aims to ensure that new bus models can safely and reliably operate in real-world conditions. Under Altoona Bus Testing, buses are scored on a scale of 1 to 100 based on their performance in each of the testing categories. A bus must receive a score of 70 to pass testing. STURAA mandates that no new bus model can be acquired with federal funding without having received a passing score during Altoona Bus Testing. Since the City of Pasadena may use federal funding towards the purchase of transit vehicles and operations, this study only examines buses that have already passed Altoona Bus Testing or are likely to begin testing in the near future.

Buy American and Buy America

In addition to Altoona Bus Testing, the U.S. federal government has two distinct requirements related to domestic content of federal purchases: Buy American and Buy America. Buy American refers to a requirement from the 1933 Buy American Act and applies to purchases by the U.S. federal government valued at more than $10,000. To comply with this requirement, the goods must be manufactured in the United States, and at least 50% of the cost of their components must come from the United States. There are exceptions to this rule: waivers can be granted if it is deemed to be in the public interest, or if the cost of U.S. components is unreasonably high compared to foreign counterparts. Buy America refers to a requirement for purchases of iron, steel, and other manufactured products incorporated into infrastructure that is funded by the U.S. federal government, including if the project is undertaken by a state or municipal government in the United States. This requirement also applies to transit agencies. If a bus does not meet Buy America standards, then it cannot be purchased with federal funding.

Any transit vehicles purchased with the federal funds from the Federal Transit Administration (FTA) must have at least 70% of the cost of the vehicle be of domestic origin. This is determined by the origin of the bus components—a component is domestic if it is manufactured in the United States, and if at least 70% of the cost of its subcomponents are manufactured in the United States. The cost of making a battery pack is about 26% of the cost of a BEB. However, the FTA has not deemed the use of imported battery cells to be contrary to the Buy America rules; battery cells are considered sub-subcomponents, which are ignored, and they are substantially transformed into battery packs, with modules, coolants, and sensors added in the United States (Canis, 2018). The iron and steel components for direct current (DC) fast chargers received a waiver for the Buy America requirements from the FTA in 2016, as there were no domestic manufacturers of the required components (FTA, 2016).

BEB Overview

Battery-Electric Technology

BEBs are propelled by an electrified drivetrain and use batteries to store electricity. When the bus needs to move, it draws energy from the battery to power a traction motor. The traction motor uses magnets to generate torque and propel the bus. BEBs also have a regenerative braking system that can capture some energy from the bus when it decelerates and use it to recharge the battery during braking. BEBs produce no tailpipe emissions and are very quiet when moving.

BEBs do suffer from some drawbacks, mainly that their range is constrained by how much energy can be stored in the battery. Batteries are heavy and require a lot of space. This factor puts constraints on how many batteries can be placed on the bus safely and may further limit the range of the bus. The range of the bus can be decreased if ridership is high, which increases the weight of the bus, or if the bus must gain elevation on its routes. The heating, ventilation, and air conditioning (HVAC) systems are also energy intensive and, in temperature extremes, can consume more energy than the propulsion system itself. This can reduce the range of the bus on days that are very hot or cold. Lastly, driver behavior can have a large impact on the range of the bus. BEBs are designed to be driven in a certain manner, and bus operators must receive driver training to properly drive the buses. Deviations from this training will impact the bus's performance. Consequently, BEBs cannot serve as a "drop-in" or a one-to-one replacement for a CNG bus for some cycles/routes. This problem is exacerbated by battery charge time. While a CNG bus can be fully refueled in minutes, a BEB can take hours to fully recharge.

Appendix A provides an overview of some of the relevant BEBs currently on the market, and more information on charging technology can be found in the Charging Infrastructure section and Appendix B.

Transit BEBs

Classified in the FTA's 12 year/500,000 mile service-life category, transit buses are Class 7 or 8 vehicles, typically used for fixed-route service, and generally range between 30 and 40 feet in length. A transit BEB is a battery-powered bus that has a length of 30 feet or more. Transit BEBs are considered a mature technology—multiple BEB models have passed Altoona testing, and there are several original equipment manufacturers (OEMs) that produce and sell transit BEBs. Articulated 60-foot ZEB models, which have two sections connected by a joint and can be up to 60 feet in length, have also been Altoona tested. As of December 2020, there were 2,703 transit BEBs that have been purchased, are on order, or deployed across in the United States (Jackson, 2020).

Transit BEBs generally have a range of up to 225 miles, depending on the duty cycle. CNG buses, on the other hand, have a range of about 350 miles. The lower range of the BEB may require additional vehicles to provide the same level of service, depending on the duty cycle. The two Altoona tested 30-foot BEBs do not currently have adequate range for the City of Pasadena's needs at the time of writing. Battery technology is expected to improve over time, however, and it is possible that a BEB can become a drop-in replacement for a CNG bus in the future. BEB charging technology and infrastructure will be discussed in further depth in the Charging Infrastructure section.

Battery-Electric Shuttle Bus and Transit Vans

A battery-electric shuttle bus (also commonly referred to as a small bus) is classified in the FTA's 5 year/150,000 mile or 7 year/200,000-mile service-life category, and is defined as a battery-powered cutaway bus with a length of less than 30 feet and a gross vehicle weight rating (GVWR) of greater than 14,000 pounds. Shuttle buses are generally medium-duty Class 4-6 buses. These buses are typically used for demand response service, such as Pasadena Dial-A-Ride, and have a wheelchair lift to serve disabled passengers. Most shuttle buses can carry 19-24 passengers. OEMs also have the ability to customize configurations based on transit needs, such as changing the floorplan and adding equipment such as fareboxes and wheelchair lifts. Battery-electric transit vans have recently been introduced to the market. These vehicles are smaller than shuttle buses and can typically carry fewer than 10 passengers.

A few OEMs offer electric shuttle buses of varying battery pack sizes, vehicle lengths, and options. At the time of writing, only one 24-foot shuttle van BEB model, manufactured by GreenPower Motor Company, and a 22 foot cutaway BEB model manufactured by Forest River, has passed Altoona testing, and the overall market for electric shuttle buses is small. Currently, the City of Pasadena does not use this type of vehicle for DAR services. However, Phoenix Motorcars' shuttle bus is anticipated to complete Altoona testing in 2022. As of December 2020, 608 battery shuttle buses have been purchased, are on order, or deployed across the United States (Jackson, 2020).

Battery-electric shuttle buses generally have a range of up to 150 miles, depending on the duty cycle, and cost about $275,000. Fossil fuel-powered counterparts, on average, have a range of 350 miles and cost around $75,000. Again, additional vehicles may be required to provide the same level of service, depending on the duty cycle, but battery technology continues to improve. By the time the City of Pasadena is subject to the ICT regulation, shuttle buses will likely have a longer range. The market for transit vans is expected to grow, and there will likely be more commercial offerings in the coming years.

FCEB Overview

Fuel Cell Electric Technology

FCEBs use an electrified drivetrain to propel the bus, but unlike BEBs, FCEBs use hydrogen to produce electricity. When the bus needs to move, hydrogen is drawn from the bus's hydrogen tank and used by a fuel cell to produce electricity. This electricity is stored in a battery until it is sent to the traction motor to generate torque and propel the bus. Since gaseous hydrogen has low energy density per volume, hydrogen must be compressed into the storage tank. Fuel cell vehicles typically store hydrogen in their tanks at a pressure of 350 bar (5,000 pounds per square inch) or 700 bar (10,000 pounds per square inch). FCEBs use hydrogen compressed to a pressure of 350 bar. The tanks on a bus typically store 50 kilograms (kg) of hydrogen, 90-95% of which can be used. An FCEB has the advantage of having a longer range than a BEB. Since hydrogen is energy dense and lightweight, the hydrogen tanks can store more energy on the bus than a battery. FCEBs are generally considered to be a drop-in replacement for a CNG bus. In addition, an FCEB can refuel quickly in about 15-20 minutes. While FCEBs must also contend with the HVAC, ridership, and driver behavior problems that BEBs face, these tend to be less severe due to FCEBs' ability to store more energy. While FCEBs have these advantages, FCEBs currently cost more than BEBs and must use hydrogen, which is more expensive than CNG and unleaded fuel and has unique challenges in obtaining or producing it (see page 13 for hydrogen infrastructure pathways).

Transit FCEBs

A transit FCEB is a hydrogen fuel-cell powered bus that has a length of greater than 30 feet and, like transit BEBs, are Class 7 or 8 vehicles, classified in the FTA's 12 year/500,000 mile service-life category, and typically used for fixed-route service. Most current FCEB models have a length of 35 feet or 40 feet. At the time of writing, there is no Altoona tested 30-foot FCEB model, but 60-foot articulated models have been Altoona tested. Transit FCEBs are considered a mature technology, but to date there are fewer commercial offerings for transit FCEBs than BEBs; however, this is anticipated to change. As of this writing, two models of FCEBs have passed Altoona testing. As of December 2021, there were only 169 transit FCEBs that have been purchased, are on order, or deployed across in the United States (Hamilton, 2021). Transit FCEBs generally have a range of up to 300 miles, depending on the duty cycle. CNG buses, on the other hand, have a range of about 350 miles. Since transit FCEBs have a longer range, they are generally considered to be a drop-in replacement for a CNG bus.

Fuel Cell Shuttle Buses

A hydrogen fuel cell shuttle bus is defined as a hydrogen fuel cell-powered cutaway bus with a length of less than 30 feet, a GVWR of greater than 14,000 pounds, and is classified in the FTA's 5 year/150,000 mile or 7 year/200,000-mile service-life category. Like shuttle BEBs, fuel cell shuttle buses are generally medium-duty Class 4-6 buses, typically used for demand response service, have a wheelchair lift to serve disabled passengers, and can carry 19-24 passengers, depending on the floorplan configuration.

The market for fuel cell shuttle buses is less developed than battery-electric shuttle buses, with fewer models of fuel cell shuttle buses available. Fuel cell shuttle buses are also at an earlier stage of commercialization and have a lower technology readiness level than battery-electric shuttle buses. As of December 2021, only nine fuel cell shuttle buses have been purchased, are on order, or deployed across the United States (Hamilton, 2021). It is unclear how mature this technology will be by 2026, when the City of Pasadena must begin purchasing ZEBs under the ICT regulation.

Fuel cell shuttle buses generally have a range of 230 miles and cost around $275,000. Fossil fuel-powered counterparts have a range of 350 miles and cost around $75,000. Since fuel cell buses have a longer range than BEBs, they are closer to serving as a drop-in replacement. Both full-sized and shuttle FCEBs refuel at 350 bar, but the filling speed may have to be adjusted for the shuttle buses to maintain hydrogen tank integrity. Hydrogen fueling challenges are discussed in more detail under Hydrogen Fueling Infrastructure Overview.

Charging Infrastructure

Depot Plug-in Charging

Most electric buses are charged using a plug-in charger, which consists of the dispenser and a charging cabinet. The dispenser has a plug that goes into the bus to provide energy to charge the battery, and the plug connects to the dispenser via a hose. The dispenser is then connected to the charging cabinet, which contains the power electronics and communications equipment used to control charging with the bus and to communicate with the charging provider's network. The current technology requires workers to manually plug in the bus when it returns from its route. The communications protocols between vehicle and charger can vary among BEB OEMs (see Charger Interoperability section for additional details).

Buses can be charged with Level 2 chargers or DC Fast Chargers (DCFC). A Level 2 charger delivers AC power to the bus at voltages of up to 240 volts. Level 2 chargers can deliver up to 19.2 kW and are typically used to charge electric cars, vans, and shuttle buses. Buses can also be charged with a DCFC. DCFCs deliver DC power to the bus at voltages of up to 600 volts. DCFCs are typically used to charge transit buses. They can also be used to quickly charge shuttle buses.

A plug-in charging system has a large physical footprint. Charging cabinet are responsible for much of the footprint, and they typically require concrete pads. Bollards are also required to protect the charging cabinets from being hit by buses or other vehicles. Some flexibility in the design/layout of a charging site does exist: The charging cabinet must typically be located within a few hundred feet of the dispenser and, as a result, the charging cabinets can be put in areas of the yard with more space (e.g. the edges). Most depots are designed with the dispensers and charging cabinets adjacent to parked buses. For example, a depot might have parking spots for the buses with a dispenser for each parking spot, as illustrated in **Figure 1-1**. In most cases, this design is the least expensive option for charging.

Figure 1-1: Plug-in Chargers Example

Since space is a major constraint, space-saving designs can be developed. A depot can also be designed whereby the buses are parked in lanes, and the dispensers and charging cabinets are located next to the buses in between the lanes, as seen in **Figure 1-2** below.

Figure 1-2: Buses Parked in Lanes Example (Source: ABB)

Another possible design would be overhead plug-in charging. In this design, the buses are parked in lanes and a structure is built over the parking lanes, similar to the example shown in **Figure 1-3**.

Figure 1-3: Overhead Plug-in Charging Example (Source: Burns McDonnell Foothill Transit In-Depot Charging and Planning Study)

A retractable spool is installed on the overhead structure, which allows the plug to be pulled down for charging. This design does not require the charging cabinets to be located next to the bus, which is advantageous when there is not enough space in between parking lanes to install the charging cabinets or dispensers. The overhead structure can also be used for other purposes, such as housing a solar photovoltaic (PV) installation. While this design does save space, the construction cost for the overhead structure is higher because a foundation needs to be laid. Foothill Transit currently uses this design.

Charger Interoperability

A key factor in plug-in charging infrastructure is charger interoperability. Charger interoperability refers to a bus charger's compatibility with multiple types of buses—if a bus charger can charge buses from multiple manufacturers, it would be considered interoperable. Interoperability has multiple dimensions: the charger must be able to plug into, charge, and communicate with buses from multiple manufacturers. Since transit agencies tend to phase-in their fleets over time, it is possible that a fleet will consist of buses from multiple OEMs and that chargers from multiple manufacturers will be deployed. The use of a fleet with buses from multiple OEMs and multiple types of chargers increases the risk that there will be interoperability problems. To promote interoperability, charger standards have been developed. There are several different charger standards. SAE J1772 standardizes the charging plug for Level 2 charging up to 19.2 kW. The Combined Charging System (CCS) standardizes the charging plug and offers a protocol for charging communication. CHAdeMO is a competing charging standard that offers a standard for the charging plug and charging communications. The major OEMs have adopted CCS standards.

Other interoperability concerns exist, one being that the plug-in charger must be able to communicate with the onboard charger via a compatible communications protocol. Another concern is whether the charger provides alternating current (AC) or DC power. The type of power the plug-in charger operates on must be the same as that of the onboard charger. Before purchasing, buses and infrastructure should be tested to ensure interoperability. For example, charging infrastructure for the shuttle BEBs and transit vans can vary. Most shuttle buses and transit vans can charge with a Level 2 charger, though many of these vehicles can also be charged faster with a DCFC. The type of charger required for DC fast charging varies by OEM, and some buses must use a high voltage DCFC. It is important to purchase charging equipment that is compatible with the specific bus purchased.

Depot Overhead Charging

Buses can also be charged with an overhead pantograph charger, which is placed over the bus. When the bus parks, a radio frequency identification (RFID) sensor on the bus signals to the charger, the charger and the bus make contact, and charging begins. There are two types of pantograph chargers: a top-down charger, in which the pantograph lowers itself down to the bus to initiate charging, and a bottom-up charger, in which the pantograph is mounted on the bus and raises itself to the charger to begin charging. Pantograph chargers tend to charge at a higher power level than plug-in charging. Most overhead chargers charge at 150-200 kilowatt (kW), though some can charge at 450-600 kW. Most depot overhead chargers charge in the 150-200 kW range to manage utility demand chargers.

An overhead pantograph charger requires an overhead structure to be built in order to mount the charger above the bus parking spots. At a very minimum, a steel structure is required. Typically, the installation of a steel structure involves building a foundation to anchor the structure. Installing the structure itself is one of the most expensive parts of the construction process but adding additional features to the structure can be done at a relatively low incremental cost. As a result, solar panels are often installed on the structure, which provides the benefit of providing power for the facility and sheltering the bus from sunlight (to prevent heat gain) and rain. Parking lanes are also built underneath the structure, and a curb is necessary to guide the buses to align with the charger and protect the charging cabinet from collisions.

The main advantage of depot pantograph charging is that the pantographs can automatically charge the bus without workers present to manage plugs. Smart charging software can be used to control when to start and stop charging, which means that some of the charging operations can be automated. However, overhead pantograph charging, as depicted in **Figures 1-4 and 1-5**, is more expensive than regular plug-in charging. The pantographs add about 30% to the cost of the charger (per correspondence with bp pulse), but this amount excludes the construction/installation costs. Since construction/installation comprise most of the cost, the overall incremental cost of the pantograph is relatively small. An overhead structure is expensive, but this solution, which becomes economical when installed to charge at least 30 buses, is not much more expensive than overhead plug-in charging. For example, the Los Angeles Department of Transportation (LADOT) is currently planning to deploy a depot overhead charging solution for some of their yards to charge a total of 104 buses.

Figure 1-4: In-Depot Overhead Charging Example (Source: CALSTART)

Figure 1-5: In-Depot Overhead Charging Example (Source: CALSTART)

SAE J3105 is the standard by which conductive automated connection charging devices for electric vehicles are designed. There are multiple types of chargers that are governed by this standard including overhead pantograph chargers. SAE J3105 provides standards for both top-down and bottom-up chargers. SAE J3105/1: Infrastructure-Mounted Cross Rail Connection is the portion of SAE J3105 that governs top-down chargers. SAE J3105/2: Vehicle-Mounted Pantograph Connection is the part of SAE J3105 that governs bottom-up chargers. Top-down chargers that comply with SAE J3105/1 will be interoperable with each other whereas bottom-up chargers that comply with SAE J3105/2 will be interoperable with each other. A SAE J3105/1-compliant top-down charger will not be interoperable with a SAE J3105/2-compliant bottom-up charger.

A potential variation of this setup includes in-ground inductive chargers, shown in **Figure 1-6**. Inductive chargers can charge a vehicle without plugging-in or needing an overhead charger. Instead, inductive chargers can charge vehicles wirelessly. The charger consists of a pad on the ground; the bus parks on top of the charging pad and wireless charging begins. Inductive chargers can charge at powers of up to 200 kW. If these chargers are used, the bus is parked on the inductive chargers at the end of the day's service. Smart charging software then controls the charging overnight. In-ground inductive chargers are currently produced by Momentum Dynamics and WAVE. At this point in time, few transit agencies use depot inductive chargers. However, this is a technology that agencies might begin to consider as an alternative to depot overhead pantograph charging.

Figure 1-6: Inductive Charging Example (Source: Momentum Dynamics)

On-route Charging

Most transit agencies use depot charging as the primary method of charging their buses. However, buses are sometimes deployed on routes that they cannot serve on a single charge. This issue can occur if the bus is on a lengthy or high-grade route, or alternatively, on days with extreme weather that increases the energy consumption of the bus's HVAC system. This is highly problematic, as the bus will run out of battery before it finishes the route.

Using overhead on-route chargers is one way to address this problem. On-route charging occurs during a gap in service—the bus will typically drive underneath an overhead on-route charger, and the bus and the charger will interface and connect in a similar manner as depot overhead charging. Most buses have only short breaks during their schedule. To charge as much of the battery as possible during a break, these overhead chargers usually charge at high power levels. The typical on-route overhead charger will charge at power levels of 450-600 kW. These chargers are commonly built at a bus stop or a bus terminus to use when the bus is on a scheduled break.

One major issue with an overhead charger is that the driver needs to align the bus with the pantograph. To achieve this, transit agencies will add markings to the ground underneath the charger to assist the driver. See **Figure 1-7** as an example of this setup.

Figure 1-7: On-route Overhead Charging (Source: ABB)

Public Charging

A transit agency could also utilize public charging networks. The use of a public charging network could serve as a form of on-route charging. Under this charging model, the buses would be charged overnight. However, if the buses were to run low on charge during the day, they would have the option to charge at a public charging station during a break in service to refill the battery and extend the range of the bus. Public charging can be used as an emergency measure if a bus runs low on battery during its operations. It could also potentially be used to extend the range of the bus if its service is expanded. Alternatively, public charging can be used as a resiliency measure if the bus depot were to lose power. Unless there is an area-wide power outage, it is unlikely that two separate charging locations would lose power simultaneously. As a result, a public charging station could provide backup charging if the bus depot were to lose power.

Public charging would likely be most useful for shuttle buses operating demand response service (e.g. Dial-A-Ride), as they have a smaller battery capacity than transit buses and can therefore recharge a high percentage of the battery during a mid-day charge. Public charging stations can have Level 2 chargers, DCFCs, or both. DCFCs can charge the battery faster and would be the more useful type of charger. However, Level 2 chargers can be useful if the bus only needs a small amount of charge.

If a transit agency opts to use public charging, it would need to identify the specific station or stations that it plans to use in advance. Transit agencies should confirm that the chargers at those specific sites are interoperable with their specific bus OEM. Since there are multiple charging standards and different charging voltages, it would be advisable to confirm interoperability by physically charging the bus at the actual station. Public charging stations typically require that customers purchase a subscription and they also charge per kWh dispensed by the charger.

Most public charging stations are designed for light-duty electric vehicles as they have head-in parking spaces. However, bus operators do not typically backup vehicles in public spaces without using a spotter to guide them. As a result, this parking configuration would not appropriate for buses. To use a public station, the buses would need to have access to a pull-through parking configuration.

Pasadena Water and Power (PWP) recently opened the Arroyo EV Charging Depot, which is located at 64 E. Glenarm Street, Pasadena, CA. This station has multiple DCFCs that can be used by buses. The site will likely be expanded within the next couple of years to include DCFCs and dedicated spots for medium- and heavy-duty vehicles. The specifics of the site layout, including the type of parking and the number of chargers were not disclosed. This station is located near the terminus for the City of

Pasadena's Route 51/52. It is likely that additional public charging stations will also be deployed in the future, which would be an opportunity for coordination to identify how these stations could potentially address the City of Pasadena's needs and to plan designs accordingly.

Hydrogen Fueling Infrastructure Overview

FCEBs consume hydrogen to power the vehicle. To fuel a fleet of FCEBs, a transit agency needs to obtain and dispense hydrogen to the buses. Currently, FCEBs have a hydrogen tank that receives hydrogen at a pressure of 350 bar. Most FCEBs store 35-50 kg of hydrogen in the tank. Transit agencies have several options for obtaining hydrogen. A transit agency can either produce the hydrogen on-site or buy hydrogen from a fuel provider and have it delivered to the fueling site. Since the transportation of hydrogen is expensive, on-site hydrogen production is usually the less expensive option. However, on-site hydrogen production requires installing infrastructure, which can present challenges depending on the space available.

Hydrogen is a flammable gas, and as a result, hydrogen infrastructure, as with other types of propulsion infrastructure, must comply with fire safety standards, especially the prominent National Fire Protection Association (NFPA) codes. Hydrogen infrastructure installations often have a lead time of ten months to two years, including the permitting process.

On-site Steam Methane Reforming (SMR)

Hydrogen can be produced using SMR. SMR requires a reformer that combines natural gas and steam at high temperatures to produce hydrogen. SMR uses little electricity, using instead a catalyst to produce the hydrogen. However, SMR does require the use of natural gas and water.

An on-site SMR system would need a minimum of 60 feet by 60 feet, or 3,600 square feet. The system can also be split into two 60-foot by 30-foot rectangles, as long as the two areas can be placed near each other. Typically, the SMR comes in two parts. One part is a container that houses the SMR modules, the electronics, and hydrogen compression equipment. The second part is the fueling station and storage. An on-site SMR system also requires a compressor to compress the hydrogen in order to dispense at a pressure of 350 bar.

Since this process produces GHGs, the State of California requires that 33% of the natural gas comes from renewable sources. SMR also consumes about 4.6 gallons of water per kg of hydrogen produced (Webber, 2007). Still, SMR can produce hydrogen in a less expensive manner, but SMR production does require investment in production equipment. See page 19 for more information on hydrogen fueling cost considerations.

On-site Electrolysis

Hydrogen can also be produced via on-site electrolysis. Electrolysis produces hydrogen by running an electrical current through pure water to split the water into hydrogen and oxygen. The hydrogen is then captured, compressed, and stored until it is dispensed into the bus. Electrolysis uses approximately 2.4 gallons of water per kg of hydrogen (Webber, 2007). An electrolyzer has a similar footprint as an SMR system and comes in two containers, with one container housing the electrolyzer and compression equipment and the second container housing storage and fueling equipment. An on-site electrolyzer system also requires a compressor to compress the hydrogen to dispense at a pressure of 350 bar.

Electrolysis is considered the cleanest method of producing hydrogen, as it does not produce any direct GHG emissions. In using electricity, indirect GHG emissions are generated when producing the electricity. However, these emissions can be mitigated if the electricity is produced from renewable sources. Electrolysis is currently an expensive method of producing hydrogen and is energy intensive— see page 19 for more information on hydrogen utility cost considerations.

Delivered Gaseous Hydrogen

Hydrogen can be produced offsite at a centralized location and then delivered to the bus fueling location. Gaseous hydrogen is typically produced at a central production facility at low pressures of 20-30 bar, then compressed to a higher pressure. The hydrogen is stored in long cylindrical tubes that are then loaded onto a truck trailer and transported to the bus fueling location. Once the tube trailer arrives at the location, the hydrogen is delivered to the fueling station. A compressor is used to increase the pressure of the hydrogen in the tube trailer. This compressed hydrogen is then delivered to storage tanks where it can be dispensed to the buses.

These tube trailers can carry only a limited amount of hydrogen, however. U.S. Department of Transportation regulations limit compression pressures to 250 bar. Furthermore, truck payload weight restrictions effectively limit a tube trailer to delivering a maximum of 280 kg of hydrogen (U.S. DOE Hydrogen and Fuel Cells Technology Office, n.d.). As a result, this option is more advantageous for fleets that require relatively low volumes of hydrogen. See page 19 for more information on hydrogen delivery cost considerations.

Delivered Liquid Hydrogen

To be delivered in liquid form, hydrogen is produced at a centralized production facility and then liquified by reducing its temperature to -253 degrees Celsius. The liquid hydrogen is then put onto a truck for delivery. Once the truck reaches the depot, it will pump the liquid hydrogen into a liquid hydrogen storage tank. The hydrogen from the storage tank is processed by liquid compression pumps, which delivers the hydrogen to a vaporizer. The vaporizer converts the liquid hydrogen to gaseous hydrogen, which is then delivered to gaseous storage tanks. The hydrogen is subsequently dispensed to the buses.

Liquid hydrogen has the advantage of being more economical than gaseous hydrogen, but some drawbacks exist. Mainly, liquid hydrogen is lost if it is left in storage for a long time. As liquid hydrogen warms up, it evaporates and turns into a gas. Hydrogen systems are designed to release this gas, known as off-gassing. Off-gassing can result in losses of 1% per day, but off-gassing can be reduced if hydrogen is dispensed to vehicles on a daily basis. A system that captures off-gassed hydrogen and compresses it into the gaseous storage tanks can also be employed.

Offsite Retail Fueling

If a transit agency is unable to invest in hydrogen fueling infrastructure, they could theoretically fuel buses at offsite retail fueling stations. A retail fueling station is a privately owned station that sells hydrogen to customers and would be analogous to a gas station or a CNG station.

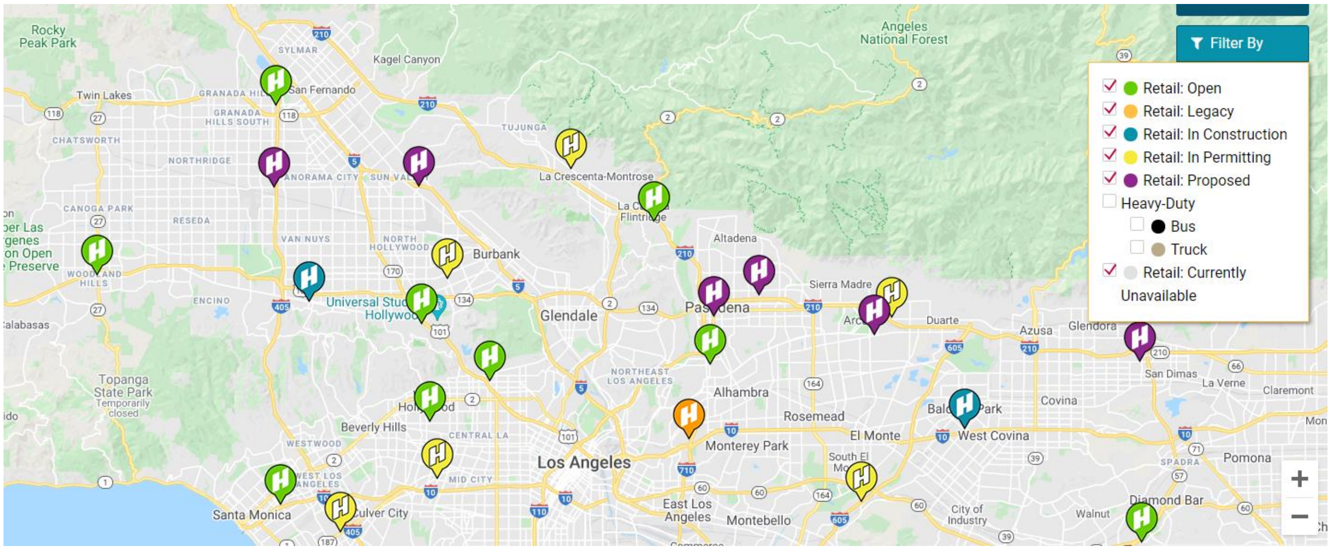
The market for retail hydrogen fueling is in the early stages of development. As the fuel cell vehicle market has matured, more retail stations have been built. While there are multiple retail stations, light-duty and heavy-duty retail fueling are distinct markets. Light-duty stations typically have 700 bar dispensers and lower levels of storage. Heavy-duty stations typically have 350 bar dispensers and require large storage capacity. Currently, there are no heavy-duty stations near Pasadena. As a result, retail fueling would not be a viable option for a fleet of transit FCEBs.

Retail fueling, however, could potentially be appropriate for fuel cell shuttle buses and dial-a-ride vehicles. Hydrogen shuttle buses use less hydrogen than a transit FCEB, and it is theoretically possible to fuel them at retail hydrogen stations. There is a True Zero hydrogen station located at 550 Foothill Boulevard, La Cañada Flintridge, CA 91011 (see **Figure 1-8**).

Figure 1-8: True Zero Light-Duty Hydrogen Fueling Station (Source: CALSTART)

The use of retail hydrogen stations as the primary source of hydrogen entails some operational risks. Retail hydrogen stations can be inoperable if they run out of hydrogen or are undergoing planned or unplanned maintenance. To lower this risk, it would be prudent to have access to multiple fueling stations. There are other stations located in the vicinity: a True Zero station is in South Pasadena at 1200 Fair Oaks Avenue, South Pasadena, CA 91030. There is also a True Zero station in the permitting process. This station will be located at 3402 Foothill Boulevard, Glendale, CA 91214. Shell has also proposed installing a hydrogen station at 290 South Arroyo Parkway, Pasadena, CA 91105. See **Figure 1-9** for a map of retail fueling stations in the Los Angeles area.

Figure 1-9: Map of Retail Fueling Stations in the Los Angeles Area (Source: California Fuel Cell Partnership)



Charging and Fueling Cost Considerations

Energy and Power

The utility costs for a ZEB fleet are dependent on two main factors: energy and power. Energy represents the total amount of electrical fuel consumed by the bus. Energy is denoted in units of kilowatt-hours (kWh). The battery of a BEB has capacity limits and can only store a certain amount of kWh of energy. The energy capacity of the battery is analogous to the number of gallons that can be stored in a gas tank. Utility companies typically sell energy by the kWh. The price of the kWh can also change depending on how much demand occurs during the day. Energy is usually most expensive in the afternoon when demand is high and costs less at night when demand is lower. As a result, transit agencies typically schedule their charging to coincide with the lowest energy rates.

Power represents the rate at which energy is consumed and is typically measured in kW. Utilities care about power; if there is too much aggregate demand, it can overwhelm the grid and cause a blackout. As a result, utilities incentivize lower power demand from their customers by charging per kW. Customers are usually charged for the maximum amount of power they demand over the course of the month, regardless of how long they draw power at that level. For example, if a transit agency normally has a power demand of 50 kW but experiences a surge in demand and consumes 100 kW for 15 minutes over the course of a month, they would be charged for demanding 100 kW. Charges for power demand are typically high and can be extremely costly. These charges are typically responsible for most of the utility bill.

Primary and Secondary Service

Utilities also charge based on the type of electrical service they provide. Utilities can provide primary and secondary service. Type of service refers to the voltage at which the utility delivers the electricity to the customer. Primary service occurs when the utility delivers electricity to the customer at a high voltage. When primary service is provided, the utility delivers electricity directly to the customer without stepping down the voltage. In this case, the customer is responsible for stepping down the voltage with their own transformer. Secondary service occurs when the utility steps down the voltage with their own transformer and delivers the electricity to the customer at a lower voltage. Primary service usually involves lower electricity rates. The decision to provide primary or secondary service is typically determined by the utility.

Strategies for Managing Utility Costs

Utility charges are determined by a variety of factors such as energy and power demand, which have a major impact on the utility charges that a transit agency must pay to charge their buses. However, there are strategies to reduce utility charges. This section will discuss some of the strategies that transit agencies can employ to minimize this cost.

Overnight Charging

Transit agencies are charged for the energy they consume. Transit agencies are typically charged by the kWh, and utilities usually have different rate structures that their customers can use. Most transit agencies use time-of-use (TOU) tariffs. Under a TOU tariff, energy charges vary throughout the day. Energy charges are typically lowest during times of low energy demand (off-peak rates) at night and are highest during the day in the late afternoon/evening hours—solar production decreases as the sun begins to set, and energy consumption increases as air conditioning loads come online. As a result, peak energy charges usually occur from approximately 4 to 8 pm. Some utilities also offer flat rate tariffs, where the cost per kWh is constant throughout the day.

Transit agencies aim to reduce the energy costs associated with charging, but transit agencies cannot reduce energy costs by reducing the amount of energy they consume, which would entail cutting transit service. If a transit agency is on a TOU tariff, they can reduce energy charges by shifting the times during which they charge the buses. Since off-peak rates are lower than peak rates, energy costs can be reduced by shifting the charging schedule so that most of the buses charge at night during off-peak hours.

Sequential Charging

Utilities typically charge a fee per kW of peak power demand. As a result, transit agencies can decrease their utility costs by lowering the peak power they draw from the grid through sequential charging. In a depot with unmanaged charging, the buses start charging as soon as they are plugged in. All buses then charge at the same time, causing maximum possible power draw. Sequential charging entails breaking the fleet into batches. The first batch of buses begins charging and continues until fully charged. Once the first batch is complete, the second batch begins charging, and so on until all batches have completed charging. This staggers the power demand on the grid throughout the night and results in lower power demand as compared to unmanaged charging.

Managed/Networked Charging

Another method of reducing utility costs and demand charges is the use of managed charging. Managed charging minimizes power demand by remotely monitoring the bus battery status, communicating with the chargers to prioritize which buses get charged, and regulating the amount of power each bus receives. Managed charging uses algorithms to control which buses should get charged and when. Managed charging software usually avoids having all buses charge at the same time and can control the power level at which they charge, thus reducing power demand. Managed charging optimizes charging and can result in even lower power demand than sequential charging.

Many smart charging systems support the use of Open Charge Point Protocol (OCPP), which is a standard for charger-to-network communication. OCPP compliant chargers allow multiple types of chargers to be integrated by a smart charging provider. While these features are not necessary for charging electric buses, they are a useful tool for larger fleets, as they can ensure all buses charge on time while also reducing maximum power demand. Reducing maximum power demand is important—demand charges and utility interconnection charges are a function of max power demand. Smart charging systems can control charging behavior to reduce maximum power, decreasing maximum power draw by up to 31 - 65% (Eichman, 2020) and greatly reducing demand charges and the cost to operate the buses. Sometimes the charger manufacturer (e.g., ABB and Siemens) will offer their own networked charging solution. However, there are also other companies who specialize in this space as network providers.

The most basic software solution will remotely monitor the bus battery status while charging. This usually comes in the form of a web portal or app that the fleet manager can access at any time. The web portal can integrate data from the fleet operations/dispatch control system, yard management system, and energy management/smart charging system. In addition, if a fleet purchases buses and chargers from multiple manufacturers, the web portal can integrate this data in one place. Basic analysis, such as which buses use the most energy, which buses are having range problems, which buses are having a disproportionate amount of maintenance downtime, and battery state-of-charge can be regularly reported to the manager. Some smart charging companies can also integrate telematics and real-time data from the buses into their smart charging systems. This information can be used by the smart charging software to prioritize which buses should be charged first to assure that all buses are ready for their respective duty cycles.

More advanced solutions will allow the charger to communicate with the utility grid. The data could be passed through in several ways, including aggregated at a network provider's cloud service or individually sent to the utility via the OpenADR (Open Automated Demand Response) 2.0b protocol, or using the OpenADR with OCPP protocol. In this case, the utility could use OpenADR with OCPP to have open communication between the electric vehicle (EV) charging stations and central management software, enabling the charging system to serve as a demand response or excess supply asset. Demand response and excess supply programs incentivize customers to shift electricity load to different times of day to facilitate grid operations and system-wide cost savings. Using OCPP on its own is also an option. Several charging manufactures support the OCPP standards, which allows the end user to manage various chargers with one compatible software management system.

To provide managed charging solutions, a network provider will typically need to collaborate with the utility serving the transit agency. In most cases, managed charging companies provide turnkey infrastructure construction and installation services. In doing so, the managed charging company provides the capital expenditures for the chargers and then signs a power purchasing agreement to sell the electricity to the transit agency. Appendix D provides details for managed/networked charging providers.

Hydrogen Fueling Cost Considerations

On-site vs. Delivered Hydrogen vs. Offsite Refueling Station

The cost of hydrogen is influenced by several factors. One key factor is the location of hydrogen production. In general, the least expensive option is to produce hydrogen on-site at the bus fueling location. Hydrogen can be produced on-site using commercialized and technologically mature equipment—see On-Site SMR and On-Site Electrolysis for detailed descriptions of these processes. Using this technology, hydrogen can be produced relatively cheaply. Some SMR equipment manufacturers have estimated that hydrogen can be produced for as low as $6 per kg. However, on-site production requires capital investment, so it is not economically feasible to produce hydrogen on-site until a volume of 200 kg of hydrogen is reached.

Delivered hydrogen must be transported to the bus fueling location—see Delivered Gaseous Hydrogen and Delivered Liquid Hydrogen for descriptions of these options. The transportation of hydrogen via truck is an expensive process, and most of the cost of delivered hydrogen comes from transportation. Since delivered hydrogen requires less on-site infrastructure, this solution is more economically feasible for transit agencies that use low volumes of hydrogen. Delivered gaseous hydrogen is the best option for transit agencies that consume less than 200 kg of hydrogen per day, which is below the threshold at which on-site production is economically feasible. Liquid hydrogen has less volume than gaseous hydrogen, and therefore more liquid hydrogen can be stored on a truck than gaseous hydrogen, making liquid hydrogen delivery more economical. Due to off-gassing, delivered liquid hydrogen is most economical when a transit agency requires a large amount of hydrogen and will refuel daily.

Even though no heavy-duty stations currently exist near the City of Pasadena, retail fueling could be appropriate for fuel cell shuttle buses and dial-a-ride vehicles. Based on pricing data collected in February 2022, the at-the-pump price charged at local retail stations is about $16-$17 per kg of hydrogen. However, it might be possible to negotiate a lower fuel price with a retail fuel provider in exchange for guaranteed fuel volume. See Offsite Refueling Station for more information.

Utility Charges for Producing Hydrogen

Utility charges are also an important factor in the price of hydrogen. Electricity is a required input for hydrogen. If hydrogen is produced by electrolysis, electricity is used as an input to produce the hydrogen. Electrolysis is energy intensive and producing hydrogen with this methodology will entail high energy and power demand (see On-site Electrolysis). The production of one kg of hydrogen requires 55 kWh. Additional energy is also required to compress the hydrogen so it can be dispensed. An electrolyzer would also have high power demands, which would lead to high utility bills. Hydrogen can be produced via electrolysis for about $10-$12 per kg. Furthermore, regardless of the source of the hydrogen, electricity is required to prepare hydrogen to be dispensed. Once hydrogen is produced or delivered, it must be compressed. In addition, the fueling station uses electricity. As a result, the use of hydrogen fuel will entail operational costs beyond that of the cost of the hydrogen and the fueling station.

Route Modelling Overview

Overview of the Electric Bus Corridor Model (EBCM)

CALSTART, in partnership with Utah State University Sustainable Electrified Transportation Center (SELECT), developed a modeling tool to analyze and predict the performance of a BEB on a predetermined route, called the EBCM. Environmental factors like terrain and climate can have a significant impact on the range of BEBs. EBCM uses seasonal weather data, bus specifications, route characteristics, ridership, and other operational data to estimate the energy consumption of a BEB for various charging scenarios (depot only, on-route only, or both). EBCM is a dynamic and highly customizable input model that can be modified according to individual transit agency preferences and needs.

CALSTART was tasked with analyzing the electrification of bus routes as part of this feasibility study. Identifying the current and future operational needs, specific to the routes each agency runs, was imperative to determine which EV solutions (vehicle and charging infrastructure) may be suitable replacements for the existing fleet.

To complete this analysis, route level data such as ridership, average speed, number of laps per day, number of stops, topography, and time in operation was collected. CALSTART referenced the Altoona Test data for the potential electric bus models that could operate these routes. See **Table 1-1** below for the complete set of customizable parameters that contributed to the modeling results.

Table 1-1. Customizable parameters that are inputs to the EBCM

Vehicle Inputs	Route Information Inputs	Bus Charging Infrastructure Inputs
Bus type & length (ft)	Service operation times	Depot charger power & user specified output (kW)
Frontal area (ft2)	Number of passengers	Bus state of charge upper & lower bounds
Curb weight (lb)	Average driving speed (mph)	Overnight dwelling time at depot charger
Battery-to-wheel and regenerative braking efficiencies	Number of bus stops along the route	Charging efficiency
Battery size (kWh)	Distance and slope of route topography	-
HVAC cooling and heating performance factors	Service area elevation & geographic coordinates	-
Desired cabin temperatures by season (°F)	Seasonal temperature highs, lows, and averages (°F)	-

As the first step in the analysis, CALSTART interviewed the fleet managers at Pasadena Department of Transportation. The purpose of this initial touchpoint was to establish a mutual understanding of each agency's goals for the analysis, as well as to gather key input parameters for the model. These meetings and subsequent follow up communications yielded important information, such as desired electric bus model options, existing bus routes of interest for electrification, bus passenger cabin HVAC and state of charge (SOC) preferred settings, charging preferences (depot vs. on-route), and other details. Following this level-setting step, CALSTART determined geographic information for the routes to be modeled by EBCM. For the fixed-route buses, the agencies supplied geographic information system (GIS) data that was converted into a useful format for the tool. Because the on-demand dial-a-ride service routes vary by day and by passenger, CALSTART worked with the fleet managers to determine a hypothetical route with similar mileage and topography to some of the usual service routes. CALSTART then traced these routes on Google Earth to collect topographical inputs for distance and slope to be inputted to the model. The electric bus performance that was modeled in EBCM was also based on battery-to-wheel and regenerative braking efficiencies from published Altoona bus reports. The aim of using Altoona data is to ensure that the model is operating on verifiable third-party data, rather than relying exclusively on marketing materials from bus manufacturers. The next step in the process is gathering locational (longitude, latitude, elevation, and time zone) and seasonal weather inputs. This step is essential for the customization of bus performance specifications for a particular agency's needs. It is also noteworthy that in the California context, extreme heatwaves are increasing in frequency and intensity. More instances of fluctuations in temperature are projected to have a significant impact on vehicle HVAC energy consumption, especially air conditioning. Air conditioning is a very energy intensive auxiliary function that can, in some cases, dramatically reduce the overall range of the electric bus. To account for these challenges, the EBCM analysis included a temperature maximum parameter of 120 degrees Fahrenheit for the summer season forecast.

The analysis yielded kWh energy consumption outputs by bus subsystem, which is divided into dynamic, heating, and auxiliary sources, and the average expected energy consumption by season. Additionally, the model estimates the remaining SOC per lap on a given route to give an approximation of how much of the regular service day can be covered by a single electric bus. The energy consumption outputs from this analysis were used to inform the development of charging schedules, costs, and location(s) for the future electric buses. The route modelling/energy analysis results for each individual transit agency is displayed in their specific chapters.

Resiliency

The introduction of BEBs introduces unique concerns relating to resiliency. All ZEBs are reliant on access to electricity. Electricity is needed to charge a BEB and to produce hydrogen. Even if hydrogen is produced and stored on-site, large amounts of power are required to compress and dispense the hydrogen. As a result, if there is a loss of power, transit agencies would be unable to charge or refuel their buses. Extreme events, such as storms, hurricanes, natural disasters, terrorism, or cyberattacks, can cause the grid to go offline for longer periods of time. For example, in 2017, the American Northeast experienced extreme winter storms, which caused disruptions to power service to the region. Likewise, in 2017, states such as Florida and Georgia experienced outages from hurricanes; in the aftermath of Hurricane Maria, Puerto Rico experienced the worst blackouts in American history. More recently, in February 2021, Texas experienced a lengthy grid outage following a polar vortex. Lengthy outages such as these could easily prevent transit agencies from engaging in routine charging of their buses, which would then disrupt normal service and core transit operations. Since many members of the community use public transport to get to and from work, such disruptions would have major economic implications and negatively affect public perception of ZEBs.

The City of Pasadena faces unique resiliency risks. The Los Angeles region is subject to several factors that can disrupt utility power to bus yards. One major threat is extreme heat, which is expected to become a much more common occurrence as climate change progresses. Extreme heat poses a threat to the grid because it decreases utilities' generation and transmission capabilities. Extreme heat also increases air conditioning usage and consequently power demand (Burrillo, 2018). These factors raise the chances for grid infrastructure overload, which further increases the risks of a brownout, blackout, or other grid outage.

