Bus and Fleet Electrification Strategic Plan

City of Gardena's GTrans

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Executive Summary

The California Air Resources Board's (CARB) Innovative Clean Transit (ICT) regulation requires all California public transit operators transition their bus fleets to zero-emission buses by 2040.[1] The goal of the ICT regulation is to reduce the high environmental burden – both greenhouse gas emissions and local air pollution – caused by the transportation sector. GTrans, the City of Gardena's public transit agency, plans to convert its entire 58-bus fleet to zero-emission buses (ZEBs) by 2035, five years before the CARB mandate. ZEBs are more expensive than traditional internal combustion engine buses (ICEBs) and require costly fueling infrastructure. Additionally, agencies may need to change their operations to accommodate shorter ranges, longer fueling (or charging) time, and the physical space required to accommodate the ZEB infrastructure (such as numerous chargers and an upgraded electric grid). Both ZEB technologies – battery-electric buses (BEBs) and fuel-cell electric buses (FCEBs) – are relatively new and evolving rapidly, which add to the complexities associated with a ZEB fleet transition. Guided by these constraints, this report addresses the following policy question:

"How can GTrans manage their fleet transition to zero-emission buses by 2035 to promote cost-effectiveness and equity within the context of rapid technological changes?"

This report's primary function is to provide GTrans with the information needed to transition their entire fleet to ZEBs over the next 15 years. We provide an estimation model that will enable GTrans to efficiently compare costs of buses and chargers as their service and ZEB technology changes. We also provide detailed methodology and background on the estimation model so that GTrans may be able to update estimates as new technologies emerge, and prices and the policy landscape change. A transition to ZEBs presents an equity opportunity. By using ZEBs, GTrans can reduce harmful emissions, disproportionately faced by historically marginalized groups. GTrans can decrease the pollution burdens. Additionally, we provide background on hydrogen fuel-cell technology, electric grid infrastructure and potential funding sources.

This report relies on a review of the relevant literature, interviews with public officials from across California and subject matter experts, and analysis of GTrans' current bus service. Our literature review and interviews found that most transit agencies desire a one-to-one ZEB-to-ICEB replacement ratio due to financial and space restraints. Most agencies' operations require buses to drive further than the current range of BEBs. This results in these agencies either procuring more buses or opting to buy more costly FCEBs that have similar operating ranges to their existing fleet.

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[1] California Air Resources Board. Innovative Clean Transit (ICT) Regulation Fact Sheet. May 16, 2019. Retrieved from https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet.

Our analysis of GTrans' service discovered that the agency has multiple BEB options that offer a one-to-one replacement ratio, given the current distances traveled in GTrans' current service area. While many of GTrans' current routes would require buses to travel more than the advertised range of BEBs each day, other routes would have a BEB travel only a few dozen miles. These under-utilized buses could fill in for other buses whose currently scheduled daily service exceeds their range. Due to these findings, we recommend that GTrans explore a transition to less-costly BEBs over the more expensive FCEBs.

In general, we recommend GTrans consider the following factors when deciding on ZEB technology:

- **Charging Logistics** - The number of chargers, energy output, and dispenser connections affects how quickly the bus fleet can charge, the number of staff members needed to manage charging every night, and the space in the bus yard occupied by charging infrastructure.
- **Overall Cost** - Comparing the unit cost of each bus option does not necessarily produce the overall cheapest option. The cheapest bus may require expensive chargers, more buses (and therefore more space needed for buses), and many more staff hours.
- **Multiple Manufacturers** - "Mixing and matching" different manufacturers is not recommended since there are logistical disadvantages, such as needing to keep various manufacturers' parts on hand for maintenance, and to have staff trained in many different technologies.
- **Replacement Ratios** - A one-to-one fleet replacement ratio is preferable.
- **Risk** - Other transit agencies provided insight into which bus types have had complications and which manufacturers were not responsive to agency inquiries, all of which add to the risk of service failure. As a new technology for GTrans and in general, ZEBs have an inherent learning curve.
- **Space** - While GTrans has a comparatively large bus yard, the agency still must strategically decide the footprint taken up by charging or refueling equipment, the buses themselves, and potential battery storage.
- **Training** - Not all manufacturers include training in their procurement costs, and not all manufacturers provide equal amounts of training. Some technologies, such as FCEBs, require the manufacturer, not the agency, to safely replace parts. However, because BEB maintenance typically takes place in-house, adoption of BEB technology requires much more training relative to FCEBs.
- **Warranty** - Warranty coverage varies by manufacturer. A key concern with ZEBs is battery replacement. A ZEB's battery is expected to degrade as the bus ages, thus decreasing its range potential. Warranties ensure that batteries can be regularly replaced.

Our cost estimation model is not intended to include all factors relevant to GTrans. Instead, it provides only the most tangible variables. GTrans undoubtedly considers other variables when procuring buses that were infeasible for us to include in this report, such as customer satisfaction or responsiveness of the manufacturer. While our model uses the most up-to-date information, GTrans will be able to update it as variables change. The steps included in our model and potential reasons to update it are listed below.

Steps	Update If…
1. Determine the agency's total daily mileage.	Routes change.
2. Use BEB range to determine necessary fleet size.	New manufacturers are available or more accurate information becomes available on ZEB range.
3. Calculate cost of the entire fleet per bus type and electricity need.	New manufacturers are available, bus price changes, or SCE alters its electricity tariff rates.
4. Narrow charger options based on bus selection.	New manufacturers are available or new charger technology emerges.
5. Approach Southern California Edison (SCE) to finalize infrastructure upgrades.	FCEB technology becomes more feasible, so GTrans would not be reliant on SCE.

Glossary of Terms

BEB
BEB stands for battery-electric bus. A BEB is a bus powered by an electric motor that draws power from on-board batteries.

Bus-Blocks
Not to be confused with a city block, a bus-block is the assigned routes or portions of routes a bus completes. It is the "work" a bus does throughout the day, from when it pulls out of the garage to when it finally comes back. The length of a bus-block is how much a bus drives each day. They are set by the transit agency and based on the bus' range and the agency's fleet availability.

Bus Yard
The facility where buses and the equipment needed to operate them are stored and maintained. Most transit agencies own the property on which the bus yard is located and larger agencies often have multiple bus yards.

CalEnviroScreen
A screening tool used to help identify communities disproportionately burdened by multiple sources of pollution and with population characteristics that make them more sensitive to pollution.

CARB
CARB stands for the California Air Resources Board, the "clean air agency" within the California state government.

Charger
The equipment used to fuel battery-electric buses, almost always located in the agency's bus yard.

CNG
CNG stands for Compressed Natural Gas. CNG can be used to fuel internal combustion engine buses with fewer negative environmental outputs than diesel. GTrans uses renewable CNG, also known as RCNG or RNG.

FCEB
FCEB stands for Fuel-Cell Electric Bus. An FCEB is a bus powered by hydrogen, making it a zero-emission bus. A fuel cell combines hydrogen and oxygen to produce electricity, heat, and water.

Fleet
All vehicles – normally buses – that transit agencies use for their operations.

Fleet Replacement Ratio
Battery-electric buses have a different range than an internal combustion engine bus. While an internal combustion engine bus can get over 300 miles for a full tank of gas, a battery-electric bus often travels less than 200 miles on a full charge. This means that a battery-electric bus fleet will be larger than an internal combustion engine bus fleet. However, some battery options give a "one-to-one" fleet replacement ratio, which means that the battery-electric fleet can be the same size as the internal combustion engine fleet.

GTrans
GTrans is the transportation department for the City of Gardena and the client to whom this report is addressed.

ICEB
ICEB stands for internal combustion engine bus. It refers to buses that use fossil fuels, such as compressed natural gas or diesel.

ICT
ICT stands for the Innovative Clean Transit rule. It was adopted by CARB in 2018, requiring all public transportation agencies to fully transition their buses to ZEBs by 2040.

kW
A kilowatt (or kW) is 1,000 watts of power.

kWh
A kilowatt hour (or kWh) is a measure of energy. One kilowatt hour equals the energy of 1,000 joules used for one hour.

Line
Synonymous with “route”, a line is an advertised path a transit vehicle travels for the purpose of transporting passengers.

OCPP
OCPP stands for open charge point protocol. OCPP compliance allows for third-party energy management software (such as smart charging software) to be compatible with their chargers.

PVR
PVR stands for peak vehicle requirement. PVR is the number of vehicles a transit agency requires to run its most frequent service, typically weekday service when school is in session.

Revenue Miles
The mileage taken from adding all the miles of passenger service, excluding mileage from buses moving between locations when out of service and no riders are on board.

Route
Synonymous with “line”, an advertised path a transit vehicle travels for the purpose of transporting passengers.

Service Area
The geographic area that is covered by a public transit agency’s routes.

Service Hours
The total number of hours in revenue-generating service.

Southern California Edison
The utility service that provides power to GTrans. Also known as SCE or SoCal Edison.

SOC
SOC stands for state of charge. We use SOC to refer to the level of battery left in a battery-electric bus when returning to a bus yard at the end of its bus-block.

Surplus Miles
The range of miles leftover in each bus after they complete their assigned bus-block. For internal combustion engine buses, this is based on how much gas is left in the tank. For battery-electric buses, this is based on how much charge is left in the battery.

UL
UL refers to the Underwriting Laboratory. UL certification indicates that a charger is safe and has passed Occupational Health and Safety Administration testing.

ZEB
ZEB stands for zero-emission bus. They are buses that produce no emissions, unlike traditional diesel or even CNG buses. There are two types of ZEBs: battery-electric buses (BEBs) and fuel-cell electric buses (FCEBs).

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Chapter 1

INTRODUCTION

The United States is the second-largest polluter on the planet, accounting for 15 percent of overall greenhouse gas (GHG) emissions.[2] Within the United States, the transportation sector is considered the primary source of greenhouse gas emissions, accounting for more than 28 percent of the total.[3] Rising GHG emissions accelerate climate change, impacting sea levels, air quality, temperatures, and climates, as well as ecosystems' health and the health of flora and fauna.[4] As a result, to mitigate the GHG emissions in California, the California Air Resources Board (CARB) passed the Innovative Clean Transit (ICT) Regulation in December 2018, which requires all public bus fleets to transition to zero-emission vehicles by 2040.[5] This regulation mandates the rollout of zero-emission buses (ZEBs) without mentioning which technology to use, leaving some freedom to transit agencies. Today, most transit agencies are exploring battery-electric buses (BEBs) and hydrogen fuel-cell electric buses (FCEBs). The 200 public transit agencies in California operate more than 12,000 buses, which are to become ZEBs by 2040.[6] The fleet transition is set to be gradual. By 2023, all agencies must have submitted their zero-emission rollout plan. By 2029, every new bus purchased in the state will be zero-emission. Eventually, by 2040, California's public transit agencies will have phased out all fossil fuel-powered buses.

Pre-COVID-19, the City of Gardena's transit agency, GTrans, operated five bus lines and serves close to three million riders each year. Considered a small transit agency with only 58 buses, its zero-emission fleet rollout plan is due on July 1, 2023. The rollout plan must include a procurement calendar for all buses, as well as the infrastructure needs and workforce training required to operate a zero-emission fleet successfully. The Gardena City Council must sign-off on the rollout plan. GTrans aims to operate an entirely zero-emission fleet by 2035 — five years before the ICT goal.

Transportation accounts for roughly 40 percent of California's total GHG emissions and 80 percent of the state's NOx emissions, one of the most toxic causes of air pollution.[7] This includes all transit (cars, trucks, buses, etc.) and not only mass transit. GTrans

[2] United States Environmental Protection Agency, Emissions by Country, Global Greenhouse Gas Emissions Data, September 2020. Retrieved from https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data#Country

[3] United States Environmental Protection Agency, Sources of Greenhouse Gas Emissions, December 2020. Retrieved from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[4] United States Environmental Protection Agency, Greenhouse Gases, March 2020. Retrieved from https://www.epa.gov/report-environment/greenhouse-gases#impacts

[5] California Air Resources Board. Innovative Clean Transit (ICT) Regulation Fact Sheet. May 16, 2019. Retrieved from https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet

[6] California Air Resources Board, California transitioning to all-electric public bus fleet by 2040, December 2018. Retrieved from https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040

[7] California Air Resources Board. Innovative Clean Transit - About. Accessed January 8, 2021. Retrieved from https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/about.

currently emits over 4,380 metric tons of carbon dioxide emissions annually.[8] *Appendix A* shows how we multiplied GTrans' gasoline consumption in 2019 by the carbon content of gasoline to estimate CO2 emissions. By converting their fleet from gasoline-powered buses to ZEBs, GTrans would have the equivalent effect of removing 20,586 personal vehicles from the road each year.[9] In addition to helping curb climate change, the transition will also reduce air pollution in their service area.

1.1 Client: GTrans

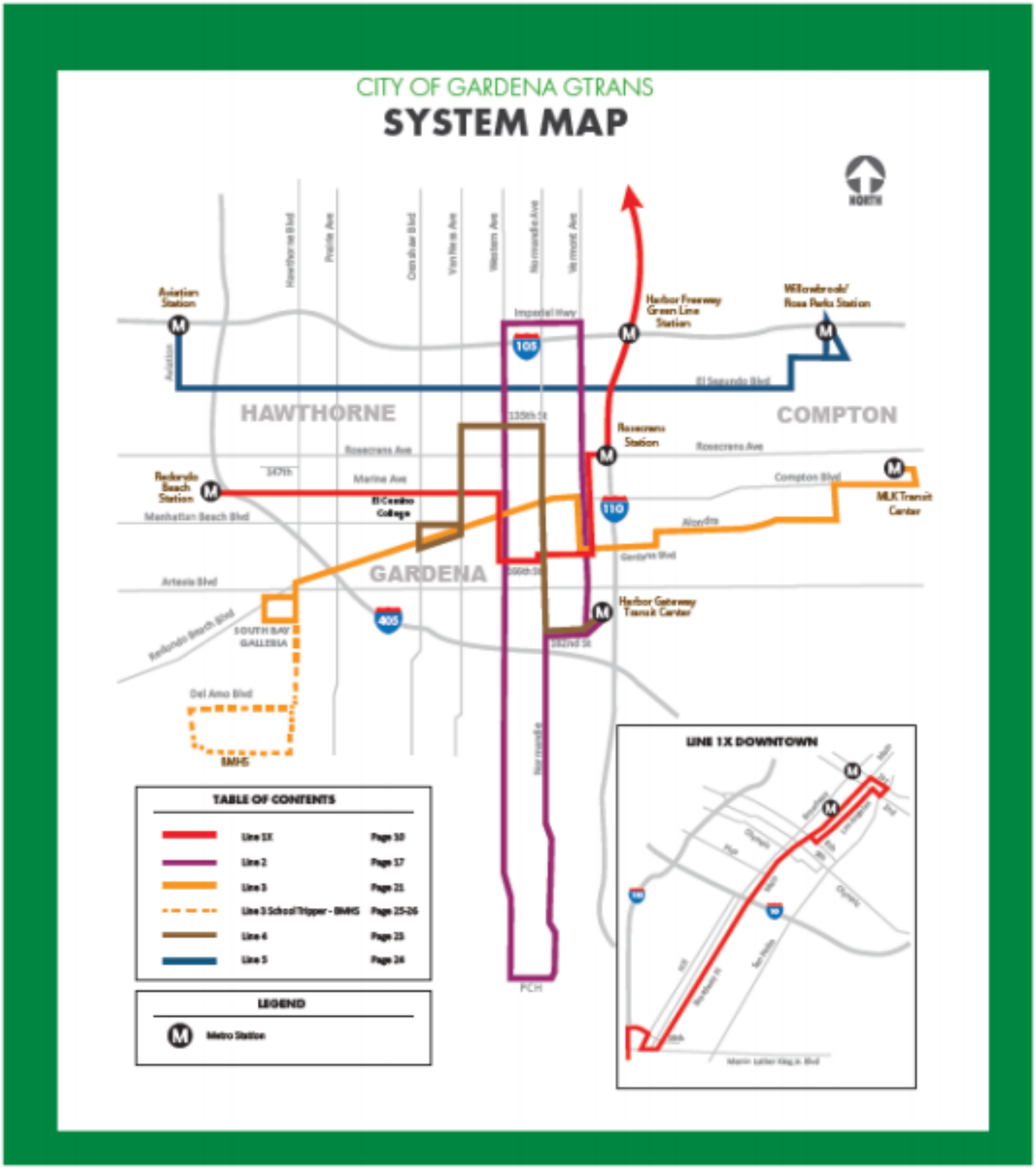
Overview[10]

Incorporated in 1930 and located 12 miles from downtown Los Angeles, the City of Gardena sits in the South Bay sub-region of Los Angeles County. The City of Gardena is surrounded by the City of Torrance to the south, the City of Los Angeles to the east, and the City of Hawthorne to the north and west. The City is governed by a Mayor, the presiding officer of a five-member City Council. The City Council appoints the City Manager, the administrator running the day-to-day business of the City.

