Final Report

Clovis Transit Fleet Electrification Feasibility Study

Katrina Sutton
Bryan Lee
Kristian Jokinen

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List of Acronyms

Acronym	Definition
AC	alternate current
APCD	Air Pollution Control District
AQMD	Air Quality Management District
BEB	battery-electric bus
BEV	Electric Schedule Business Electric Vehicle
BTM	behind-the-meter
CAPEX	capital expenditure
CARB	California Air Resources Board
CCS	combined charging system
CEC	California Energy Commission
CLEEN	California Lending for Energy and Environmental Needs
CMAQ	Congestion Mitigation and Air Quality
CNG	compressed natural gas
CO	carbon monoxide
CO2	carbon dioxide
CO2e/MWh	carbon dioxide equivalent per megawatt-hour
CTTC	California Transit Training Consortium
DAC	disadvantaged community
DAR	Dial-A-Ride

Acronym	Definition
DCFC	direct current fast charger
DER	distributed energy resource
DGS	Department of General Services
DOT	U.S. Department of Transportation
EBCM	Electric Bus Corridor Model
EnergIIZE	Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles
EV	electric vehicle
EVITP	Electric Vehicle Infrastructure Training Program
EVSE	electric vehicle supply equipment
°F	degrees Fahrenheit
FCEB	fuel cell electric bus
FCRTA	Fresno County Rural Transit Agency
FTA	Federal Transit Administration
FTM	front-of-the-meter
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
GIS	geographic information system
GVWR	gross vehicle weight rating
HRDSAM	Heavy-Duty Refueling Station Analysis Model
HVAC	heating, ventilation, and air conditioning
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project

Acronym	Definition
IAAS	infrastructure-as-a-service
ICE	internal combustion engine
ICT	Innovative Clean Transit (regulation)
IIJA	Infrastructure Investments and Jobs Act
ISRF	Infrastructure State Revolving Fund
ITC	Investment Tax Credit
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
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
NFPA	National Fire Protection Association
NOx	nitrogen oxides
NREL	National Renewable Energy Laboratory
OCPP	Open Charge Point Protocol
OEM	original equipment manufacturer
OpenADR	Open Automated Demand Response
OPEX	operating expenditure
PEM	proton exchange membrane

Acronym	Definition
PG&E	Pacific Gas and Electric
PM	particulate matter
PPA	power purchase agreement
PV	photovoltaic
RAISE	Rebuilding American Infrastructure with Sustainability and Equity
RFID	radio frequency identification
RFP	Request For Proposal
SARTA	Stark Area Regional Transit Authority
SMR	steam methane reforming
SOC	state of charge
STURAA	Surface Transportation and Uniform Relocation Assistance Act
TCO	total cost of ownership
TIRCP	Transit and Intercity Rail Capital Program
TOU	time-of-use
V	volts
VW	Volkswagen
ZEB	zero-emission bus

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Executive Summary

Project Overview

Clovis Transit provides public transportation to the City of Clovis with four fixed routes (Stageline) and a demand-response paratransit service (Roundup). To roll out a zero-emission bus (ZEB) fleet that will help combat climate change and improve air quality, Clovis Transit is preparing a Transit Fleet Electrification Plan to examine the economic and technological feasibility of this transition. The study is intended to provide transit agency personnel, elected officials, and policymakers with information needed to help make decisions to achieve full deployment of ZEBs and plan in accordance with California’s Innovative Clean Transit (ICT) regulation, which commences in 2026 for Clovis Transit and mandates that all transit fleets be 100% zero-emission by 2040.

ZEB Introduction

The deployment of a ZEB fleet generates substantial environmental and health benefits for residents within a transit agency's service areas. Two ZEB technologies currently exist: the battery-electric bus (BEB), which uses electricity from a battery to power the bus, and the hydrogen fuel cell electric bus (FCEB), which uses hydrogen to produce electricity that propels the bus.

- BEBs are propelled by an electrified drivetrain, use batteries to store electricity, produce zero tailpipe emissions, and make little noise when moving. Battery technology is expected to improve over time, and BEBs may become a drop-in replacement for all internal combustion engine (ICE) bus duty cycles in the future.
- FCEBs also have an electrified drivetrain to propel the bus but instead use hydrogen to produce electricity. FCEBs have a longer range than BEBs and are generally considered to be a drop-in replacement for an ICE bus, with a refuel time of about 15-20 minutes.

Replacement Plan

Although the ICT regulation does not obligate Clovis Transit to start purchasing ZEBs until 2026, Clovis Transit plans to transition to zero-emission between 2024 and 2040, with its first three new ZEBs to be deployed by the end of 2024. Clovis Transit is considering expanding the existing service with new routes, increased frequency, and wider service territory. The replacement plan includes additional vehicles for a planned fleet expansion and spare buses. Because of this expansion, Clovis Transit's fleet is expected to grow from 41 vehicles to 56, including an expected 10 spare buses (four full-sized spares and six small bus spares).

Route Modeling Results

Clovis Transit's current fleet is made up of 41 vehicles. Bus route modeling for Clovis Transit's fixed-route service showed that some BEBs cannot serve as a drop-in replacement depending on the original equipment manufacturer (OEM). However, it is anticipated that in coming years technological improvements will allow BEBs to serve as a direct replacement for an increasing amount of Clovis Transit's service. On the other hand, both FCEBs used for CALSTART's route modeling can serve as a drop-in replacement for fixed-route service because their energy capacity exceeds energy demand for each shift. Results for Clovis Transit's paratransit fleet, which uses shuttle buses, showed that the BEB tested has sufficient battery capacity to complete the current paratransit duty cycle.

Based on the current cost of ZEBs, fueling infrastructure implications, and Clovis Transit's needs, BEBs are recommended due to their lower overall total cost of ownership (TCO). The costs, infrastructure needs, and other considerations behind this recommendation are explained in more detail below.

Charging and Fuel Cost Consideration

The utility costs for a ZEB fleet are dependent on two main factors: energy and power. There are strategies to reduce utility charges, including overnight charging during off-peak hours, sequentially charging the fleet in different batches, and managed charging. For FCEBs, the cost of hydrogen is influenced by several factors, one of which is the location of hydrogen production. It is important to remember that electricity is a required input to produce hydrogen, and the fueling station uses electricity. The use of hydrogen fuel thus entails operational costs beyond that of the hydrogen and the fueling station.

Clovis Transit's utility costs were calculated assuming all vehicles charge during off-peak hours. Clovis Transit will be using Pacific Gas and Electric's (PG&E's) BEV-2 rates. Because Clovis Transit will need to relocate their depot to house the new electric fleet and this location has not yet been determined, CALSTART was unable to account for potential utility upgrades needed and the amount of power available at the future depot in Table ES-1 below.

Table ES-1. Cost Breakdown Estimates by Utility Rate and Charging Type

		BEV-2 (secondary)	
		Sequential	Unmanaged
OEM 1	Total Annual Electric Cost ($/yr)	$358,067.10	$367,240.86
OEM 2	Total Annual Electric Cost ($/yr)	$353,194.00	$373,834.96
OEM 3	Total Annual Electric Cost ($/yr)	$353,596.82	$371,944.34

If Clovis Transit were to roll out a fleet of FCEBs, the main requirement would be to obtain hydrogen fuel (Table ES-2). Depending on the number of FCEBs Clovis Transit choses to purchase, the cost of refueling can vary. The fleet would consume approximately 1,650 kilograms (kg) of hydrogen per week, which equates to approximately 85,800 kg per year.

Table ES-2. Onsite Hydrogen Production Equipment Costs

Expense	Onsite Electrolysis	Delivered Liquid Hydrogen	Delivered Gaseous Hydrogen	Onsite Steam Methane Reforming	Offsite Retail Fueling
Capital Expenditure	$7,024,829	$3,247,254	$2,658,633	$5,524,829	$0
Annual Cost of Hydrogen Fuel	$1,648,976.16	$1,593,926.88	$1,526,366.40	$1,648,976.16	Offsite fueling not currently available

Depot Conceptual Design

Clovis Transit needs to identify a possible location for their new transit facility. A hypothetical depot was created to understand the space requirements needed to store and charge a BEB fleet. The depot was assumed to house and charge 21 full-sized BEBs and 35 shuttle buses, which anticipates expansion plans and spare buses. At Clovis Transit's request, staff parking, a bus wash, and one office/maintenance building were included in the space estimate. The electrical demand of these additional buildings was not assessed. If all of the buses are housed at one location, the space required for bus parking and infrastructure is estimated to be approximately 163,000 square feet or 3.75 acres.

Resiliency

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 front-of-the-meter (FTM) utility infrastructure, electrification requires the deployment of behind-the-meter (BTM) infrastructure (on the customer's side of the meter).

Clovis Transit faces several unique resiliency risks in the Central Valley that can disrupt utility power to bus yards. Extreme heat, an expected common occurrence as climate change progresses, will further increase the possibility of grid outages and damage to electrical equipment used by transit agencies. Resiliency can be obtained through FTM and BTM approaches, but since Clovis Transit is using PG&E's BEV-2 rate, it is unlikely any FTM rates will be applicable. There are many options for Clovis Transit's BTM resiliency, however. Since Clovis Transit will need to build a new depot, it will be possible to install a solar photovoltaic and battery storage system, which can be sized to provide resiliency for some or all of Clovis Transit's needs.

Maintenance Considerations

A number of transit agencies have reported that BEBs have fewer moving parts and therefore fewer parts to replace, meaning the main cost of preventative care is labor and time. While transit agencies have reported some issues regarding unscheduled maintenance for BEBs, which have proved to be costly, OEMs and other transit agencies in California have reported that newer generations of buses have proven to be more reliable and have had lower maintenance costs. 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 compressed natural gas-powered 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.

ZEBs have unique systems like electric drivetrains, batteries, fuel cells, and hydrogen storage tanks that require specialized training to service effectively and operate with maximum performance. The City of Clovis's staff will need training to be able to maintain and repair zero-emission vehicles.

Estimated Costs and Financial Resources

Transitioning to a ZEB fleet will be more expensive than operating an ICE fleet. CALSTART calculated the TCO for operating Clovis Transit's BEB fleet to be around $58.4 million (with a 14% discount factor and over a 14-year time horizon).

The TCO for Clovis Transit's ICE bus fleet, calculated over 11 years starting in 2022 when 11 new ICE buses will be added to Clovis Transit's bus fleet, is estimated to be $2.08 million. However, due to fluctuations in the economy, fuel cost can impact TCO significantly. CALSTART completed a sensitivity analysis considering the change in fuel cost from $3 per gallon to $7.5 per gallon.

Clovis Transit will need a financing strategy to transition to zero-emission. Transitioning to a ZEB fleet will require substantial financial resources, but there are myriad financing options for transit agencies to deploy ZEBs. These include state and federal incentive programs and prospective financing mechanisms, in addition to traditional financing models. The most important item that Clovis Transit will need to accomplish is securing the location and funding to build a transit facility. If Clovis Transit can utilize property already owned by the City of Clovis, they can avoid having to purchase land. The purchase of the buses will need to be financed, which can be done through various grant and funding sources to cover the incremental cost of ZEBs, or the difference between the cost of a ZEB and a fossil fuel-powered bus. Using grants to cover the incremental cost of the buses would allow Clovis Transit to purchase ZEBs with the funding sources they normally employ to purchase ICE buses.

Greenhouse Gas Emissions

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, diesel 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 greenhouse gases contribute to climate change regardless of origin. CALSTART found that all electric and hydrogen pathways produce fewer emissions than diesel.

I. Introduction to Zero-Emission Buses

Project Description

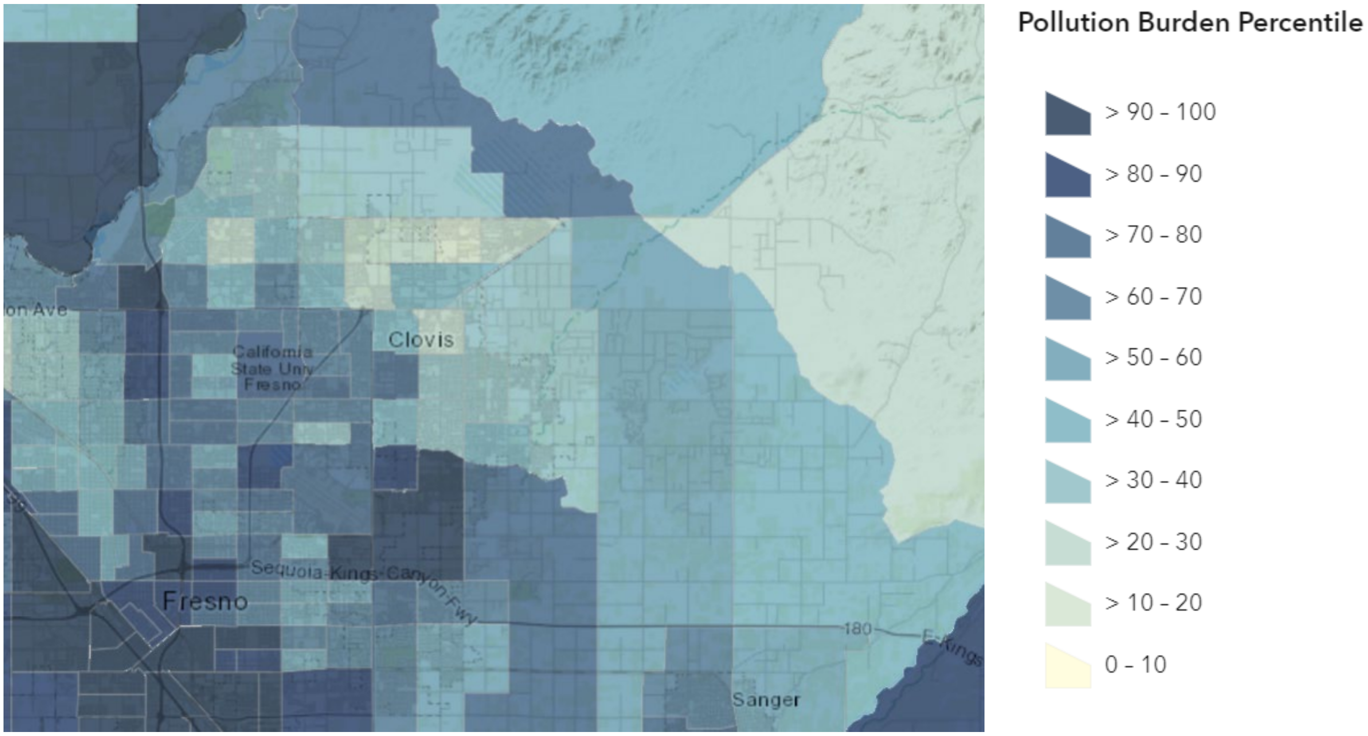
Clovis Transit provides public transportation to the City of Clovis with four fixed routes (Stageline) and a demand-response paratransit service (Roundup). Clovis Transit is preparing a Transit Fleet Electrification Plan to examine the economic and technological feasibility of this transition. The study is intended to provide transit agency personnel, elected officials, and policymakers with information needed to help make decisions regarding the rollout of a fully zero-emission bus (ZEB) transit fleet.

Overview of ZEBs

The Benefits of ZEBs

In California, most transit agencies use a fleet of buses powered by compressed natural gas (CNG). These buses have an internal combustion engine (ICE) that burns CNG to create torque and propel the bus. The current CNG buses have proven to be reliable technology capable of handling most transit bus duty cycles, but they do have several drawbacks, including noise pollution, tailpipe emissions, and high infrastructure costs. 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. Many parts of Clovis and surrounding areas of Fresno have elevated levels of ozone and are also designated as a disadvantaged community (DAC) by the California Environmental Protection Agency, as seen in the CalEnviroScreen 3.0 data (Figure 1). This designation is based on a combination of air quality, pollution, and economic metrics. The areas shaded in dark blue are considered a DAC.

Figure 1. CalEnviroScreen 3.0 Pollution Burden Map



Zero-emission buses (ZEBs) are buses that produce zero tailpipe emissions and therefore do not produce any GHGs or criteria emissions during bus operations. In practical terms, a ZEB cannot use an ICE and must use an electrified drivetrain. There are currently two ZEB technologies in existence: the battery-electric bus (BEB), which uses electricity from a battery to power the bus, and the fuel cell electric bus (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 ICE, ZEBs produce less GHG emissions than CNG buses. ZEBs also generate less noise.

The Innovative Clean Transit Regulation

The Innovative Clean Transit (ICT) regulation issued by the California Air Resources Board (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, Clovis Transit qualifies as a small transit agency—it is located in the San Joaquin Valley Air Basin and operates fewer than 65 buses in annual maximum service. Small transit agencies must submit a non-binding 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 ICE 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 ICE 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 ICE buses to ZEBs, if any. This schedule for bus conversion must identify the number of buses, bus types, and the propulsion systems being removed and converted.

f. A description on how a transit agency plans to deploy ZEBs in DACs as listed in the latest version of CalEnviroScreen.[1]

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.

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 – 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

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[1] View the latest version of CalEnviroScreen at https://oehha.ca.gov/calenviroscreen.

acquired with federal funding without having received a passing score during Altoona Bus Testing. Since Clovis Transit 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.

BEBs

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: ZEB Specifications 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: Charging Infrastructure Specifications.

Transit BEBs

Classified in the Federal Transit Administration's (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 Bus 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 2021, there were 3,364 transit BEBs that have been purchased, are on order, or deployed across the United States (Hamilton, 2021).

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. 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 further 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 (lbs.). Shuttle buses are generally medium-duty Class 4-6 buses. These buses are typically used for demand response service 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, has passed Altoona Bus Testing, and the overall market for electric shuttle buses is small. However, Phoenix Motorcars' shuttle bus is anticipated to complete Altoona Bus Testing in 2022. Clovis Transit's paratransit service includes minivans in their fleet, but zero-emission minivan options are unavailable. As of December 2021, 652 battery-electric shuttle buses have been purchased, are on order, or deployed across the United States (Hamilton, 2021).

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 Clovis Transit 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.

FCEBs

Fuel Cell Electric Technology

FCEBs use an electrified drivetrain to propel the bus, but unlike BEBs, FCEBs use gaseous hydrogen to produce electricity. When the bus needs to move, hydrogen is drawn from the bus's hydrogen tank and processed through 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. The compression process allows more hydrogen to be stored in the tank. Fuel cell electric vehicles typically store hydrogen in their tanks at a pressure of 350 bar (5,000 lbs. per square inch) or 700 bar (10,000 lbs. 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 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/producing it (see page 19).

Transit Fuel Cell Electric Buses

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 35-40 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 Bus Testing. As of December 2021, there were 169 transit FCEBs that have been purchased, are on order, or deployed across 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 Electric Shuttle Buses

A hydrogen fuel cell electric shuttle bus is defined as a hydrogen fuel cell cutaway bus with a length of less than 30 feet, a GVWR of greater than 14,000 lbs., and is classified in the FTA's 5 year/150,000 mile or 7 year/200,000-mile service-life category. Similar to shuttle BEBs, fuel cell electric 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 electric shuttle buses is less developed than battery-electric shuttle buses, with fewer models of fuel cell electric shuttle buses currently available. Fuel cell electric 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 electric 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 and how many vehicle options will be available by 2026, when Clovis Transit must begin purchasing ZEBs under the ICT regulation.

Fuel cell electric shuttle buses generally have a range of 230 miles and cost around $275,000. Data on the cost of a fuel cell electric shuttle bus is scarce. However, cost data from pilot/demo fuel cell electric shuttle buses indicates that the price is approximately equal to a battery-electric shuttle bus. Fossil fuel-powered counterparts have a range of 350 miles and cost around $75,000. Since fuel cell electric 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 for Electric Buses

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 connects with 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 most common current technology requires workers to manually plug in the bus when it returns from its route but wireless technology is gaining maturity and acceptance. 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 direct current fast chargers (DCFC). A Level 2 charger delivers alternate current (AC) power to the bus at voltages of up to 240 volts (V). Level 2 chargers can deliver up to 19.2 kilowatts (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 V. DCFCs are typically used to charge transit buses. They can also be used to quickly charge shuttle buses.

Figure 2. Plug-in Chargers Example

A plug-in charging system has a large physical footprint. The charging cabinet is responsible for much of the footprint and typically requires 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 2. In most cases, this design is the least expensive option for charging.

Figure 3. Buses Parked in Lanes Example (Source: ABB)

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 3.

Figure 4. Overhead Plug-in Charging Example (Source: Burns McDonnell Foothill Transit In-Depot Charging and Planning Study)

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 4.

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 is considered interoperable. Interoperability has multiple dimensions: the charger must be able to plug-in to, 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 vehicles via a compatible communications protocol. Another concern is whether the charger can provide either 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 charge 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 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.

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

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 charging operations can be automated, thereby saving labor costs. However, overhead pantograph charging, as depicted in Figure 5 and Figure 6, is more expensive than regular plug-in charging. The pantographs add about 30% to the cost of the charger (per correspondence with Amply Power), but this amount excludes the construction/installation costs. Since construction/installation comprise the majority 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 is currently planning to deploy a depot overhead charging solution for some of their yards to charge a total of 104 buses.

Figure 6. In-Depot Overhead Charging Example (Source: CALSTART)

SAE J3105 is the standard by which conductive automated connection charging devices for electric vehicles (EVs) are designed. It supports a DC power output of up to 1.2 MW. 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.

In-Ground Inductive

Figure 7. Inductive Charging at Antelope Valley Transit Authority (Source: CALSTART)

A potential variation of this setup includes in-ground inductive chargers, shown in Figure 7. 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 250 kW for on-route charging. If these chargers are used for depot applications, the bus parks 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, WAVE, and Electreon. 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.

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.

Overhead on-route charging 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 8 as an example of this setup. In-ground inductive charging can also be used for on-route charging. Inductive charging can charge a bus at a power level up to 250kW. The benefit of in-ground charging is that it has no moving parts and is less impactful visually to the cityscape.

Figure 8. On-route Overhead Charging (Source: ABB)

Hydrogen Fueling Infrastructure Overview

FCEBs utilize hydrogen to produce electricity 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. One kg of hydrogen has approximately 33.33 kWh of usable energy (diesel has about 12 kWh/kg). Transit agencies have several options for obtaining hydrogen. A transit agency can either produce the hydrogen onsite or buy hydrogen from a fuel provider and have it delivered to the fueling site. Since the transportation of hydrogen is expensive, onsite hydrogen production is usually the less expensive option. However, onsite hydrogen production requires installing fueling infrastructure (similar to CNG), 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. There are a lot of safety sensors and training required as well.

Onsite Steam Methane Reforming

Hydrogen can be produced using steam methane reforming (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 hydrogen. However, SMR does require the use of natural gas and water.

An onsite 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 onsite 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 29 for more information on hydrogen fueling cost considerations.

Onsite Electrolysis

Hydrogen can also be produced via onsite 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 onsite 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 30 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 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 320 kg of hydrogen (U.S. Department of Energy 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 29 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 deliver 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 economical advantages compared to 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 electric 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 larger storage capacity. Currently, there are no heavy-duty stations near Clovis Transit. As a result, retail fueling would not be a viable option for a fleet of transit FCEBs. As the market for hydrogen fuel increases, there may be retail fueling stations built near Clovis Transit.

Retail fueling could potentially be appropriate for fuel cell electric shuttle buses and paratransit vehicles. Hydrogen shuttle buses use less hydrogen than a transit FCEB, and it is theoretically possible to fuel them at retail hydrogen stations. However, there are no hydrogen fueling stations in the Fresno area at this time this study was conducted.

Route Modeling

Overview of the Electric Bus Corridor Model

CALSTART, in partnership with Utah State University SELECT, developed a modeling tool to analyze and predict the performance of a BEB on a predetermined route. Environmental factors like terrain and climate can have a significant impact on the range of BEBs. The Electric Bus Corridor Model (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 the Clovis Area Transit System Electrification 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 trips per day, number of stops, topography, and time in operation was collected. CALSTART referenced the Altoona Bus Testing data for the potential electric bus models that could operate these routes. See Table 1 below for the complete set of customizable parameters that contributed to the modeling results.

Table 1. Customizable Parameters for EBCM

Vehicle Inputs	Route Information Inputs	Bus Charging Infrastructure Inputs
Bus type and length (feet)	Service operation times	Depot charger power & user specified output (kW)
Frontal area (square feet)	Number of passengers	Bus state of charge upper & lower bounds
Curb weight (lbs.)	Average driving speed (miles per hour)	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 Clovis Transit's fleet manager. The purpose of this initial touchpoint was to establish a mutual understanding of the agency's goals for this 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 paratransit service routes vary by day and by passenger, CALSTART worked with the fleet manager 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 input in the model. The electric bus performance modeled in EBCM was also based on battery-to-wheel and regenerative braking efficiencies from published Altoona Bus Testing 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 (°F) for the summer season forecast.

The analysis yielded kilowatt-hour (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 modeling/energy analysis results are discussed in Section II. Clovis Transit.

Assumptions

CALSTART used the following assumptions to model Clovis Transit's routes:

- 40-foot buses for the fixed-route service
- Maximum temperature in summer of 120°F
- Depot charging only
- Lowest temperature in winter of 36°F
- Summer cabin setpoint of 77°F
- Winter cabin setpoint of 68°F

Charging and Fueling Cost Considerations

Charging 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 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 kWh. The price of 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 the majority 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.

Utility Rate Structures

Pacific Gas and Electric (PG&E) offers two different rate options under its Electric Schedule Business Electric Vehicle (BEV) schedule for commercial vehicle charging: BEV-1 and BEV-2. BEV-1 is applicable for customers with kW usage at or below 100 kW and so is not relevant for Clovis Transit. In addition to BEV-2, a separate Schedule B-20 is also available. See the descriptions below for differences between the rates and when each would apply. There is no specific rate option for hydrogen production or storage. Depending on the product and amount of hydrogen stored, power and energy costs can vary. For example, producing hydrogen onsite is estimated to consume anywhere from 48-65 kWh/kg of hydrogen produced. See **Appendix G: Evaluation of Hydrogen Vehicle Refueling Options Report** for more information.