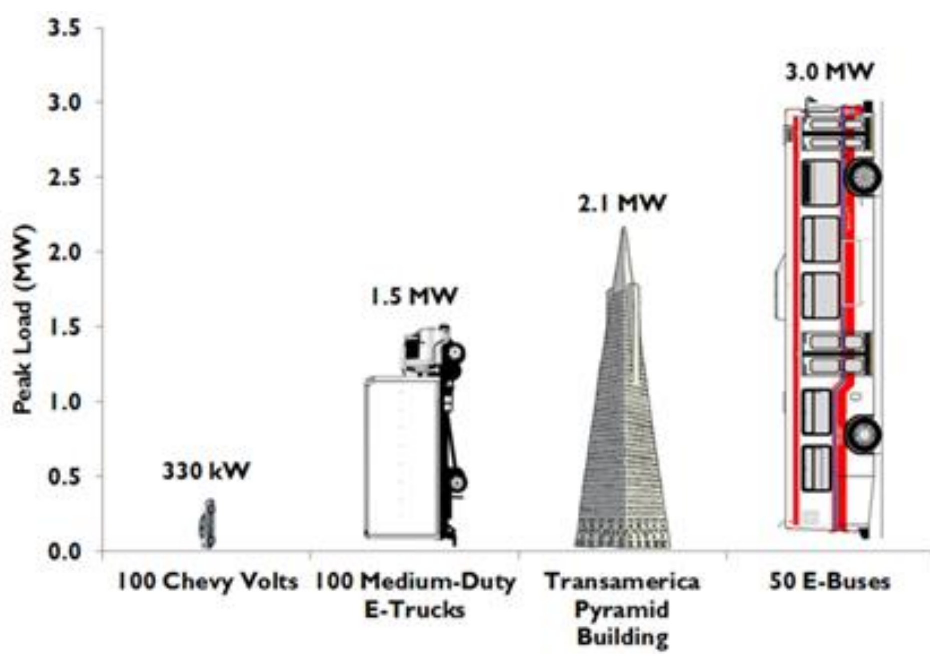
Extreme heat can also cause equipment to overheat, posing a threat to any electrical equipment owned by a transit agency (National Academies of Science, Engineering, and Medicine, 2017).

Public Safety Power Shutoffs (PSPS) are a major risk to power supply in the Los Angeles region. These shutoffs occur when environmental conditions increase the chances that utility infrastructure will spark a wildfire. While the risk of wildfire occurring in Los Angeles proper is low, there is a high risk that wildfire can disrupt electrical supplies. PWP obtains power from a variety of sources. While some power is generated locally, these municipal utilities import a significant percentage of power from generation facilities to the north of Los Angeles and even from other states. Much of this power is transported through the northern transmission corridor. If a PSPS is declared in that region, it disrupts power supplies to the entire Los Angeles region. Furthermore, natural disasters can pose resiliency risks. Earthquakes can potentially down power lines and damage utility substations, which would threaten power supply to bus depots.

Addressing resiliency concerns should be a priority for transit agencies deploying ZEBs. The City of Pasadena can obtain resiliency through two main methods. One method is to obtain in front-of-the-meter (FTM) resiliency. FTM resiliency is provided on the utility's side of the meter. Resiliency can also be provided behind-the-meter (BTM). BTM refers to resiliency solutions located on the customer's side of the meter. A BTM resiliency solution would be controlled by the transit agency. Both FTM and BTM solutions are discussed in more detail on page 23.

Regardless of whether the resiliency is BTM or FTM, providing full resiliency for a bus depot is difficult. ZEBs consume a large amount of energy and draw a lot of power from the grid. This is especially true for BEBs, which use electricity directly as fuel. **Figure 1-10** depicts a hypothetical scenario in which fifty electric buses are charged at a power level of 60 kW. This illustration shows that a fleet of fifty buses would generate power demand of three megawatts (MW), which exceeds the power demand from the TransAmerica Pyramid Building (a skyscraper in San Francisco). In the event of a grid outage, it is difficult to replace the energy and power lost from the grid.

Figure 1-10: EV Peak Power Demand Scenarios (CALSTART, 2015)



The City of Pasadena is expected to have significant energy consumption and power draw. The energy consumption and power draw for each transit agency is provided in **Table 1-2** below. These figures represent energy consumption and power draw for weekday service, the maximum energy consumption and power draw. Furthermore, these figures exclude any energy or power demand from on-site buildings or maintenance bays.

Table 1-2: Daily Energy Consumption and Power Demand

Energy Consumption / Power Demand Time	The City of Pasadena
Weekday Energy Consumption (kWh)	9,563
Weekday Power Demand (kW)	2,792
Weekend Energy Consumption (kWh)	4,341
Weekend Power Demand (kW)	1,500

The remainder of this section will explore various options for providing resiliency for a transit agency.

FTM Resiliency

FTM resiliency is provided by the utility, and the utility can provide resiliency in several ways, such as installing energy storage assets or distributed generation assets at power plants or at a substation. If power is lost, the assets can be deployed and can provide power to customers downstream. Utilities typically charge for resiliency services to offset the cost of these assets. Some utilities offer special electrical tariffs to customers that opt to accept utility resiliency services. These tariffs often entail higher energy charges.

For example, the Los Angeles Department of Water and Power (LADWP) offers various options for resiliency, including a special pilot rate for electric buses. Under these rates, fleets have the option of providing their own resiliency, accepting FTM resiliency from LADWP, or not having any resiliency. If a customer opts to receive FTM resiliency from LADWP, they can choose the length of time they will receive resiliency in the event of a grid outage. LADWP's resiliency is provided by FTM batteries. Each of these options is associated with a specific tariff.

Utilities can also provide FTM resiliency in other ways. Typically, a fleet is served with a single feeder. A utility could bring a second feeder to the fleet to act as a redundant source of power. Alternatively, if a utility has local power plants, they can potentially use the power plants as a backup source of power in the event of an outage.

BTM Resiliency

A fleet can also receive BTM resiliency. BTM resiliency consists of generation and storage assets that are located on the customer's side of the meter and, in most cases, on-site at the fleet's depot. Transit agencies have multiple options for deploying BTM resiliency, such as opting to serve as the owner-operator of resiliency equipment. Under this ownership model, the transit agency provides the capital funding to purchase and install the equipment and is responsible for operating and maintaining the equipment. Transit agencies can also engage with a third-party energy services company to purchase power. The third-party energy services company would be responsible for purchasing and installing the equipment. The energy services company would retain ownership of the equipment and would sign a power purchasing agreement with the transit agency to sell the energy produced by the equipment. There are also myriad other hybrid business models that can be used to operate BTM resiliency equipment. The following is an overview of different assets that can be used to provide BTM resiliency.

Solar and Storage

Solar PV systems can be used to provide BTM resiliency. Solar PV panels convert solar radiance from light to produce electricity. As a result, solar PV produces electricity during the day, with peak production occurring at about 1 pm. Solar PV arrays can be installed anywhere with access to direct sunlight. Solar PV arrays are often installed on rooftops, but arrays can also be constructed over parking lots. This solution requires the construction of a steel structure over the parking lot to install the panels. Many transit agencies have started installing solar panels over the bus parking lanes. This configuration allows the transit agency to maximize the solar potential of their yard and provides shade for the buses, keeping the buses cool and reducing the HVAC load.

While solar PV can produce renewable energy, it does suffer from two main drawbacks. First, solar PV is not an energy dense generation asset. ZEBs are extremely energy intensive, and a large quantity of solar panels is required to power the charging for a fleet of ZEBs. Since many bus depots are space constrained, it is usually not possible to install enough solar panels on a depot to power the charging for a ZEB fleet, especially for transit agencies in urban areas. It is difficult, then, to provide full resiliency to a ZEB fleet from solar PV alone. Solar PV is also an intermittent resource that only produces power during the day, which can be used to help power facilities at a bus depot, but most of the buses will be charging at night to take advantage of lower energy charges. As a result, a mismatch arises between when the solar panels produce electricity and when charging occurs; if a transit agency were to experience a grid outage, they would not have any resources to power charging at night.

One way to solve the intermittent power problem would be to pair solar PV with battery storage. Under this solution, battery storage would be used to absorb excess energy that is produced during the day and store it for later use. The batteries could be used to store power until nighttime or until there is a grid outage. Batteries can help to mitigate the intermittency problem. In addition, batteries can respond very quickly to grid outages and can ensure continuity of power. However, batteries are expensive and have a large physical footprint, resulting in limits to energy storage capacity on a bus depot.

Another variation of solar and storage would be battery swapping. ZEBs are currently designed so that the batteries remain on the bus at all times. When the batteries need to be recharged, the bus must physically go to a charger. The charging process requires hours, which prevents the bus from being used during that time. However, it is theoretically possible to recharge a bus by removing the depleted batteries from the bus and swapping them with fully charged batteries. The concept of battery swapping is not new and has been considered to speed up the charging process in light-duty EVs. If battery swapping were employed, depleted batteries can be removed from the bus and then charged during the day using solar power. The charged batteries could then be installed on the bus at the end of the day.

While battery swapping is a theoretical possibility, the current ZEB design, which is optimized for meeting safety regulations, is not conducive to this option. Batteries are extremely heavy, and they are often placed on the roof of the bus or in other areas that are not easily accessible. It would therefore be difficult to remove batteries on a regular basis. At the time of writing, none of the OEMs have a bus that can employ battery swapping, though some industry interest exists in conducting research to develop battery swapping and business models that can support this practice.

Generators

A transit agency could also use a generator to provide power in the event of a grid outage. Generators typically use fossil fuels such as diesel or natural gas. These fuels are combusted in an internal combustion engine, which is used to produce electricity. Most generators are reciprocating engines. Generators are useful; they are energy dense, produce a large amount of power without having a large physical footprint, and can feasibly be sized to power a majority of or the entire fleet. The physical footprint required for generators at each transit agency is described in Appendices K, L, and M. Generators can also respond relatively quickly to outages and take about ten minutes to full ramp up to maximum power generation. In addition, generators do not have to operate at full power at all times and can run at partial capacity without major efficiency losses. However, this solution is problematic—since generators burn fossil fuels, they produce GHG emissions. In addition, they can produce criteria emissions such as particulate matter (PM) and NOx. As a result, there are environmental and air quality consequences to using generators.

Further, there are regulatory restrictions on the use of generators. The South Coast Air Quality Management District (AQMD) has a mandate to regulate stationary sources of air pollution in the Southern California region. Since generators emit criteria emissions, they are subject to regulation by AQMD. The main regulation is Rule 1110.2, which has stringent regulations on emissions from generators. However, there are some ways that a generator can be exempted from Rule 1110.2. For example, a backup generator is exempt from Rule 1110.2. In Rule 1110.2, AQMD defines a backup generator as a standby internal combustion engine or turbine that is used for non-utility power and does not operate for more than 200 hours per year. Backup generators are only allowed to operate during an emergency power failure or outage or for routine testing and maintenance. Backup generators that use natural gas as a fuel can be operated when the California Independent System Operator (CAISO) declares a Stage II or Stage III electrical emergency. A Stage II emergency occurs when CAISO declares that they have taken all actions to avoid an outage and are not able to provide expected energy demand. A Stage III emergency occurs when CAISO declares that it cannot meet minimum contingency reserve requirements and a grid outage is about to occur or has occurred. To apply for a backup generator permit, a transit agency would need to submit Form 400A, Form 400-CEQA, and an application fee according to Rule 301. It takes approximately four to six months to obtain a permit. The permit process can be expedited to three months, but this will result in a higher application fee.

There are cases when a transit agency might exceed the 200-hour limit. If there is an extended power outage, then it is possible that the generator will need to be used for more than 200 hours in a year. If a transit agency is on pace to exceed 200 hours of operation in a year, they can apply for a variance to operate the generator for more than 200 hours. To apply for a variance, the transit agency would need to schedule a hearing with AQMD's Hearing Board. At the hearing, the transit agency can explain why they need the variance, and a decision to grant or deny the variance is given the same day. It can take up to 15 days to schedule a hearing, so it is important to schedule a hearing before the 200-hour operation limit is exceeded.

If a transit agency wanted to avoid obtaining a backup generator permit, they theoretically could rent a backup generator during a grid outage. If a transit agency decided to do this, they would need to rent a generator that has been permitted by AQMD. Renting a generator in the event of an outage could be beneficial as it would allow the transit agency to avoid the capital expenditures associated with purchasing and installing a generator. However, it does take time to rent a generator and have it delivered to the site; the bus depot would be without power until the generator arrives. Furthermore, in the event of a grid outage, other entities would be seeking backup generators, making it difficult to find a generator during an emergency outage. It is recommended that a backup generator be located on-site at all times.

Stationary Fuel Cells

A stationary fuel cell can also be used to provide power in the event of a grid outage. Fuel cells typically consume a fuel and use an oxidation reaction to produce electricity. Fuel cells are most often associated with hydrogen vehicles, which use a fuel cell that oxidizes hydrogen to produce electricity to power the vehicle. However, a fuel cell, like those designed by Bloom Energy and Doosan, can also be designed to use other hydrogen-rich fuels such as natural gas as the source of fuel. Stationary fuel cells are fuel cells deployed for non-vehicle usage and serve an equivalent function as a backup generator.

Stationary fuel cells are comparable to backup generators in that they consume a fuel to produce electricity, but they produce fewer emissions than backup generators. If a stationary fuel cell uses hydrogen as fuel, then there would be zero direct GHG emissions from using the fuel cell. A fuel cell that uses natural gas as fuel, however, would still produce GHG emissions, but since fuel cells use an oxidation reaction rather than combustion to produce electricity, they produce far fewer criteria emissions. As a result, the regulations on fuel cells are less restrictive than those for backup generators.

Stationary fuel cells do have some drawbacks, one of which is that they are most efficient when operating at full power. Fuel cells cannot easily operate at partial capacity. Furthermore, starting up a fuel cell takes time, meaning a fuel cell cannot immediately respond to a grid outage. Fuel cells work best then in conjunction with other assets and when there is a constant load, such as from a building, for them to serve. AC Transit is currently using a stationary fuel cell as a part of their energy portfolio.

Microgrids

A microgrid is a local grid that uses distributed energy resources (DER) and energy storage assets to provide power to a specific campus or locality. In the transit context, a microgrid would consist of DERs that can provide power and resiliency services to the transit agency's depot. A microgrid can use a combination of DERs. A key feature of a microgrid is that it can disconnect from the utility grid and generate power for itself. This functionality is managed by a switch at the point of connection with the utility grid and a controller that decides when to connect to and disconnect from the grid. When microgrids use a variety of generation and storage sources, it provides the microgrid with options for deploying the most appropriate type of power generation. For example, if a grid outage were to occur during the day, the microgrid could opt to provide power with solar panels to maximize its use of carbon-free energy, whereas if the outage were to occur at night, the microgrid could opt to use a natural gas generator or batteries when intermittent energy sources are not generating power.

A microgrid can also provide other services for a transit agency. Microgrids can help transit agencies engage in demand response. While transit agencies can reduce their power demand by using smart charging software, many larger agencies will still have high power needs. A microgrid can allow agencies to further reduce their demand by storing self-generated energy or excess power from the grid during times of low power demand and deploying it to partially or completely charge a fleet of buses. This solution would reduce the spike in power demand caused by charging, which would aid in grid management and reduce demand charges for the transit agency. The microgrid controller can also be programmed to interact with energy markets and sell self-generated power during times when demand for grid power is high, allowing the transit agency to help manage the utility grid and generate revenue. The utility could also benefit from microgrids being used in this manner. If the microgrid is able to prevent demand spikes, it could also potentially reduce the need to upgrade utility distribution infrastructure. It should be noted that the function of the microgrid can be limited. If a microgrid includes a backup generator, the generator can only be used for emergency purposes and cannot be used to provide ancillary services.

Maintenance and Training

Many similarities exist between ZEBs and CNG buses, but ZEBs have unique systems such as electric drivetrains, batteries, fuel cells, and hydrogen storage tanks that require specific operational and maintenance needs. These systems have particular needs and require specialized training to service. In addition, ZEBs must be operated and driven differently than a CNG bus to obtain the maximum performance from the buses.

The bus operations and maintenance work for the City of Pasadena's bus fleet is contracted out to a transportation services company.

If an agency uses a transportation service contractor, the maintenance and operations is provided by the contractor. As a result, the contractors will need to provide trained bus drivers and maintenance staff. Since some of these transportation service contractors also serve other fleets with ZEBs, their drivers and mechanics might have previous experience with ZEBs. This section will provide an overview of the maintenance and training that is required to operate a ZEB fleet and associated infrastructure.

Bus Operator Training

Bus operators will need training to drive and operate ZEBs. ZEBs need to be driven in a certain manner to optimize performance and bus range. Typically, electric buses maximize their range when accelerated slowly. Poor driver behavior, such as rapidly accelerating from a stop, can reduce bus range by up to 25%. As a result, ensuring the bus operators drive the buses in the correct manner is vital to maximizing the benefits of ZEBs. Range anxiety, where the driver fears that they do not have enough charge to complete their route, has also been widely documented. This fear has resulted in operators prematurely ending their route and returning to the depot to charge the bus. To avoid this problem, bus operators need to understand the range and capabilities of the bus. Bus operators also need to learn how to correctly use technologies such as regenerative braking.

Bus Technician Training

ZEBs have different maintenance needs and operation best practices than traditional internal combustion engine buses. ZEBs replace the internal combustion engine with an electric drivetrain, which changes the maintenance needs of the bus. While maintaining a traditional bus, a maintenance technician needs to have expertise in maintaining and repairing internal combustion engines and moving parts like belts, alternators, and pumps. In addition, expertise in mechanical systems such as steering, HVAC, and suspension is vital. However, with ZEBs, the vast majority of the moving parts are replaced with electric components, such as batteries, DC-to-DC converters, and electric motors. Since there are few moving parts on a ZEB, most of the maintenance tasks relate to preventative maintenance. As a result, the most vital skills for maintenance technicians to become proficient in are high voltage safety and proper use of personal protective equipment to minimize the risk of electrical shocks and arc flashes. Mechanics should consider obtaining the NFPA 70E: Standards for Electrical Safety in the Workplace and High Voltage OSHA 1910.269 8 Hour Qualified Training Course certificates. Maintenance technicians will also need to become proficient in bus inspection, preventative maintenance, and how to handle removed battery systems to effectively maintain the buses. Knowledge of standard bus mechanical systems is also important. If a fleet has hydrogen FCEBs, the maintenance technicians need additional skills. Hydrogen is a highly flammable gas, meaning that it requires specialized skills. Technicians working on hydrogen buses need training in high pressure gases and hydrogen safety. Local first responders need to receive training in EV and hydrogen safety so they can effectively respond in the event of an accident.

Technicians receive their training through a variety of sources, which usually starts in an automotive program at either a community college or trade school. While at community college/trade school, technicians are introduced to automotive safety, vehicle systems, engines, and mechanical systems. Many students will also learn about electric and hybrid drivetrains. Many community colleges such as Rio Hondo College and San Bernardino Valley College have devoted EV Associate of Sciences programs.

After completing community college/trade school, technicians are then hired by a fleet or a transportation services company. Technicians usually receive on-the-job training after they are hired. Their employer often provides one-on-one training so the technician can work on real-life maintenance and repair issues. Bus OEMs also provide training to technicians. This training typically begins one week before the bus is delivered. The OEM will send a field service representative to provide bus operator training to the contractor's drivers. The field service representative provides safety, preventative maintenance, and diagnostic/troubleshooting training to the mechanics. Since this training is specific to the buses and is generally at a more advanced level, it is important that the technicians have some experience with the basics of zero-emission vehicle maintenance before attending the OEM's training. The pricing for OEM-specific training is provided on page 34.

The field service representative is also vital for training mechanics on more advanced maintenance tasks. During the warranty period, if repairs or troubleshooting beyond preventative maintenance are needed, the field service representative can be called to teach the mechanics how to fix the issue. It is important to use the warranty period to provide further training to its mechanics. If there are problems with any of the non-drivetrain components on the bus (e.g. the HVAC system), many component manufacturers offer similar services.

There are other avenues for obtaining maintenance technician training. SunLine Transit in Thousand Palms, California, is currently operating the West Coast Center of Excellence in Zero Emission Technology (WCCoE). The WCCoE offers workforce development training for transit agencies. As a part of this training, the WCCoE offers technician training in multiple formats, including on-site at the WCCoE, virtual training, and webinars. On-site training at the WCCoE includes hands-on lab work with actual buses.

The Southern California Regional Transit Training Consortium (SCRTTC) also offers training for ZEB technicians. SCRTTC is a membership-based organization that counts many Southern California transit agencies as members. SCRTTC works with OEMs to provide training in a wide range of zero-emission technologies and bus mechanical systems. This organization works with the OEMs to provide train-the-trainer programs, including classroom and hands-on training.

Workforce Development Training Plan

The City of Pasadena does not hire their own mechanics or bus operators. Instead, they contract with a transit company to provide mechanics and bus operators. The contractor is responsible for hiring and providing training to mechanics and bus operators. When ZEBs are purchased, the contractors will need to ensure that their workers have the skills to maintain the buses. Since many traditional vehicle maintenance competencies (such as suspension, mechanical systems, HVAC systems, etc.) are transferable for maintaining ZEBs, the easiest way to develop a workforce is to upskill the existing bus operators and maintenance staff. The prerequisite knowledge required to begin ZEB maintenance training is a firm understanding of high-voltage electrical systems and safety. The contractor will need to provide high-voltage electrical training for their maintenance staff before they begin training.

To upskill the existing staff, a transit agency should purchase training packages from the OEM. OEM-provided training teaches maintenance staff how to operate and maintain a zero-emission drivetrain system. The OEM-provided training begins about a week before the delivery of the buses. The OEM sends a field service representative to provide bus operator training to the contractor's drivers. The field service representative will also train the maintenance staff. Since there are few moving parts on a zero-emission bus, the majority of the maintenance tasks relate to preventative maintenance. As a result, the field service representative provides safety, preventative maintenance, and diagnostic/troubleshooting training to the contractor's mechanics. The field service representative is also vital for training mechanics on more advanced maintenance tasks. During the warranty period, if repairs or troubleshooting beyond preventative maintenance are needed, the contractor may call out the field service representative to fix the issue and teach the mechanics how to fix it. Using the warranty period to provide on-the-job training to the mechanics is vital to developing the skills of the maintenance staff. Overtime the maintenance staff will accrue enough knowledge to work independently from the field service representative. This knowledge can be institutionalized by pairing more experienced maintenance staff with junior staff and new hires to teach them maintenance best practices. OEM-provided training can also be supplemented with training provided by other organizations such as the SCRTTC, the California Transit Association, American Public Transportation Association, CalACT, and the National Transit Institute.

Bus Maintenance Requirements

BEB Maintenance

BEBs have an electric drive train that is powered by electricity from an energy storage system, and consequently lack some of the components in an internal combustion engine bus, especially some of the mechanical systems in the propulsion system. The maintenance needs for the propulsion system are therefore different in BEBs than internal combustion engine buses. Despite these differences, BEBs do share many mechanical systems with internal combustion engine buses, such as brakes, suspension, door opening systems, the cab, and chassis, so some of the maintenance needs will be similar.

Those transit agencies that have already deployed BEBs, can provide lessons about the maintenance needs for these vehicles. A number of these agencies reported that BEBs have fewer moving parts and therefore fewer parts to replace. BEBs do not require oil changes and do not have belts that need to be replaced. As a result, certain aspects of preventative maintenance for BEBs is lower than for CNG buses, with the main cost being labor and time.

Transit agencies have reported some issues in regard to unscheduled maintenance for BEBs, with the earlier generation of BEBs experiencing some problems and failures with major components such as high voltage batteries and inverters. Another common issue has been the wires from the high voltage batteries. These wires are held together by connector pins. On many buses, these connector pins have corroded and come apart, preventing energy from being transferred from the battery to the drivetrain. Some BEBs have also experienced problems with the low voltage batteries. In these buses, auxiliary equipment such as the security camera system continued to draw power even after the bus was turned off. This issue depletes the battery. Despite these problems, the drivetrain itself has proven to be very reliable, and most buses only experience minor problems with the drivetrain.

Unfortunately, these problems have been costly, and the cost of unscheduled maintenance is higher for BEBs than for CNG buses. The bus availability in a fleet of BEBs has also been significantly lower than for CNGs. One transit agency reported that the availability for CNG buses is about 95%, while BEB availability is about 70%. This low rate of availability has been caused by the fact that repairs on BEBs can take time to resolve. Some parts can be difficult to obtain, and sometimes diagnosis of a problem is not quickly resolved. As a result, BEBs can be out of service for up to 20-30 days in the event of an issue. To improve bus availability, ensuring the quick delivery of parts is vital. Transit agencies can also mitigate this problem by stocking extra parts.

Since some transit agencies have already deployed BEBs, there is data available on maintenance needs and costs. Foothill Transit has a fleet of BEBs: twelve 35-foot Model year 2014 buses and two 40-foot Model year 2016 buses (Eudy, 2020). The National Renewable Energy Laboratory (NREL) has been tracking the maintenance costs for this fleet and has compared it to the costs for the CNG fleet. NREL found that the maintenance costs for the 35-foot BEB fleet is $0.84 per mile and $0.53 per mile for the 40-foot BEB fleet. CNG buses have lower maintenance costs of $0.23-$0.42 per mile. Since all three fleets are out of warranty and Foothill Transit has taken over maintenance, these figures are comparable.

Although this data indicates that the maintenance costs are higher for the BEB fleet, there are several caveats in the data to consider. First, the BEBs had lower scheduled maintenance costs than the CNG fleet. The 35-foot and 40-foot BEB fleet had scheduled maintenance costs of $0.05 and $0.04, respectively. The CNG fleet had scheduled maintenance costs of $0.10. As a result, the main difference in cost between the BEB fleets and the CNG fleet is unscheduled maintenance. Some of the unscheduled maintenance figures were also skewed by an issue with the low-voltage batteries, which had to be changed out frequently. The bus manufacturer is working to resolve these issues, and the low-voltage battery problem is not expected to emerge in future generations of their bus. When the cost of the low-voltage battery problem is excluded, the maintenance cost for the 35-foot and 40-foot BEBs are $0.72 and $0.48, respectively.

NREL also measures data on bus availability, which is defined as the percentage of days the bus is available for service. NREL issued a report analyzing BEB availability at Foothill Transit. This report found that Foothill Transit's CNG bus fleet had an availability of 95.1%. The fleet of 35-foot BEBs had a bus availability of 83.1%, and the 40-foot fleet had a bus availability of 81.6%. In most cases, general maintenance is the cause of bus unavailability. However, other issues such as problems with the electric drive or energy storage system can cause the buses to be unavailable. Significant variation of bus availability exists within the fleet; that is, some buses will have lower availability than others. For example, between Q3 and Q4 2019, some buses had a bus availability as high as 82% and others as low as 42%. Moreover, bus unavailability tends to increase as the buses get older, much like bus maintenance costs.

Maintenance and bus availability figures are also for older generations of buses. Since buses have continued to develop and become more technologically mature, newer generations of buses are likely to have fewer problems with unscheduled maintenance and unavailability. During interviews with CALSTART, OEMs and other transit agencies in the Southern California region reported that newer generations of buses have proven to be more reliable and have had higher bus availability.

FCEB Maintenance

Like BEBs, FCEBs have an electric drive train that is powered by energy from a battery. Many of the maintenance tasks will be similar for both BEBs and FCEBs, but FCEBs are unique in that energy is provided to the battery by a fuel cell. Since FCEBs use high pressure gases, many maintenance tasks are similar to that of a CNG bus. However, the fuel cell and its supporting systems introduce maintenance needs that increase the amount of required maintenance tasks and the overall maintenance cost. NREL has been investigating the maintenance needs and costs for FCEBs: tracking and reporting on the maintenance needs of several FCEBs deployed at SunLine Transit, NREL has compared them to the CNG buses deployed at the same agency. NREL reports that on a cost per mile basis, the FCEBs have a higher maintenance cost than the CNG buses. The maintenance cost for CNG buses has been reported at $0.23 - $0.42 per mile whereas the maintenance cost for the FCEB fleet was reported at $0.56/mile (Eudy, 2020a).

It is important to note that many of the maintenance tasks are common between a CNG fleet and an FCEB fleet. Like BEBs, FCEBs still have many of the same mechanical systems as CNG buses. This includes systems such as brakes, suspension, door opening systems, the cab, and the chassis. Not surprisingly, both types of buses had to undergo maintenance on systems such as the brakes, low voltage batteries, and suspension. However, there are a couple of systems that seem to be responsible for the majority of the difference in cost between the two types of buses, such as the propulsion system. The maintenance cost of the propulsion system is more than three times higher for FCEBs than for CNG buses. In addition, basic preventative maintenance and inspection is also approximately twice as high for FCEBs than for CNG buses.

NREL also reports on the reliability of FCEBs. NREL uses bus availability as their metric to measure reliability. NREL's analysis of SunLine's fleet indicates that FCEBs have lower bus availability than CNG buses. SunLine's CNG fleet had an availability of 87% whereas the FCEBs had an availability of 73%. The availability for each individual bus ranged from 60% to 89% between January 2017 and July 2019. Approximately one third of bus unavailability was caused by routine problems with bus mechanical systems. However, one quarter of bus unavailability was caused by issues with the fuel cell and/or propulsion system. The FCEB's lower availability was influenced heavily by an event in 2017, where two of the older buses were both unavailable for an entire month—this outlier event lowered the availability figure for the FCEBs.

As a part of this study, CALSTART interviewed SunLine Transit to better understand their experiences with an FCEB fleet. SunLine Transit stated that their experience has been positive and that much of the maintenance for FCEBs is similar to CNG buses. Most of the maintenance work they have done has been routine maintenance. However, there are some general preventative maintenance and inspection tasks that are unique to FCEBs. For example, the fuel cell system has several components that need to be replaced regularly, such as particulate filters, deionizing filters (to deionize the water in the fuel cell coolant system), and air filters. These additional tasks increase the cost in comparison to preventative maintenance for CNG buses.

SunLine Transit also provided information about maintenance for the propulsion system. SunLine stated that they do not directly perform maintenance on the fuel cell. Instead, any fuel cell maintenance is handled by the fuel cell manufacturer. The fuel cell manufacturer has a field representative that can be on-site within one day to fix any fuel cell-related issues that arise. If there is a problem that cannot be solved quickly, the fuel cell can be removed and sent to the fuel cell manufacturer for repairs. If this occurs, the fuel cell manufacturer provides a replacement fuel cell that can be used until the issue is resolved. SunLine Transit noted that the drivetrain and fuel cell systems have been very reliable and that they have not needed to receive a replacement fuel cell yet. Instead, most of the maintenance on the propulsion system has been due to balance-of-plant components and systems that support the fuel cell, including pumps and the fuel cell cooling system. Other transit agencies have also had this experience and have reported that most bus outages result from problems with balance-of-plant components or auxiliary components such as the HVAC system, rather than from the fuel cell or the drivetrain. SunLine noted that they have been able to obtain replacement parts easily from the fuel cell manufacturer, which gets buses back in operation quickly. In addition, most of the maintenance performed on the buses to date has been through their warranty and helped to reduce the cost of maintenance. However, once the warranty is finished, the cost of maintenance is subject to increase. According to NREL's data, out of warranty, older buses have higher maintenance costs per mile than newer buses in warranty.

In addition, the amount of unscheduled maintenance for FCEBs at SunLine fell between 2017 and 2019, which implies that the buses have become more reliable. This decrease might be occurring as the buses become more technologically mature—it is possible that maintenance costs between FCEBs and CNG buses can converge in the future.

Infrastructure Maintenance Requirements

Plug-in Charging Infrastructure

Charging infrastructure requires maintenance, though most of the components are non-moving parts with fewer maintenance needs. Most maintenance tasks focus on changing air filters in the charger and performing inspections. However, components can break from time to time. Since there is an established supply chain for these components, repairs are usually routine and completed quickly. For many chargers, the biggest threat is accidentally damaging the charger receptacle by driving over it. The use of DC fast chargers and networked chargers can increase maintenance needs; DC fast chargers have cooling equipment that can need maintenance and repair. Networked chargers also have data and communications equipment that can potentially break.

Transit agencies can rely on their charger manufacturer to provide maintenance. The chargers usually come with a warranty during which the manufacturer is responsible for maintenance and repair tasks. If the transit agency opts to pay for networked charging services, the chargers can communicate with the network and can alert the charging company to any problems the charger is experiencing. After the warranty period expires, the transit agency can opt for an extended warranty, pay for a maintenance package, or take over maintenance with their own staff. Charging companies typically plan for up to two planned outages per year to do routine maintenance. Although the actual maintenance tasks are relatively easy to carry out, the labor costs of the maintenance can be substantial, as a certified electrician is needed to perform all maintenance tasks. In addition, if the transit agency uses overhead plug-in chargers, a manlift is required to elevate maintenance worker to the chargers.

The Electric Vehicle Infrastructure Training Program (EVITP) provides training to electricians on how to install EV charging infrastructure. Electricians who complete this program can receive EVITP certification. This certification is accepted as industry-standard, and some California Energy Commission (CEC) grants even require that a certain percentage of electricians working on EV charging infrastructure have EVITP certification. EVITP also provides training on maintaining, troubleshooting, and commissioning EV chargers. It is recommended that maintenance staff who work on chargers obtain EVITP certification.

Overhead Charging Maintenance

Unlike plug-in chargers, overhead chargers have moving parts that require a prescribed set of preventative maintenance that needs to be performed regularly. Every month, the overhead charger requires an inspection to ensure that the wiring and the brushes are functioning property. Every six months, maintenance technicians measure the energy and charging capacity to make sure the charger is outputting the correct amount of power. On a yearly basis, maintenance technicians inspect the charger to ensure that the wiring and communication systems are working properly. Maintenance is typically carried out by the OEM, and the manufacturer will normally offer a maintenance service package.

Hydrogen Production Equipment and Fueling Stations Maintenance

The type of maintenance on-site hydrogen production equipment requires depends on the type of hydrogen infrastructure in place. If hydrogen is produced on-site, the transit agency will require an electrolyzer or SMR, in addition to compression and dispensing equipment. If the transit agency receives delivered hydrogen, storage tanks and a fueling station are required.

NREL has conducted research on maintenance needs for hydrogen production equipment and fueling stations. According to NREL, the compressor is the single component most likely to fail (Eudy, 2018). The compressor is used to take hydrogen from the hydrogen production equipment and compress it to be placed in high pressure storage. Since hydrogen cannot be compressed into the dispenser without the compressor, this component is very important to ensure fuel availability. Therefore, NREL recommends that transit agencies have redundant compressors so their system can still operate if one compressor fails. NREL also notes that dispensers and the hydrogen chilling system also frequently require maintenance (Saur, 2020). CALSTART estimated this frequency by using Argonne National Laboratory's Heavy-Duty Refueling Station Analysis Model (HDRSAM). This analysis has been included in Appendix N.

To better understand maintenance needs for electrolyzers, CALSTART interviewed SunLine Transit. SunLine Transit has an electrolyzer and has paired the electrolyzer with a solar panel array to power it. SunLine Transit states that most of the maintenance for their electrolyzer has focused on route maintenance tasks. Maintenance workers perform a daily walk-through to inspect for safety issues or operating malfunctions. Maintenance workers also perform a weekly inspection to check water plumbing systems, compressor oil levels, and any system faults or alarms. SunLine also stated electrolyzers are more vulnerable to problems. Since SunLine Transit operates in extreme heat during the summer, cooling and chilling of the hydrogen has historically been an obstacle. However, to address this issue, SunLine Transit added auxiliary cooling systems, which has effectively eliminated this problem.

SunLine Transit reported few problems with infrastructure unavailability, partly because obtaining replacement hardware components such as compressors is relatively easy with an established supply chain. Some of the controls are manufactured in Europe and were previously difficult to obtain, but these parts are now stocked in Northern California. SunLine Transit did mention that a brief power outage prevented them from operating the electrolyzer. To mitigate this problem, SunLine Transit is building a redundant system to store and produce hydrogen in the event of an outage.

Another factor in infrastructure maintenance is hydrogen purity. It is vital that hydrogen, whether produced on-site or delivered, is pure and does not contain contaminants. Contaminants in the hydrogen, as listed in **Figure 1-15**, can reduce the performance of the fuel cell. The impact of contaminants on fuel cell performance depends on the type and concentration of the contaminant. Some contaminants will only cause the fuel cell to lose power, which will degrade the performance of the bus. This issue could be fixed by flushing out the hydrogen storage tanks and the fuel cell, which is difficult and costly. However, some contaminants can cause catastrophic damage to the fuel cell. SAE J2719 outlines the relevant contaminants. Sulfur compounds are the most serious and destructive contaminants. Carbon compounds such as carbon monoxide (CO) and CO2 block the catalyst surface on the fuel cell, which reduces efficiency. Compounds such as ammonia affects the membrane, which reduces the efficiency of the fuel cell system. Removing water from the hydrogen gas is also important because it can facilitate the infiltration of other contaminants into the system (Tiger Optics, 2020).

The hydrogen production pathway affects the types of contaminants that are likely to be present. Electrolysis is the least likely to produce contaminants, as it uses pure water for input. SMR, however, uses natural gas and is at risk of being contaminated with ammonia, sulfur compounds, CO, and CO2. After the hydrogen is produced, atmospheric compounds such as nitrogen, water, and oxygen can contaminate the hydrogen through leaks in the system (Tiger Optics, 2020).

The State of California recognizes the problem from contaminants, and the CEC requires that any hydrogen fueling station that receives grant funding must be tested for contaminants at least every three months. The CEC also requires that hydrogen quality be tested any time the hydrogen could have been exposed to contaminants during maintenance or other activities.

Figure 1-14: Typical Hydrogen Contaminants (CARB, 2016)

Impurity Source	Typical Contaminant
Air	N_2, NO_X, (NO, NO_2), SO_X (SO_2, SO_3), NH_3, O_3
Reformate hydrogen	CO, CO_2, H_2S, NH_3, CH_4
Bipolar metal plates (end plates)	Fe_3+, Ni_2+, Cu_2+, Cr_3+
Membranes (Nafion)	Na+, Ca_2+
Sealing gasket	Si
Coolants, DI water	Si,Al, S, K, Fe, Cu, Cl, V, Cr
Battlefield pollutants	SO_2, NO_2, CO, propane, benzene
Compressors	Oils

The cost of maintenance for hydrogen infrastructure can vary depending on the ownership model for the equipment. Many hydrogen infrastructure providers prefer to own the infrastructure and sign an agreement to provide hydrogen to the fleet. Under these agreements, the infrastructure provider is responsible for providing maintenance. For example, the Stark Area Regional Transit Authority (SARTA) (the transit agency serving Canton, Ohio, and the surrounding Stark County) receives delivered liquid hydrogen that is trucked from Canada. SARTA has 9,000 gallons of liquid hydrogen storage and a fueling station. The liquid hydrogen storage and fueling equipment is owned by Air Products. SARTA has a contract with Air Products, who owns, operates, and maintains the equipment. SARTA pays $10,000 per month plus the cost of fuel (Eudy, 2019). However, other hydrogen companies have a different business model and will construct the fueling station. After completing the fueling station, the hydrogen infrastructure company will provide maintenance for a fixed cost. The maintenance cost can be reduced if the transit agency's staff can carry out routine maintenance tasks, leaving major maintenance tasks to the hydrogen company.

Required Tools and Facility Upgrades

To adequately service the buses, the maintenance staff will need to have proper tools and facilities. Many of the tools used to maintain traditional internal combustion engine buses can also be used to service electric buses. However, some specialized equipment is needed to handle EV high-voltage components such as batteries, inverters, and traction motors. The following are examples of necessary tools and equipment:

- OEM-specific diagnostic tools to troubleshoot problems on the bus
- High impedance multimeters to monitor current in the electrical systems
- Insulated hand tools (wrenches, screwdrivers, pliers, etc.) to protect workers from shock
- Personal protective equipment including Class 0 rubber high voltage gloves (which need to be inspected and tested regularly), leather overgloves, insulated dielectric boots, face shield, insulating rubber apron, and insulated electrical rescue hook
- Overhead crane to lift batteries from the roof of the bus
- Forklift to remove inverters and HVAC systems from the roof of the bus
- Scaffolding with fall protection so technicians can access the roof of the bus
- Lifting jigs for batteries and inverters
- OEM-specific tools to fix bus mechanical systems
- Manlift (if using overhead plug-in or pantograph chargers) to perform routine maintenance and repairs

Although FCEBs operate in a similar manner as BEBs, they have additional maintenance and operational needs. Since hydrogen is a highly flammable gas, there are many regulations that govern the maintenance of hydrogen vehicles. NFPA has published safety standards for hydrogen facilities. These standards are published in the NFPA 2 Hydrogen Technologies Code. NFPA 2 was most recently updated in 2020. NFPA 2 has several provisions that are relevant to hydrogen fuel cell bus maintenance depots:

- Repair rooms must be separated from the rest of the building by a one-hour fire resistant wall.
- A gas detection system must be provided and ready to activate the following if hydrogen level exceeds 25% of the lower flammability limit:
    - Initiation of audible and visual signals
    - Deactivation of heating systems
    - Activation of the exhaust system (unless the exhaust system operates continuously)
- Infrared flame detectors are required to detect hydrogen fires since hydrogen burns invisibly.
- Defueling is required for all work on the fuel system or all hot works (welding or open flame) within 18 inches of vehicle fuel supply container. The maintenance garage must have equipment to defuel the bus's hydrogen tanks.

Local authorities and fire departments can impose additional fire safety requirements. Meeting these requirements can be expensive and vary depending on the type of improvements required. For example, when AC Transit adopted hydrogen fuel cell buses, they were required to install a two-hour fire wall, an ignition-free heating system for the garage, a hydrogen lower flammability limit detector, and Class 1 Div. 2 electrical equipment throughout the garage. AC Transit spent $1.5 million to provide these upgrades (CALSTART, 2016). SARTA, however, had an existing garage and only needed to purchase air handlers to ventilate the garage and sensors to detect the presence of hydrogen. These upgrades cost about $100,000 (Eudy, 2019).

Training Costs

OEM-specific training is typically part of procurement contracts. California Department of General Services (DGS) has procurement contracts that transit agencies can use to purchase buses at a fixed price without having to issue a Request for Proposal (RFP). These DGS contracts also include pricing for bus technician and bus operator training, as well as for maintenance manuals. See **Table 1-3** for a breakdown of these costs.

Table 1-3: ZEB Maintenance and Operator Training Costs

Item	OEM 1	OEM 2	OEM 3	OEM 5
Operator Training (total of 56 hours)	$12,250.00	$11,667.04	$11,200.00	$11,667.04
Technician Training (total of 304 hours)	$66,500.00	$107,001.92	$44,797.44	$141,657.92
Maintenance Packages Manual (per manual)	$300.00	$741.00	$500.00	$815.54
Preventative Maintenance and Procedure Manual (per manual)	$300.00	$298.15	$100.00	$298.15
Parts Manual (per manual)	$200.00	$153.46	$500.00	$153.46
Operator's Manual (per manual)	$100.00	$87.69	$250.00	$87.69

Estimated Costs

Transitioning to a ZEB fleet will require substantial financial resources. **Table 1-4** provides a breakdown of associated costs and a cost comparison between transitioning to a fully BEB fleet and a fully FCEB fleet. These costs assume that the buses and infrastructure will be acquired through capital purchases and that the buses will be purchased according to each transit agency's fleet replacement plan. The assumptions used for **Table 1-4** are detailed under Financial Analysis and Cost Estimates in Section II.

Table 1-4: Estimated Costs to Transition to a ZEB Fleet

Transit Agency	BEB Fleet Costs	FCEB Fleet Costs
Pasadena Department of Transportation - Scenario 1	$58,822,948	$61,762,767
Pasadena Department of Transportation - Scenario 2	$75,721,390	$81,107,913

Financing Strategies & Resources

Transit agencies have multiple options for funding the deployment of ZEBs. Bus OEMs offer several models for financing the procurement of buses and infrastructure. In addition, there are myriad governmental programs available to help fund vehicles and infrastructure. This section provides an overview of financing options.

Traditional Financing Models

Bus OEMs offer a variety of financing mechanisms that transit agencies can use to obtain buses. This includes capital purchases, bus/battery leasing, and infrastructure as a service.

Capital Purchases

Traditionally, buses are obtained through capital purchases. A capital purchase is a transaction in which an OEM or infrastructure provider transfers ownership of a bus or infrastructure to a transit agency in exchange for a capital payment. In a traditional capital purchase, a transit agency typically releases RFPs, in which they outline the number of buses and type of infrastructure they would like to procure and release the duty specifications the buses need to meet. OEMs and infrastructure providers are then invited to submit bids, and the transit agency selects a winning bid and awards a contract. However, several states have now issued statewide contracts for buses. Under a statewide contract, the state negotiates a contract with bus OEMs to purchase buses at a fixed price. Transit agencies can purchase buses from a statewide contract and thereby avoid the RFP process. The State of California has statewide contracts with several bus OEMs through California DGS. CalACT has also developed a statewide contract for zero-emission shuttle buses.

A capital purchase allows a transit agency to make a single payment to obtain a bus. The bus's value is then depreciated over the entire life of the bus. Capital purchases can be problematic; they require transit agencies to have access to a large amount of money. It is often difficult for transit agencies to obtain enough funding to make a lump sum payment, especially smaller transit agencies.

Battery Leasing

When compared to conventional diesel- and/or gas-powered vehicles, EVs often come at a higher upfront capital cost. In most cases, the largest cost is the battery itself, which is why some OEMs have developed battery leasing programs to lower the barrier to entry for fleets and allow the manufacturer to recoup the cost of the battery over an extended contract. In this model, the BEB can be purchased without the battery pack at a lower price that is cost competitive with conventional vehicles. The upfront cost of the battery itself is covered by a participating financial partner and enables battery warranties to be guaranteed for the duration of the lease. Under this model, the transit agency would then make monthly or annual lease payments for the battery. Battery leasing helps transit agencies because it reduces capital expenditures for the buses. This model effectively shifts a large portion of the bus cost into lease payments, which allows transit agencies to finance their purchase through operational budgets, rather than capital expenditures.

While this is a promising model for the acceleration of transit fleet electrification, it is a newer idea that is still in development at most OEMs. A price comparison between leasing and owning the battery remains uncertain; battery leasing is a nascent business model, and it is unclear which, if any, transit agencies have utilized this option. **Table 1-5** provides a brief overview of BEB OEM battery leasing options.