GTrans is the City of Gardena's Transportation Department. Created in 1940, GTrans is one of the three municipal transit agencies serving the South Bay sub-region of the county. Pre-COVID-19, GTrans served over three million riders annually across 136,000 service hours. GTrans' current fleet consists of 52 hybrid buses and six BEBs deployed over five fixed routes (*Figure 1.1*). The BEBs include five that were converted hybrid buses and one manufactured BEB.

[8] Davis, Stacey & Robert Bundy. *Transportation Energy Data Book*. Ed. 39. U.S. Department of Energy. Retrieved from https://tedb.ornl.gov.
[9] United States Environmental Protection Agency. Greenhouse Gas Emissions from a Typical Passenger Vehicle. 2004. Retrieved from https://nepis.epa.gov/.
[10] The information in this overview is summarized from the following source: City of Gardena's GTrans. (2020) *Overview of the Transit System, FY2020-2022 Short-Range Transit Plan* (P.3).

Figure 1.1: City of Gardena GTrans System Map



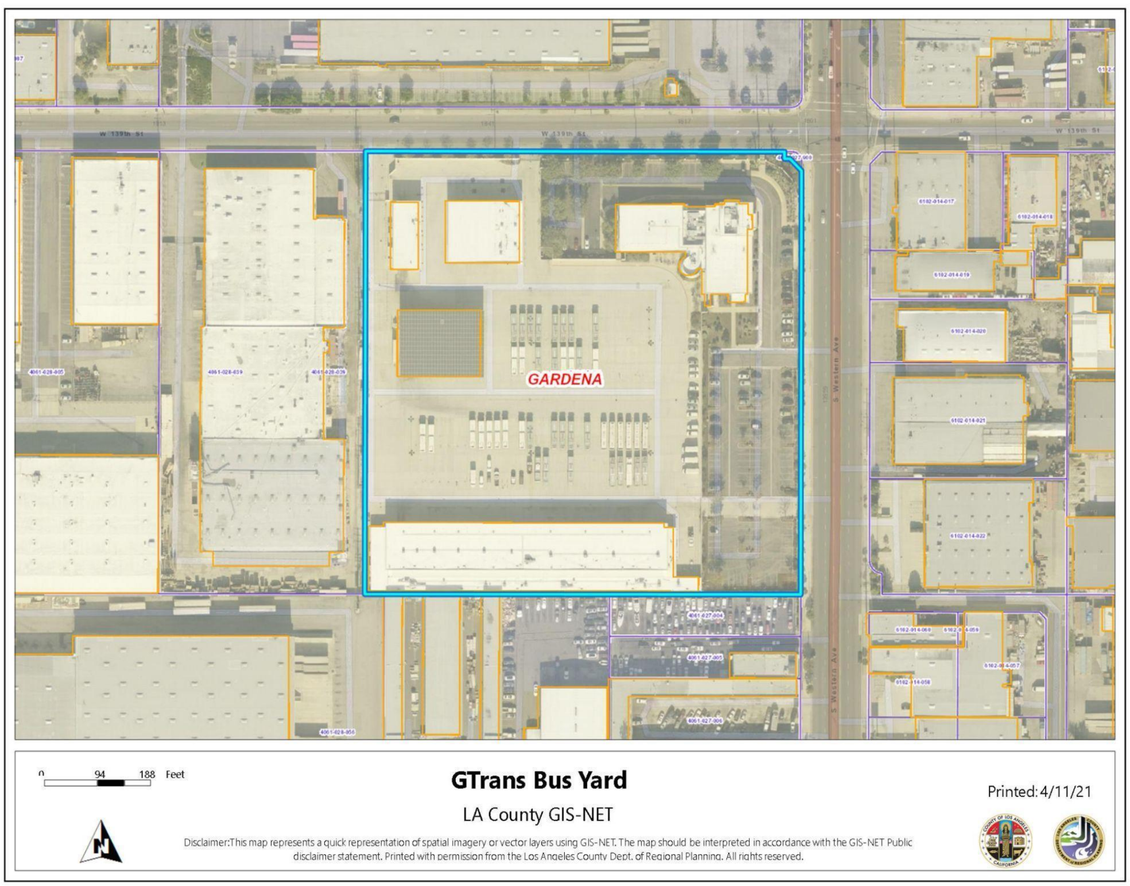
The agency provides fixed-route service on five bus routes – four local and one express – that run through the City of Gardena, as well as the neighboring communities of Carson, City of Los Angeles, Compton, Hawthorne, Lawndale, Redondo Beach, Torrance, and other unincorporated areas of Los Angeles County.

GTrans' buses travel as far as downtown Los Angeles, supplementing the service offered by Los Angeles County Metropolitan Transportation Authority's (Metro) A and C Lines (light rail), J Line (bus rapid transit), and local bus service. Additionally, GTrans' service area overlaps with Beach Cities Transit, City of Compton's Renaissance Transit, Lawndale Beat, Los Angeles Department of Transportation, and Torrance Transit. More than two-thirds of GTrans' service area is outside Gardena's city limits, indicating the agency serves more than just Gardena's residents.

Facilities

Since May 2009, GTrans has located its maintenance and transportation facility on a 9.2-acre site at 139th Street and Western Avenue in the City of Gardena (*Figure 1.2*). This facility received the LEED Silver certification and houses the agency's administrative, maintenance, and operations functions. Divided into four buildings, it includes a 14-bay bus garage, fueling stations, bus wash, and administrative offices, all equipped with energy-efficient lighting, heating, and air-conditioning. The lot also includes a canopy structure covered with solar energy panels.

Figure 1.2: GTrans Bus Yard



1.2 Innovative Clean Transit

California policymakers have set ambitious GHG targets as part of the state's climate change and air quality goals.[11] To meet these targets, California must overhaul its transportation sector.[12] In 2018, CARB adopted the Innovative Clean Transit (ICT) regulation that requires all public transportation agencies to fully transition their bus fleet to ZEBs by 2040.[13]

ICT also requires that all bus purchases after 2028 be ZEBs.[14] Ahead of this deadline, the regulation mandates a gradual increase of the percentage in new buses purchased by transit agencies to be ZEBs. The schedule of ZEB purchases depends on agency size. ICT defines a large agency as an agency that operates at least 100 buses serving an urbanized area with more than 200,000 people. All other agencies are small. ICT ZEB purchase requirements start for large agencies and small agencies in 2023 and 2026, respectively. *Appendix D* shows the ICT purchase requirements for agencies. CARB requires that 25 percent and 100 percent of GTrans' bus purchases be ZEB by 2026 and 2029, respectively.

Each California transit agency must submit a ZEB rollout plan to CARB that outlines how it proposes to transition its fleet to ZEBs.[15] The deadline for large agencies was July 1, 2020, while GTrans and other small agencies must submit their plans by July 1, 2023.[16]

1.3 Policy Question

How can GTrans manage their fleet transition to zero-emission buses by 2035 to promote cost-effectiveness and equity within the context of rapid technological changes?

This report's function is to present GTrans, as well as the Gardena City Council, with the necessary background information and model to evaluate choices for transitioning their bus fleet to ZEBs. While this report concludes with potential options, given the 15-year time horizon for full implementation, it is just as essential to have a clear cost

[11] Hannah Hageman. "A Checkup On California's Efforts To Combat Climate Change." *Weekend Edition Sunday*. NPR. March 14, 2020. Retrieved from https://www.npr.org/2020/03/15/815828879/tracking-californias-2030-climate-goals.
[12] California Air Resources Board. Innovative Clean Transit - About. Accessed January 8, 2021. Retrieved from https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/about.
[13] California Air Resources Board. Innovative Clean Transit Fact Sheet. April 2019. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2019-07/ICTreg_factsheet.pdf.
[14] Ibid.
[15] Ibid.
[16] Ibid.

estimation model to evaluate all the technological variables to make feasible budget decisions. As technology changes, updated numbers can be input to provide new projections.

To that end, this report analyzes the costs and benefits of various BEB options and concludes with recommendations on how to weigh various BEB and charger options given the estimated costs. However, this report will *not* offer a hard recommendation as to which BEB or charger option to procure, since the long implementation timeline and the changing nature of technology and prices would make that recommendation moot very quickly. We do not recommend FCEBs because they are currently much more expensive, yet do not improve GTrans' service capabilities. However, the report includes an analysis of FCEBs so GTrans has the background information and evaluation model should future opportunities in hydrogen fueling and overall cheaper fuel-cell technology emerge.

Relying on the CalEnviroScreen disadvantaged communities score, this report finds that a majority of GTrans service area goes through disadvantaged communities. GTrans has an equity opportunity in using ZEB to reduce harmful emissions.

1.4 Basics of an Electric Bus Fleet

Currently, two technologies – BEBs and FCEBs – dominate the ZEB market. Both BEBs and FCEBs are significantly more expensive than traditional diesel or compressed natural gas (CNG) buses. Transit agencies must also invest in the infrastructure that supports fueling or charging the ZEBs. To pay for the costs of ZEBs, transit agencies seek to acquire funding from federal, state, and local programs. The Biden Administration is committed to funding the transition to ZEBs. As part of the American Jobs Plan, the White House called on Congress to allocate $46 billion of Federal funds to purchase clean energy technology, including ZEB and the corresponding infrastructure.[17] Although the plan does not offer details and still needs to pass Congress, it does signal to transit agencies a potential for heightened direct payments in the future. Furthermore, we expect ZEB costs to decrease as the technology becomes more saturated. In the meantime, the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) and Low Carbon Fuel Standard (LCFS). The HVIP provides vouchers for the ZEB purchases and LFCS allows agencies to sell off carbon reduction credits.

While the per-unit costs of BEBs are less than FCEBs, BEBs are more challenging to operate and have a more limited range than both ICEBs and FCEBs. The significant amount of electricity needed to charge an entire BEB fleet results in transit agencies

[17] The White House. FACT SHEET: The American Jobs Plan. March 31, 2021. Retrieved from https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/.

needing to devote their workforce to new complex operational and infrastructure challenges. Agencies are adept at matching ICEBs with routes, but running a fully-BEB fleet consists of optimizing a whole new set of variables:

- Bus range now depends on the nature of the route and age of the battery.
- Charging times vary based on the amount of charge left in a bus battery.
- Investments must be made to increase grid capacity.
- Charging must be scheduled during the most cost-effective hours.
- Retraining bus operators and mechanics to maximize BEB range and life.

Additionally, transit agencies must work with their utility companies to determine electricity rates, which are subject to a complex regulatory process that involves numerous state actors. Unlike fuel prices, which are relatively stable with a single price based on market forces, energy prices for electricity change according to demand, time of day, day of the week, and time of year. Planning for events such as a grid failure or blackout, which may leave a fleet of buses with no charge to run, only adds to the complexity as transit agencies consider solar panels and large-scale battery storage to minimize risk.

In contrast, transit agencies can seamlessly replace CNG buses or other ICEBs with FCEBs without changing many of their operations. Hydrogen fuel can be delivered and stored like CNG. FCEB and CNG buses take the same time to refuel – about 20 minutes – and their range is similar. However, the convenience of limited operational changes offered by FCEBs comes at a higher per-unit capital and fuel cost, according to our analysis.

Although some transit agencies have selected one technology, most ZEB rollout plans submitted to CARB include a combination of both BEBs and FCEBs. Since these relatively new technologies are rapidly changing, transit agencies must regularly update their plans to respond to technological advances. However, these agencies are generally much larger than GTrans and have more operational capacity to manage multiple technologies. Our estimation model revealed that GTrans has some BEB options with one-to-one fleet replacement ratios, and therefore does not need to invest in costly FCEB technology and infrastructure. However, we still include FCEB background and analysis in this report for future reference.

Fuel Cell Technology

While BEBs use batteries to store electricity, FCEBs use hydrogen to generate electricity that powers the wheels. The fuel cell circulates hydrogen through an anode, and oxygen through a cathode. The combination of these two materials creates an electrochemical reaction that generates electricity, as well as heat and water.[18] A

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[18] U.S Department of Energy, Office of Energy Efficiency and Renewable Energy. Fuel Cells. Accessed April 2, 2021. Retrieved from https://www.energy.gov/eere/fuelcells/fuel-cells

primary advantage of fuel-cell technology is that it offers buses a range of approximately 300 miles.[19] In addition to a larger range than BEBs, the time required to refuel an FCEB is considerably shorter. Agencies report refueling times between 15 and 20 minutes, which is similar to the fueling time for ICEBs (see *Appendix B* for a list of agency interviews).

Fuel cells are comparable to internal combustion engines in that they use fuel to generate power. As a result, they require more maintenance than BEBs. Additionally, while manufacturers have improved the safety and durability of their hydrogen tanks to make FCEBs safer than ICEBs, FCEBs are less safe than BEBs – hydrogen remains highly flammable in the presence of oxygen.[20]

When choosing among different and new technologies, it is also crucial to consider the perception communities may have of the technologies. Researchers find high levels of ignorance centering on fuel-cells and using hydrogen as fuel, mainly related to the volatility and high flammability of hydrogen.[21] Since the technology is relatively new and unknown, some transportation agencies are reluctant to adopt it.

To receive as much funding as possible, GTrans must purchase buses built in the United States, which are Buy America compliant. Only one bus manufacturer, New Flyer of America, offers Buy America compliant FCEBs at the time of writing.

1.5 Basics of the Electric Grid[22]

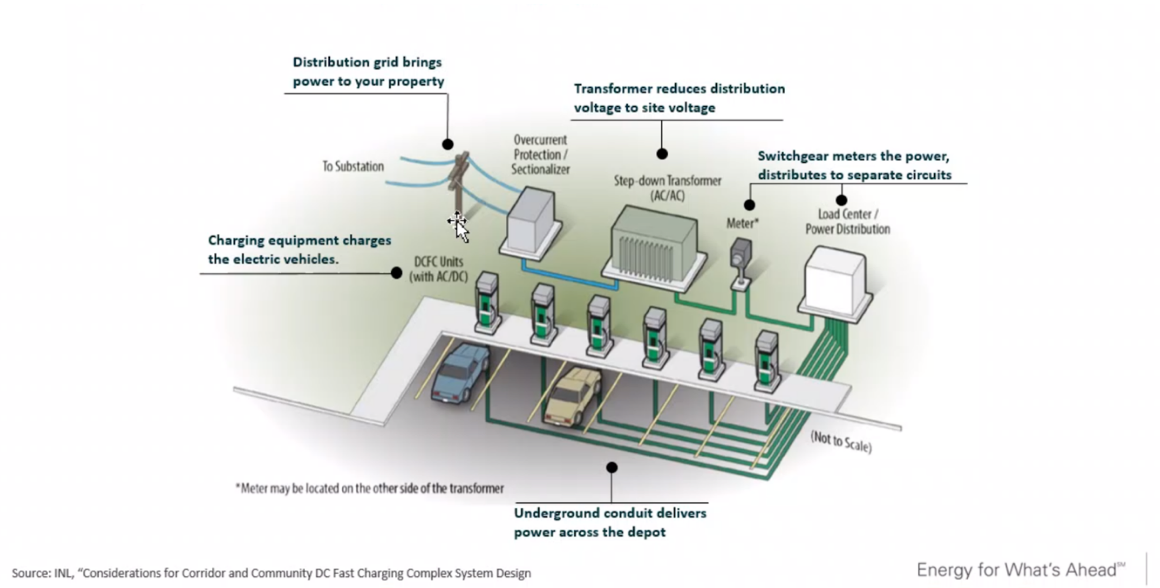
The electric "grid" refers to a complex, interconnected electric system that can be broken down into four main components: generation, transmission, distribution, and load. Generation refers to the creation of electric energy via fossil fuels or renewables, such as wind or solar. Transmission refers to the movement of power over long distances and is essential to move electricity from the generation site to the consumer. The distribution system takes the electricity from the transmission system and brings it to the consumer. In most cases, the electricity passes through a transformer that reduces the voltage to serve the "load," the consumer of electric energy. The size of

[19] Data given by New Flyer of America, manufacturer of fuel-cell electric buses.
[20] Hyundai Motor Group. What Makes Fuel Cell Electric Vehicles Safe? Accessed March 22, 2021. Retrieved from https://tech.hyundaimotorgroup.com/article/what-makes-the-fuel-cell-electric-vehicle-safe/
[21] M. Ingaldi & D. Klimecka-Tatar (2020) People's Attitude to Energy from Hydrogen --From the Point of View of Modern Energy Technologies and Social Responsibility. *Energies*, *13*(24), 6495. People's Attitude to Energy from Hydrogen—From the ... - MDPIhttps://www.mdpi.com › pdf
[22] Unless otherwise noted, information from this section comes from a lecture that can be found here: *Transmission 101: How the Grid Works*. Accessed March 2021. Retrieved from https://www.eesi.org/briefings/view/070913transmission

loads depends on the energy needs of the consumer. For example, the load of a house would be much smaller than an industrial facility.