BEV-2

BEV-2 separates commercial EV charging from non-EV commercial usage and/or any other loads. This rate is applicable for fleets with over 100 kW charging demand and was designed for both primary or secondary service options (see above for definitions). As with other rates, energy is charged on a $/kWh basis with seasonal and hourly variations. There is a monthly meter charge.

Demand Charges

Traditional maximum kW demand charges are replaced with monthly kW allocation subscription charges. For this rate, the customer chooses how many 50-kW blocks of power to subscribe to per month. This amount can be adjusted throughout the month until the last day of the billing cycle. If the customer exceeds their maximum kW block, the customer pays twice the price per kW.[2]

B-20

Electric Schedule B-20 is available for customers that have exceeded 999 kW for at least three consecutive months during the past year, regardless of transportation needs or any other business application. Clovis Transit would be utilizing this rate if BEV-2 was not an option. Like BEV-2, energy is charged on a $/kWh basis with seasonal and hourly variations.

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[2] For more information on the BEV-2 rate structure, see https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_BEV.pdf

Demand Charges

Traditional maximum kW demand charges are similar to other rates. Maximum demand is defined as the highest in 15-minute increments for the billing month. Unlike BEV-2, there is a daily meter charge.[3]

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 4:00 to 8:00 p.m. 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 the majority of buses charge at night during off-peak hours.

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 energy and 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

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[3] For more information on the B-20 rate structure, see https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_B-20.pdf

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% and greatly reducing demand charges and the cost to operate the buses (Eichman, 2020). 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 Open Automated Demand Response (OpenADR) 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 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 manufacturers 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 (CAPEX) for the chargers and then signs a power purchasing agreement to sell the electricity to the transit agency. Appendix C: Managed Storage Solutions provides details for managed/networked charging providers.

Hydrogen Fueling Cost Considerations

Onsite 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 onsite at the bus fueling location. Hydrogen can be produced onsite using commercialized and technologically mature equipment—see Onsite Steam Methane Reforming and Onsite Electrolysis sections 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, onsite production requires capital investment, so it is not economically feasible to produce hydrogen onsite 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 sections for descriptions of these options. The transportation of hydrogen via truck is an expensive process, and the majority of the cost of delivered hydrogen comes from transportation. Since delivered hydrogen requires less onsite 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 onsite 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 Clovis Transit, retail fueling could be appropriate for fuel cell electric shuttle buses and paratransit 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 Retail Fueling section 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 Onsite 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.

Summary of Clovis Transit's Hydrogen Vehicle Refueling Options Report

CALSTART engaged with external consultant Jerald A. Cole to complete a deep dive into Clovis Transit's hydrogen vehicle refueling options. The full report is provided in Appendix G: Evaluation of Hydrogen Vehicle Refueling Options Report, but the following paragraphs summarize the key takeaways from Cole's research.

This study used a framework of 11 FCEBs of 40 feet in length traveling 135 miles per day to model what a hydrogen refueling station would like for Clovis Transit, considering both delivered hydrogen and onsite hydrogen production. These 11 FCEBs would need 25 kg of hydrogen daily per bus, adding up to a total of 275 kg per day. To ensure sufficient reserve is on hand, this report recommends constructing a 1,000 kg storage system for hydrogen fuel. The impact of station costs on hydrogen cost was estimated using the Department of Energy's Heavy-Duty Refueling Station Analysis Model (HRDSAM).

Because of transportation costs, liquid hydrogen is relatively cheaper according to HRDSAM modeling. However, if Clovis Transit were to have gaseous hydrogen delivered from the H2B2 project (in Kerman, California, about 25 miles away; see FCEB Hydrogen Fueling Infrastructure Deployment Plan for more detail on this project), it could be more cost effective then shipping liquid hydrogen from Sacramento. However, Plug Power is planning to build a liquid hydrogen production facility in Fresno County, which could provide Clovis Transit with an affordable option for liquid hydrogen delivery (Adler, 2021). Liquid hydrogen can provide enough fuel for about two weeks, and distributors could plan to make deliveries every 10 days to ensure a buffer.

Onsite hydrogen production is generally more expensive than delivered hydrogen. Plant ownership models and equipment vary among providers: some offer the entire system (i.e., compressor, storage, delivery) while others provide only the hydrogen production equipment. A hydrogen-as-a-service model may also be available. Cost can vary depending on the hydrogen configuration distribution, from necessary storage to the dispenser. Space requirements, including set back requirements, with tube trailer storage are 5,100 square feet (61 feet by 84 feet). Without tube trailer storage, meaning only pump, compressor, and minimal storage equipment are implemented, space requirements decrease to approximately 3,200 square feet (37 feet by 84 feet).

Resiliency

BEBs introduce 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 onsite, 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.

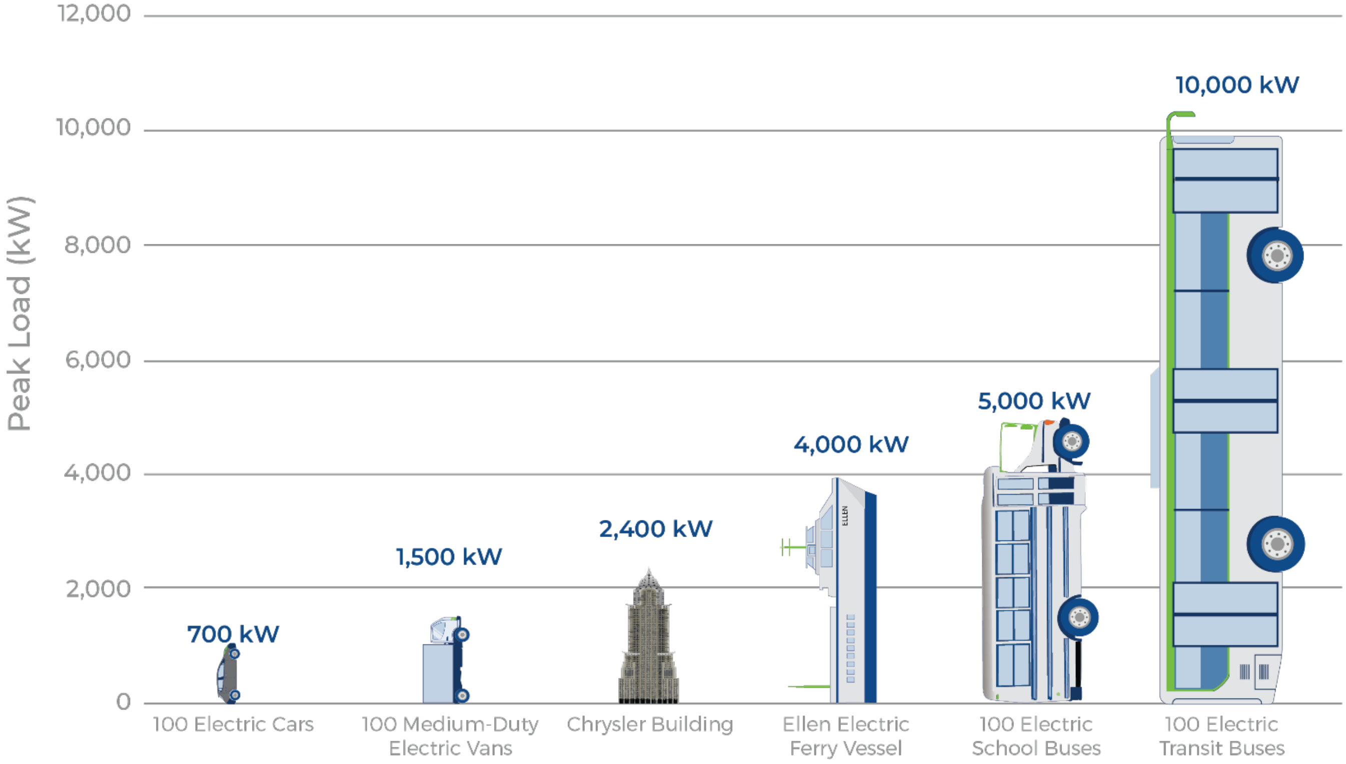
Clovis Transit faces unique resiliency risks. California's Central Valley is subject to several factors that can disrupt utility power to bus yards. One major threat is extreme heat, which is expected to become a much more common occurrence as climate change progresses. Extreme heat poses a threat to 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 are a major risk to power supply in the Central Valley. These shutoffs occur when environmental conditions increase the chances that utility infrastructure will spark a wildfire. While the risk of wildfire occurring in Clovis proper is low, there is a high risk that wildfire can disrupt electrical supplies. PG&E supplies electricity to Clovis Transit. PG&E obtains power from a variety of sources (CEC, 2020). PG&E has three options available to Clovis Transit to decide how much GHGs the electricity they use generates – base plan, 50% solar, and 100% solar. The base plan has a GHG intensity of 160 lbs. carbon dioxide equivalent per megawatt-hour (CO2e/MWh) with the majority of energy coming from renewables and nuclear power. The 50% solar plan guarantees a minimum of 50% energy comes from solar and has a reported GHG intensity of 80 lbs. CO2e/MWh. The100% solar choice guarantees 100% of the customer's energy comes from solar power and produces zero lbs. CO2e/MWh. 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. Clovis Transit can obtain resiliency through two main methods: front-of-the-meter (FTM) resiliency and behind-the-meter (BTM) resiliency. FTM resiliency is provided on the utility's side of the meter. 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 below.

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 9 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 3 megawatts (MW), which exceeds the power demand from the Chrysler Building. In the event of a grid outage, it is difficult to replace the energy and power lost from the grid.

Figure 9. EV Peak Power Demand Scenarios (Source: CALSTART)



Clovis Transit's fleet is expected to have significant energy consumption and power draw, which is provided in Table 2 below. These figures represent energy consumption and power draw for weekday service (fixed-route and paratransit), the maximum energy consumption and power draw. Furthermore, these figures exclude any energy or power demand from onsite buildings or maintenance bays.

Table 2. Daily Energy Consumption and Power Demand

Energy Consumption / Power Demand Time	Clovis Transit
Weekday Energy Consumption (kWh)	5,872
Weekday Power Demand (unmanaged, kW)	2,235
Weekday Power Demand (sequential, kW)	1,335

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. No similar rate structure was found for PG&E customers.

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.

In a study recently conducted by FCRTA, examined the grid constraints and resiliency needs in Fresno County. It concludes that developing shared charging infrastructure and adding solar and energy storage can be beneficial as more electricity demand and harsh weather impact the region in the coming years (FCTRA, 2022).

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, onsite 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 the majority 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. This is a common strategy for industrial vehicles such as forklifts.

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 ICE, 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 resiliency is described in Appendix F: Clovis Transit Conceptual Framework and Supporting Documents. Generators can also respond relatively quickly to outages and take about 10 minutes to fully 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 San Joaquin Valley Air Pollution Control District (APCD) has a mandate to regulate stationary sources of air pollution in the San Joaquin Valley. Since generators emit criteria emissions, they are subject to regulation by APCD. APCD regulates engines above 50 horsepower and all such engines must have a permit. If a transit agency were to use engines of 50 horsepower or below, the generator can be installed without a permit. However, due to the high loads associated with charging buses, using engines with 50 horsepower or below is unlikely to be practical. If a diesel generator is used, it must be a Tier 4 Final Engine. APCD allows for the use of backup generators during an emergency, which is defined as an unforeseen power outage. Backup generators are allowed to operate during an emergency power outage and may operate for the duration of the outage. The generator may also be used for up to 200 hours per year to conduct testing and maintenance. Backup generators cannot be used to provide demand response services to utilities. Using a generator for this purpose requires a full-time permit. This permit has more stringent emissions limits and in many cases requires the use of exhaust treatment equipment.

To receive a permit for a backup generator, a transit agency would need to obtain an Authority to Construct permit. This permit allows the transit agency to physically install a generator. To obtain this permit, a transit agency needs to submit an Authority to Construct/Permit to Operate Application Form and a Supplemental Application Form. Once the generator is installed, a startup inspection needs to be conducted. During this inspection, an inspector from APCD verifies that the installed generator is the same model as the generator that was permitted. Once the startup inspection is completed, a Permit to Operate is awarded. The Permit to Operate gives the holder the right to operate the generator. This permit lasts for the life of the generator.

This process can be lengthy as APCD has a backlog of permits that need to be processed. It is advisable to apply for a permit early in the construction process and to not procure a generator until the Authority to Construct permit has been awarded. There are some factors that can also delay a permit. If a school is within 1,000 feet of a proposed generator, this triggers a public notice. During the public notice, the parents of students who attend that school are given 30 days to comment on the permit for the generator. The parents can also request a public hearing. Public notices can be triggered if the generator is large and is expected to produce a disproportionate amount of air pollution or if the generator is deemed likely to produce disproportionate health risks to the public (based on public health modeling).

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 CARB or APCD. The rented generator can only be operated during an emergency and must be removed from the site after the emergency ends. Renting a generator in the event of an outage could be beneficial as it would allow the transit agency to avoid the CAPEX 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 might be possible to secure a generator from a rental company. Generator rental companies can guarantee access to a rental generator in exchange for a monthly payment.

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 hydrogen as a fuel where the oxidation reaction takes place 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.

Proton exchange membrane (PEM) fuel cells use hydrogen to produce power. PEM fuel cells are used in FCEBs, but they can also be used for stationary applications. One advantage of PEM fuel cells is their ability to load follow (i.e., quickly increase and decrease their power level) for rapid response to outages and/or changes in power demand that occur during charging.

Solid oxide fuel cells can use natural gas to produce power. These fuel cells use an oxidation reaction to convert natural gas to electricity. They operate most effectively at a constant power level and therefore struggle to load follow. This can be problematic because charging tends to have rapid increases and decreases in power demand. This solution is ideal when a base load (like a building) requires a constant load for which the fuel cell can provide power.

Stationary fuel cells are advantageous in that they produce zero criteria emissions. As a result, they are less heavily regulated than generators, and it is likely that they would not require a permit to operate. However, there are few examples of fuel cells being used to support vehicle charging. AC Transit is currently using a stationary fuel cell as a part of their energy portfolio. It is likely that the total cost of ownership (TCO) for fuel cells will need to fall to make this solution more economically viable.

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.

Training and Workforce Development

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.

Clovis Transit’s fleet is maintained by the City of Clovis. The City of Clovis has a Public Works facility that is used to maintain the City’s municipal fleet. Clovis Transit’s fleet is also housed and maintained at this facility by city employees. 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 energy efficiency 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 ICE buses. ZEBs replace the ICE 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 ICEs 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, the majority 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 nearby community colleges such as Fresno City College, Kern Community College District, and San Joaquin Delta 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 43.

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 for 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.

Workforce Development Training Plan

The City of Clovis has three types of maintenance staff. The most skilled employees, Journeymen Mechanics, have a deep understanding of the vehicles, vehicle systems, and how the vehicle systems interact with each other. Journeymen Mechanics are responsible for carrying out major vehicle repairs. The City of Clovis currently employs seven Journeymen Mechanics. The City also employs Assistant Mechanics. Assistant Mechanics assist the Journeyman Mechanics. The City currently employs two Assistant Mechanics. The City also hires Service Technicians, who work on low-level repairs like vehicle lights and oil changes. The City of Clovis currently employs three service technicians.

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. CALSTART interviewed maintenance staff to better understand their expertise in maintaining zero-emission vehicles and to assess their training needs. City maintenance staff reported that they have limited experience maintaining ZEBs. While they have experience maintaining mechanical systems like suspension and braking and low-voltage systems, they do not feel safe working on high voltage electrical systems or the drivetrain. Maintenance staff stated that receiving high voltage electrical safety is their main priority. Clovis Transit currently has two battery-electric shuttle buses. Maintenance staff has relied heavily on the OEM for maintenance of high voltage electrical systems.

The City of Clovis intends to upskill their current maintenance staff so they can maintain ZEBs. The City of Clovis will prioritize training for their Journeymen Mechanics and Assistance Mechanics. CALSTART recommends the following training sequence for the Journeymen and Assistant Mechanics:

1. High voltage Electrical Safety: The prerequisite knowledge required to begin ZEB maintenance training is a firm understanding of high voltage electrical systems and safety. During this training, maintenance staff learn how to use multimeters, how to identify high voltage components and cables, how to use personal protective equipment, and safety procedures for working with high voltage equipment. OEMs view high voltage electrical training as a prerequisite for OEM-provided maintenance training. As a result, maintenance staff need to receive high voltage safety training before they receive any instruction on bus maintenance. There are several options for obtaining this training:

2. The California Transit Training Consortium (CTTC) provides high voltage safety training. The prerequisite for their high voltage safety training course is a course in using a digital volt-ohm meter. CTTC provides three levels of high voltage safety training. Awareness training is a four-hour course that is offered to any employee who is on the floor of the vehicle repair workshop. Certification training is a 16-hour course that teaches workers how to use personal protective equipment, tools, and arc flash rescue equipment and procedures. Lastly, the advanced class is offered to any technicians who will physically be working on the vehicle. This training aligns with NFPA 70E and OSHA 1910.269 certification.

3. SunLine Transit's West Coast Center of Excellence has a ZEB Maintenance course that includes instruction on high voltage safety.

4. High Pressure Gases and Hydrogen Safety Training: If Clovis Transit opts to deploy an FCEB fleet, the maintenance staff will need to learn how to safely handle high pressure gases and hydrogen.
5. OEM-provided training: Bus OEMs provide training to teach maintenance staff to repair their specific system. Clovis Transit 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 drivers and maintenance staff. Since there are few moving parts on a ZEB, the majority of the maintenance tasks relate to preventative maintenance. Bus OEMs also provide training on their diagnostic tools and how their bus systems function. Maintenance staff learn how to use the diagnostic tool to identify and resolve faults.
6. Warranty Period: During the warranty period, if repairs or troubleshooting beyond preventative maintenance are needed, Clovis Transit 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 for 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.
7. Supplemental Training: Clovis Transit can obtain additional training from SunLine Transit's West Coast Center of Excellence and CTTC. CTTC provides specialized training on topics like electronic brakes and electrical system diagnosis. Other organizations like the California Transit Association, American Public Transportation Association, CalACT, and the National Transit Institute also provide supplementary training.

Training Costs

The City of Clovis's staff will need training to be able to maintain and repair zero-emission vehicles. There are costs associated with training. This section will provide an overview of these costs.

The City of Clovis has multiple options for obtaining training. CTTC offers training in high voltage electrical safety, as well as specialized training in bus systems. Transit agencies can access CTTC's trainings by joining the consortium as a member. Current membership fees range from $1,000 per year for small transit agencies (around 5-7 vehicle technicians) to $5,000 per year for large transit agencies (more than 100 vehicle technicians). Members of the consortium receive unlimited access to training courses. It is important to note that membership fees are subject to change. In the short-term, CTTC will likely raise membership fees by 20%. Membership structure can also be changed in the future.

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 3 for a breakdown of these costs.

Table 3. ZEB Maintenance and Operator Training Costs

Item	OEM 1	OEM 2	OEM 3	OEM 4
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

Maintenance Costs

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 ICE bus, especially some of the mechanical systems in the propulsion system. The maintenance needs for the propulsion system are therefore different in BEBs than ICE buses. Despite these differences, BEBs do share many mechanical systems with ICE 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 are lower than for fossil fuel-powered 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, but these problems can be costly.

The following maintenance data compares maintenance costs between CNG buses and BEBs; although Clovis Transit uses diesel buses, there is more data available for transiting from CNG buses to BEBs. 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 are $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 per mile, respectively. The CNG fleet had scheduled maintenance costs of $0.10 per mile. 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 per mile, 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 less common for newer 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 lower maintenance costs. Data from Antelope Valley Transit Authority indicates that maintenance costs for 40-foot BEBs are an average of $0.29 per mile (July 2019 – March 2022). Utah Transit Authority reported maintenance costs of $0.41 per mile (April 2019 – October 2021) for their 40-foot BEBs.

FCEB Maintenance

Like BEBs, FCEBs have an electric drivetrain 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 onsite 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 DCFC and networked chargers can increase maintenance needs; DCFCs have cooling equipment that can need maintenance and repair. Furthermore, any worker who maintains or repairs DCFCs must be a certified electrician. 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 expensive, as a certified electrician is needed to perform all maintenance tasks on DCFCs. Data from NREL indicates that maintenance costs for DCFCs are approximately $1,500 per year per charging cabinet (Johnson, 2020). 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 properly. 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 onsite hydrogen production equipment requires depends on the type of hydrogen infrastructure in place. If hydrogen is produced onsite, 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 G: Evaluation of Hydrogen Vehicle Refueling Options Report.

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.

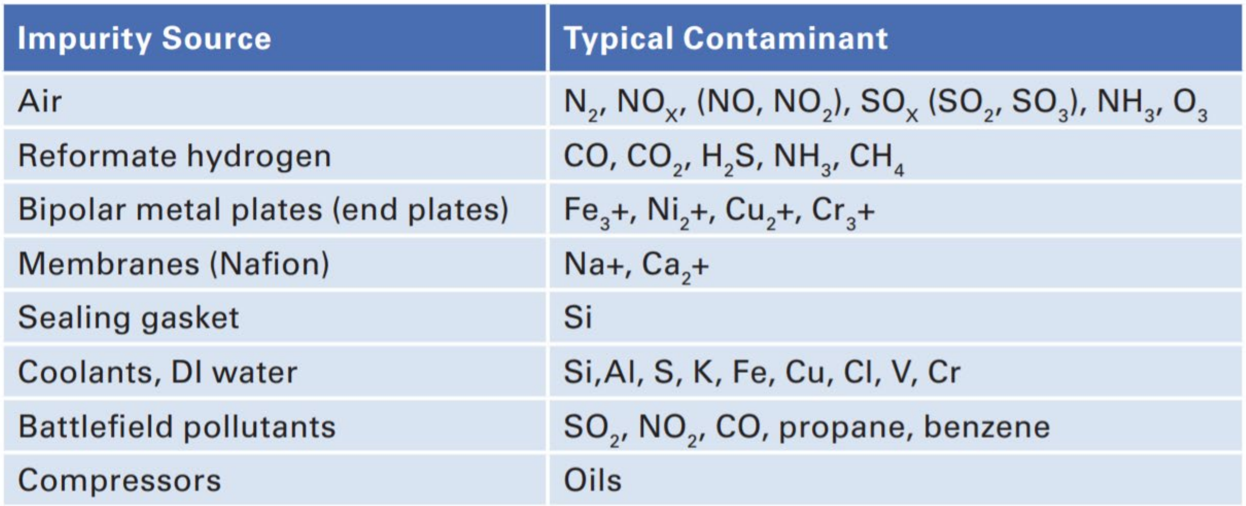
SunLine Transit reported few problems with infrastructure unavailability, partly because obtaining replacement hardware components such as compressors is relatively easy with an established supply chain. Some of the controls are manufactured in Europe and were previously difficult to obtain, but these 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 onsite or delivered, is pure and does not contain contaminants. Contaminants in the hydrogen, as listed in Figure 10, 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 affect 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 10. 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 ICE 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 FCEB 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 FCEBs, 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).

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 Private 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 CAPEX 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 CAPEX.

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 4 provides a brief overview of BEB OEM battery leasing options.

Table 4. 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

Like bus/battery leasing, infrastructure-as-a-service (IAAS) is another method for reducing CAPEX associated with deploying ZEBs, particularly charging and resiliency infrastructure. IAAS can also be combined with battery leasing to further reduce CAPEX. 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.

The IAAS model can also provide tax benefits in some cases. Some types of infrastructure can qualify for the Investment Tax Credit (see page 61) and other tax benefits. Since a transit agency is a public agency that does not pay taxes, they cannot directly take advantage of these tax credits. However, under the IAAS model, the infrastructure provider retains ownership, and they can benefit from the tax credits. This option would allow the infrastructure provider to pass some of the tax benefits onto the transit agency in the form of lower PPA rates. In some cases, an IAAS company may also give transit agencies the option to convert the PPA to a capital purchase of the infrastructure once the tax benefits have been realized. An overview of IAAS companies can be found in Appendix D: Energy Storage Solutions.

Funding Sources and Incentives for Buses and Infrastructure

Clovis Transit is currently funded with local funds and does not accept federal funding. However, due to the high cost of transitioning to ZEBs, Clovis Transit will likely need to accept federal funding in the future. The promising funding option that Clovis Transit 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 CAPEX 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 has 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 the collection of fees that supports the program 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. The CEC proposed $30.1 million of funding for FY 2022-23 and $13.8 million in funding for FY2023-24 for zero emission medium- and heavy-duty vehicles and infrastructure under the Clean Transportation Program. The Clean Transportation Plan also plans to invest $30 million from zero-emission vehicles and infrastructure general funds into transit activities (CEC, 2022).

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 APCDs and air quality management districts (AQMDs). ZEBs with a GVWR of greater than 14,000 lbs. are eligible for funding under Carl Moyer. The APCDs and AQMDs are the entities that issue the grants and determine funding for the program. This is a competitive funding opportunity.

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 (EVSE), DCFC EVSE, 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, onsite 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.
- EV Jump Start – for transit agencies in a designated DAC (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 opened the first round of funding for EV Fast Track in March 2022. A second round of funding is planned to open in Q3 2022. The first round for EV Jump Start is planned to open in Q2 and close in Q3 2022. A second round of EV Jump Start is scheduled to open in Q4 2023. The hydrogen pathway is scheduled to open in Q2 2022. A second round is scheduled to open in Q4 2022. 70% of funding will be allocated to EV projects and 30% will be allocated to hydrogen (CALSTART, 2021). This is a competitive funding opportunity.

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. This is a competitive funding opportunity.

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 include 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 term of up to 30 years. These loans can be used to fund projects that use commercially proven technology to reduce GHG emissions or pursue other environmental objectives. Eligible projects include energy storage, renewable energy generation assets, stationary fuel cells, EVs, alternative fuel vehicles, and alternative fuel vehicles refueling stations (California Infrastructure and Economic Development Bank, n.d.).