Table 1-5: Battery Leasing Options

Bus OEM	Battery Leasing Options
BYD	Yes
New Flyer	Unknown
Proterra	Yes
GreenPower Motor Company	No
Phoenix Motorcars	No, but considering offering battery leasing in the future

Infrastructure-as-a-Service (IAAS)

Like bus/battery leasing, IAAS is another method for reducing the capital expenditures associated with deploying ZEBs, particularly charging and resiliency infrastructure. IAAS can also be combined with battery leasing to further reduce capital expenditures. Under an IAAS model, a company will provide turnkey service, managing the construction and installation of charging infrastructure. Under this model, the infrastructure company will typically maintain ownership of the chargers and any resiliency equipment. The infrastructure company then signs a power purchase agreement (PPA) with the transit agency to sell the power produced and dispensed to the buses. IAAS companies can develop PPAs where power is sold on a per kWh basis or a per mile basis. Most IAAS companies prefer to sell power on a per kWh basis. IAAS companies typically combine the infrastructure with managed/networked charging to minimize demand charges and the cost of electricity. IAAS allows transit agencies to deploy infrastructure without the upfront capital expenditures. An overview of IAAS companies can be found in Appendix D.

Funding Sources and Incentives for Buses and Infrastructure

The City of Pasadena does not currently receive state or federal formula funding (except for the Low Carbon Transit Operations Program). The main funding option that the City of Pasadena has to fund the transition to a ZEB fleet is to apply for competitive grants to pay for buses or bus facilities. Grant funding can be used to reduce the capital expenditures associated with purchasing buses or chargers. Alternatively, there are situations where grants can be combined with traditional financing models to fund the fleet. This section provides an overview of governmental funding opportunities.

State Funding Sources and Incentives

California State Budget Allocations

The California State Budget allocated $2.7 billion for the 21-22 fiscal year and a total of $3.9 billion over the next three years. Millions of dollars of funding are specifically being earmarked for ZE transit buses and associated refueling/charging infrastructure:

- $1.3 billion over 3 years to deploy over 3,000 ZE drayage trucks, transit buses, and school buses
- $500 million for zero-emission clean truck, buses, and off-road equipment
- $200 million for medium-and heavy-duty ZEV fueling and charging infrastructure
- $407 million to demonstrate and purchase or lease clean bus and rail equipment and infrastructure that increase intercity rail and intercity bus frequencies.

Clean Transportation Program – CEC

The Clean Transportation Program was created to fund projects that help transition California's fuels and vehicle types to achieve California's climate policies. The Clean Transportation Program is funded from fees levied on vehicle and vessel registrations, vehicle identification plates, and smog abatement. The Clean Transportation Program was created by Assembly Bill 118 and was extended to January 1, 2024 by Assembly Bill 8. The Clean Transportation Program funds multiple classes of vehicles. Every year the CEC develops an Investment Plan Update to identify how the program's funds will be allocated. For FY 2021-22, the CEC proposed that $30.1 million in Clean Transportation Program funding and $208 million in general funds would be used to fund medium- and heavy-duty vehicle charging and hydrogen fueling infrastructure. For FY 2022-23, the CEC proposed $30.1 million of Clean Transportation Program funding for zero-emission medium- and heavy-duty vehicles and infrastructure. The amount that will be allocated from general funds in FY 2022-23 has not yet been determined (California Energy Commission, 2021).

Carl Moyer Program – CARB

The Carl Moyer Program provides grant funding for engines, equipment, and other sources of air pollution that exceed CARB's regulations for on-road heavy-duty vehicles. The Carl Moyer Program is managed by CARB in collaboration with local air pollution control districts and air quality management districts. ZEBs with a GVWR of greater than 14,000 pounds are eligible for funding under Carl Moyer. The air pollution control districts and air quality management districts are the entities that issue the grants and determine funding for the program.

Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE) – CEC, CALSTART

EnergIIZE is a program that was launched by the CEC and is being managed by CALSTART. EnergIIZE will provide $50 million of funding to entities to help finance the purchase of charging and hydrogen infrastructure. EnergIIZE will fund medium- and heavy-duty infrastructure and is intended to primarily benefit communities with disproportionately high levels of air pollution. EnergIIZE program will only cover a part of the infrastructure hardware and software costs. For EV projects, charging equipment eligible for funding includes Level 2 electric vehicle supply equipment, DCFC electric vehicle supply equipment, charge management software, switchgear, electrical panel upgrades, wiring and conduit, and meters. For hydrogen projects, equipment that is eligible for funding includes compressors, liquid and gaseous pumps, piping and pipelines, hydrogen dispensers with hoses and nozzles, high-pressure storage, on-site production equipment, chillers, switchgear, electrical panel upgrades, wiring and conduit, and meters. Construction, labor, and utility upgrade costs are not eligible for funding under this program.

The EnergIIZE program offers four pathways to fund infrastructure. Each of these pathways has different eligibility criteria:

- EV Fast Track – for fleets that own or have a purchase order for a vehicle registered in the State of California as a result of State or Federal vehicle incentive funded projects (such as HVIP, Volkswagen Settlement, Carly Moyer, TIRCP, etc.)
- EV Jump Start – for transit agencies in a designated Disadvantaged Community (according to CalEnviroScreen 3.0)
- EV Public Charging Stations – for public charging station developers
- Hydrogen – for the development of hydrogen refueling stations for medium- and heavy-duty vehicles (either liquid hydrogen or gaseous hydrogen)

The pathway that a transit agency qualifies for determines the amount of funding that they can receive. Under the EV Fast Track pathway, applications are evaluated on a first-come, first-served basis. EV Fast Track will fund 50% of hardware and software costs incurred, up to a maximum of $500,000. EV Jump Start funding is awarded on a competitive basis. EV Jump Start will fund 75% of hardware and software costs incurred, up to a maximum of $750,000. Hydrogen pathway funding is awarded on a competitive basis. The Hydrogen pathway will finance 50% of hardware and software costs incurred, up to a maximum of $2,000,000.

At the time of writing, CALSTART has completed its first round of funding under the EnergIIZE program. Additional funding will be available in 2023.

Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) – CARB, CALSTART

California HVIP is a program that was launched by CARB and is managed by CALSTART. HVIP provides vouchers that are used to finance the purchase of clean transportation vehicles. HVIP's vouchers are applied at the point-of-purchase, which reduces the purchase price of the vehicle when it is purchased. ZEBs are eligible to receive vouchers under HVIP. Vouchers are allocated on a first-come, first-serve basis.

California Infrastructure and Economic Development Bank (IBank)

The IBank was created in 1994 to fund infrastructure and economic development projects in California. The IBank was started by the Bergeson-Peace Infrastructure and Economic Development Bank Act and is operated by GO-Biz. IBank can issue low-interest bonds that can be used to finance projects for public agencies or nonprofits. The IBank has programs that can be used to finance the transition to a zero-emission fleet. The Infrastructure State Revolving Fund (ISRF) program provides low-Interest financing for infrastructure projects. ISRF provides loans of $50,000 to $25 million over a term of up to 30 years at a fixed interest rate. These loans are funded through the sale of Infrastructure State Revolving Fund Revenue Bonds. Public transit projects, which includes but is not limited to, vehicles and maintenance and storage yards, are eligible for funding through ISRF. ISRF applicants must be a public agency, joint power authority, or nonprofit corporation formed by an eligible entity. ISRF accepts applications on an ongoing basis (California Infrastructure and Economic Development Bank, 2016).

The IBank also offers the California Lending for Energy and Environmental Needs (CLEEN) program. CLEEN provides loans from $500,000 to $30 million over a team of up to 30 years. These loans can be used to fund projects that use a commercially proven technology to reduce greenhouse gas emissions or pursue other environmental objectives. Eligible projects include energy storage, renewable energy generation assets, stationary fuel cells, electric vehicles, alternative fuel vehicles, and alternative fuel vehicles refueling stations (California Infrastructure and Economic Development Bank, n.d.).

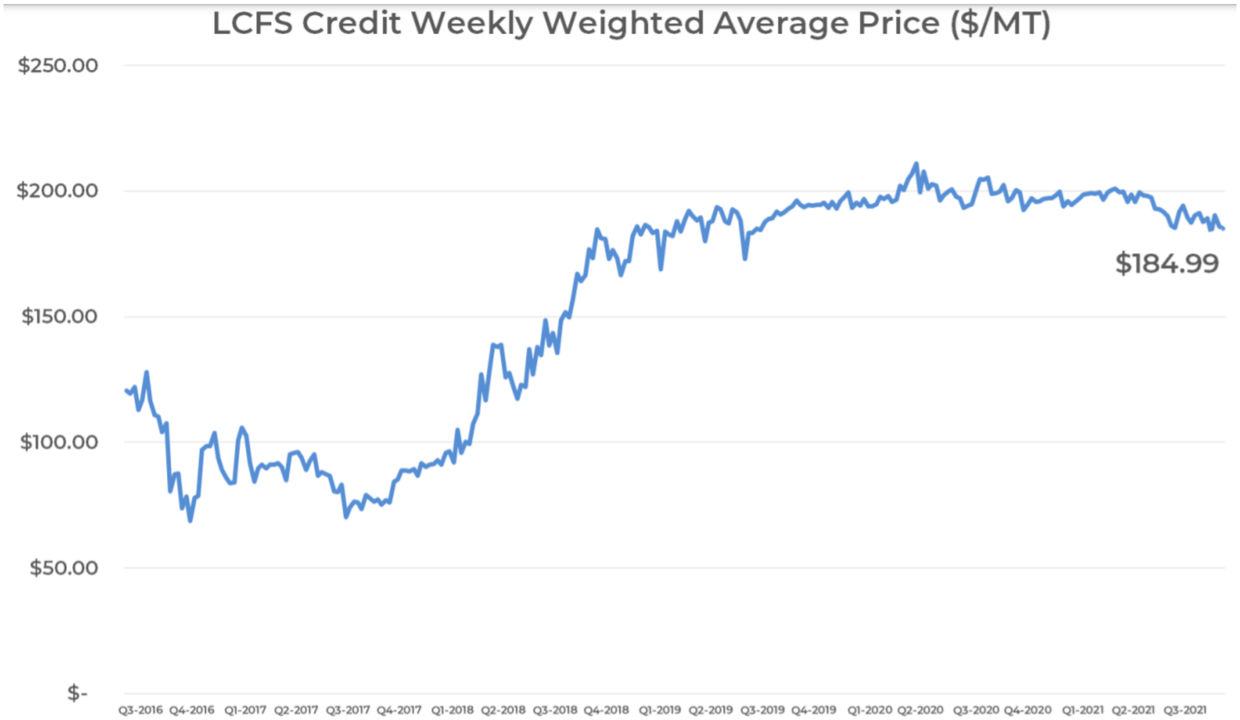
Low Carbon Fuel Standard (LCFS) Program – CARB

The LCFS Program is run by CARB and creates a mechanism for the users and producers of low-carbon fuels (including electricity) to generate credits for the use of these low-carbon fuels. These credits can then be sold in the LCFS market. The LCFS program sets standards for the maximum carbon intensity that a fuel can have. If an entity uses fuels that are below the carbon intensity standards, they generate LCFS credits. However, if an entity uses fuels that exceed the carbon intensity standards, they generate deficits and must purchase LCFS credits to negate their deficits.

LCFS credits are generated based on the fuel type, fuel quantity, and carbon intensity of the fuel used (in this case electricity or hydrogen). Over time, the standards for carbon intensity become more stringent, making it more difficult to earn LCFS credits. Transit agencies must comply with CARB reporting requirements to earn LCFS credits. To generate LCFS credits, the chargers or hydrogen production equipment must be registered with CARB. Once the equipment is registered, the owner of the equipment can begin generating LCFS credits.

LCFS credits can be sold to polluters that need to negate their deficits based on the going market rate. However, as of 2021, CARB has set a purchase price for LCFS credits at $221.67 per credit, effectively creating a price ceiling. LCFS credits have traded at about $200 per credit since Q4 2019 (CARB, n.d.). Sales of LCFS credits represents a significant revenue mechanism. The profits from LCFS credits can be used to fund either vehicle purchases or charging infrastructure. **Figure 1-15** shows historic LCFS prices from January 2016 through August 2021.

Figure 1-15: Historical LCFS Prices January 2016 – May 2021 (Source: SRECTrade)



Transit and Intercity Rail Capital Program (TIRCP) – Caltrans

TIRCP provides grants to fund capital improvements that will modernize California's rail, bus, and ferry public transit facilities. The objective of the program is to reduce GHG emissions, expand transit service, increase transit ridership, and improve transit safety. Funded projects are expected to reduce GHG emissions, vehicle miles traveled, and congestion. TIRCP is funded through the Greenhouse Gas Reduction Fund (GGRF) and the Cap-and-Trade program. TIRCP funds can be used to finance site upgrades and the deployment of zero-emission infrastructure at bus depots and facilities.

Low Carbon Transit Operations Program (LCTOP) – Caltrans

The LCTOP is one of several programs that is funded by the GGRF, which is funded by revenues from the state's cap-and-trade system. State law requires continual appropriation of 5% of the revenue from the GGRF to be allocated to the LCTOP. State law requires the program's funds to provide transit operating or capital assistance that meets any of the following criteria:

1. The funding can directly enhance or expand transit service by enabling new or expanded bus or rail services, water-borne transit, or expanded intermodal transit facilities, and may include equipment acquisition, fueling, and maintenance, and other costs to operate those services or facilities.
2. The funding can fund operational expenditures that increase transit mode share.
3. The funding can fund the purchase of ZEBs, including electric buses, and the installation of the necessary equipment and infrastructure to operate these ZEBs.

VW Mitigation Trust – CARB

The purpose of the VW Environmental Mitigation Trust is to fully mitigate the excess NOx emissions released during the Volkswagen emissions scandal. This program was established as a part of the settlement that VW reached with the EPA. The VW Mitigation Trust has allocated $423 million to the State of California to fund the deployment of clean transportation vehicles. $130 million of these funds is devoted to replacing older, high emission buses with BEBs or FCEBs. Transit, school, and shuttle buses are eligible for funding.

Federal Funding Sources and Incentives

Bus & Bus Facilities (5339) – USDOT/Caltrans

The Bus & Bus Facilities program is managed by the FTA. This program provides capital funding to replace, rehabilitate, and purchase transit vehicles and construct bus-related facilities. The FTA allocates funding to states to administer these grants. In California, Caltrans has been delegated the responsibility of managing these grants. Public agencies and nonprofit organizations that are involved in public transit may apply for these grants.

Congestion Mitigation and Air Quality (CMAQ) Improvement Plan – USDOT

CMAQ provides funds directly to states. These funds may be used to finance projects that reduce traffic congestion and improve air quality. The main objective of this program is to reduce CO, ozone, and PM emissions. This program is primarily intended to fund projects in areas that do not meet national air quality standards. The Infrastructure Investment and Jobs Act (IIJA) provides $13.2 billion of funding over five years. Under IIJA, there are new project types that are eligible for funding under CMAQ. The purchase of medium- or heavy-duty zero-emission vehicles and supporting infrastructure is eligible for funding under CMAQ. Shared micromobility projects are also eligible for funding. CMAQ funds can also be used to provide operating assistance for public transportation projects.

Investment Tax Credit (ITC) – IRS

Internal Revenue Code Section 48 provides a tax credit for investments in certain types of energy projects. Section 48 provides tax credits for a wide range of renewable energy investments. Renewable energy technologies such as solar PV, fuel cells, small wind microturbines, and combined heat and power are eligible for tax credits. The IIJA amended the terms of the ITC. Solar PV projects are eligible for a tax credit equal to 30% of the cost of system through 2033. Tax exempt entities can directly take advantage of the ITC (US Department of Energy, 2022).

Low or No Emissions Program (Low-No) – USDOT/FTA

Low-No provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses. Low-No funding can also be used to acquire charging or fueling infrastructure for the buses, pay for construction costs, or obtain or lease facilities to house a fleet. In FY2021, $182 million was allocated for the Low-No program. However, the enactment of IIJA will expand funding for the Low-No program. IIJA allocates an additional $5.25 billion for the Low-No program over five years. To be eligible for this funding, a transit agency will need to submit a plan for transitioning to zero-emission buses. This plan must demonstrate a long-term fleet management plan that addresses how the transit agency will meet the costs of transitioning to zero-emission, the facilities and infrastructure that will be needed to be deployed to serve a zero-emission fleet, the transit agency's relationship with their utility or fuel provider, and the impact that the transition will have on the transit agency's current workforce. Under IIJA, transit agencies may apply for Low-No funding with other entities, such as an OEM, that will participate in the implementation of the project. IIJA also requires that 5% of grant funds awarded be used to fund workforce training to prepare their current workforce to maintain and operate the buses.

Rebuilding American Infrastructure with Sustainability and Equity (RAISE) grants – USDOT

The RAISE grant is the latest iteration of the BUILD and TIGER grant program. This program is intended to invest in road, rail, transit, and port projects. The objective of this program is to fund projects that are difficult to support through traditional USDOT programs. Public entities, such as municipalities, are eligible to apply for this program. RAISE is a competitive grant program.

Prospective Financing Mechanisms

IBank Climate Catalyst Fund

The state’s IBank is poised to create a new low-interest loan program for public fleets. The Climate Catalyst Fund was created in June 2020 and received its first funds in September 2021. The objective of this fund is to provide a financing mechanism to support the State of California's climate and sustainability infrastructure. The Climate Catalyst Fund's goal is to provide low-interest loans for projects that support the state's climate objectives. The IBank is in the process of developing the criteria that will be used to award projects. The Climate Catalyst Fund will initially prioritize projects that advance forest biomass management. However, the Climate Catalyst Fund's scope is expected to increase over time. From discussions with the Governor's Office of Business Development as well as the Director of the IBank, Scott Wu, CALSTART understands that the Fund's scope will eventually encompass zero-emission fleets. These low interest loans could be used to fund vehicle purchases, as well as charging infrastructure projects.

Medium- and Heavy-Duty Zero-Emission Vehicle Fleet Purchasing Assistance Program – CARB

Under existing California law, CARB administers an Air Quality Improvement Program which promotes the use of zero-emissions vehicles by providing rebates for their purchase. In 2021, legislation was signed into law in the state establishing a Medium- and Heavy-Duty Zero-Emission Vehicle Fleet Purchasing Assistance Program, within the Air Quality Improvement Program, and make financing tools and nonfinancial support available for the operators of medium- and heavy-duty vehicle fleets to help them transition to zero-emissions vehicles. The bill requires the financial tools offered by this program to be available to fleets by January 1, 2023.

Zero Emissions Truck, Bus, and Infrastructure Finance Program – Southern California Edison (SCE)

SCE has filed with the California Public Utilities Commission to establish a Zero Emissions Truck, Bus, and Infrastructure Finance Program, by funding zero-emissions trucks, buses, and associated infrastructure with $20 million.

Section II: Executive Summary

Section II: Pasadena Department of Transportation Executive Summary

The City of Pasadena provides transit service for Pasadena, California, and parts of the surrounding area, providing both fixed-route (Pasadena Transit) and demand response (Pasadena Dial-A-Ride) services. The City of Pasadena aims to transition the Pasadena Transit and the Pasadena Dial-A-Ride fleets to zero-emission buses. When planning this transition, the City of Pasadena is likely looking at two different scenarios for future service: Scenario 1 where it maintains current routes using the current fleet, and Scenario 2 where it implements an additional expansion route that would require additional vehicles to the fleet. The City of Pasadena aims to begin service using zero-emission buses in 2027. The City of Pasadena aims to complete full conversion to zero-emission buses for Pasadena Dial-A-Ride in 2033 and for Pasadena Transit in 2040.

Bus route modeling showed the current duty cycle for fixed-route transit operations can be served with a 1:1 drop-in replacement using FCEBs. Modeling was also done for BEBs. Our modeling indicates that, based on today's technology, between 15 and 25 of the 26 vehicle assignments can be served on a drop-in basis depending on the OEM. It is anticipated that in coming years technological improvements will allow BEBs to serve as drop-in replacements for an increasing amount of Pasadena Transit's service. For Pasadena Dial-A-Ride, the available BEB on the market can serve as a drop-in replacement. This feasibility study focuses on the feasibility of deploying a fully BEB fleet and a fully FCEB fleet. Since BEBs can serve as a 1:1 replacement for Pasadena Dial-A-Ride, whereas they cannot for Pasadena Transit, this study also considered a mixed fleet consisting of FCEB fixed-route transit vehicles and BEB demand response vehicles. Based on the current cost of ZE buses, fueling infrastructure, and The City of Pasadena's needs, the FCEB and mixed fleet pathways are cheaper than a BEB pathway. Although the long-term recommended plan is to transition to a mixed fleet of FCEB and BEB, in order to advance the ZEB transition, a Pasadena Transit BEB fleet will be initially pursued while the FCEB infrastructure is developed.

Transitioning to a ZE fleet will be more expensive than operating a RNG bus fleet. The cost of operating a RNG bus fleet according to the current fleet replacement plan is projected to cost $29,982,281 between 2022 and 2040. When this amount is discounted at a rate of 4% per year (discounted to 2022 dollars), this amounts to a net present value of $17,721,132. The cost of transitioning to a fully BEB fleet will be more than the cost of operating a RNG bus fleet. The costs of transitioning to a full BEB fleet are projected to be:

- Transitioning to a fully BEB fleet under Scenario 1 is projected to cost $59,456,098 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $39,002,706. This is based on the assumption that Pasadena Transit will operate 44 transit buses and Pasadena Dial-A-Ride will operate 15 vehicles (a total of 59 vehicles combined).
- Transitioning to a fully BEB fleet under Scenario 2 is projected to cost $78,667,385 between 2022 and 2040. Discounting

this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $48,635,938. This is based on the assumption that Pasadena Transit will operate 64 transit buses and Pasadena Dial-A-Ride will operate 15 vehicles (a total of 79 vehicles combined).

The cost of transitioning to an FCEB fleet depends on the pathway used to obtain hydrogen. The most cost effective hydrogen pathway would be to produce hydrogen on-site via SMR. Based on this pathway, the cost of transitioning to a fully FCEB fleet are projected to be:

- Transitioning to a fully FCEB fleet under Scenario 1 is projected to cost $56,181,098 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $35,974,785. This is based on the assumption that Pasadena Transit will operate 29 transit buses and Pasadena Dial-A-Ride will operate 15 vehicles (a total of 44 vehicles combined).
- Transitioning to a fully FCEB fleet under Scenario 2 is projected to cost $75,392,385between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $45,724,474. This is based on the assumption that Pasadena Transit will operate 42 transit buses and Pasadena Dial-A-Ride will operate 15 shuttle buses (a total of 57 vehicles combined).

The City of Pasadena is also considering deploying a mixed fleet consisting of FCEB fixed-route transit buses and battery-electric demand response buses. The City of Pasadena is considering this option because the route modeling suggests that some transit routes cannot be served on a drop-in basis by BEBs. However, the results of the bus demonstration indicates that Dial-A-Ride vehicles can be replaced by battery electric technology on a 1:1 basis. Based on this pathway, the cost of transitioning to a mixed fleet is projected to be:

- Transitioning to a mixed fleet under Scenario 1 is projected to cost $61,724,731 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $38,816,478. This Is based on the assumption that Pasadena Transit will operate 29 transit buses and Pasadena Dial-A-Ride will operate 15 vehicles (a total of 44 vehicles combined)
- Transitioning to a mixed fleet under Scenario 2 is projected to cost $81,962,251 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $48,520,127. This is based on the assumption that Pasadena Transit will operate 42 transit buses and Pasadena Dial-A-Ride will operate 15 shuttle buses (a total of 57 vehicles combined).

These figures include the capital expenditures associated with utility upgrades, purchasing and installing chargers, and the cost of the buses. In addition, this analysis takes into account operational costs such as maintenance costs, the cost of electricity from the utility the cost of hydrogen, and the cost of maintaining charging/fueling infrastructure. This analysis does not include the cost of acquiring land for a depot, building a depot, or labor associated with operating the buses.

PWP has a resilient and reliable grid. However, if there was an extended grid outage, it would compromise the City of Pasadena's ability to charge their buses and would disrupt their ability to provide service. PWP is interested in providing a resiliency option to The City of Pasadena; PWP owns a power plant with 200 MW of generation capacity, located locally in Pasadena. PWP stated that this plant can potentially be used as a resiliency measure. If the grid were to experience an outage, PWP could turn on their power plant and provide power to the City of Pasadena, among other customers. PWP has also stated that they are looking into deploying FTM batteries so they can continue to provide power in the event of an outage.

For on-site BTM resiliency, the City of Pasadena can use solar and storage or natural gas generators. If solar and storage is used, the City of Pasadena will need a 2,948 kW PV solar array and a battery storage system with a power capacity of 2,628 kW and storage capacity of 31,006 kWh to provide full resiliency. If natural gas generators are used, it would require 3,000 kW generator capacity to provide full resiliency to the fleet.

The City of Pasadena has identified 2180 East Foothill Blvd as a possible location for their new transit facility. This transit facility is currently in the design phases. The City of Pasadena will need to install both FTM and BTM infrastructure. PWP has stated that there is enough grid distribution capacity to serve this site. As a result, the main required FTM infrastructure is a transformer. The installation of a transformer typically takes 4-6 months but can take up to one year. The installation of the transformer can be incorporated into the construction of the transit facility. The City of Pasadena needs to coordinate with PWP to ensure that the final design for the site will accommodate the transformer and to schedule the installation of the transformer.

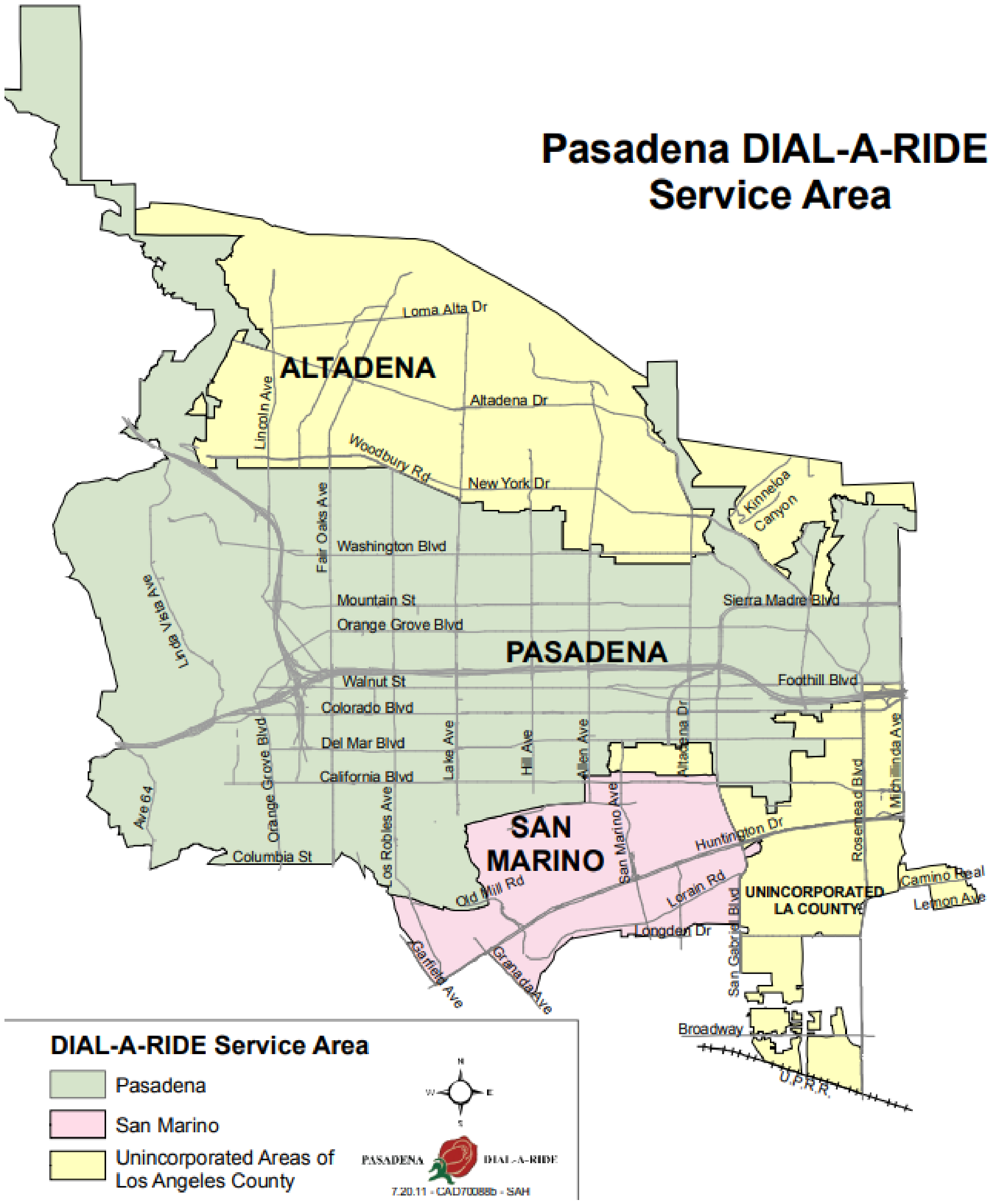
Section II

Section II: Pasadena Department of Transportation

The City of Pasadena provides both fixed-route service (operated as Pasadena Transit) in Pasadena and portions of Altadena and demand response service (operated as Pasadena Dial-A-Ride) in Pasadena, San Marino, Altadena, and other unincorporated Los Angeles County areas. Pasadena Dial-A-Ride is provided seven days. Pasadena Transit provides essential transit connections throughout Pasadena. All of its six fixed-route service lines also connect with Metro's L Line (formerly known as the Gold Line). Pasadena Transit is provided Monday through Sunday. Currently, all the buses in the fleet have internal combustion engines. When planning the transition to a zero-emission fleet, the City of Pasadena is likely looking at two different scenarios for future service: Scenario 1 where it maintains current routes served by the current fleet, and a Scenario 2 where it implements an additional expansion route that would require additional vehicles to the fleet.

Pasadena Dial-A-Ride began its service in Pasadena in 1984. It is a shared, curb-to-curb transportation service provided for residents in Pasadena, San Marino, Altadena, and the other unincorporated Los Angeles County areas in the service area (i.e., Chapman Woods, Kinneloa area, and the unincorporated area of the City of San Gabriel) who are 60 years and older or for those under 60 years old who have a disability. This service is provided seven days per week. Since this service is demand response, buses do not adhere to a fixed route. Demand response shuttles are typically able to also drive on residential streets and have limitations in service areas due to street width or other conditions.

Figure 2-1: Pasadena Dial-A-Ride Service Area



Pasadena Transit, which began its service in 1994, operates multiple fixed routes on weekdays, with some routes operating on reduced or modified weekend schedules:

- Route 10 operates between Old Pasadena and the Allen L Line Station. This route runs on weekdays, with reduced service on weekends.
- Route 20 provides a two-way loop along the Fair Oaks Avenue and Lake Avenue corridors. The Fair Oaks Avenue corridor extends from Woodbury Road in the north to Glenarm Street in the south. The Lake Avenue corridor extends from Woodbury Road in the north to California Blvd. in the south. It operates on weekdays with reduced service on weekends. Route 20 buses operate in a clockwise and counterclockwise direction.
- Route 31/32 provides service from Northwest Pasadena to the Sierra Madre Villa L Line Station. It operates on weekdays with reduced service on weekends. Route 31/32 covers the Washington Blvd. corridor between Lincoln Avenue and Altadena Drive. The route is branched at Altadena Drive with the Route 31 serving south Altadena Drive and Foothill Blvd. and the Route 32 branch serving north Altadena Drive, New York Drive, and Sierra Madre Villa. The two branches terminate at the Sierra Madre Villa L Line Station.

- Route 40 provides service between Old Pasadena and the Sierra Madre Villa L Line Station. It operates on weekdays with reduced service on weekends.
- Route 51/52 runs between Old Pasadena and the ArtCenter and the Jet Propulsion Laboratory (JPL) (Route 51 goes to the Art Center and Route 52 is an extended version of Route 51 that goes to the JPL). The full Route 51/52 operates only on weekdays. On weekends, the Route 51 serves a truncated route between the Memorial Park L Line Station and the Rose Bowl.
- Route 60 operates between the Hastings Ranch area and the Sierra Madre Villa L Line Station to Pasadena City College. It operates limited hours on weekdays only.

Figure 2-2: Pasadena Transit Service Area

Pasadena Transit is also examining the following proposed routes:

- Route H is operated as a demonstration route from January to June 2022 that provides service between the Sierra Madre Villa L Line Station and the Huntington Library. It operates on weekends only. This study assumes that Pasadena Transit will adopt Route H as a permanent service.
- Metro is proposing Pasadena Transit assume Metro Lines 177 and 256 as part of the Metro NextGen Bus Plan. Line 177 operates between Caltech and JPL. Line 177 is expected to operate during peak hours (6 am – 9 am and 3 pm – 6 pm) on weekdays only. Line 256 will provide service between the Highland Park L Line Station and the Sierra Madre Villa L Line Station. It is planned to be a bi-directional schedule with departures every 30 minutes from each terminus.

This study will examine two scenarios:

Scenario 1: Pasadena Transit continues its current service and adopts an additional route that can be served with the current fleet. Scenario 1 assumes that the City of Pasadena will deploy 44 transit vehicles and 15 dial-a-ride vehicles (59 vehicles combined) under an all BEB fleet, 29 transit vehicles and 15 dial-a-ride vehicles (44 vehicles combined) under a FCEB fleet, and 29 FCEB transit vehicles and 15 BEB dial-a-ride vehicles (44 vehicles combined) under a mixed fleet.

Scenario 2: Pasadena Transit continues its current service adopts Scenario 1 and adopts an additional route that will require additional vehicles. Scenario 2 assumes that the City of Pasadena will deploy 64 transit vehicles and 15 dial-a-ride vehicles (79 vehicles combined) under a BEB fleet, 42 transit vehicles and 15 dial-a-ride vehicles (57 vehicles combined) under a FCEB fleet, and 42 FCEB transit vehicles and 15 BEB dial-a-ride vehicles (57 vehicles combined) under a mixed fleet.

The City of Pasadena Fleet and Bus Depot

Pasadena Dial-A-Ride consists of 13 Starcraft Allstar 25-foot shuttle buses and two Dodge Caravan vans. There is a replacement plan in which the demand response fleet buses will be replaced every four years. Seven shuttle buses will be replaced on a four-year cycle beginning in 2022 and six shuttle buses will be replaced on a four-year cycle beginning in 2023. The two minivans in the demand response fleet will be replaced on a four-year cycle, starting in 2022.

Pasadena Transit's fixed-route fleet consists of a total of 29 buses: Four Starcraft Allstar 25-foot shuttle buses, 21 El Dorado EZ Rider II BRT 32-foot, and four New Flyer Xcelsior XN35 35-foot buses. If Pasadena Transit is to assume all routes proposed by Metro, 13 additional buses will be needed to handle the expanded service.

The City of Pasadena's bus depot is currently located at 303 Allen Avenue in between Corson Street and Locust Street in the city of Pasadena. This depot contains maintenance bays and parking for the fleet. Some of the fleet is also being housed at yards located at 2140 East Walnut Street and 768 West Woodbury Road. The depot is leased and does not have enough space to house the entire fleet. The City of Pasadena is planning to develop a new transit facility that would be used to house their fleet. A potential site for the new transit facility is located at 2180 East Foothill Blvd and is in the planning/engineering stages. The City of Pasadena is seeking funding to build the transit facility.

Energy Analysis

To understand the energy needs of the fleet, CALSTART used its proprietary EBCM to model the amount of energy the buses would use over the course of a day. EBCM uses several transit agency-specific variables that are used to calculate energy needs. These variables include factors such as the speed of the bus, ridership, and HVAC setpoints. CALSTART worked with the City of Pasadena to obtain parameters for these variables. EBCM also considers variables that are specific to the route and the environment the bus will encounter while in operation, such as grade and temperature (which affects HVAC load).

To obtain data about grade, CALSTART collected GIS data to determine the path that the buses travel on their route. This data was used to obtain the elevation at multiple points along the bus's route. HVAC load is also a major factor; in extreme climates, HVAC can consume more energy than the propulsion system. As a result, HVAC load has a significant impact on energy needs and the range of the bus. The Los Angeles region is known to have hot temperatures during the summer, with occasional heat waves. To ensure that the buses will be able to perform under worst case conditions, EBCM was programmed to model 120 degrees Fahrenheit in the summer.

These results can be used to determine whether ZEBs can serve as a drop-in replacement for the current fleet and which routes are most suitable to deploy ZEBs. A BEB is considered to be a drop-in replacement if it can complete its shift with a SOC of at least 20%. Likewise, an FCEB is considered to be a drop-in replacement if it can complete its shift with 10% of its hydrogen capacity remaining. See Appendix F for in-depth EBCM results.

Pasadena Dial-A-Ride Fleet

To estimate the energy needs for Pasadena Dial-A-Ride's fleet, CALSTART hosted a bus demonstration. CALSTART facilitated the demonstration of shuttle buses from two different OEMs. Each demonstration took place over two days. On the first day, the bus was driven on dial-a-ride service. The City of Pasadena provided a manifest (Manifest 903) with a list of locations that a dial-a-ride vehicle would drive to on a typical service day. It is important to note that the dial-a-ride demonstrations were held on a Wednesday. Operating the buses on the same day of the week helps to control for traffic patterns. Most of the driving for the dial-a-ride demonstration was on surface streets. Key variables from the demonstrations are outlined below in **Table 2-1**:

Table 2-1: Pasadena Dial-A-Ride Fleet Bus Demonstration Parameters

Variable	OEM 4	OEM 5
Number of People Onboard During the Demonstration	3	2
Average Driving Speed	15 miles per hour	15 miles per hour
Average Temperature	79° F	55° F
Date of Demonstration	October 21, 2021	December 16, 2021

Table 2-2 displays the results from the dial-a-ride bus demonstration.

Table 2-2: The City of Pasadena's Dial-A-Ride Service Daily Energy Needs Analysis

Demonstration Metric	OEM 4	OEM 5
Mileage	119	76.3
Energy (kWh)	78	66.15
Energy Economy (kWh per mile)	0.655	0.867

The main objective of this demonstration was to determine whether each OEM's bus can serve as a drop-in replacement for a conventional shuttle bus. The results of this demonstration indicate:

- OEM 4's bus can serve as a drop-in replacement for a Pasadena Dial-A-Ride vehicle. OEM 4's bus completed the entire route, using less than 80% of the battery's capacity.
- OEM 5's bus can serve as a drop-in replacement for a Pasadena Dial-A-Ride vehicle. OEM 5's bus did not complete the entire day's service. However, OEM 5 offers various battery sizes for their vehicle and offers a battery with approximately 50% more energy storage capacity than the one used on the demonstration vehicle. OEM 5's bus completed most of the route. The energy economy measured during the demonstration was measured and extrapolated to the size of the larger battery. Based on this methodology, OEM 5's bus is deemed to be a drop-in replacement.

The results of this demonstration were used to estimate the energy consumption of a fleet of battery electric shuttle buses. If Pasadena Dial-A-Ride replaces its entire fleet with electric shuttle buses and deploys all of the buses on a daily basis, the buses are estimated to consume up to 1,548 kWh per day.

Currently, there is only one fuel cell shuttle bus available. Since this vehicle is not yet Altoona tested, there is no performance data for this bus. However, the bus can be installed with a 13 kg or 19 kg hydrogen tank. Since 90% of the hydrogen in a tank is recoverable, the maximum amount of hydrogen available is 11.7 kg and 17.3 kg for the 13 kg and 19.2 kg hydrogen tanks, respectively. These amounts equate to an energy equivalence of 185 kWh and 259.51 kWh, respectively.

Based on these results, CALSTART deems that the fuel cell shuttle bus will be a drop-in replacement for the current buses. Each kg of hydrogen has 33.333 kWh of energy. However, the efficiency of the fuel cell is 50%, meaning that 16.667 kWh is available to the drivetrain. Based on this assumption, each bus will use a maximum of approximately 6 kg of hydrogen per day. If Pasadena Dial-A-Ride replaces its entire fleet with fuel cell shuttle buses and deploys all of the buses on a daily basis, the fleet is expected to consume about 90 kg of hydrogen per day.

Pasadena Transit Fleet

Pasadena Transit's fixed-route fleet provides service to Routes 10, 20, 31/32, 40, 51/52, and 60. In addition, under Scenario 1, Pasadena Transit will provide service to Route 177. Under Scenario 2, Pasadena Transit will provide service to both Route 177 and Route 256. To estimate the energy needs for the fixed-route fleet, EBCM was used to estimate the amount of energy that the buses will consume on these routes. CALSTART worked with Pasadena Transit to calibrate the assumptions for those variables. The assumptions used in EBCM are outlined below in **Table 2-3**:

Table 2-3: Pasadena Transit Fixed-Route Fleet EBCM Parameters

Variable	Value
Average Number of People on the Bus During Service	13
Average Driving Speed	10 miles per hour
Heating HVAC Setpoint	72°F
Cooling HVAC Setpoint	68°F

CALSTART also obtained data that is specific to each route. Pasadena Transit provided timetables for all routes to model the exact time schedule and duty cycle for each individual bus. Routes 177 and 256 are currently being operated by Metro, so the service operations for these routes were modeled based on Metro's timetable.

Scenario 1

Using EBCM, CALSTART estimated the energy needs of each individual bus based on Scenario 1, which assumes that Routes 10, 20, 31/32, 40, 51/52, and 60 continue according to the status quo and that Pasadena Transit adopts Route 177.

Figure 2-3 illustrates the operating schedule for the buses and the routes that they will be deployed on for weekdays under Scenario 1, and **Figure 2-4** displays the operating schedule for the buses and the routes that they will be deployed on for weekends under Scenario 1. The blue color indicates the intervals during which the bus is in operation, while the white unshaded squares indicate when the bus is not in operation and thus able to charge. Each square represents the half hour after its labeled time.

Figure 2-3: Pasadena Transit Weekday Operating Schedule (Scenario 1)

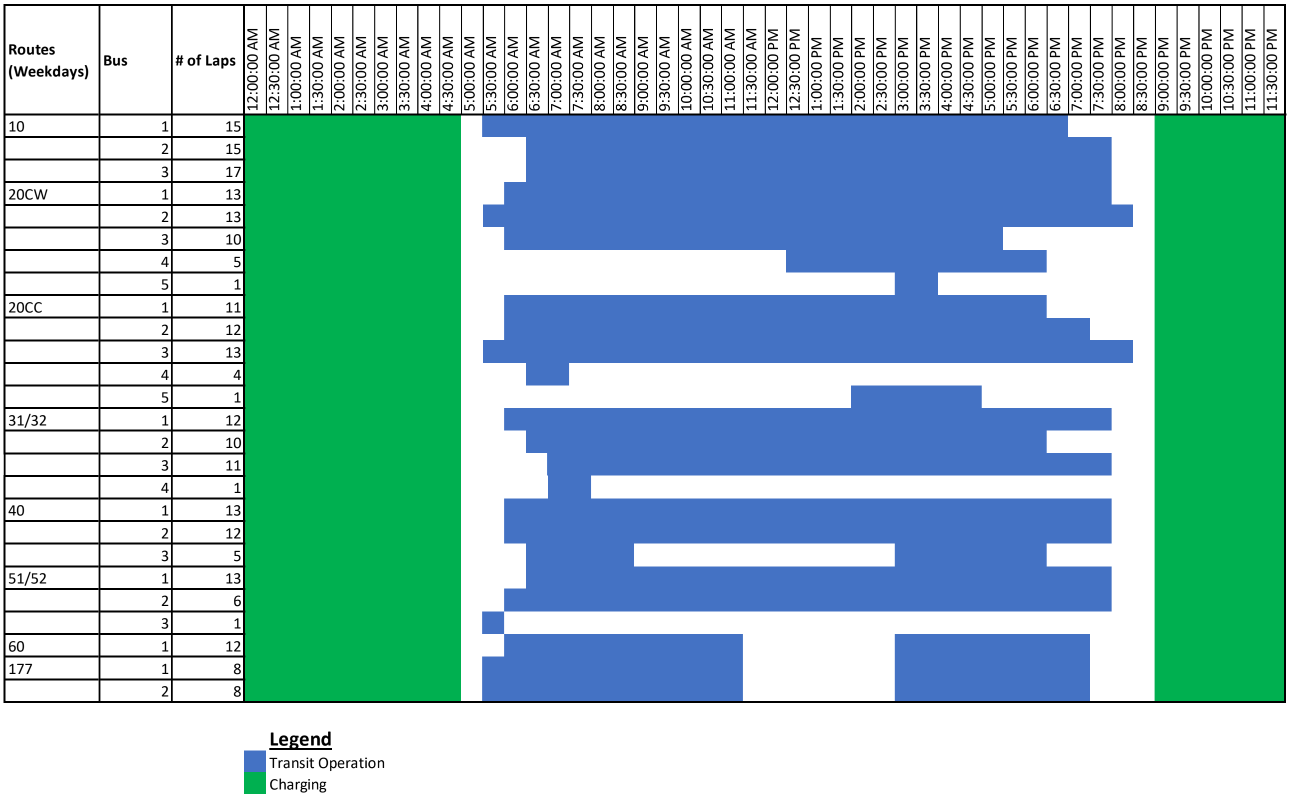
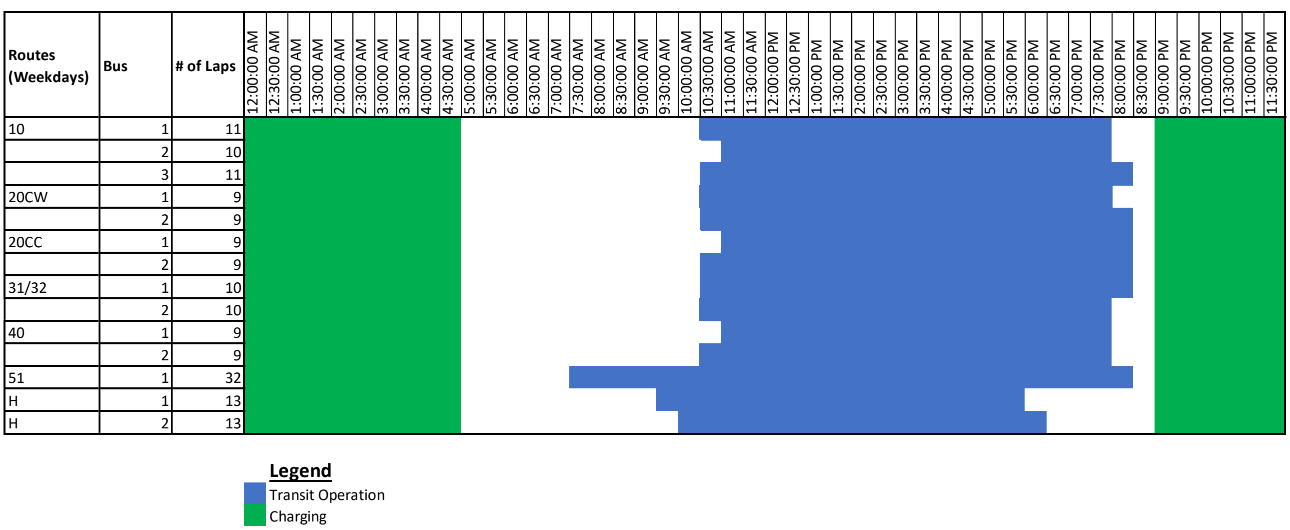


Figure 2-4: Pasadena Transit Weekend Operating Schedule (Scenario 1)



The energy analysis for each shift under Scenario 1 is provided in **Table 2-4**, and the energy needs analysis for Pasadena Transit weekend service under Scenario 1 is provided in **Table 2-5.** A drop-in replacement is defined as a run that completes its route with a SOC of more than 20%. In these figures, there are some buses that cannot serve as a drop-in replacement for a RNG bus. These runs have been highlighted. Runs that complete their route with a SOC of 10% or more have been highlighted in yellow. While these buses are not a drop-in replacement with current technology in 2021, it is likely that these buses could become a drop-in replacement in the future with improvements in battery technology. Buses that return to the depot with less than 10%

SOC have been highlighted in orange. Orange denotes that it is uncertain whether these buses will become a drop-in replacement in the future.