When charging an entire BEB fleet, GTrans' bus yard would have a much larger load than it currently has. *Figure 1.3* outlines the infrastructure involved in charging electric vehicles once electricity is taken off the distribution grid. Several layers of infrastructure are involved once electricity moves out of the distribution system before it finally hits the load of an electric vehicle. The electricity passes through a sectionalizer, then a transformer, then switchgear meters to finally get onto underground conduits that deliver electricity to the chargers.

Figure 1.3: Components of Depot Charging[23]



Typically, when an electricity customer needs to upgrade the amount of power they consume on a utility's grid, the customer is responsible for all infrastructure upgrades on their property, while the utility is responsible for all infrastructure upgrades prior to the power reaching the lot. In general, this means the utility pays for all upgrades prior to the meter (updating the transformer and the distribution grid, etc.), while the customer would need to pay for upgrading the load center, circuits, and conduits.

However, as we shall see later in this report, Southern California Edison's (SCE's) *Charge Ready Program* for transit agencies can cover the cost of infrastructure upgrades beyond the meter up to the charger itself. Currently, the *Charge Ready*

[23] Francfort, J., & Smart, J. (2017, June 8). *Considerations for Corridor and Community DC Fast Charging Complex System Design.* Retrieved from Idaho National Laboratory: https://www.energy.gov/sites/prod/files/2017/06/f34/van024_francfort_2017_o.pdf

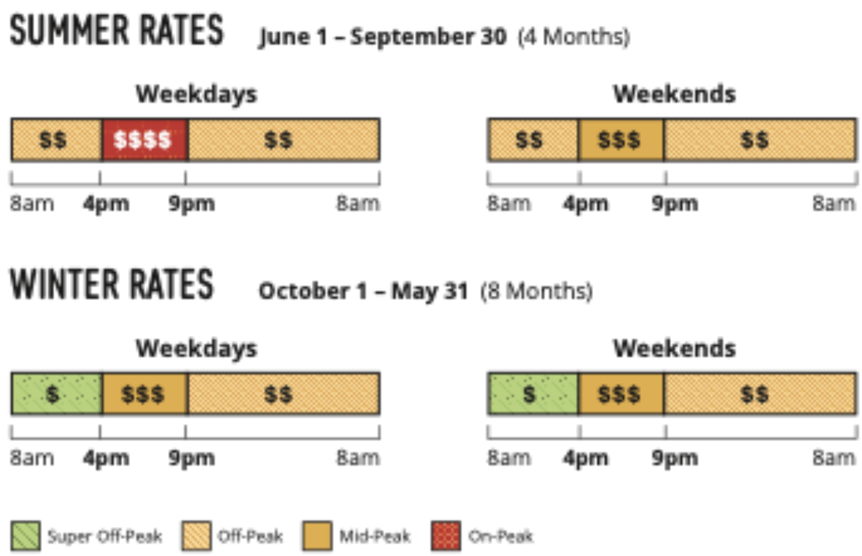
Program is a non-competitive program, with applications from transit agencies getting approved on a first-come-first-serve basis as long as they meet some baseline qualifications (explored later). This may be subject to change as demand for the program grows.

A Note on Electricity Rates

Electricity is priced very differently than fuel. When we fill up our cars with gasoline, we follow a simple system of price per gallon. Gas prices may go up or down, but, in general, we are confident that they will not fluctuate more than two dollars for any given year. We understand the cost of a "full tank" in our cars very intuitively by simply multiplying the number of gallons our tank may hold by the price per gallon of gas. This very predictable system of pricing makes it easy for transit agencies to budget for fuel, purchasing CNG and hydrogen in bulk, and using it to fill up their buses to full tanks.

Electricity is priced as energy, not fuel, which makes costs much less predictable. The price of electricity varies based on two main variables: the amount of energy being consumed (the "demand") and the time at which a customer consumes it ("super off-peak," "off-peak," "mid-peak," or "on-peak"). *Figure 1.4* shows how the prices compare to each other. We can see that rates differ by time of year (summer and winter), day of the week (weekday or weekend), and time of day (broken up into various categories of "peak"). Times when electricity is in the highest demand is when it is priced the highest. Summer weekday evening hours are the most expensive because many people are home from work and running air conditioners while also having all of their lights on. Winter mornings are the cheapest because most people are at work and their houses are usually not temperature-controlled until they get home.

Figure 1.4: The Electricity Rate System[24]



For an industrial consumer of electricity such as GTrans, pricing has an added element in the form of a demand surcharge, an extra amount per kWh of consumption that is added to electricity rate when GTrans is using a lot of power. Hence, while charging the bus fleet during off-peak hours seems to be the most economical, one must consider the possibility of a surcharge being added because of the high demand that GTrans would be putting on its grid.

Currently, SCE has eliminated demand surcharges for transit agencies that are charging electric vehicles (see *Appendix C* for their current pricing scheme, which we use for calculations in later sections of this report.) However, some bus manufacturers have claimed that SCE will likely reinstitute demand charging within the next five years.[25] Therefore, it is important to note that *SCE may bring demand charging back in the future*. For example, Long Beach Transit, in their 2018 FTA report, mentions a total electricity rate tariff of $0.264 per kWh, of which electricity consumption accounted for 25 percent of the price (at $0.066 per kWh), other taxes and fees on the utility bills accounted for 13 percent of the price (at $0.036 per kWh), and the cost for electricity demand accounted for the majority of their electricity bill at 61 percent, or $0.162 per kWh.

[24] Southern California Edison. (2021, February 1). *Time-Of-Use (TOU) Rate Plans*. Retrieved from Southern California Edison: https://www.sce.com/residential/rates/Time-Of-Use-Residential-Rate-Plans
[25] According to an interview with Ballard Fuel Cell Systems (see *Appendix B* for a list of interviews).

Chapter 2

PROBLEM IDENTIFICATION

There are some challenges that must be considered for a fully ZEB fleet. First, the range of BEBs differs from that of ICEBs, with some transit agencies reporting even higher ranges than advertised by BEB manufacturers, and many others reporting much lower ranges. Second, charging BEBs takes considerably longer than refueling ICEBs. Third, FCEBs are very expensive by comparison and lack large-scale market testing and insight. BEBs currently fall in between these two bus types. Finally, electricity generation is unreliable and electricity storage is cost-prohibitive. Additionally, while not a challenge, altering the bus fleet presents an opportunity to lessen the exposure to GHGs for communities already exposed to high levels of transit emissions. This section addresses these multiple issues.

2.1 Range and Logistics Challenges with BEBs

BEBs have been very popular in California, with large transit agencies such as San Francisco Metropolitan Transit Authority (SFMTA) and even smaller ones like Foothill Transit adopting the technology. Maintenance costs for BEBs are lower than those for ICEBs, and BEBs do not produce harmful tailpipe emissions. However, the BEB range is very limited compared to ICEBs. Manufacturers advertise ranges close to or over 200 miles per charge, while transit agencies that currently operate BEBs report a true range between 100 and 150 miles. In comparison, ICEBs can get over 300 miles per tank.[26]

Two technologies exist for battery charging:

- **En-route charging:** Buses can be quick-charged en-route, often using an overhead pantograph (*Figure 2.1*). The pantograph is the link between the bus itself and the power source. En-route pantograph chargers can charge buses in short 3–6-minute intervals.[27] Transit agencies often schedule the charging to occur when the bus operator is taking a break. A pantograph can automatically come down from the power source and connect to the bus. This technology allows buses to remain in operation longer, as they do not need to re-charge at the bus yard. The primary constraint is that transit agencies must own land along their routes to place the chargers. Since GTrans does not own any land along their routes (except for their bus facility), this option is not feasible.

[26] This number was quoted to us by various transit agencies during interviews.
[27] ABB. Pantograph down for electric buses. Accessed April 7, 2021. Retrieved from https://new.abb.com/ev-charging/products/pantograph-down.

Figure 2.1: An LA Metro bus charging at a pantograph charger

- **Depot charging:** Buses can also be charged at their depot, before and after their operation hours. The time required for charging differs among buses but takes several hours, considerably longer than refueling for ICEBs and FCEBs, which can get their tanks filled up in 20 minutes. BEBs must also be immobile during that time. As a result, transit agencies must find a way to provide the same quality of service they provided before, while taking into account the time needed to charge buses. Additionally, as we describe later in this report, overnight, on-site staff often must be available to plug in and unplug buses and rotate them in and out of the appropriate charging stations.

2.2 High Cost of FCEBs

The second zero-emission technology consists of hydrogen FCEBs. In a hydrogen fuel-cell bus, the engine separates hydrogen molecules and creates a constant flow of electricity, as long as there is fuel. The advertised range for hydrogen FCEBs is similar to ICEBs, averaging 300 miles per tank.[28] The refueling process takes less than 20 minutes as opposed to the several-hour charge time for depot-charged BEBs. As such, buses can be used continually, without having to wait for them to be charged. However, FCEBs are considerably more expensive than any other technology currently available. In addition to the bus' cost, the supply of hydrogen, whether on-site or off-site, remains very new and requires significant upfront costs. *Table 2.1* compares the costs for a BEB fleet and an FCEB fleet for AC Transit. The scenario assumes a one-to-one replacement ratio per fossil-fueled bus replaced by a ZEB. According to this data, transitioning to an all-BEB fleet will cost $1,949,365,265, including fleet, infrastructure, fuel, and maintenance costs; transitioning to an all-FCEB fleet with the same replacement ratio would cost $2,496,817,760. Based on 2019 bus-blocks and routes,

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[28] This number was quoted to us by various transit agencies during interviews (*Appendix B*)

GTrans will be able to use a one-to-one replacement ratio for BEBs. As a result, and as illustrated by the table, FCEBs would be more expensive than BEBs, both in terms of bus costs and infrastructure costs, without improving GTrans' service capabilities.

Table 2.1: Transition Costs per Scenario, AC Transit[29]

	Baseline	2b: All BEB	3b: All FCEB	4: Mixed Fleet
Fleet	$567,845,000	$789,310,000	$1,024,560,000	$906,635,000
Infrastructure	–	$176,231,508	$45,220,000	$176,231,508
Fuel	$321,283,074	$284,587,189	$418,122,230	$363,900,134
Maintenance	$747,680,824	$699,236,568	$1,008,915,529	$886,537,380
Totals	**$1,636,808,899**	**$1,949,365,265**	**$2,496,817,760**	**$2,333,304,022**

2.3 Complexity of Power Generation and Storage

In addition to technological challenges, GTrans expects difficulties with its power source. Budgets become unpredictable because of variable electricity rates. The threat of blackouts looms large for transit operators who may realize that none of their buses are charged as a new day dawns. Additionally, transit agencies that are exploring green renewable energy may find that their entirely ZEB fleet may not even be that green if the electricity powering their buses is not produced sustainably.

As a result, GTrans, like many other transit agencies, are looking to have solar panels installed on their lot to provide some safety and predictability. In theory, the electricity generated from the solar panels could subsidize the electricity taken from the grid, thus lowering energy costs. GTrans could use solar energy to power batteries, which would provide valuable charging capacity in the event of a blackout.

However, there are several complexities with transit agencies' plans to generate solar power and leverage battery storage. First, solar panels are not as reliable as getting electricity through the common grid, especially during the night when solar panels do not generate electricity while buses need to be charged. Second, large-scale battery storage is expensive, and the limited capacity of solar generation often means that battery storage is not worth the investment for small transit agencies. In fact, in its history of conducting feasibility studies for its transit clients, SCE has yet to recommend

[29] Alameda Contra Costa Transit District. (2020). *Zero-Emissions Bus Rollout Plan: Version 1.* Alameda Contra Costa Transit District.

battery storage to any agency.[30] However, not many transit agencies' yards have the same square footage availability and SCE is open to discussing this option with GTrans.

As such, GTrans will probably use solar panels to offset its electricity bill with SCE and explore various avenues to monetize its solar generation – from net-metering to power purchase agreements (PPAs). Net-metering simply requires an understanding with the utility company to deduct from the electricity bill based on how much solar is fed back onto the grid. This agreement is how most residential roof-top solar owners save on their electricity bills. A PPA is more complex and requires a company to negotiate with the utility to buy the electricity generated by solar on GTrans' lot.[31] The more cost-efficient avenue depends largely on the amount of energy that GTrans will be able to generate from its solar arrays, something that GTrans can only ascertain with follow-on feasibility studies (to be discussed later in this report).

2.4 Equity Opportunity

Air pollution disproportionately affects low-income and other historically disadvantaged communities.[32] Since zero-emission vehicles are part of the solution towards healthier and more equitable communities, GTrans's ZEB transition will improve outcomes for underserved neighborhoods.

According to the California Office of Environmental Health Hazard Assessment, several parts of the City of Gardena are designated disadvantaged communities based on pollution burden and population characteristics.[33] This report identifies disadvantaged communities in the GTrans service area at the census tract level, providing a visual representation of which lines go through the most disadvantaged communities. Most ZEB rollout plans use a phased approach and some grants, such as the Transit and Intercity Rail Capital Program, require agencies to provide evidence that their projects benefit disadvantaged communities.[34] If GTrans applies to this grant or a similarly structured one, they can reuse this information or methodology.

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[30] According to a 2021 interview with SCE (*Appendix B*).
[31] United States Environmental Protection Agency. (2021, April 13). *Solar Power Purchase Agreements* . Retrieved from Green Power Partnership. Retrieved from https://www.epa.gov/greenpower/solar-power-purchase-agreements
[32] Hajat A, Hsia C, O'Neill MS. Socioeconomic Disparities and Air Pollution Exposure: a Global Review. Curr Environ Health Rep. 2015 Dec;2(4):440-50. doi: 10.1007/s40572-015-0069-5. PMID: 26381684; PMCID: PMC4626327.
[33] California Office of Environmental Health Hazard Assessment, SCalEnviroScreen 3.0, June 2018. RetrCalifornia Office of Environmental Health Hazard Assessment, SCalEnviroScreen 3.0, June 2018. Retrieved from https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30ieved from https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30
[34] California State Transportation Agency, Transit and Intercity Rail Capital Program April 2020. Retrieved from https://calsta.ca.gov/subject-areas/transit-intercity-rail-capital-prog

CalEnviroScreen reports data at the census tract level.[35] Its formula for determining the disadvantaged communities score considers both pollution burden, an average of exposures and environmental effects, and population characteristics, which is itself an average of sensitive populations and socioeconomic factors.[36] Pollution Burden is based on ozone concentrations, PM (particulate matter) 2.5 concentrations, diesel PM Emissions, drinking water quality, pesticide use, toxic releases from facilities, traffic density, cleanup sites, groundwater threats, hazardous waste, impaired water bodies, and solid waste sites and facilities.[37] Population Characteristics are based on cardiovascular diseases, low birth-weight births, asthma emergency department visits, educational attainment, linguistic isolation, poverty, unemployment, and housing-burdened low-income households.[38]

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[35] California Office of Environmental Health Hazard Assessment, SCalEnviroScreen 3.0, June 2018. Retrieved from https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30

[36] Ibid.

[37] Ibid.

[38] Ibid.