Low Carbon Fuel Standard (LCFS) Program – CARB

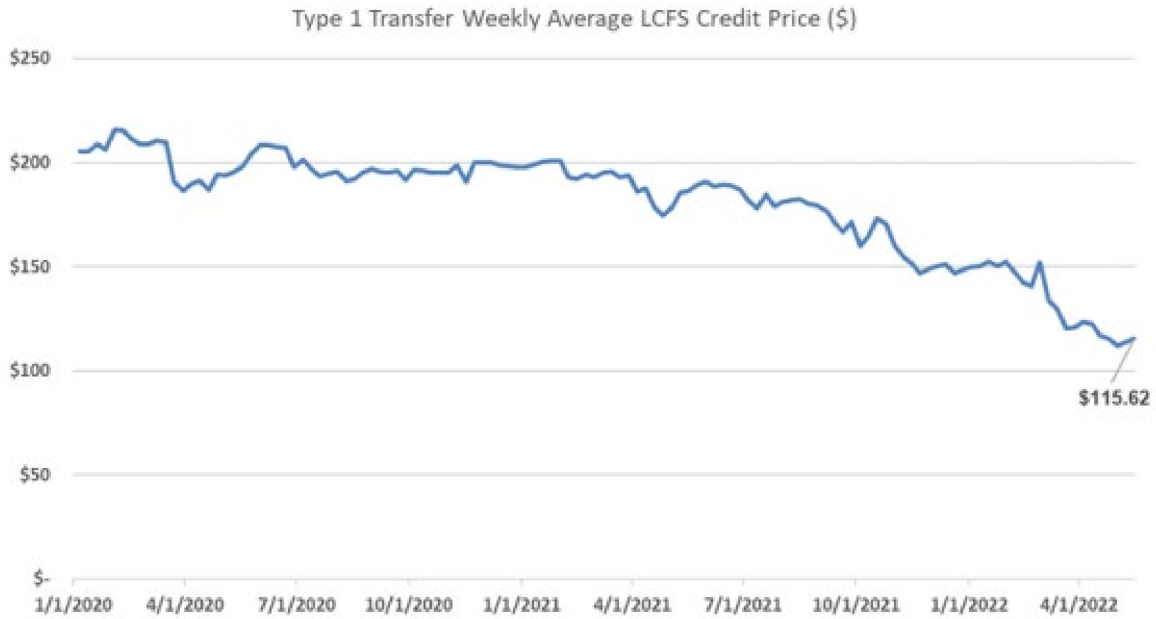
The LCFS Program is run by CARB and creates a mechanism for the users and producers of low-carbon fuels (including electricity) to generate credits for the use of these low-carbon fuels. These credits can then be sold in the LCFS market. The LCFS program sets standards for the maximum carbon intensity 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. The price of LCFS credits has been volatile in recent years. Prior to 2021, LCFS credits were trading at about $200 per credit. However, the price of LCFS credits has fallen substantially in 2022. At the beginning of 2022, LCFS credits traded at about $150. As of May 2022, the price has fallen to about $115 per credit. Since May, the price has fallen further to about $100 per credit. This decline in price has been attributed to increasing adoption of renewable diesel, RNG, and electric vehicles leading to an increase in the supply of credits.

Sales of LCFS credits can provide a significant revenue mechanism. The profits from LCFS credits can be used to fund either vehicle purchases or charging infrastructure. Figure 11 shows historic LCFS prices from January 2020 through May 2022.

Figure 11. Historical LCFS Prices January 2020 – May 2022 (SRECTrade, 2022)



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. This is a competitive funding opportunity.

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. This funding is available through an allocation request. 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 OPEX 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.

Volkswagen (VW) Mitigation Trust – CARB

The purpose of the VW Environmental Mitigation Trust is to fully mitigate the excess NOx emissions released during the Volkswagen emission 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 and Bus Facilities (5339) – U.S. Department of Transportation (DOT)/Caltrans

The Bus and 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. The Infrastructure Investment and Jobs Act (IIJA) increased funding for the Bus and Bus Facilities program for five years between FY2022 and FY2026. Approximately $1 billion per year in both formula funding and competitive grants will be provided through the Bus and Bus Facilities program for the entire United States (FTA, 2021). In California, Caltrans has been delegated the responsibility of managing Bus and Bus Facilities formula grants. Public agencies and nonprofit organizations that are involved in public transit may apply for competitive grants.

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

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 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. Solar PV projects are eligible for a tax credit equal to 10% of the cost of system for projects that begin construction in 2022 or after. Only the owner of the system can claim the ITC. Small wind power (100 kW of capacity or less) is eligible for the same tax credits as solar. Fuel cells are eligible for the ITC and are limited to $1500 per 0.5 kW in capacity. Lastly, combined heat and power equipment qualifies for an ITC of 10% (Congressional Research Service, 2018).

It is important to note that the ITC for some technologies will phase out over time. The solar ITC is permanent and will remain at 10% beyond 2022. However, the ITC for wind, fuel cells, and CHP has been approved until 2024. It is unclear whether the ITC for these technologies will be enacted beyond this date. Since transit agencies are tax-exempt entities, they would not be able to directly take advantage of these tax credits. However, if a separate entity, such as an IAAS company, owned and operated the energy assets, they would be able to benefit from these tax credits and pass these benefits on to Clovis Transit.

Low or No Emissions Program (Low-No) – DOT/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 IIJA expanded funding for the Low-No program. IIJA allocates an additional $5.25 billion for the Low-No program over five years, starting in FY2022. Approximately $1.12 billion will be allocated per year (FTA, 2021). This represents a major increase in funding for ZEBs. This is a competitive funding opportunity.

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, which 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 – DOT

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 DOT programs. Public entities, such as municipalities, are eligible to apply for this program. RAISE is a competitive grant program. This is a competitive funding opportunity.

Prospective Financing Mechanisms

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. SB-372, was introduced in the California Senate in early 2021. This bill establishes a Medium- and Heavy-Duty Zero-Emission Vehicle Fleet Purchasing Assistance Program, within the Air Quality Improvement Program, to 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. This bill passed the State Senate with broad support and was approved by the Governor in October 2021. The bill requires that the financial tools offered by this program be available to fleets by January 1, 2023.

II. Clovis Transit

Clovis Transit Overview

Clovis Transit provides public transportation to the City of Clovis with four fixed routes (Stageline) and a demand-response paratransit service (Roundup) using a fleet of 30 buses, nine vans, and one trolley. Fixed-route and paratransit services are provided Monday through Friday from 6:30 a.m. to 6:30 p.m. and on Saturday from 7:00 a.m. to 3:30 p.m. Paratransit service runs on Sunday from 7:00 a.m. to 3:00 p.m.

The fixed-route service provides transit options to key destinations in and around the City of Clovis, including the Sierra Vista Mall, the Civic Center, Walmart, Target, city schools, and Fresno State University. However, some of the more newly developed areas remain unserved by transit, including Clovis Community College. Three of the four fixed-route service lines offer easy connections to Fresno Area Express transit network. The City pays over $300,000 to Fresno Area Express to provide service to one route with 15-minute headway times.

The Clovis Transit fleet is part of the City's emergency plan. All vehicles need to be available in case of an emergency even if the power is out.

Clovis Transit Fleet

The current fleet is made up of 41 vehicles: 13 Glaval/GMC cutaway (27-foot) buses, six Arboc low floor (26-foot) buses, three Champion low floor (28-foot) buses, seven Champion (32-foot) buses, nine vans for the paratransit service, one trolley for special events, and two all-electric Phoenix Motorcar Zeus buses. All vehicles except for the Zeus buses have ICEs. Both Zeus shuttle buses had operation challenges associated with charging and charging infrastructure; they are not dedicated to any specific duty cycle.

Clovis Transit's bus depot is located at 155 N. Sunnyside Avenue in Clovis. The City is considering a new location as the current facility cannot accommodate more buses.

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-specific variables to calculate energy needs, like the speed of the bus, ridership, and HVAC setpoints. CALSTART worked with Clovis Transit 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, like 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 buses' routes. 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 major impact on energy needs and the range of the bus. The Central Valley has mild winters and hot summers. To ensure that the buses will be able to perform under worst-case conditions, EBCM was programmed to model temperatures of 120°F 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 a drop-in replacement if it can complete its shift with an SOC of at least 30%. Likewise, an FCEB is considered a drop-in replacement if it can complete its shift with 10% of its hydrogen capacity remaining.

Fixed-Route

Clovis Transit provides service for Routes 10, 50, 70, and 80. Routes 70 and 80 are school routes that run only during the school year. To estimate the energy needs for the fixed-route fleet, EBCM was used to estimate the amount of energy that the buses would consume on these routes. CALSTART worked with Clovis Transit to calibrate the assumptions for those variables. The assumptions used in EBCM are outlined in Table 5.

Table 5. EBCM Fixed-Route Assumptions

Variable	Value
Average Number of People on Bus During Service	10
Average Driving Speed	20 miles per hour
Heating HVAC Setpoint	68°F
Cooling HVAC Setpoint	77°F

Clovis Transit currently runs cutaway buses under 35 feet on all routes. Below shows the route modeling results for summer months, the most energy intensive season for Clovis Transit. OEMs 1–3 are 40-foot buses, and OEM 4 is a 25-foot bus. In Table 6, some buses cannot serve as a drop-in replacement for a fossil fuel-powered bus. A drop-in replacement is defined as a run that completes its route with an SOC of less than 30%. Runs that complete their route with an SOC of 10% to 30% have been highlighted in yellow. While these buses are not a drop-in replacement with technology in 2022, it is likely that, with improvements in battery technology over time, these buses could become a drop-in replacement. 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 6. Fixed-Route Modeling Results

Route	Laps	OEM 1 (kWh)	OEM 2 (kWh)	OEM 3 (kWh)	OEM 4 (kWh)
10	6	331.67	344.12	377.81	121.07
50	6	371.29	386.06	437.44	116.57
70	2	46.29	48.29	53.00	16.82
80	2	29.95	31.45	35.26	10.27

The results from Table 6 show that all buses can complete Routes 70 and 80. For Routes 10 and 50, OEM 1 would be the closest to completing these routes as operated currently. OEMs 2–4 end the day with SOC below 10%. Routes 10 and 50 run about 135 miles per day. Other transit agencies report BEBs can consistently complete routes of about 150 miles. EBCM models worst-case scenarios, so it is possible that EBCM has overestimated the energy needed to complete the routes. Technology changes in the future may allow the buses to complete the routes with enough range at the end of the day.

An FCEB is considered a drop-in replacement if it can complete its shift with 10% of its hydrogen capacity remaining. The usable 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 each FCEB is detailed in Table 7.

Table 7. FCEB Energy Capacity

OEM	kWh Equivalent
OEM 5	562.51
OEM 6	750.02

Based on these figures, both FCEB OEMs can serve as a drop-in replacement because their energy capacity exceeds energy demand for each shift. It is estimated that transit FCEBs will consume approximately 275 kg of hydrogen per weekday.

Paratransit

Clovis Transit's Roundup fleet provides paratransit service to seniors and people with disabilities. Clovis Transit uses shuttle buses for this service and wants to continue to use that vehicle vocation for this service. To estimate the energy needs for the paratransit fleet, CALSTART used EBCM. Clovis Transit provided a list of the most frequent locations the DAR service visits. Because the route the vehicles travel varies, this average was used as a placeholder for a typical service day. The route was 21 miles over an assumed eight-hour workday. The assumptions used in EBCM are outlined in Table 8.

Table 8. Paratransit EBCM Assumptions

Variable	Value
Average Number of People on the Bus During Service	3
Average Driving Speed	25 miles per hour
Heating HVAC Setpoint	68°F
Cooling HVAC Setpoint	77°F

The results of the model are summarized in Table 9. OEM 4 was the only manufacturer to complete Altoona Bus Testing at the time of modeling. The modeling results from EBCM show OEM 4 has sufficient battery capacity to complete the daily DAR duty cycle.

Table 9. Paratransit Battery Capacity

Route	OEM 4 (kWh)
Paratransit	54.47

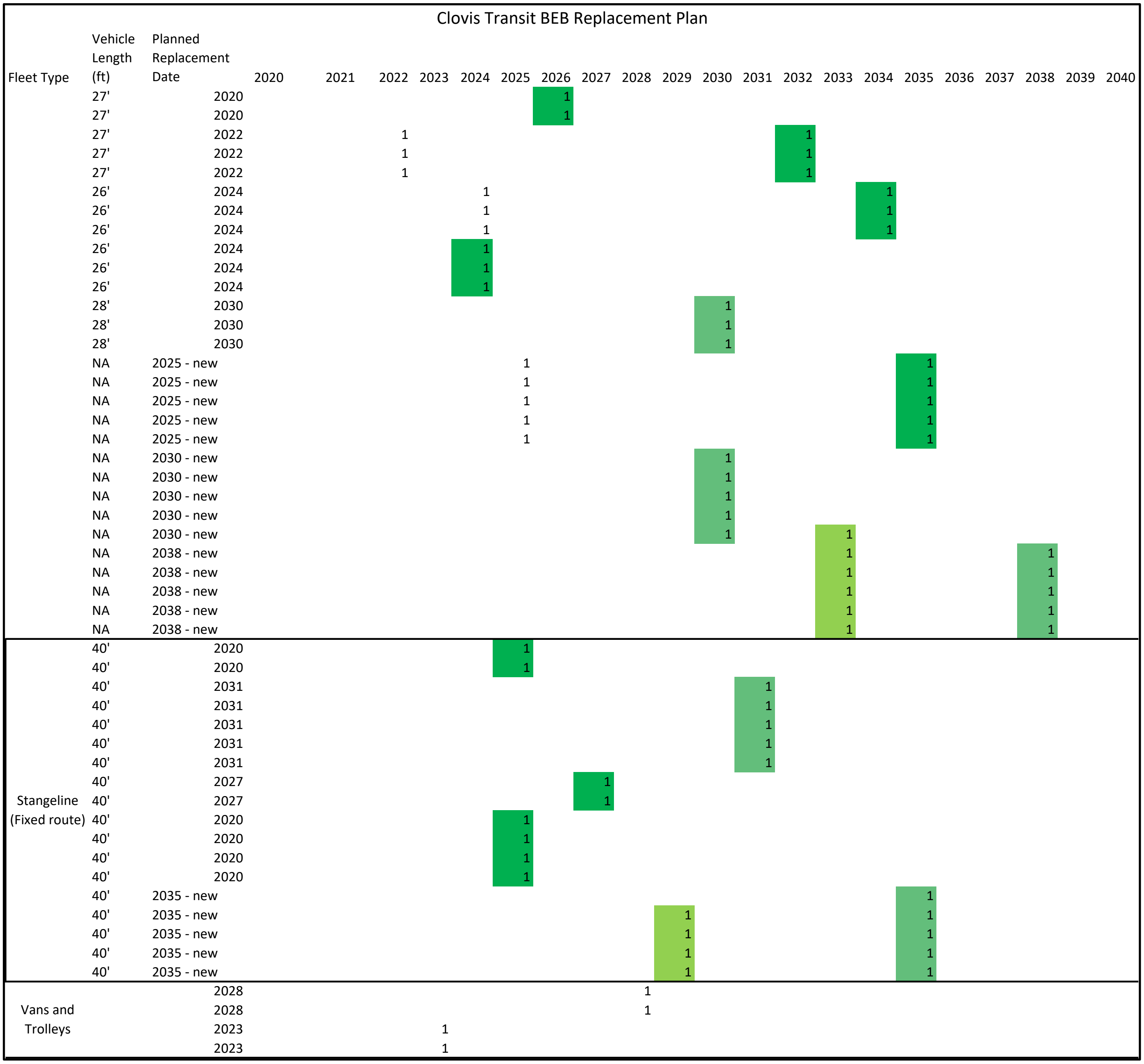
Fleet Replacement Plan

Clovis Transit plans to replace the current ICE fleet with ZEBs as the buses reach the end of their useful life. Clovis Transit currently owns 41 buses. Although the ICT regulation does not obligate Clovis Transit to start purchasing buses until 2026, Clovis Transit plans to deploy ahead of this deadline. Many of the buses are reaching or have reached the end of their useful life and need to be replaced. Clovis Transit plans to purchase three ZEBs that will be deployed by the end of 2024. Clovis Transit also intends to purchase six ZEBs and deploy them by the end of 2025. In 2026, Clovis Transit plans to acquire two ZEBs, followed by two in 2027, and four in 2029. Figure 12 below illustrates the fleet replacement plan. A 100% ZEB fleet will occur in 2035. Clovis Transit is planning to expand the existing service with at least one additional route.

The replacement plan includes additional vehicles for a planned fleet expansion and spare buses. Because of the expansion and spare buses, Clovis Transit's fleet is expected to grow to 56, including 10 spare buses—four full-sized spares and six small-bus spares. Light-duty vehicles in the paratransit fleet are not included as they are exempt from ICT compliance.

This report focuses on a fleet of 100% BEB or 100% FCEB. Mixed technology fleets (i.e., having both BEBs and FCEBs) are a viable option for many transit agencies. However, operating a mixed-fuel fleet involves maintaining charging and refueling infrastructure, which is often infeasible from a space and cost perspective. A mixed fleet analysis for Clovis Transit can be found in the Mixed Fleet Analysis section.

Figure 12. Clovis Transit BEB Replacement Plan



Clovis Transit BEB Replacement Plan

Fleet Type	Vehicle Length (ft)	Planned Replacement Date	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
	27'	2020							1														
	27'	2020							1														
	27'	2022			1										1								
	27'	2022			1										1								
	27'	2022			1										1								
	26'	2024					1										1						
	26'	2024					1										1						
	26'	2024					1										1						
	26'	2024					1																
	26'	2024					1																
	26'	2024					1																
	28'	2030											1										
	28'	2030											1										
	28'	2030											1										
	NA	2025 - new						1										1					
	NA	2025 - new						1										1					
	NA	2025 - new						1										1					
	NA	2025 - new						1										1					
	NA	2025 - new						1										1					
	NA	2030 - new											1										
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	NA	2030 - new											1										
	NA	2030 - new											1			1							
	NA	2038 - new														1					1		
	NA	2038 - new														1					1		
	NA	2038 - new														1					1		
	NA	2038 - new														1					1		
	NA	2038 - new														1					1		
Stangeline (Fixed route)	40'	2020						1															
	40'	2020						1															
	40'	2031												1									
	40'	2031												1									
	40'	2031												1									
	40'	2031												1									
	40'	2031												1									
	40'	2027								1													
	40'	2027								1													
	40'	2020						1															
	40'	2020						1															
	40'	2020						1															
	40'	2020						1															
	40'	2035 - new																1					
	40'	2035 - new										1						1					
	40'	2035 - new										1						1					
	40'	2035 - new										1						1					
	40'	2035 - new										1						1					
Vans and Trolleys		2028									1												
		2028									1												
		2023				1																	
		2023				1																	

Utility Analysis

Clovis Transit will be using BEV-2 rates (see **Utility Rate Structures**). The costs were calculated assuming all vehicles charge off-peak between 11:00 p.m. and 5:00 a.m. Because Clovis Transit has space constraint issues at their current location, they will need to relocate their depot to house the new electric fleet. Since this location has not yet been determined, CALSTART is unable to account for potential utility upgrades needed and the amount of power available at the future depot. Table 10 below has a breakdown of cost estimates depending on the utility rate (BEV-2 vs. B-20) and charging type (sequential vs. unmanaged). Utility and charging infrastructure costs were not included.

Table 10. Annual Cost Breakdown Estimates by Utility Rate and Charging Type

OEM	Charge/Cost Type	B-20 (secondary)		BEV-2 (secondary)		% Change	
		Sequential	Unmanaged	Sequential	Unmanaged	Sequential	Unmanaged
OEM 1	Meter Charges	$19,609.92	$19,609.92	$16,992.00	$ 16,992.00	-13%	-13%
	Energy Charge	$257,826.37	$257,826.37	$310,113.66	$310,113.66	20%	20%
	kW Charges	$421,165.80	$539,470.80	$30,961.44	$40,135.20	-93%	-93%
	Total Annual Electric Cost ($/yr)	$698,602.09	$816,907.09	$358,067.10	$367,240.86	-49%	-55%
OEM 2	Meter Charges	$19,609.92	$19,609.92	$16,992.00	$16,992.00	-13%	-13%
	Energy Charge	$253,774.91	$253,774.91	$305,240.56	$305,240.56	20%	20%
	kW Charges	$421,165.80	$705,097.80	$30,961.44	$51,602.40	-93%	-93%
	Total Annual Electric Cost ($/yr)	$694,550.63	$978,482.63	$353,194.00	$373,834.96	-49%	-62%
OEM 3	Meter Charges	$19,609.92	$19,609.92	$16,992.00	$16,992.00	-13%	-13%
	Energy Charge	$254,109.81	$254,109.81	$305,643.38	$305,643.38	20%	20%
	kW Charges	$414,856.20	$667,240.20	$30,961.44	$49,308.96	-93%	-93%
	Total Annual Electric Cost ($/yr)	$688,575.94	$940,959.94	$353,596.82	$371,944.34	-49%	-60%

As broken down above, the BEV-2 rate has a slightly higher energy cost ($/kWh), but overall, it results in significantly lower power cost (see kW Charge rows). Peak kW unmanaged charging was 2,235 kW, and managed charging peaked at 1,335 kW.

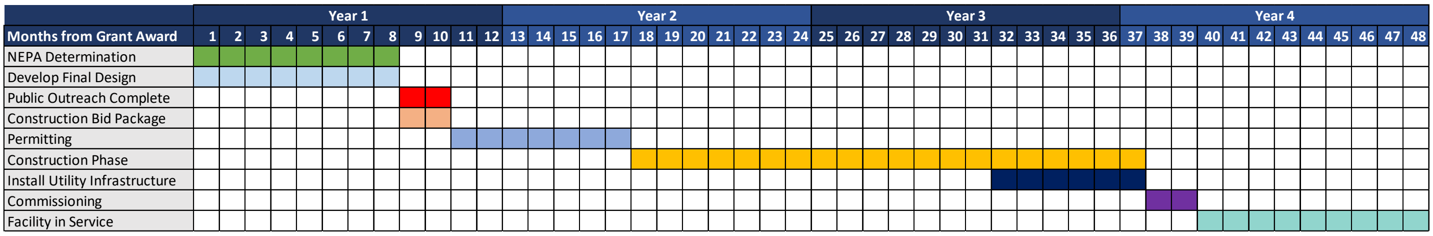
Infrastructure Analysis

BEB Charging Infrastructure Deployment Plan

To deploy a BEB fleet, Clovis Transit will first need to build a permanent transit facility. To move forward, Clovis Transit must secure property and funding to build this facility. After the property and funding has been secured, environmental review and a final draft of the depot will need to be completed.

Next, Clovis Transit 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 expected 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 will be ready for use. A Gantt chart outlining the proposed construction timeline is included below in Figure 13.

Figure 13. Clovis Transit Facility Construction Timeline



	Year 1												Year 2												Year 3												Year 4											
Months from Grant Award	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
NEPA Determination	■	■	■	■	■	■	■	■																																								
Develop Final Design	■	■	■	■	■	■	■	■																																								
Public Outreach Complete									■	■																																						
Construction Bid Package									■	■																																						
Permitting											■	■	■	■	■	■	■																															
Construction Phase																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■											
Install Utility Infrastructure																																■	■	■	■	■	■											
Commissioning																																						■	■									
Facility in Service																																								■	■	■	■	■	■	■	■	■

If the construction process adheres to the proposed timeline, construction is expected to take 39 months. The main barrier to beginning this process is obtaining land and 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 infrastructure 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 equipment.

The depot will need FTM equipment, mainly a transformer. Clovis Transit will also need to deploy BTM equipment at their depot to bring power from the transformer to the chargers.

To serve the charging site, Clovis Transit will need to deploy the following infrastructure:

- Seven transit bus power cabinets
- 21 transit bus depot chargers
- 35 shuttle bus chargers
- Three DCFCs (shuttle bus backup chargers)
- One electric bus switchboard (480 V)
- Four electrical panelboards (120/208 V)
- One 500-kVA transformer (see **Utility Analysis** section for more details)
- 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 is estimated to be approximately 163,000 square feet. More information can be found in **Appendix F: Clovis Transit Conceptual Framework and Supporting Documents**.

Clovis Transit will transition to zero-emission between 2024 and 2040. To minimize the amount of construction work needed to install BTM infrastructure, it is advisable to install all BTM upgrades at the same time. To save time and reduce costs, BTM infrastructure installation should begin during the construction phase to allow the infrastructure to be installed before concrete is laid and to reduce the cost of deploying conduit by reducing the amount of trenching. In addition, Clovis Transit will need to install conduit directly to the location where each of the chargers will be located. This strategy allows Clovis Transit 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 Clovis Transit were to roll out a fleet of FCEBs, the main requirement would be to obtain hydrogen for the fleet. Depending on the number of FCEBs Clovis Transit choses to purchase, the cost of refueling can vary. The fleet would consume approximately 1,650 kg of hydrogen per week, which equates to approximately 85,800 kg per year. Clovis Transit would have several options for obtaining hydrogen for the fleet: produce hydrogen onsite via SMR or electrolysis, or alternatively opt to receive delivered gaseous or liquid hydrogen. Lastly, Clovis Transit could fuel at public fueling stations. Table 11 below has a breakdown of costs per hydrogen source.

Table 11. Onsite Hydrogen Production Equipment Costs

Expense	Onsite Electrolysis	Delivered Liquid Hydrogen	Delivered Gaseous Hydrogen	Onsite SMR	Offsite Retail Fueling
CAPEX	$7,024,829.00	$3,247,254.00	$2,658,633.00	$5,524,829.00	$0
Annual Cost of Hydrogen Fuel	$1,648,976.16	$1,593,926.88	$1,526,366.40	$1,648,976.16	Offsite fueling not currently available

Several of these options can be eliminated immediately. Producing hydrogen onsite via electrolysis is not viable because the utility costs would be high. Producing 1 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. Clovis Transit would consume about 16,253 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 677 kW. This method for producing hydrogen is not viable; the amount of energy required to produce this much hydrogen is more than double the amount of energy the entire BEB fleet uses. In addition, there would still be high power demand for electrolysis.