Table 2-4: Pasadena Transit Weekday Service (Scenario 1)

Route	Bus	# of Laps	OEM 1 (kWh)	OEM 2 (kWh)	OEM 3 (kWh)
10	1	15	325.55	361.43	342.82
	2	15	325.56	361.43	342.82
	3	17	364.23	401.46	383.79
20CW	1	13	318.63	329.29	340.79
	2	13	318.63	329.29	340.79
	3	10	233.35	253.43	262.28
	4	5	130.13	140.17	141.46
	5	1	26.57	28.58	29.49
20CC	1	11	258.23	280.32	290.05
	2	12	281.74	305.84	316.46
	3	13	318.63	329.29	340.79
	4	4	104.2	112.23	115.04
	5	1	20.98	22.99	23.87
31/32	1	12	344.88	347.28	362.14
	2	10	294.17	290.99	303.37
	3	11	317.97	339.23	357.84
	4	1	25.20	23.11	24.35
40	1	13	331.00	350.76	361.57
	2	12	302.08	325.66	335.63
	3	5	131.69	139.29	143.44
51/52	1	13	379.85	396.18	430.13
	2	6	168.21	175.75	191.42
	3	1	23.34	24.60	27.21
60	1	12	237.12	246.92	257.61
177	1	8	319.82	333.32	381.00
	2	8	319.82	333.32	381.00
Total			**6,221.58**	**6,582.16**	**6,827.16**

Legend

Route completed with SOC of less than 10 percent

Route completed with SOC of 10 percent or more

Table 2-5: Pasadena Transit Weekend Service (Scenario 1)

Route	Bus	# of Laps	OEM 1 (kWh)	OEM 2 (kWh)	OEM 3 (kWh)
10	1	11	229.74	236.45	264.43
	2	10	229.74	236.45	244.55
	3	11	229.74	236.45	244.55
20CW	1	9	224.50	242.57	250.53
	2	9	224.50	242.57	250.53
20CC	1	9	224.50	242.57	250.53
	2	9	224.50	242.57	250.53
31/32	1	10	275.30	301.41	321.61
	2	10	272.0	315.11	324.20
40	1	9	243.75	257.44	264.91
	2	9	243.75	257.44	264.91
51	1	32	293.06	306.03	332.15
H	1	13	227.68	235.84	258.65
H	2	13	227.68	235.84	258.65
Total			**3,370.44**	**3,588.74**	**3,780.73**

Legend

Route completed with SOC of less than 10 percent

Route completed with SOC of 10 percent or more

In **Table 2-4**, Route 177 for OEM 3 consumes enough energy that it ordinarily would not be considered a drop-in replacement. However, Route 177 only operates in the morning and the afternoon during peak hours. As a result, there is an extended break during which the buses can recharge.

It should be noted that on some routes there is a major inequality in the number of laps that the buses perform per day. This discrepancy occurs when enough ridership during some parts of the day justifies the addition of a bus for a few laps. If the laps are distributed more equitably between the buses, it could mean that more runs will be easier to electrify. Pasadena Transit would benefit from having to purchase fewer buses. In addition, fewer buses would charge simultaneously, which would decrease the maximum power demand. These options are explored in Appendix G. Route 177 may be considered a drop-in replacement as well due to the long break between the AM and PM service time, giving the buses adequate time to charge.

An FCEB is considered a drop-in replacement if it can complete its shift with 10% of its hydrogen capacity remaining. The useable hydrogen tank capacity of each OEM was calculated. Each kg of hydrogen has 33.333 kWh of energy. However, the efficiency of the fuel cell is 50%, meaning that 16.667 kWh is available to the drivetrain. Based on these assumptions, the energy capacity of these FCEBs is detailed in **Table 2-6.**

Table 2-6: Hydrogen Fuel Analysis for FCEBs

OEM	KWh Equivalent
OEM 6	562.51
OEM 7	750.02

Based on these figures, both FCEB OEMs can serve as a drop-in replacement for shifts because their energy capacity exceeds energy demand for each shift. It is estimated that FCEBs will consume approximately 400 kg of hydrogen per weekday and each bus would consume an average of 15.2 kg of hydrogen per day. During weekend service, the buses are estimated to consume about 250 kg of hydrogen per day, with the average bus consuming about 15.3 kg of hydrogen per day.

Scenario 2

CALSTART estimated the energy needs of each individual bus based on Scenario 2, which assumes that Pasadena Transit enacts Scenario 1 and also operates Metro's Route 256.

Figure 2-5 displays the charging schedule for the buses and the routes they will be deployed on for weekdays under Scenario 2, and **Figure 2-6** displays the charging schedule for the buses and the routes they will be deployed on for weekends under Scenario 2. The blue color indicates the intervals during which the bus is in operation, while the white unshaded squares are when the bus is not in operation and thus able to charge. Each square represents the half hour after its labeled time.

Figure 2-5: Pasadena Transit Weekday Operating Schedule (Scenario 2)

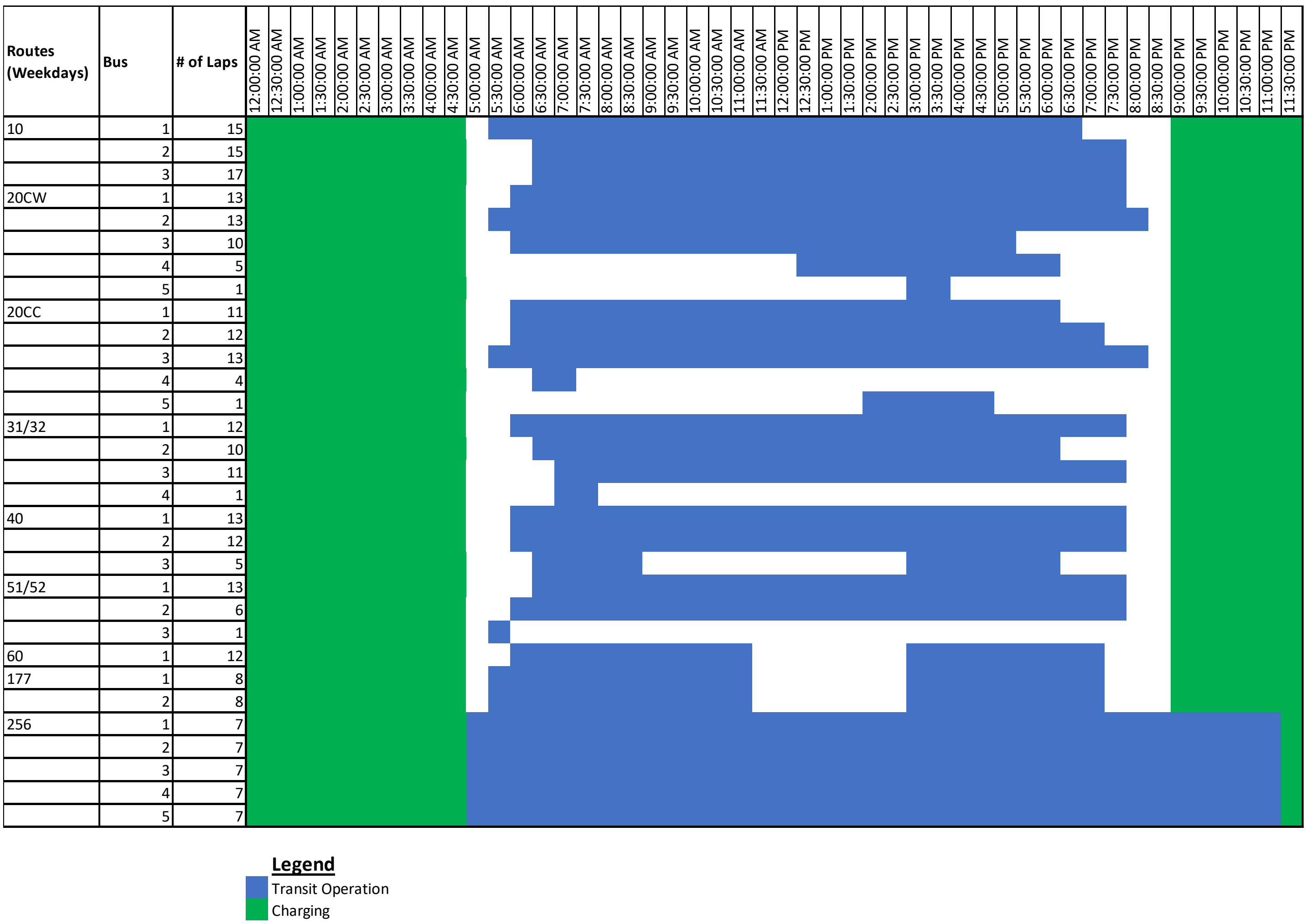
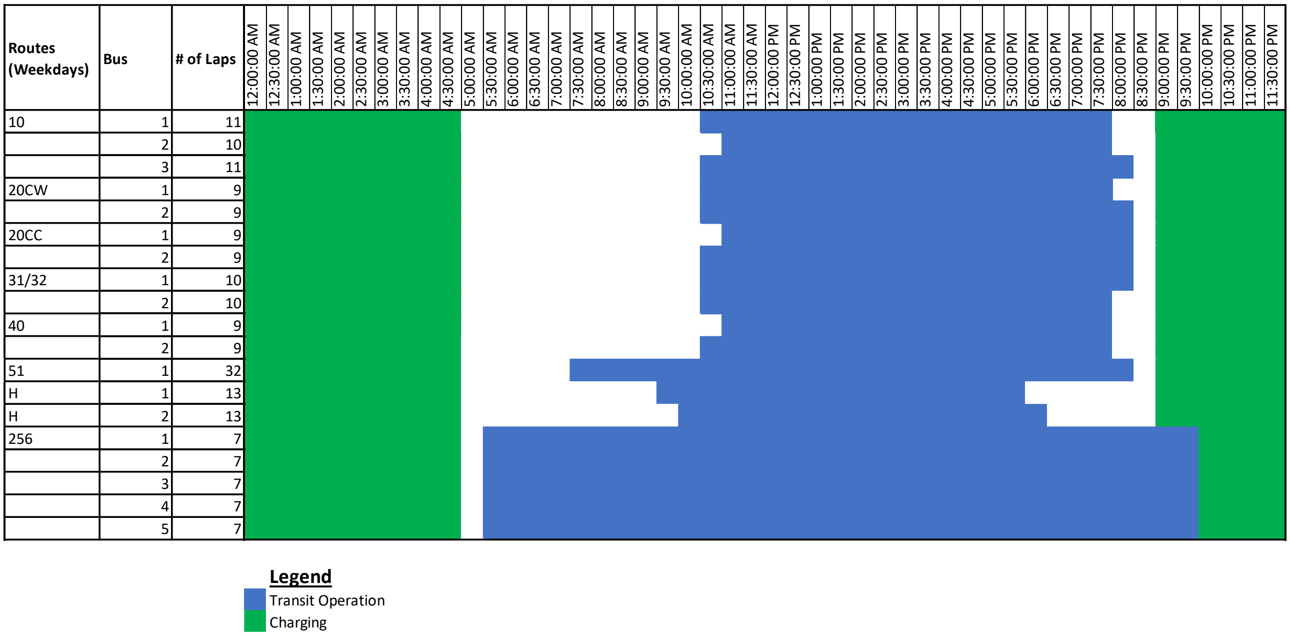


Figure 2-6: Pasadena Transit Weekend Operating Schedule (Scenario 2)



The energy analysis for weekdays under Scenario 2 is provided In **Table 2-7**, and the energy analysis for weekend service under Scenario 2 is provided in **Table 2-8**.

Table 2-7: Pasadena Transit Scenario 2 Weekday Service

Route	Bus	# of Laps	OEM 1 (kWh)	OEM 2 (kWh)	OEM 3 (kWh)
Scenario 1			6175.23	6582.16	6827.16
256	1	7	464.26	483.58	547.17
	2	7	464.26	483.58	547.17
	3	7	464.26	483.58	547.17
	4	7	464.26	483.58	547.17
	5	7	464.26	483.58	547.17
Total			**8,496.53**	**9,000.06**	**9,563.01**

Table 2-8: Pasadena Transit Scenario 2 Weekend Service

Route	Bus	# of Laps	OEM 1 (kWh)	OEM 2 (kWh)	OEM 3 (kWh)
Scenario 1			3,370.44	3,588.74	3,780.73
256	1	7	464.26	483.58	547.17
	2	7	464.26	483.58	547.17
	3	7	464.26	483.58	547.17
	4	7	464.26	483.58	547.17
	5	7	464.26	483.58	547.17
Total			**5,691.74**	**5,910.04**	**6,102.03**

Legend

Route completed with SOC of less than 10 percent

Route completed with SOC of 10 percent or more

For Route 256, no BEB model can serve as a drop-in replacement. Using the same methodology employed for Scenario 1, an FCEB can serve as a drop-in replacement for Route 256. It is estimated that FCEBs will consume approximately 540 kg of hydrogen per weekday and each bus would consume an average of 18.6 kg of hydrogen per day. During weekend service, the buses are estimated to consume about 385 kg of hydrogen per day, with the average bus consuming about 18.3 kg of hydrogen per day.

Pasadena Transit Route 51/52 Demonstration

CALSTART also hosted a demonstration of shuttle buses on Pasadena Transit Route 51/52. The City of Pasadena wanted to conduct this demonstration to determine if shuttle buses can be used to replace the transit bus that currently serves this route. The main reason for exploring this option is that ridership on this route is lower than other routes. In addition, there is little room to turn the bus around at the route terminus and the roads on this route are narrow, meaning that shuttle buses could be easier to maneuver on this route. Since electric shuttle buses have a smaller battery than transit buses, they were not expected to be able to be able to serve the route as a drop-in replacement. However, electric shuttle buses are less expensive than transit buses. As a result, it would be economically viable to replace transit buses with electric shuttle buses on a 2:1 basis. The main objective of this demonstration was to determine whether an electric shuttle bus is able to serve Route 51/52 on a 2:1 basis.

During this demonstration, the bus followed the transit bus that was serving Route 51/52. The Route 51/52 demonstrations were held on a Thursday, operating on the same day of the week to control for traffic patterns. The entire Route 51/52 demonstration was on surface streets. However, this route involves significant elevation gain.

Table 2-9 displays the parameters for the bus demonstration.

Table 2-9: Pasadena Transit Route 51/52 Bus Demonstration Parameters

Variable	OEM 4	OEM 5
Number of People Onboard During the Demonstration	2	2
Average Driving Speed	15 miles per hour	15 miles per hour
Average Temperature	75° F	55° F
Date of Demonstration	October 22, 2021	December 17, 2021

Table 2-10 displays the results from the bus demonstration on Route 51/52.

Table 2-10: The City of Pasadena Route 51/52 Daily Energy Needs Analysis

Demonstration Metric	OEM 4	OEM 5
Mileage	101	83.8
Energy (kWh)	56	71.4
Energy Economy (kWh per mile)	0.554	0.852
Laps Completed	8	7

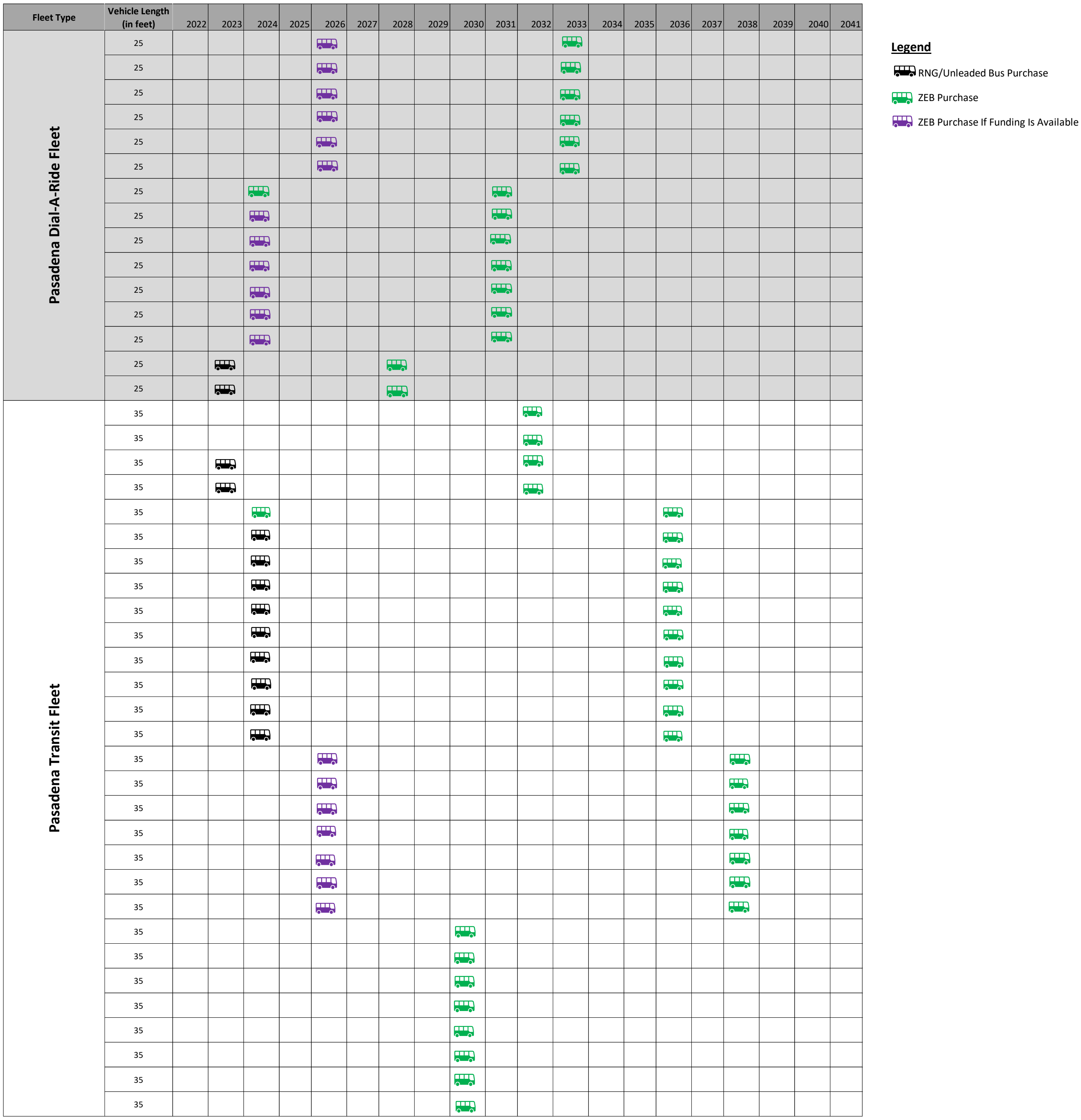
The objective of the demonstration was to determine whether the shuttle buses can serve this route on a 2:1 basis. The buses travel a maximum of 13 laps per day. As a result, a bus was deemed to be a 2:1 replacement if it could complete at least 7 laps, using less than 80% of the battery's capacity. As a result, both vehicles are able to serve as a 2:1 replacement for a transit bus on Route 51/52.

Fleet Replacement Plan

The City of Pasadena currently operates 29 transit buses through Pasadena Transit and 15 shuttle buses through Pasadena Dial-A-Ride (44 total vehicles). The City of Pasadena will replace its fleet with ZEBs over multiple years. CALSTART developed a fleet replacement plan based on the City of Pasadena's fleet replacement schedule. The City of Pasadena plans to replace the current fleet as the buses reach the end of their useful life.

There are several assumptions that guided this fleet replacement plan. The first assumption is that Pasadena Transit will be replacing their fleet with 35-foot buses. The second assumption is that any bus can be deployed on any route, meaning a particular bus will not be dedicated to a specific route. This fleet replacement plan also assumes that the City of Pasadena will comply with the ICT Rule by beginning to purchase ZEBs after 2026, when the ICT Rule comes into effect for small transit agencies. This fleet replacement shows how RNG and unleaded buses will be phased out over time. This replacement plan is based on the 2018 Short-Range Transit Plan but has been revised based on current funding opportunities. The fleet replacement plan is displayed in **Figure 2-7**.

Figure 2-7: The City of Pasadena Transit Fleet Replacement Plan



According to this plan, the first ZEB purchases that are required by the ICT rule would take place in 2027. If this plan is followed, Pasadena Dial-A-Ride would be fully zero-emission by 2033 and Pasadena Transit would be fully zero-emission by 2040. If funding becomes available to fund the additional cost for zero emission vehicles earlier, an accelerated replacement plan transition to a ZEB fleet is in Figure 2-7, labeled in purple.

It is important to note that the City of Pasadena is planning to expand service. Specifically, Pasadena Transit may adopt routes from Metro according to the Metro NextGen Bus Plan. As a result, Pasadena Transit will need to purchase more buses.

Furthermore, based on the energy modelling results, BEBs currently cannot serve as a drop-in replacement on all routes (unlike FCEBs). As a result, additional BEBs would need to be purchased to operate these routes. Based on the energy modelling, Pasadena Transit would need to deploy 44 BEBs or 29 FCEBs to meet the service needs of Scenario 1. Pasadena Transit would need to deploy 64 BEBs or 42 FCEBs to meet the service needs of Scenario 2. Both of these figures include spare buses.

The ZEB Rollout Plans outlined In **Figure 2-8** and **Figure 2-9** were calculated by modifying the existing fleet replacement plan. Since BEBs are not a drop-in replacement for a RNG bus, additional BEBs must be procured to operate these routes. A transit agency can choose when they purchase the additional buses but might wish to purchase the extra buses immediately to obtain environmental benefits of the bus earlier. Alternatively, a transit agency might delay purchasing extra BEBs with the expectation that the range of the buses will improve in the future, which might increase the number of routes where they can serve as a drop-in replacement. These ZEB Rollout Plans assume that the extra buses are spaced out over the course of the planned deployment and that additional buses are included in every planned bus purchase. This approach allows Pasadena Transit to maintain the same level of service and flexibility so all buses can serve all routes.

The fleet replacement plan outlined above assumes that the buses will be deployed in accordance with the minimum requirements of the ICT Rule. Under this plan, ZEBs will not be purchased until after 2026. However, if funding becomes available, it might be possible to deploy buses ahead of this schedule identified in purple in Figure 2-7. The main barrier to deploying ZEBs is the procurement and construction of a transit facility. If a transit facility is obtained and built quickly, ZEB purchases could potentially begin ahead of the 2026 ICT mandate. If the City of Pasadena wishes to deploy buses before a transit facility is built, they will need to use public stations, if available, or otherwise secure a location to deploy temporary chargers.

Figure 2-8: Scenario 1 ZEB Rollout Plan

Year	BEBs		FCEBs	
	Pasadena Transit	Pasadena Dial-A-Ride	Pasadena Transit	Pasadena Dial-A-Ride
2022				
2023				
2024				
2025				
2026				
2027		3		2
2028		3		2
2029				
2030	8	3	8	2
2031				
2032	7		4	
2033	8	6	5	9
2034	8		5	
2035				
2036				
2037	13		7	
2038				
2039				
2040				
2041				
Total	**44**	**15**	**29**	**15**

Figure 2-9: Scenario 2 ZEB Rollout Plan

Year	BEBs		FCEBs	
	Pasadena Transit	Pasadena Dial-A-Ride	Pasadena Transit	Pasadena Dial-A-Ride
2022				
2023				
2024				
2025				
2026				
2027		3		2
2028		3		2
2029				
2030	12	3	10	2
2031				
2032	10		6	
2033	12	6	7	9
2034	12		6	
2035				
2036				
2037	18		13	
2038				
2039				
2040				
2041				
Total	**64**	**15**	**42**	**15**

The energy modeling used to develop these fleet replacement plans is based on 120 degrees Fahrenheit weather, which would represent the worst-case conditions the buses will operate in. As a result, the buses will operate in more favorable conditions most of the time, which would reduce the energy needs of the bus and improve their performance. In addition, this assessment is based on current BEB technology. It is very likely that there will be improvements in technology over time, which would reduce the number of buses that the City of Pasadena would need to purchase.

The City of Pasadena has the option to purchase either BEBs or FCEBs. There are multiple factors that need to be considered when selecting a technology, the main factors being the capability of the technology, capital costs and total cost of ownership, and infrastructure viability. Based on the energy analysis, FCEBs are able to serve as a drop-in replacement for RNG buses, whereas BEBs are only drop-in replacements for Pasadena Dial-A-Ride and a very limited amount of Pasadena Transit service. However, this is only one of several factors that need to be considered when making this decision. The rest of this section will be devoted to exploring these factors. CALSTART ultimately recommends that the City of Pasadena transitions to a fully BEB fleet.

Utility Analysis

PWP Overview

The City of Pasadena is served by PWP. PWP is the not-for-profit municipal utility that serves the City of Pasadena and is owned by the City of Pasadena. It, along with other municipal utility such as Glendale and Burbank, form part of the Southern California Public Power Authority (SCPPA). PWP power assets include 11 substations, 662 miles of distribution lines, and 11,082 utility poles; they deliver over 1 million MWh (megawatt-hour) of energy annually with a peak demand of 320 MW (PWP, 2020).

PWP uses a variety of resources to provide power to its service territory. The majority of PWP's power is derived from renewable energy (PWP, n.d.). PWP additionally imports power from across California and as far north as British Columbia. This power is obtained from PPAs directly with PWP and SCPPA and is delivered using the electric transmission grid. PWP owns the Glenarm Power Plant, located in the City of Pasadena, which is a 71 MW natural gas power plant (Stantec, n.d.). In 2017, it completed an update of one of its gas turbines to maximize efficiency.

PWP has a sustainability goal to achieve 60% of its power from renewable sources (PWP, 2020). According to their 2020 Annual Report, they currently obtain 37.5% of their power from renewables. PWP has a goal to eliminate coal-fired electricity generation from their portfolio no later than 2027. PWP receives 108 MW from a coal-fired power plant in Utah; the contract expires in 2027 (PWP, 2018). In 2017, PWP's power mix had a higher percentage of eligible renewable than the state average, which is 29% renewable, and a higher percentage of coal in their power mix (PWP, 2018).

PWP Utility Tariffs

The City of Pasadena's buses are currently primarily domiciled at 303 N. Allen Ave. in Pasadena, which is in PWP's service territory. This is a leased property by the transit services contractor, and the City of Pasadena has been searching for a new location to house their transit fleet due to existing space constraints and the need to have a facility that is indefinitely available for transit use. The transition to BEBs will lead to a significant increase to the City of Pasadena's utility costs. The power demand from charging the BEBs would qualify The City of Pasadena for the Large (L-1) rate. The transit agency will have power demand greater than 300 kW and the voltage to be delivered will be less than 17 kilovolts (kV) (Pasadena Code of Ordinances, 13.04.067).

PWP's TOU tariff means the City of Pasadena will be charged a different rate for energy depending on the time of day and season. The winter rate schedule runs from October through May. The winter on-peak rate applies on all weekdays (excluding holidays) from 6 am-10 pm. The winter off-peak rate applies all-day weekends and from 10 pm-6 am on weekdays. The summer rate schedule runs from June through September. The summer on-peak hours are noon-8 pm daily; the off-peak hours are daily from 8 pm-noon (Pasadena Code of Ordinances, 13.04.067). Additionally, there is a grid access charge, a meter charge, a transmission charge, and a distribution charge. These utility rates are current as of February 2022. However, utility rates may change in the future. Any ZEB operational strategy should be adjusted to any future changes.

Demand charges are assessed based on the maximum kW that is consumed over past four months of service. The Large (L-1) tariff has a constant demand charge that is charged at the same $/kW rate regardless of the time of day or month.

The City of Pasadena Utility Costs

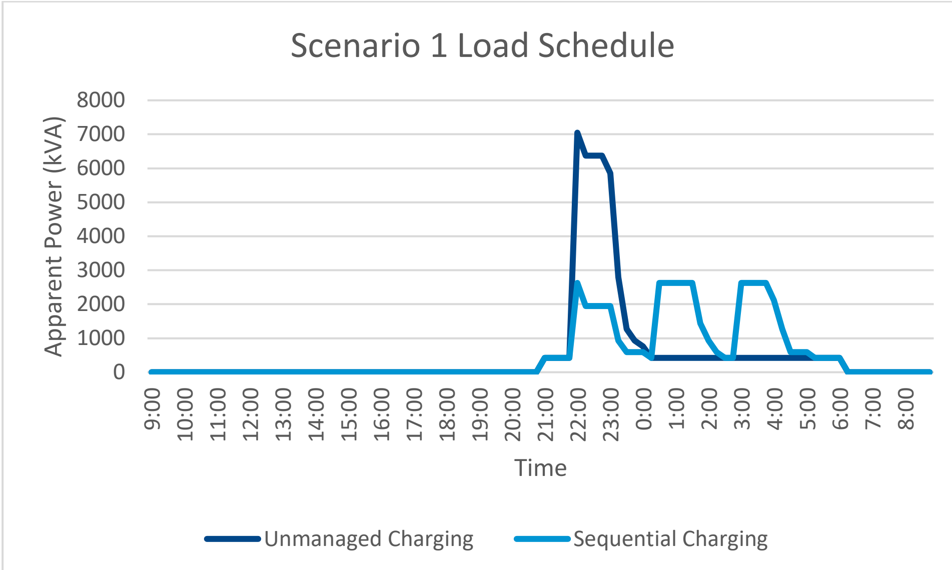
Pasadena Transit operates Routes 10, 20, 31/32, 40, 51/52, and 60. In addition, under Scenario 1, Pasadena Transit will provide service to Route 177. Under Scenario 2, Pasadena Transit will provide service to both Route 177 and Route 256. Both Scenario 1 and Scenario 2 also include utility costs for Pasadena Dial-A-Ride.

Based on PWP's Large (L-1) tariff and the energy and projected power demand, **Table 2-11** shows the projected annual utility costs for operating the fixed-route and dial-a-ride fleets under Scenario 1. These figures assume that the entire fleet has been converted to BEB. In addition, these figures assume that the buses begin charging at 9 pm at night and are ready for service at about 5 am, which is illustrated in **Figure 2-10**.

Table 2-11: Scenario 1 Utility Analysis (150 kW charging)

	OEM 1 + OEM 4		***OEM 2 + OEM 4***		***OEM 3 + OEM 4***	
Charge	**Unmanaged**	**Sequential**	**Unmanaged**	**Sequential**	**Unmanaged**	**Sequential**
Bureaucracy Charges	$18,575	$18,5745	$18,575	$18,575	$18,575	$18,575
Energy Charges (per kWh)	$240,173	$240,173	$253,325	$253,325	$262,700	$262,700
Demand Charges (per kW)	$932,447	$358,391	$932,447	$392,159	$932,447	$493,463
Total	**$1,191,195**	**$617,139**	**$1,204,347**	**$664,059**	**$1,213,722**	**$774,738**

Figure 2-10: Scenario 1 Load Schedule

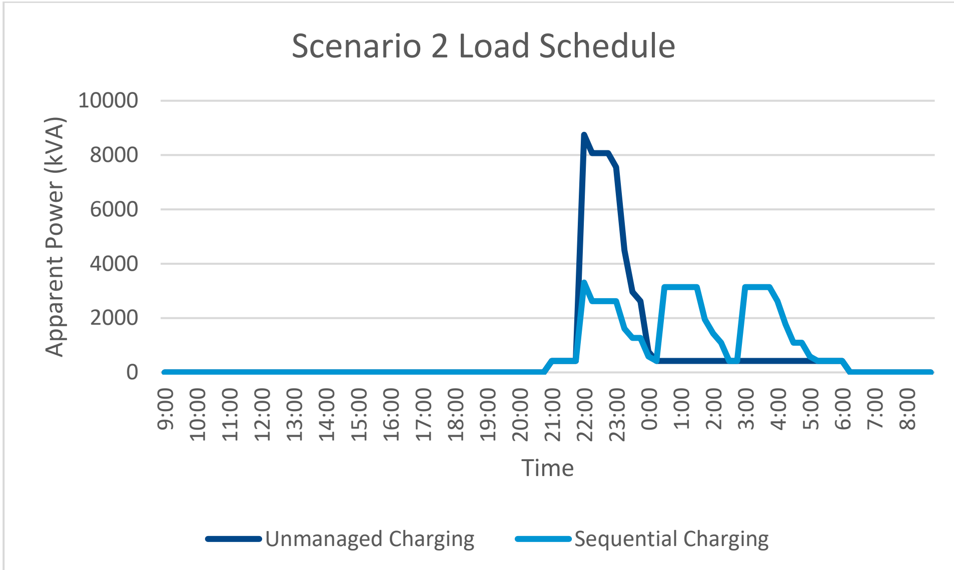


The Scenario 2 projected annual utility costs for operating the Pasadena Transit's and Pasadena Dial-A-Ride's buses are displayed in **Table 2-12**. The figures for sequential charging assume that the City of Pasadena will be levied utility charges based on the PWP's Large (L-1) tariff for unmanaged charging. This is a secondary service rate. These figures also assume that the buses will charge using the standard charger offered by the OEM. Furthermore, the figures for sequential charging assume that the fleet will be charged in multiple batches, as shown in **Figure 2-11**.

Table 2-12: Scenario 2 Utility Analysis (150 kW charging)

	OEM 1 + OEM 4		*OEM 2 + OEM 4*		*OEM 3 + OEM 4*	
Charge	**Unmanaged**	**Sequential**	**Unmanaged**	**Sequential**	**Unmanaged**	**Sequential**
Bureaucracy Charges	$18,575	$18,575	$18,575	$18,575	$18,5745	$18,575
Energy Charges (per kWh)	$343,697	$343,697	$359,379	$359,379	$377,081	$377,081
Demand Charges (per kW)	$1,270,127	$459,695	$1,303,895	$493,463	$1,067,519	$628,535
Total	**$1,632,399**	**$821,967**	**$1,681,849**	**$871,417**	**$1,463,175**	**$1,024,191**

Figure 2-11: Scenario 2 Load Schedule



Utility Infrastructure

To power fleet charging, the utility needs to be able to deliver enough power to the depot. To do this, the utility needs to have appropriate FTM utility infrastructure in place. The City of Pasadena is currently planning to build a new transit facility at 2180 East Foothill Blvd. This facility is planned to house a bus depot, maintenance bays, and offices. The facility is expected to be able to house approximately 40-45 ZEBs, with the rest of the fleet being housed at a separate location.

The City of Pasadena's new transit facility will need utility upgrades to bring power to the chargers and the rest of the transit facility. CALSTART held discussions with the City of Pasadena and PWP to determine the utility upgrades that will be required. During these discussions, PWP stated that there is adequate grid distribution capacity to serve this location. As a result, the location will only require a transformer. The type of transformer required depends on the power demand from the site.

An electric service feasibility study was conducted by PWP that provided the site Interconnection point and circuit load for 2180 East Foothill Blvd, two service Integration designs and approximate costs for each. The study is based on a 5000A 277/480V 3PH 4W service. The site would be connecting into the Maple circuit. With the addition of the City of Pasadena's vehicle charging load, there is potential for the circuit to become overloaded. PWP can mitigate this overload potential by transferring some existing service to other circuits. PWP has adequate grid capacity to charge the vehicles. There is existing conduit infrastructure to the site from the Maple circuit, but it needs to be tested before it can be re-used.

The first proposed service Integration design would be secondary service where PWP uses their equipment to step down the voltage for the customer. Because the power demand exceeds 5,000 amps, two 2,500 kVA transformers would need to be installed, and each 2,500 kVA transformer would also need dedicated switchgears. It is important to note that the maximum amount of power that can be supplied to the site is 5,000 kVA. A subterranean vault room would have to be built; the cost for this would be incurred by the City of Pasadena. The lead time for this upgrade is typically 4-6 months. However, if there are delays, it can take up to one year. PWP estimates this would cost approximately $350,000, not including the cost for the vault room.

PWP's second proposed Integration design would be primary service. In this case, instead of PWP installing a utility transformer, The City of Pasadena would need to supply their own transformer to step down the voltage. The installed cost of this would depend on the vendor that supplies and installs the transformers. PWP estimates this would cost approximately $120,000.

It is important to note that the City of Pasadena's new transit facility is still in the design phase. Space will need to be allocated to accommodate the transformers. The most likely scenario is that the designs will need to incorporate a dedicated room to house the transformers. The transformers cannot be physically installed onsite until late in the construction process. The transformers cannot be installed until the room that houses them is physically built out. The City of Pasadena will need to coordinate with PWP to ensure that their site design will accommodate transformers. Coordination will also be needed to plan the installation of the transformers while the transit facility is being built.

Utility-Owned Charging Infrastructure

PWP has constructed and opened several charging stations in Pasadena. The first public charging station that Pasadena opened was the Marengo Charging Plaza. This charging station, which is located on the top floor of a parking garage at 155 East Green Street, houses 24 Tesla Superchargers and 20 DCFCs. In 2021, PWP opened the Arroyo EV Charging Depot, which is located at 64 East Glenarm Street. This charging station houses 20 Tesla Superchargers and 6 DCFCs. PWP is planning to Install additional DCFCs at the Arroyo EV Charging Depot at a future date. Both of these charging stations are open to the public to charge vehicles.

Public charging stations can potentially be used by the City of Pasadena to charge small buses. The usefulness of a public charging station will be determined by several factors including whether the available chargers are interoperable with the buses and the parking configuration of the station. Public charging stations can be used as an emergency measure to extend the range of a vehicle if it runs low on charge during service. In addition, public charging stations can be used as a resiliency measure if a bus depot loses power. Since the Marengo Charging Plaza is located in a parking garage that buses cannot fit in, it is not an appropriate location to charge buses. However, the Arroyo EV Charging Depot does not have this constraint and, depending on availability, may present an opportunity to charge for a limited number of buses.

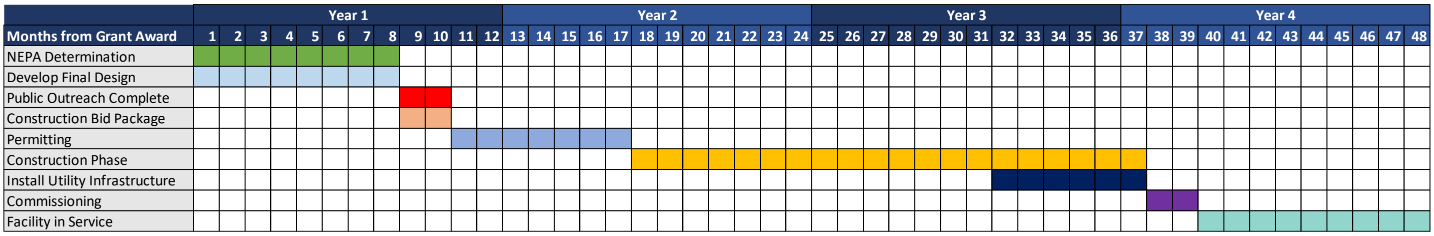
PWP stated that they might be able to provide a facility to charge some of the City of Pasadena's buses. The main challenge that the City of Pasadena faces when deploying ZEBs is building a transit facility with charging infrastructure. If the City of Pasadena were to deploy ZEBs before their transit facility is built, PWP stated that they might be able to provide a charging site. A charging site will need to be in a secure location to prevent vandalism or theft of the vehicles. In addition, the charging site will need to be designed to allow transit buses to easily navigate the yard. The site should be designed to allow for pull-through parking so buses can easily access the charging equipment.

Charging and Hydrogen Infrastructure Analysis

BEB Charging Infrastructure Deployment Plan

To deploy a BEB fleet, the City of Pasadena will first need to build a permanent transit facility. The City of Pasadena plans to build a transit facility at 2180 East Foothill Blvd. Initial designs for the site have been drafted and the construction process could begin once the Pasadena Department of Transit has secured funding to build the depot. The City of Pasadena has already completed some of the environmental review process but will need to undergo an updated environmental review. The City of Pasadena will also need to develop a final design for the depot. Once this is completed, the City of Pasadena will need to ensure it has completed public outreach on the proposed design and develop a construction bid package. In addition, the project will go through the permitting process. Once a construction firm has been selected and permitting is complete, construction may begin. Construction is scheduled to take 20 months. During the construction phase, utility infrastructure will also need to be installed After construction is complete, commissioning will take place. After commissioning, the facility is ready to be used. A Gantt chart outlining the proposed construction timeline is included below in **Figure 2-12.**

Figure 2-12: The City of Pasadena Transit Facility Construction Timeline



If the construction process adheres to the proposed timeline, construction is expected to take 39 months. As a result, to begin deploying buses by 2027, the City of Pasadena should initiate the construction process by 2023. The main barrier to beginning this process is obtaining funding to build the depot.

In addition to building a transit facility, installing charging infrastructure is vital for the successful deployment of a BEB fleet. Deploying BEB chargers is more than simply installing the chargers. In addition to FTM utility infrastructure, electrification requires the deployment of BTM infrastructure (on the customer's side of the meter). BTM infrastructure carries the power from the utility transformer, where the utility delivers power to the depot, to the actual chargers. BTM infrastructure upgrades entail installing appropriately sized transformers and switchgear. In addition, conduit through which the circuits can deliver power to the chargers is required. Conduit is typically underground, and the depot must be trenched to install this.

The depot will need FTM equipment. The main FTM equipment that will need to be deployed is a transformer. The type of transformer required will depend on the maximum power demand of the site. The most likely outcome is that the City of Pasadena will require either one or two 2,500 kVA transformers. The City of Pasadena will also need to deploy BTM equipment on their depot to bring power from the transformer to the chargers.

To serve the charging site under Scenario 1, the City of Pasadena will need to deploy the following infrastructure:

- 16 Transit Bus Power Cabinets
- 46 Transit Bus Depot Chargers
- 15 Shuttle Bus Chargers
- 3 DC Fast Chargers (shuttle bus backup chargers)
- Electric Bus Switchboard (480 V)
- 2 Electrical Panelboards (120/208 V)
- A transformer (see Utility Infrastructure section for more details)500 kVA Transformer
- Main Service Switchboard
- Automatic Transfer Switch (if natural gas generators are used to provide resiliency)

To serve the charging site under Scenario 2, the City of Pasadena will need to deploy the following infrastructure:

- 22 Transit Bus Power Cabinets
- 64 Transit Bus Depot Chargers
- 15 Shuttle Bus Chargers
- 3 DC Fast Chargers (shuttle bus backup chargers)
- 3 Electric Bus Switchboards (480 V)
- 2 Electrical Panelboards (120/208 V)
- A transformer (see Utility Infrastructure section for more details)500 kVA Transformer

- Main Service Switchboard
- Automatic Transfer Switch (if natural gas generators are used to provide resiliency)

If all of the buses are housed at one location, the space required for bus parking and infrastructure under Scenario 1 is estimated to be approximately 111,500 square feet, and Scenario 2 would require approximately 147,600 square feet. More information can be found in Appendix K.

The City of Pasadena will transition to zero-emission between 2027 and 2040. To minimize the amount of construction work needed to install BTM infrastructure, it is advisable to install all of the BTM upgrades at the same time. To save time and reduce costs, BTM infrastructure installation should begin during the construction phase of the transit facility. This would allow the infrastructure to be installed before concrete is laid. This would reduce the cost of deploying conduit by reducing the amount of trenching. In addition, the City of Pasadena will need to install conduit directly to the location where each of the chargers will be located. This strategy allows the City of Pasadena to install the infrastructure without having to do multiple rounds of trenching. The site will then be "charger ready" and as the buses are deployed, additional chargers can be added by simply running circuitry through the conduit to the chargers. To achieve this, preplanning will need to be conducted to identify where each of the chargers will be located on the site.

FCEB Hydrogen Fueling Infrastructure Deployment Plan

If the City of Pasadena were to rollout a fleet of FCEBs, the main requirement would be to obtain hydrogen for the fleet. Under Scenario 1, the fleet would consume approximately 3,130 kg of hydrogen per week, which equates to approximately 162,760 kg per year. Under Scenario 2, the fleet would consume approximately 4,100 kg per week or approximately 213,200 kg per year. The City of Pasadena would have several options for obtaining hydrogen for the fleet: produce hydrogen on-site via SMR or electrolysis, or alternatively opt to receive delivered gaseous or liquid hydrogen. Lastly, the City of Pasadena could fuel at public fueling stations.