Chapter 3

METHODS

3.1 Data Sources

To reliably assess the current landscape of available ZEB technologies, as well as the various components involved in a ZEB fleet transition, we collected and made use of data from the following sources:

- Literature review.
- Manufacturer interviews.
- Transit agency interviews.
- Utility interviews.
- Secondary data from GTrans, other agencies, and manufacturers.

To assess the most effective ZEB technologies for GTrans, we analyzed the data in four general categories. *Table 3.1* outlines the four areas used to determine ZEB technologies associated with an effective ZEB fleet transition, the data sources used to help us understand them, and a description and detail of the data.

Table 3.1: ZEB Fleet Transition Area and Associated Data Sources

Area	Data Source(s)	Description	Detail
GTrans' Current State	• Agency interviews • Secondary data • Utility interviews	• Approximately 25 meetings with GTrans • Approximately three interviews with Southern California Edison	GTrans data, including bus routes, mileage, operational and spatial constraints, as well as general fleet data.
Background for ZEB Technologies	• Literature review • Academic study review	• 5 key academic studies • Approximately 40 studies, assessments, and reports (*Appendix E)*	Literature review topics include: BEBs, FCEBs, chargers, batteries, transportation equity, fleet management, and relevant policy pertaining to ZEBs. Academic studies pertaining to battery life, range and energy needs, chargers, hydrogen fuel efficiency and cost-modeling.
ZEB Technology Options and Associated Variables	• Manufacturer interviews • Secondary data	• Approximately five interviews with ZEB manufacturers • Approximately six interviews with BEB charger manufacturers	ZEB manufacturer specifications, including mileage, cost, battery life, warranty, energy needs, and reliability. BEB charger specifications.
Insights from Other California Transit Agencies	• Agency interviews • Agency ZEB rollout plans	• Approximately 11 interviews with California transit agencies • Review of 15 existing ZEB rollout plans from large and small California transit agencies	Assessment of constraints and obstacles encountered during/after the ZEB transition for other California transit agencies.

GTrans' Current State

The most crucial GTrans data are current fleet composition, route analysis, and existing infrastructure. The current fleet composition informs us of the agency's future ZEB needs by providing information on the length, propulsion system, and estimated retirement of the buses. The route analysis provided us with the range requirements for each GTrans bus, which informs our recommendation for GTrans's ZEB fleet technology needs. We also used the route analysis to ensure ZEBs are deployed equitably in GTrans' service area. Current infrastructure includes information on the operations and space limitations of the GTrans bus yard, as well as grid and solar infrastructure.

ZEB Technology Options and Associated Variables

We used ZEB manufacturer specifications to collect information on costs of buses, battery charging times, and maximum distance traveled on a single charge. This information helped us understand the types of vehicles that could work for GTrans' service area and operations. BEB procurement necessitates BEB charger procurement. Thus, we use BEB charger manufacturer specifications, collected from manufacturer interviews to understand kW output potential, costs per unit, charger dispensers, connection/cable types, warranties, and other preferred certifications. Charger information helped us understand the menu of fueling and charging infrastructure that could work for GTrans' service area and operations.

Insights from Other California Transit Agencies

Many California transit agencies have already submitted ZEB rollout plans to CARB. Each agency faces different operational and technological constraints, and we interviewed contacts to understand the methodology they used to address these constraints. These rollout plans and interviews also proved valuable in helping us understand how other agencies managed the limited range of BEBs, the equitable rollout of ZEBs, and how they address the rapidly evolving ZEB technology. Additionally, these conversations helped us explore the potential funding opportunities available to GTrans for this project and provided us with examples of how other agencies have addressed the infrastructure and workforce components of a ZEB transition.

Background for ZEB Technologies

To gain crucial background and context for the rollout and implementation of ZEB fleets locally, nationally, and internationally, we conducted an informal literature review. We reviewed various academic studies, assessments, and reports that focused on the development of ZEB technology, cost estimates and implementation evaluations. While a complete list of articles is included in *Appendix E*, *Table 3.2* below outlines the most important articles and key takeaways.

Table 3.2: Key Academic Articles to Provide Background and Context to ZEB Implementation

Article Reference	Key Takeaways
Aikaterini Deliali, Dany Chhan, Jennifer Oliver, Rassil Sayess, Krystal J. Godri Pollitt & Eleni Christofa (2020): *Transitioning to zero-emission bus fleets: state of practice of implementations in the United States*, Transport Reviews, DOI: 10.1080/01441647.2020.1800132	This article examines BEB and FCEB implementations nationwide and gives a high-level overview of costs, efficiency and performance. It identifies four key elements of success in implementing a ZEB fleet: correctly identifying the fleet size, picking a technology type that works for an agency's unique needs, properly training staff on new technologies, and effectively collaborating with stakeholders (such as the public utility) to ensure that no problems arise.
Jing-Quan Li (2016) *Battery-electric transit bus developments and operations: A review*, International Journal of Sustainable Transportation, 10:3, 157-169, DOI: 10.1080/15568318.2013.872737	This article gives a history of battery technology to power vehicles and highlights the ongoing trend of battery storage getting cheaper and more space efficient year-upon-year. It also identifies the key problem with BEBs as their limited range, despite having better fuel efficiency than ICEBs. The article studies three "range remedy methods:" having fully charged back-up vehicles, battery swapping, and fast opportunity charging mid-route.
Melaina, M., & Penev, M. (2013, September). *Hydrogen Station Cost Estimates: Comparing Hydrogen Station Cost Calculator Results with other Recent Estimates*. National Renewable Energy Laboratory.	Although this report is from 2013, it provides a useful overview of all of the price elements of building a hydrogen station, from its capacity to its utilization and average output. It also offers a useful framework for estimating hydrogen station capital and variable costs by type of station: gaseous or liquid hydrogen truck delivery, or onsite generation via a steam methane reformer or electrolysis.
The Hydrogen Council, McKinsey & Company, & E4tech. (2020, January). *Path to Hydrogen Competitiveness: A Cost Perspective*. The Hydrogen Council.	Currently, the price of hydrogen fuel and infrastructure is very high, with many transit agencies and manufacturers betting on the market forces reducing the cost in the coming years. It can be difficult to navigate various stakeholders' predictions on the hydrogen market without a proper understanding of what drives it and what is needed to stabilize it. This report explains the elements of the hydrogen supply chain and vehicle manufacturing, providing a pathway for costs to reduce up to 80 percent through various scale-up scenarios: strong government investment, policy alignment from the federal to the local level, and market creation in other

	industries like heating and airline refueling. While this report does not finally recommend an FCEB option given the current costs, the 15-year time-horizon for implementation may see hydrogen becoming a viable technology option for GTrans. To that end, we provide background on hydrogen fuel in this report. The article authored by the Hydrogen Council provides an in-depth analysis of the signs that GTrans may look for to start investing in hydrogen.
Euby, L., Prohaska, R., Kelly, K., & Post, M. (2016, January). *Foothill Transit Battery Electric Bus Demonstration Results*. National Renewable Energy Laboratory. LeCroy, C., & Scott, C. (2019, July). *GTrans Zero-Emission Repower Bus Project*. CALSTART.	These two cited evaluations for actual implementations of BEBs (one at Foothill and one at GTrans itself) provide a post-mortem and valuable lessons-learned from initial implementations and pilots of BEBs. While they do not involve the sort of calculations that would involve transitioning an entire fleet (like those estimated in this report), they do provide an overview of the variables that must be tracked as the fleet is transitioned bit-by-bit, to ensure that costly miscalculations are avoided before they arise.

3.2 Methodology

This report aims to unify various data sources to create an estimation model that will inform GTrans' path to a fully zero-emission fleet by 2035. We present our findings in digestible tables representing technology options for buses and chargers, their numbers and costs. To that end, we used the GTrans route data to understand the agency's current requirements. We then applied the ZEB manufacturer specifications, academic articles, and other agencies' ZEB rollout plans and interviews to create a framework of how GTrans can successfully transition their fleet to ZEBs.[39]

Using the current GTrans service schedule, we confirmed the total mileage required of the GTrans bus fleet. Rather than accepting estimates provided by GTrans, we manually calculated the distance traveled for weekend, weekday, and school day services by inputting the GTrans bus paddles (an internal bus route that includes non-passenger loading stops) into Google Maps.

From there, we calculated how many buses were needed to meet that demand based on the range of each bus type included in our evaluation. The range was determined by assuming buses would return to the GTrans bus yard with 10 percent state of charge

[39] *Appendix B* illustrates the agencies we interviewed and ZEB rollout plans we used to inform our analysis.

(SOC) and averaging the mileage provided by the bus manufacturer and reported ranges from transit agencies across California. We also assumed that any bus with at least 2/3rds capacity remaining in its range had a surplus of available service miles and could theoretically continue being deployed.

Our outputs included a low, medium, and high estimate for fleet size because of these assumptions. Of course, the necessary fleet size varies by bus type. Knowing the necessary fleet size for each bus type, we calculated the costs for purchasing and fueling each option. Of note, each bus manufacturer includes or offers a standard warranty with each bus purchase, and our analysis weighs the warranty associated with each bus type evaluated. We completed the same steps for each bus type, including BEBs and FCEBs.

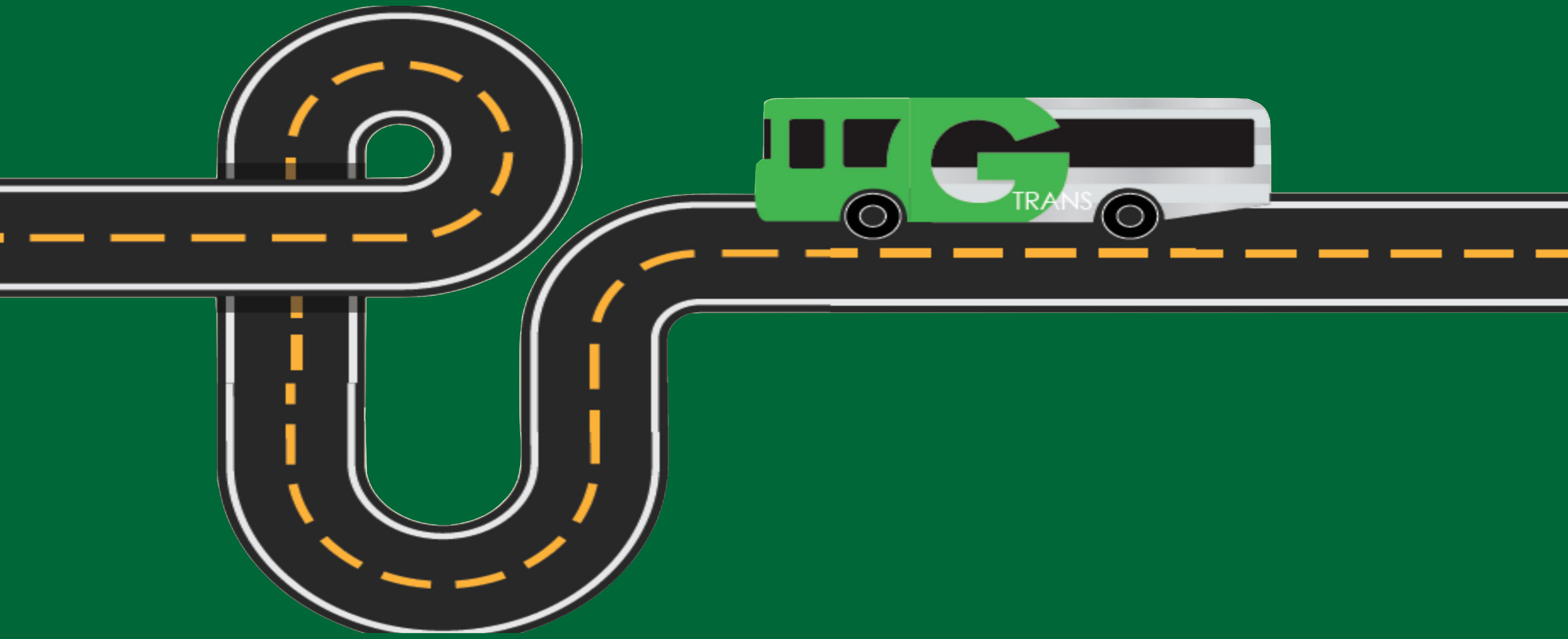
Next, we used our bus fleet and mileage estimates, as well as charger manufacturers' specification information, to inform our recommendations. We did not adjust any of the information received from the charger manufacturer and accepted their estimates as is. The final step is approaching SCE with an estimate of GTrans' electricity needs based on GTrans' future BEB fleet size and mileage. We also apply any filters to SCE's determination of GTrans' electricity rates and grid capacity. Altering any of the information included in our calculation, such as bus range or total mileage required of the GTrans bus fleet, changes GTrans' electricity needs, which may alter SCE's determination.

In summary, the methodology follows five main steps:

1. Determine the agency's total daily mileage.
2. Use BEB range to determine necessary fleet size.
3. Calculate the cost of the entire fleet per bus type and electricity need.
4. Narrow charger options based on bus selection.
5. Approach SCE to finalize infrastructure upgrades.

Chapter 4

EVALUATION



The primary criterion for comparing various fleet and charger options is the total cost. To that end, different costs will be estimated in three categories:

- Cost of buses
- Cost of chargers
- Cost for fuel (for daily operation).

Capital investments and regularly occurring operational costs associated with buses, chargers, and fuel shall be outlined in their respective sections.

4.1 Relevant Variables

As stated earlier, our analysis aims to discern how GTrans can manage its fleet transition efficiently. It is not enough to maximize cost-efficiency with solely the new buses themselves. Focusing only on the cheapest bus option ignores other critical issues such as energy use and fuel costs, warranties that save on maintenance and battery replacement, capital infrastructure investments, and more. Often, a more expensive bus option can lead to savings years later. Fewer batteries must be replaced at the operator's expense, less infrastructure needs to be upgraded, and operational changes become more seamless.

To weigh decisions on various procurement options for transition to zero-emissions within its bus fleet, our analysis focused on estimating costs along with the following categories:

- Total buses needed in the new fleet.
- Costs of daily operation:
  - Daily fuel costs
  - Daily maintenance costs
- Costs incurred at the time of procurement:
  - Cost of purchasing the fleet ("fleet costs")
  - Cost of the warranty plan
  - Cost of chargers
  - Cost of training drivers and mechanics in new bus technology
- Capital investments needed:
  - Costs of infrastructure associated with chargers ("charger infrastructure").
  - Costs of infrastructure related to fuel ("fuel infrastructure").

Table 4.1 summarizes the input variables that are used to estimate the costs, their sources and high-level methodology.

Table 4.1: Input Variables to Estimate Costs

Cost	Input Variable(s)	Definition
Buses Needed	Range per bus	The total miles a bus travels on a fully charged battery (for BEBs), or on a full tank of hydrogen fuel (for FCEBs).
	Miles per bus-block and total miles driven by GTrans buses at peak.	The predetermined path a bus drives every day is called a "bus-block." It may have multiple drivers, service numerous lines, or spend some of the day in a parking lot before going back into service. Regardless, a bus-block refers to the path of a single bus on a single day. A bus-block is not a purely exogenous variable. Bus-blocks may be recut depending on the operational needs of the transit agency. The sum of all the miles in all of the bus-blocks is the total miles driven by GTrans' buses at peak (see *Appendix F*.) Currently GTrans' total service at peak covers 6,467.8 miles (used for calculations).
Daily Fuel	Power/fuel rate	For BEBs, this is the price of electricity. Utility companies charge a certain number of cents per kWh of consumption of energy. The rate changes depending on the time of year (summer or winter), day of the week (weekend or weekday), time of day (off-, mid-, and on-peak) and demand on the grid. Off-peak is the cheapest rate and usually runs from midnight to 4:00 am. See *Appendix C* for electricity tariff rates for electric vehicle charging. For more background on electricity rates, refer to p.13-15. For FCEBs, this is the price of hydrogen fuel ("hydrogen"). Like gasoline, the price of hydrogen – measured in price per kilogram (kg) – fluctuates over time (days and weeks), but there is no surcharge for fueling at a specific time of day.
	Battery efficiency rate	For BEBs in kWh per mile, this is how much energy is consumed by the battery for every mile the bus travels.
	FCEB efficiency rate	Often reported as miles per kg. To compare to kWh per mile, we take the inverse of miles per kg and get kg per mile, the amount of fuel needed for a mile of travel.
Capital	Current grid capacity	While not strictly an input variable, it is a crucial constraint. Electric grids are serviced by substations that can only handle the delivery of a set amount of electricity. To exceed the current grid capacity, the agency or the power utility would need to invest in costly infrastructure. This report does not explore current grid capacity, as that information is proprietary to SCE, GTrans' utility. This report is instead structured to give GTrans the calculations they need to approach SCE for a method of service study to evaluate current grid capacity.