To model the cost of obtaining, storing, and dispensing hydrogen, CALSTART used NREL's HDSAM model. The CAPEX for hydrogen produced onsite is expected to cost $7,024,829. The annual cost for fuel (assuming $6/kg) is $1,648,976.16. 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 site.

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; some newer tube trailers can deliver up to 1,100 kg of gaseous hydrogen at once. To serve the entire fleet, Clovis Transit would need to receive one truck delivery per day or once every two to three days. This situation would likely be incompatible with Clovis Transit's operations. However, if this option was pursued, the expected annual cost of hydrogen would be approximately $1,593,926.88.

Liquid hydrogen is typically delivered in larger quantities, and most liquid hydrogen trucks can deliver up to 4,500 kg of hydrogen. When Clovis Transit is fully zero-emission, the fleet could consume enough fuel to justify the use of liquid hydrogen. The annual hydrogen fuel cost is projected to be approximately $1,526,366.40, 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 Clovis. The closest light-duty station is along I-5 at Harris Ranch about 60 miles away. This distance would be too far to feasibly travel to refuel, and the price of retail hydrogen is currently high. A new hydrogen production plant is being commissioned about 25 miles away in Kerman, CA.[4] CALSTART spoke to a representative for the H2B2 project, and they are planning to use the hydrogen to open a light-duty refueling station. An agreement could be made to procure local hydrogen. Local hydrogen can cut down on transportation costs. 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, 2020a). As a result, the market for retail hydrogen fueling could change in the future.

The most viable option for Clovis Transit to fuel an FCEB fleet would be to use onsite SMR. Onsite SMR is only economically viable at volumes of at least 200 kg 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, Clovis Transit

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[4] For more information about the H2B2 project, go to https://www.h2b2.es/project/solar-pv-hydrogen-production-plant-in-central-california/

would need to build a hydrogen station. The station would be designed to accept hydrogen from a tube trailer. Clovis Transit would then schedule deliveries of hydrogen. Once demand reaches 200 kg per day, an onsite 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.

When the onsite SMR is installed, the equipment used to accept delivered hydrogen can be left onsite. This will allow Clovis Transit to accept delivered hydrogen when the SMR is undergoing scheduled maintenance or if there is an equipment fault. Clovis Transit is projected to pay approximately $1,648,976.16 per year for hydrogen. 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 CAPEX associated with some of these options, such as a hydrogen fueling station. Clovis Transit would need to invest in a fueling station if it decides to obtain hydrogen via onsite electrolysis, delivered liquid hydrogen, or onsite SMR. Clovis Transit could avoid this CAPEX if it was able to obtain hydrogen from retail fueling stations; however, this is currently not a feasible option. The CAPEX and annual fuel costs are displayed in Table 11. There are additional costs associated with deploying onsite hydrogen production equipment, which is explored further in **Appendix G: Evaluation of Hydrogen Vehicle Refueling Options Report**.

Resiliency

FTM Resiliency

In utilizing PG&E's BEV-2 rate, it is unlikely Clovis Transit can take advantage of any FTM rates. FTM batteries and energy assets are managed and maintained so the utility can continue to provide power to their customers in the event of an outage. 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 obtain resiliency while avoiding the CAPEX associated with deploying resiliency assets. PG&E does not currently offer a special utility rate for resiliency. A utility can feasibly offer a special utility rate if there are multiple customers that can make use of it. PG&E has a large service territory, and there could be other customers in Clovis Transit's area that could make use of this rate.

BTM Resiliency

There are many options for Clovis Transit's BTM resiliency. Since Clovis Transit will need to build a new depot, it will be possible to install a solar PV and battery storage system. Clovis Transit is in a region prone to grid interruptions, which would impact refueling the ZEB fleet and revenue service. First, extreme heat will increase the likelihood of grid failures and damage the electrical equipment used by transportation agencies, which is expected to become more regular as climate change intensifies. Second, as the climate changes and high heat risk grows, the chance of events such as wildfire might also cause an interruption in power at the transit agency.

Clovis Transit must take some action to overcome these issues by adding resiliency measures (i.e., solar, battery storage, and/or a backup generator), which will provide grid independence. CALSTART developed a few system sizing scenarios based on the hour of outage from 24 hours to 35 hours and various combinations of critical load as shown in Table 12. The critical load is the bus charging electricity load. Each case represents the system sizing associated with the outage hours and critical electric load. For example, to have 24 hours of resiliency with the 50% critical load, the required solar sizing would be 600 kW with the battery sizing of 827 kW and 3,200 kWh. The addition of the infrastructure would add a lifetime cost of $5 million, as shown in Table 12. All calculations were completed with the help of NREL REOPT tool; all assumptions made for the calculation are listed below:

- The future depot will host a solar infrastructure of up to 1 MW.
- The BEV-2 utility rate structure was used to estimate the operational cost, considering the solar infrastructure's 25-year useful life.
- A discount factor of 14% was used to evaluate the life-cycle cost.
- The Clovis Transit depot's present address was used to calculate the solar potential.
- An average of 3% of the inflation rate in fuel was used, as per the EIA-predicted average nominal annual commercial escalation rate from 2020–2045 in their reference case scenario.
- The current LCFS credits were considered in this analysis to estimate the life-cycle cost.
- The fuel burn rate by the generator was considered at 0.076 gal/kwh.

Due to a limited available area for installing more solar, CNG/diesel generators were used for system sizing. However, at a later stage, either stationary fuel cell generators or additional solar power at the depot might replace these generators.

Table 12. Resiliency Analysis

Resiliency Analysis								
Scenario	Outage Hours	Critical Load Factor	Battery		Solar Sizing (kW)	Generator Sizing (kW)	Result	Life-cycle Cost (25 Years)
			Battery Power (KW)	Battery Energy (kWh)				
Case 1	24	50%	830	3,300	600	0	Yes	$5,027,880
Case 2	24	50%	500	2,000	1,000	300	Yes	$5,726,224
Case 3	24	50%	450	1,800	320	300	Yes	$5,166,057
Case 4	24	100%	720	2,000	1,000	780	Yes	$6,080,386
Case 5	24	100%	1,200	4,500	800	300	Yes	$5,347,112
Case 6	35	100%	1,200	5,300	1,000	300	Yes	$5,409,815

Depot Conceptual Design

A hypothetical depot for Clovis Transit was created to understand the space requirements needed to store and charge a BEB fleet. The depot was assumed to house and charge 21 full-sized BEBs and 35 shuttle buses.

The electrical equipment for charging the vehicles is in Table 13 below. At Clovis Transit's request, staff parking, a bus wash, and one office/maintenance building were included in the space estimate. The electrical demand of these additional buildings was not assessed.

Table 13. Electric Equipment for Bus Charging

Equipment	Quantity
Transit bus power cabinet (ABB HVC 150C)	7
Transit bus depot charger (ABB HVC 150C)	21
Shuttle bus charger (ClipperCreek CS-100)	35
DCFC (ABB Terra 54)	3
Electric bus switchboard (480 V)	1
Electrical panelboard (120 / 208 V)	4
Transformer (primary: 480 V, secondary: 120/208 V)	1
Utility transformer	1

The site assessment estimated approximately 163,000 square feet (3.75 acres) of space would be needed for Clovis Transit's new depot. For a complete report and single line diagram of the site design, see **Appendix F: Clovis Transit Conceptual Framework and Supporting Documents**.

Estimated Costs

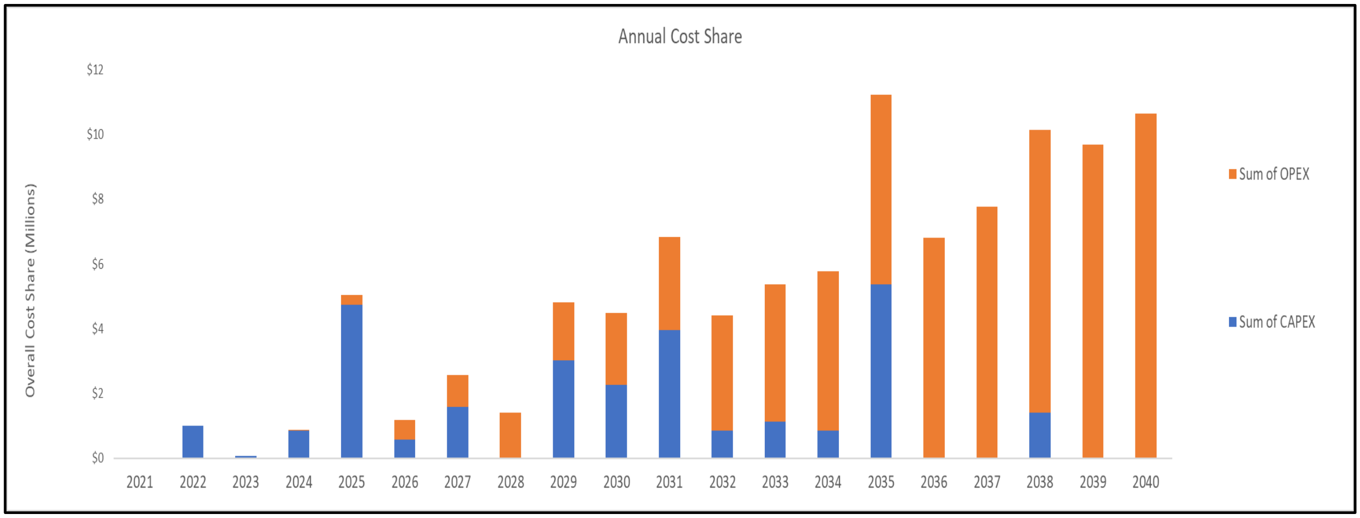
Transitioning to a ZEB fleet will require substantial financial resources. Table 14 provides a cost comparison for maintaining an ICE fleet and transitioning to a fully BEB fleet. Because the most economically feasible option for Clovis Transit to obtain hydrogen fuel exceeds the utility costs that would be associated with charging a BEB fleet, CALSTART did not compute TCO for a fully FCEB fleet. These costs assume that the buses and infrastructure will be purchased according to Clovis Transit's fleet replacement plan.

Table 14. Estimated Costs to Transition to a BEB Fleet

Fleet Type	Fleet Size	Discounted TCO
ICE Fleet Cost	11 shuttle buses	$1.9 million
BEB Fleet Costs	57 buses (35 large transit buses and 22 shuttle buses)	$58.3 million

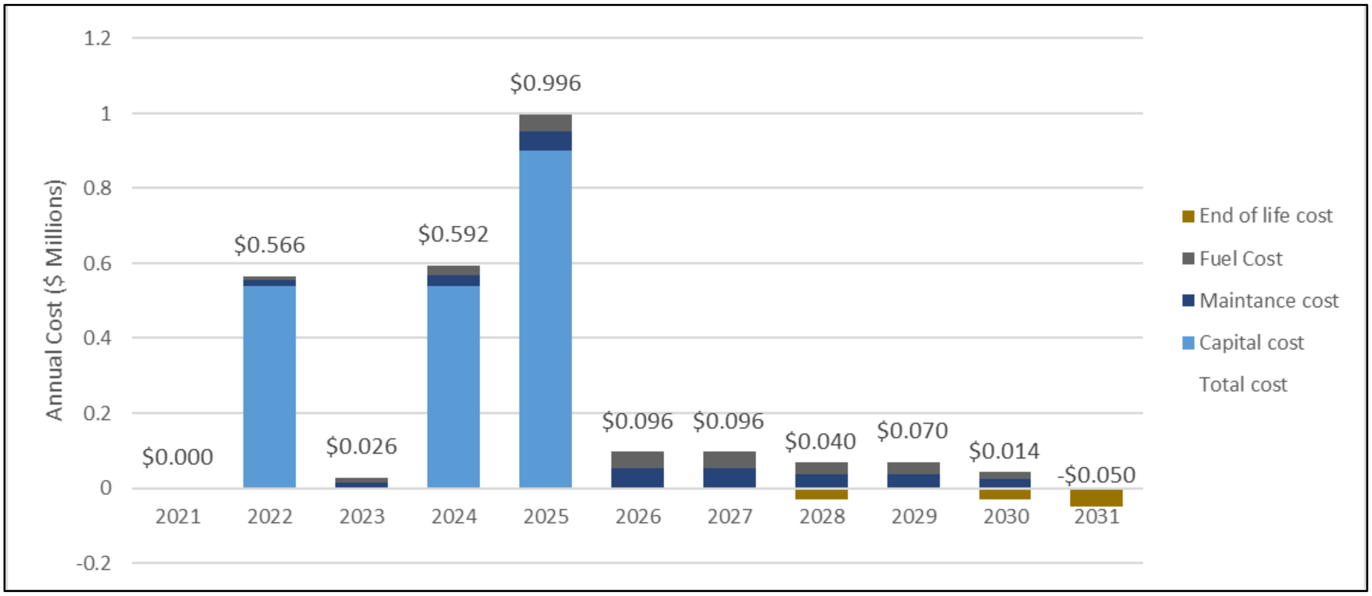
The discounted TCO of converting Clovis Transit's conventional fleet of 57 buses (35 large transit buses and 22 shuttle buses) to BEBs is $58.3 million. This study takes a 14% discount factor (i.e., discounting the amount to 2022 dollars) into account. Figure 14 shows the corresponding costs for each year from 2022 to 2040. (Figure 12. Clovis Transit BEB Replacement Plan is provided in the Fleet Replacement Plan section, which also lists the assumptions used to calculate these total costs.) The acquisition cost of BEBs and infrastructure was incorporated in CAPEX for this cost calculation, while additional costs such as operation, mid-life maintenance, and periodic maintenance were incorporated in operating expenditures (OPEX).

Figure 14. TCO for BEBs and ICE Vehicles



Similarly, adding ICE buses to the present fleet will also have a significant impact of around $2.2 million, considering the average diesel cost of $6.88 per gallon in California. The capital cost of purchasing 11 new buses is the most significant contributor to TCO (Figure 15).

Figure 15. Annual TCO for ICE Vehicle



The running cost of ICE shuttle buses also depends considerably on fuel cost. (The relationship between fuel cost and the overall cost is shown on page 85.)

TCO for BEB Fleet

CALSTART estimated the TCO of Clovis Transit's BEB fleet from 2022 to 2040. Table 15 below shows the replacement planning and strategy. This replacement plan includes a spare bus as well as replacement buses for ICE vehicles. The whole fleet replacement will add 57 new BEBs to fleet operations, including 35 large transit buses and 22 small shuttle buses.

The TCO estimates were based on various factors, such as vehicle parameters and end-of-life assumptions. The assumptions used to conduct the analysis are detailed below:

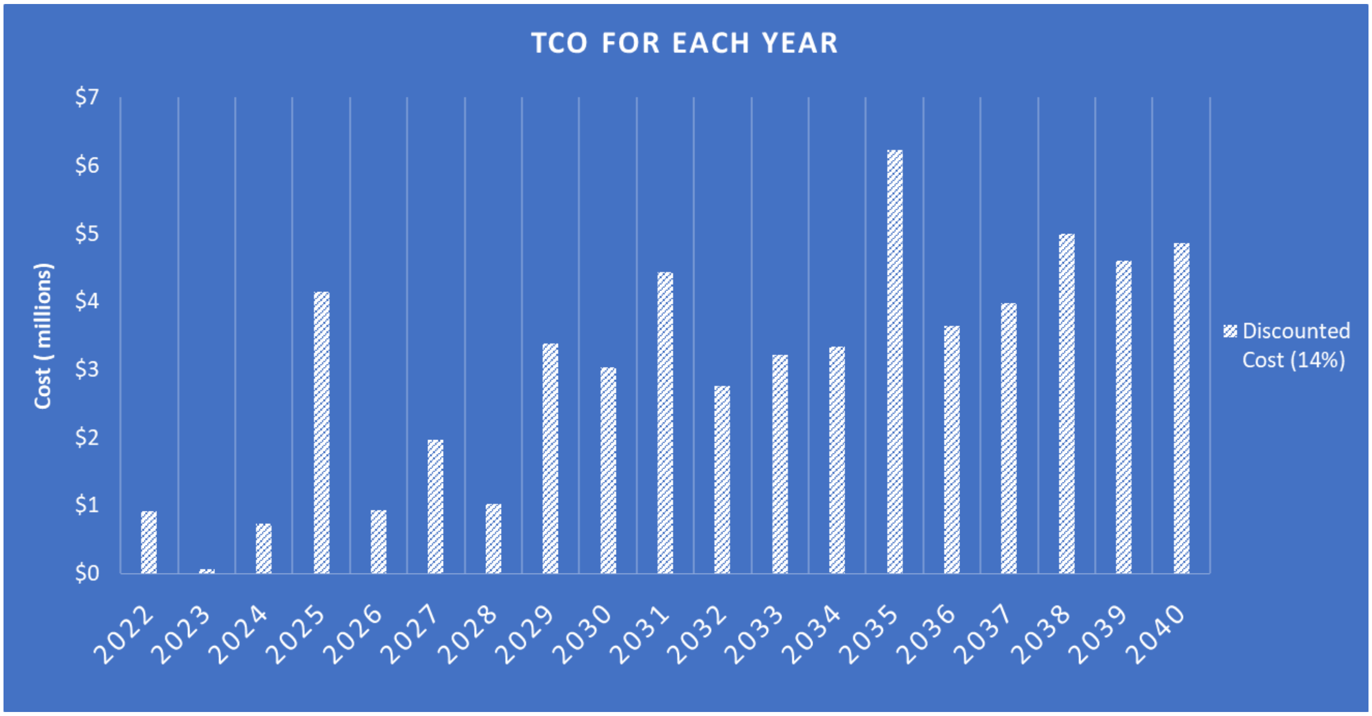
- The capital cost of the BEBs was considered to be $700,000.
- The maintenance cost of a transit bus was considered to be $0.72/mile.
- The maintenance cost of the shuttle bus was considered to be $0.20/mile.
- The average annual miles traveled for a transit bus was considered to be 42,244. The average for shuttle buses was considered to be 7,665 miles.
- The utility cost/cost of charging for transit buses was estimated to be $16,350 per bus per year.
- Similarly, utility cost/charging cost for shuttle buses was estimated to be $2,762 per bus per year.
- Siemens chargers have a capital cost of $85,000 (for two buses), while ABB chargers have a capital cost of $96,635 (for three buses).
- The construction/installation cost for these chargers was considered to be $125,000.
- In this TCO calculation, incentives were not considered.

The TCO for operating Clovis Transit's BEB fleet is $100.1 million dollars, including $28 million for CAPEX and $72.5 million for OPEX. CALSTART also estimates the overall discounted cost for the complete replacement of BEBs with a 14% discount factor to be approximately $59 million, as shown in Table 15. The overall yearly cost, considering the 14% discount factor, is shown in Figure 16.

Table 15. Overall Discounted Cost to Replace BEBs ($ Millions)

Year	CAPEX	OPEX	Total Cost	Yearly Discounted Cost (14%)
2022	1.0	0.0	1.0	0.9
2023	0.1	0.0	0.1	0.1
2024	0.8	0.0	0.9	0.7
2025	4.7	0.3	5.0	4.1
2026	0.6	0.6	1.2	0.9
2027	1.6	1.0	2.6	2.0
2028	0.0	1.4	1.4	1.0
2029	3.0	1.8	4.8	3.4
2030	2.3	2.2	4.5	3.0
2031	3.9	2.9	6.8	4.4
2032	0.8	3.6	4.4	2.8
2033	1.1	4.2	5.4	3.2
2034	0.8	4.9	5.8	3.3
2035	5.4	5.9	11.2	6.2
2036	0.0	6.8	6.8	3.6
2037	0.0	7.8	7.8	4.0
2038	1.4	8.7	10.1	5.0
2039	0.0	9.7	9.7	4.6
2040	0.0	10.6	10.6	4.9
Total	**27.6**	**72.4**	**100.1**	**58.3**

Figure 16. Yearly TCO for BEBs



TCO for ICE Fleet

The TCO for Clovis Transit's ICE fleet was calculated over 11 years starting from 2022 to 2031, when 11 new ICE buses will be added to Clovis Transit's fleet (Table 16). In 2031, ICE buses will be replaced by BEBs, which was considered in the BEB cost analysis section above.

Table 16. ICE Bus Induction Plan

Year	Number of New Buses Added to Fleet
2022	3
2024	3
2025	5

The TCO calculations were based on route characteristics, vehicle specifications, and end-of-life assumptions. The assumptions for the cost calculations were as follows:

- Upfront capital cost per vehicle was assumed as $180,000.
- The annual average distance traveled by each vehicle was considered to be 8,000 miles.
- The maintenance cost was considered to be $ 0.60 per mile (DOT, 2011).

- The lifetime of a vehicle was assumed to be seven years.
- End-of-life cost for each vehicle was considered to be $10,000 (American Bus Sales, 2015).

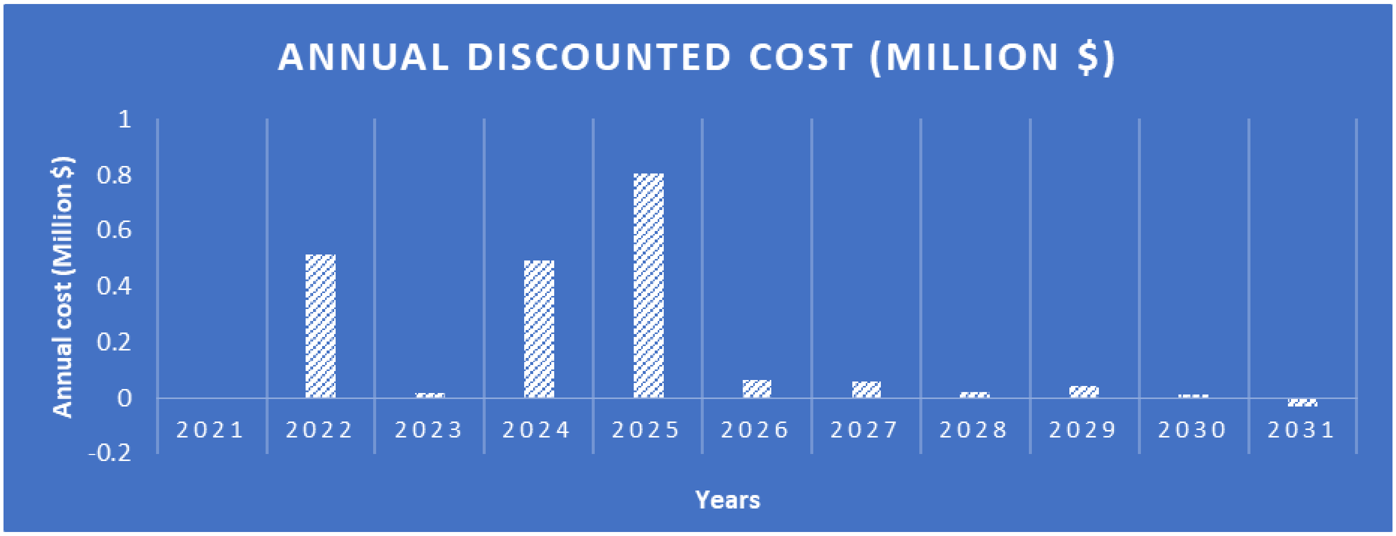
A discount factor of 14% was assumed for calculating the TCO for the ICE fleet. Assuming the current scenario to be true until 2030, buses at an average will be travelling 8,000 miles per year with diesel costing an average of $ 6.88 per gallon. The yearly cost for CAPEX and OPEX is shown in Table 17.

Table 17. Annual CAPEX, OPEX, and Discounted TCO for ICE Fleet

Years	CAPEX Cost	OPEX cost	Discounted TCO (million $)
2022	$540,000	$ 26,191	$0.52
2023	$0	$ 26,191	$0.02
2024	$540,000	$ 52,382	$0.51
2025	$900,000	$ 96,033	$0.82
2026	$0	$ 96,033	$0.08
2027	$0	$ 96,033	$0.07
2028	$0	$ 69,842	$0.03
2029	$0	$ 69,842	$0.05
2030	$0	$ 43,651	$0.01
2031	$0	$0	-$0.03

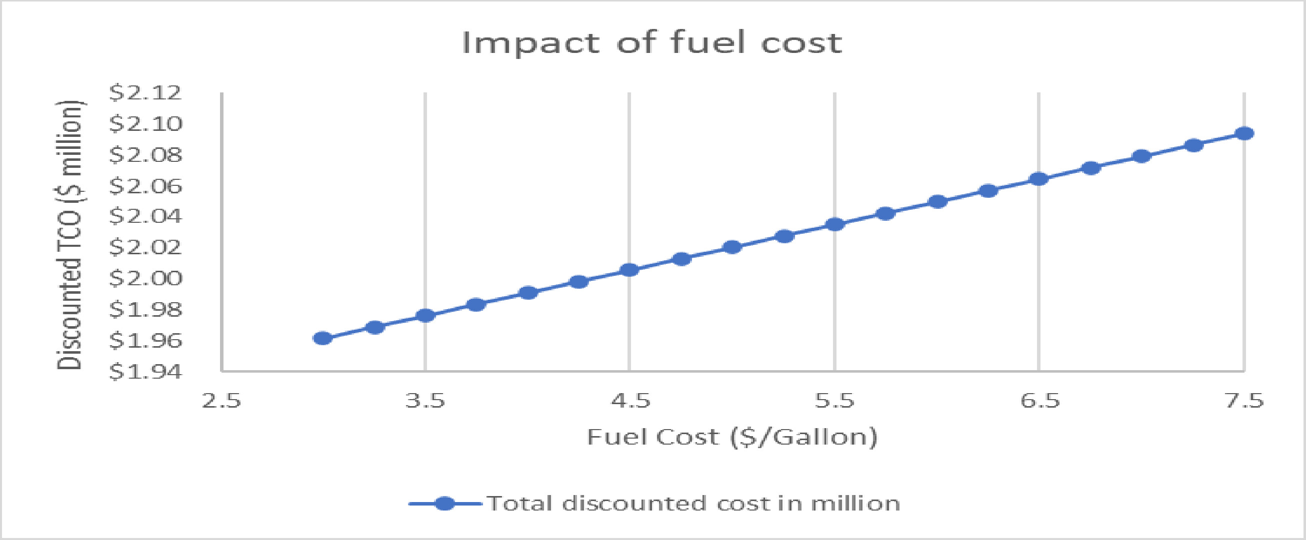
The TCO for Clovis Transit's ICE vehicles would be $ 2.08 million (discounted to 2022 dollars). Figure 17 shows the annual discounted TCO.