Several of these options can be eliminated immediately. Producing hydrogen on-site via electrolysis is not viable because the utility costs would be high. Producing one kg of hydrogen via electrolysis requires 55 kWh of energy. Furthermore, compressing the hydrogen so it can be dispensed at 350 bar consumes between 1.7 and 6.4 kWh per kg of hydrogen (Monterey Gardner, 2009). This analysis uses the average of this range, which is 4.1 kWh per kg. Based on these figures, the production of hydrogen via electrolysis would require 59.1 kWh per kg of hydrogen. Under Scenario 1, the City of Pasadena would consume about 28,960 kWh per day to produce hydrogen. Assuming the best-case scenario (that minimizes power demand) where the electrolyzer produces hydrogen 24 hours per day, power demand would be 1,207 kW. Under Scenario 2, the City of Pasadena would consume approximately 37,233 kWh per day. Under the best-case scenario, this would entail power demand of 1,551 kW. This method for producing hydrogen is not viable; the amount of energy required to produce this much hydrogen would exceed the amount of energy that the entire BEB fleet uses by a factor of five. In addition, there would still be high power demand for electrolysis. Hydrogen produced via electrolysis is expected to cost $1,686,887 per year under Scenario 1 and $2,210,884 under Scenario 2. As a result, the utility bills would be higher than that of a BEB fleet, which makes this option financially infeasible. In addition, utility upgrades might be required to deliver this much power to the electrolyzer.

The use of delivered gaseous or liquid hydrogen is also financially infeasible. Hydrogen can be delivered in gaseous form but only in limited quantities. Most trucks can only deliver approximately 250-280 kg of hydrogen. To serve the entire fleet, the City of Pasadena would need to receive multiple truck deliveries per day. This situation would likely be incompatible with the City of Pasadena's operations. However, if this option was pursued, the expected annual cost of hydrogen would be approximately $1,318,356 under Scenario 1 and $1,726,920 under Scenario 2. Liquid hydrogen is typically delivered in larger quantities and most liquid hydrogen trucks can deliver up to 4,500 kg of hydrogen. When the City of Pasadena's fleet is fully zero-emission, the fleet would consume enough fuel to justify the use of liquid hydrogen. The annual hydrogen fuel price is projected to be approximately $1,362,301 under Scenario 1 and $1,784,484 under Scenario 2, but these figures still greatly exceed the utility charges incurred for a BEB fleet.

Another option would be retail fueling. At the time of writing, there are no heavy-duty hydrogen stations currently in existence or planned in or near Pasadena. However, there are some light-duty stations near Pasadena. While Pasadena Dial-A-Ride could theoretically fuel at a light-duty station, the price of retail hydrogen is currently high. At this point in time, the use of retail fueling is currently infeasible due to the lack of heavy-duty hydrogen fueling stations and the high price of hydrogen at light-duty stations. However, the market for retail hydrogen fueling is rapidly changing, and the CEC has awarded grants to expand California's retail hydrogen fueling market (CEC, 2020). As a result, the market for retail hydrogen fueling can change in the future.

The most viable option that the City of Pasadena has to fuel an FCEB fleet would be to use on-site SMR. On-site SMR is only economically viable at volumes of at least 200 kg per day (about 13 buses per day). Although delivered hydrogen is not a viable option for fueling the entire fleet, it could be used temporarily to fuel the fleet until the fleet size increases to consume more than 200 kg per day. There are two options for using delivered hydrogen. One option would be to use a mobile refueler. A mobile refueler is usually delivered in a shipping container, trailer, or other non-permanent structure. The mobile refueler would accept delivered hydrogen. When the fleet grows to the point where it consumes more than 200 kg per day, a hydrogen station with onsite production can be built and the mobile refueler removed. The pricing for deploying a mobile refueler is not available. Alternatively, the City of Pasadena would need to build a hydrogen station. The station would be designed to accept hydrogen from a tube trailer. The City of Pasadena would then schedule deliveries of hydrogen. Once demand reaches 200 kg per day (about 13 buses per day), an on-site SMR can be deployed at the location. The capital cost of this approach is not clear because this process involves replacing equipment as the fleet grows.

Based on the fleet replacement plan, the City of Pasadena would be expected to reach a demand of 200 kg per day in 2033. When the on-site SMR is installed, the equipment used to accept delivered hydrogen can be left on-site. This will allow the City of Pasadena to accept delivered hydrogen when the SMR is undergoing scheduled maintenance or if there is an equipment fault. The City of Pasadena is projected to pay approximately $1,069,333 per year for hydrogen under Scenario 1 and $1,400,724 per year for hydrogen under Scenario 2. This amount also exceeds the utility costs that would be associated with charging a BEB fleet.

It is important to note that, in addition to the cost of the fuel, there are capital expenditures associated with some of these options, such as a hydrogen fueling station. The City of Pasadena would need to invest in a fueling station if it decides to obtain hydrogen via on-site electrolysis, delivered liquid hydrogen, or on-site SMR. The City of Pasadena could avoid this capital expense if it was able to obtain hydrogen from retail fueling stations; however, this is currently not a feasible option. The capital expenditures and annual fuel costs for each hydrogen pathway under Scenario 1 and Scenario 2 are displayed in **Table 2-13** and **Table 2-14**. There are additional costs associated with deploying on-site hydrogen production equipment, which is explored further in Appendix J.

Table 2-13: Hydrogen Cost Analysis – Scenario 1

Expense	On-site Electrolysis	Delivered Liquid Hydrogen	Off-site Retail Fueling	On-site SMR
Capital Expenditures	$5,411,019	$2,208,627	$0	$4,650,006
Annual Cost of Hydrogen Fuel	$1,686,887	$1,362,301	Off-site fueling not currently available	$1,069,333

Table 2-14: Hydrogen Cost Analysis – Scenario 2

Expense	On-site Electrolysis	Delivered Liquid Hydrogen	Off-site Retail Fueling	On-site SMR
Capital Expenditures	$5,411,019	$2,208,627	$0	$4,650,006
Annual Cost of Hydrogen Fuel	$2,210,884	$1,784,484	Off-site fueling not currently available	$1,400,724

Resiliency

PWP has a resilient and reliable grid. However, if there was an extended grid outage, it would compromise the City of Pasadena's ability to charge their buses and would disrupt their ability to provide service. Such an event is especially problematic because Pasadena Transit integrates with other forms of public transit, such as Metro's L Line and numerous regional bus lines. This means that any disruption to the fleet would have impacts on the wider Los Angeles region. As a result, the City of Pasadena needs to have a resiliency option in the event of an extended outage and be able to deploy measures that would allow them to operate at full capacity in the event of a grid outage.

FTM Resiliency

PWP recognizes that a grid outage would put the City of Pasadena in a precarious position. As a result, PWP is interested in providing a resiliency option to the City of Pasadena. PWP owns a power plant with 200 MW of generation capacity. This plant is located in Pasadena. PWP stated that this plant can potentially be used as a resiliency measure. If the grid were to experience an outage, PWP could turn on their power plant and provide power to the City of Pasadena, among other customers.

PWP has also stated that they are looking into deploying FTM batteries to provide power to their customers in the event of an outage. It is important to note that other utilities offer FTM resiliency options to their customers. These utilities typically finance this resiliency through a special utility tariff. Under this tariff, customers pay a higher rate for energy (per kWh) in exchange for resiliency. This strategy is beneficial because it allows the transit agency to avoid the capital expenses associated with deploying resiliency assets. The City of Pasadena should consider exploring options for FTM resiliency and establishing a special utility tariff with PWP.

BTM Resiliency

Despite the fact that PWP can potentially offer a FTM resiliency solution, the City of Pasadena should also consider a BTM resiliency solution. A BTM resiliency solution could protect the City of Pasadena in the event of a disruption to the local grid. Having a BTM resiliency solution could also complement FTM resiliency and provide additional protection in case of an outage. This section will outline a BTM resiliency strategy for Scenario 1 and Scenario 2.

To develop these resiliency strategies, CALSTART used Sandia National Laboratory's Microgrid Design Toolkit (MDT). MDT can be programmed with information specific to the site being analyzed, such as the load profile and energy needs of the site/fleet. Furthermore, factors such as the type of assets that can be included in the energy portfolio and the cost of different energy assets can be programmed into MDT. Users can also input objectives and criteria that the microgrid needs to be able to meet, which can include minimizing the capital and operational costs of the microgrid, the percentage of energy needs the microgrid meets, or ensuring that a certain percentage of the energy produced comes from renewable energy. Once this information is input into the model, MDT projects the performance of all possible combinations of energy assets. It then selects the set of energy assets that can meet the objectives. MDT and the assumptions programmed into the model are explained in more detail in Appendix I. NREL's REopt model was also used to evaluate resiliency scenarios.

This analysis assumes that the City of Pasadena's options for BTM resiliency are limited. The City of Pasadena does not yet have a property for its depot. However, due to the scarcity of land in Pasadena, it is likely that any depot occupied in the future will be space constrained. This factor limits the type of generation assets that can be deployed. The results of the resiliency analysis are outlined below.

Scenario 1

The City of Pasadena has multiple options for providing resiliency to the fleet under Scenario 1. The fleet has a peak power demand of 2,628 kW, and the buses consume between approximately 7,700 and 8,342 kWh per day. Based on modeling results from NREL's REopt Lite tool, to provide resiliency for the entire fleet during a seven-day grid outage entirely using solar and storage would require a 2,948 kW PV solar array and a battery energy storage system with a power capacity of 2,628 kW and storage capacity of 31,006 kWh. On the assumption that the panels have an efficiency of 19%, a solar array with a surface area of approximately 15,515.8 square meters (3.8 acres) would be required to fully power the fleet during a seven-day outage. In addition, the required battery storage system would occupy an area of approximately 325 square meters (0.08 acres).

Alternatively, the City of Pasadena could employ backup generators. In the event of a grid outage, the City of Pasadena would need three 1000 kW/1250 kVA generators. In theory, either a natural gas generator or a diesel generator could be used. However, natural gas generators would be the preferred option because they produce fewer emissions. A natural gas turbine would need access to a gas pipeline to obtain fuel. If the generator maintains access to fuel, it is capable of powering the fleet indefinitely during an outage. However, if the generator is permitted as a backup generator, its operations would be limited to 200 hours per year. It is theoretically possible that the generator could lose access to fuel if the natural gas network is disrupted during an emergency. However, disruptions to the natural gas network are rare, and a simultaneous disruption to both the grid and the natural gas network is exceedingly rare. If the City of Pasadena wanted to protect against this possibility, it would be advisable to install a 2,000-gallon CNG storage tank. The addition of the natural gas storage tank would provide one day of fuel in the event of a gas network disruption.

The natural gas generators and the CNG storage tank would require a physical footprint of 1,310 square feet. This figure includes equipment clearances. Natural gas generators entail high capital expenditures and a future depot might be space constrained, but it would be possible to scale down the natural gas generators. According to MDT modelling, if the City of Pasadena used two 1,000 kW/1,250 kVA generators, it would be able to provide 85% of the fleet's energy needs. If the City of Pasadena used a single 1,000 kW/1,250 kVA generator, it would be able to provide 54% of the fleet's energy needs. The generators would be able to provide this power indefinitely as long as it maintains access to its fuel source.

Other factors can affect the viability of resiliency options. Resiliency is typically customized to a particular site, so the specific qualities of a depot can affect resiliency options. The City of Pasadena has identified 2180 East Foothill Blvd as a possible location for a transit facility. A feasibility study should be completed to determine what resiliency assets can be hosted on this site In addition, there are financial considerations that should affect the decision about which resiliency option to deploy. These considerations are discussed in the Financing Strategy section.

Scenario 2

The City of Pasadena has multiple options for providing resiliency to the fleet under Scenario 2. The fleet has a peak power demand of 2,792 kW and the buses consume between approximately 10,000 and 11,100 kWh per day. Based on modeling results from NREL's REopt Lite tool, to provide resiliency for the entire fleet during a seven-day grid outage, entirely using solar and storage would require a 3,805 kW PV solar array and a battery storage system with a power capacity of 3,138 kW and storage capacity of 38,180 kWh. On the assumption that the panels have an efficiency of 19%, a solar array with a surface area of approximately 20,026.3 square meters (4.9 acres) would be required to fully power the fleet during a seven-day outage. In addition, the required battery storage system would occupy an area of approximately 400 square meters (0.10 acres).

Alternatively, the City of Pasadena could use generators. The City of Pasadena could employ the resiliency options as in Scenario 1 and deploy three 1,000 kW/1,250 kVA natural gas generators and a 2,000-gallon CNG storage tank. These assets would have the same space requirement as in Scenario 1. If the City of Pasadena faced financial constraints or space constraints on a site, they would be able to scale down the resiliency assets. Two 1,000 kW/1,250 kVA natural gas generators would be able to provide 74% of the fleet's energy needs. A single 1,000 kW/1,250 kVA natural gas generator would be able to provide 46% of the fleet's energy needs. The generators would be able to provide this power indefinitely as long as it maintains access to its fuel source.

Similar to Scenario 1, a feasibility study should be completed to determine what resiliency assets can be hosted on the proposed transit facility at 2180 East Foothill Blvd.

Financial Analysis and Cost Estimates

CALSTART developed cost estimates for the City of Pasadena's transition to both a BEB fleet and an FCEB fleet. This financial analysis assumes that the buses are deployed according to the Fleet Replacement Plan (see page 56 and 57).

Table 2-15 outlines the expected cost of purchasing and operating a RNG fleet. This scenario represents a continuation of the status quo between 2022 until 2040. Under this status quo scenario, the City of Pasadena is projected to spend $29,982,281 for fleet replacement between 2022 and 2040. When this amount is discounted at a rate of 4% per year (discounted to 2022 dollars), this amounts to a net present value of $18,429,997.

Since the City of Pasadena already has access to CNG fueling infrastructure, this figure includes the capital expenditures associated with purchasing buses. In addition, this analysis takes into account operational costs such as maintenance costs, midlife bus repairs, and the cost of fuel. This analysis does not include the cost of acquiring land, building costs, or labor associated with operating the buses.

Table 2-15: RNG Fleet Financial Analysis

	Capital Expenditures		Operational Expenditures			Total Costs	
Year	Transit Buses	Shuttle Buses	Bus Maintenance	Midlife Repairs	RNG Fuel Costs	Total Cost	Net Present Value (2022 dollars)
2022							
2023							
2024							
2025							
2026							
2027		$360,000	$10,275	$25,200	$25,641	$421,116	$332,814
2028		$360,000	$20,549	$25,200	$51,282	$457,032	$347,306
2029			$20,549		$51,282	$71,832	$52,487
2030	$5,200,000	$360,000	$77,071	$401,200	$179,487	$6,217,758	$4,368,515
2031			$77,071		$179,487	$256,558	$173,322
2032	$2,600,000		$100,195	$188,000	$230,769	$3,118,964	$2,026,019
2033	$3,250,000	$1,620,000	$175,335	$348,400	$410,256	$5,803,992	$3,625,156
2034	$3,250,000		$204,240	$235,000	$474,359	$4,163,599	$2,500,549
2035			$204,240		$474,359	$678,599	$391,874
2036			$204,240		$474,359	$678,599	$376,802
2037	$4,550,000		$244,706	$329,000	$564,103	$5,687,808	$3,036,767
2038			$244,706		$564,103	$808,808	$415,221
2039			$244,706		$564,103	$808,808	$399,251
2040			$244,706		$564,103	$808,808	$383,895
Total	**$18,850,000**	**$2,700,000**	**$2,072,588**	**$1,552,000**	**$4,807,692**	**$29,982,281**	**$18,429,977**

The costs for transitioning to a BEB fleet are outlined In **Table 2-16** and **Table 2-17**. These tables outline the expected cost of purchasing and operating a BEB fleet under Scenario 1 and Scenario 2, respectively:

- **Table 2-16** outlines the expected cost of purchasing and operating a BEB fleet under Scenario 1. Transitioning to a fully BEB fleet under Scenario 1 is projected to cost $59,456,098 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $39,002,706.
- **Table 2-17** outlines the expected cost of purchasing and operating a BEB fleet under Scenario 2. Transitioning to a fully BEB fleet under Scenario 2 is projected to cost $78,667,385 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $48,635,938.

These figures include the capital expenditures associated with purchasing and installing chargers and the cost of the buses. In addition, this analysis takes into account operational costs such as maintenance costs, the cost of electricity from the utility, and the cost of maintaining charging infrastructure. This analysis does not include labor associated with operating the buses. Since the resiliency options available to the City of Pasadena are uncertain, the cost of resiliency assets was not included. These figures include the cost of utility service planning. However, they do not include any additional utility infrastructure upgrade costs. The cost estimates for a BEB fleet will increase if additional utility upgrades are required. The cost estimates also include an additional land cost. The City of Pasadena's planned depot has capacity to house 57 buses. Since there are routes where BEBs cannot serve on a 1:1 basis with an RNG bus, additional buses will need to be purchased. For scenarios where the number of BEBs exceeds the capacity of the depot, additional land will need to be rented to accommodate the additional buses. This analysis incorporates a land cost.

Table 2-16: BEB Fleet Financial Analysis (Scenario 1)

	Capital Expenditures						Operational Expenditures				Total Costs	
Year	Transit Buses	Shuttle Buses	Driver and Maintenance Training	Charging Infrastructure	Utility Infrastructure	Land Cost	Bus Maintenance	Midlife Repairs	Infrastructure Maintenance	Utility Costs (fueling costs)	Total Cost	Net Present Value (2022 dollars)
2022												
2023					$350,000	$3,275,000					$3,625,000	$3,351,516
2024												
2025				$6,600,000					$24,000		$6,624,000	$5,662,223
2026									$24,000		$24,000	$19,726
2027		$840,000	$78,750				$29,484	$63,000	$24,000	$33,766	$1,069,000	$844,846
2028		$840,000					$58,968	$63,000	$24,000	$67,531	$1,053,499	$800,573
2029							$58,968		$24,000	$67,531	$150,499	$109,968
2030	$5,680,000	$840,000					$176,925	$497,608	$24,000	$191,339	$7,409,872	$5,206,077
2031							$176,925		$24,000	$191,339	$392,264	$264,999
2032	$4,970,000						$254,338	$380,282	$24,000	$270,126	$5,898,746	$3,831,713
2033	$5,680,000	$1,680,000					$401,779	$560,608	$24,000	$427,699	$8,774,086	$5,480,268
2034	$5,680,000						$490,251	$434,608	$24,000	$517,741	$7,146,600	$4,292,063
2035							$490,251		$24,000	$517,741	$1,031,992	$595,950
2036							$490,251		$24,000	$517,741	$1,031,992	$573,028
2037	$9,230,000						$634,019	$706,238	$24,000	$664,059	$11,258,316	$6,010,907
2038							$634,019		$24,000	$664,059	$1,322,078	$678,719
2039							$634,019		$24,000	$664,059	$1,322,078	$652,615
2040							$634,019		$24,000	$664,059	$1,322,078	$627,514
Total	**$31,240,000**	**$4,200,000**	**$78,750**	**$6,600,000**	**$350,000**	**$3,275,000**	**$5,164,214**	**$2,705,344**	**$384,000**	**$5,458,790**	**$59,456,098**	**$39,002,706**

It is important to note that the financial analysis provided in **Table 2-16** is based on the current technological capabilities of BEBs. BEB technology is expected to improve and the range of BEBs will increase in the future. While current BEBs are not projected to be a drop-in replacement for all of the City of Pasadena bus fleet vehicle assignments, improvements in BEB range could serve more shifts on a drop-in basis, reducing the number of buses that would need to be purchased. If BEB range were to increase by 10%, then the City of Pasadena would only need to purchase 40 transit buses and 15 shuttle buses. Under these conditions, the total cost between 2022 and 2040 is projected to be $54,324,513. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $34,827,134.

Table 2-17: BEB Fleet Financial Analysis (Scenario 2)

	Capital Expenditures						Operational Expenditures				Total Costs	
Year	Transit Buses	Shuttle Buses	Driver and Maintenance Training	Charging Infrastructure	Utility Infrastructure	Land Cost	Bus Maintenance	Midlife Repairs	Infrastructure Maintenance	Utility Costs (fueling costs)	Total Cost	Net Present Value (2022 dollars)
2022												
2023					$350,000	$3,275,000					$3,625,000	$3,351,516
2024												
2025				$6,600,000							$6,600,000	$5,424,719
2026												
2027		$840,000	$78,750				$33,088	$63,000	$24,000	$33,092	$1,071,929	$814,578
2028		$840,000					$66,175	$63,000	$24,000	$66,184	$1,059,359	$774,063
2029							$66,175		$24,000	$66,184	$156,359	$109,856
2030	$8,520,000	$840,000					$245,936	$714,912	$24,000	$231,642	$10,576,490	$7,145,098
2031							$245,936		$24,000	$231,642	$501,578	$325,816
2032	$7,100,000						$368,163	$543,260	$24,000	$341,948	$8,377,372	$5,232,482
2033	$8,520,000	$1,680,000					$581,011	$777,912	$24,000	$540,499	$12,123,423	$7,281,013
2034	$8,520,000						$727,684	$651,912	$24,000	$672,866	$10,596,463	$6,119,193
2035							$727,684		$24,000	$672,866	$1,424,551	$791,002
2036							$727,684		$24,000	$672,866	$1,424,551	$760,579
2037	$12,780,000						$947,694	$977,868	$24,000	$871,417	$15,600,979	$8,009,125
2038							$947,694		$24,000	$871,417	$1,843,111	$909,811
2039							$947,694		$24,000	$871,417	$1,843,111	$874,819
2040							$947,694		$24,000	$871,417	$1,843,111	$841,172
Total	**$45,440,000**	**$4,200,000**	**$78,750**	**$6,600,000**	**$350,000**	**$3,275,000**	**$7,580,312**	**$3,791,864**	**$336,000**	**$7,015,458**	**$78,667,385**	**$48,635,938**

If the City of Pasadena were to transition to an FCEB fleet, it would need to select a hydrogen fueling pathway. The hydrogen fueling pathway impacts the costs associated with deploying an FCEB fleet. **Table 2-18** provides an overview of the costs associated with each hydrogen production pathway.

Table 2-18: Hydrogen Production Pathways Financial Analysis

Hydrogen Production Pathway	Cost Estimates	Net Present Value
Scenario 1		
On-site SMR	$61,762,767	$37,585,750
On-site Electrolysis	$68,375,238	$41,608,721
Delivered Gaseous Hydrogen*	$60,867,226	$36,377,107
Delivered Liquid Hydrogen	$62,301,551	$37,293,412
Scenario 2		
On-site SMR	$81,107,913	$46,137,566
On-site Electrolysis	$87,406,807	$50,072,114
Delivered Gaseous Hydrogen*	$80,532,287	$45,152,594
Delivered Liquid Hydrogen	$81,969,469	$46,065,583
* Deemed to not be feasible as it would conflict with the City of Pasadena's operations		

The most cost-effective method for obtaining hydrogen under both Scenario 1 and Scenario 2 would be through on-site SMR. The cost of transitioning to a fully FCEB fleet using on-site SMR hydrogen production is detailed in **Table 2-19 (Scenario 1)** and **Table 2-20 (Scenario 2).** These tables outline the expected cost of purchasing and operating a BEB fleet under Scenario 1 and Scenario 2, respectively:

- Under Scenario 1, an FCEB fleet is projected to cost $61,762,767 between 2022 and 2040. A discount rate of 4% per year (discounted to 2022 dollars) amounts to a net present value of $39,089,180.

- Under Scenario 2, an FCEB fleet is projected to cost $81,482,913 between 2022 and 2040. A discount rate of 4% per year (discounted to 2022 dollars) amounts to a net present value of $48,350,575.

These figures include the capital expenditures associated with building a hydrogen fueling station (see Appendix N for the methodology for estimating the hydrogen fueling station costs) and the cost of the buses. In addition, this analysis takes into account operational costs such as maintenance costs, the cost of hydrogen, and the cost of maintaining hydrogen infrastructure. This analysis does not include the cost of acquiring land, building any facilities, or labor associated with operating the buses. Since both Scenario 1 and Scenario 2 for a FCEB fleet do not exceed the capacity of the planned depot, no land cost was considered in this analysis.

Table 2-19: FCEB Financial Analysis (Scenario 1)

	Capital Expenditures				Operational Expenditures				Total Costs	
Year	Transit Buses	Shuttle Buses	Driver and Maintenance Training	Hydrogen Infrastructure	Bus Maintenance	Midlife Repairs	Infrastructure O&M	Hydrogen Costs	Total Cost	Net Present Value (2022 dollars)
2022										
2023										
2024										
2025				$4,650,006			$190,564		$4,840,570	$4,137,740
2026							$190,564		$190,564	$156,630
2027		$560,000	$153,325		$25,017	$42,000	$190,564	$46,493	$1,017,398	$804,065
2028		$560,000			$50,033	$42,000	$190,564	$92,985	$935,583	$710,966
2029					$50,033		$190,564	$92,985	$333,583	$243,746
2030	$9,560,000	$560,000			$187,652	$311,440	$190,564	$325,449	$11,135,105	$7,823,377
2031					$187,652		$190,564	$325,449	$703,665	$475,371
2032	$4,780,000				$243,952	$134,720	$190,564	$418,435	$5,767,671	$3,746,569
2033	$5,975,000	$2,520,000			$426,903	$357,400	$190,564	$743,884	$10,213,751	$6,379,479
2034	$5,975,000				$497,279	$168,400	$190,564	$860,116	$7,691,359	$4,619,231
2035					$497,279		$190,564	$860,116	$1,547,959	$893,908
2036					$497,279		$190,564	$860,116	$1,547,959	$859,527
2037	$8,365,000				$595,806	$235,760	$190,564	$1,022,840	$10,409,970	$5,557,968
2038					$595,806		$190,564	$1,022,840	$1,809,210	$928,800
2039					$595,806		$190,564	$1,022,840	$1,809,210	$893,077
2040					$595,806		$190,564	$1,022,840	$1,809,210	$858,728
Total	**$34,655,000**	**$4,200,000**	**$153,325**	**$4,650,006**	**$5,046,302**	**$1,291,720**	**$3,049,024**	**$8,717,390**	**$61,762,767**	**$39,089,180**

Table 2-20: FCEB Financial Analysis (Scenario 2)

	Capital Expenditures				Operational Expenditures				Total Costs	
Year	Transit Buses	Shuttle Buses	Driver and Maintenance Training	Hydrogen Infrastructure	Bus Maintenance	Midlife Repairs	Infrastructure O&M	Hydrogen Costs	Total Cost	Net Present Value (2022 dollars)
2022										
2023										
2024										
2025				$4,814,959			$190,564		$5,005,523	$4,278,742
2026							$190,564		$190,564	$156,630
2027	$1,195,000	$560,000	$153,325		$62,819	$75,680	$190,564	$73,610	$2,310,998	$1,826,415
2028	$1,195,000	$560,000			$125,638	$75,680	$190,564	$147,220	$2,294,102	$1,743,329
2029					$125,638		$190,564	$147,220	$463,422	$338,618
2030		$560,000			$166,814	$42,000	$190,564	$196,294	$1,155,672	$811,959
2031					$166,814		$190,564	$196,294	$553,672	$374,041
2032	$5,975,000				$275,031	$168,400	$190,564	$318,977	$6,927,972	$4,500,279
2033	$5,975,000	$2,520,000			$568,539	$357,400	$190,564	$662,491	$10,273,994	$6,417,106
2034	$7,170,000				$698,400	$202,080	$190,564	$809,711	$9,070,755	$5,447,660
2035	$5,975,000				$806,617	$168,400	$190,564	$932,395	$8,072,975	$4,661,942
2036					$806,617		$190,564	$932,395	$1,929,575	$1,071,425
2037	$9,560,000				$979,764	$269,440	$190,564	$1,128,688	$12,128,457	$6,475,482
2038					$979,764		$190,564	$1,128,688	$2,299,017	$1,180,254
2039	$4,780,000				$1,066,338	$134,720	$190,564	$1,226,835	$7,398,457	$3,652,086
2040	$8,365,000				$1,217,842	$235,760	$190,564	$1,398,592	$11,407,758	$5,414,606
Total	**$50,190,000**	**$4,200,000**	**$153,325**	**$4,814,959**	**$8,046,635**	**$1,729,560**	**$3,049,024**	**$9,299,410**	**$81,482,913**	**$48,350,575**

The City of Pasadena is also considering deploying a mixed fleet consisting of FCEB transit buses and battery-electric shuttle buses. The City of Pasadena is considering this option because the route modeling suggests that some transit routes cannot be served on a drop-in basis by BEBs. However, the results of the bus demonstration indicates that Dial-A-Ride vehicles can be replaced by battery-electric technology on a 1:1 basis. The costs for transitioning to a mixed fleet are outlined In **Table 2-21** and **Table 2-22**. These tables outline the expected cost of purchasing and operating a mixed-fleet fleet under Scenario 1 and Scenario 2, respectively:

- **Table 2-21** outlines the expected cost of purchasing and operating a mixed fleet under Scenario 1. Transitioning to a mixed fleet under Scenario 1 is projected to cost $61,724,731 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $38,816,478.
- **Table 2-22** outlines the expected cost of purchasing and operating a mixed fleet under Scenario 2. Transitioning to a mixed fleet under Scenario 2 is projected to cost $81,962,251 between 2022 and 2040. Discounting this amount at a rate of 4% per year (discounted to 2022 dollars) results in a net present value of $48,520,127.

These figures include the capital expenditures associated with purchasing and installing chargers and the cost of the buses. In addition, this analysis takes into account operational costs such as maintenance costs, the cost of electricity from the utility, and the cost of maintaining charging infrastructure. This analysis does not include labor associated with operating the buses. Since the resiliency options available to The City of Pasadena are uncertain, the cost of resiliency assets was not included. These figures include the cost of utility service planning. However, they do not include any additional utility infrastructure upgrade costs. The cost estimates for a BEB fleet will increase if additional utility upgrades are required. Since both Scenario 1 and Scenario 2 for a mixed fleet do not exceed the capacity of the planned depot, no land cost was considered In this analysis.

Table 2-21: Mixed-Fleet Financial Analysis (Scenario 1)

	Capital Expenditures					Operational Expenditures						Total Costs	
Year	Transit Buses	Shuttle Buses	Driver and Maintenance Training	Hydrogen Infrastructure	Electric Infrastructure & Utility Upgrade	Bus Maintenance	Midlife Replacement	Hydrogen Infrastructure Maintenance	Electric Bus Infrastructure Maintenance	Hydrogen Fuel Costs	BEB Charging Cost	Total Cost	Discounted Cost
2022													
2023													
2024													
2025				3,005,207	731,700			190,564	3,000			3,930,471	3,359,783
2026								190,564	3,000			193,564	159,095
2027		560,000	153,325			25,017	42,000	190,564	3,000	46,414	11,255	1,031,575	815,269
2028		560,000				50,033	42,000	190,564	3,000	92,828	22,510	960,936	730,232
2029						50,033		190,564	3,000	92,828	22,510	358,936	262,271
2030	9,560,000	560,000				187,652	311,440	190,564	3,000	325,213	33,766	11,171,634	7,849,042
2031						187,652		190,564	3,000	325,213	33,766	740,194	500,049
2032	4,780,000					243,952	134,720	190,564	3,000	418,199	33,766	5,804,201	3,770,298
2033	5,975,000	2,520,000				426,903	357,400	190,564	3,000	743,294	84,414	10,300,575	6,433,709
2034	5,975,000					497,279	168,400	190,564	3,000	859,525	84,414	7,778,183	4,671,375
2035						497,279		190,564	3,000	859,525	84,414	1,634,783	944,046
2036						497,279		190,564	3,000	859,525	84,414	1,634,783	907,737
2037	8,365,000					595,806	235,760	190,564	3,000	1,022,250	84,414	10,496,794	5,604,324
2038						595,806		190,564	3,000	1,022,250	84,414	1,896,034	973,373
2039						595,806		190,564	3,000	1,022,250	84,414	1,896,034	935,936
2040						595,806		190,564	3,000	1,022,250	84,414	1,896,034	899,938
Total	**34,655,000**	**4,200,000**	**153,325**	**3,005,207**	**731,700**	**5,046,302**	**1,291,720**	**3,049,024**	**48,000**	**8,711,565**	**832,888**	**61,724,731**	**38,816,478**

Table 2-22: Mixed-Fleet Financial Analysis (Scenario 2)

	Capital Expenditures					Operational Expenditures						Total Costs	
Year	Transit Buses	Shuttle Buses	Driver and Maintenance Training	Hydrogen Infrastructure	Electric Infrastructure & Utility Upgrade	Bus Maintenance	Midlife Replacement	Hydrogen Infrastructure Maintenance	Electric Bus Infrastructure Maintenance	Hydrogen Fuel Costs	BEB Charging Cost	Total Cost	Discounted Cost
2022													
2023													
2024													
2025				3,687,534	731,700			190,564	3,000			4,612,798	3,943,039
2026								190,564	3,000			193,564	159,095
2027	1,195,000	560,000	153,325			62,819	75,680	190,564	3,000	73,531	11,255	2,325,175	1,837,619
2028	1,195,000	560,000				125,638	75,680	190,564	3,000	147,063	22,510	2,319,455	1,762,596
2029						125,638		190,564	3,000	147,063	22,510	488,775	357,143
2030		560,000				166,814	42,000	190,564	3,000	196,057	33,766	1,192,201	837,625
2031						166,814		190,564	3,000	196,057	33,766	590,201	398,719
2032	5,975,000					275,031	168,400	190,564	3,000	318,741	33,766	6,964,502	4,524,008
2033	5,975,000	2,520,000				568,539	357,400	190,564	3,000	661,901	84,414	10,360,818	6,471,336
2034	7,170,000					698,400	202,080	190,564	3,000	809,121	84,414	9,157,579	5,499,804
2035	5,975,000					806,617	168,400	190,564	3,000	931,804	84,414	8,159,799	4,712,081
2036						806,617		190,564	3,000	931,804	84,414	2,016,399	1,119,635
2037	9,560,000					979,764	269,440	190,564	3,000	1,128,098	84,414	12,215,280	6,521,838
2038						979,764		190,564	3,000	1,128,098	84,414	2,385,840	1,224,827
2039	4,780,000					1,066,338	134,720	190,564	3,000	1,226,245	84,414	7,485,281	3,694,945
2040	8,365,000					1,217,842	235,760	190,564	3,000	1,398,002	84,414	11,494,582	5,455,816
Total	**50,190,000**	**4,200,000**	**153,325**	**3,687,534**	**731,700**	**8,046,635**	**1,729,560**	**3,049,024**	**48,000**	**9,293,585**	**832,888**	**81,962,251**	**48,520,127**

Financing Strategy

The City of Pasadena will need a financing strategy to transition to a zero-emission fleet. The most important item that the City of Pasadena will need is to secure the location and funding to build a transit facility. If the City of Pasadena can utilize property already owned by the City of Pasadena, they can avoid having to purchase land. Otherwise, land will need to be purchased to house the fleet. The financial resources needed for a facility may potentially be obtained by winning a competitive grant(s) that funds capital expenditures. Grant programs such as Caltrans's TIRCP and the U.S. Department of Transportation's RAISE can also be used toward purchasing a bus depot or financing utility and BTM infrastructure upgrades. The U.S. Department of Transportation also provides other competitive federal grants that could potentially be used as funding. For example, the Bus and Bus Facilities grant, if awarded, could be used to help fund the purchase of buses and related equipment, and the construction of bus facilities. However, grant funding should not be considered as a guaranteed source of funding as these are highly competitive grant programs.

Once a transit property has been acquired and the infrastructure upgrades have been completed, the operational costs are expected to be covered by the City of Pasadena's operating budget. However, the purchase of the buses needs to be financed. Bus purchases can be financed with various grant and funding sources (see Financing Strategies & Resources on page 35). Most of these grant and finance programs will only partially finance the cost of the buses. To maximize funding for bus purchases, it would be advisable to apply for and stack multiple grants, though it is unlikely that grants will pay for the entire transition to a zero-emission fleet. The main objective when pursuing grants should be to cover the incremental cost of ZEBs, or the difference between the cost of a ZEB and a RNG bus. Using grants to cover the incremental cost of the buses would allow the City of Pasadena to purchase ZEBs with the funding sources they normally employ to purchase buses.

The City of Pasadena should also consider which finance methods would be most appropriate for their agency. If the City of Pasadena is amenable to capital expenditures, then traditional financing models would be the most appropriate. However, if the City of Pasadena prefers to avoid or reduce capital expenditures, then financing models such as bus/battery leasing or IAAS would be more appropriate. These financing models would effectively allow the City of Pasadena to pay capital expenditures from their operational budget.

There are additional financial considerations that need to be considered when deploying resiliency assets. The most likely candidates for the City of Pasadena would be solar and storage or natural gas generators. However, there are unique financial considerations that need to be evaluated when selecting an asset. One major drawback of natural gas generators is that they are subject to air quality regulations and would likely be permitted as backup generators. As a result, they can only be used in the event of a grid outage and would remain idle for most of the time. This solution is problematic because generators have a high capital cost, meaning that the levelized cost of energy (per kWh) produced by the generator would be very high. Unlike generators, there are no restrictions on when solar and storage can be used. A solar and storage system is eligible for net metering, and excess energy produced can be exported to the grid and sold back to the utility. Furthermore, the storage system can be used to "peak shave" and reduce overall power draw from the grid during times of high power demand when using the battery to provide energy. This scenario is useful because it can reduce demand charges, which are a major component of utility costs. Furthermore, a solar and storage system could potentially generate revenue by providing ancillary grid services. Since solar and storage can provide a transit agency with savings and/or revenue, the levelized cost of energy would be much lower than for a natural gas generator.

In addition, solar and storage is better situated to take advantage of the ITC. The ITC provides a tax credit for investment, in particular DERs. Solar is eligible for a 30% ITC through 2033. Generators are only eligible for a 10% ITC if they are used in a combined heat and power system (a system where waste heat from the generator is captured and used to provide heating for a building or industrial process). Since air quality regulations limit backup generator use to 200 hours per year, they would likely not be useable in a combined heat and power system.

Previously, only the entity that owned the DER was eligible for the ITC. In addition, tax-exempt entities, such as the City of

Pasadena, could not benefit from the ITC as they do not pay federal taxes. At that time, the only option for tax-exempt entities to benefit from the ITC would be to finance the ITC-eligible DERs through an IAAS model where a third-party owns the asset, realizes the benefits of the ITC, and passes the benefits on to the customer in the form of lower PPA rates. The IIJA, however, enacted provisions that allows tax-exempt entities to receive ITC tax credits as a direct payment. This mechanism would allow the City of Pasadena to directly benefit from the ITC.

LCFS Credits

Once the buses are deployed, LCFS credits can also be used to finance capital expenditures and operational expenses. LCFS credits can be used in many ways. If the City of Pasadena owns the charging equipment, they would earn the LCFS credits and could redeem them for cash. In addition, transit agencies can transfer their LCFS credits to their utility for a certain period to fund utility upgrades. LCFS credits can also benefit a transit agency even if they don't own the charging equipment or if they opt to use an IAAS financing model. If this were to occur, the infrastructure provider would receive the LCFS credits. The infrastructure provider could then pass on the benefits of the LCFS credits to the transit agency in the form of lower PPA rates.

The estimated value of the LCFS credits for Pasadena Transit under Scenario 1 are displayed in **Table 2-23** and Scenario 2 in **Table 2-24**. **Table 2-25** shows the estimated value of the LCFS credits for Pasadena Dial-A-Ride. These projections provide the nominal revenue generated by LCFS credits. They also provide a net present value which assumes a 4% discount rate (discounted to 2022 dollars) and a LCFS credit value of $200.

Table 2-23: Pasadena Transit Fixed-Route Fleet LCFS Credit Value – Scenario 1 (displacing diesel fuel)

Year	Revenue	Net Present Value	Leveled cost per kWh
2022	$0.00	$0.00	$0.00
2023	$0.00	$0.00	$0.00
2024	$0.00	$0.00	$0.00
2025	$0.00	$0.00	$0.00
2026	$0.00	$0.00	$0.00
2027	$0.00	$0.00	$0.00
2028	$0.00	$0.00	$0.00
2029	$0.00	$0.00	$0.00
2030	$137,721.94	$96,761.61	$0.16
2031	$137,721.94	$93,040.01	$0.16
2032	$206,582.91	$134,192.32	$0.15
2033	$292,659.13	$182,794.03	$0.15
2034	$378,735.34	$227,458.63	$0.14
2035	$378,735.34	$218,710.22	$0.14
2036	$499,242.04	$277,211.38	$0.13
2037	$499,242.04	$266,549.41	$0.13
2038	$499,242.04	$256,297.51	$0.12
2039	$499,242.04	$246,439.91	$0.12
2040	$499,242.04	$236,961.45	$0.11
Total	**$4,028,366.83**	**$2,236,416.49**	**$0.13**

Table 2-24: Pasadena Transit Fixed-Route Fleet LCFS Credit Value – Scenario 2 (displacing diesel fuel)

Year	Revenue	Net Present Value	Levelized cost per kWh
2022	$0.00	$0.00	$0.00
2023	$0.00	$0.00	$0.00
2024	$0.00	$0.00	$0.00
2025	$0.00	$0.00	$0.00
2026	$0.00	$0.00	$0.00
2027	$0.00	$0.00	$0.00
2028	$0.00	$0.00	$0.00
2029	$0.00	$0.00	$0.00
2030	$195,113.44	$137,084.11	$0.16
2031	$195,113.44	$131,811.65	$0.16
2032	$292,670.16	$190,112.95	$0.15
2033	$414,616.05	$258,967.96	$0.15
2034	$536,561.95	$322,245.20	$0.14
2035	$536,561.95	$309,851.16	$0.14
2036	$707,286.21	$392,730.93	$0.13
2037	$707,286.21	$377,625.89	$0.13
2038	$707,286.21	$363,101.82	$0.12
2039	$707,286.21	$349,136.36	$0.12
2040	$707,286.21	$335,708.04	$0.11
Total	**$5,707,068.04**	**$3,168,376.08**	**$0.13**

Table 2-25: Pasadena Dial-A-Ride Fleet LCFS Credit Value (displacing gasoline fuel)

Year	Revenue	Net Present Value	Leveled cost per kWh
2022	$0.00	$0.00	$0.00
2023	$0.00	$0.00	$0.00
2024	$0.00	$0.00	$0.00
2025	$0.00	$0.00	$0.00
2026	$0.00	$0.00	$0.00
2027	$12,040.52	$9,515.80	$0.18
2028	$23,618.31	$17,947.97	$0.17
2029	$23,155.57	$16,919.55	$0.16
2030	$34,033.65	$23,911.59	$0.15
2031	$34,033.65	$22,991.92	$0.15
2032	$34,033.65	$22,107.61	$0.14
2033	$85,084.13	$53,143.30	$0.14
2034	$85,084.13	$51,099.32	$0.13
2035	$85,084.13	$49,133.96	$0.13
2036	$85,084.13	$47,244.20	$0.12
2037	$85,084.13	$45,427.11	$0.12
2038	$85,084.13	$43,679.91	$0.11
2039	$85,084.13	$41,999.92	$0.11
2040	$85,084.13	$40,384.54	$0.10
Total	**$841,588.38**	**$485,506.70**	**$0.13**

It is important to note that the number of LCFS credits awarded depends on the quantity of GHG emissions avoided by using BEBs. As California's grid becomes cleaner, the amount of GHG emissions avoided will increase. The number of LCFS credits awarded is therefore likely to increase as the grid becomes less carbon intensive., and the value of the LCFS credits earned has the potential to increase. The methodology used to make these calculations can be found in Appendix O.

Implementation Plan

The City of Pasadena has many options for deploying a ZEB fleet. As discussed under Financial Analysis and Cost Estimates, the most practical option would be to deploy a BEB fleet. While BEBs cannot currently serve as a drop-in replacement for RNG buses on all the City of Pasadena's routes and would require purchasing more BEBs than FCEBs, a fully BEB fleet is less costly than deploying a fully FCEB fleet due to higher FCEB capital costs. In addition, the cost of hydrogen is greater than the utility costs associated with BEBs. As a result, a fully BEB fleet is more cost effective than a fully FCEB fleet. However, when the cost of land required to house additional buses is taken into account, the cost of a BEB fleet and a FCEB fleet is near parity.

The analysis for BEBs is also based on a worst-case scenario. Currently, there is a large inequality in the number of miles each bus is driven within the same route. As discussed in Appendix G, there are options for redistributing laps so that the miles are shared more equitably between buses and help to reduce the intensity of the duty cycle for buses assigned to high-mileage shifts. Furthermore, the analysis for BEBs is based on current technology. As battery technology improves, BEBs will be able to obtain a longer range and become a drop-in replacement for more routes, reducing the number of buses that need to be purchased. The cost of BEBs and FCEBs is also expected to decrease over time.

If the City of Pasadena were to deploy a BEB fleet, they have options for charging the buses. The City of Pasadena will primarily charge the buses using depot charging. However, the City of Pasadena could also theoretically employ overhead on-route charging to conduct midday charging to extend the range of the bus. CALSTART believes that overhead on-route charging is not a practical solution. Overhead on-route chargers require an overhead mast and a charging cabinet. This infrastructure would likely infringe on public property such as sidewalks. In addition, the bus stops can only accommodate one bus at a time. As a result, if a bus stopped to conduct an overhead fast charge, other buses would not be able to pick up or drop-off passengers at that stop. Due to the level of disruption that overhead on-route charging would cause to transit operations, CALSTART deems that this is not a viable option.

Currently, the main barrier to deploying a BEB fleet would be the provision of a site to house Pasadena Transit's and Pasadena Dial-A-Ride's fleets. Significant construction must be invested in a site to install infrastructure so it can host a fleet. Conducting infrastructure upgrades on a leased depot would not be advisable because the City of Pasadena would need to obtain permission from the property owner. In addition, due to the high costs associated with construction, it would not be financially viable to upgrade a leased depot, as any improvements to the site would effectively be left behind if the City of Pasadena were to move depots. As a result, a BEB fleet cannot be deployed until a permanent depot is obtained.

The City of Pasadena is planning to build a new transit facility at 2180 East Foothill Blvd. This transit facility is currently in the design phases. The City of Pasadena will need to install both FTM and BTM infrastructure. PWP has stated that there is enough grid distribution capacity to serve this site. As a result, the main required FTM infrastructure is a transformer. The installation of a transformer typically takes 4-6 months but can take up to one year. The installation of the transformer can be incorporated into the construction of the transit facility. The City of Pasadena needs to coordinate with PWP to ensure that the final design for the site will accommodate the transformer and to schedule the installation of the transformer.

According to the Fleet Replacement Plan (see pages 56 and 57), the first buses are scheduled to arrive in 2027. The City of Pasadena should work to ensure that construction is completed before the buses arrive. Construction is expected to take 39 months according to the proposed construction timeline. As a result, the construction process should be initiated in 2023 to ensure that the site is ready by 2027. The main barrier to starting the construction process is funding. Once the construction starts, the City of Pasadena should work with PWP to submit a request for electrical service. The transformer cannot be installed until the room or vault that houses it is built. The City of Pasadena should coordinate the construction schedule with PWP so they can install the transformer in a timely manner.