The purpose of this model is not to provide exact estimates for any of the metrics, particularly predicted over 15 years. Such an endeavor would require a longitudinal study that would make the report useless to the timeline in which the decisions are being made. Additionally, the input variables themselves are ranges. For example, while a BEB manufacturer may have an advertised range per bus on a full charge (itself advertised as a range), once a bus is put in service, that range will shift. Local climate, traffic, elevation, even how hilly some lines are as opposed to others, all contribute to a shift in the actual range of a fully charged BEB. Some agencies have experienced longer mileage than advertised; many, less. Therefore, we have attempted to find reasonable ranges for each input variable to give range estimates for our outputs. Sources for our estimates for input variables are outlined in *Table 4.2*.

Table 4.2: Sources for Input Variable Estimates

Input Variable	Source(s)	Detail
Power/Fuel Rate	• Southern California Edison	See *Appendix C* for current ZEV charging tariffs.
Battery Efficiency Rate	• Stakeholder Interviews • Manufacturer Estimates	Several California transit agencies have been using BEBs and FCEBs for many years already. Their stated ranges have been combined with manufacturer estimates, and several studies pertaining to battery efficiency and range for BEBs to provide the estimates used in this report.
Range per Bus		
Total Miles in Bus-Block	• GTrans	The 2019, pre-pandemic bus-block and schedule was used to provide estimates more accurate to post-pandemic service. Google Maps was used to calculate the miles traveled for each bus-block.
Current Energy/Fuel Capacity	• Southern California Edison	This report does not explore current grid capacity because it is beyond the scope of the research institution. However, background on grid elements and the process of implementing charger infrastructure are explained in relevant sections of this report. GTrans will have to approach SCE with final fleet size and charger needs for them to conduct a method of service study to understand needed grid improvements. This report provides the calculations needed to get the method of service study process started with SCE.

4.2 Cost of Buses

Methodology for Calculating Fleet Cost and Daily Fuel Cost Estimates

For each bus model, we found a low, middle, and high estimate for the fleet size. The low and high estimates are based on the best- and worst-case scenario for ZEB transitions under current conditions, and give a range within which the actual fleet size will fall. For cost calculations, we use the middle estimate, which we believe is the most accurate.

As an example of our methodology, we use two battery options – 160 kWh and 388 kWh – of the New Flyer XE40 BEB (2019) on Line 1 to demonstrate how we estimate fleet size. This is a 40-foot bus model that comes with five battery capacity options. The larger the battery capacity, the longer the range of the bus. However, larger battery capacity means a larger battery, which adds weight and diminishes efficiency.[40] *Table 4.3* outlines the input variables and costs associated with the bus model and battery options (all sourced from the manufacturer unless otherwise noted) and bold text indicates the options shown in our example.

Table 4.3: Costs and Input Variables for the New Flyer XE40 BEB (2019)

Battery Energy Capacity (kWh)	Range (mi)	Cost of Bus ($)	Efficiency Rate (kWh/mi)[41]
311 (standard)	131	$ 741,768	2.4
160	**61**	**$ 693,757**	**2.4**
213	74	$ 729,168	2.4
388	**165**	**$ 791,583**	**2.4**
466	196	$ 828,091	2.4

Low Estimate

Summing the miles for each bus-block yields the total operating miles per day. *Appendix F* illustrates the number of miles per bus-block and the total miles served daily (6,467.8 miles). Dividing the total operating miles per day by the range of each ZEB

[40] In an interview with New Flyer, the manufacturer reported the efficiency is constant across battery sizes. We know this is infeasible because larger batteries are heavier and therefore have less efficiency. This was confirmed in interviews with other manufacturers and transit agencies, but we have no other way of acquiring this information. As a result, we must use a constant efficiency across all New Flyer BEB options.

[41] Sourced from the AC Transit ZEB rollout plan.

option gives us the low estimate of the number of buses needed for that bus option. *Table 4.4* shows this calculation for the two example options on Line 1.

Table 4.4: Low Estimate for XE40 on Line 1

Bus Option	Total Miles	Range	Low Estimate
XE40 BEB 160kWh	1248	61	**21**
XE40 BEB 388kWh	1248	165	**8**

The actual fleet size will always be more than the low estimate for two reasons:

1. Transit agencies will have inefficiencies in how they cut bus-blocks, for which the calculation of the low estimate does not account.
2. Since the number of buses in service fluctuates throughout the day, some buses are only used for a portion of the day and do not use up their entire range.

Nevertheless, the low estimate is illuminating because it provides a baseline under which the fleet size may never cross.

High Estimate

We found a high estimate of the buses needed by assuming a ZEB can only serve one current bus-block. To calculate this estimate, we first divided the miles in a bus-block by the range and rounded up to yield the number of buses needed for that bus-block. The sum of the number of buses needed for each bus-block gives us the high estimate of buses needed for the fleet. *Table 4.5* provides an example of how we calculated the high estimate for Line 1, using the same two bus options.

Table 4.5: High Estimate for XE40 on Line 1

		New Flyer XE40 BEB (2019)	
Bus-Blocks		160kW Battery (Range 61 mi)	388kWh Battery (Range 165 mi)
Bus-Block ID	Estimated Miles	Buses Needed (High)	Buses Needed (High)
1-1	261	5	2
1-2	218	4	2
1-3	260	5	2
1-4	388	7	3
1-5	120	2	1
Totals	1248	23	10

The actual fleet size will always be lower than this estimate because it assumes buses can only serve one *current* bus-block each, and that GTrans would not use a bus to serve two different bus-blocks. For example, if two current CNG buses each traveled 100 miles a day and the BEB's range was 90 miles, this estimate would say we need four buses to cover the bus-blocks when in actuality three would suffice.

Similar to the low estimate, the high estimate (while never being approached) is illuminating. The difference between the high estimate and the middle estimate may be thought of as a rough measure of inefficiency in how bus-blocks are cut.

Middle Estimate

We used the high estimate to create a realistic, middle estimate for the ZEB fleet's size per bus option. The first step was to calculate the range of miles leftover in each bus after they complete their assigned bus-block, which we call "surplus miles." The sum of each bus' surplus miles gives us the total surplus miles of the fleet for each bus option. A bus with enough capacity left over after running its scheduled service could be sent out to cover a portion of another bus-block (recall that not accounting for this is the reason the high estimate is unrealistic). According to GTrans, a bus can be sent back out into the field if it has more than two-thirds capacity remaining. For example, a bus with a 150-mile range would be sent back out if it had more than 100 miles remaining on its charge. Therefore, a more meaningful estimate is usable surplus miles, defined as the surplus miles of buses with more than two-thirds capacity. *Table 4.6* shows the surplus miles and usable surplus miles for our two example options.

Table 4.6: Surplus Miles for XE40 on Line 1

Bus-Blocks		New Flyer XE40 BEB (2019)					
		160kWh Battery (Range 61 mi)			388kWh Battery (Range 165 mi)		
Bus-Block ID	**Estimated Miles**	**Buses Needed (High)**	**Surplus Miles**	**Usable Surplus Miles**	**Buses Needed (High)**	**Surplus Miles**	**Usable Surplus Miles**
1-1	261.2	5	43.3	43.3	2	69.4	0
1-2	218	4	25.6	0	2	112.6	112.6
1-3	259.9	5	44.6	44.6	2	70.7	0
1-4	388.3	7	38	0	3	107.6	0
1-5	120.3	2	1.5	0	1	45	0
Totals	1247.7	23	153	87.9	10	405.3	112.6

We divide the usable surplus miles by the bus range to get the estimate of excess buses. We then subtract the excess buses from the high estimate. This calculation gives us a realistic, middle estimate of the BEB bus fleet. *Table 4.7* shows the excess buses and middle estimate for our example.

Table 4.7: Middle Estimate of Buses Needed for GTrans' Line 1

	New Flyer XE40 BEB (2019)	
Bus Estimates	160kWh	388kWh
High estimate	23	10
(Excess Buses)	2	1
Middle Estimate	**21**	**9**

Cost Evaluation for Fleet Options

As a small transit agency, GTrans will rely on purchasing pre-approved buses via an existing statewide RFP, rather than enter into a costly and labor-intensive bidding process on its own. Therefore, they may choose between three bus manufacturers: New Flyer, Proterra, and Gillig. New Flyer offers both BEB and FCEB options, while Gillig and Proterra only sell BEBs. *Tables 4.8*, *4.9*, and *4.10* show New Flyer's five BEB options (each with different ranges and costs) and one model of FCEB, Proterra's two BEB options, and Gillig's recommended BEB option, respectively. Proterra and Gillig provided us with a high and low estimate for range, and we list the midpoint of this span. New Flyer only reported a maximum range estimate. For consistency, we reduced the range for all New Flyer's options by 13 percent, which was the average difference between the midpoint and high range estimates across the other manufacturers.

Table 4.8: New Flyer Procurement Options

	XE40 BEB (2019)					**XHE40 FCEB (2019)**
Battery Size	160 kWh	213 kWh	311 kWh	388 kWh	466 kWh	100kWh + FCEB
Cost	$693,757	$729,168	$741,768	$791,583	$828,091	$1,014,979
Efficiency (kWh/mi)	2.4	2.4	2.4	2.4	2.4	0.12
Range (mi)	61	74	131	165	196	300

Table 4.9*:* Proterra Procurement Options

	BEB	
Battery Size	440 kWh	660 kWh
Cost	$749,000	$847,000
Efficiency (kWh/mi)	2.15	2.35
Range (mi)	198	275

Table 4.10: Gillig Procurement Options

	BEB
Battery Size	444 kWh
Cost	$827,500
Efficiency (kWh/mi)	2.05
Range (mi)	165

Tables 4.11, *4.12*, and *4.13* show the results of our low, middle, and high estimates using the methodology described in the previous section. Many of these estimates are lower than the actual number of buses in GTrans' fleet (52). We showed these estimates for comparison purposes. But in reality, Gardena must have enough buses to cover its peak vehicle requirement (PVR), or the maximum number of vehicles in service at one time, as well as its reserve buses. GTrans' pre-pandemic PVR was 43,

shown in *Appendix F*. The Federal Transit Administration allows transit agencies to have 20 percent more buses than their PVR.[42] Transit agencies call this extra allowance the spare ratio. We added 20 percent to each estimate (low, middle, and high) to account for the spare ratio. The minimum buses for GTrans' ZEB transition is 52 (43 PVR plus nine spare ratio).

Table 4.11: New Flyer ZEB Fleet Size Estimates

	XE40 BEB (2019)					**XHE40 FCEB (2019)[43]**
Battery Size	160 kWh	213 kWh	311 kWh	388 kWh	466 kWh	100 kWh + hydrogen fuel-cell
Low Estimate	131	108	62	50	41	
Middle Estimate	149	123	72	58	50	52
High Estimate	162	136	94	84	76	
Efficiency (kWh/m or kg/m)	2.4	2.4	2.4	2.4	2.4	0.12

Table 4.12: Proterra ZEB Fleet Size Estimates

	ZX5 Catalyst E2	
Battery Size	440 kWh	660 kWh
Low Estimate	41	30
Middle Estimate	48	41
High Estimate	76	59
Efficiency (kWh/m)	2.15	2.35

[42] Federal Transit Administration. Spares Ratio. Accessed April 7, 2021. Retrieved from https://www.transit.dot.gov/funding/procurement/third-party-procurement/spares-ratio.
[43] We assume a one-to-one replacement ratio for FCEB. Thus, the high or low estimates are not relevant.

Table 4.13: Gillig ZEB Fleet Size Estimates

	40' buses
Battery Size	444 kWh
Low Estimate	50
Middle Estimate	58
High Estimate	84
Efficiency (kWh/m)	2.05

The yearly fuel cost for each bus option is a function of the daily fuel costs, which we calculate by multiplying costs of power or fuel (per kWh of electricity and per kg of hydrogen) by the bus efficiency (kWh per mile for BEBs and kg per mile for FCEBs). The electricity costs vary by time of year. The estimated summer and winter rates for electricity and the average hydrogen costs are shown in *Table 4.14*. Both electricity rates include a 3.6¢ per kWh charge for taxes and fees, which Long Beach Transit, an SCE customer, estimated in 2020.[44] For simplicity, we assume SCE allocates summer and winter dates equally. To calculate the annual electricity costs, we multiply the daily fuel costs for summer and winter by 182.5 (half of 365) and sum up both seasons. To calculate the annual hydrogen cost, we multiply the daily fuel costs by 365.

Table 4.14: Fuel Rates[45]

	Cost per kWh or kg
Electricity Summer Off-Peak	$0.12682
Electricity Winter Off-Peak	$0.10433
Hydrogen[46]	$7.40

[44] Federal Transit Administration. Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses. April 2020. Retrieved from https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-05/FTA-Report-No.-0163.pdf.

[45] The electricity rates are provided by SCE and we assume all buses are charged during off-peak times. The rates include a $.036 per-kWh estimate for taxes and fees.

[46] The hydrogen rate is provided by Ballard Fuel Cell Systems as an average cost of the different supply methods, observed in different transit agencies.

The tariffs listed here are purely for the consumption of electricity. Normally, there would be a separate tariff based on the demand as well. However, SCE has currently eliminated demand tariffs for electric vehicle charging (see *Appendix C* for the prices reported by SCE).[47]

The list price of each bus option includes base warranties for the propulsion system and energy storage. New Flyer's base propulsion and battery warranties cover two years or 100,000 miles and six years or 300,000 miles, respectively.[48] Proterra's propulsion warranty is one year or 50,000 miles and its battery warranty covers the entire 12-year lifespan of the bus (no mileage cap).[49] Gillig's propulsion warranty covers one year or 50,000 miles and they did not provide us with energy storage warranty information.[50] Each manufacturer offers optional extended warranties. Per GTrans' instructions, we did not include any extended warranty options in our calculations.

We compare the total costs for each procurement option in *Table 4.15*. The table uses the middle estimates described earlier in this section for the number of buses needed. As discussed earlier, GTrans' minimum fleet size is 52 buses. Therefore, for all options that our model estimates less than the minimum, we substitute 52 for the cost calculations. Four options – New Flyer's 466 kWh BEB, New Flyer's FCEB, and Proterra's 440kWh and 660 kWh BEBs – offer a one-to-one replacement ratio. The lowest cost option is New Flyer's 466 kWh bus, which we estimate would cost about $39,000,000 to transition the fleet.

[47] It is very important to note that demand charges may return in the future, and they may more than double the cost of charging a bus fleet. As stated earlier in this report, Long Beach Transit in their 2018 FTA report mentions a total electricity rate tariff of $0.264 per kWh, of which electricity consumption accounted for 25 percent of the price (at $0.066 per kWh), other taxes and fees on the utility bills accounted for 13 percent of the price (at $0.036 per kWh), and the cost for electricity demand accounted for the majority of their at 61 percent or $0.162 per kWh. *Source*: Federal Transit Administration. Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses. April 2020. Retrieved from https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-05/FTA-Report-No.-0163.pdf.
[48] Per email correspondence with New Flyer.
[49] Per email correspondence with Proterra.
[50] Per email correspondence with Gillig.