Figure 17. Annual Discounted TCO for ICE Buses



However, due to fluctuations in the economy, fuel cost can impact TCO significantly—hence the need to assess the impact of fuel cost on TCO. CALSTART completed a sensitivity analysis considering the change in fuel cost from $3 per gallon to $ 7.5 per gallon (as shown in Figure 18). The details for the TCO calculations are shown in **Appendix H: ICE Bus Fleet Cost Calculation Report**.

Figure 18. Sensitivity Analysis for Fuel Cost



Mixed Fleet Analysis

Clovis Transit can also consider a mixed fleet of BEBs and FCEBs. For this analysis, the mixed fleet was assumed to be four full-sized BEBs, 11 full-sized FCEBs, and 22 small BEBs. Full BEB and FCEB estimates were compared as reference. An estimate of the cost of a continued fossil fuel-powered fleet is also listed below.

It is important to note that these results represent modeling data and do not necessarily reflect a real-world scenario. Different methodologies were applied to arrive at the mixed fleet calculations than those applied to the BEB and ICE TCO results—caution should be taken when comparing these sections. Construction costs and labor were not included in the mixed fleet analysis; constructions costs for hydrogen facilities are likely to be higher than electric infrastructure due to the specialized nature of the equipment.

Table 18 below outlines the estimated depot space requirements. Electric infrastructure and hydrogen refueling infrastructure must both be accounted for with a mixed fleet. These land requirements include an average space requirement for delivered and onsite hydrogen along with bus parking, maintenance space, an office building, bus wash, and staff parking.

Table 18. Mixed Fleet Land Requirements for Infrastructure

Fleet Mix	Stageline (Fixed Route)	Roundup (Paratransit)	Vehicle Total	Depot Land Requirement (avg; acres)
100% BEB Fleet	35	22	57	3.66
100% FCEB Fleet	13	22	35	3.67
Mixed Fleet	15	22	37	3.72
Fossil Fuel Fleet	13	22	35	3.56

Table 19 details one-time costs and annual costs for Clovis Transit's mixed fleet. One-time costs include the vehicle purchase costs, land costs, facility upgrade, and personnel training costs. Annual costs include fuel costs and maintenance costs. The assumptions used to arrive at these results are provided below:

- Bus costs:
    - Full-sized FCEB: $1,195,000
    - Full-sized BEB: $700,000
    - Full-sized fossil fuel-powered bus: $650,000
    - Small BEB: $282,674
    - Small FCEB: $225,000
    - Small fossil fuel-powered bus: $150,000
- BEB utility upgrades: $1,000,000
- Hydrogen facility upgrades: $1,500,000
- Fuel costs: $2.34/gal
- Charger and installation costs: $210,000
- Space assumptions: See **Appendix F: Clovis Transit Conceptual Framework and Supporting Documents**, **Appendix G: Evaluation of Hydrogen Vehicle Refueling Options Report**, and *Best Practices in Hydrogen Fueling and Maintenance Facilities for Transit Agencies.*[5]
- Land cost: $1 million/acre
- Training costs for BEB: $78,750
- Training costs for FCEB: $153,325
- Maintenance costs for BEB: $0.48/mile
- Maintenance costs for FCEB: $0.56/mile

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[5] View this report at https://calstart.org/wp-content/uploads/2018/10/Best-Practices-in-Hydrogen.pdf.

Table 19. One-Time and Annual Costs for Mixed Fleet

Fleet Mix	Vehicle # Total	Vehicle cost ($)	Fuel Cost ($/yr)	Fueling Infrastructure Cost (avg; one time)	Total Est Land Cost	Facility Upgrades (one time)	Maintenance Costs ($/yr)	Training Costs (one time)	Total ($)
100% BEB Fleet	57	$30,718,828	$358,067.10	$5,880,000	$3,655,303.03	$1,000,000	$279,446.40	$78,750	$41,970,394.53
100% FCEB Fleet	35	$20,485,000	$1,140,399	$4,613,886.25	$3,674,242.42	$1,500,000	$326,020.80	$153,325	$31,846,299.07
Mixed Fleet	37	$22,163,828	$464,833.55	$4,861,471.75	$3,723,599.63	$2,500,000	$309,870	$232,075	$34,225,254.33
Fossil Fuel Fleet	35	$11,750,000	$165,148.35	-	$3,556,588.61	-	-	-	$15,471,736.97

Financing Strategy

Clovis Transit will need a financing strategy to transition to a zero-emission fleet. The most important step that Clovis Transit will need to take is to secure both the location and funding to build a transit facility. If Clovis Transit can utilize property already owned by the City of Clovis, they can avoid having to purchase land. Otherwise, land will need to be acquired to house the fleet. The financial resources needed for a facility may potentially be obtained by winning a competitive grant(s) that funds CAPEX. Grant programs such as Caltrans's TIRCP and the DOT's RAISE can also be used toward purchasing a bus depot or financing utility and BTM infrastructure upgrades. The DOT 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 programs.

Once a transit property has been acquired and the infrastructure upgrades have been completed, the operational costs are expected to be covered by Clovis Transit'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**). 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 fossil fuel-powered bus. Using grants to cover the incremental cost of the buses would allow Clovis Transit to purchase ZEBs with the funding sources they normally employ to purchase buses.

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

There are additional financial considerations that need to be factored in when deploying resiliency assets. The most likely candidates for Clovis Transit 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 be used only in the event of a grid outage and would remain idle for the vast majority 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 specific DERs. Solar is eligible for a 10%, permanent ITC. Generators are only eligible for a 10% ITC if they are used in a combined heat and power system (i.e., 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 usable in a combined heat and power system. Furthermore, the ITC for combined heat and power systems expires at the end of 2023.

If Clovis Transit opts to deploy DERs that are eligible for the ITC, acquiring them through a third-party ownership model, such as IAAS, would likely be the best option. The entity that owns the DER is eligible for the ITC. As a public agency, Clovis Transit is a tax-exempt entity and would not be able to benefit from the ITC. However, if Clovis Transit were to finance the ITC-eligible DERs through an IAAS model where a third party owns the asset, the infrastructure provider can realize the benefits of the ITC and pass the benefits on to Clovis Transit in the form of lower PPA rates. If Clovis Transit opts to deploy DERs that are eligible for the ITC, the use of an IAAS financing model should be seriously considered.

LCFS Credits

Once the buses are deployed, LCFS credits can also be used to finance CAPEX and OPEX. LCFS credits can be used in many ways. If Clovis Transit 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 of time to fund utility upgrades. LCFS credits can also benefit a transit agency even if they do not own the charging equipment or if they opt to use an IAAS financing model. Under an IAAS model, 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.

CALSTART developed a model to estimate the value of the LCFS credits over the lifetime of the project. This projection assumes that the price of LCFS credits is $100. The projected value of the LCFS credits for the fixed-route fleet is displayed in Table 20.

Table 20. LCFS Credit for Fixed-Route Fleet

Year	Revenue	Net Present Value	Levelized Revenue per kWh
2022	$0	$0	0
2023	$0	$0	0
2024	$0	$0	0
2025	$32,946	$29,289	0
2026	$32,335	$27,640	0
2027	$31,728	$26,078	$0.10
2028	$31,117	$24,592	$0.09
2029	$30,510	$23,185	$0.09
2030	$29,899	$21,847	$0.08
2031	$54,815	$38,512	$0.08
2032	$54,815	$37,031	$0.07
2033	$54,815	$35,606	$0.07
2034	$54,815	$34,237	$0.07
2035	$79,730	$47,884	$0.07
2036	$79,730	$46,042	$0.06
2037	$79,730	$44,271	$0.06
2038	$79,730	$42,569	$0.06
2039	$79,730	$40,931	$0.06
2040	$104,646	$51,656	$0.05
Total	**$911,091**	**$571,372**	**$0.07**

The projected value of the LCFS credits for the paratransit fleet is displayed in Table 21.

Table 21. LCFS Credits for Paratransit Fleet

Year	Revenue	Net Present Value	Levelized Revenue per kWh
2022	$0	$0	$0.00
2023	$0	$0	$0.00
2024	$6,365	$5,885	$0.00
2025	$6,250	$5,556	$0.00
2026	$10,224	$8,739	$0.00
2027	$10,032	$8,245	$0.10
2028	$9,838	$7,775	$0.09
2029	$9,647	$7,331	$0.09
2030	$24,579	$17,959	$0.08
2031	$24,579	$17,269	$0.08
2032	$30,251	$20,436	$0.07
2033	$41,595	$27,019	$0.07
2034	$47,267	$29,523	$0.07
2035	$56,720	$34,065	$0.07
2036	$56,720	$32,754	$0.06
2037	$56,720	$31,495	$0.06
2038	$66,173	$35,330	$0.06
2039	$66,173	$33,972	$0.06
2040	$66,173	$32,665	$0.05
Total	**$589,305**	**$356,018**	**$0.07**

III. Sustainability and Environmental Impact

GHG Emissions Comparisons

ZEBs provide environmental benefits for transit service areas. As noted in detail under **Section I. Introduction to Zero-Emission Buses**, buses with an ICE produce tailpipe emissions such as GHGs, NOx, and PM during operation that drive climate change, harm air quality, and affect human health. Clovis Transit plans to transition from fossil fuel-powered buses to ZEBs. ZEBs 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 bus operations. Buses also produce upstream emissions, which are emitted during the production of fuel. For example, diesel 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.

CALSTART analyzed emissions by using Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool. AFLEET calculates GHG, PM, NOx, and volatile organic compound (VOC) emissions for diesel-, CNG-, and battery-powered buses. AFLEET uses data from Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model to calculate upstream emissions. AFLEET calculates tailpipe emissions using data from the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES).

Users can provide customized inputs to AFLEET to generate emissions calculations. CALSTART programmed AFLEET with the following assumptions:

- Vehicle Type: Transit Bus
- State: California
- Diesel Bus Fuel Economy: 7.39 miles per gallon
- BEB Fuel Economy: 43 miles per diesel gallon equivalent (GreenPower, n.d.)
- FCEB Fuel Economy: 15.9 miles per diesel gallon equivalent (Eudy and Post, 2020a)
- Source of Electricity: Western Electricity Coordinating Council (WECC)

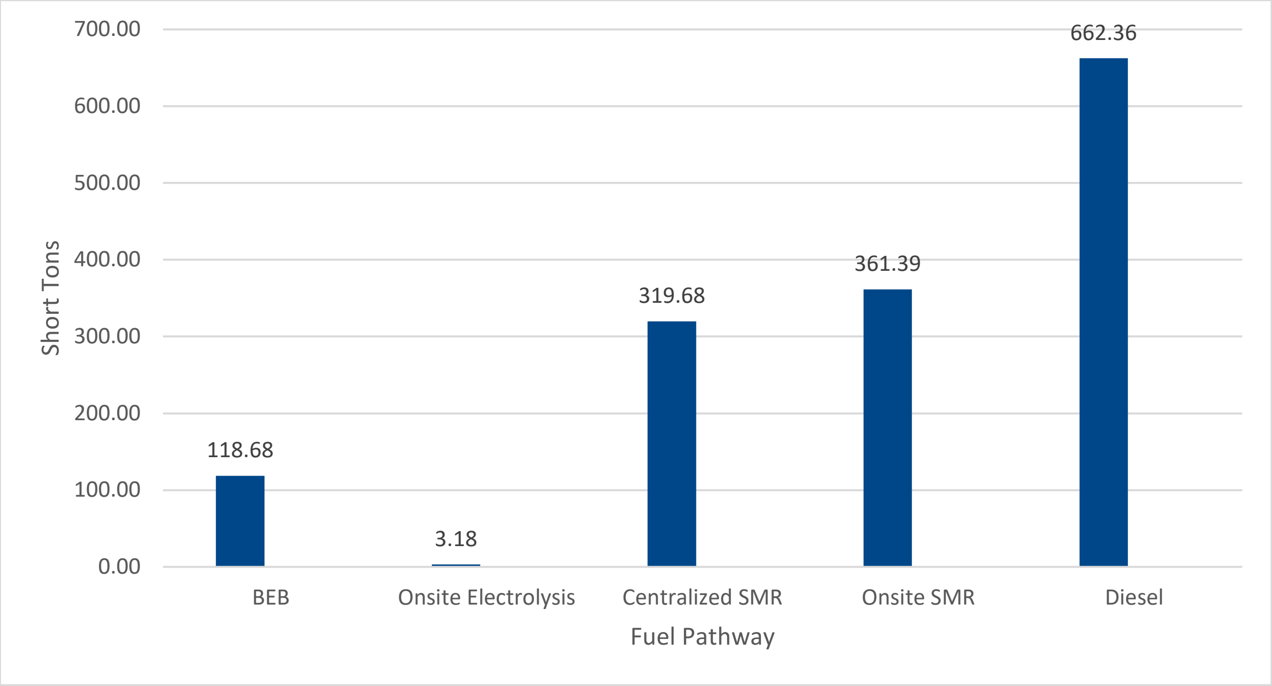
- Annual Mileage per Bus: 7,757 miles per year (46 buses travelling 356,820 miles per year)

All other parameters were left with the default values. Based on these parameters, emissions were calculated for diesel buses, BEBs, and FCEBs. Several hydrogen pathways for FCEBs were calculated assuming that the hydrogen was produced with 100% renewable energy, including:

- Centralized SMR: Gaseous hydrogen produced at a centralized plant using SMR
- Onsite SMR: Gaseous hydrogen produced onsite using SMR
- Onsite Electrolysis: Gaseous hydrogen produced onsite using electrolysis

The GHG emissions analysis is displayed below in Figure 19, which shows the number of short tons of GHG emissions produced annually for each fueling pathway.

Figure 19. Annual GHG Emissions by Fuel Pathway



CALSTART found that all electric and hydrogen pathways produce fewer emissions than diesel. The reduction in emissions is heavily dependent on the fuel pathway adopted. SMR hydrogen pathways produce fewer GHG emissions reductions than BEB or onsite electrolysis pathways.

Emissions analysis for criteria pollutants are displayed in Table 22 below. Figures are expressed as lbs. of emissions per year.

Table 22. Criteria Pollutants by Fuel Pathway

Fuel Pathway	CO	NOx	PM10	PM2.5	VOC
BEB	0.00	0.00	80.24	10.23	0.00
Onsite Electrolysis	0.00	0.00	80.24	10.23	0.00
Centralized SMR	0.00	0.00	80.24	10.23	0.00
Onsite SMR	0.00	0.00	80.24	10.23	0.00
Diesel	1,382.79	2,033.22	84.17	13.37	72.46

CALSTART found that transitioning to ZEBs would entirely eliminate CO, NOx, and VOC emissions regardless of the fuel pathway pursued. Deploying ZEBs would also provide small reductions in PM10 and PM2.5 emissions.

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 above on page 92, BEBs have a lower life-cycle environmental impact than fossil fuel-powered buses. However, there are opportunities to further improve the life-cycle environmental impact by recycling and re-manufacturing 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 life-cycle 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 reduce 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, NY, 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 United States, 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 U.S. Department of Energy, several universities, national laboratories, and research institutes, this is a research and development project in the 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 research 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 United States.

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 life-cycle 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 integrate 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 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.

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Appendix A: ZEB Specifications

Note: these are best case scenarios for vehicle ranges. Actual mileage may vary.

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 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 ZX5 MAX

PROTERRA

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 ZX5+

PROTERRA

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 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.

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.

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/*

Future Models:

AQMD is funding the development of another fuel cell shuttle bus. This bus is being developed by a partnership between A-1 Alternative Fuel Systems, Southern California Gas Company, Plug Power, SEA Electric LLC, Turtle Top, Hometown Manufacturing, and Luxfer Gas Cylinders. They are currently developing two models of a fuel cell shuttle bus. One model will have a GVWR of 14,500 lbs. and the second model will have a GVWR of 22,500 lbs. The buses will be able to travel over 250 miles on a single fill. The buses will also have CARB certification and will go through Altoona Bus Testing. The bus is expected to be available for public purchase in Q1 of 2023.

Appendix B: Charging Infrastructure Specifications

The following electrical cabinets and 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 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 6 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

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 like 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 graphics, logos, and colors to cater to each specific entity brand.

Tritium - Veefil PK

TRITIUM

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
by Ideanomics

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

CLIPPERCREEK
RELIABLE. POWERFUL. MADE IN AMERICA.

Clipper Creek
CS-100, 70/80 Amp (Selectable) EVSE, 240V, with 25-foot 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: Managed Storage 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, like 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 (now owned by ChargePoint) 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 like peak shaving, demand response, and renewables integration. Their system can also be used to track fleet data like 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 onsite 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 onsite 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 onsite 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.

Amply (owned by BP) 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. Amply'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. Amply also offers charging infrastructure installation with the necessary electrical equipment to connect the systems and CAPEX 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. Amply 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 D: Energy Storage Solutions

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

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)

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	Energy JH3, JH4 • Duration for ≥ 1 hour • Continuous power supply Power 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

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

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

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 – 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 – 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

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 like 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 E: Clovis Transit Route Modeling Results

Runs that complete their route with a SOC of 10% to 30% have been highlighted in yellow. While these buses are not a drop-in replacement with technology in 2022, it is likely that, with improvements in battery technology over time, these buses could become a drop-in replacement. 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 E-1. Route 10 Modeling Results

Route 10			
Lap	OEM 1 (kWh/mi)	OEM 2 (kWh/mi)	OEM 3 (kWh/mi)
1	39.34	50.55	45.93
2	43.44	49.15	50.03
3	47.28	46.36	53.87
4	49.42	43.58	56.02
5	51.56	40.79	58.15
6	51.56	39.07	58.15
7	49.07	40.14	55.66
Total	331.67	309.65	377.81

Table E-2. Route 50 Modeling Results

Route 50			
Lap	OEM 1 (kWh/mi)	OEM 2 (kWh/mi)	OEM 3 (kWh/mi)
1	46.29	48.40	54.63
2	50.70	52.81	59.62
3	53.69	55.80	63.05
4	55.82	57.93	65.63
5	56.69	58.80	66.72
6	56.07	58.18	66.10
7	52.01	54.12	61.70
Total	371.2868444	386.0579235	437.4412357

Table E-3. Route 70 Modeling Results

Route 70			
Lap	OEM 1 (kWh/mi)	OEM 2 (kWh/mi)	OEM 3 (kWh/mi)
1	22.19	25.54	19.98
2	24.10	27.46	21.74
Total	46.29	53.00	41.72

Table E-4. Route 80 Modeling Results

Route 80			
Lap	OEM 1 (kWh/mi)	OEM 2 (kWh/mi)	OEM 3 (kWh/mi)
1	14.57	15.51	12.67
2	15.37	14.47	11.87
Total	29.95	29.98	24.54

Table E-5. Paratransit Route Modeling Results

Average Paratransit route	
Lap	OEM 4 (kWh/mi)
1	44.56

Appendix F: Clovis Transit Conceptual Framework and Supporting Documents

A copy of conceptual designs of electric bus charging infrastructure for Clovis Transit, completed on CALSTART's behalf by FLUX Energy Systems, begins on the following page.

1. Objective

Flux Energy Systems, Inc. (Flux) was engaged by CALSTART, Inc to complete conceptual designs of electric bus charging infrastructure for Clovis Transit. Clovis Transit is planning a new Transit Center in Clovis, CA to serve thirty-five (35) shuttle buses as well as twenty-one (21) transit buses. This document evaluates the relevant design codes, physical space requirements, electrical infrastructure and charging requirements for the transit and shuttle buses. 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

3. Site Design Assumptions

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

- Transit Buses:
    - Total quantity of chargers: 21 charges (4 spare chargers)
    - Charging duration: 11pm – 5am (6 hours)
- Shuttle Buses:
    - Total quantity of chargers: 25
        - 35 standard chargers (6 spare 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	180
ClipperCreek CS-100 (Dial-a-Ride Shuttle Bus)	16.64	208 VAC	80
ABB Terra 54 (Dial-a-Ride Shuttle Bus)	50	480 VAC	60

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. DC fast chargers were not incorporated into the Load Schedule as it was assumed these chargers would only be utilized during the daytime for fast charging purposes instead of drawing power during the nighttime.

Table 2. Charging equipment for electric transit and shuttle buses

Bus Type	Max Input Power (kW)	Battery Size (kWh)	Range (miles)
Transit Bus	150	450	163 - 232
Dial-a-Ride Shuttle Bus	16.64	118	150

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	2.3	0.7	1.6
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. Both the transit and 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	47 x 10.5	494
Shuttle Bus	30 x 10	234

5. Proposed Design

Clovis Transit has provided preliminary quantities of transit and the shuttle buses at the future Transit Center. Flux evaluated the electrical infrastructure to power the electric buses.

Table 5. Quantity of parking stalls for two design options

	Quantity
Transit Bus	21
Dial-a-Ride Shuttle Bus	35
DC Fast Charger	3
Total	59

Based on the above-mentioned design criteria, a preliminary conceptual site plan was developed to incorporate seven (7) pull through bus lanes with five (5) buses per lane for Dial-a-Ride shuttle buses. Three of the bus lanes had dedicated space for shuttle DC fast charging. There were also seven (7) pull through bus lanes with three (3) buses per lane for transit buses. A 2-1/2 feet concrete island was placed between alternating pull through lanes for charger infrastructure installation. Refer to Figure 1 for overall site layout. Additionally, one hundred (100) standard perpendicular parking stalls were provided for staff parking. The proposed Clovis Transit will also contain an office and maintenance building and a bus wash building. An approximate area of 163,000 square feet would be required to implement the parking lanes and 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.

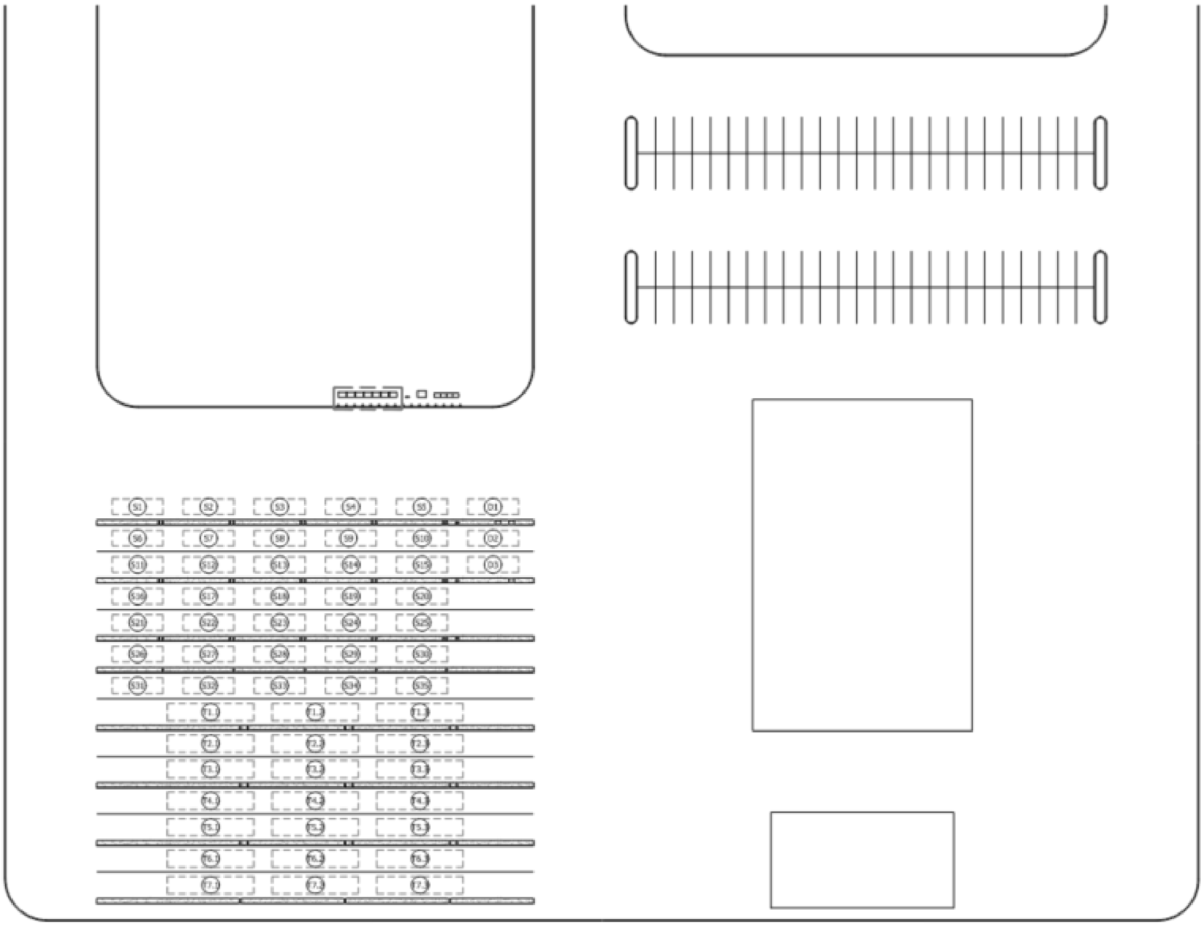


Figure 1. Conceptual Site Plan. "S" denotes shuttle bus charging stalls and "T" transit bus.