Construction will also need to occur BTM on the depot. Typically, the utility will deliver power to the site at a utility transformer. The transformer is then connected to switchgear, which then connects to the chargers. Most BTM construction involves installing switchgear, the chargers, and the wires that connects the chargers to the switchgear. Generally, the wires are installed underground, which requires trenching.

The buses are scheduled to be phased-in over time, and they will not all arrive during the same year. In light of this, it is important to plan ahead. Since all the buses will not be arriving at the same time, it does not make sense to install all the chargers at once and expose unused chargers to wear and tear. Instead, the rest of the site should be constructed so that it is “EV Ready" by installing electrical panels as well as conduit and wires running to the locations where the unused chargers will eventually be installed. This approach will allow chargers to be installed quickly as they are needed.

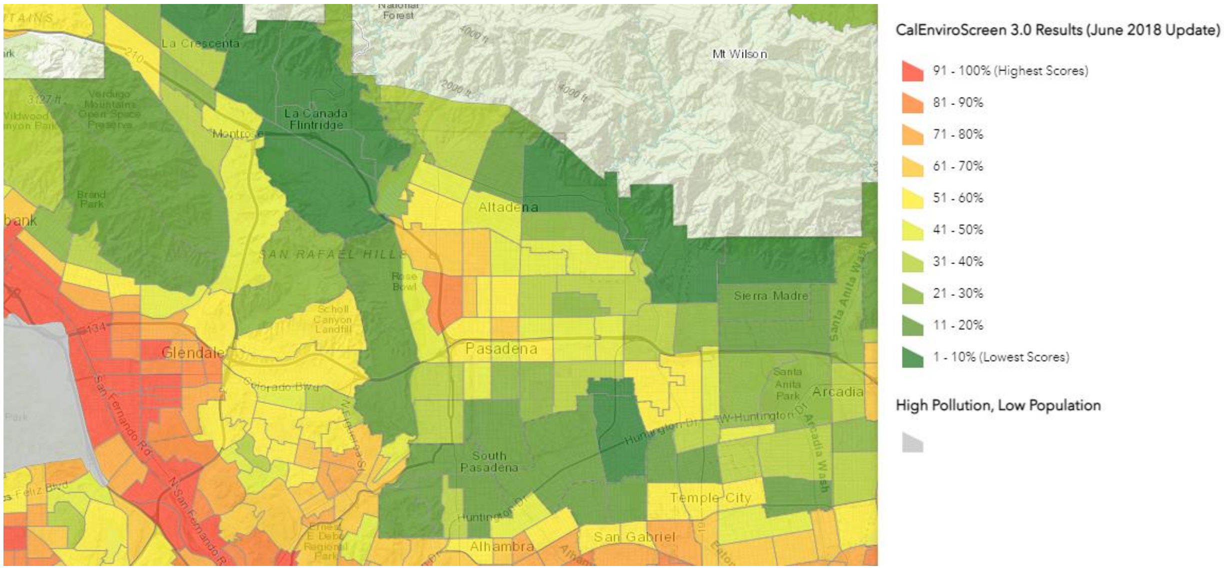
It is vital that construction, utility upgrades, and the BTM construction occur before the buses arrive. If this is not completed, then the buses will not be able to charge. The City of Pasadena should coordinate with their construction management firm and PWP to ensure that construction and the utility upgrades are coordinated with the delivery of the buses. If the buses arrive before the utility upgrades and/or site construction are complete, the City of Pasadena can use temporary chargers at a different site until the permanent charging infrastructure is ready for use.

The City of Pasadena is considering deploying pilot buses ahead of the ICT Rule requirements. A pilot deployment would consist of a deployment of buses ahead of the planned 2027 transition to zero-emission. The objective of a pilot deployment would be to accelerate the deployment of ZEBs and to gain operational experience with the buses before starting the full-fleet transition. The two main challenges to a pilot deployment would be the lack of a charging site and funding. If the City of Pasadena were to deploy ZEBs before their transit facility is built, they will need to use public charging stations or secure a place to install temporary chargers. PWP has stated that they support a pilot deployment and can provide a temporary charging site if a pilot demonstration occurs.

Disadvantaged Communities

The City of Pasadena's fleet serves disadvantaged communities. Disadvantaged communities are defined by CalEnviroScreen. Under CalEnviroScreen, each census tract in California was given a score based on Pollution Burden and Population Characteristics, which includes socio-economic and demographic traits. Each census tract was then given a percentile score to denote its performance relative to other census tracts. A higher percentile is a worse score. Under CalEnviroScreen 3.0, a disadvantaged community was defined as a census tract in the top 25th percentile (75th percentile or above). In addition, there are some census tracts that did not have an overall CalEnviroScreen score because they are sparsely populated and therefore do not have a Population Characteristics score. Census tracts that have a pollution score in the top 5th percentile but do not have an overall CalEnviroScreen score are also considered to be disadvantaged communities. Under CalEnviroScreen 3.0, Pasadena has one census tract that is designated as a disadvantaged community. Census Tract 6037461600, which is marked in dark orange and is located due east of the Rose Bowl is Pasadena’s sole disadvantaged community.

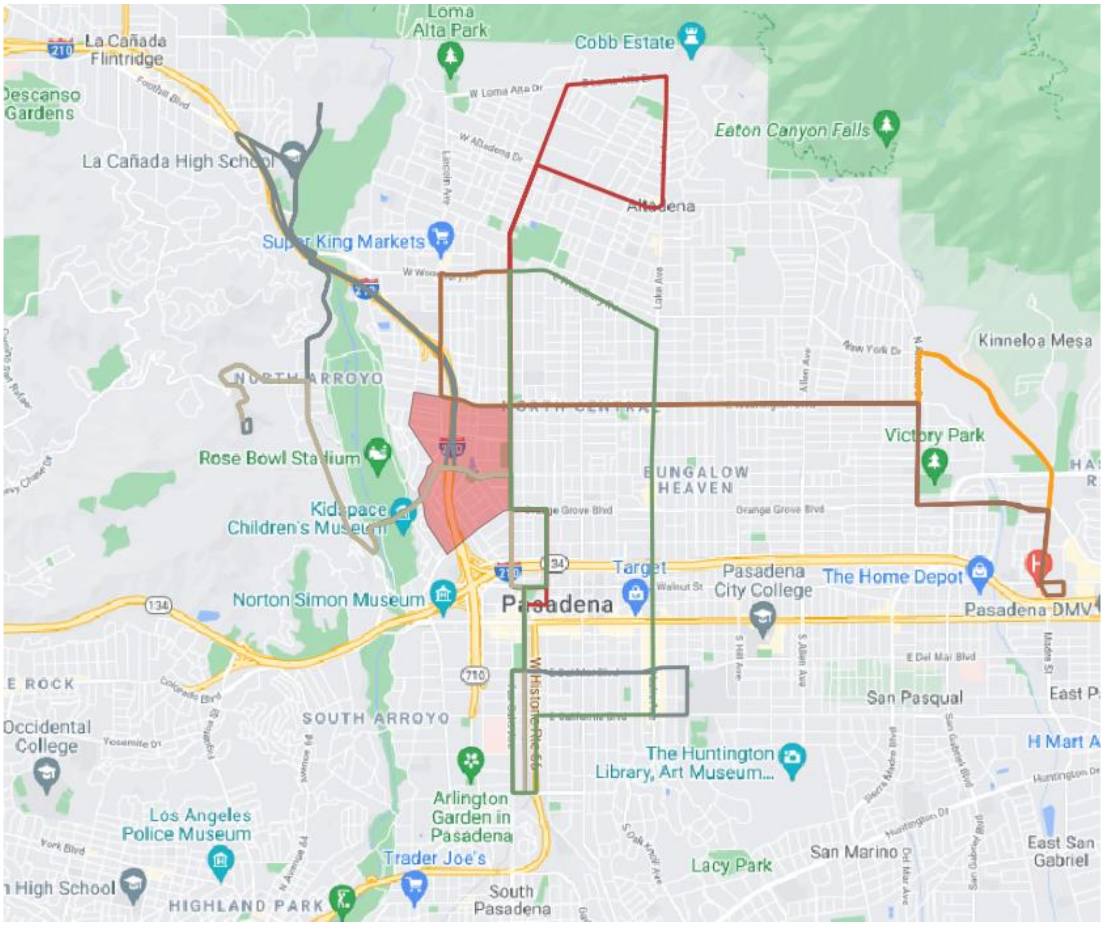
Figure 2-26: Disadvantaged Communities in Pasadena (CalEnviroScreen 3.0)



In 2021, the California Environmental Protection Agency made changes to the scoring criteria for CalEnviroScreen. This change in methodology was made in CalEnviroScreen 4.0. Under this new scoring system, Census Tract 6037461600 is no longer in the top 25th percentile. In CalEnviroScreen 4.0, the California Environmental Protection Agency proposed a new definition of a disadvantaged community. Under this definition, any census tract that is in the top 25th percentile in CalEnviroScreen 4.0 is a disadvantaged community. Any census tract that has a Pollution Burden Score in the top 5th percentile but does not have an overall CalEnviroScreen score is also considered to be a disadvantaged community. Lastly, any census tract that was designated as a disadvantaged community under the CalEnviroScreen 3.0 methodology is also considered to be a disadvantaged community (California Environmental Protection Agency, 2021). Based on this proposed definition, Census Tract 603746160 would remain Pasadena's sole disadvantaged community under CalEnvironScreen 4.0. It is important to note that this definition has not yet been finalized and is subject to change.

The City of Pasadena aims to deploy zero-emission buses in its disadvantaged community to help improve air quality. Pasadena Transit Routes 20, 31/32, 51/52, and 88 go through this disadvantaged community. As a result, replacing RNG buses with ZEBs on these routes would reduce emissions and help improve air quality in the disadvantaged community. Furthermore, these routes run through Old Pasadena and near Metro light rail stations. As a result, these routes provide this community with access to economic centers and other forms of mobility.

Figure 2-27: Pasadena Transit Routes Serving Disadvantaged Communities



It is important to note that although Pasadena only has one census tract designated as a disadvantaged community, it has other census tracts with high pollution burden scores. Most of these high Pollution Burden census tracts are in the northwestern part of Pasadena near the disadvantaged community. Pasadena Transit's routes also serve these areas and will provide air quality and mobility benefits to these census tracts as well. Furthermore, a significant portion of Pasadena Dial-A-Ride's stops are in the northwestern part of Pasadena. As a result, the transition to zero-emission shuttle buses will also improve air quality in this area.

Section III

Section III: Sustainability and Environmental Impact

Emissions Comparisons

ZEB technology provides environmental benefits for transit service areas. As noted in detail under Section I: Benefits of ZEBs, buses with an internal combustion engine produce tailpipe emissions, such as GHGs, NOx, and PM, during operation that drive climate change, harm air quality, and affect human health. The City of Pasadena has transitioned from diesel-powered buses to RNG-powered buses, which produce fewer tailpipe emissions than diesel. ZEBs, however, produce no tailpipe emissions, and therefore aide in improving local air quality and residents' respiratory health.

Tailpipe emissions are not the only emissions associated with the operation of buses. Buses also produce upstream emissions, which are emitted during the production of the fuel that buses use. For example, RNG must be extracted, processed, and transported to buses. The production processes of electricity and hydrogen also generate emissions. As a result, even ZEBs will produce some upstream emissions. Upstream emissions are generally emitted where the fuel is produced and not in the area where the buses operate, but GHGs contribute to climate change regardless of origin.

This section will provide comparisons of both tailpipe and upstream emissions for each bus technology, including RNG-powered buses, BEBs, and FCEBs. **Table 3-1** and **Table 3-2** show the estimated pollution produced by the operation of the buses used by the City of Pasadena. These figures do not encompass any emissions related to the manufacture of the buses. ZEBs are assumed to have no tailpipe emissions, and all emissions related to the operation of ZEBs occur upstream in the supply chain when the electricity or hydrogen is produced. By contrast, RNG buses produce both upstream and tailpipe emissions during operation. The majority of RNG bus operational emissions occur at the tailpipe.

In addition, **Table 5-1** through **Table 5-5** calculate the emissions produced through five different hydrogen production pathways:

1. **Delivered Gaseous Hydrogen Pathway #1:** SMR at central plants to produce gaseous hydrogen
2. **Delivered Gaseous Hydrogen Pathway #2:** Electrolysis at central plants using solar energy to produce gaseous hydrogen (fully renewable gaseous hydrogen production)
3. **On-site SMR Hydrogen Production Pathway:** SMR at the refueling station to produce gaseous hydrogen

4. **On-site Electrolysis Hydrogen Production Pathway:** Electrolysis at the refueling station using California grid electricity to produce gaseous hydrogen
5. **Delivered Liquid Hydrogen Production Pathway:** SMR at central plants to produce liquid hydrogen

The figures in **Table 3-1** and **Table 3-2** represent the annual emissions that occur from the entire fleet. The methodology for these calculations is detailed in Appendix L.

Table 3-1: Emissions Calculations for Pasadena Department of Transportation Scenario 1

Emission Type	CNG	BEB	FCEB SMR Central	FCEB Solar Electrolysis Central	FCEB On-site SMR	FCEB On-site Electrolysis	FCEB Central SMR LH2
GHG Emissions (metric tons per year)							
CO2	1,828	431	630	60	700	643	742
CH4	10.35	0.842	1.159	0.117	1.818	1.255	1.369
N2O	0.37	0.008	0.006	0.001	0.017	0.011	0.007
Total GHGs	2,237	459	666	64	759	684	785
Criteria Pollutant Emissions (kg per year)							
CO	38,902	444	202	62	419	662	314
NOx	2,163	422	265	59	513	629	386
PM10	20	68	30	9	24	101	48
PM2.5	16	29	24	4	19	43	32
SOx	297	107	125	15	124	159	151

Table 3-2: Emissions Calculations for Pasadena Department of Transportation Scenario 2

Emission Type	CNG	BEB	FCEB SMR Central	FCEB Solar Electrolysis Central	FCEB On-site SMR	FCEB On-site Electrolysis	FCEB Central SMR LH2
GHG Emissions (metric tons per year)							
CO2	2,596	616	870	86	967	888	1025
CH4	14.70	1.201	1.601	0.167	2.511	1.734	1.891
N2O	0.53	0.011	0.008	0.002	0.023	0.016	0.010
Total GHGs	3,177	654	920	91	1049	945	1085
Criteria Pollutant Emissions (kg per year)							
CO	55,249	633	279	88	578	914	434
NOx	3,073	602	365	84	709	869	534
PM10	29	97	42	13	33	139	66
PM2.5	23	41	33	6	26	59	44
SOx	421	152	172	21	171	220	208

The calculations indicate that a fully BEB or FCEB fleet will produce significantly lower amounts of GHG emissions than a RNG fleet. BEBs produce the lowest operational GHG emissions, compared to their hydrogen or RNG-powered counterparts. If hydrogen is produced with renewable energy, however, FCEBs will generate the lowest amounts of GHGs.

Natural gas is a fossil fuel composed primarily of methane. When burned, natural gas produces CO2, which is also a GHG. Furthermore, methane itself is a GHG and is a more potent GHG than CO2. Methane contributes to climate change as it leaks into the atmosphere throughout the natural gas supply chain. Over time, methane slowly decays into CO2, reducing its global warming potential. The calculations account for this occurrence and assume a 100-year time horizon for measuring the climate impact of methane leaks.

CNG buses use natural gas and produce GHG emissions during operation. BEBs also use natural gas indirectly. Natural gas is a major source of electricity generation in California's grid. BEBs produce fewer GHG emissions than CNG buses because the combustion of methane in power plants is more efficient than in an internal combustion engine in a bus. In addition, the opportunities for methane leakage are fewer. Furthermore, the California grid also uses a substantial and increasing amount of renewable energy sources such as solar, wind, and hydropower. In addition, an electric drivetrain is more efficient than an internal combustion engine. As a result, electricity is a less GHG-intensive fuel than CNG.

The GHG-intensity of hydrogen depends on the production pathway. SMR hydrogen pathways consume natural gas to produce hydrogen. As a result, SMR pathways essentially replace natural gas with a direct product of natural gas. A transition to FCEBs with hydrogen produced from SMR does have a net effect of reducing emissions due to the reduced leakage and the higher efficiency of the SMR process. If hydrogen is produced using electrolysis with electricity from the power grid, then there will still be a net reduction of emissions. However, this reduction is smaller than the benefit from a transition to BEBs or hydrogen using SMR, which occurs because of the lower efficiency of the electrolysis process. Of the energy that is used to produce hydrogen, only about half of it is stored as hydrogen. Lastly, liquid hydrogen has the highest GHG-intensity of the hydrogen production pathways. Hydrogen must be produced and then converted into gaseous form in a process called liquefaction. The liquefaction process is extremely energy intensive.

The following tables indicate the emissions from RNG buses. They are broken into upstream emissions and tailpipe emissions. This distinction is important because tailpipe emissions occur locally in the community. ZEBs have zero tailpipe emissions. As a result, the tailpipe emission figures for RNG buses represents the annual reduction in local pollution from transitioning to ZEBs. While GHG emissions contribute to climate change regardless of origin, criteria pollutants have a local impact on air quality. As a result, the reduction of criteria pollutants will provide local benefits for air quality and public health. The results are displayed in **Table 3-3** and **3-4**.

Table 3-3: Projected Emissions from RNG Buses Operated by Pasadena Department of Transportation Scenario 1

Pasadena Department of Transportation Scenario 1 CNG Emissions	Upstream	Tailpipe	Total
GHG Emissions (metric tons per year)			
CO2	197.00	1,630.53	1,827.52
CH4	4.83	5.52	10.35
N2O	0.04	0.33	0.37
Total GHGs	352.77	1,884.25	2,237.02
Criteria Pollutant Emissions (kg per year)			
CO	912.80	37,988.89	38,901.69
NOx	1,125.76	1,037.64	2,163.39
PM10	17.37	3.06	20.43
PM2.5	13.23	3.20	16.42
SOx	296.61	-	296.61

Table 3-4: Projected Emissions from RNG Buses Operated by Pasadena Department of Transportation Scenario 2

Pasadena Department of Transportation Scenario 2 CNG Emissions	Upstream	Tailpipe	Total
GHG Emissions (metric tons per year)			
CO2	279.78	2,315.73	2,595.51
CH4	6.86	7.84	14.70
N2O	0.06	0.47	0.53
Total GHGs	501.01	2,676.08	3,177.09
Criteria Pollutant Emissions (kg per year)			
CO	1,296.38	53,953.10	55,249.49
NOx	1,598.84	1,473.68	3,072.52
PM10	24.67	4.34	29.01
PM2.5	18.79	4.54	23.33
SOx	421.25	-	421.25

Renewable Natural Gas (RNG)

The ICT regulation does not require the City of Pasadena to purchase ZEBs until 2026. Since the current buses will be replaced at the end of their useful life, many ZEBs will not be deployed until long after 2026. This has raised concerns that traditionally-powered buses will continue to produce emissions until ZEB purchases begin.

These emissions can be mitigated through the use of RNG. RNG is produced by capturing the methane that arises when organic waste such as manure, compost, or food waste decomposes. Like with fossil-based natural gas, the primary component is methane (CH_4, which is itself a potent GHG). Unlike with fossil-based natural gas, RNG is not sourced from fossil fuels but from biotic material. The carbon had previously been in the atmosphere before it was sequestered, which means that it does not have a net effect of moving carbon from the ground to the atmosphere. In fact, in the ideal case, capturing and burning the methane from the decomposition of biomass could prevent methane from entering the atmosphere, thus having a beneficial effect on climate change.

RNG can be obtained through a natural gas fuel provider. When using RNG as a fuel, a fleet does not typically use RNG directly. To obtain RNG, a fleet signs a contract with a fuel provider. The fuel provider then produces RNG and injects it into a pipeline to introduce it into the natural gas network. Gas is then drawn from the natural gas network and dispensed/sold at a fueling station. The fleet's use of RNG is recorded and documented. Since fuel is drawn from the natural gas network, there is no guarantee that the specific natural gas molecules that a transit agency consumes is RNG. However, emissions savings occur because the RNG injected into the network displaces regular CNG that would have been produced in the absence of the RNG contract.

RNG contracts can be signed with natural gas fuel providers. A typical contract specifies the volume of RNG that will be delivered over a specified time period. The purchaser of RNG can also select a carbon intensity for the RNG that will be delivered. The desired carbon intensity will determine the viable pathways that can be used to produce the RNG. Prices for fuel will depend on market conditions for RNG.

The City of Pasadena has already transitioned to RNG. The combustion of RNG still produces tailpipe emissions. However, since RNG prevents methane, which has a high GWP value, from reaching the atmosphere, it actually produces negative upstream GHG emissions. This helps to mitigate some of the tailpipe emissions. The GREET Model was used to calculate the emissions produced by using RNG. The results are displayed below in **Table 3-5** and **Table 3-6**.

Table 3-5: Projected Emissions from RNG Buses Operated by The City of Pasadena Scenario 1

The City of Pasadena Scenario 1 RNG Emissions	Upstream	Tailpipe	Total
GHG Emissions (metric tons per year)			
CO2	-1,519.75	1,630.53	110.78
CH4	10.06	5.52	15.58
N2O	-0.03	0.33	0.30
Total GHGs	-1,225.84	1,884.25	658.41
Criteria Pollutant Emissions (kg per year)			
CO	-1,017.00	37,988.89	36,971.89
NOx	-277.28	1,037.64	760.36
PM10	-133.54	3.06	-130.48
PM2.5	-136.58	3.20	-133.38
SOx	1.79	-	1.79

Table 3-6: Projected Emissions from RNG Buses Operated by The City of Pasadena Scenario 2

The City of Pasadena Scenario 2 RNG Emissions	Upstream	Tailpipe	Total
GHG Emissions (metric tons per year)			
CO2	-2,158.36	2,315.73	157.37
CH4	14.28	7.84	22.12
N2O	-0.04	0.47	0.43
Total GHGs	-1,740.97	2,676.08	935.11
Criteria Pollutant Emissions (kg per year)			
CO	-1,444.37	53,953.10	52,508.73
NOx	-393.80	1,473.68	1,079.88
PM10	-189.66	4.34	-185.32
PM2.5	-193.98	4.54	-189.44
SOx	2.54	-	2.54

Battery Recycling

As vehicle electrification expands across all market segments, the demand for batteries will increase. The growth of the EV industry and parallel renewable energy sectors has contributed to an exponentially increasing demand for critical materials such as lithium, nickel, and cobalt, among others. The extraction processes for these materials have environmental and social impacts. Furthermore, batteries degrade over time and have a finite lifespan. These factors raise questions about how to process batteries when they reach the end of their useful life and the life-cycle sustainability of this technology. As demonstrated in the Emissions Comparisons section on page 88, BEBs have a lower life-cycle environmental impact than CNG buses. However, there are opportunities to further improve the life-cycle environmental impact by recycling and remanufacturing the materials that have been extracted. The technological benefit of EV batteries is that many of the materials used in primary production can be recycled nearly an infinite number of times and retain the same level of quality or performance. This means that recycled secondary materials maintain the same characteristics and quality as raw-earth primary materials, for a fraction of the environmental, social, and economic cost. This section outlines options for recycling and reusing batteries.

Battery Recycling Companies

One of the main concerns about using battery technology is its lifecycle environmental impact. The materials that are used to produce batteries have environmental and social consequences. Furthermore, as batteries reach the end of their useful life, they produce a waste stream that has environmental ramifications. Forward thinking leaders are already developing solutions to these problems. Battery recycling companies take batteries that have reached the end of their useful life, break them down into their raw materials, and reinsert them back into the manufacturing process. These steps help to lessen the impacts of battery materials and reduces the amount of waste associated with batteries. A few companies and research teams have emerged as foundational stakeholders in battery recycling and are highlighted below.

Li-Cycle is a rapidly growing company that is focused on the mission of transforming the lithium-battery economy into a circular supply chain. Li-Cycle is based on a “Spoke & Hub” model where batteries are transformed into a static product at the Spoke facility and are then transferred to the Hubs where the cathode and anode materials are processed into battery-grade materials for remanufacturing or other applications. Once this process is completed, materials such as copper, aluminum, and ferrous metals are provided back to the commodity markets. Their technology can recycle any type of lithium-ion battery from all kinds of vehicle with any cathode chemistry, any SOC (meaning that batteries do not require discharging prior to recycling), any format (pack, module, battery, cell), and any condition (damaged/undamaged). Li-Cycle works with all sources of batteries, including but not limited to, OEMs, fleets, battery collection organizations, and refurbishment centers. To incentivize parties to collaborate in battery sourcing, Li-Cycle offers different financial models based on the percentage of battery grade materials in collected batteries. As an additional value add, Li-Cycle offers services such as replacement kit management, logistics, and witnessed destruction. In a first for the industry, Li-Cycle is in the process of building a hydrometallurgical refinery in Rochester, New York, that will be able to take lithium, cobalt, nickel, manganese, and other materials from lithium-ion batteries and produce chemicals that can be used to make new batteries. The company currently serves the North American market (the U.S., Canada, and Mexico) and expects to serve markets outside of the continent soon. In the future, Li-Cycle plans to build out a global network of recycling and refinery facilities to create a closed loop system across all markets.

RecycLiCo is a patented process of American Manganese Inc, a critical materials and metals company. In partnership with the Department of Energy (DOE), several universities, national laboratories, and research institutes, this is a research and development project in demonstration stage that aims to target the downstream phase of battery recycling in the commercial refining process. RecycLiCo can refine materials from many types of batteries, including lithium-manganese-cobalt-oxide and lithium manganese oxide, with a focus on chemistries with the highest recovery rates. Since it is not yet a commercialized process, the team has relied upon OEMs and other battery collection organizations to send pre-shredded materials for recycling, but they have the goal to serve a global market in the future, with Extended Producer Responsibility legislation emerging in many countries. RecycLiCo seeks a holistic approach to the battery supply chain to enable localized regions to become less reliant on raw materials from faraway places and achieve higher self-sufficiency in remanufacturing and production.

Redwood Materials is a battery materials company with a major focus on recycling as an input to produce advanced battery materials domestically while mining used products to do so. Once a battery is fully recycled, the secondary materials are funneled directly back to major battery production facilities such as Panasonic and Envision AESC. While the company recycles electronics beyond the vehicle sector, it has prioritized the EV industry as one where battery recycling can make the largest impact on sustainability, economics, and supply chain resiliency. Redwood Materials currently processes approximately 45,000 vehicle batteries per year with an estimated output of 20,000 tons of material and has built partnerships with several vehicle OEMs and fleets to source the batteries it recycles. While the batteries they process can come from anywhere, they have strategically placed their Nevada facilities in close vicinity to the largest EV market (i.e., California) to keep the logistics, economic, and environmental footprints as small as possible—with plans to scale up in the future in areas where EVs become more prevalent. Their process is technology agnostic, meaning that they can process all lithium-ion battery technologies, as well as are researching recycling methods for future battery technologies, such as solid state. Redwood is committed to defining pathways for closing the loop to create a circular supply chain model in collaboration with its partners with the understanding that future critical material supplies will face shortages and with the goal to drive down the cost of battery production in the U.S.

Second Life Batteries

Batteries used in transportation applications have a large energy storage capacity. Many BEB OEMs install batteries in excess of 300 kWh. Batteries used in EVs are typically replaced when they degrade to 80% capacity. While these batteries are no longer suitable for transportation applications, they still retain high energy storage capacity. As a result, these batteries can theoretically be refurbished and reused in a second-life application. A second-life battery is most suited for an application where it would undergo fewer charge/discharge cycles, such as in a stationary energy storage system or a microgrid. Once the battery degrades to the point where it can no longer serve in a stationary energy storage application, the battery can be sent to a battery recycling company for disposal.

Reusing a battery is a promising way to extend its lifespan and reduce its lifecycle environmental impact. Some EV OEMs have started experimenting with repurposing retired batteries for second-life applications. Nissan and Renault have formal programs for reusing retired batteries. In addition, many of the bus OEMs are examining ways to design batteries to easily integrated into second-life applications and are exploring the possibility of selling second-life batteries. The use of second-life batteries is expected to increase in the future.

Fuel Cell Stack/Module Recycling

Similar to batteries, fuel cell manufacturers are innovating processes to optimize the usage and lifetime of the materials used in the production of fuel cell stacks and modules. Although fuel cells function like batteries in zero-emission vehicles, they are structurally different (consisting of an anode and cathode with hydrogen being supplied to the cathode to create a flow of electricity) and do not gradually degrade over time in the same way as a battery. While there is currently not a sound business model for fuel cell second life applications, the future of recycling this hardware looks positive.

Ballard Power Systems Inc is a manufacturer of proton exchange membrane (PEM) fuel cell products for heavy-duty vehicle applications. The company supplies its FCMove module for partner transit bus OEMs New Flyer of America and ElDorado National. Ballard has operationalized its fuel cell takeback system where fleet owners assume the responsibility of returning the fuel cell module after it reaches its end of life at 20,000-30,000 hours. Once the module is sent back to the facility, it is disassembled into individual cells where some materials can be cleaned and reused up to six more times in newly produced modules. A key component of the module, platinum, is almost completely recovered during this process, which helps to reduce production costs since it is the most expensive material. Research to determine how all components of the fuel cell can be either recycled or reused is under way, but there are currently very few buses at the end of life on roads since the technology is still relatively new (the average transit bus lifetime is 12 years). Once the process is fully in place, Ballard will be able to serve all its global markets and is committed to making their entire value chain circular, including the production of the hydrogen that is used to fuel their modules (i.e., hydrogen produced from waste streams). Additionally, Ballard is exploring requirements that will mandate their upstream suppliers to use only recyclable components to ensure smoother and more economically viable recycling options for its customers.

Section IV

Section IV: City of Pasadena Contact Information

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Appendix A

Appendix A: Zero-emission Bus Specifications

Battery-Electric Transit Buses (BEBs)

Proterra – ZX5 features faster acceleration, industry-leading gradeability, and a range of more than 125 miles per charge. The ZX5 has a capacity of up to 29 passengers.

PROTERRA

Proterra ZX5

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	29
Lift Capable	Yes
Battery Size	225 kWh
Approximate nameplate single-charge range	95-125 miles
Length	35 Ft
Source	*https://www.proterra.com/wp-content/uploads/2021/01/Proterra-ZX5-Spec-Sheet-35-Foot-Bus-U.S..pdf*

Proterra – ZX5 MAX is approximately five feet longer than the standard Proterra ZX5 bus model, which can accommodate 40 passengers and run up to 329 miles on a single charge.

PROTERRA

Proterra ZX5 MAX

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	40
Lift Capable	Yes
Battery Size	675 kWh
Approximate nameplate single-charge range	221-329 miles
Length	40 Ft
Source	*https://www.proterra.com/wp-content/uploads/2021/01/Proterra-ZX5-Spec-Sheet-40-Foot-Bus-U.S..pdf*

Proterra – ZX5+ is a 35-foot bus that can run up to 240 miles on a single charge and has a capacity of up to 29 passengers.

PROTERRA

Proterra ZX5+

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	29
Lift Capable	Yes
Battery Size	450 kWh
Approximate nameplate single-charge range	172-240 miles
Length	35 Ft
Source	*https://www.proterra.com/wp-content/uploads/2021/01/Proterra-ZX5-Spec-Sheet-35-Foot-Bus-U.S..pdf*

New Flyer – XCELSIOR XE is a 35-foot bus that can be configured to carry up to 35 passengers standing and 32 seating. The XCELSIOR has two battery options at 350 kWh and 440 kWh.

New Flyer XCELSIOR XE 35' All-Electric Transit Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	Up to 32 seats, up to 35 standees
Lift Capable	Yes
Battery Size	350 kWh, 440 kWh
Approximate nameplate single-charge range	179, 220 miles
Length	35 Ft
Source	*https://www.newflyer.com/site-content/uploads/2021/03/Xcelsior-CHARGE-NG-Brochure-1.pdf*

New Flyer – XCELSIOR XE, a more extended version of its 35-foot counterpart, is capable of operating with three different battery sizes (350 kWh, 440 kWh, and 525 kWh). Each battery size gives varies in range, going up to 251 miles on a single charge.

New Flyer XCELSIOR XE 40' All-Electric Transit Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	Up to 40 seats, up to 44 standees
Lift Capable	Yes
Battery Size	350 kWh, 440 kWh, 525 kWh
Approximate nameplate single-charge range	174, 213, 251 miles
Length	40 Ft
Source	*https://www.newflyer.com/site-content/uploads/2021/03/Xcelsior-CHARGE-NG-Brochure-1.pdf*

BYD – K9S is a 35.8-foot bus with a maximum load of 33 passengers, including the driver. The K9S can travel up to 157 miles on a single charge.

BYD K9S 35' All-Electric Transit Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	32 + 1
Lift Capable	Yes
Battery Size	266 kWh
Approximate nameplate single-charge range	Up to 157 miles
Length	35.8 ft
Source	*https://en.byd.com/bus/35-electric-transit-bus/*

BYD – K9M is a 40-foot plus bus with two battery sizes, 313 kWh and 352 kWh. The passenger load varies on configuration and can comfortably sit between 38 and 43 passengers depending on the battery size. This Altoona-tested model can run up to 160 miles contingent on the battery size selected.

BYD K9M 40' All-Electric Transit Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	Up to 37+1 / Up to 42+1 MD
Lift Capable	Yes
Battery Size	313 kWh / 352 kWh MD
Approximate nameplate single-charge range	Up to 156 miles / Up to 160 miles MD
Length	40.2 ft / 40.9 ft MD
Source	*https://en.byd.com/bus/40-foot-electric-transit-bus/#specs*

Fuel Cell Electric Buses (FCEBs)

New Flyer – Xcelsior Charge H2 is a battery-electric vehicle that uses compressed hydrogen as an energy source. Fuel cell electric technology is an innovative way to obtain extended-range operation similar to existing transit vehicles with a fully zero-emission solution.

New Flyer Xcelsior Charge H2

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	Up to 40 seats / Up to 42 standees
Lift Capable	Yes
Battery Size	37.5 kg
Approximate nameplate single-charge range	Up to 350 miles on a single charge
Length	40'
Source	*https://www.newflyer.com/site-content/uploads/2021/01/Xccelsior-CHARGE-H2-Brochure_2021.pdf*

EL Dorado – AXESS-FC is the only hydrogen bus in the federally certified industry for 3-point seat belts. It features a heavy-duty low floor adapted for applications such as airport shuttles and college transit. The Axess-FC offers optional ADA-compliant wheelchair ramps, has completed Altoona testing, and passed numerous side-impact and roof crush tests to ensure passenger safety.

El Dorado AXESS FC

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	43 Max
Lift Capable	Yes
Approximate nameplate single-charge range	Up to 260 miles
Length	40'
Source	*https://en.byd.com/bus/40-foot-electric-transit-bus/#specs*

Shuttle Buses/Vans

Lightning eMotors — Electric Zero-Emission Transit Passenger Van is equipped with an electric drivetrain that delivers efficiency. The Lightning Electric Transit passenger van carries up to 15 passengers and can run up to 260 miles on a single charge.

LIGHTNING eMOTORS

Ford Transit Van (Mobility Trans) with Lightning System

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	15 passengers (including driver)
Lift Capable	Yes
Battery Size	80 kWh/120 kWh
Approximate nameplate single-charge range	Up to 260 miles
Source	*https://lightningemotors.com/wp-content/uploads/2021/05/LeM_G4_Transit_passenger_van_sheet_May2020_v1.0_online.pdf*

Lightning eMotors – Ford E-Transit is currently unavailable in the market but is expected to be commercially available in 2022.

LIGHTNING eMOTORS

Ford E-Transit

SPECIFICATIONS	SPECIFICTION VALUE(S)
Approximate nameplate single-charge range	126 miles estimated
Availability	2022
Source	*https://lightningemotors.com/transit-vans-ford-vs-lightning/*

Lightning eMotors — Electric Zero Emission F-550 Bus has an estimated range of over 100 miles while producing zero emissions on the road. The F-550 Bus's charging capabilities are flexible, with Level 2 AC charging as standard and DC Fast Charging also being available, providing up to 80 kW.

Electric ZE F-550 Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Battery Size	128 kWh
Approximate nameplate single-charge range	100 miles estimated
Length	About 18 ft
Source	*https://lightningemotors.com/lightningelectric-f550/*

Phoenix Motorcars — Ford E-450 Cutaway Bus: The Starcraft Allstar is powered by Phoenix Motorcars, designed to offer sustainable transportation for shared mobility and commuter transporter. The bus features seating configurations accommodating 12-20 (14 with two-seat ADA option available). Phoenix provides a five-year/60,000 drive system and provides an extended battery warranty of 8 years/300,000 miles.

Ford E-450 Cutaway Bus (Starcraft Allstar) with Phoenix Motorcars System

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	12-20 Passengers (14 with 2 seat ADA option)
Lift Capable	Yes
Battery Size	86-129 kWh
Approximate nameplate single-charge range	80-110 miles
Source	*https://www.creativebussales.com/featured-product--Phoenix-Motorcars*

Phoenix Motorcars – ZEUS 400 Shuttle Bus is fully customizable with a battery capacity of 140 kWh and a single-charge range of up to 150 miles. The ZEUS 400 is eligible for the Phoenix Motorcar's PMC Battery Warranty of 5 Years/150,000 Miles, the PMC Drive System Warranty of 5 Years/60,000 Miles, the Bumper-to-Bumper Warranty of 3 Years/36,000 Miles, and the Body Structure Warranty of 5 Years / 100,000 Miles.

ZEUS 400 Shuttle Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	Up to 23 passengers forward seating, 12/2, 14/2, 16/2 ADA
Lift Capable	Yes
Battery Size	140 kWh
Approximate nameplate single-charge range	150 miles
Length	22 ft
Source	*https://www.phoenixmotorcars.com/products/#shuttles*

US Hybrid – H2 Ride offers the H2 Ride Fuel Cell Shuttle Bus, a 22-foot vehicle, and carries up to 12 passengers (two wheelchairs) plus a driver.

US Hybrid H2 Ride Fuel Cell Shuttle Bus

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	12
Lift Capable	Yes
Length	22'

GreenPower — EV Star is a multi-purpose, zero-emission, min-E Bus with a range of up to 150 miles and offers dual charging capabilities as a standard feature. The EV Star can be used for paratransit, employee shuttles, micro-transit, and vanpool service. The EV Star is the only Buy America compliant and Altoona-tested vehicle in its class.

Green Power EV Star

SPECIFICATIONS	SPECIFICTION VALUE(S)
Passenger Capacity	19 FF / 21 Perimeter
Lift Capable	Yes
Battery Size	118 kWh
Approximate nameplate single-charge range	Up to 150 miles
Length	25'
Source	*https://greenpowermotor.com/gp-products/ev-star/*

GreenPower – EV Star+ is a cutaway bus with a broader body to utilize the interior space. It is designed for paratransit fleet operations—a larger seating capacity and wheelchair position options are available. The bus is ideal for hospitals, carpooling services, airport shuttles, and campus transportation.

Green Power EV Star+

SPECIFICATIONS		SPECIFICTION VALUE(S)
Passenger Capacity		24
Lift Capable		Yes
Battery Size		118 kWh
Approximate nameplate single-charge range		Up to 150 miles
Length		25'
Availability		Yes
Source		*https://greenpowermotor.com/gp-products/ev-star-plus/*

Appendix B

Appendix B: Charging Infrastructure Specifications

The following electrical cabinets and electric vehicle supply equipment (EVSE) units were evaluated by CALSTART. A side-by-side comparison between these products, including prices, is included. The cost of the plug-in charging equipment varies depending on the manufacturer. Most plug-in chargers cost approximately $40,000 to $60,000 per bus depending on the power level. This amount includes only the cost of the charging equipment and does not include construction and installation costs, nor the cost of an overhead structure if overhead plug-in charging is deployed.

Proterra 60 kW Power Control System

PROTERRA

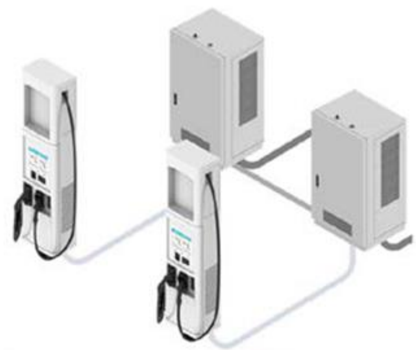
Proterra 60 kW Power Control System
Proterra is a U.S. based electric bus manufacturer that builds chargers to support its heavy-duty EV product line. Proterra's 60 kW Power Control System is one of the most straightforward charging station solutions specifically designed for electric buses. The cabinet module (shown left) provides up to 60 kW of power to a single EVSE unit to charge a single electric bus. The ground level EVSE can be swapped out for an overhead pantograph connector for a more compact bus yard design. Depending on the bus, the battery can be completely recharged in approximately six hours. Manual labor is limited to plugging the EVSE into the bus in the evening after returning to the bus yard, then unplugging it in the morning prior to beginning daily revenue service. Existing examples can be seen at Greensboro Transit Authority.

Proterra 125 kW Power Control System

Proterra 125 kW Power Control System
The 125 kW Power Control System is a simple solution with twice the power of the 60 kW version. The electrical cabinet (shown left) provides up to 125 kW of power to a single EVSE unit to charge a single electric bus. The bus's battery can be recharged in approximately three hours, which gives the fleet manager the flexibility to park two electric buses next to each other and manually transfer the plug halfway through the night.

BTC Power 100 – 350 kW Modular High Power DC Fast Chargers

BTC Power 100 – 350 kW Modular High Power DC Fast Chargers
Based in Santa Ana, California, BTC Power manufactures High-Performance DC Charging Systems. The electrical cabinet (which BTC calls the "Power Engine") can provide power at 100, 150, or 200 kW. Two Power Engines can also be interconnected to deliver up to 350 kW of power to one EVSE. The EVSE itself offers two dispenser units that can power two electric buses sequentially on a first-come, first-served basis. When the first bus has completed charging, the second bus will begin charging without needing manual intervention. BTC Power also adds smart charging software to their EVSEs with the goal of making it very easy for a network provider to integrate a data management solution into the charging station. Existing examples include Los Angeles International Airport and Porterville Transit.



BTC Power 200 – 475 kW High Performance DC Charging System

BTC POWER

BTC Power 200 – 475 kW High Performance DC Charging System
BTC Power was selected to be the sole North American provider of Porsche's High Performance DC Charging System. Capable of delivering up to 475 kW, this design utilizes two cabinet modules: one to convert the energy from AC to DC (called a "Power Box") and the other to provide liquid cooling to the EVSE units (called a "Cooling Box"). These cabinets connect to two EVSEs and can charge both simultaneously. Additional EVSE can be added with the inclusion of another Power Box. Generally, one cooling box can support up to three power boxes and charge six buses simultaneously at whatever power level is desired. Like BTC's other chargers, the High Performance DC Charging System is smart charging software capable, which makes it very easy to integrate a data management solution. At the time of this writing, there are no existing examples at a transit agency.

ABB
HVC 150 E-Bus
Charger (NAM)

ABB HVC 150 E-Bus Charger (NAM)

ABB is a leading EV charger manufacturer that has been building electric bus chargers in Europe for several years and is expanding operations to the United States. Manufactured in Portland, Oregon, the HVC 150 E-Bus Charger, which uses CCS1 or CCS2 connectors, can deliver 150 kW to the bus. The system utilizes one electrical cabinet to support up to three EVSE, and charges each one on a first come, first serve basis. The chargers are smart enough to smoothly transfer power from one EVSE to the next when the bus is fully charged, and ABB offers additional services such as remote diagnostic and management through their ABB Ability data management program. Several transit agencies, including TriMet in Portland, Oregon and Utah Transit Authority, are utilizing their chargers.
 	