Table 4.15: Total Lifetime Costs by ZEB Option

	New Flyer XE40 BEB (2019)					New Flyer XHE40 FCEB (2019)	Proterra ZX5 Catalyst E2 (2021)		Gillig
	160kWh Battery	**213kWh Battery**	**311kWh Battery**	**388kWh Battery**	**466kWh Battery**	**100kWh Battery w/ Hydrogen**	**440kWh Battery**	**660kWh Battery**	**444kWh Battery**
Buses Needed	149	123	72	58	52	52	52	52	58
Operation									
Daily Fuel (Summer)	$2,013	$2,013	$2,013	$2,013	$2,013	$5,709	$1,803	$1,971	$1,719
Daily Fuel (Winter)	$1,656	$1,656	$1,656	$1,656	$1,656	$5,709	$1,483	$1,621	$1,414
Annual Fuel	$669,555	$669,555	$669,555	$669,555	$669,555	$2,083,961	$599,810	$655,606	$571,912
Procurement									
Fleet Costs	$103,369,793	$89,687,664	$53,407,296	$45,911,814	$42,729,496	$52,372,900	$38,948,000	$43,705,200	$47,995,000
Training	$119,949	$119,949	$119,949	$119,949	$119,949	$71,312	$0[51]	$0[51]	$0[52]
Total Bus Costs	**$103,489,742**	**$89,807,613**	**$53,527,245**	**$46,031,763**	**$42,849,445**	**$52,444,212**	**$38,948,000**	**$43,705,200**	**$47,995,000**

[51] Training costs are included in Proterra's bus prices.
[52] Training costs are included in Gillig's bus prices.

A Fuel Cell Electric Bus Fleet

Given that the range of FCEBs is similar to ICEBs, we can assume a one-to-one fleet replacement ratio for the New Flyer XHE40 FCEB (2019) model. Thus, we obtain a fleet size estimate of 52 FCEBs (*Table 4.11*). It is important to note that using 52 buses with the current bus-blocks will not fully use the range available. While the concept of surplus miles is not as relevant for FCEBs as it is for BEBs, mainly because refueling an FCEB takes considerably less time, we still give an estimate of the surplus miles with each bus option.

The cost of a new FCEB bus, the training costs, the warranty and maintenance costs, and the fueling costs are shown in *Table 4.16*. Fueling costs include fuel-related infrastructure costs, shown in the next section.

Table 4.16: Procurement Costs for the New Flyer XHE40 FCEB (2019)

Input	Value
New Bus Cost	$1,014,978.69
Training (Operators and Technicians) Costs	$71,312.48
Extended Warranty 3yrs/200K miles	$17,309.76
Extended Warranty 4yrs/200K miles	$18,677.76
Extended Warranty 10yrs/400K miles	$33,680.16
Battery Energy Capacity	100kWh
Range	300 miles[53]
Efficiency	0.12 kg/mile

[53] Quoted from manufacturer.

Infrastructure Needed for Fuel Cell Electric Buses[54]

Hydrogen Supply

To run an FCEB fleet, GTrans needs a reliable supply of hydrogen, as well as infrastructure to safely park and maintain it. Both can be funded through grants, and manufacturers and suppliers have a designated grants team to help GTrans. While the choice of a supply method depends on the fleet size and space available, a total of four options ensure a reliable supply of hydrogen (*Table 4.17*):

- **Off-site generation:** Hydrogen is delivered to GTrans in a compressed gaseous form or liquid form.
- **On-site generation:** GTrans uses an onsite steam methane reformer (SMR) or electrolyzer to generate its own hydrogen fuel.

The two off-site generation supply methods are similar: hydrogen is generated off-site, then trucked out to and stored on the GTrans lot before getting dispensed to FCEBs. Since a liquid tanker truck can transport a larger quantity of hydrogen than a gaseous tube truck, it is more economical to deliver liquid hydrogen.[55] To that end, compressed hydrogen delivery is not shown in this table.

[54] The information in this section has been quoted in an interview with Ballard Fuel Cell Systems. Source: Krueger, S., Truitt, J., & Trujillo, D. (2021). *USA Hydrogen Mobility 2021 - Fuel Cell Electric Coaches for Gardena.* Ballard.
[55] U.S Department of Energy, Office of Energy Efficiency and Renewable Energy. Liquid Hydrogen Delivery. Accessed March 20, 2021. Retrieved from https://www.energy.gov/eere/fuelcells/liquid-hydrogen-delivery

Table 4.17: Hydrogen Supply Options

	Off-site generation	On-site generation	
	Liquid Hydrogen Delivery	Steam Methane Reformer	Electrolyzer
Infrastructure needed	Liquid Storage Tank, Pump & Vaporizer, Compressors, Compressed Storage Tanks, Dispenser	SMR, Compressor, Compressed Storage Tanks,	Electrolyzer, Storage Tanks, Station Modules, Dispensers
Cost per mile	$0.78	$0.31	
Cost per KG of H2	$8.60	$4.36	
Cost per bus	$100,000.00	$200,000.00	
Cost per fleet	$4,900,000.00	$9,800,000.00	$12,600,000 for full-scale
Optimized Footprint	30ft x 60ft for 50 buses	2 x 4,000 sq. ft. for 50 buses	55ft x 45ft for 20 buses
Example	OCTA Station	AC Transit's HyGear – Emeryville, CA	SunLine – Thousand Palms, CA

Contractors would deliver liquid hydrogen through a cryogenic trailer to the GTrans lot, stored in liquid storage tanks, then vaporized and compressed before being dispensed to the buses. To efficiently use this supply method, GTrans needs to acquire liquid storage tanks, a liquid hydrogen pump and vaporizer, compressors, compressed hydrogen storage tanks, and a dispenser. Based on the facilities at the OCTA station, a reliable supply of hydrogen through liquid delivery costs $100,000 per bus. A kilogram of hydrogen will cost $8.60 to produce. A complete installation occupies an area of 30 by 60 feet for 50 buses or 34 by 41feet for 15 buses.[56]

The second kind of supply is through the on-site generation of hydrogen. Hydrogen can be generated using an SMR or an electrolyzer. An SMR generates hydrogen in three steps[57]:

- With a catalyst, methane reacts with high-temperature steam under 3-25 bar pressure, producing hydrogen, carbon dioxide, and carbon monoxide.
- Then, the carbon monoxide reacts with the high-temperature steam and, helped by a catalyst, generates more hydrogen and carbon dioxide.

[56] Krueger, S., Truitt, J., & Trujillo, D. (2021). *USA Hydrogen Mobility 2021 - Fuel Cell Electric Coaches for Gardena.* Ballard.
[57] U.S Department of Energy, Office of Energy Efficiency and Renewable Energy. Hydrogen Production: Natural Gas reforming. Accessed April 6, 2021. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

- Finally, through pressure-swing adsorption, carbon dioxide is removed, leaving pure hydrogen.

To efficiently use this supply method, GTrans needs to acquire an SMR, a compressor, and compressed hydrogen storage tanks. This method is of particular interest for GTrans, as the SMR receives methane from the existing natural gas pipeline. Based on the facilities at AC Transit's HyGear hydrogen plant in Emeryville, CA, a reliable supply of hydrogen through SMR costs $210,000 per bus. A kilogram of hydrogen will cost $4.36 to produce. A complete installation requires an 8,000 square-foot area, though some containers can be stacked to reduce the footprint.[58]

Finally, hydrogen can be generated on-site through electrolysis. Similar to a fuel-cell, an electrolyzer circulates water through an anode and a cathode, generating hydrogen and oxygen. To use this supply method, GTrans needs to acquire an electrolyzer, hydrogen storage tanks, station modules, and a dispenser. Based on SunLine's new facilities in Thousand Palms, CA, a hydrogen plant using electrolysis would cost $12,600,000 for a 20-bus fleet. A complete installation occupies an area of 55 by 45 feet for a fleet of 20 buses.[59]

Choosing the best supply method for an FCEB fleet depends on several factors. While it is the least expensive option, SMR is not 100 percent renewable as it uses natural gas to generate hydrogen. Both the liquid hydrogen delivery and the electrolysis options can be 100 percent renewable, assuming that the delivery trucks used are zero-emission vehicles – likely hydrogen-powered trucks – and that the electricity needed for the electrolysis is 100 percent renewable – likely to be generated through solar panels or wind farms. Additionally, generating on-site enables GTrans to better control costs and allows them to be independent from fuel producers and delivery incidents or delays. It is crucial to keep in mind that each option's footprint is different and will determine the space available to maintain, park, and clean buses.

<u>Maintenance and Parking Infrastructure</u>

As mentioned earlier, hydrogen is a highly flammable and volatile gas, and GTrans must update its maintenance and parking infrastructure to ensure riders' and operators' safety. The required retrofits include increased air ventilation, spark-proof electrical, gas, and infrared detection devices. These retrofits build on the equipment needed for CNG buses, and thus the cost per bay varies on whether the CNG retrofits have been applied. As summarized in *Table 4.18*, without pre-existing CNG retrofits, GTrans will spend $125,000 per bay; with pre-existing CNG retrofits, GTrans will spend $50,000 per

[58] Krueger, S., Truitt, J., & Trujillo, D. (2021). *USA Hydrogen Mobility 2021 - Fuel Cell Electric Coaches for Gardena.* Ballard.
[59] Ibid.

bay. Note that one bay can service 3-4 buses and GTrans' facility houses 14 bays. The total infrastructure cost will once again depend on the fleet size.

Table 4.18: Retrofits for FCEBs

	Pre-existing CNG retrofits	No CNG retrofits
Per bay	$50,000.00	$125,000.00

4.3 Cost of Chargers

Methodology for Calculating Charger Cost

While GTrans may select from three bus manufacturers during each procurement cycle, there is a more extensive menu of charger manufacturers to evaluate. In Foothill Transit's landscape assessment of chargers for BEBs (matrix shown in *Appendix J*), there were 11 manufacturers under review, each with several charger options. Foothill Transit conducted their charger analysis and provided us with their findings. They ranked chargers according to their specifications, warranty, reliability and standards, network, additional services offered by the manufacturer, and pricing. The following manufacturers performed the best in the analysis: Heliox, ABB, BTC Power, and Proterra. While our team contacted all charger manufacturers listed within the Foothill Transit charger analysis, at the time of writing, only six were fully interviewed due to response rate.

When evaluating the available menu of chargers, one must consider agency use-case and constraints:

- GTrans aims for overnight (10:00pm – 4:00am) full-depot charging. That is, all charging is to take place on the property within six hours.
- GTrans prefers charger options that have CCS1 connections (universal charging for BEBs in the United States). They also prefer chargers with Underwriting Laboratories (UL) certification, Open Charge Point Protocol (OCPP), and Buy America compliant. A UL certification indicates that a charger is safe and has passed Occupational Health and Safety Administration testing. OCPP compliance allows for third-party energy management software to be compatible with their chargers. Buy America compliance ensures that GTrans is able to secure funding sources that require procurement products to be made in the United States.
- Additionally, we must ensure that selected chargers are compatible with BEBs with battery capacities that range from 160 kWh to 660 kWh. GTrans does not prefer V2G (vehicle to grid capable charger) to V1G (grid to vehicle only charger) and are thus agnostic toward bidirectional current capability with chargers.
- A final preference noted by GTrans centers on chargers that have multiple connection capability, as multiple connections have less spatial impact on the GTrans lot. However, it should be noted that chargers with multiple connection capabilities often split the available kW output potential, which may extend the amount of time that a BEB spends charging – potentially compromising the window of charging for the entire BEB fleet.

Calculating the number of chargers needed requires knowing the total number of BEBs that GTrans will have in their fleet by 2035, their battery capacity, and the SOC needed when returning to the bus yard. We must also consider each procurement cycle, as outlined in GTrans' *Path to Zero Emissions – Fleet Planning* document (*Appendix K*). This document assumes GTrans will replace its current fleet at a one-to-one ratio with ZEBs. Thus, we must consider each charger option in relation to the variables mentioned above, including charger output (kW), output per dispenser (kW), number of dispensers, and pricing. In sum, we must take into account the following variables:

- Total number of buses by procurement year
- Hours available for charging
- State of charge (SOC)
- Daily Energy Needed to Fully Charge Fleet (kW)
  - $Daily\ Energy\ Needed\ to\ Fully\ Charge\ Fleet\ =\ \#\ buses\ \times\ (battery\ capacity\ \times\ SOC)$
- Charger power needed (kW)
  - $Charger\ power\ needed\ =\ \frac{Daily\ Energy\ Needed\ to\ Fully\ Charge\ Fleet}{hours\ available\ for\ charging}$
- Minimum power needed per dispenser (kW)
  - $Minimum\ power\ needed\ per\ dispenser\ =\ \frac{charger\ power\ needed}{BEB\ battery\ capacity}$
- Charger output (kW)
- Output per dispenser (kW)
- Price per charger

At time of writing, we have interviewed six charger manufacturers: Tritium, Schaltbau E-Mobility, BTC Power, ABB, Proterra, and Rhombus Energy Solutions. While Heliox received a high rating from Foothill Transit, they are not under consideration for GTrans as their chargers are "Opportunity Chargers," which are chargers designed for en-route charging, and GTrans aims for depot-only charging. Schaltbau E-Mobility depot chargers are not UL certified or Buy America compliant, so they are currently not a viable option for GTrans. Furthermore, Momentum Dynamics, Siemens, and ChargePoint have not responded at the time of this writing.

BTC Power, ABB, Proterra, and Rhombus Energy Solutions provided recommendations given GTrans' constraints. Proterra also helped inform our model for determining the number of chargers needed based on agency constraints. Tritium provided information on their chargers; however, they were unable to give a confident launch date, nor were they able to give an estimated price for their recommended charger without an NDA.

There are ten charger options available for consideration in this paper: one option from BTC Power, two options from ABB, two options from Rhombus Energy Solutions, and five options from Proterra. *Table 4.19* illustrates the available procurement options at present. BEB manufacturer, battery capacity, hours available to charge, and SOC are shown in *Table 4.20*. Lastly, the table in *Appendix G* shows the projected number of BEBs by each procurement year according to each BEB option, using the middle fleet size estimates detailed in *Tables 4.11*, *4.12* and *4.13* shown above.

Table 4.19: Available Charger Options[60]

Charger Option	Manufacturer	Model	Dispenser Count	Output (kW)	Output per Dispenser (kW)	Cost	Compliance
BTC 1	BTC	Gen 4 350 kW	2	350	180	$100,000	OCPP, UL, Buy America
ABB 1	ABB	150kW Depot	1	150	150	$75,000	OCPP, UL, Buy America
ABB 2	ABB	150kW Depot	2	150	75	$90,000	OCPP, UL, Buy America
Rhombus 1	Rhombus	60kW EVSE	1	60	60	$31,980	OCPP, UL, Buy America
Rhombus 2	Rhombus	125kW EVSE	1	125	125	$43,367	OCPP, UL, Buy America
Proterra 1	Proterra	150 kW System	1	150	150	$69,400	OCPP, Buy America, Pending UL
Proterra 2	Proterra	150 kW System	2	150	75	$76,900	OCPP, Buy America, Pending UL
Proterra 3	Proterra	250 kW System	1	250	250	$101,100	OCPP, Buy America, Pending UL
Proterra 4	Proterra	250 kW System	2	250	125	$116,100	OCPP, Buy America, Pending UL
Proterra 5	Proterra	1.5 MW System	20	1500	75	$605,700	OCPP, Buy America, Pending UL

Table 4.20: BEB Manufacturer, Battery Capacity, Hours Available to Charge, and SOC

Manufacturer	# of Buses by 2035 (mid est)	Battery Capacity (kWh)	Hours to Charge	State of Charge
Proterra	52	440	6	0.1
Proterra	52	660		
New Flyer	149	160		
New Flyer	123	213		
New Flyer	72	311		
New Flyer	58	388		
New Flyer	52	466		
Gillig	58	444		

The following table illustrates the number of chargers needed for all ten charger options, across various BEB procurement options for the year 2035, when GTrans is expected to have a fully ZEB fleet. In the first row of *Table 4.21*, for example, we consider a scenario where GTrans selects only the 440kWh BEB from Proterra for their entire ZEB fleet. Here, we display the total number of buses for the 2035 procurement year, the daily energy needed to fully charge the fleet, the charger power needed, and the minimum power needed per dispenser. We then calculate the number of chargers needed by dividing the daily energy needed to fully charge the fleet by each charger option's maximum kW output.

As we shall see in the next section, due to smart charging, GTrans will not need to use the daily energy needed to fully charge their fleet. This number is helpful as a guide to

[60] At present, Proterra's UL certification is pending.

understand how much energy is needed to charge every bus from zero charge to full charge every day, which would never happen in an actual day of service. Buses will come back in various SOCs and some buses on shorter routes will not need a full battery. Multiplying the miles a bus runs with its efficiency (as shown in *Tables 4.11-13* and used to calculate daily fuel costs in *Table 4.15*) is a much more accurate measure of how much energy is used daily in kWs.