Table 6. Parking stall and drive aisle area per the design assumptions

	Quantity	Width (feet)	Length (feet)	Total Footprint (square feet)
Transit Bus Parking Stall	7	13	215	19,565
Shuttle Bus Parking Stall	7	13	215	19,565
Staff Parking Stall	100	9	18	16,200
Center Drive Aisle	3	30	237	21,330
Perpendicular Drive Aisle	3	45	418	56,430
Office & Maintenance Building	1	-	-	17,605
Bush Wash Building	1	-	-	4,230
Concrete Island	8	2.5	215	4,300

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)	7
Transit Bus Depot Charger (ABB HVC 150C)	21
Shuttle Bus Charger (ClipperCreek CS-100)	35
DC Fast Charger (ABB Terra 54)	3
Electric Bus Switchboard (480 V)	1
Electrical Panelboard (120 / 208 V)	4
Transformer (Primary: 480 V, Secondary: 120/208 V)	1
Utility Transformer	1

Revision Table

Revision	Date	Prepared By	Description
00	04/26/2022	Flux	Submission to Client
01	05/03/2022	Flux	Updated conceptual design for pull through buses
02	5/13/2022	Flux	Updated maintenance building orientation and removed curve.

NOTES:

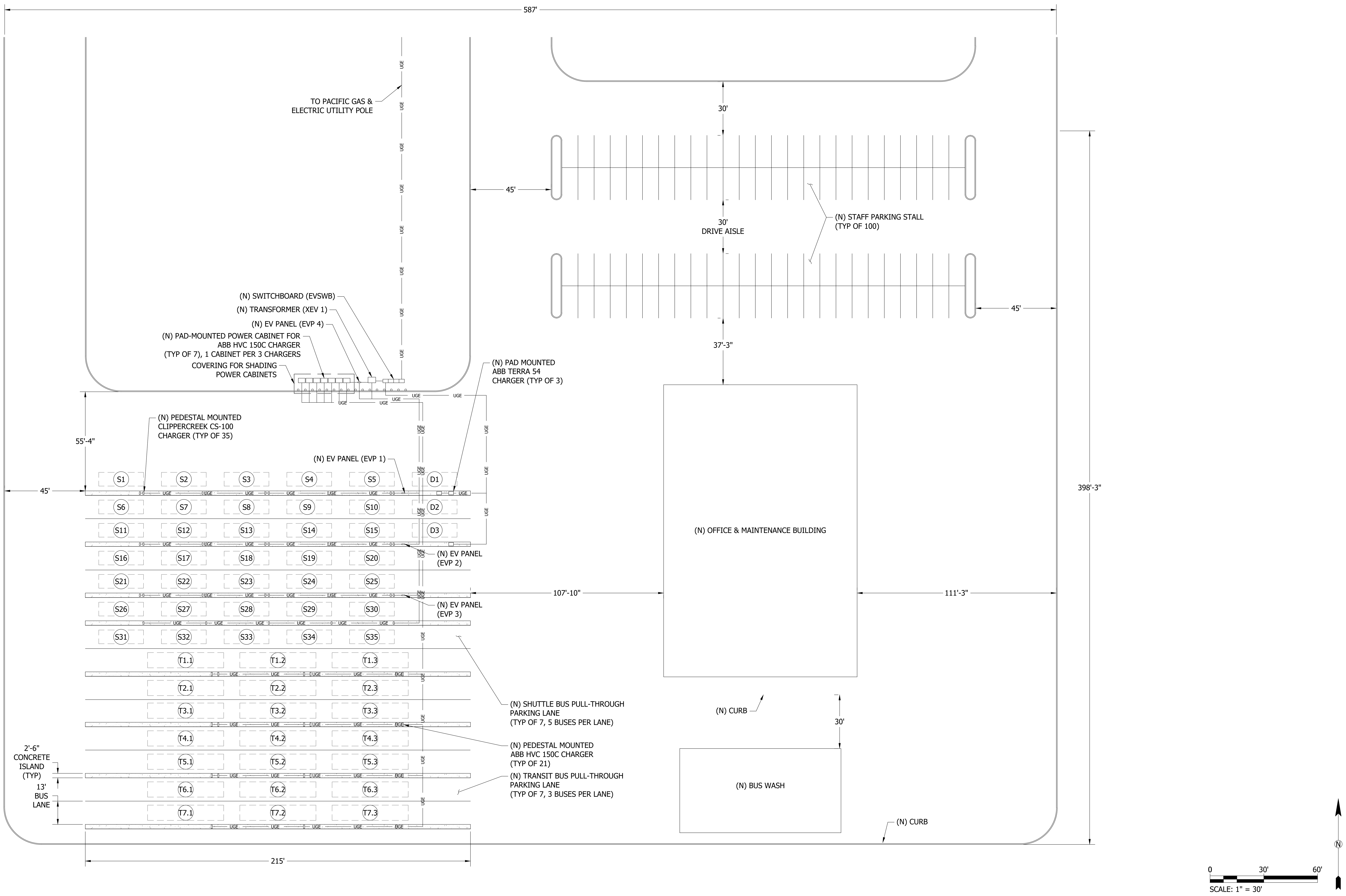
1. THIS IS AN ELECTRICAL PLAN ONLY. COMPLIANCE WITH CHAPTER 11 OF THE CALIFORNIA BUILDING CODE HAS NOT BEEN CONSIDERED FOR STAFF PARKING.
2. MAXIMUM DC CABLE LENGTH SHALL NOT EXCEED 492 FEET.
3. CONDUITS TO EV PANELS SHOWN FOR REFERENCE ONLY. THEY WILL LIKELY SHARE A TRENCH WITH OTHER ELECTRICAL CONDUITS.

LEGEND

———	ROAD / DRIVE AISLE
— UGE — UGE —	(N) UNDERGROUND ELECTRIC CABLE
▭	ELECTRIC SHUTTLE BUS CHARGER
▯	DC FAST CHARGER
▭	ELECTRIC TRANSIT BUS CHARGER
○	BOLLARD

ABB HVC 150C CHARGER SPECIFICATIONS	
MAX OUTPUT POWER (KW)	150
VOLTAGE (V)	277/480
MAX CHARGING CURRENT (A)	200
CLIPPERCREEK CS-100 CHARGER SPECIFICATIONS	
MAX OUTPUT POWER (KW)	16.64
VOLTAGE (V)	208
MAX CHARGING CURRENT (A)	80
ABB TERRA 54 CHARGER SPECIFICATIONS	
MAX OUTPUT POWER (KW)	50
VOLTAGE (V)	150 - 920 VDC
MAX CHARGING CURRENT (A)	125

SITE INFORMATION	
TOTAL # OF EVSE	56
TOTAL # OF TRANSIT BUS STALLS	21
TOTAL # OF SHUTTLE BUS STALLS	35
UTILITY	PACIFIC GAS & ELECTRIC
TRANSIT BUS CHARGER MODEL	ABB HVC 150C DEPOT
SHUTTLE BUS CHARGER MODEL	CLIPPERCREEK CS-100
DC FAST CHARGER MODEL	ABB TERRA 54



FLUX ENERGY SYSTEMS

CALSTART

CLOVIS TRANSIT

REVISION	DATE	DRWN BY	APRVD.	DESCRIPTION
A	05/12/2022	AM	AB	CONCEPTUAL DESIGN SUBMITTAL

TBD
CLOVIS, CA

NUMBER OF CHARGING UNITS: 56

NUMBER OF CHARGING PORTS: 56

ELECTRIC BUS
CHARGING SYSTEM

SEAL:

CONFIDENTIALITY STATEMENT

CONCEPTUAL DESIGN

ELECTRICAL SITE PLAN

E-1.0

NOTES:

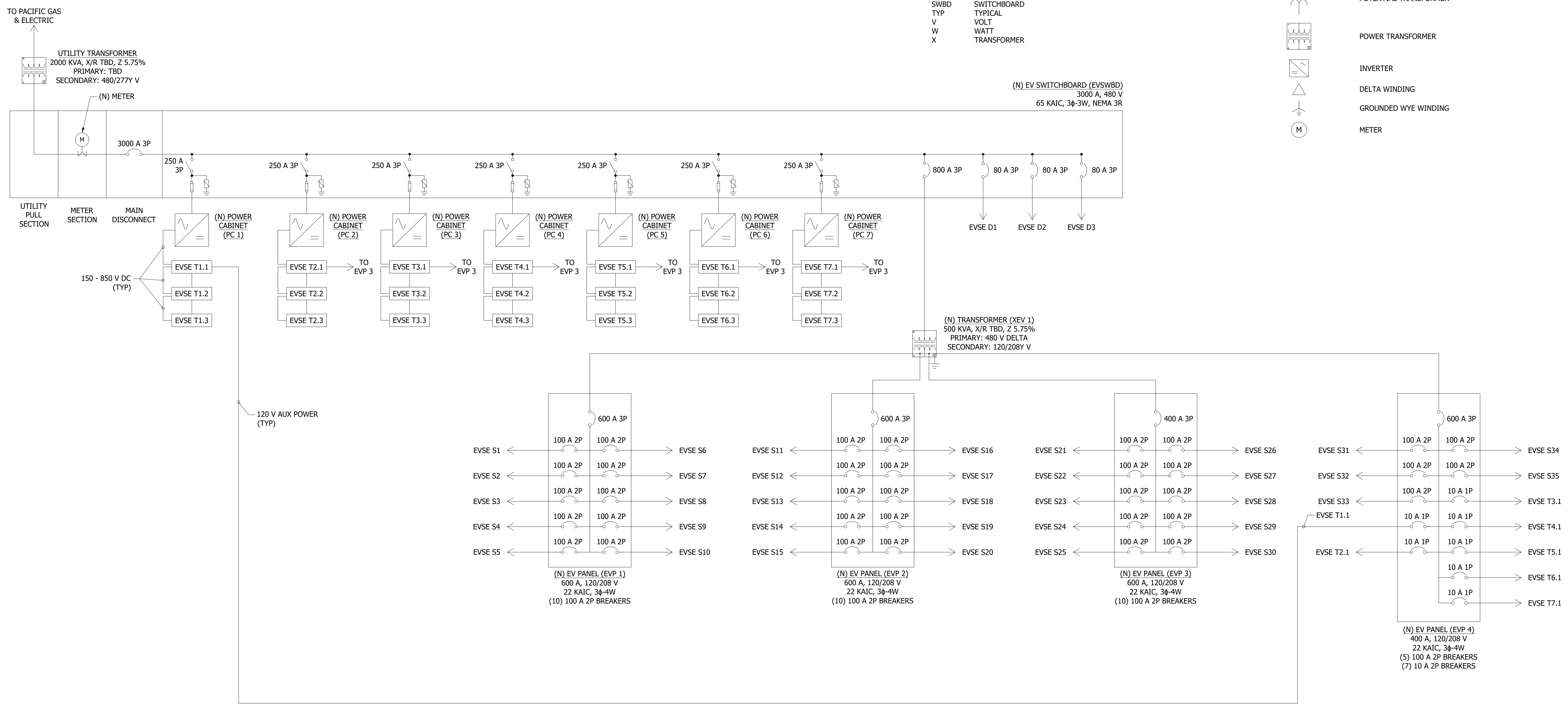
1. ALL WORK WILL CONFORM WITH THE FACILITY'S STANDARD PRACTICE FOR MATERIALS, EQUIPMENT AND CONSTRUCTION.
2. LOAD MANAGEMENT VIA SMART CHARGING AND COMMUNICATION BETWEEN CHARGERS NOT INCLUDED.

ABBREVIATIONS

A	AMPERES
AC	ALTERNATING CURRENT
EA	EACH
ELEC	ELECTRICAL
EVSE	ELECTRICAL VEHICLE SUPPLY EQUIPMENT
(E)	EXISTING
KVA	KILOVOLT AMPERE
KW	KILOWATT
KWH	KILOWATT HOUR
MAX	MAXIMUM
MIN	MINIMUM
(N)	NEW
PC	POWER CABINET
PH, ϕ	PHASE
SLD	SINGLE LINE DIAGRAM
SWBD	SWITCHBOARD
TYP	TYPICAL
V	VOLT
W	WATT
X	TRANSFORMER

LEGEND

JUNCTION / TERMINATION
TAP
CIRCUIT BREAKER
CIRCUIT BREAKER, DRAW OUT
SWITCH
FUSE
FUSIBLE CUTOUT
FUSED DISCONNECT SWITCH
SURGE ARRESTOR
GROUNDING ELECTRODE
CURRENT TRANSFORMER
POTENTIAL TRANSFORMER
POWER TRANSFORMER
INVERTER
DELTA WINDING
GROUNDED WYE WINDING
METER



FLUX ENERGY SYSTEMS

CALSTART

CLOVIS TRANSIT

REVISION	DATE	DRWN BY	APRVD.	DESCRIPTION
A	05/12/2022	AM	AB	CONCEPTUAL DESIGN SUBMITTAL

TBD
CLOVIS, CA

NUMBER OF CHARGING UNITS: 56
NUMBER OF CHARGING PORTS: 56

ELECTRIC BUS CHARGING SYSTEM

SEAL:

CONFIDENTIALITY STATEMENT

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CONCEPTUAL DESIGN

SINGLE LINE DIAGRAM

E-1.1

PANEL SCHEDULE: EV SWITCHBOARD (EVSWBD)

VOLTAGE (L-N):	N/A	ENCLOSURE TYPE:	NEMA 3R
VOLTAGE (L-L):	480	MOUNTING:	PAD MOUNTED
PHASE:	3	KAIC RATING:	65
WIRES:	3	LOCATION:	OUTDOOR
MINIMUM BUS CAPACITY (A):	3000	NOTES:	
MAIN OCPD (A):	3000		

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	Ø PHASE LOADS (VA)						POLE	TRIP AMPS	DESCRIPTION	CKT NO.
				A	B	C	A	B	C				
1	PC 1	250	3	50000			50000			3	250	PC 5	2
3					50000			50000					4
5						50000			50000				6
7	PC 2	250	3	50000			50000			3	250	PC 6	8
9					50000			50000					10
11						50000			50000				12
13	PC 3	250	3	50000			50000			3	250	PC 7	14
15					50000			50000					16
17						50000			50000				18
19	PC 4	800	3	50000			200208			3	800	XEV 1	20
21					50000			191888					22
23						50000			192152				24
25	EVSE D1	80	3	18000			18000			3	80	EVSE D2	26
27					18000			18000					28
29						18000			18000				30
31							18000			3	80	EVSE D3	32
33								18000					34
35									18000				36
37													38
39													40

PHASE:	A	B	C
CONNECTED LOAD PER PHASE (VA):	604208	595888	596152
CONNECTED LOAD PER PHASE (A):	2178	2148	2149
TOTAL DEMAND LOAD (VA):	1796		

PANEL SCHEDULE: EV PANEL (EVP 2)

VOLTAGE (L-N):	120	ENCLOSURE TYPE:	NEMA 3R
VOLTAGE (L-L):	208	MOUNTING:	RACK MOUNTED
PHASE:	3	KAIC RATING:	22
WIRES:	4	LOCATION:	OUTDOOR
MINIMUM BUS CAPACITY (A):	600	NOTES:	
MAIN OCPD (A):	600		

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	Ø PHASE LOADS (VA)						POLE	TRIP AMPS	DESCRIPTION	CKT NO.
				A	B	C	A	B	C				
1	EVSE S11	100	2			8320	8320			2	100	EVSE S16	2
3					8320			8320					4
5	EVSE S12	100	2			8320			8320	2	100	EVSE S17	6
7				8320			8320						8
9	EVSE S13	100	2		8320			8320		2	100	EVSE S18	10
11						8320			8320				12
13	EVSE S14	100	2	8320			8320			2	100	EVSE S19	14
15					8320			8320					16
17	EVSE S15	100	2			8320			8320	2	100	EVSE S20	18
19				8320			8320						20
21													22
23													24
25													26
27													28
29													30
31													32
33													34
35													36
37													38
39													40

PHASE:	A	B	C
CONNECTED LOAD PER PHASE (VA):	58240	49920	58240
CONNECTED LOAD PER PHASE (A):	484	415	484
TOTAL DEMAND LOAD (KVA):	166		

LOAD SCHEDULE

LOAD	QUANTITY	POWER (KW)	VOLTAGE (V)	CURRENT (A)
TRANSIT BUS CHARGER (ABB HVC 150C)	21	150	480 / 277	180
SHUTTLE BUS CHARGER (CLIPPERCREEK CS-100)	35	16.64	208	80
DC FAST CHARGER (ABB TERRA 54)	3	50	480	60
LOAD[1]		3882.4		

1. LOAD MANAGEMENT SOFTWARE WILL LIMIT BUS CHARGING LOAD TO A MAXIMUM OF 1632 KW PER NEC 625.42.

PANEL SCHEDULE: EV PANEL (EVP 1)

VOLTAGE (L-N):	120	ENCLOSURE TYPE:	NEMA 3R
VOLTAGE (L-L):	208	MOUNTING:	RACK MOUNTED
PHASE:	3	KAIC RATING:	22
WIRES:	4	LOCATION:	OUTDOOR
MINIMUM BUS CAPACITY (A):	600	NOTES:	
MAIN OCPD (A):	600		

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	Ø PHASE LOADS (VA)						POLE	TRIP AMPS	DESCRIPTION	CKT NO.
				A	B	C	A	B	C				
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 S9	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													22
23													24
25													26
27													28
29													30
31													32
33													34
35													36
37													38
39													40

PHASE:	A	B	C
CONNECTED LOAD PER PHASE (VA):	58240	49920	58240
CONNECTED LOAD PER PHASE (A):	484	415	484
TOTAL DEMAND LOAD (KVA):	166		

PANEL SCHEDULE: EV PANEL (EVP 3)

VOLTAGE (L-N):	120	ENCLOSURE TYPE:	NEMA 3R
VOLTAGE (L-L):	208	MOUNTING:	RACK MOUNTED
PHASE:	3	KAIC RATING:	22
WIRES:	4	LOCATION:	OUTDOOR
MINIMUM BUS CAPACITY (A):	600	NOTES:	
MAIN OCPD (A):	600		

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	Ø PHASE LOADS (VA)						POLE	TRIP AMPS	DESCRIPTION	CKT NO.
				A	B	C	A	B	C				
1	EVSE S21	100	2			8320	8320			2	100	EVSE S26	2
3					8320			8320					4
5	EVSE S22	100	2	8320					8320	2	100	EVSE S27	6
7					8320		8320						8
9	EVSE S23	100	2			8320		8320		2	100	EVSE S28	10
11					8320				8320				12
13	EVSE S24	100	2	8320			8320			2	100	EVSE S29	14
15					8320			8320					16
17	EVSE S25	100	2			8320			8320	2	100	EVSE S30	18
19				8320			8320						20
21													22
23													24
25													26
27													28
29													30
31													32
33													34
35													36
37													38
39													40

PHASE:	A	B	C
CONNECTED LOAD PER PHASE (VA):	58240	58240	49920
CONNECTED LOAD PER PHASE (A):	484	484	415
TOTAL DEMAND LOAD (KVA):	166		

PANEL SCHEDULE: EV PANEL (EVP 4)

VOLTAGE (L-N):	120	ENCLOSURE TYPE:	NEMA 3R
VOLTAGE (L-L):	208	MOUNTING:	RACK MOUNTED
PHASE:	3	KAIC RATING:	22
WIRES:	4	LOCATION:	OUTDOOR
MINIMUM BUS CAPACITY (A):	400	NOTES:	
MAIN OCPD (A):	400		

CKT NO.	DESCRIPTION	TRIP AMPS	POLE	Ø PHASE LOADS (VA)						POLE	TRIP AMPS	DESCRIPTION	CKT NO.
				A	B	C	A	B	C				
1	EVSE S31	100	2			8320	8320			2	100	EVSE S34	2
3					8320			8320					4
5	EVSE S32	100	2	8320					8320	2	100	EVSE S35	6
7					8320		8320						8
9	EVSE S33	100	2			8320		264		1	10	EVSE T3.1	10
11					8320				264	1	10	EVSE T4.1	12
13	EVSE T1.1	10	1	264			264			1	10	EVSE T5.1	14
15	EVSE T2.1	10	1			264		264		1	10	EVSE T6.1	16
17									264	1	10	EVSE T7.1	18
19													20
21													22
23													24
25													26
27													28
29													30
31													32
33													34
35													36
37													38
39													40

PHASE:	A	B	C
CONNECTED LOAD PER PHASE (VA):	25488	33808	25752
CONNECTED LOAD PER PHASE (A):	212	281	214
TOTAL DEMAND LOAD (KVA):	85		

FLUX
ENERGY SYSTEMS

CALSTART

CLOVIS TRANSIT

REVISION	DATE	DRWN BY	APRVD.	DESCRIPTION
A	05/12/2022	AM	AB	CONCEPTUAL DESIGN SUBMITTAL

TBD
CLOVIS, CA

NUMBER OF CHARGING UNITS: 56
NUMBER OF CHARGING PORTS: 56

ELECTRIC BUS
CHARGING SYSTEM

SEAL:

CONFIDENTIALITY STATEMENT

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CONCEPTUAL DESIGN

PANEL SCHEDULE

E-1.2

Appendix G: Evaluation of Hydrogen Vehicle Refueling Options Report

A copy of Jerald A. Cole's study performed on CALSTART's behalf to examine the possibility of a hydrogen refueling station for Clovis Transit begins on the following page.

Clovis Transit

Evaluation of Hydrogen Vehicle Refueling Options

Prepared for: Clovis Transit

Prepared by: CALSTART, Inc.

May 2022

Jerald A. Cole, *Hydrogen Ventures (Under contract with CALSTART)*
Katrina Sutton, *CALSTART*

Acknowledgements

A great many people and organizations were contacted and contributed to this report. The CALSTART team would like to acknowledge and thank the following for their assistance, without which this report would not have been possible.

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Stephen Jones, BayoTech

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Ghassan Sleiman, First Element Energy

DeLisa Leighton, BayoTech

Monica Valdez, FuelCell Energy

Jeremy Holland, Mortensen

Chris Wallington, GenH2

G. Scott Samuelsen, U.C. Irvine

Blake Lane, U.C. Irvine

John Chimenti, Air Products

Kevin Harris, Hexagon Purus

Kristen Cleven, Air Products

Jim Corboy, H2B2

Introduction

In this study we attempt to provide a sense for what a hydrogen refueling station would look like for Clovis Transit. Using a framework of 11 fuel cell electric buses traveling an average of 135 miles per day, a daily demand of 275 kg hydrogen was estimated. Using this basis, the study then looks at different hydrogen supply modes and different station configurations.

For delivered hydrogen both liquid and gaseous hydrogen were considered, as well as different quantities per delivery. The DOE model Hydrogen Delivery Scenario Analysis Model (HDSAM) was then used to estimate the cost of hydrogen at the Clovis Transit depot.

We also looked at on site hydrogen production via both electrolysis and steam methane reforming (SMR). A vendor-supplied spreadsheet was updated using publicly available data on utility rates to estimate the cost of producing hydrogen with commercially available equipment.

Next, the impact of station costs on hydrogen cost was estimated with the Heavy-Duty Refueling Station Analysis Model (HRDSAM). Three gaseous and three liquid stations were investigated. The impacts of CAPEX, O&M, and utilities were estimated using the model.

Finally, using a combination of vendor information and an analysis of the 2020 NFPA 2 hydrogen technologies code was applied to estimate approximate footprint of a generic single dispenser hydrogen station.

Overview of hydrogen demand and delivery

This analysis is based on an expected fleet consisting of:

- Two fixed routes with three 40-foot buses per route all day
    - Route 10 - 135 mi/bus/day
    - Route 50 - 135 mi/bus/day
- Two school bus routes in the morning and one in afternoon/evening (for school times)
    - Route 70 - 20 miles/day
    - Route 80 - 16 miles/day
- Dial-a-Ride out every day - 21 miles/day
    - Midweek - 10 buses/4 vans
    - Wekend - approx 5 buses/2 vans

In addition, it is expected that the fixed route fleet will be expanded with five additional 40-foot buses and an additional 15 shuttles for the DAR fleet.

For current purposes we are assuming that even if the school buses and shuttles are converted to FCEVs, their low mileage and smaller size mean that they will have little impact on hydrogen demand. As such the analysis focuses on having 11 40-foot FCEBs, each driving 135 miles per day.

In terms of fuel economy, AC Transit reports that their legacy fuel cell bus fleet averages 5.0 miles/kg-H2, while their newer New Flyer buses achieve 8.15 mile/kg-H2 in the 2020 time frame[1]. On the other hand Eudy and Post (2020)[2] report a fuel economy of 5.5 mile/kg-H2 for 40-foot FCEBs in the SunLine Transit fleet.

In comparing the climate in Fresno County with that of the bay area and the Palm Desert area, the Calstart team has elected to use the Sunline experience as a basis for estimating fuel requirements. This is mainly based on the need for air conditioning in the hot summer. In this regard, 135 miles per day translates into a 25 kg fill for each bus daily. For 11 buses this means 275 kg needs to be dispensed each day. This compares well with Sunline's experience where they pump approximately 320 kg/day into 12 buses[3].

This also has implications for the amount of on-site storage needed. In past discussions with owner/operators of older style stations, a constant refrain was that the stations were not designed with enough storage. That experience led operators to conclude that projects should be designed for double the planned daily capacity, and that there should be enough storage on site for three days' worth of operation. In our current scenario for Clovis Transit, the additional five buses account for future expansion. Three days' consumption would be 825 kg, but due to equipment limitations the station should be designed with 1,000 kg fixed ground storage under most scenarios.

Frequency of delivery based on vehicle demand

Tube Trailer Hydrogen

Standard 44-foot hydrogen tube trailers contain 320 kg H2 at a pressure of 180 bar (2600 psig), although there are composite cylinder tube trailers available that can provide up to 1100 kg at 500 bar (7200 psig). In addition, both Air Products and BayoTech advertise on their respective web sites 520 bar (7500 psig) trailer delivery at 500 kg in half size (approx. 20 ft) trailers.

However, with a typical bump-stop delivery, the actual amount of hydrogen delivered is somewhat less than trailer capacity, and can be significantly less, depending on the pressure of gas remaining in the station storage vessels as well as the total volume of stationary storage. It also depends on whether a transfer pump is used. Many of the earlier stations in California simply let the tube trailer reach equilibrium with the on-site storage cylinders. As a result, sometimes the tube trailer could return to the production facility still half full. Newer stations should have transfer pumps so that this is not an issue.