HVC150C:
• HVC150C charger with one remote depot box, 7m cables:
• HVC150C charger with two remote depot boxes, 7m cables:
• HVC150C charger with three remote depot boxes, 7m cables:
• OPTION: Pedestal for one depot box:
• OPTION: Cable management for one depot box:
• OPTION: Long distance support package:
    ○ Extends distance between power cabinet and remote depot box to 150M
• OPTION: Robustness package:
    ○ Required for systems installed in harsh climates
 	
HVC-C Depot Plug-In
HVC100C (100 kW)
• 1:1 Charger: Depot with 7M cable
• 1:2 Charger: Depot, 7M cables, sequential charging package
• 1:3 Charger: Depot, 7M cables, sequential charging package
 	
HVC100C Buy America
• 1:1 Charger: Depot with 7M cable, BAA
• 1:2 Charger: Depot, 7M cables, sequential charging package, BAA
• 1:3 Charger: Depot, 7M cables, sequential charging package, BAA
 	
HVC150C (150 kW)
• 1:1 Charger: Depot with 7M cable
• 1:2 Charger: Depot, 7M cables, sequential charging package
• 1:3 Charger: Depot, 7M cables, sequential charging package
 	
HVC150C Buy America
• 1:1 Charger: Depot with 7M cable, BAA
• 1:2 Charger: Depot, 7M cables, sequential charging package, BAA
• 1:3 Charger: Depot, 7M cables, sequential charging package, BAA
 	
Options Robustness Package
• For installation in very cold / hot climates
• Long Distance Package
• Extends distance between power cabinet and depot to 150 M
• Standard without LD Package is 20 M
• Power Cabinet Metal Frame Foundation
• Depot Box Pedestal

- Cable Management
- Standard installation is mounted on Depot Box Pedestal
- Commissioning Variable dependent on site

HVC-PD Overhead Pantograph
HVC150PD (150 kW)
- Charger with pantograph mounted on ABB mast
- Charger with pantograph mountable on existing structure

HVC150PD Buy America
- Charger with pantograph mounted on ABB mast, BAA
- Charger with pantograph mountable on existing structure, BAA

HVC300PD (300 kW)
- Charger with pantograph mounted on ABB mast
- Charger with pantograph mountable on existing structure

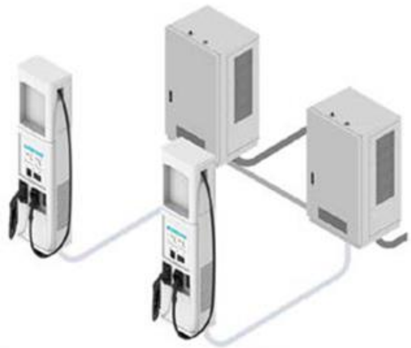
HVC300PD Buy America
- Charger with pantograph mounted on ABB mast, BAA
- Charger with pantograph mountable on existing structure, BAA

HVC450PD (450 kW)
- Charger with pantograph mounted on ABB mast
- Charger with pantograph mountable on existing structure

HVC450PD Buy America
- Charger with pantograph mounted on ABB mast, BAA
- Charger with pantograph mountable on existing structure, BAA

Options
- Robustness Package
- For installation in very cold / hot climates
- Long Distance Package
- Extends distance between power cabinet and depot to 150 M
- Standard without LD Package is 20 M
- Power Cabinet Metal Frame Foundation
- RFID Antenna Kit
- For installing pantographs in close proximity
- Commissioning Variable dependent on site

Web Tools
ABB Connected Services
- Charger Connect
- Covers costs associated with cellular network connectivity, software upgrade support, data connection to ABB
- Operator Pro / EVE Platform
- Data management, reporting, charger status visibility



Terra -
Terra HP and
Terra 54HV:

Terra Terra HP and Terra 54HV
Terra Budgetary numbers on Terra HP and Terra 54HV: Terra HP 175 kW unit w 1 power cabinet and dispenser: Terra HP 350 kW unit w 2 power cabinets and dispenser: Terra 54HV 50 kW unit: OPTION: Terra 54HV Cable Management Quick budgetary numbers for our HVC150C: • HVC150C charger with one remote depot box, 7m cables: • Same as above, BAA: • HVC150C charger with two remote depot boxes, 7m cables: • Same as above, BAA: • HVC150C charger with three remote depot boxes, 7m cables: • Same as above, BAA • OPTION: Pedestal for one depot box: • OPTION: Cable management for one depot box • OPTION: Long distance support package: ○ Extends distance between power cabinet and remote depot box to 150M • OPTION: Robustness package: ○ Required for systems installed in harsh climates Included in above: Project management, Engineering, Transport and packaging in continental US, on-site commissioning and start up, Charger connection fees for 2 years. 2-year warranty. Excluded in above: Interconnection DC cables, installation and civil works, options as listed below

Heliox – Fast DC 150 Charger

Heliox Fast DC 150 Charger
Heliox is a Netherlands-based EV charging infrastructure company that develops charging infrastructure for electric vehicles. Manufactured in the Netherlands, this 150 kW charger charges one vehicle on a first come, first serve basis. Heliox also has the world's largest opportunity and depot charge network. This charger can charge any J1772 and/or J3105 compatible truck, bus, or heavy-duty vehicle. Most of Heliox's customers are transit agencies in Europe, but the company is expanding into the U.S. market, having recently opened a headquarters in Portland, Oregon.

ChargePoint -
Express Plus Double Stacked Power Block

ChargePoint Express Plus Double Stacked Power Block
ChargePoint is a San Francisco Bay Area-based electrical vehicle charging company. Founded in 2007, it operates over 57,000 charging stations worldwide. ChargePoint has multiple models of chargers and available for passenger vehicles, buses, and trucks. The Express Plus model is designed for ultra-fast DC charging. Thanks to its flexible modular architecture, it can expand to high charging capacity without any stranded investment by adding power modules, stations, and power blocks, per demand. Speed and dynamic power sharing are some of the many benefits of the Express Plus model.

Siemens -
RAVE US 750V 150 kW CCS Cascade DC

Siemens
RAVE US 750V 150 kW CCS Cascade DC

Siemens is a German-based industrial giant with a major footprint in the bus charging infrastructure industry, with multiple models of depot and on-route charging to choose from. The RAVE brand charger can provide an EV with fast and efficient charging for both depot and on-route charging whenever necessary. Examples of usage of Siemens chargers include Metro Transit in Minneapolis, Minnesota, and TriMet in Portland, Oregon.

Sicharge UC 200

- Sicharge UC 200 power control cabinet rated at 200A, 480V input with 150kW, 100-1,000Vdc output. Canada version will have 600Vac input. Supports up to four (4) sequential remote dispensers. Enclosure is NEMA 3R/IP54, with UL, CE, cUL certifications. Communications is OCPP 1.6 and future to OCPP 2.0 over cellular. Emergency stop is on the cabinet and the dispenser. Cabinet size is: 43.3" width x 39.4" depth x 87.0" height. Requires a concrete pad. Warranty is two years.

Sicharge UC 400

- Sicharge UC 400 is two Sicharge UC 200 power control cabinets that provide 300kW of power rated at 100-1,00Vdc. Supports up to four (4) sequential remote dispensers. Incoming power can be two dedicated conduit runs, one to each cabinet, or an AC Combiner Box can be used for the incoming location. This means less conduit work under the cabinets. The outgoing DC power cabinet can also be used to simplify the installations. Enclosures are NEMA 3R/IP54, with UL, CE, cUL certifications. Communications is OCPP 1.6 and future to OCPP 2.0 over cellular. Emergency stop is on the cabinet and the dispenser (if used). Two Power Cabinets are approx. 86.7" width x 39.4" depth x 87.0" height. Height will increase if a combiner cabinet is provided. Requires a concrete pad. Warranty is two years.

200 Amp Dispenser

- Sicharge UC free-standing dispenser with one CCS1 cable and cable holder. Siemens touch screen 7" display and emergency stop button also included. NEMA 3R/IP54 rated enclosure. Unit will have communications to the power control cabinets via fiber optic or CAT5/6 copper ethernet. Warranty is two years.

BYD -
EVA100KS/02 and EVA200KS/01

BYD
EVA100KS/02 and EVA200KS/01

BYD is a Chinese automotive company known for building EVs. Their market consists of buses (transit and coach), vans, cars, and trucks. BYD also has a variety of chargers that it markets with its vehicles. All BYD EVs come with standard AC-DC Quick Charge Inverters. This makes for simplified fleet integration. BYD chargers are available in configurations from 40kW to 100kW per charging connector. Due to the proprietary design of the BYD charging connector and architecture, BYD buses can only be paired with BYD chargers. Each BYD bus comes with its own charger. Examples of usage are Antelope Valley Transit Authority (AVTA) in Lancaster-Palmdale, California.

Blink -
DC Fast Charger

Blink
DC Fast Charger

Blink Charging is a Florida-based charging company that produces multiple lines of charging infrastructure. Blink has a variety of business models that can work for all different types of fleets. Blink's DC Fast Charger has a simplified 2-piece design that connects with an advanced metering infrastructure interface and smart meter capability for demand response and energy management. This charger can provide an 80% charge in 30 minutes (pending battery size).

Blink Charging Station Highlights:

- Blink Level 2 charging stations are currently the fastest Level 2 networked chargers on the market.
- Blink Level 2 charging stations can add up to 80 miles of charge to EVs in one hour.
- Blink charging stations are equipped with an easy-to-use payment processing system that can be accessed via the Blink Mobile app.
- The Blink Network offers real-time online access to revenue and usage reports.
- Every Blink unit comes with a 1 year manufacturer's warranty.
- The Blink Network offers remote maintenance, software upgrade, and support capability.

Delta -
EVHU503 and EVHU104

Delta
EVHU503 and EVHU104

Delta is a Taiwan-based company that provides power and thermal solutions. Delta provides DC fast chargers and has 50 kW and 100 kW models. Their chargers are compatible with CHAdeMO and CCS-1 protocols. Delta chargers have two charging receptacles and can charge buses simultaneously. Delta also offers energy management software.

Efacec -
HV350

Efacec HV350
Efacec is a Portugal-based charging company that has a variety of high-power chargers, which includes 160, 175, and 350 kW models. The high-power models can charge both in a standalone mode or integrated in any network with any central system. These chargers can charge both cars and buses and has a DC output of up to 920 V. Efacec chargers can be customized with graphic, logos, and colors to cater to each specific entity brand.

Tritium -
Veefil PK

Tritium Veefil PK
Tritium is an Australian DC fast charger manufacturer with a large global market that is partially owned by fueling infrastructure giant Gilbarco Veeder-Root. Tritium's sophisticated modular, scalable architecture consists of three main free-standing components: a user unit that holds one or two connectors, a power unit, and a control unit. Depending on the number of power units and user units, the system output can be scaled from 175 kW to 475 kW of power.

WAVE – Inductive Charger

WAVE Inductive Charger
WAVE delivers fast, safe, high-power charging within seconds of scheduled stops and natural dwell times. Medium- and heavy-duty EVs gain substantial range and operation time without manual plug-in operations or mechanical contact. With power ranging from 125kW to 500kW and higher, WAVE's high-power systems are ideal for powering EVs for mass transit, warehouse and distribution centers, shuttle services, seaports, and more. What is commercially available today is a 250-kW charger that can supply power in various configurations; where power is split down to two (2) 125 kW chargers and soon split to four (4) 62.5 kW plates with smart charging for the depot.

Clipper Creek – CS-100, 70/80 Amp (Selectable) EVSE, 240V, with 25 ft cable

Clipper Creek
CS-100, 70/80 Amp (Selectable) EVSE, 240V, with 25 ft cable

The CS 100 is the world's first UL listed EV charging station manufactured in the United States. The CS-100 is a UL Listed Level 2 EVSE offering 19.2 kW for EV charging. The CS-100 works with all SAEJ1772 compliant vehicles. This charger is ideal for vehicles that can accept high power charging, and future proofing installations.

This is the recommended charger for charger for the GreenPower and Phoenix Motorcars buses.

- 208V to 240V - 100 Amp Branch Circuit (70/80 Selectable Amps continuous)
- 25-foot charging cable
- Rugged, fully sealed NEMA 4 for installation indoors or outdoors
- Automatic circuit reclosure after minor power faults
- Cold Load Pickup: Time-delayed and randomized to allow seamless re-energizing of unit following power outages
- External Control Input: Allows external control from smart meter (AMI), billing or load management device
- UL Listed
- ETL LISTED

Compatible Accessories:

- The Wall Mount Retractor from ClipperCreek is the ideal solution for sites that need cable management, keeping charging cables off the ground and vehicle connectors protected.

Compatible Mounting Solutions:

- CS Pedestal (0300-00-015)
- EVSE Size Comparison Chart (click to view larger)

Charging Power
- 70/80 Amp Selectable (19.2kW max)

Product Dimensions
- 17” W x 22” H x 12” (mounting holes 16” on center)

Product Weight
- 36 lbs

Installation
- Hardwired

Supply Circuit
- 208/240V, 100A

Warranty
- 1 year

Charge Cable Length
- 25 feet (22 feet usable)

Vehicle Connector Type
- SAE J1772

Accessories Included
- Connector Lock & Keys

Enclosure
- Fully Sealed NEMA 4

Environment Rating
- Indoor and Outdoor

Operating Temperature

- -22°F to 122°F (-30°C to +50°C)

Certifications

- UL, cULus, ETL, cETLus

Appendix C

Appendix C: Hydrogen Fueling Infrastructure Specifications

If a transit agency opts to transition to an FCEB fleet, they will need to install hydrogen fueling infrastructure. Typical hydrogen fueling infrastructure includes a compressor, hydrogen storage tanks, and a hydrogen dispenser. In addition, either on-site hydrogen production equipment or infrastructure to accept delivered hydrogen is required. This section provides an overview of the market for hydrogen fueling infrastructure.

NEL Hydrogen offers reliable, cost-efficient electrolyzers and is recognized as an industry leader of Alkaline and PEM water electrolysis. Their water electrolyzers make a superior choice for Industry, Transport and Power-to-X applications. Multiple, scalable, flexible, modular product ranges are set to meet any customer requirements. The H2Station® is the new generation fast 70MPa fueling of Fuel Cell Electric Vehicles (FCEV). Compared with its market-leading predecessor, CAR-100, fueling capacity is up three times – at one third of the space – enabling installation at even compact gas stations. The peak rush-hour capacity of up to 100 kg in three hours, allows a flexible scaling of capacity as demand grows. Storage can be dimensioned to address a fueling demand of up to 500 kg per day for cars, up to 1500 kg per day for buses, trucks, and any hydrogen supply configuration. Consider their compact and user-friendly hydrogen dispenser for fueling of both 35 and 70 MPa vehicles from a H2Station™.

One H2 is emerging as a leader in providing scalable hydrogen fuel systems coupled with cost effective delivered hydrogen fuel for use in industrial vehicle and truck markets. Their holistic, end-to-end solution guarantees the production, delivery, and monitoring of zero-emission hydrogen fuel. The hydrogen fuel dispenser is manufactured and designed in-house and made of durable stainless-steel construction with a 15+ year life. The dispenser has 350 bar or 700 bar refueling options along with various safety features, such as a flame detector gas sensor e-stop on dispenser with secondary reset safety relays (inside cabinet).

Bayotech is a full-service hydrogen supplier, offering localized production, transport, storage and fueling solutions. Their expanded product line now includes hydrogen dispensing equipment and zero-emission fuel cell power generators and light towers. The MicroPak Series of multi-cylinder trailers with 350 bar/5075 psig cylinders is designed primarily for hydrogen, helium, and air. The smallest MicroPak trailer weighs less than 1,000lbs which allows for a non-HazMat licensed driver to haul it, while the Gas Transport Series allows for gas storage that can be towed with a standard sized pick-up truck. Cylinders can range from 3,600 psig to 7,500 psig and can incorporate gas specific accessories, such as a heated regulator system (hrs-2) for CNG, booster pumps for CNG refueling and defueling, and pressure reduction systems for other gases. Customers pay for fuel by the kilogram and choose from multiple modes of supply. Advantages include minimal capital investment in infrastructure, short term contracts and flexibility to meet fluctuating demands. BayoTech produces the hydrogen locally and distributes to nearby consumers via three-times more efficient high-pressure transport trailers. Avoiding long transportation distances saves money while minimizing carbon intensity.

Air Products is the world's largest supplier of merchant hydrogen and a leader in hydrogen fuel infrastructure. Their SmartFuel® technology brings safe, reliable, and cost-effective hydrogen to hydrogen-powered applications around the world. On-site generation of hydrogen is an alternative to delivered product and offers customers a unique way to supply their fueling station. Two technologies are available: methane reformers and electrolyzers. Air Products' PRISM® hydrogen generators are steam methane reformers that use a highly efficient, robust process that minimizes operating costs. PRISM hydrogen generators are designed to supply fueling stations up to 1,800 kgs per day. The hydrogen purity from these generators will meet the stringent requirements of fuel cell applications. Their SmartFuel® portable fueling units provide totally self-contained hydrogen dispensing capabilities with zero-emissions and no utility hook-ups. The fueling station holds up to 150 kg of hydrogen and can be used for both short- and long-term deployments. A familiar hose-and-nozzle dispenser automatically fills the vehicle's fuel cell with hydrogen gas at a pressure of ~5,000 psi (350 bar). These stations have been deployed in numerous locations around the world and can be delivered to customers with very short lead-times. It provides a highly reliable, cost-effective, automated capability at the convenience of your location.

Air Liquide has been developing unique expertise in the mastery of the entire hydrogen chain (production, storage, and distribution) for more than 40 years. In the U.S., Air Liquide will utilize an innovative pathway for hydrogen sourcing at the Braintree, Massachusetts hydrogen fueling station using a water electrolysis system, Proton On-site PEM electrolysis, to generate on-site produced hydrogen. Their stations can fill the fuel tanks of vehicles with hydrogen stations ranging from 35mpa up to 70mpa. Air Liquide offers a range of standardized or tailor-made products and solutions to meet specific needs. They have supplied a hydrogen station in Oslo, Norway, to recharge five buses operated by a Norwegian transportation company, and another one in Aargau, Switzerland, where the local authorities also operate five buses. At this point, 100 hydrogen stations have been designed and built by Air Liquide around the world.

Linde has established a leading position in the H2 fueling space and is particularly renowned for its high-performance technologies to refuel fuel-cell vehicles and is also offering more and more concepts for green hydrogen. Multiple Ionic Compressors from Linde are available for refueling, each one compressing the gaseous H2 to the 350-bar pressure required for the buses and to 700 bar for passenger cars. This combined bus/car fueling station can serve up to 15 buses and numerous cars. The station's carbon footprint is neutral, since it generates hydrogen using three electrolyzers powered by energy from certifiable renewable sources for zero emissions from source to service. Their compression technologies are at the heart of every H2 fueling station. Ionic technology is used to compress gaseous H2 to up to 100 MPa and the cryopump efficiently supplies hydrogen in liquid form ready for refueling. Linde has already built over 190 H2 fueling stations around the world and in San Francisco, California. Linde is leading the way in sustainable production of H2 through its joint venture in ITM Linde Electrolysis, the cutting edge of electrolysis technologies.

Appendix D

Appendix D: Managed Charging Solutions

Networked or managed charging is helpful as it allows transit agencies to minimize their peak power demand. This helps to lower utility costs for transit agencies and helps utilities manage the grid. Networked and managed charging is typically a separate service from the physical hardware of the EVSE and electrical cabinets. Companies that specialize in this space call themselves "Electric Vehicle Service Providers" or simply "network providers." However, unlike the EVSEs, there are a small, but growing, number of companies that focus on charging heavy-duty vehicles, such as electric buses. This section provides an overview of networked charging companies.

I/O Control Corporations offers software to inform smart systems, including remote monitoring, analytics, and prioritizing charging on specific buses. Their Electrical Load Management System (ELMS) product offering is a cloud-based application that enables remote electric bus charging management across multiple depot locations. It allows transit operators to set up their preferred parameters so that buses can be charged automatically according to specific schedules and vehicle limits. I/O Controls supplies a charging control gateway for each charging station. The pricing for the gateway includes a monthly fee for the first year with a 1 year warranty, and the transit entity is charged a yearly fee for the hardware for subsequent years of use. Currently, the ELMS and charging gateway combination is only offered for charging of BYD buses but I/O Controls can work with other vehicle manufacturers to make their hardware and software compatible with other bus technologies. I/O Controls also offers a Health Alert Management System (HAMS) which is currently being used by Antelope Valley Transit Authority in Lancaster, California. This operating system functions as a control for how much power a particular bus draws from the grid. The HAMS features AIMS (Alert, Inquire, Manage, Store) functionality. The Alert function sends a text or email message when there is an issue with the vehicle's charge cycle or during regular route service. The Inquire feature monitors the health status of the vehicle such as SOC, mileage, battery voltage, and other parameters and is updated once per minute. The Manage feature uses cloud-based software to maintain and edit information provided by the HAMS module. The Store feature allows for unlimited data uploads to the cloud for future use and analytics.

ViriCiti is a trusted solution for over 350+ operators worldwide and offers a system that is integrated with over 50 OEMs. The company is known for its telematic data logging system for buses on the road, but also offers solutions for managing electric bus chargers through their Charger Monitoring and Smart Charging packages. Both of these systems are OCPP compliant and OEM agnostic, meaning they support open standards and can communicate with a variety of charging station and vehicle types. No additional hardware is needed to monitor the chargers if they are OCPP1.6 compliant or higher. The first package offers a single dashboard view for easy visualization of vital Key Performance Indicators (KPIs) (e.g., charger status and location, connected vehicle ID and SOC, energy consumption, etc.) which serves to quickly identify and troubleshoot bugs, increase EVSE uptime, and reduce maintenance time and costs. Their new Depot View product provides a visual overview of the vehicle and chargers in the fleet's depot. It shows which vehicles are connected to which chargers and their remaining SOC. Depot View also shows the status of the chargers (available, busy, faulted). ViriCiti's data management solution can track EVSE performance and enable smart charging capabilities. Viriciti's smart charging systems allow for fleet-wide management of charging through scheduled load balancing and can provide benefits such as peak shaving, demand response, and renewables integration. Their system can also be used to track fleet data such as battery SOC, bus energy efficiency, and bus downtime. ViriCiti offers modular based license subscriptions which allows customers to customize and only pay for the features they need. Licensing is offered per charger socket on a yearly subscription basis. The average cost of charger monitoring is $18 per socket/month and the average cost for smart charging is $25 per socket/month (as of Summer 2021). The ViriCiti team offers 24/7 customer support. ViriCiti was purchased by ChargePoint, which is a charging infrastructure provider, in August 2021.

Greenlots (a member of the Shell Group) is another network provider that specializes in smart charging and fleet scheduling services. Greenlots provides a turnkey solution for EV charging, which includes a site evaluation, hardware procurement and validation, engineering and construction services, and operation and maintenance services. Greenlots works closely with Shell's Solutions Development team to provide battery systems that integrate with charging stations to provide additional microgrid and energy management solutions. Their Greenlots SKY EV Charging Network Software offers real-time network management and status of EV chargers, a variable pricing engine which can set pricing based on usage, time intervals, or sessions, and a billing and payment management system through the Greenlots mobile app or charging station. Additionally, the SKY EV system provides access to advanced analytics and customizable reporting with alerts to improve EVSE uptime and access to data such as revenue, energy delivered, and avoided CO2 emissions. The SKY EV system utilizes the OCPP standard and features a multi-layer security system to protect sensitive data. In addition to EVSE manufacturer hardware warranties, Greenlots offers a quality assurance program called "Greenlots Care" which provides trained technicians to make on-site repairs within 24-48 hours as well as a supplemental parts warranty to ensure a charger uptime guarantee of 95%. Other included services are preventative and corrective maintenance, warranty management, reporting, and performance SLAs. Finally, Greenlots offers a Charging-as-a-Service package, which is based on a recurring annual fee which aims to reduce steep upfront costs for the fleet customer. Greenlots is currently working with Foothill Transit on their electric buses.

Electriphi is a wholly owned subsidiary of Ford Motor Company that offers end-to-end fleet electrification solutions including charging management and infrastructure deployment. Electriphi works alongside fleets to simplify EV management and ease the transition from conventional to electric fleets through planning, deployment assistance, and ongoing operational services. On the implementation side, Electriphi offers testing and integration services for vehicle telematics systems prior to service deployment at the customer site. Their monthly software-as-a-service (SaaS) monitoring and management system tracks charging station status, network connectivity, and equipment fault detection, as well as offers sophisticated smart charging algorithms that ensures that vehicles are charged on time at the most optimal energy cost (while taking into account vehicle dispatch schedules, route information, TOU energy rates, demand charge windows, and more). Customers may purchase a baseline operational charging system for remote fleet control and data access and may add on managed/smart charging features which can be accessed from the same online dashboard. Electriphi also offers advanced energy services such as ESS system integration, active demand response, and V2G management. Electriphi's software compatibility is constantly evaluated based on current market offerings and is suitable for use with most major EV charging equipment manufacturers for both Level 2 and Level 3/DCFC stations. Pricing is available as an upfront, non-recurring cost or a yearly SaaS fee.

The Mobility House is a network provider that serves over 350 fleets and offers charging system management software called ChargePilot. Their software helps transit agencies engage in peak shaving and schedule charging to reduce demand charges. While their system does not connect to onboard vehicle telematics, it is compliant with multiple EVSEs at once, yielding high interoperability. To keep the fleet charged when vehicles need to be deployed and to optimize costs, the system monitors the bus SOC while plugged into the charger and calculates charge times and duration based on site-specific electricity rates. The fleet only has to supply the desired departure time and desired SOC per vehicle, and the system coordinates the rest via a local controller that is installed on-site and is connected to all the chargers. Mobility House is able to assist fleets with the charger procurement process to ensure that they are OCPP compliant, and therefore ChargePilot compliant, before purchase and installation. ChargePilot can also take solar resources and distributed generation assets into account when managing charging by integrating the data from renewables on-site into the system operations. Mobility House offers a hybrid business model with a one time setup cost per site which includes hardware installation and commissioning, and then operates its software service on a monthly, yearly, or multi-year subscription basis according to the customer's business needs and plans. The pricing is project and volume-dependent with flexibility to operate on a Charging-as-a-Service (per mile) system. As part of this package, Mobility House provides 24/7 monitoring on all sites with quick alerts and remote fixes in the case that there is a system failure. Mobility House offers a complimentary demonstration workshop for interested customers to help calculate an individual fleet's cost savings with their managed charging solution.

bp pulse (formerly AMPLY Power) offers smart charging services for transit fleets and beyond through power demand services, telematics, scheduled maintenance, and battery SOC monitoring. They work with the existing infrastructure to add charging capacity by analyzing the electrical capacity and redesigning the depot layout. bp pulse's system integrates with onboard vehicle telematics to coordinate and manage the charging stations on schedules based on available electricity and bus SOC. They offer various payment mechanisms based on the customer's need, such as a monthly licensing fees per charger or an energy-as-a-service per kWh model. bp pulse also offers charging infrastructure installation with the necessary electrical equipment to connect the systems and capital expenditures can be bundled into their Charging-as-a-Service (CaaS) solution. Their Pantograph In-Depot

Equipment, or PIDE Canopy Mount, allows for overhead DC fast chargers to be installed to solar canopies, which can greatly optimize depot space and the use of solar energy. Pricing is customized to each fleet's needs and varies based on numerous factors such as combined grants to offset costs, utility partnerships, and energy rates per utility. bp pulse works with EVSE OEMs to develop hardware agnostic warranties and the software includes a triage system to alert fleet operators of any potential issues before a contracted service technician is deployed to repair the system.

Proterra provides electric buses but also provides fleet planning and EV charging services. Through a turnkey solution, Proterra can provide an "energy delivery system" that offers a comprehensive solution for establishing EV infrastructure. This includes smart energy management, and electrical utility make-ready.

AmpUp is a software company and network provider for smart charge scheduling, dynamic access control, and energy optimization built into one platform. Their mobile app software was originally founded to offer peer-to-peer shared charging to increase charger access in residential areas and decrease the cost to EV owners. They have since expanded their product to include a solution for commercial entities and various customer types. All the charge management is facilitated through OCPP which allows the software to communicate with the hardware and means that the AmpUp solution is brand agnostic. The software determines when a charging station is on or offline, when it will become available, and when the plugged-in vehicle will charge based on customized pricing preferences. AmpUp's service is offered on a monthly or yearly software subscription basis with an additional per vehicle cost for an added telematics bundle, which offers an integration with their partner's (Smartcar) system. In California, AmpUp will also assist with fleet financing ROI by redeeming carbon credits on behalf of the customer and passing it along to them. The AmpUp system will pass on station data to the third-party carbon credit processor who will prepare and submit the required paperwork in order to receive the credit payment. These credits can be returned to the customer via check or can be directly put back into their AmpUp portal towards vehicle charge management expenses.

Appendix E

Appendix E: Energy Storage Options

Tesla – Megapack: A 1 Gigawatt hour (GWh) project provides record energy capacity—enough to power every home in San Francisco for six hours. Every Megapack arrives pre-assembled and pre-tested in one enclosure from our Gigafactory—including battery modules, bi-directional inverters, a thermal management system, an AC main breaker and controls.

Tesla Megapack

SPECIFICATIONS	SPECIFICTION VALUE(S)
Max Energy Capacity	3 MWh
Technology	Lithium-ion
Inverter Capacity	1.5 MW
Connection	AC output interface
Dimensions (L x W)	*23 ft 5 in x 5 ft 3 in (7.14 m x 1.60 m)*
Size	250 MW, 1 GWh power plant per 3 acre
Weight	51,000 lbs
Source	*https://www.tesla.com/megapack*

BYD – Utility ESS: BYD mainly provides two kinds of indoor/outdoor solutions for on-grid, off-grid, and hybrid use. BYD energy storage systems can be fit for various needs based on its flexible and modular design.

BYD Utility ESS

BYD Build Your Dreams®

SPECIFICATIONS	SPECIFICTION VALUE(S)
Max Energy Capacity	250kW/1MWh 500kW/1MWh 1MW/1MWh 1.8MW/800kWh
Technology	Lithium-ion Iron-Phosphate
Connection	AC output & DC input interface
Size	40ft Container
Source	*https://en.byd.com/energy/utility-ess/*

LG – ESS: LG Chem's L&S (Lamination & Stacking) process minimizes dead space, enables higher energy density, and enhances the sustainability of cell structures. LG Chem's SRS® (Safety Reinforced Separator) increases the mechanical and thermal stability of battery cells.

LG Energy Storage System (ESS)

LG Energy Solution
ESS Battery Division

SPECIFICATIONS	SPECIFICTION VALUE(S)
Max Energy Capacity	6.8MWh
Technology	Lithium-ion
Voltage Flexibility	14 Modules (~800V) 17 Modules (~1000V) 24 Modules (~1500V)
Connection	AC/DC Panel
Energy Flexibility	1) 25.8in 2) 37.4in 3) 47.2in
Size	40ft HC ISO Enclosure with HVAC
Grid Scale	<u>Energy</u> JH3, JH4 · Duration for ≥ 1 hour · Continuous power supply <u>Power</u> JP3 · Duration for < 1 hour · High power supply
Source	*https://www.lgessbattery.com/us/grid/intro.lg*

NGK Insulators – NAS Battery Cell: The NAS battery system is designed to easily expand the capacity as much as needed in one site or several separate sites. The scalability of NAS installation to many tens or hundreds of MW for durations of six to seven hours is at a scale that can defer or eliminate some transmission, distribution, and generation investments especially when used in association with variable renewables for a clean solution.

NGK NAS Battery System

NGK INSULATORS
Surprising Ceramics.

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Density	367 Wh/l 222 Wh/kg per battery cell
Power Density	36 W/kg per battery cell
Technology	Sodium-sulfur
Voltage	2V per battery cell
Connection	PCS (AC/DC power conversion system)
C-Rate	1/6 = 0.17 per battery cell
Dimensions (L x W)	9cm x 50 cm per battery cell
Weight	5 kg per battery cell
Size	Up to 50MW, 300MWh
Source	*https://www.ngk-insulators.com/en/product/nas-about.html*

NGK Insulators – NAS Container Type Unit: The NAS battery system is a "Plug and Play" design built around standard 20-foot ocean freight containers. The containerized design expedites transportation and installation and helps minimize installation costs.

NGK NAS Battery Container Type Unit

NGK INSULATORS
Surprising Ceramics.

SPECIFICATIONS	SPECIFICTION VALUE(S)
Rated Output	800 kW and 4,800 kWh
Configuration	Four container subunits, series connected. A subunit includes six NAS modules, each rated at 33 kW and 200 kWh
Dimension (W x D x H)	6.1 x 5.6 x 5.5 m
Weight	86 tonnes
Source	*https://www.ngk-insulators.com/en/product/nas-configurations.html*

NGK Insulators – NAS Package Type Unit: The enclosure package and battery modules are installed on site. This design achieves more compact system comparing with containerized design.

NGK NAS Battery
Package Type Unit

NGK INSULATORS
Surprising Ceramics.

SPECIFICATIONS	SPECIFICTION VALUE(S)
Rated Output	1,200kW and 8,640kWh
Configuration	40 NAS modules, each rated at 30kW and 216kWh
Dimension (W x D x H)	10.2 x 4.4 x 4.8 m
Weight	132 tonnes
Source	*https://www.ngk-insulators.com/en/product/nas-configurations.html*

NEC - GBS-C53-LD40: Long-Duration (LD) Grid Battery Systems

NEC \Orchestrating a brighter world

NEC - GBS-C53-LD40

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	4 MWh
Power Rating	4 MW
Technology	Nanophosphate® lithium-ion battery
DC Voltage	944V nominal (750V – 1050V DC operating range)
Connection	50Hz or 60Hz connection frequency options Optional step-up transformer to MV AC output 480VAC output (typical)
DC Efficiency	97% (C/2 rate)
Dimensions (LxWxH)	53' x 8.5' x 9.5' (16.2m x 2.6m x 2.9m)
Mass	140,000 lbs
Source	*http://www.cls-energy.com/files/nec_grid_brochure.pdf*

NEC - GBS-C40-LD28: Long-Duration (LD) Grid Battery Systems

NEC - GBS-C40-LD28

NEC \Orchestrating a brighter world

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	2.8 MWh
Power Rating	2.8 MW
Technology	Nanophosphate® lithium-ion battery
DC Voltage	944V nominal (750V – 1050V DC operating range)
Connection	50Hz or 60Hz connection frequency options Optional step-up transformer to MV AC output 480VAC output (typical)
DC Efficiency	97% (C/2 rate)
Dimensions (LxWxH)	40' x 8.5' x 9.5' (12.2m x 2.6m x 2.9m)
Mass	100,000 lbs
Source	*http://www.cls-energy.com/files/nec_grid_brochure.pdf*

NEC - GBS-C20-LD12: Long-Duration (LD) Grid Battery Systems

NEC - GBS-C20-LD12

NEC \Orchestrating a brighter world

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	1.2 MWh
Power Rating	1.2 MW
Technology	Nanophosphate® lithium-ion battery
DC Voltage	944V nominal (750V – 1050V DC operating range)
Connection	50Hz or 60Hz connection frequency options Optional step-up transformer to MV AC output 480VAC output (typical)
DC Efficiency	97% (C/2 rate)
Dimensions (LxWxH)	20' x 8.5' x 9.5' (6.1m x 2.6m x 2.9m)
Mass	47,000 lbs
Source	*http://www.cls-energy.com/files/nec_grid_brochure.pdf*

NEC - GBS-C53-HR20: High-Rate (HR) Grid Battery System

NEC - GBS-C53-HR20

NEC \Orchestrating a brighter world

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	575kWh
Power Rating	2 MW
Technology	Nanophosphate® lithium-ion battery
DC Voltage	960V nominal (750V – 1050V DC operating range)
Connection	50Hz or 60Hz connection frequency options Optional step-up transformer to MV AC output 480VAC output (typical)
DC Efficiency	96% (1C rate)
Dimensions (LxWxH)	53' x 8.5' x 9.5' (16.2m x 2.6m x 2.9m)
Mass	64,000 lbs
Source	*http://www.cls-energy.com/files/nec_grid_brochure.pdf*

Saft – Intensium® Max 20 High Energy: Initially developed for grid installations, Intensium® Max brings rail energy-efficiency and smart-grid technologies to an aging transport infrastructure and has the potential to transform the relationship between the transport and energy industries.

Saft – Intensium® Max 20 High Energy

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	2.5 MWh
Storage Capacity	420 kWh
Voltage (V)	1000 V Class 811 1500 V Class 1216
Technology	Lithium-ion
Peak Charge	1.5 MW
Battery System	1000 V Class 9 Energy Storage System Units (ESSU) 14 battery modules in series One Battery Management Module (BMM) 1500 V Class 6 Energy Storage System Units (ESSU) 21 battery modules One Battery Management Module (BMM)
Dimensions (LxWxH) w/o HVAC	6.1 x 2.4 x 2.9
Size	20 ft container
Weight	<30 tons
Source	*https://www.saftbatteries.com/products-solutions/products/intensium%C2%AE-max-efficient-trackside-energy-storage*

Samsung – E3-M123: To maximize economics and efficiency, the high efficiency battery solution minimizes power loss by enabling high power output and minimizes total footprint by reducing footprint of PCS and battery systems.

SAMSUNG SAMSUNG SDI

Samsung – E3-M123

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	6.0MWh
Cell Capacity	111 Ah
Technology	
Energy	12.3 kWh
Operating Voltage	96-126 V
Dimension (W x D x H)	344 x 160 x 1,012 mm
Weight	90 kg
Size	40 ft container
Source	*http://www.samsungsdi.com/upload/ess_brochure/201803_SamsungSDI%20ESS_EN.pdf*

Samsung – E3-R135: To maximize economics and efficiency, the high efficiency battery solution minimizes power loss by enabling high power output and minimized total footprint by reducing footprint of PCS and battery systems.

SAMSUNG SAMSUNG SDI

Samsung – E3-R135

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	6.0MWh
Cell Capacity	111 Ah
Energy	135 kWh
Technology	
Operating Voltage	1,056~1,386 V
Dimension (W x D x H)	415 x 1,067 x 2,124 mm
Weight	1,170 kg
Size	40 ft container
Source	*http://www.samsungsdi.com/upload/ess_brochure/201803_SamsungSDI%20ESS_EN.pdf*

Kokam by SolarEdge – KCE (Kokam Containerized ESS) 20ft.: In addition to offering customers a wide range of standard battery solutions, Kokam also works with customers to create customized solutions to address their unique needs. Compared to general system, Kokam's system saves 70% of power consumption.

Kokam by SolarEdge – KCE (Kokam Containerized ESS) 20ft

SPECIFICATIONS	SPECIFICTION VALUE(S)	
Energy Storage	1MWh	
System Configuration	1 Bank	
Technology		
Bank Configuration	10 Racks (2C5R)	
Installed Energy	Natural Air Cooling	Forced Air Cooling
Nominal Voltage	1,516kWh	1,516kWh
Operating Voltage Range	736Vdc	736Vdc
Max. Charge Power	670 ~ 826Vdc	670 ~ 826Vdc
Peak Discharge Power	1,516kW (1P)	1,516kW (1P)
Max. Discharge Power	3,032kW (2P)	4,548kW (3P)
Round Trip DC Efficiency	1,516kW (1P)	2,880kW (1.9P)
Size	20 ft container	
Source	*https://kokam.com/ess-solution*	

Kokam by SolarEdge – KCE (Kokam Containerized ESS) 40ft.: KCE racks have an extremely compact design (Max.194.3kWh per Rack) with parallel connection up to 1MWh~10MWh. They accommodate user-specific energy and voltage requirements and are equipped with multiple layers of safety mechanisms.

Kokam by SolarEdge - KCE (Kokam Containerized ESS) 40ft

Kokam by SolarEdge

SPECIFICATIONS	SPECIFICTION VALUE(S)	
Energy Storage	2MWh	
System Configuration	2 Bank	
Technology		
Bank Configuration	13 Racks (2C5R)	
Installed Energy	Natural Air Cooling	Forced Air Cooling
Nominal Voltage	3,942kWh	3,942kWh
Operating Voltage Range	736Vdc	736Vdc
Max. Charge Power	670 ~ 826Vdc	670 ~ 826Vdc
Peak Discharge Power	3,942kW (1P)	3,942kW (1P)
Max. Discharge Power	7,884kW (2P)	11,826kW (3P)
Round Trip DC Efficiency	3,942kWh	5,518kW (1.4P)
Size	40 ft container	
Source	*https://kokam.com/ess-solution*	

Hitachi ABB – Battery Energy Storage System PQpluS™: PQpluS™ is available in a wide range of power and energy ratings, making it the right choice for end users, system integrators, and aggregators, as well as users with the right control system for utility scale applications. In addition to functions such as peak shaving and power quality, PQpluS™ can be managed by third party controller to perform site energy management, integration of renewables, and grid services.

Hitachi ABB – Battery Energy Storage System PQpluS

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	68.5 kWh per rack
Electrical Grid Connection	380 VAC-415 VAC 50/60 Hz
Electrical Rated Output	30 kW / 68.5 kWh
Inverter Rated Power (at 400 V)	30 kW per module
Technology	Lithium-ion based on NMC technology
Min 30 kW power & 68.5 kWh energy to max 360 kW &411 kWh rated system	• 2 x PQstorI (30kW each) inverter and 1 x battery rack: 60 kW (max) and 68.5 kWh (max) • 9 x PQstorI (30kW each) inverter and 4 x battery racks: 270 kW (max) and 274 kWh (max)
Power/ energy requirement above 360 kW/ 411 kWh	• Up to 32 x PQstorI inverters: max power 960 kW • Up to 14 x battery racks: max energy 960 kWh Multiple modules of inverters/ batteries can operate in parallel to build storage capacity up to 1.6 MW/ 2.2 MWh. For example, a 960 kW/ 1100 kWh rated PQpluS require the following modules: • Inverter modules: 32 modules of 30 kWh PQstorI • Battery modules: 2 off 8 x battery racks
Weight	562 kg
Source	*https://www.hitachiabb-powergrids.com/offering/product-and-system/energystorage/pqplus*

Hitachi ABB – e-mesh™ PowerStore™: Hitachi ABB Power Grids e-meshTM PowerStoreTM is a scalable microgrids and energy storage solution that is designed to ensure reliable power availability, grid stability, highest possible penetration of renewable energy together with an intelligent control system for both grid-connected and off-grid systems. e-mesh™ PowerStore™ is available in two variants, Integrated and Modular, for installations across utilities, remote communities, independent power producers, commercial, and industrial establishments.

Hitachi ABB – e-mesh™ PowerStore™:

SPECIFICATIONS	SPECIFICTION VALUE(S)
Energy Storage	50kW, 250kW, up to MW scale
Variants	Integrated and Modular
Source	*https://www.hitachiabb-powergrids.com/offering/solutions/grid-edge-solutions/our-offering/e-mesh/powerstore*

Appendix F

Appendix F: Pasadena Department of Transportation Route Modelling Results

Note: For the buses that did not go to the maximum number of laps, an estimate was taken from the lap(s) that was closest to the appropriate time of day. The red cell highlight denotes the lap where the bus drops below 20% SOC. The worst-case scenarios were modeled, with peak summer temperatures or 120F.

Table F-1: Pasadena Department of Transportation Route 10 Modeling Results

Route 10			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	14.75	22.71	15.88
2	15.97	23.57	17.1
3	17.9	23.57	19.03
4	19.5	24.21	20.63
5	20.92	24.21	22.05
6	22.05	25.12	23.18
7	22.91	25.76	24.04
8	23.55	25.76	24.68
9	23.55	25.76	24.68
10	24.46	25.35	25.59
11	25.1	25.35	26.23
12	25.1	24.07	26.23
13	24.69	22.69	25.82
14	23.41	22.69	24.54
15	22.04	20.63	23.16
16	19.97	20.63	21.1
17	18.75	19.41	19.88
Total	**364.62**	**401.49**	**383.82**

Table F-2: Pasadena Department of Transportation Route 20 Modeling Results

Route 20			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	18.63	19.45	20.34
2	20.57	21.39	22.27
3	22.17	22.99	23.87
4	23.58	24.4	25.28
5	24.71	25.53	26.42
6	25.57	26.39	27.28
7	27.12	27.94	28.83
8	27.76	28.58	29.47
9	27.76	28.58	29.47
10	27.36	28.17	29.06
11	26.07	26.89	27.78
12	24.7	25.52	26.4
13	22.63	23.45	24.34
Total	**318.63**	**329.28**	**340.81**

Table F-3: Pasadena Department of Transportation Route 31/32 Modeling Results

Route 31/32			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	26.91	23.11	24.35
2	28.04	25.05	26.29
3	28.9	26.65	27.89
4	29.55	29.19	30.43
5	30.45	30.05	31.29
6	31.09	30.7	31.94
7	31.09	31.6	32.84
8	30.69	32.24	33.48
9	29.4	31.84	33.07
10	28.03	30.55	31.79
11	25.96	29.18	30.42
12	24.74	27.11	28.35
Total	**344.85**	**347.27**	**362.14**

Table F-4: Pasadena Department of Transportation Route 40 Modeling Results

Route 40			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	20.13	21.1	21.93
2	22.06	23.04	23.87
3	23.67	24.64	25.47
4	25.08	26.05	26.88
5	26.21	27.18	28.02
6	27.07	28.04	28.87
7	28.62	29.59	30.42
8	29.26	30.23	31.06
9	29.26	30.23	31.06
10	28.85	29.83	30.66
11	27.57	28.54	29.37
12	26.2	27.17	28
13	24.13	25.1	25.93
Total	**338.11**	**350.74**	**361.54**

Table F-5: Pasadena Department of Transportation Route 51/52 Modeling Results

Route 51/52			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	23.34	24.6	27.21
2	25.28	26.53	29.14
3	26.88	28.13	30.74
4	28.29	29.55	32.16
5	29.42	30.68	33.29
6	30.28	31.54	34.15
7	31.83	33.09	35.7
8	32.47	33.73	36.34
9	32.47	33.73	36.34
10	32.06	33.32	35.93
11	30.78	32.04	34.65
12	29.41	30.66	33.28
13	27.34	28.6	31.21
Total	**379.85**	**396.2**	**430.14**

Table F-6: Pasadena Department of Transportation Route 60 Modeling Results

Route 60			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	15.39	16.21	17.1
2	16.84	17.66	18.55
3	18.04	18.86	19.75
4	19.95	20.77	21.66
5	20.6	21.41	22.3
6	21.08	21.89	22.79
7	21.76	22.57	23.46
8	22.24	23.05	23.94
9	21.93	22.75	23.64
10	20.97	21.79	22.68
11	19.94	20.76	21.65
12	18.39	19.21	20.1
Total	**237.13**	**246.93**	**257.62**

Table F-7: Pasadena Department of Transportation Route 177 Modeling Results

Route 177			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	33.15	34.84	40.8
2	36.17	37.86	43.82
3	39.13	40.82	46.78
4	41.17	42.86	48.82
5	42.83	44.52	50.48
6	43.55	45.24	51.2
7	43.2	44.88	50.84
8	40.62	42.31	48.27
Total	**319.82**	**333.33**	**381.01**

Table F-8: Pasadena Department of Transportation Route 256 Modeling Results

Route 256			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	59.15	61.91	70.99
2	63.59	66.35	75.43
3	66.65	69.41	78.49
4	69.14	71.9	80.99
5	70.22	72.98	82.07
6	69.69	72.45	81.53
7	65.83	68.59	77.67
Total	**464.27**	**483.59**	**547.17**

Table F-9: Pasadena Department of Transportation Route 88 Modeling Results

Route 88			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	20.95	21.99	24.44
2	22.15	23.19	25.64
3	23.21	24.25	26.7
4	24.06	25.1	27.55
5	25.18	26.22	28.68
6	25.86	26.9	29.36
7	26.34	27.38	29.84
8	26.34	27.38	29.84
9	26.04	27.08	29.53
10	25.07	26.12	28.57
Total	**245.2**	**255.61**	**280.15**

Table F-10: Pasadena Department of Transportation Route H Modeling Results

Route H			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	16.1	16.73	18.48
2	16.67	17.3	19.06
3	17.12	17.75	19.51
4	17.12	17.75	19.51
5	17.48	18.11	19.86
6	17.96	18.58	20.34
7	17.96	18.58	20.34
8	18.32	18.94	20.7
9	18.32	18.94	20.7
10	18.14	18.76	20.52
11	18.14	18.76	20.52
12	17.51	18.14	19.89
13	16.85	17.48	19.23
Total	**227.69**	**235.82**	**258.66**

Table F-11: Pasadena Department of Transportation Route 51/52S Modeling Results

Route 51/52S			
Lap	OEM 1 (kWh/lap)	OEM 2 (kWh/lap)	OEM 3 (kWh/lap)
1	23.34	24.6	27.21
2	26.88	28.13	30.74
3	28.29	29.55	32.16
4	30.28	31.54	34.15
5	30.93	32.18	34.79
6	32.47	33.73	36.34
7	32.47	33.73	36.34
8	32.06	33.32	35.93
9	29.41	30.66	33.28
10	27.34	28.6	31.21
Total	**293.47**	**306.04**	**332.15**

Appendix G

Appendix G: Pasadena Department of Transportation Service Changes

Route 20 is an example of a route where the number of buses that need to be deployed can be reduced by redistributing some of the laps in a more equitable manner. If this is done, the BEBs can serve as a drop-in replacement for all OEMs. **Table G-1** below provides an energy analysis if the laps are more equitably distributed between the buses.