Additionally, *Table 4.22* shows the total price per charger option across various BEB procurement options. The total price per charger option is determined by multiplying the per-unit cost of each charger (listed in *Table 4.19*) with the corresponding number of chargers necessary for GTrans to procure (listed in *Table 4.21*). Taken together, *Table 4.21* and *Table 4.22* allow GTrans to evaluate each charger option by number (and, in turn, spatial impact) and cost, according to the specific bus option that GTrans opts to procure. Other considerations are detailed in section 5.2 below.

Table 4.21: Number of each Charger Option by Bus Option [61]

Bus & Manufacturer	Year	Total # of Buses	Daily Energy Needed to Fully Charge Fleet (kW)	Charger Power Needed (kW)	Minimum Power Needed Per Dispenser (kW)	BTC Power	ABB 1	ABB 2	Rhombus 1	Rhombus 2	Proterra 1	Proterra 2	Proterra 3	Proterra 4	Proterra 5
440 kWh Bus from Proterra	2035	52	18,954	3,159	60.75	10	22	22	53	26	22	22	13	13	3
660 kWh Bus from Proterra	2035	52	28,431	4,739	91.13	14	32	32	79	38	32	32	19	19	4
160 kWh Bus from New Flyer	2035	149	21,456	3,576	24.00	11	24	24	60	29	24	24	15	15	3
213 kWh Bus from New Flyer	2035	123	23,579	3,930	31.95	12	27	27	66	32	27	27	16	16	3
311 kWh Bus from New Flyer	2035	72	20,153	3,359	46.65	10	23	23	56	27	23	23	14	14	3
388 kWh Bus from New Flyer	2035	58	20,254	3,376	58.20	10	23	23	57	28	23	23	14	14	3
466 kWh Bus from New Flyer	2035	52	21,809	3,635	69.90	11	25	25	61	30	25	25	15	15	3
444 kWh Bus from Gillig	2035	58	23,177	3,863	66.60	12	26	26	65	31	26	26	16	16	3

Table 4.22: Cost of each Charger Option by Bus Option

Bus & Manufacturer	Year	Total # of Buses	BTC Power	ABB 1	ABB 2	Rhombus 1	Rhombus 2	Proterra 1	Proterra 2	Proterra 3	Proterra 4	Proterra 5
440 kWh Bus from Proterra	2035	52	$1,000,000	$1,650,000	$1,980,000	$1,694,940	$1,127,542	$1,526,800	$1,691,800	$1,314,300	$1,509,300	$1,817,100
660 kWh Bus from Proterra	2035	52	$1,400,000	$2,400,000	$2,880,000	$2,526,420	$1,647,946	$2,220,800	$2,460,800	$1,920,900	$2,205,900	$2,422,800
160 kWh Bus from New Flyer	2035	149	$1,100,000	$1,800,000	$2,160,000	$1,918,800	$1,257,643	$1,665,600	$1,845,600	$1,516,500	$1,741,500	$1,817,100
213 kWh Bus from New Flyer	2035	123	$900,000	$1,425,000	$1,710,000	$1,535,040	$997,441	$1,318,600	$1,461,100	$1,213,200	$1,393,200	$1,211,400
311 kWh Bus from New Flyer	2035	72	$800,000	$1,275,000	$1,530,000	$1,343,160	$910,707	$1,179,800	$1,307,300	$1,112,100	$1,277,100	$1,211,400
388 kWh Bus from New Flyer	2035	58	$700,000	$1,275,000	$1,530,000	$1,311,180	$867,340	$1,179,800	$1,307,300	$1,011,000	$1,161,000	$1,211,400
466 kWh Bus from New Flyer	2035	52	$800,000	$1,350,000	$1,620,000	$1,407,120	$910,707	$1,249,200	$1,384,200	$1,112,100	$1,277,100	$1,211,400
444 kWh Bus from Gillig	2035	58	$1,200,000	$1,950,000	$2,340,000	$2,078,700	$1,344,377	$1,804,400	$1,999,400	$1,617,600	$1,857,600	$1,817,100

[61] The "Daily Energy Needed to Fully Charge Fleet" estimate is based on our middle fleet size estimate for each BEB option.

4.3.1 Note on Smart Charging

Charging BEBs and doing so well is a much more complex problem than refueling ICEBs. For ICEBs, the cost of fuel is constant at the time of purchase, and the fuel efficiency of the bus stays relatively constant as well. One may safely predict the total cost of filling up a tank and the number of miles that the bus may drive on that tank.

For BEBs, however, the single most important determiner of the cost of charging the battery is *when* (at what time of day) one chooses to charge the bus, followed by the number of buses being charged simultaneously. These two variables determine the consumption and demand tariffs involved in charging a BEB fleet.

However, the range of a bus on a full charge also varies greatly. Batteries degrade over time (think about how a laptop eventually starts dying quicker and quicker the older it gets, even on a full charge). For BEBs, this depends on a multitude of factors – from terrain (such as incline on the route), driver practice (for example, how often they hit the brakes), age of the battery, how often it is charged and how quickly (fast charging tends to degrade batteries much more quickly than slow charging), and more.

To reduce costs, a series of complex optimization calculations must be made. Depending on schedules and bus-blocks, it may be more efficient to top off the charge on buses that return with high SOC first to reduce demand. Newer BEBs with longer battery ranges may need to be prioritized for routes that require hill driving, while older BEBs for shorter school trippers. For buses that must be charged during the day, it may be best to use solar power rather than paying for energy from the grid. Keeping all of these variables straight on a day-to-day basis, especially when deciding the order and amount to charge all the buses at night, becomes too complex of a task for transit agency staff.

To that end, GTrans must procure a smart charging system. A smart charging system is a software that pulls data from the buses themselves, the chargers, and all electricity meters to optimize time and amount of charge for the entire fleet. From the buses, it can pull SOC and GPS data, along with battery degradation, terrain influences, among other variables. From the electricity meters, it can pull demand and consumption amounts to calculate costs. It can also control how much energy is going into various charge points.

Our calculations in *Tables 4.21* and *4.22* above are used purely for comparative purposes. They do not account for the myriad of variables in the real world of day-to-day BEB fleet operation that impact the cost of charging. However, many interviews have stated that a smart charging system is imperative for the management of a BEB fleet and may reduce charging costs by 20 percent or more, according to smart charging companies, including one that is currently collaborating with GTrans.

Chapter 5

RECOMMENDATIONS and NEXT STEPS

5.1 Funding Sources

GTrans can take advantage of funding and grant opportunities offered by the State of California as well as SCE's Charge Ready Program. The Low Carbon Fuel Standard (LCFS) Program and the Charge Ready Program are discussed in detail as they are key pillars of other agency's rollout plans.

Table 5.1: Potential Funding Sources[62]

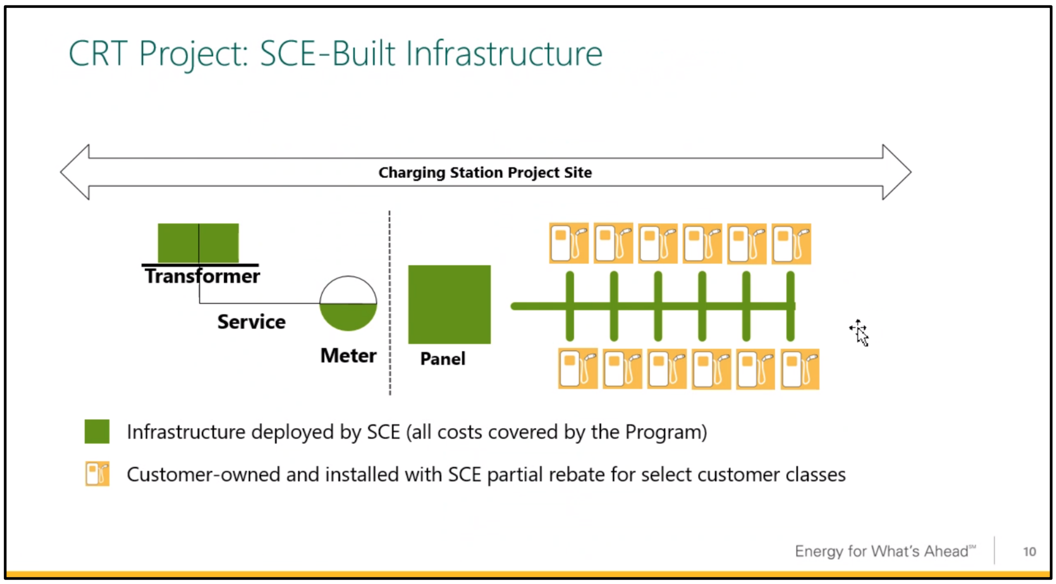
Fund/Grant	Agency	Description	Procedure Notes
Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)	CARB	Voucher program aimed at reducing the purchase cost of zero-emission vehicles. A transit agency would decide on a vehicle, contact the vendor directly, and then the vendor would apply for the voucher.	Vendor handles the application process.
Low Carbon Transit Operations Program (LCTOP) and Transit and Intercity Rail Capital Program (TIRCP)	CARB / Caltrans	LCTOP is a formula-driven program and TIRCP is a competitive program. Both fund projects that support new or expanded bus and rail services, improve multimodal facilities and can include equipment, fueling, maintenance and other costs.	Agency must demonstrate GHG emissions reductions.
Volkswagen Environmental Mitigation Trust Funding	CARB	Volkswagen's settlement provides nearly $130 million for zero-emission transit, school, and shuttle bus replacements. Transit may be eligible for up to $65 million.	As of the date of this report, applications are now open for transit agencies. The grant is a one-time deal.
Carl Moyer Program	CARB	Funding to help procure low-emission vehicles and equipment. Transit buses are eligible for up to $80,000 funding.	The Southern California Air Quality management district determines which projects are funded within the region.

[62] This is a condensed version of a comprehensive table prepared by OCTA with information irrelevant to GTrans removed. *Source:* California Air Resources Board. ICT-Rollout Plans. Accessed April 14, 2021. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2020-09/OCTA%20ZEB%20Rollout%20Plan_ADA08122020.pdf

SCE's Charge Ready Program[63]

As explained earlier (page 12), all on-site electricity infrastructure upgrades (those occurring after the meter) that come with increased grid demand on GTrans' actual site would traditionally have to be paid for by GTrans. However, under the Charge Ready Program, SCE would also pay for upgrades beyond the meter, including panel upgrades and conduits. GTrans would have to purchase the chargers (*see Figure 5.1*).

Figure 5.1: <u>CRT Project: SCE-Built Infrastructure</u>



The Charge Ready Program is a first-come, first-served funding program for transit agencies which are customers of SCE to apply for charging infrastructure funding. It operates in five phases and requires the customer (GTrans) to have procured the chargers and BEBs before construction. In order to apply, GTrans will have to submit charger and BEB acquisition plans that will allow SCE to do a project site evaluation and method of service study to determine current grid capacity and upgrades needed. Much of the evaluation done in this report can be used to apply for the Charge Ready Program and to begin a method of service study.

Depending on the results of the method of service study, there are two options for the Design and Build Phase of the Charge Ready Program (see *Appendix H*): either SCE or GTrans may choose to build the infrastructure required. SCE will do the prior design, procurement, construction, and maintenance of necessary equipment on both sides of the meter up to the first point of interconnection with the planned location of the customer's charging equipment. In this case, GTrans will have to provide an easement

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[63] Information for this section comes from interviews with SCE staff. *Appendix H* provides more in-depth documentation produced by SCE.

to allow SCE to construct on its land.[64] If GTrans chooses to construct, then it will have to submit detailed plans to SCE, who will advise on regulations for electricity infrastructure.

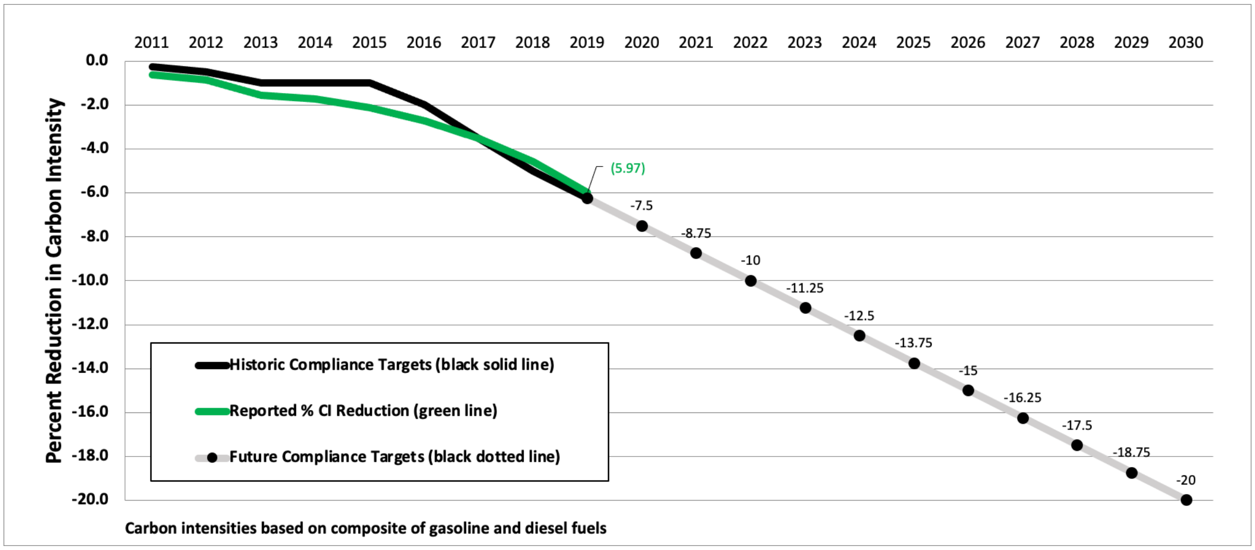
Appendix H provides a high-level overview of the Charge Ready Program using SCE documentation.

Low Carbon Fuel Standard Program

Administered by CARB, the LCFS is a program that encourages the adoption of alternative fuels to decrease the state's GHG emissions. The program aims to reduce transportation emissions by 20 percent by 2030 and sets carbon intensity targets that gradually reach this goal.[65] *Figure 5.2* illustrates the carbon intensity targets for 2011 through 2030 and the historical compliance. By fueling buses with low carbon fuels – such as electricity, hydrogen, and CNG – that are less carbon-intensive than the target, agencies earn LCFS credits.[66] Agencies that burn fuels which are more carbon-intensive than the target (such as diesel) earn deficits. To comply with the regulation, organizations that are credit-deficient must purchase credits from credit-generating organizations.[67] Agencies holding LCFS credits can choose to sell their credits or hold on to them for future compliance.[68]

[64] At time of writing, GTrans has already provided SCE with an easement for a previous project. This may need to be revisited.
[65] California Air Resources Board. Low Carbon Fuel Standard. Accessed April 2, 2021. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2020-09/basics-notes.pdf.
[66] Ibid.
[67] Ibid.
[68] Ibid.