With a drop and swap delivery option, the amount of hydrogen transferred per delivery can be noticeably higher. In this situation a nearly empty tube trailer is disconnected from the station and a new one put in its place. Staff at the UCI station report that their trailers are replaced when the pressure drops from an initial 7200 psig to about 1000 psig. As a result, the amount of hydrogen transferred is still less than the amount delivered. Part of this is because of limitations on the cylinders on the tube trailer (they don't

---

[1] Chen, J. et al. Zero Emission Transit Bus Technology Analysis. 23 June 2021.

[2] Eudy, L. and Post, M. SunLine Transit Agency American Fuel Cell Bus Progress Report. NREL/PR-5400-71312, April 2020.

[3] Loper, B. Sunline Transit Agency, Personal Communication, October 2019.

want to be completely evacuated) and part because there is a minimum suction pressure for the transfer pump (compressor), which might be as low as the 30 – 50 bar range for 4500 psig storage, or much higher for 12,500 psig storage.

Liquid Hydrogen Delivery

Air Products has proposed to develop a system for Clovis based on the hydrogen refueling system at the Orange County Transit Authority Santa Ana depot. This would consist of a single 18,000 gallon (4800 kg) cryogenic tank with liquid pump and evaporation system. This would provide approximately 14 days'worth of hydrogen under the baseline scenario. Air Products has said that they would refill the tank every ten or eleven days.

Financial Analysis

Delivered Hydrogen

There are two options for delivered hydrogen: liquid or compressed gas. And then with compressed gas there are two approaches commonly used: passive transfer (bump drop) and drop and swap. Which approach is eventually selected is something likely to be negotiated with your gas supplier, but footprint is also certainly a consideration.

Liquid Hydrogen

A liquid hydrogen system like those used in West Sacramento and Emeryville evaporates the gas and then compresses it into medium and high-pressure storage. However, the systems at SARTA and OCTA use Air Products' cryo compression (AC Transit has Messer cryo compressors), which pumps liquid hydrogen up to 98 MPa before evaporating it. This results in significant energy savings over gaseous compression and eliminates the need for a gaseous compressor.

In addition, with delivered liquid hydrogen there can be a significant savings on transportation costs. A large (*e.g. 18,000 gallon*) cryogenic tank would hold enough hydrogen for two weeks of station operation using our base case. Being monitored remotely by the gas provider a fresh shipment might be delivered every ten days, leaving a cushion of 2 – 3 days to protect against supply disruptions. This, in fact, is exactly what Air Products has suggested to the Calstart team. This would be essentially what is currently installed at Orange County Transportation Authority's depot in Santa Ana where ten FCEBs are being fueled.

Gaseous Delivery

Gaseous delivery was once considered uneconomical for transport distances greater than 200 miles, but with the advent of composite high pressure tubes, the approach chosen needs to be assessed on a case by case basis. For large-volume consumers such as vehicle refueling stations gaseous hydrogen could be uneconomical for other reasons. At UCI for example the station needs to receive two shipments on most days, and staff report running out of gas at least once a week. (*N.B.*: virtually all new First Element stations will have liquid delivery regardless of distance to the production facility)

For Clovis there is one possible exception. The H2B2 project in Kerman is only 25 miles from the Stageline depot. If the offtake price at Kerman is favorable, it is possible that the most economical option for fueling buses could be to shuttle a single trailer back and forth between the depot and Kerman every three days or so.

Comparison of Gaseous vs Liquid Delivery

To get a relative sense of how delivery costs compare for different scenarios, we ran DOE's *Hydrogen Delivery Scenario Analysis Model* (HDSAM). In this case we considered a station with a capacity of 500 kg/day dispensing 275 kg/day in back-to-back 25 kg fills. For liquid, the model assumed that the station would have 2,000 kg of liquid storage and would receive shipments of 1,800 kg when storage was down to 10 % of capacity. The model also factors in the cost of liquefaction but does not include the cost of the hydrogen at the production plant gate. One of the features of HDSAM is that it automatically configures an optimal station configuration. We are ignoring that for now because it assumes a retail station with features that are different from large vehicle fleet refueling. The balance of plant costs up to and including the nozzle are addressed later in this section.

For gaseous fueling, the station capacity is the same as with liquid. However, the shipping distance is further. For liquid hydrogen we assumed a 277 km distance from Clovis to the Air Products Liquefaction plant in Sacramento, CA. For gas we assumed a 392 km distance from the Air Products hydrogen depot in Wilmington, CA. Different scenarios were run for tube trailer capacity. Current trailers have 250 and 350 kg capacity and are able to offload about 90 percent of the charge if the trailer is 500 bar. We also looked a newer technology with 500 and 1100 kg tube trailers, although we are not aware of any examples in actual commercial service at this time.

Results are summarized in the following table in 2016 dollars.

Type	Trailer Capacity	Compression	Storage	Buffer	Transport	Liquefaction	Total
Liquid	4,000 kg	$-	$1.14	$0.02	$0.41	$1.78	**$3.35/kg**
Gas	250 kg	$1.21	$1.24	$0.05	$2.75	$-	**$5.25/kg**
Gas	350 kg	$1.21	$1.18	$0.04	$1.97	$-	**$4.40/kg**
Gas	500 kg	$1.21	$1.13	$0.04	$1.38	$-	**$3.76/kg**
Gas	1100 kg	$1.21	$1.07	$0.03	$0.63	$-	**$2.94/kg**

The absolute magnitude of these numbers is not what's important, because the model makes a great number of assumptions that may not be applicable to the Clovis project. Rather, the comparative numbers should be of more interest because we've done our best to provide an apples-to-apples comparison. What is clear is how much the transportation cost is impacted by the capacity of the compressed gas trailer. With all but the largest trailer, gaseous delivery is more expensive than delivered liquid, and this is almost entirely driven by transportation costs (fuel, truck, trailer, labor).

Next, we look at transportation distance. Here we compare the cost of transporting 250 kg of gaseous hydrogen from Wilmington versus moving it from Kerman. It's clear that if the cost of the gas is essentially the same, then delivered gaseous hydrogen, even in small quantities, becomes competitive with liquid shipped from Sacramento.

Distance	Trailer Capacity	Compression	Storage	Buffer	Transport	Total

392 km	250 kg	$1.21	$1.24	$0.05	$2.75	**$5.25/kg**
40 km	250 kg	$1.21	$1.06	$0.05	$0.77	**$3.09/kg**

On-site Production (SMR & Electrolysis)

On-site production of hydrogen is generally more expensive, and at best, on par with the cost of delivered hydrogen. However, on-site production can provide security of supply, especially when it is backed up with the possibility of delivered hydrogen in the event of scheduled or unscheduled equipment shutdown.

Recent experiences in both Southern and Northern California have shown that reliance on centralized hydrogen production – at least for the time being – can result in widespread shortages. Even though Air Products' Santa Clara facility is back online, there are still frequent reports on social media platforms of stations having little to no hydrogen available. Likewise, a temporary shutdown of the Air Products Transfill facility[4] in Wilmington, CA left Southern California FCEV drivers scrambling to find fuel from other suppliers such as Air Liquide. Stations with on-site production, including Riverside, Burbank, Ontario, and Newport Beach had limited capacity, but continued to produce hydrogen on site when central supply is unavailable.

For this study, we looked at the two most common approaches for on-site production of hydrogen. These are on-site electrolysis and on-site steam methane reforming (SMR). Other possible production methods were not considered practical or viable for at the scale of a refueling facility for a small transit district. Examples of methods not considered for this report include solid waste pyrolysis, coal gasification, autothermal reforming (ATR), and exothermic gas generators (partial oxidation). However, methanol reforming and natural gas pyrolysis are discussed briefly at the end of this report.

The team asked BayoTech to provide a comparison of costs for SMR vs electrolysis for a production rate of 500 kg/day[5]. The results are shown in the following table, adjusted for estimated current industrial utility rates in Clovis.

Assumptions	SMR	Electrolysis
Capacity	500 kg/day	
Delivery Pressure	~14 bar	30 bar
Project life	20 years	
Electricity	$0.0898/kWh	
Water	$0.00206/gallon	
Nat Gas	$14.28/MMBtu	
CapEx	$3,030,000	$2,110,000*
OpEx	$9500/month	$6,667/month
Levelized Cost of H2	$4.30/kg	$6.01/kg

*Includes stack replacement at year 10

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[4] https://www.marketwatch.com/press-release/air-products-to-build-second-liquid-hydrogen-production-facility-in-california-2019-01-07

[5] Jones, S. Personal communication, March 2022.

This is a simplified cost analysis with straight line depreciation of the asset over the life of the project and does not consider WACC, IRR, NPV, or other factors that would require input from Clovis Transit. However, it is an apples-to-apples comparison.

Balance of Plant

Regardless the means of hydrogen supply, the gas needs to be compressed, stored, and delivered to a dispenser. Some suppliers, including APCI and Nel Hydrogen prefer to provide the entire system. Others provide only the front half. For OneH2 that means everything up to and including medium-pressure (450 bar) storage; for ITM Power, it means 30 bar hydrogen at the exit of the electrolyzer, for BayoTech it means 14 bar hydrogen at the back end of the pressure swing adsorption unit

For this part of the system, the CALSTART team contacted Powertech Labs in Surrey, BC. Powertech is the premier test facility in the world for CNG and high-pressure compressed hydrogen vehicle and filling station components. The company offers independent equipment testing and certification services to national and international standards, materials performance assessment, failure analysis, and D/P FMEA for vehicle OEMs. Powertech's quality management system is registered to ISO 9001 which covers all aspects of Powertech's products and services. Powertech is also an accredited laboratory in the Standards Council of Canada Program for the Accreditation of Laboratories.

The system described by Powertech includes the following:

- IRDA communication fills, as per SAE J2601-1 and SAE J2601-2.
- PLC control system, capable of remote access for monitoring, fault clearing, and data file downloads (internet connection required).
- Flow measurement, accurate to ±5% at 1 kg hydrogen dispensed.
- Documentation, including manufacturers' manuals where applicable, and drawing package and operations manuals in PDF format.
- Containerized package with compressor, pre-cooling and controls.
- Two 350 bar, stand-alone, dual-hose dispensers, including user interface.
- Hydrogen cooling system for 700 bar, T40 fills.
- Perform H35 ambient fills to 95% SOC or greater, with starting vehicle pressure of 50 bar, as defined by SAE J2601-2. Option pricing is available for pre-cooled H35 fills.
- Four simultaneous 350 bar fills of 35-kg hydrogen tanks starting at 100 bar.
- 700 kg of hydrogen storage at 450 bar to accommodate simultaneous bus fueling.
- Two compressors capable of compressing hydrogen with the following specifications:
    - Min suction pressure of 54 bar (800 psig)
    - Max output pressure of 442 bar (6,500 psig)
    - 10.1 kg/hr (per compressor) at 52 bar (800 psig) suction pressure

Figure 1: Powertech fuel processing module and high-pressure storage at the Riverside hydrogen refueling station. Image Credit: Hydrogen Ventures.

Not all these items track exactly with the Clovis station configuration as currently envisioned because Powertech has provided a generic specification that is at least close to what Clovis would need. Still, this provides a good sense of how the station could be configured and provides some sense of scale and cost. To the extent possible, equipment will be preassembled and tested prior to shipment from Powertech.

The Powertech proposal includes two medium-pressure compressors capable of compressing 485 kg/day H2 to 450 bar for H35 refueling. Part of that will be tapped for possible future higher-pressure storage at 875 bar if the decision is made to add 700 bar refueling in the future.

The medium-pressure storage and dispensers are designed to be able to provide four simultaneous 35 kg fills and will be able to dispense a minimum of 420 kg over a 24-hour period.

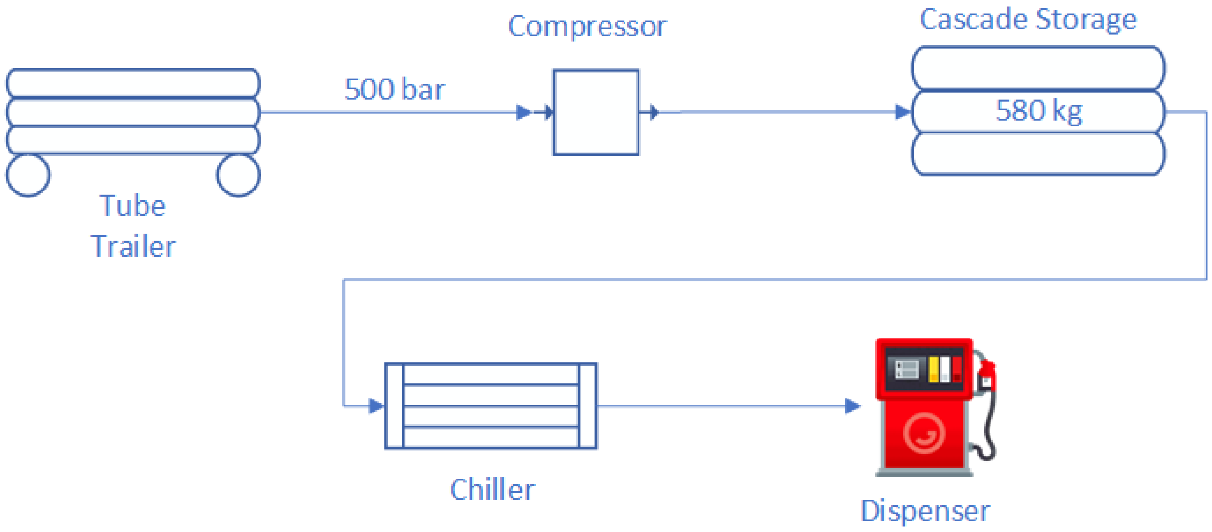
The approximate cost for the system as presented here is about $3 million. There are also two options being offered. One is a precooling system for 350 bar fills that would be about $150k, and addition of a third medium-pressure compressor for about $250k. All told, the capital cost of the station adds about $5.00/kg to the cost of delivered hydrogen over a 15-year project life.

Powertech estimates that equipment delivery would be 48 – 52 weeks after receipt of order.

For a more detailed analysis of station costs, we employed DOE's *Heavy Duty Refueling Station Analysis Model* (HDRSAM). The current version of HDRSAM generates estimates in 2016 dollars (as does HDSAM), but it allows for more customized station configurations and also models liquid hydrogen-based stations. This makes it possible to investigate a greater range of options and perform sensitivity analyses. On top of all that HDRSAM estimates O&M and energy costs and factors both into the cost of dispensed hydrogen. For this study three liquid hydrogen and three gaseous hydrogen stations configurations were evaluated. These are discussed below.

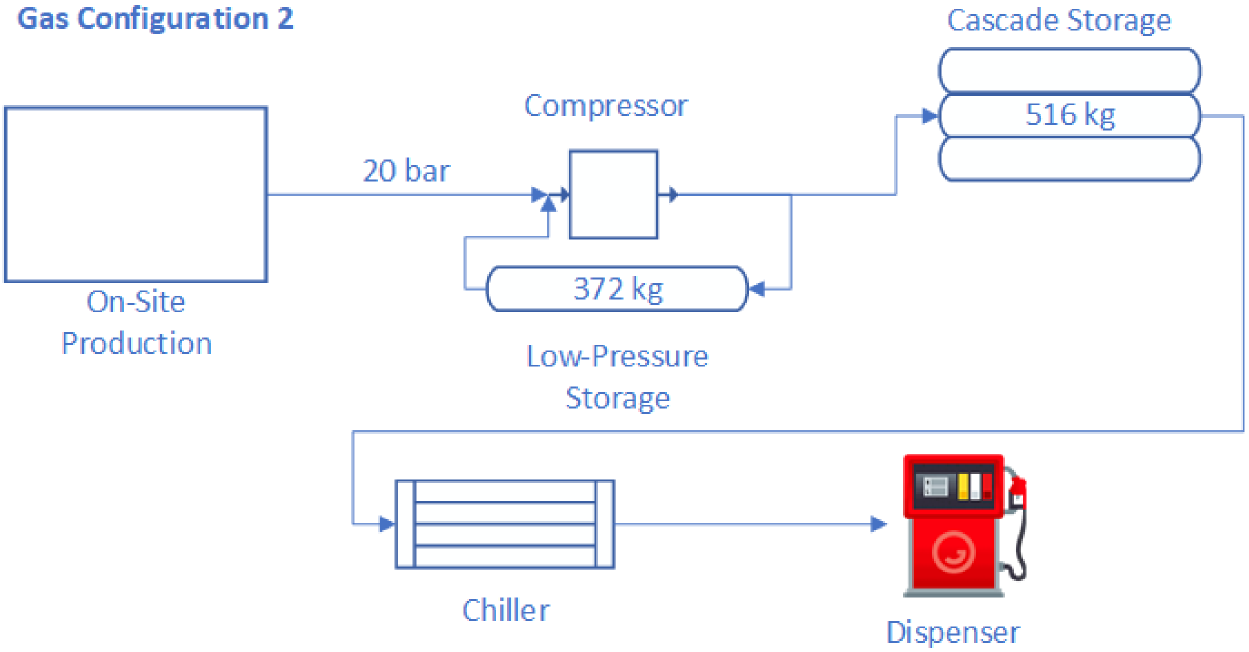
The fixed inputs to the model were that there would be 11 buses to be filled per day, at a maximum of 3 per hour, with 25 kg per fill. After that there is a choice of gaseous or liquid delivery. Other choices to be made are the type of gas supply, the dispensing configuration, and whether to use optimistic or conservative estimates of station component costs (conservative used for all cases). The model then "optimizes" the station configuration and provides output such as cost estimates, vessel sizes, power consumption, and station footprint.

Gas Configuration 1



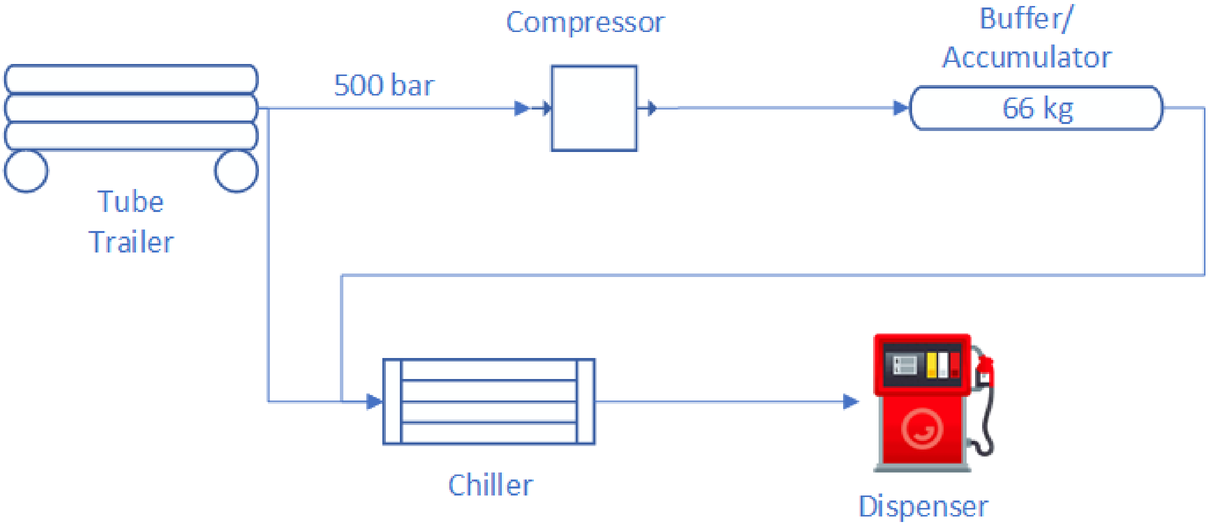
Gaseous station configuration 1 is shown above as a greatly simplified process flow diagram. This is similar to most dump and bump station configurations. A tube trailer is delivered to the station and gas is transferred to a cascade storage system. Initially the gas is transferred passively due to the pressure difference between the tube trailer and the depleted cascade storage system. At some point the compressor takes over and fills the cascade storage system to its maximum capacity. The cascade system selected by the model consists of one high-pressure cylinder and two each medium- and low-pressure cylinders. The transfer can take several hours, after which the tube trailer is disconnected and hauled off.

Gas Configuration 2



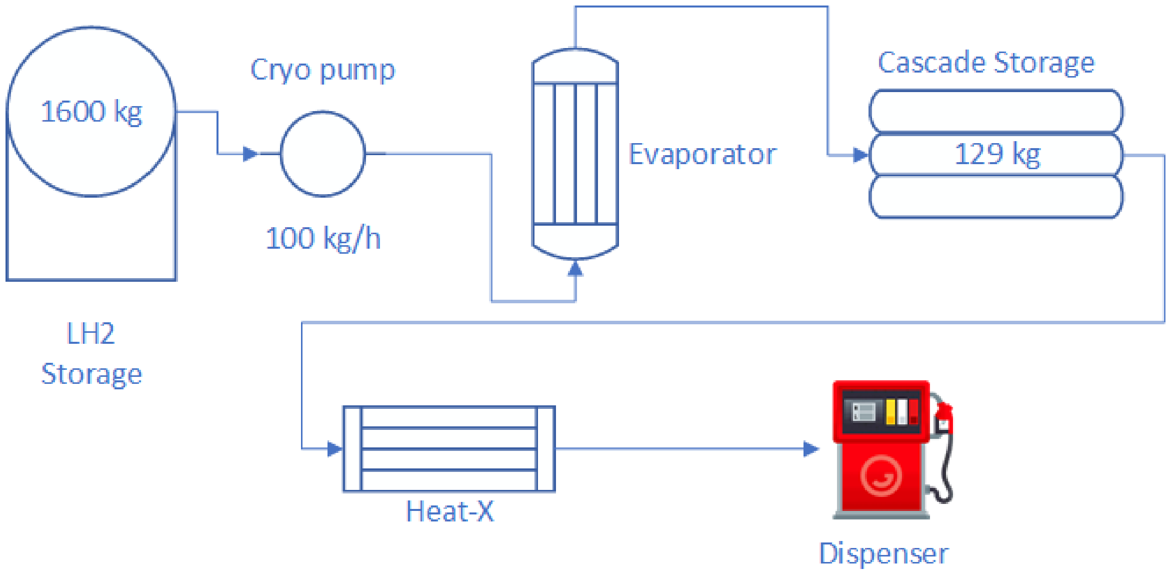
Gas configuration 2 imagines on site production with a delivery pressure of 20 bar. Due the the greater pressure differential across the compressor, pumping costs are higher, as will be discussed later. It is assumed that the on-site production unit will be sized for station capacity, plus a buffer. That necessitates a low-pressure storage tank to be used during the approximately 2-1/2 hours when all 11 buses are being filled.

Gas Configuration 3



Gas configuration 3 is a drop and swap configuration. In this instance the tube trailer itself is used as the cascade system. The compressor and accompanying buffer/accumulator tank are used only when the high-pressure tubes in the trailer falls below the minimum pressure of 430 bar. This appears to be similar to the approach used at the UCI station. This avoids much of the cost of a large cascade system but requires either multiple trailers or a single high-capacity trailer. In either case an enclosure for two trailers is required.

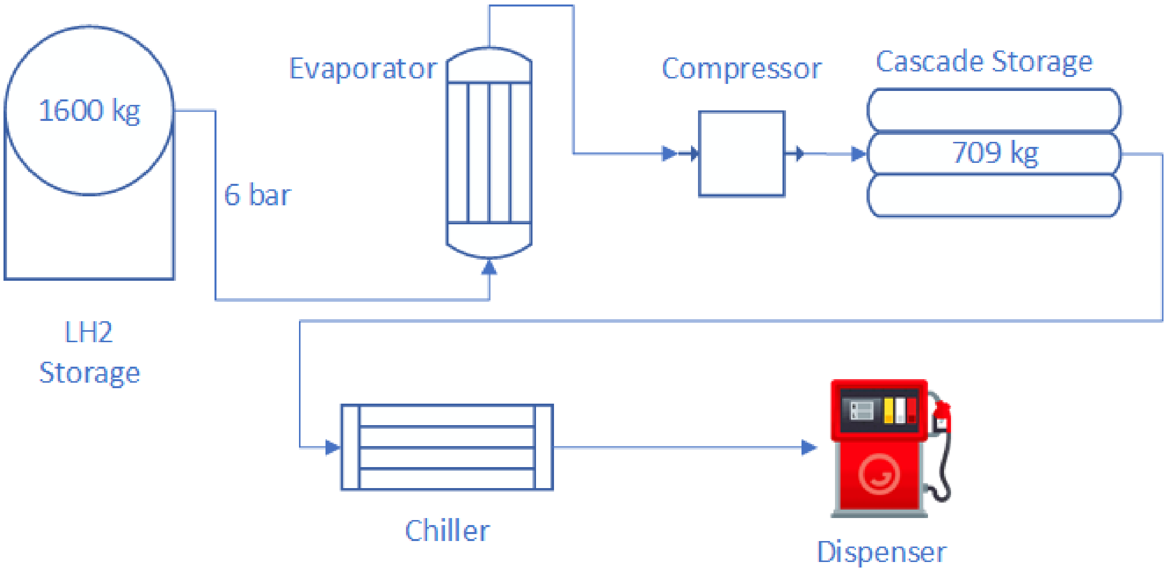
Liquid Configuration 1



Liquid station configuration 1 is the baseline for this study. Hydrogen is delivered by truck and transferred to an on site dewar. A submerged cryo pump transfers the liquid through an evaporator to a cascade storage system. Note that unlike the gaseous configurations, there is no refrigeration system to chill the hydrogen for T40 fills. Instead, a heat exchanger is coupled with the evaporator to take advantage of enthalpy absorbed by the evaporating hydrogen. Also, the cascade storage system is much smaller. This can be achieved because liquid hydrogen is pumped much faster gas can be compressed. Also, since the compressibility of liquid hydrogen is much smaller than that of the gas, the power needed to bring it to pressure is significantly reduced.