Table G-1: Route 20 Energy Analysis with Redistributed Laps

Route	Bus	# of Laps	OEM 1	OEM 2	OEM 3
20CW	1	9	222.99	241.07	249.03
	2	9	222.99	241.07	249.03
	3	10	233.35	253.43	262.28
	4	9	210.32	228.39	233.22
	5	5	101.16	116.8	121.25
20CC	1	11	258.23	280.32	290.05
	2	8	180.61	196.67	203.75
	3	9	222.99	241.07	249.03
	4	8	185.44	201.5	208.58
	5	5	101.17	127.03	131.44

Route 31/32 is a route where the number of laps each bus performs is distributed inequitably. Some of the buses on this route are not able to serve as a drop-in replacement and the modelling indicates that two of the buses will return to the depot with less than 10% SOC. Redistributing the laps would beneficial as it would reduce the energy requirements for some buses. Due to scheduling issues, the ability to redistribute laps between buses is very limited. However, if redistribution occurs, it reduces the number of laps that the most active bus must perform. This redistribution is not enough to make both of these buses drop-in replacements. However, it does reduce the laps that one of the buses will have to perform, which opens up the possibility of the route becoming a drop-in replacement in the future with advances in technology. See **Table G-2** below for this analysis.

Table G-2: Route 31/32 Energy Analysis with Redistributed Laps

Route	Bus	# of Laps	OEM 1	OEM 2	OEM 3
31/32	1	11	320.13	324.17	337.79
	2	10	294.17	290.99	303.37
	3	11	317.97	339.23	357.84
	4	2	54.95	48.16	50.64

Route completed with SOC of less than 10 percent

Route completed with SOC of 10 percent or more

Route 51/52 is another route where the number of buses required can be reduced by redistributing some of the laps in a more equitable manner. If this is done, the BEBs can serve as a drop-in replacement for all OEMs. **Table G-3** below provides an energy analysis if the laps are more equitably distributed between the buses.

Table G-3: Route 51/52 Energy Analysis with Redistributed Laps

Route	Bus	# of Laps	OEM 1	OEM 2	OEM 3
51/52	1	7	216.37	225.16	243.44
	2	6	165.55	175.75	191.42
	3	7	191.31	204.11	222.39

Appendix H

Appendix H: Resiliency Methodology

To analyze resiliency solutions, CALSTART used the MDT. MDT allows users to input relevant site-specific characteristics such as energy consumption (including time of use), power demand load schedules, frequency of outages and grid failures, and solar energy production potential. Users also select what types of DERs can be included in the energy portfolio and input equipment characteristics such as estimated capital expenditures and fuel utilization rates. Once this data is input into the model, the user can specify performance objectives that the resiliency measures are intended to achieve. MDT then provides quantitative analysis to determine feasible designs that can meet all of the performance objectives. MDT assumes that there are tradeoffs between the different design objectives. For example, increasing the reliability and time that the microgrid can operate involves installing additional generation and storage assets, which increases the cost. To balance these tradeoffs, MDT's algorithms create a Pareto frontier to optimize performance of the design parameters. It then recommends designs on the Pareto frontier that are able to meet all of the design parameters.

CALSTART's MDT model optimized for several criteria. The first criteria was capital expenditures and aimed to design a microgrid at the lowest cost possible. The second criteria was energy availability, or the percentage of the load's needs that can be provided by the resiliency assets. The energy portfolio was designed to attain a minimum energy availability of 95%. MDT was also programmed to maximize the use of solar energy. Only designs that can meet all of these parameters are considered viable.

MDT was also programmed to consider a variety of microgrid components. MDT was programmed to consider solar panels and battery storage as power sources. The software was also programmed to consider natural gas turbines.

The assumptions programmed into MDT are shown in **Tables H-1 and H-2**:

Table H-1: MDT Assumptions for Renewable Energy Sources

Renewables	Costs
Carport Solar Cost	\$1.72 per W dc (Feldman, 2021)
Battery Cost (installed, including balance of system)	\$469/kWh (Feldman, 2021)
Battery Maintenance Cost	2.5% of battery cost over life of the battery (W. Cole, 2020)

Table H-2: MDT Assumptions for Generators

Generators	Costs (Ericson, 2019)
Diesel Generator (CAPEX, installed)	\$800/kW
Diesel Generator Maintenance Costs	\$35/kW/year
Diesel Fuel Costs	\$4/gallon
Diesel Generator Startup Success Rate	94.7%
Natural Gas Generator (CAPEX, installed)	\$1000/kW
Natural Gas O&M Costs	\$35/kW/year
Natural Gas Fuel Costs	\$0.70/therm
Natural Gas Generator Reliability	97.3%
Natural Gas Storage Tank	\$100,000 (U.S. DOE, 2014)

CALSTART also provided analysis about resiliency systems that provide resiliency using 100% renewable energy. This option would entail using on-site solar and storage. NREL's REopt Lite tool was used to provide this analysis. NREL's REopt Lite tool allows users to input site-specific information, which can be included in the analysis. REopt Lite was used to calculate the required specifications of a solar and storage system that can provide 100% resiliency to the fleet during a seven-day outage. REopt Lite then provided the required size of the PV system and required the power capacity and energy storage capacity of the battery that would be required to provide full resiliency.

Once these outputs were provided, the required physical footprint of the solar PV system was calculated. NREL's PVWatts tool uses the following formula to calculate the required solar PV array area that is required:

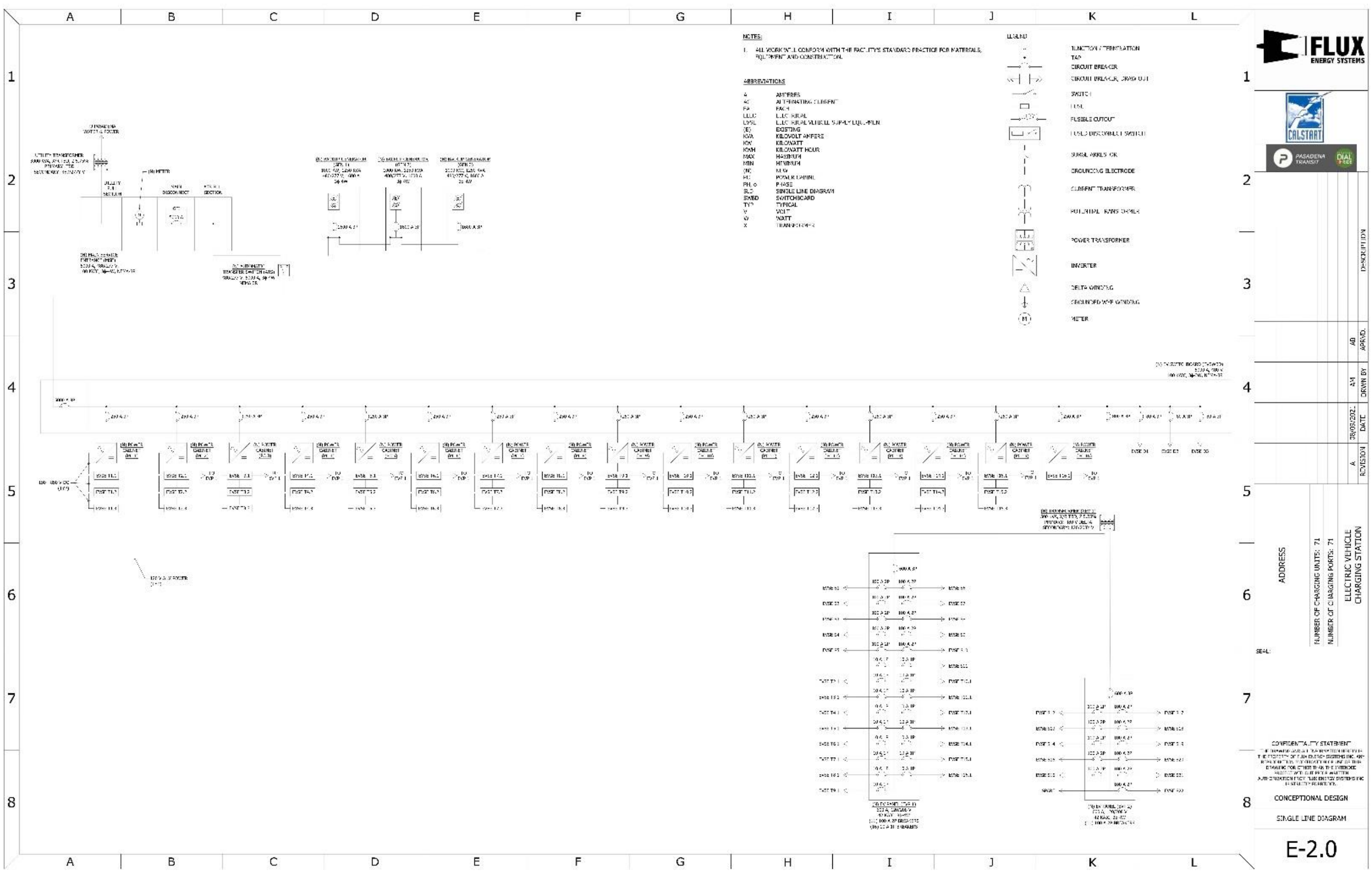
$$Size\ (kW) = Array\ Area\ (m^2)\ x\ \frac{1\ kW}{m^2}\ x\ Module\ Efficiency\ (\%)$$

This analysis assumed that solar PV modules have an efficiency of 19%.

Appendix I

Appendix I: Pasadena Department of Transportation Conceptual Framework and Supporting Documents

Figure I-1: Pasadena Department of Transportation Single-Line Diagram



PANEL SCHEDULE: EV SWITCHBOARD (EVSWBD)

VOLTAGE (L-N): N/A	ENCLOSURE TYPE: NEMA 3R
VOLTAGE (L-L): 480	MOUNTING: PAD
PHASE: 3	KAIC RATING: 100
WIRES: 3	LOCATION: OUTDOOR
MINIMUM BUS CAPACITY (A): 5000	NOTES:
MAIN OCPD (A): 5000	

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	A	A	B	B	C	C	POLE	TRIP AMPS	DESCRIPTION	CKT NO.
1				50000	50000								2
3	FC 1	250	3			50000	50000			3	250	FC 9	4
5								50000	50000				6
7				50000	50000								8
9	FC 2	250	3			50000	50000			3	250	FC 10	10
11								50000	50000				12
13				50000	50000								14
15	FC 3	250	3			50000	50000			3	250	FC 11	16
17								50000	50000				18
19				50000	50000								20
21	FC 4	250	3			50000	50000			3	250	FC 12	22
23								50000	50000				24
25				50000	50000								26
27	FC 5	250	3			50000	50000			3	250	FC 13	28
29								50000	50000				30
31				50000	50000								32
33	FC 6	250	3			50000	50000			3	250	FC 14	34
35								50000	50000				36
37				50000	50000								38
39	FC 7	250	3			50000	50000			3	250	FC 15	40
41								50000	50000				42
43				50000	50000								44
45	FC 8	250	3			50000	50000			3	250	FC 16	46
47								50000	50000				48
49				118004	18000								50
51	XFM1	800	3			117600	18000			3	90	EVSE D1	52
53								131440	18000				54
55				19000	19000								56
57	EVSE D2	80	3			19000	19000			3	90	EVSE D3	58
59								19000	19000				60
	CONNECTED LOAD PER PHASE (KVA)			972		972		988					
	CONNECTED LOAD PER PHASE (A)			3503		3503		3563					
	TOTAL DEMAND LOAD[1] (KVA)					2502							

LOAD SCHEDULE

LOAD	QUANTITY	POWER (KW)	VOLTAGE (V)	CURRENT (A)
EV CHARGER (ABB HVC 150C)	46	150	480	200
EV CHARGER (CLIPPERCREEK CS-100)	22	16.64	208	80
EV CHARGER (ABB TERRA 54)	3	50	150 - 920 VDC	125
LOAD[1]		7415.1		

1. LOAD MANAGEMENT SOFTWARE WILL LIMIT BUS CHARGING LOAD TO A MAXIMUM OF [illegible] KW [illegible]

PANEL SCHEDULE: EV PANEL 1 (EVP 1)

VOLTAGE (L-N): 120	ENCLOSURE TYPE: NEMA 3R
VOLTAGE (L-L): 208	MOUNTING: RACK
PHASE: 3	KAIC RATING: 42
WIRES: 4	LOCATION: OUTDOOR
MINIMUM BUS CAPACITY (A): 600	NOTES:
MAIN OCPD (A): 600	

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	A	A	B	B	C	C	POLE	TRIP AMPS	DESCRIPTION	CKT NO.
1	EVSE S1	100	2	8320	-			-	8320	2	100	EVSE S6	2
3						8320	8320						4
5	EVSE S2	100	2					8320	8320	2	100	EVSE S7	6
7				8320	8320								8
9	EVSE S3	100	2			8320	8320			2	100	EVSE S8	10
11								8320	8320				12
13	EVSE S4	100	2	8320	8320					2	100	EVSE S9	14
15						8320	8320						16
17	EVSE S5	100	2					8320	8320	2	100	EVSE S10	18
19				8320	8320								20
21	EVSE T1.1	10	1			264	8320			2	100	EVSE S11	22
23	EVSE T2.1	10	1					264	8320				24
25	EVSE T3.1	10	1	264	264					1	10	EVSE T10.1	26
27	EVSE T4.1	10	1			264	264			1	10	EVSE T11.1	28
29	EVSE T5.1	10	1					264	264	1	10	EVSE T12.1	30
31	EVSE T6.1	10	1	264	264					1	10	EVSE T13.1	32
33	EVSE T7.1	10	1			264	264			1	10	EVSE T14.1	34
35	EVSE T8.1	10	1					264	264	1	10	EVSE T15.1	36
37	EVSE T9.1	10	1	264	264					1	10	EVSE T16.1	38
	CONNECTED LOAD PER PHASE (VA)			59624		59660		67880					
	CONNECTED LOAD PER PHASE (A)			499		495		565					
	TOTAL DEMAND LOAD[1] (KVA)					107							

PANEL SCHEDULE: EV PANEL 2 (EVP 2)

VOLTAGE (L-N): 120	ENCLOSURE TYPE: NEMA 3R
VOLTAGE (L-L): 208	MOUNTING: RACK
PHASE: 3	KAIC RATING: 42
WIRES: 4	LOCATION: OUTDOOR
MINIMUM BUS CAPACITY (A): 600	NOTES:
MAIN OCPD (A): 600	

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	A	A	B	B	C	C	POLE	TRIP AMPS	DESCRIPTION	CKT NO.
1	EVSE S12	100	2	8320	-			-	8320	2	100	EVSE S17	2
3						8320	8320						4
5	EVSE S13	100	2					8320	8320	2	100	EVSE S18	6
7				8320	8320								8
9	EVSE S14	100	2			8320	8320			2	100	EVSE S19	10
11								8320	8320				12
13	EVSE S15	100	2	8320	8320					2	100	EVSE S20	14
15						8320	8320						16
17	EVSE S16	100	2					8320	8320	2	100	EVSE S21	18
19				8320	8320								20
21	SPARE	-	-				8320			2	100	EVSE S22	22
23								-	8320				24
	CONNECTED LOAD PER PHASE (VA):			58240		58240		66560					
	CONNECTED LOAD PER PHASE (A):			280		280		320					
	TOTAL DEMAND LOAD[1] (KVA):					183							

1. LOAD MANAGEMENT SOFTWARE LIMITS OVERALL CHARGING LOAD. LOADS SHOWN IN PANEL SCHEDULES ARE FOR SIZING CONDUCTORS AND OVERCURRENT PROTECTION

FLUX ENERGY SYSTEMS

REVISION	DATE	DRWN BY	APRVD.
A	28/09/2021	AM	AB

ADDRESS

NUMBER OF CHARGING UNITS: 71

NUMBER OF CHARGING PORTS: 71

ELECTRIC VEHICLE CHARGING STATION

SEAL:

CONCEPTIONAL DESIGN

LOAD CALCULATIONS

E-2.1

Figure I-2: Pasadena Department of Transportation Design Memo

1. Objective

Flux Energy Systems, Inc. (Flux) was engaged by CALSTART, Inc to complete conceptual designs of electric bus charging infrastructure for Pasadena Transit. Pasadena Transit is planning a new Transit Center in Pasadena, CA to serve twenty-two (22) shuttle buses as well as transit buses. Pasadena Transit has not yet defined the quantity of transit buses, so this document evaluates the relevant design codes, physical space requirements, electrical infrastructure, charging requirements and back-up generators for emergency site power for two potential configurations. This document should be used with the Single Line Diagram and Load Schedule also completed by Flux for this project.

2. Relevant Design Codes

The project should be designed to consider, at a minimum, the following building and electrical codes:

- 2019 California Electrical Code
- 2017 National Electrical Code (NFPA 70)
- 2019 California Building Code
- 2019 California Fire Code
- 2006 Pasadena Electrical Service Requirements Regulation 21

3. Site Design Assumptions

In developing the electric vehicle charging plan, Flux considered the following design requirements as specified by Pasadena Transit:

- Transit Buses:
  - Total quantity of chargers: To be determined
  - Charging duration: 11pm – 5am (6 hours)
- Shuttle Buses:
  - Total quantity of chargers: 25
    - 22 standard chargers
    - 3 DC fast chargers
  - Charging duration: 9pm – 6am (9 hours)

4. Equipment Electrical and Physical Requirements

The electrical specifications for the charging equipment used to model the system are defined in Table 1.

Table 1. Charging equipment for electric transit and shuttle buses

Charger Type	Max Output Power (kW)	Voltage (V)	Max Input Current (A)
ABB HVC 150C (Transit Bus)	150	480 VAC	200
ClipperCreek CS-100 (Dial-a-Ride Shuttle Bus)	16.64	208 VAC	80
ABB Terra 54 (Dial-a-Ride Shuttle Bus)	50	480 VAC	64

Flux used the electric transit and shuttle buses in Table 2 to define maximum power and total energy needed for the site. While the exact load management strategy has not yet been defined, Flux assumed a charging profile that preserves Lithium-Ion battery health thus reducing the long-term effects of battery degradation. Upon final equipment selection, coordination with the load management software provider and bus battery manufacturer should be completed to finalize the electrical loading. Refer to the Load Schedule for the charging profile.

Table 2. Charging equipment for electric transit and shuttle buses

Bus Type	Max Input Power (kW)	Battery Size (kWh)	Range (miles)
Transit Bus	150	225	95 – 125
Dial-a-Ride Shuttle Bus	16.64	94	100

The footprint of the selected charging equipment was used to determine physical space requirements on site. Table 3 provides the total equipment footprint area. This value excludes equipment clearance requirements, but clearance requirements as indicated by the equipment specifications and relevant codes were incorporated in the overall equipment placement on the site.

Table 3. Total equipment footprint Area

Equipment Type	Equipment Width (ft)	Equipment Depth (ft)	Total Equipment Footprint Area (sq ft)
ABB HVC 150C Power Cabinet	3.8	2.5	9.7
ABB HVC 150C Depot Charger Box	1.9	0.7	1.4
ClipperCreek CS-100 Charger	1.4	1	1.4
ABB Terra 54 Charger	1.8	2.6	4.7

Parking stall dimensions for the transit buses and shuttle buses were assumed based on Table 4. These dimensions were used to determine the required physical footprint of the proposed transit center for the options that were evaluated. The transit buses were to be diagonal parking stalls. Meanwhile shuttle buses were designed for perpendicular stalls. Drive aisles between the parking rows were designed to be forty-five (45) feet.

Table 4. Parking stall dimensions for the transit buses and shuttle buses

Parking Stall Type	Dimensions (ft x ft)	Total Area (sq ft)
Transit Bus	40 x 12	480
Shuttle Bus	26 x 9	234

In addition to providing charging equipment to satisfy fleet electrification goals, site resiliency options were explored. Several alternatives were considered including solar and storage as well as natural gas generators. Since a site has not been selected for the bus depot, a solar plus storage resiliency option could not be evaluated. As a result, , natural gas generators were selected as the resiliency measure. Natural gas generators were sized to satisfy peak charging demands over the course of one day. Additionally, compressed natural gas tanks were provided on site to with fuel reserves for one day of generation to meet site loads.

5. Proposed Designs

Pasadena Transit has not yet finalized the total quantities of transit buses at the future Transit Center, so Flux analyzed the physical space required for two options as defined in Table 5. Flux also evaluated the electrical infrastructure to power Option 1 by the utility as well as the infrastructure for emergency back-up power.

Table 5. Quantity of parking stalls for two design options

	Option 1 (Qty)	Option 2 (Qty)
Transit Bus	46	64
Dial-a-Ride Shuttle Bus	22	22
DC Fast Charger	3	3
Total	71	89

Option 1.

Based on the above-mentioned design criteria, a preliminary conceptual site plan was developed to incorporate twenty-two (22) perpendicular parking stalls for Dial-a-Ride shuttle buses, three (3) perpendicular stalls for shuttle DC fast charging, and forty-six (46) diagonal parking stalls for transit buses as shown in Figure 1. An approximate area of 111,500 square feet would be required to implement the parking stalls, charging infrastructure including relevant trenching, as well as drive aisles for vehicular mobility. Table 6 provides a breakdown of the parking stall and drive aisle area per the design assumptions.

Figure 1. Option 1 Conceptual Site Plan. "S" denotes shuttle bus charging stalls and "T" transit bus.

Table 6. Option 1 parking stall and drive aisle area per the design assumptions

	Quantity	Width (feet)	Length (feet)	Total Footprint (square feet)
Transit Bus Parking Stall	46	12	40	22,080
Shuttle Bus Parking Stall	25	9	26	5,850
Center Drive Aisle	2	45	395	35,550
Perpendicular Drive Aisle	2	30	237	14,220

The required electrical equipment for this option is outlined in Table 7. Refer to the Single Line Diagram for more detailed equipment specifications.

Table 7. Required electrical equipment for option 1

Equipment	Quantity
Transit Bus Power Cabinet (ABB HVC 150C)	16
Transit Bus Depot Charger (ABB HVC 150C)	46
Shuttle Bus Charger (ClipperCreek CS-100)	22
DC Fast Charger (ABB Terra 54)	3
Electric Bus Switchboard (480 V)	1
Electrical Panelboard (120 / 208 V)	2
Transformer (Primary: 480 V, Secondary: 120/208 V)	1
Utility Transformer	1
Main Service Switchboard	1
Natural Gas Generator	3
Automatic Transfer Switch	1
Natural Gas Fuel Tank	1

In the event of a grid outage, the Transit Agency would not be able to maintain its service, so Flux evaluated options for emergency back-up power. For this conceptual design, natural gas generators were were selected to satisfy charging demands over the course of one day. Based on the charging demands, three (3) 1000 kW/1250 kVA natural gas generators and one (1) standard size 2,000 gallon compressed natural gas tank would be required. If the natural gas generators and the fuel tank were to be installed on site, it would require an approximate area of 1,310 square feet. See Table 8 for the required footprint for this equipment on the project site. The total equipment footprint provided in Table 8 does not include clearance requirements.

Table 8. footprint of generators project site

Equipment	Quantity	Width / Diameter (ft)	Length (ft)	Total Area
1000 kW Natural Gas Generator	3	8.8	27.4	723.4 square feet
2000-gallon Natural Gas Tank	1	5.4	11.8	63.7 square feet

Option 2.

An alternative preliminary conceptual site plan was developed to incorporate ten (10) perpendicular parking stalls for Dial-a-Ride shuttle buses, three (3) perpendicular stalls for shuttle bus DC fast charging, and sixty-four (64) diagonal parking stalls for transit buses as shown in Figure 2. An approximate area of 147,600 square feet would be required to implement the parking stalls, charging infrastructure, and drive aisles for vehicular mobility. Table 10 provides a breakdown of the parking stall and drive aisle area per the design assumptions. A single line diagram and load schedule was not created for this option nor was back-up power considered.

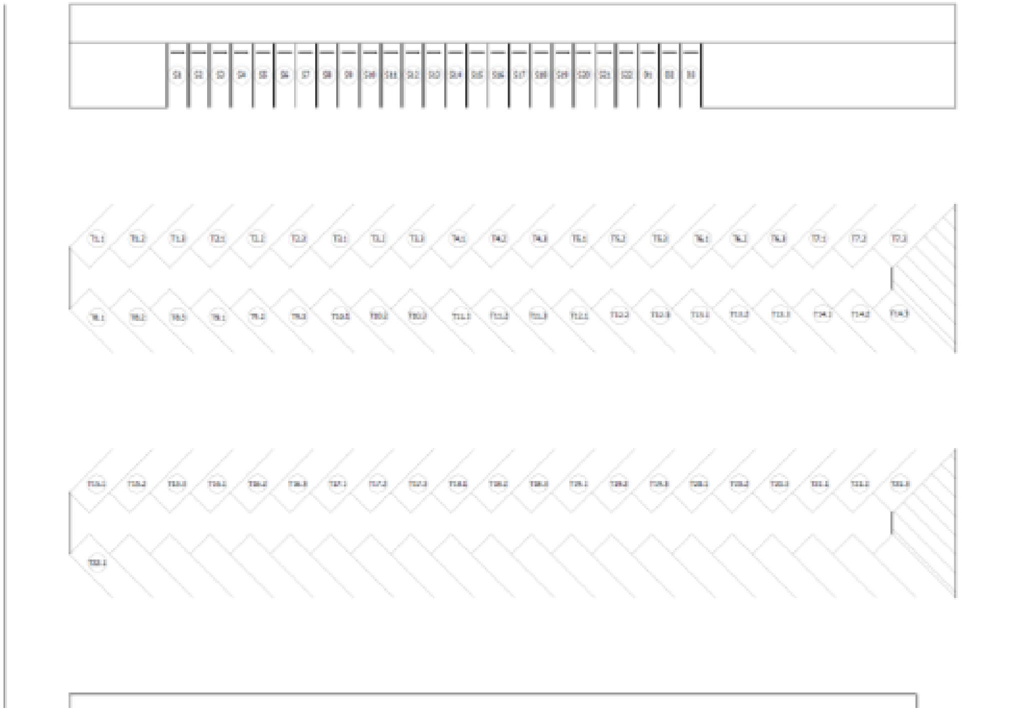


Figure 2. Option 2 Conceptual Site Plan. "S" denotes shuttle bus charging stalls and "T" transit bus.

Table 9. Option 2 parking stall and drive aisle area per the design assumptions

	Quantity	Width (feet)	Length (feet)	Total Footprint (square feet)
Transit Bus Parking Stall	64	12	40	30,720
Shuttle Bus Parking Stall	25	9	26	5,850
Center Drive Aisle	3	45	395	53,325
Perpendicular Drive Aisle	2	30	297	17,820

The required list of electrical equipment for this option is outlined in Table 10.

Table 10. Required electrical equipment for option 1

Equipment	Quantity
Transit Bus Power Cabinet (ABB HVC 150C)	22
Transit Bus Depot Charger (ABB HVC 150C)	64
Shuttle Bus Charger (Clippercreek CS-100)	22
DC Fast Charger (ABB Terra 54)	3
Electric Bus Switchboard (480 V)	3
Electrical Panelboard (120 / 208 V)	2
Transformer (Primary: 480 V, Secondary: 120/208 V)	1
Utility Transformer	1
Main Service Switchboard	1
Automatic Transfer Switch	1

Appendix J

Appendix J: Cost Estimates Methodology

When developing the cost estimates in this report, CALSTART considered several factors. CALSTART's projections modeled the costs that will be incurred between 2021 and 2040. The projections divided costs into two categories: capital expenditures and operational expenditures. Capital expenditures consist of one-time expenses that are required to obtain buses and equipment. The capital expenditures that were considered in the cost estimates include the cost of transit and shuttle buses, driver and maintenance training, charging/fueling infrastructure, utility infrastructure (for BEB cost estimates only), and resiliency assets (for BEB cost estimates only). Operational expenditures represent ongoing costs associated with running the fleet. This includes bus maintenance costs, infrastructure maintenance, and utility/fueling costs. Operational expenditures also include major midlife repairs to the buses. For CNG buses, this would include the cost of replacing the engine. This is assumed to occur in year six of bus operations. For BEBs and FCEBs, this would include the cost of replacing the battery or fuel cell midway through the life of the bus. BEB and FCEB manufacturers offer an extended warranty that covers the battery or fuel cell system for the entire lifetime of the bus (12 years/500,000 miles). The cost of the extended warranty was used as the midlife replacement cost for ZEBs. CALSTART provided cost comparisons for scenarios where the City of Pasadena deploys a fully CNG, BEB, and FCEB fleet. CNG fleet cost estimate assumptions are described in **Table J-1**.

Table J-1: CNG Fleet Cost Estimates Assumptions:

Expense	Assumptions
Transit Buses (including equipment such as farebox, security cameras, etc.)	$650,000
Shuttle Buses (including equipment such as farebox, security cameras, etc.)	$180,000
Driver and Maintenance Training	$0 (Not required for CNG buses)
CNG Fueling Infrastructure	$0 (Assuming thePasadena Department of Transportation uses existing CNG fueling stations and infrastructure)
Bus Maintenance	$0.23/mile
CNG/RNG Fuel Costs	Based on historical CNG/RNG bills for The City of Pasadena
Transit Bus Mid-life Engine Replacement	$47,000 (CARB, 2018)
Shuttle Bus Mid-life Engine Replacement	$21,000 (CARB, 2018a)

The assumptions for the cost estimates for a BEB fleet are based on plug-in charging. According to these scenarios, the buses will be charged overnight and will not use any on-route charging. The cost estimates also assume that the buses will be deployed according to the fleet replacement plan. **Table J-2** explains the assumptions that were used for each of these expenses:

Table J-2: BEB Fleet Cost Estimates Assumptions:

Expense	Assumptions
Transit Buses	Averaged cost of the transit bus OEMs (according to the statewide contracts) + $30,000 for cost of auxiliary equipment (farebox, security cameras, etc.)
Shuttle Buses	Averaged cost of the shuttle bus OEMs + $30,000 for cost of auxiliary equipment (farebox, security cameras, etc.)
Driver and Maintenance Training	Costs according to the statewide contracts
Charging Infrastructure	See Charging Infrastructure Cost Estimates section on page 152.
Utility Infrastructure	Estimates based on interviews with municipal utilities
Resiliency Assets	See assumptions in Appendix H: Resiliency Methodology
Bus Maintenance	$0.48/mile
Infrastructure Maintenance	$1,500 per charging cabinet (Johnson, 2020)
Utility Costs	Based on PWP utility rates. Utility costs were assumed to scale linearly as buses are deployed.
Mid-life Battery Replacement	Average cost of the extended warranty for the battery (12 years/500,000 mile warranty)

The assumptions for the cost estimates for an FCEB fleet are based on the cheapest method of hydrogen production for each agency. The cost estimates also assume that the buses will be deployed according to the fleet replacement plan. **Table J-3** explains the assumptions that were used for each of these expenses.

Table J-3: FCEB Fleet Cost Estimates Assumptions:

Expense	Assumptions
Transit Buses	Averaged cost of the transit bus OEMs (according to the statewide contracts) + $30,000 for cost of auxiliary equipment (farebox, security cameras, etc.)
Shuttle Buses	Averaged cost of the shuttle bus OEMs + $30,000 for cost of auxiliary equipment (farebox, security cameras, etc.)
Driver and Maintenance Training	Costs according to the statewide contracts
Hydrogen Fueling Infrastructure	See Hydrogen Fueling Infrastructure Cost Estimates section on page 152.
Bus Maintenance	$0.56
Infrastructure Maintenance	The HDRSAM Model estimates the operation and maintenance cost for the hydrogen station.
Hydrogen Costs	See Table N-11
Mid-life repairs	Average cost of the extended warranty for the fuel cell system (12 years/500,000 mile warranty)

Charging Infrastructure Cost Estimates

CALSTART calculated the costs associated with deploying bus chargers. To deploy charging infrastructure, upgrades must be made to the depot. This can include the installation of electrical components such as transformers and electrical panels. It includes trenching and the installation of conduit and wires. It also includes the installation of safety equipment such as wheel stops and bollards. **Table J-4** outlines the cost assumptions associated with each type of upgrade.

Table J-4: Charging Infrastructure Equipment Cost Assumptions

Equipment	Unit Cost	Source
1500 kVA Utility Transformer	$92,000	NREL Distribution System Upgrade Cost Database (Horowitz, 2019)
Main Disconnect	$12,500	NREL Distribution System Upgrade Cost Database
Meter	$6,000	Southern California Edison (SCE, 2021)
Automatic Transfer Switch	$43,000	Average of prices from automatic transfer switch distributors
Panel Board	$3,000	Average of prices from panel board distributors
225 kVA Transformer	$53,000	NREL Distribution System Upgrade Cost Database
Transit Bus Chargers (per bus)	$35,000-$45,000	Average of prices from transit bus charger manufacturers
Shuttle Bus Chargers (per bus)	$3,000	Average of prices from shuttle bus charger manufacturers
Bollards	$800	DOE Costs Associated With Non-Residential EVSE (U.S. DOE, 2015)
Wheel Stops	$100	DOE Costs Associated With Non-Residential EVSE
Trenching (per foot)	$150	DOE Costs Associated With Non-Residential EVSE

The conceptual designs were used to identify the equipment that is required to install charging infrastructure on each site. This information was used to estimate the cost of equipment. According to the DOE, equipment costs are typically 35% of the total installed cost (U.S. DOE, 2015). The equipment costs were adjusted by this factor to determine total installed cost. The figures do not include resiliency. The assumptions for determining the cost of resiliency are outlined in Appendix H.

Table J-5: Charging Infrastructure Cost Estimates

Transit Agency	Estimated Charging Infrastructure Cost
The City of Pasadena	$6,600,000

Please note that these cost estimates in **Table J-5** are for budgetary purposes only and are based on high-level conceptual designs. The actual cost of charging infrastructure will depend on market conditions at the time of construction. Full engineering documents and cost estimates should be developed before issuing an RFP for this project.

Hydrogen Fueling Infrastructure Cost Estimates

CALSTART calculated the costs associated with deploying hydrogen fueling infrastructure. The capital expenditures associated with deploying hydrogen infrastructure consists of the cost of a hydrogen fueling station and the cost of hydrogen production equipment. CALSTART used Argonne National Laboratory's HDRSAM to calculate the cost of a fueling station. HDRSAM allows users to input parameters for a hydrogen station. CALSTART produced fuel station cost estimates for several scenarios including on-site hydrogen production via SMR, on-site hydrogen production via electrolysis, delivered gaseous hydrogen, and delivered liquid hydrogen. CALSTART customized the parameters based on the needs of each individual fleet. **Tables J-6 to J-8** outline the parameters used for each of these scenarios.

Table J-6: On-site Hydrogen Production HDRSAM Assumptions

Parameter	Pasadena Department of Transportation
Station Type	Gaseous Hydrogen
Hydrogen Source	20 bar H2 supply
Fleet Size (buses being fueled per day)	31 buses
Dispensing Options	350 bar Cascade dispensing
Production Volume	Mid
Assumed Start-up Year	2027
Construction Period	1 year
Analysis Period	20 years
Max Dispensed Hydrogen per Vehicle	25 kg
Fueling Rate	3.6 kg/minute
Vehicle Lingering Time	2 minutes
Number of Dispensers	2
Maximum Number of Fills per Hour	6

Table J-7: Delivered Gaseous Hydrogen HDRSAM Assumptions

Parameter	Pasadena Department of Transportation
Station Type	Gaseous Hydrogen
Hydrogen Source	Tube-Trailer Supply
Fleet Size (buses being fueled per day)	31 buses
Dispensing Options	350 bar Cascade dispensing
Production Volume	Mid
Assumed Start-Up Year	2027
Construction Period	1 year
Analysis Period	20 years
Max Dispensed Hydrogen per Vehicle	25 kg
Fueling Rate	3.6 kg/minute
Vehicle Lingering Time	2 minutes
Number of Dispensers	2
Maximum Number of Fills per Hour	6

Table J-8: Delivered Liquid Hydrogen HDRSAM Assumptions

Parameter	Pasadena Department of Transportation
Station Type	Gaseous Hydrogen
Dispensing Option	350 bar via vaporization and compression
Fleet Size (buses being fueled per day)	31 buses
Dispensing Options	350 bar Cascade dispensing
Production Volume	Mid
Assumed Start-up Year	2027
Construction Period	1 year
Analysis Period	20 years
Max Dispensed Hydrogen per Vehicle	25 kg
Fueling Rate	3.6 kg/minute
Vehicle Lingering Time	2 minutes
Number of Dispensers	2
Maximum Number of Fills per Hour	6

All other parameters in the model that were not listed in **Tables J-6 to J-8** were set to the default values.

Table J-9: Fueling Station Costs

Hydrogen Pathway	Pasadena Department of Transportation
On-site SMR	$3,411,019
On-site Electrolysis	$3,411,019
Delivered Gaseous Hydrogen	$2,208,627
Delivered Liquid Hydrogen	$2,370,162

It is important to note that the cost of a fueling station (see **Table J-9**) is dependent on the hydrogen pathway pursued. The difference in cost is due to the fact that each pathway requires different infrastructure.

The other component of fueling infrastructure capital expenditures is the cost of production equipment. It is important to note that delivered hydrogen pathways do not require any production equipment because the hydrogen is not produced on-site. However, on-site SMR and on-site electrolysis production pathways require the installation of production equipment. On-site SMR equipment was assumed to incur a capital cost of $1,238,987. This figure is the default capital expenditure for SMR equipment from NREL's H2A Model. On-site electrolyzer equipment is assumed to have a capital cost of $3 million (J. Cole, 2020).

The operational costs of the hydrogen fleet were also calculated. The operational costs are recurring costs that occur on an annual basis. CALSTART investigated hydrogen infrastructure maintenance costs and the cost of hydrogen. Hydrogen infrastructure maintenance costs were estimated using the HDRSAM Model. Based on the results of the HDRSAM Model, the annual maintenance costs were calculated and recorded in **Table J-10**.

Table J-10: Annual Maintenance Costs

Hydrogen Pathway	Pasadena Department of Transportation
On-site SMR	$179,506
On-site Electrolysis	$179,506
Delivered Gaseous Hydrogen	$153,781
Delivered Liquid Hydrogen	$209,175

CALSTART also explored the cost of hydrogen. The cost of hydrogen was explored on a levelized per kg basis. Based on interviews with the hydrogen industry, CALSTART assumed that hydrogen produced via on-site SMR could be obtained for $6 per kg. The cost of on-site electrolysis production was calculated using PWP's utility rates. The cost of delivered gaseous and liquid hydrogen was assumed to be $8 per kg. However, there is a cost to dispense hydrogen, as the dispensing process uses fuel and energy. HDRSAM produced estimates for the cost of dispensing. This amount was added to the cost of the hydrogen, as seen below in **Table J-11**.

Table J-11: Cost of Hydrogen

Hydrogen Pathway	Pasadena Department of Transportation
On-site SMR	$6.57
On-site Electrolysis	$10.37
Delivered Gaseous Hydrogen	$8.10
Delivered Liquid Hydrogen	$8.37

Appendix K

Appendix K: LCFS Calculation Methodology

The number of LCFS credits that an agency can earn is calculated according to the following formula:

$$\#\ of\ LCFS\ Credits = CI\ Standard - \left(\frac{CI\ Electricity}{EER}\right) x\ Energy\ Density\ x\ EER\ x\ kWh\ x\ 10^{-6}$$

The Carbon Intensity (CI) Standard variable represents the standard baseline value for carbon intensity of energy (as measured in grams of CO2 equivalent per megajoule of energy) that CARB had designated to use as a benchmark from which to calculate savings of emissions. CI Standard depends on the type of fuel that is being displaced by the zero-emission vehicles. The two fuels that were examined in this report include diesel (which is being displaced by zero-emission transit buses) and gasoline (which is being displaced by zero-emission shuttle buses). CARB designates a different CI Standard value each year for each type of fuel. This value is scheduled to decrease over time, which makes it more difficult to earn LCFS credits over time. The CI Standard changes according to the following schedule in **Figures K-1 and K-2**:

Table K-1: CI Standard for Diesel and Fuels Intended to Replace Diesel (CARB, 2020)

Year	Average Carbon Intensity (gCO_2e/MJ)	Year	Average Carbon Intensity (gCO_2e/MJ)
2010	Reporting Only		
2011*	94.47	2021	91.66
2012	94.24	2022	90.41
2013**	97.05	2023	89.15
2014	97.05	2024	87.89
2015	97.05	2025	86.64
2016***	99.97	2026	85.38
2017	98.44	2027	84.13
2018	96.91	2028	82.87
2019****	94.17	2029	81.62
2020	92.92	2030 and subsequent years	80.36

Table K-2: CI Standard for Gasoline and Fuels Intended to Replace Gasoline (CARB, 2020)

Year	Average Carbon Intensity (gCO_2e/MJ)	Year	Average Carbon Intensity (gCO_2e/MJ)
2010	Reporting Only		
2011*	95.61	2021	90.74
2012	95.37	2022	89.50
2013**	97.96	2023	88.25
2014	97.96	2024	87.01
2015	97.96	2025	85.77
2016***	96.50	2026	84.52
2017	95.02	2027	83.28
2018	93.55	2028	82.04
2019****	93.23	2029	80.80
2020	91.98	2030 and subsequent years	79.55

The CI Electricity represents the actual value of carbon intensity of electricity (as measured in grams of CO2 equivalent per megajoule of energy) that CARB estimated in 2021 to be the actual average carbon intensity of California's electricity grid. This number is updated every year, and it is expected to decrease over time. In 2021, CARB set this value at 75.93 gCO_2e / MJ. The LCFS calculations provided in this report assume that the CI Electricity value remains at 75.93 through 2040.

The EEER stands for Energy Economy Ratio. For electricity used for transportation, CARB has designated this value to be 5. This represents the higher efficiency of conversion of electrical energy to motion, compared to the inherent inefficiency of a combustion engine where a large portion of the energy is wasted as useless heat due to the laws of thermodynamics. For this reason, the carbon intensity of electricity used for transportation is divided by 5 to represent the fact that each megajoule of energy can produce five times the work that a megajoule of liquid hydrocarbon fuel could.

Energy Density is a simple fixed conversion factor which represents the number of megajoules in a kWh. There are 3.6 megajoules in a kWh.

The kWh label simply represents the quantity of kWh of electrical energy that is used for transportation.

The final term is an adjustment factor of 10^{-6}. This is used to convert the amounts of CO2 equivalent from grams to metric tons. This is because the values for carbon intensity are measured in grams, but each low-carbon fuel standard credit represents one metric ton of CO2 equivalent.

Appendix L

Appendix L: Sustainability Calculations Methodology

The calculations for the upstream pollution data were conducted using Greenhouse Gases, Regulated Emissions, and Energy use in Technologies Model (GREET), an Excel-based calculation tool which was developed by Argonne National Laboratory. GREET provides figures for emissions factors per megajoule of energy used for transportation purposes from various fuels and fuel pathways, including from California grid electricity, combustion of CNG, and multiple different pathways for producing hydrogen. CALSTART modeled the amount of energy which ZEBs would use on an annual basis for Pasadena Department of Transportation under each service scenario. CALSTART multiplied these quantities of energy by the emissions factors for each pollutant, to quantify the amount of pollution that each agency and service pattern would produce.

These numbers measure only emissions produced by the transit service operation but do not attempt to quantify the fundamental environmental benefit to public transit, which is displacing private car travel. They also do not attempt to quantify the emissions produced by the manufacturing or disposal of buses.

In addition to the BEBs powered by the California grid, and the conventional CNG buses, five pathways for production of hydrogen for FCEBs were considered. These are SMR on the site of the fueling station to make gaseous hydrogen, SMR at a central plant to make gaseous hydrogen, electrolysis using grid energy on the site of the fueling station to make gaseous hydrogen, electrolysis using solar energy at a central plant to make gaseous hydrogen, and SMR at a central plant to make liquid hydrogen. Upstream emissions from these six zero-emissions bus options were calculated using GREET.

CALSTART estimated the fuel consumption based on mileage data. M.J. Bradley and Associates had estimated the fuel consumption of CNG buses in Southern California at 4.1 miles per diesel gallon equivalent, which translates to 33 megajoules per mile (Lowell, 2013). This efficiency factor was multiplied by the total annual mileage under each scenario. The quantities of CNG fuel were then multiplied by the emissions factors for the different types of pollution in GREET, to calculate the upstream pollution from CNG bus operation.

Tailpipe emissions from CNG buses were estimated using CARB's Emissions Factors Model (EMFAC). This Excel-based model contains estimates for the tailpipe emissions per mile for CNG-powered transit buses in Los Angeles County. These emissions factors were multiplied by the annual mileage under each scenario and added to the upstream emissions numbers to obtain the total emissions.

GREET contains estimates for the emissions of CO2, methane, and nitrous oxide, as well as a combined total GHG emissions. The figure for total GHG emissions is a measure of the total warming impact of the GHG emissions produced. This figure is necessary because some GHGs contribute more to climate change than others. The impact that a particular gas has on climate change is quantified into a figure called global warming potential. Global warming potential is a multiplicative factor that is used to compare the warming impact of a gas in relation to CO2. For example, a gas with a global warming potential of three has triple the warming impact of CO2. The conversion of emissions to global warming potential provides a metric that can be used to directly compare emissions between different fuel pathways.

The Total GHG emissions calculation is the sum of each gas multiplied by its global warming potential. EMFAC provides emission results for each GHG (CO2, methane, and nitrous oxide) separately, but not the combined total for GHG emissions. CALSTART calculated the combined total for GHG emissions from CNG bus operation using the same global warming potential numbers from GREET, which is displayed below in **Table L-1**.

Table L-1: Global Warming Potential Factors

GHG	**Global Warming Potential**
CO2	1
Methane	30
Nitrous Oxide	265

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