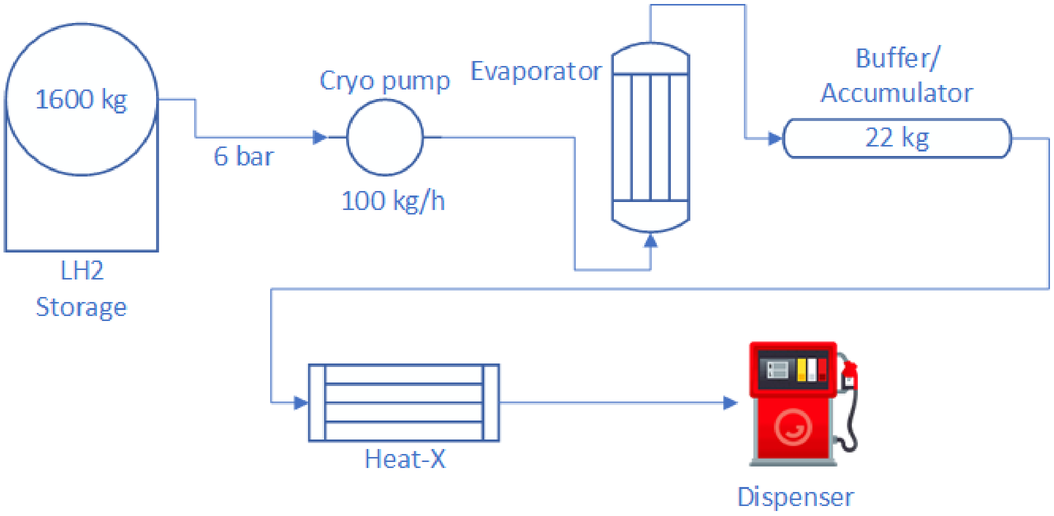
This configuration is like that currently being used at SARTA.

Liquid Configuration 2



Liquid station configuration 2 is an earlier generation station design. In this case liquid under about 90 psig pressure leaves the storage vessel under its own pressure. It passes through a small evaporator before being delivered to a conventional gaseous compressor. The rate the hydrogen comes out is slow, so the model indicates a rather large cascade storage system. From that point on it looks like configuration 1.

Liquid Configuration 3



Liquid station configuration 3 is the latest generation of liquid supplied hydrogen stations. This is similar to the OCTA station design, and is in fact the configuration recommended by Air Products when they were being interviewed for this study. In this case the cascade system is eliminated and replaced with a buffer tank, which serves as a capacitor to smooth out the effects of the submerged liquid pump. The liquid is pumped to the dispenser feed pressure of 450 bar in real time while the vehicle is being refueled.

The economics of each of these six configurations are compared in the following two tables.

Configuration	Capex	O&M (annual)	Energy (annual)
Gas 1	$ 2,007,143	$ 120,020	$ 9,801
Gas 2	$ 2,635,331	$ 127,449	$ 59,255
Gas 3	$ 1,532,012	$ 120,020	$ 9,801
Liq 1	$ 1,684,791	$ 182,653	$ 2,678
Liq 2	$ 2,246,445	$ 172,016	$ 28,473
Liq 3	$ 1,595,600	$ 182,653	$ 2,678

In this first table we see that Gas 3 and Liquid 3 are the least expensive up front. In the case of gas three this comes from replacing a $625k cascade system with a $150k buffer system. The difference between Liquid 1 and Liquid 3 is not as dramatic because the cascade system for the former was considerably smaller and less expensive.

The next table shows the contributions of Capex, O&M, and Energy to the cost of hydrogen in $/kg.

Configuration	Capex	O&M (annual)	Energy (annual)	Total
Gas 1	$ 3.37	$ 1.23	$ 0.10	$/kg 4.70
Gas 2	$ 4.36	$ 1.31	$ 0.59	$/kg 6.26
Gas 3	$ 2.57	$ 1.23	$ 0.10	$/kg 3.90
Liq 1	$ 3.00	$ 1.88	$ 0.03	$/kg 4.91
Liq 2	$ 3.69	$ 1.77	$ 0.29	$/kg 5.75
Liq 3	$ 2.84	$ 1.88	$ 0.03	$/kg 4.75

It is clear that configurations Gas 2 and Gas 3 represent the extremes in terms of cost, though liquid 2 is also on the high side.

Estimated Energy and Power Demand

Delivered Hydrogen

FirstElement have provided us with station energy demand for both liquid and gaseous delivery options. This is based on the assumption that the station will dispense a maximum 100 kg/hr. On this basis the installed power would be 300 kVA for liquid hydrogen and 1200 kVA for gaseous delivery. Both assume 480 V 3ϕ service

These numbers are essentially the peak power needed to run the station, with most of the power going to compression and chilling. When the station is not refueling or recharging the high-pressure storage tanks, it will simply be consuming hotel power to run the lights, computer, communications, and keep the chiller in standby.

HDSAM calculates that the specific power to operate the station is 0.969 kWh/kg-H2 for gas and 0.3 kWh/kg-H2 for liquid.

On-site Production (SMR & Electrolysis)

For on-site production,the energy consumption is significantly higher, and is on top of the power needed for station operation. This is especially true for electrolysis. With electrolysis the total energy consumption is typically 60 - 65 kWh per kg of hydrogen produced. This includes the production of hydrogen, plus compression to medium pressure storage. An additional compressor would be needed to handle 70 MPa refueling. Actual stack consumption is generally 48 – 50 kWh/kg, while the overall system power consumption is usually in the vicinity of 57.5 kWh/kg.

Electrolysis

The CALSTART team has contacted multiple suppliers of electrolysis systems for costs and specifications. The specific power requirements were Nearly identical as shown in the following table.

Supplier	**Stack Power**	**Output**	**Ancillary Power****	**Specific Power**
Plug Power	0.88 MW	425 kg/day	135 kW	57.3 kWh/kg
ITM Power	1.7 MW	864 kg/day	370 kW	57.5 kWh/kg
Nel Hydrogen	1.1 MW	531 kg/day	150 kW	56.5 kWh/kg
Cummins	0.86 kW	431 kg/day	130 kW	55.1 kWh/kg

**Estimated based on product specifications

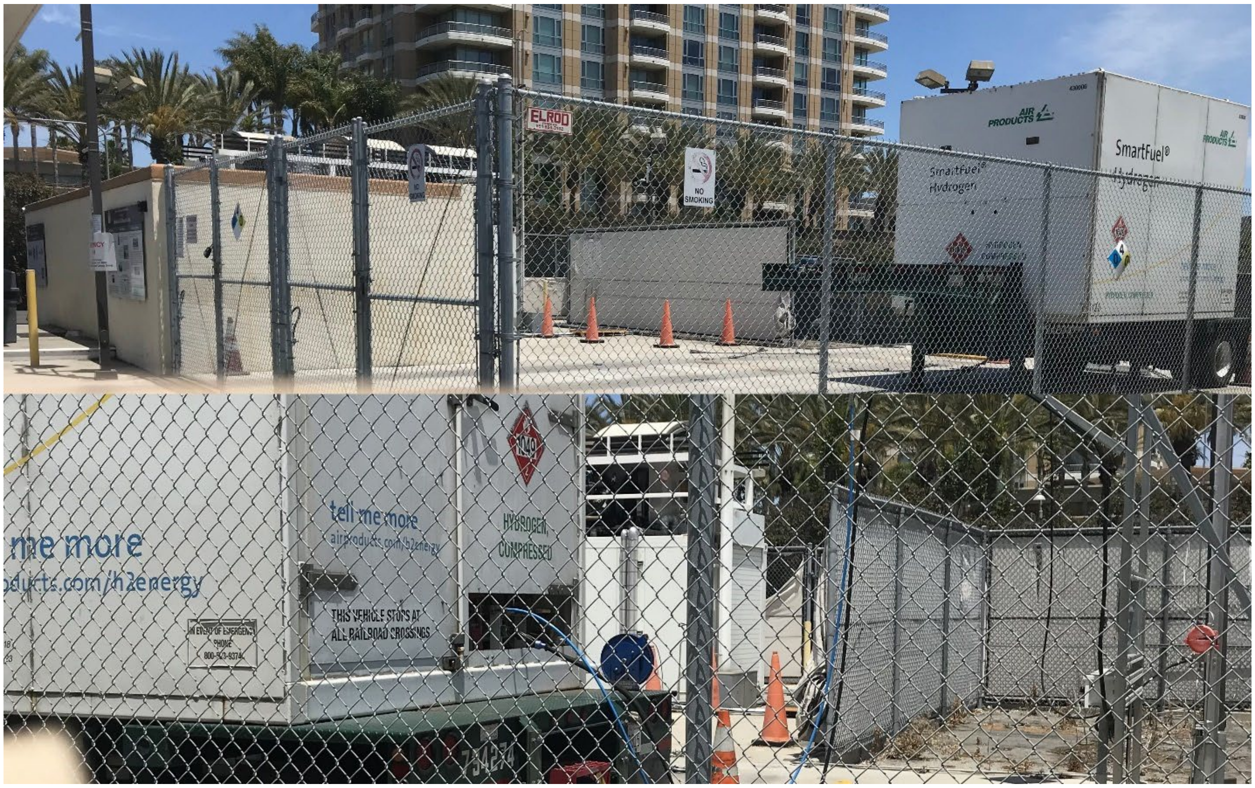
A good example installation of an electrolyzer is the Nel MC400 unit located at SunLine Transit in Palm Desert, California. Electricity is supplied to the building at 1200 VAC and is rectified and transformed to 2 MW of 12,000 VDC power for the stacks. A separate power system provides power to compressors, chillers, and other ancillary equipment.

On Site Reforming

The peak power demand for the BayoTech H2-1000 SMR system is reported to be 200 kW and steady state is around 110 kW. A typical unit will draw 2,000 – 2,300 kWh/day of 480 V 3 ph power.

Space Requirements

The following figure shows two views of the UCI drop and swap refueling station. The fenced-in area measures roughly 50 x 60 feet. The walled area visible in the top left is a fire-proof block wall that shields the hydrogen package (compressor, chiller, cascade, valves and controls). The hydrogen package itself is only about the size of a standard 20-foot container. The enclosure actually has room for two side-by-side 35 to 40 foot tube trailers, but currently receives roughly 4 20-foot trailers every three days. Some of the area in the fenced off area is surplus, but a lot of it is a result of conservative standoff distances in place at the time the station was designed. With the newer 2020 NFPA 2 a considerably smaller enclosure could almost certainly have been designed.



The next figure is Air Products' Orange County Transportation Authority (OCTA) refueling facility. The 18,000 kg LH2 tank sits along with the evaporators and auxiliaries inside an approximately 40' x 80' fenced enclosure. This does not, however, include the fueling island and canopy.

This figure was captured from Google Maps™. The LH2 tank is visible in the lower right. Just above the tank are four banks of evaporators and above that two buffer storage tanks are visible. The two sedans in the upper left corner provide a sense of scale. The dispenser island is not shown in the photo but requires only a 2' x 4' footprint. Again, there appears to be a lot of unused space; well in excess of what would be required by current NFPA guidelines.

Both UCI and OCTA stations were designed prior to the 2020 release of the NFPA 2 guidelines, which allow for much closer placement of equipment with generally smaller standoff distances. In addition, both stations are placed in relatively unconfined spaces with no directly adjacent buildings or other major infrastructure.

FirstElement Fuel has provided us guidance that the footprint for a 100 kg/h LH2 system that would meet the needs for this project is 13’ x 35’ including pump, compressor, evaporators, and both liquid and gaseous storage. Ehrhart et al. (2020)[6] have analyzed the footprint for 600 kg/day stations with delivered gas, delivered liquid, and on-site electrolysis. They have shown that the hydrogen package footprint is only slightly affected by the technology employed. Therefore, we will use the 13’ x 35’ reference as a basis for evaluating the overall station footprint for clovis.

Certain assumptions need to be made to assess the station footprint. For this study we are assuming that the station is adjacent to the property line on two sides, and that there are no adjacent buildings, air intakes, sewer vents, or sources of ignition within 50 feet of the station. This will give us the minimum footprint of the enclosure.

As shown in the next figure, the hydrogen package is assumed to be enclosed on three sides by an 11-foot tall 2-hour rated fire wall. The package itself is set back 19 feet from the property line on two sides, and separated from the wall by the height of the wall on two sides, and by five feet on the third side. On the open end of the enclosure bollards are placed five feet in front of the hydrogen package, spaced every four feet. Note that the distance of the hydrogen package from the fire wall on two sides is equal to the height of the wall.

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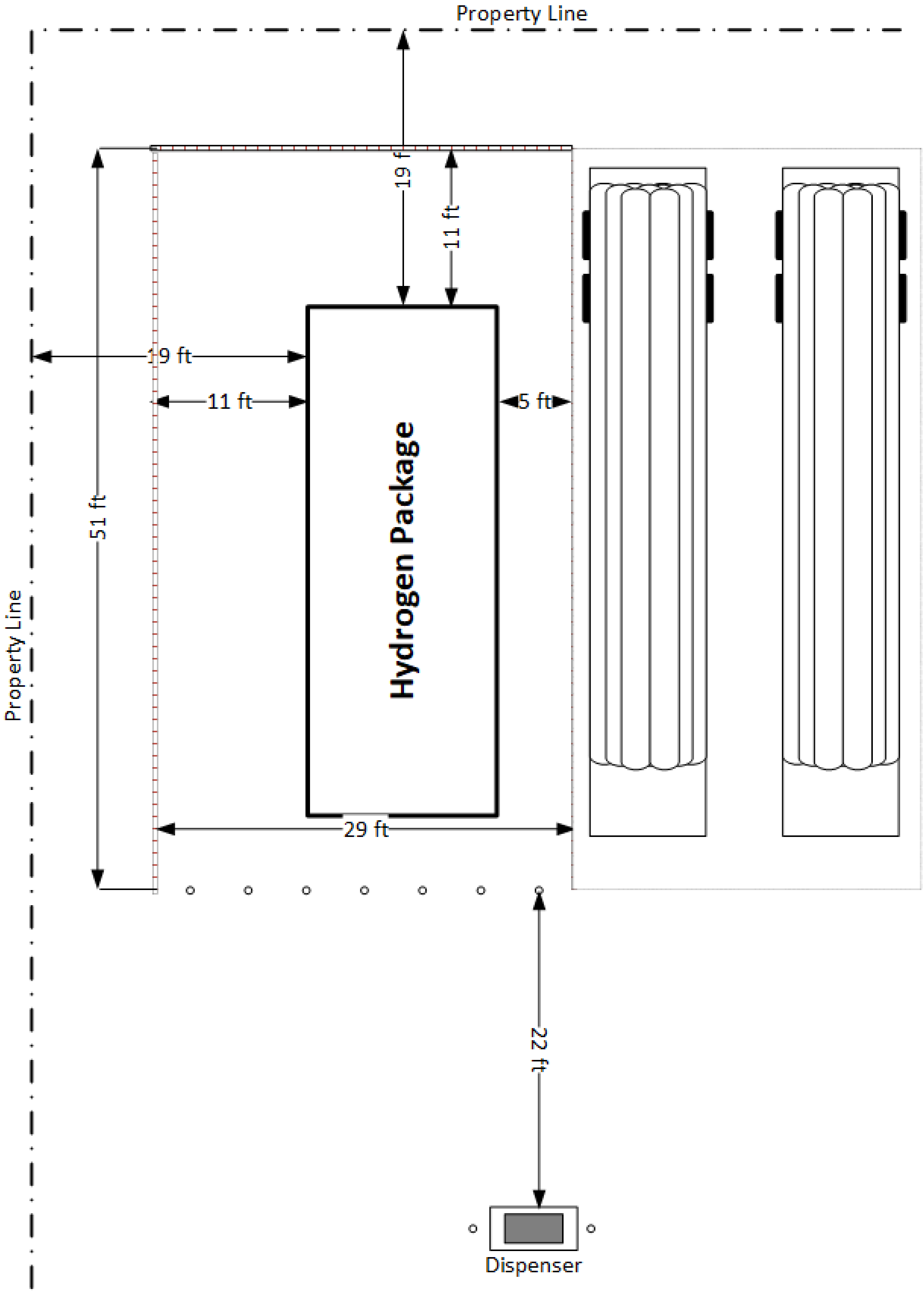
[6] Ehrhart, B.D. et al. Hydrogen Refueling Reference Station Lot Size Analysis for Urban Sites. SAND2020-2796, March 2020.


Property Line
19 ft
11 ft
19 ft
11 ft
5 ft
51 ft
Property Line
Hydrogen Package
29 ft
22 ft
Dispenser

The position of the dispenser is somewhat arbitrary if it is at least 5 feet from the hydrogen storage and 10 feet from the property line. For this exercise the dispenser has been placed 22 feet from the hydrogen package enclosure to provide an aisle one lane wide for bus refueling, and to allow access for hydrogen delivery. In addition, a 24-foot wide fenced enclosure could be added to accommodate two 40 foot trailers for a drop-and-swap installation. The entire project then measures 61’ x 84’ ((5125 square feet) with the trailer enclosure and 37’ x 84’ (3110 square feet) without the trailer enclosure.

If the station is located near other buildings the setback requirements can increase dramatically, especially for an LH2 station, so this should be considered an optimistic estimate of station size.

Closing Thoughts

Several equipment providers prefer to provide hydrogen as a service (HaaS). Air Products, One-H2, and Kaizen Clean Energy have all told the Calstart team that this is their preferred business model. In these cases, the hydrogen cost works out to $7 - $8/kg per earlier discussions. Air Products, in fact, usually wants to own and maintain everything up to the dispenser nozzle. They have said, however, that the realities of government grants and other funding often require compromise on their end.

BayoTech no longer produces their 200 and 500 kg/day SMR units and currently offers only one product – their 1000 kg/day model. However, BayoTech has told the Calstart team that if Clovis Transit were to purchase one of their units BayoTech would contract to acquire any unused hydrogen. Specific terms were not provided, but BayoTech assured us that the system would become a profit center for Clovis Transit.

There are two on-site hydrogen technologies that did not make it into the body of this report, but which deserve brief mention because they have been attracting a lot of attention in the trade literature as of late. These are steam methanol reforming (SMeR) and methane pyrolysis (MeP). Neither of these technologies are new or novel, but they are generally deployed for purposes other than small on-site production of hydrogen.

SMeR is carried out at milder conditions than SMR, leading to lower equipment costs and reduced energy input. SMeR has a smaller equipment footprint than SMR as well. It is getting a lot of attention recently because of its potential in the maritime industry. Methanol is a dense storage medium for transporting hydrogen. Its properties are like water and so it can be transported inexpensively at normal temperatures and pressures. It also has low aquatic toxicity, so spills are less of a concern. However, the technical maturity of SMeR, and its process economics at small scale have not been adequately demonstrated. In addition, it requires the storage and handling of large quantities of methanol, with its attendant health and safety issues.

MeP is one pathway to production of carbon black, though in that application the process is often carried out oxidatively with extremely low oxygen concentrations. Broadly speaking, there are three versions of MeP: Thermal pyrolysis, catalytic pyrolysis, and non-thermal plasma pyrolysis. Thermal pyrolysis is carried out at temperatures of 1,000 – 1,200 °C, while catalytic pyrolysis is often done around 700 – 800 °C, depending on the catalyst. Non-thermal plasma pyrolysis can be carried out at room temperature and several sources have stated that changing the temperature has little effect on process efficiency.

One thing in common with all MeP processes is that they produce approximately 3 kg carbon black for each kg of hydrogen. In fact, at the recent ACT Expo in Long Beach, a GenH2 representative told the Calstart team that sales of the carbon black are central to the economics of their Hyrolysis® process. It should be pointed out that BASF[7] stated in 2019 that "carbon value is a hurdle" as well as pointing out that the carbon quality is highly variable.

Collection of the carbon is another concern with MeP. The industry standard is to collect the carbon with a cyclone, followed by a baghouse, and then a wet scrubber. This is all followed by a PSA unit to remove residual methane and byproduct hydrocarbons.

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[7] Daloz, W. *et al.* The Quest for CO2-Free Hydrogen – Methane Pyrolysis at Scale. ARPA-E Methane Cohort Kickoff, Houston, December 10, 2019.

Appendix H: ICE Bus Fleet Cost Calculation Report

Table H-1. TCO for ICE Bus Fleet

Description/ Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Total
New buses added	0	3	-	3	5	-	-	-	-	-	-	-
Number of buses retired	-	-	-	-	-	-	-	3	-	3	5	-
Number of buses in operation	0	3	3	6	11	11	11	8	8	5	0	-
Capital cost	0	$540,000	-	$540,000	$900,000	-	-	-	-	-	-	$1,980,000
Total miles travelled by all buses	0	24,000	24,000	48,000	88,000	88,000	88,000	64,000	64,000	40,000	-	-
Maintenance cost	0	$14,400	$14,400	$28,800	$52,800	$52,800	$52,800	$38,400	$38,400	$24,000	-	$ 316,800
Fuel consumed (gallon)	0	1,714.29	1,714.29	3,428.57	6,285.71	6,285.71	6,285.71	4,571.43	4,571.43	2,857.14	-	-

Description/ Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Total
Fuel cost	0	$11,791	$11,791	$23,582	$43,233	$43,233	$43,233	$31,442	$31,442	$19,651	-	$259,398.86
End of life cost	-	-	-	-	-	-	-	$(30,000)	-	$(30,000)	$(50,000)	$(110,000)
Total cost	0	$566,191	$26,191	$592,382	$996,033	$96,033	$96,033	$39,842	$69,842	$13,651	$(50,000)	$2,446,198.86
Discounted cost (14%)	0	$523,475	$23,284	$506,370	$818,667	$75,896	$72,977	$29,112	$49,070	$9,222	$(32,479)	$2,075,595.55
Total discounted cost in millions	**$-**	**$0.52**	**$0.02**	**$0.51**	**$0.82**	**$0.08**	**$0.07**	**$0.03**	**$0.05**	**$0.01**	**$(0.03)**	**$ 2.08**

Table H-2. Scheduled Replacement Planning of ICE to BEB

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total qualified vehicle purchase/year	0	0	3	0	6	11	2	2	0	4	8
ZEB purchase/year (total)	0	0	0	0	3	6	2	2	0	4	8

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ZEB purchase/year (small) (Shuttle)					3		2			0	8
ZEB purchase/year (large) (Transit)						6		2		4*	
ICE vehicle purchase/year (all small)	0	0	3	0	3	5	0	0	0	0	0
Year	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**total**
Total qualified vehicle purchase/year	5	3	6	3	10	0	0	5	0	0	68
ZEB purchase/year (total)	5	3	6	3	10	0	0	5	0	0	57
ZEB purchase/year (small) (Shuttle)	0	3	6*[6]	3	5	0	0	5	0	0	35

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[6] Cells with an asterisk mark represent spare buses. These buses will run only in case of maintenance and service needs.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ZEB purchase/year (large) (Transit)	5				5						22
ICE vehicle purchase/year (all small)	0	0	0	0	0	0	0	0	0	0	11

Appendix I: Stakeholder Input

Community Engagement

One day of community outreach was completed on Friday, December 16, 2022. Three informational sessions were held throughout the day (morning, afternoon, and evening). The goal of these sessions was to present the findings of the techno-economic feasibility study developed by CALSTART and the proposed next steps for Clovis Transit to transition to a zero-emission fleet, as well as invite the public to voice their comments or questions about Clovis Transit's fleet.

Clovis residents were able to attend online via Zoom or in person at Clovis City Hall at 1033 Fifth Street, Clovis, CA 93612. The sessions were advertised online though social media and on the City of Clovis website.[7] A draft of the final techno-economic feasibility report was also available online for the public to review. The attendee totals for each session are listed in Table I-1 below; no public comments were received in any of the three sessions.

Table I-1. Community Outreach Attendee Totals

Time	Number of Attendees Online	Number of Attendees in Person
10 a.m. PST	0	0
2 p.m. PST	1	0
6 p.m. PST	0	0

Municipal Engagement

A Clovis City Council meeting was held at 6 p.m. PST on Tuesday, February 21, 2023. During this meeting, a presentation was made to the City Council that provided a high-level overview of the techno-economic feasibility report, focusing on the costs associated with

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[7] View the announcement for the public meeting at https://cityofclovis.com/public-meeting-on-the-electrification-feasibility-study-draft/.

transitioning to a zero-emission fleet and the zero-emission fleet requirements from CARB. The final report was also shared with the City Council for their review.

The agenda item,[8] titled "Consider – Various Options Addressing the Findings and Recommendations Provided by the Clovis Transit Fleet Electrification Feasibility Study Regarding the Required Zero-Emission Conversion of the Transit Fleet," asked the City Council to "consider and provide direction." Specifically, Clovis Transit required input from the City Council on what fuel type it should begin preparing for its zero-emission fleet—battery-electric, hydrogen fuel cell, or mixed—when writing the ICT report to submit to CARB.

The City Council expressed concern about the cost of transitioning to a zero-emission fleet and the robustness of ZEB technology. Specifically, the City Council questioned where the City of Clovis would get funding for this transition, as well as the safety of hydrogen storage technology. The possibility of stranded assets was an additional concern; the City Council questioned whether future technology advancements and/or revised standards from CARB would require Clovis Transit to adopt a different technology, resulting in the need for new vehicles and/or infrastructure. A question of the shareability of these assets was also discussed. Given that Clovis Transit will have to move to a new depot to accommodate this transition, it was suggested that perhaps Clovis Transit and Clovis's Public Utilities fleet should share the costs of zero-emission infrastructure assets.

The City Council recommended that Clovis Transit write the ICT report as a mixed fleet of both hydrogen fuel cell and battery-electric vehicles. The City Council also recommended that Clovis Transit continue to purchase internal combustion engine vehicles up until they are required to purchase ZEBs per CARB's ICT regulation. Before Clovis Transit submits the ICT report to CARB, the City Council will have the opportunity to review it; the City Council must approve it before submission.

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[8] The full agenda for this City Council meeting can be found at https://cityofclovis.com/government/city-council/city-council-agendas/.