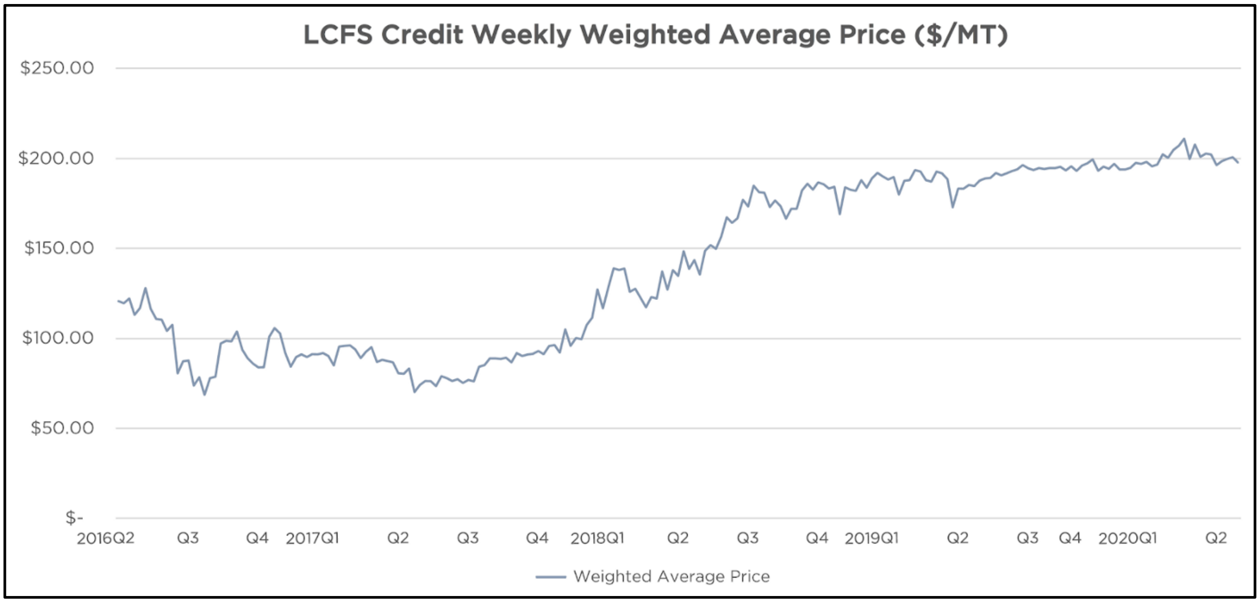
Figure 5.2: LCFS Carbon Intensity Goals and Historical Compliance[69]



CARB allocates one credit per metric ton of CO_2 displaced.[70] The LCFS price fluctuates depending on the supply and demand of the credits available. In anticipation of a future high demand for credits, CARB is considering setting a price cap of $200 (2016 dollars) per credit.[71] Some experts believe this price cap will be unenforceable, and agencies will find avenues to charge higher prices than the cap.[72] *Figure 5.3* shows the fluctuation of LCFS prices, and the current price of about $200 per credit.

[69] California Air Resources Board. Data Dashboard. Accessed April 4, 2021. Retrieved from https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm.
[70] California Air Resources Board. Low Carbon Fuel Standard. Accessed April 2, 2021. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2020-09/basics-notes.pdf.
[71] Hudson, Abbey, Dione Garlick, and Caroline Monroy. Calif. Low Carbon Fuel Standard Price Cap Is A Trade-Off. February 7, 2021. Retrieved from https://www.gibsondunn.com/wp-content/uploads/2020/02/Hudson-Garlick-Monroy-Calif.-Low-Carbon-Fuel-Standard-Price-Cap-Is-A-Trade-Off-Law360-02-07-2020.pdf.
[72] Bledsoe, Joshua, Brian McCall, and Kevin Homrighausen. CARB Attempts to Contain LCFS Credit Prices, Latham's Clean Energy Law Report, Latham & Watkins LLP. January 3, 2020. Retrieved from https://www.cleanenergylawreport.com/california/carb-attempts-to-contain-lcfs-credit-prices/

Figure 5.3: Price of LCFS.[73]



The number of LCFS credits generated depends on the carbon intensity of the fuel consumed.[74] CARB considers the emissions in generating and transporting the fuel when allocating the carbon intensity.[75]

Since we currently estimate that GTrans emits over 4,380 metric tons of CO2 emissions annually, LCFS credits offer an opportunity to offset a significant amount of the agency's costs. To illustrate the total amount of *possible* LCFS credits available to GTrans, we considered a scenario where the agency switched to all BEB buses powered by an electrical source with a carbon intensity of zero, such as wind or solar. Under this scenario, GTrans would earn credits worth over $850,000 annually. This is unrealistic because the California electricity mixture is not entirely zero-emissions. SCE's Electric Fleet Fuel Savings Calculator estimates that under the current California electricity mixture, GTrans would earn about $400,000 in LCFS credits annually if they converted to completely BEBs.[76]

[73] eIQ Mobility. How Fleets Can Harness California's Low Carbon Fuel Standard Credits. May 18, 2020. Retrieved from https://medium.com/@eiqmobility/how-fleets-can-harness-californias-low-carbon-fuel-standard-credits-7f3c4b2e9bde.
[74] Ibid.
[75] Ibid.
[76] Southern California Edison. Fleet Fuel Calculator. Accessed April 4, 2021. Retrieved from https://fleetfuelcalculator.sce.com.

5.2 Bus and Charger Considerations

Due to the current speed of zero-emission technology development, the potential options discussed here should be considered seriously but can rank lower in the future, based on new information or inclusion of additional factors specific to GTrans.

While it may be tempting to examine *Tables 4.15* and *4.22* and rush toward the cheapest option, many factors are not directly quantifiable, making a cheap option very expensive once buses start hitting the lot and SCE comes with grid upgrades. In general, we recommend GTrans consider the following factors when deciding on ZEB technology:

- **Charging Logistics** – The number of chargers, energy output, and dispenser connections (splitting kW output for each additional dispenser and connection) affect how quickly the bus fleet can charge within their available window of charging. Furthermore, the number of staff members needed to manage charging every night (changing and manually connecting buses to chargers) and the space in the bus yard occupied by charging infrastructure present additional logistical considerations.
- **Overall Cost** – Comparing the unit cost of each bus option does not necessarily produce the overall cheapest option. The cheapest bus may require more chargers, more buses (and therefore more space needed for buses), and many more staff hours.
- **Multiple Manufacturers** – "Mixing and matching" different manufacturers is not recommended since there are logistical disadvantages, such as needing to keep various manufacturers' parts on hand for maintenance, and to have staff trained in many different technologies.
- **Replacement Ratios** – A one-to-one fleet replacement ratio is preferable because it minimizes cost and space restraints.
- **Risk** – Other transit agencies provided insight into which bus types have had complications and which manufacturers were not responsive to agency inquiries, all of which add to the risk of service failure. As a new technology for GTrans and in general, ZEBs have an inherent learning curve.
- **Space** – While GTrans has a comparatively large bus yard, the agency still must strategically decide the footprint taken up by charging or refueling equipment, the buses themselves, and potential battery storage.
- **Training** – Not all manufacturers include training in their procurement costs, and not all manufacturers provide equal amounts of training. Some technologies, such as FCEBs, require the manufacturer, not the agency, to safely replace parts. However, because BEB maintenance typically takes place in-house, the adoption of BEB technology requires much more training than FCEBs.
- **Warranty** – Warranty coverage varies by manufacturer. A key concern with ZEBs is battery replacement. A ZEB's battery is expected to degrade as the bus

ages, thus decreasing its range potential. Warranties ensure that batteries can be regularly replaced.

While there is no "best" option, we examine two bus and charger options (the Proterra 440 kWh and New Flyer 466 kWh buses and the BTC Power and Proterra 4 chargers) that rank high across several of the factors listed above but still have disadvantages. These case studies illuminate how factors that are not readily quantifiable interact with our cost estimates. They are compared below, and their specifications are available in *Table 4.15* (page 44) for the BEBs and *Tables 4.21* and *4.22* (page 56) for the chargers.

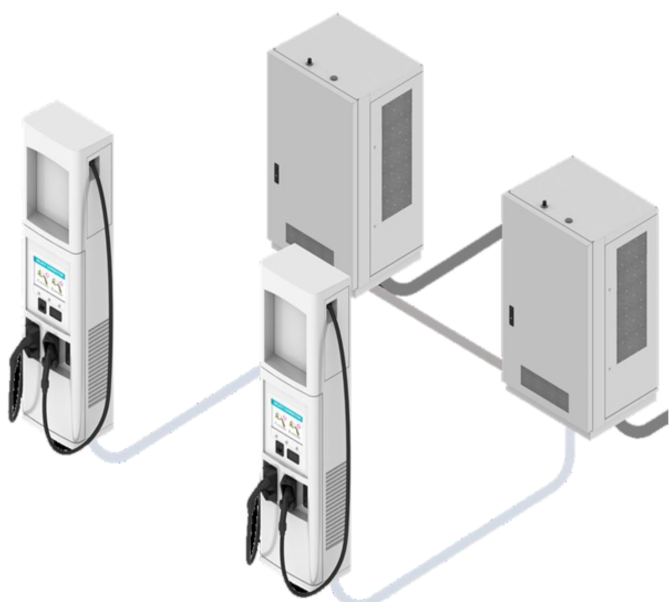
Table 5.2: Weighing the Pros and Cons to Two BEB Options

BEB Make and Model	Pros	Cons
Proterra 440 kWh	This bus is one of the cheapest options, has a better warranty and lower operating cost than most other BEB options. It also has a one-to-one fleet replacement ratio.	Other agencies, especially Foothill Transit, have reported issues with the bus and manufacturer reponse. Their complaints, however, did pertain to older models of buses. While not quantifiable, this could have consequences for costs later-on, especially if replacement parts or batteries impacting service are needed.
New Flyer 466 kWh	New Flyer is a more established bus manufacturer, and therefore has many non-quantifiable advantages. They understand transit agencies, their processes and needs. They also are investing in multiple technologies – which means that GTrans can stick with the same manufacturer but keep up with technology changes.	New Flyer is, however, more expensive, with shorter warranties, slightly higher operating costs, and training not included in the cost of procurement. They are also a new player in the ZEB technology space, leading to issues with technology. Additionally, their focus on investing in multiple technologies might leave them too spread out to gain expertise in any one technology quickly.

Table 5.3: Weighing the Pros and Cons to Two Charger Options

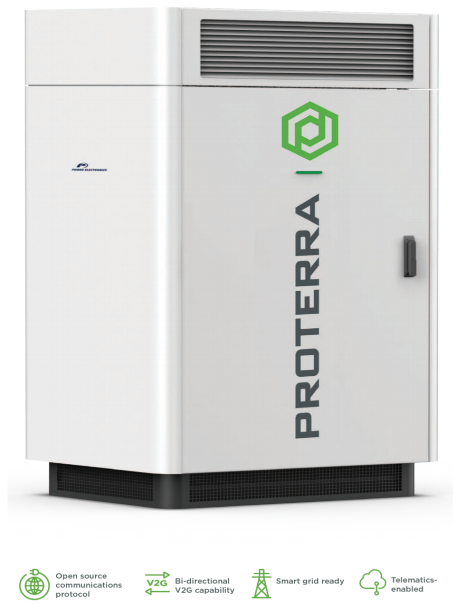
Chargers	Pros	Cons
BTC Power (Gen 4 350 kW HPC Distributed System)	This is one of the cheaper options, and it has two dispensers per unit, allowing it to charge more buses per unit purchased.	The size of the power cabinets are themselves relatively small, but they are spaced out, which leaves a lot of dead space on the lot (*Figure 5.4* below). While on paper this charger may seem like a space-efficient option, actual measurements of a unit will have to be taken to determine feasibility.
Proterra 4 (250 kW Depot Charger)	This charger (*Figure 5.5* below) has much flexibility – it can charge one to four buses simultaneously (albeit with the total kW divided by each dispenser). This charger also has one of the longest warranties, from three to five years.	The price does not include dispenser pedestal mounts, which means a lot of expense to be added if GTrans needs to place the chargers in locations on their lot where they must be mounted. Such considerations may not become apparent until many years into the fleet transition.

Figure 5.4: BTC Power, Gen 4 350kW HPC Distributed System[77]



[77] BTC Power. 350KW HIGH POWER DC CHARGER. Accessed March 26, 2021. Retrieved from https://www.btcpower.com/index.php?action=350kw-DCFC

Figure 5.5: Proterra, 250 kW Depot Charger[78]



5.3 Equity Opportunity: Disadvantaged Communities Score

Based on the CalEnviroScreen 3.0 tool, a majority of census tracts in the GTrans service area are considered a disadvantaged community per the CalEnviroScreen tool. Thus, transitioning to ZEBs represents the most significant equity opportunity. Some transit agencies, such as LADOT, benefited from grants requiring the agency to prioritize ZEB rollout in disadvantaged communities.[79] For instance, although GTrans plans to remove Line 4, it passes through the most census tracts considered disadvantaged. Those living and working in those communities face disproportionate exposure to poor environmental health, and replacing a CNG bus with a ZEB can lessen their exposure to harmful pollutants. Notably, Line 1 is the only line that passes through more disadvantaged communities than Line 4. However, it is the longest line, going from the City of Gardena to downtown Los Angeles. Since current BEBs generally have shorter ranges than CNG buses, implementing BEBs on a shorter line would be more ideal for initial ZEB deployment.

Figure 5.6 combines GTrans' route information with CalEnviroScreen data, allowing us to find a feasible opportunity to advance equity.

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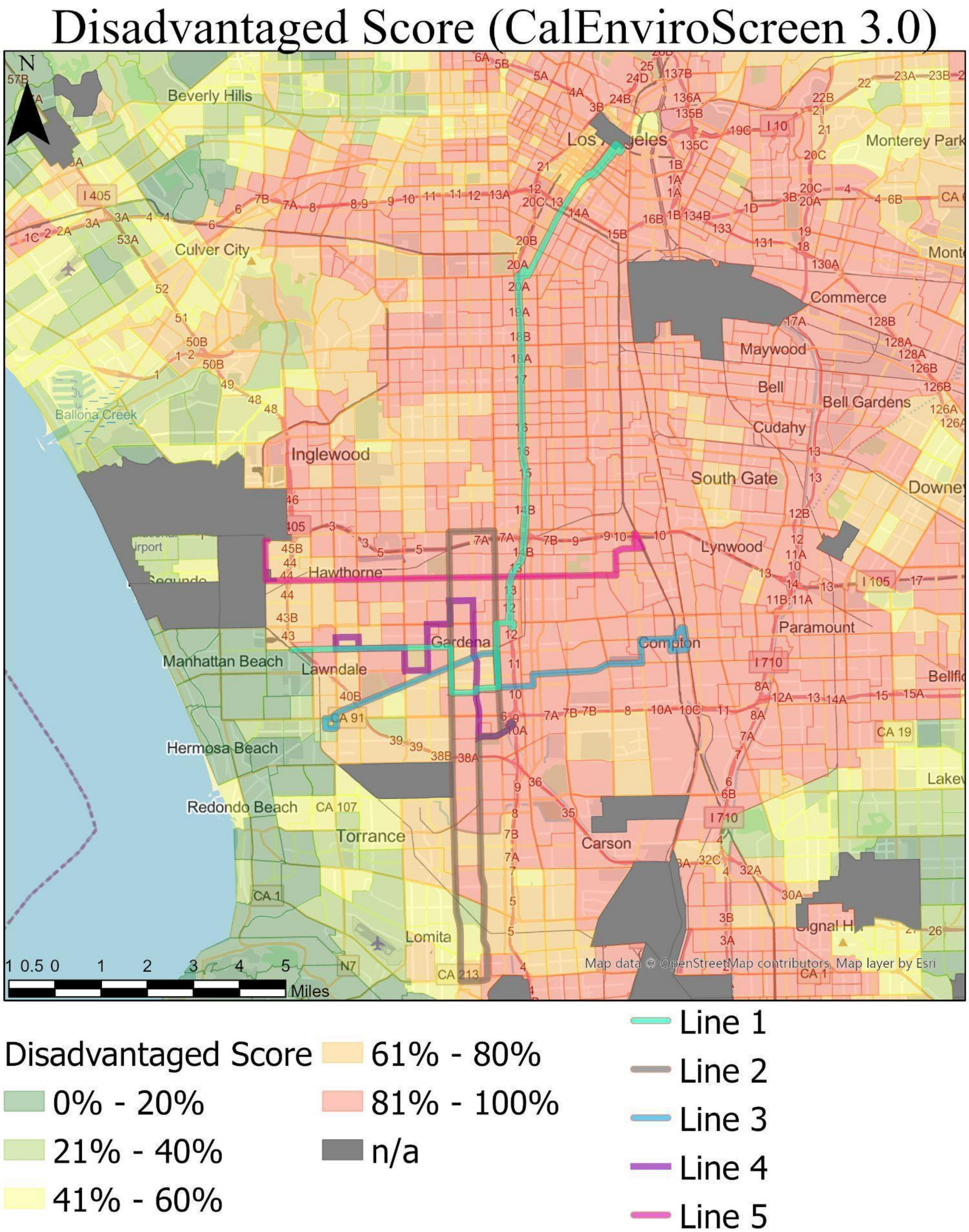
[78] Proterra. Proterra energy fleet solutions. Accessed March 26, 2021. Retrieved from https://www.proterra.com/wp-content/uploads/2020/10/SPEC_CHG-SYS_250_V9_10.27.20.pdf
[79] According to an interview with LADOT Chief of Transit (see Appendix B for a list of interviews).

Figure 5.6: Disadvantaged Communities Score



5.4 How to Use this Report in the Future

As mentioned throughout this document, the purpose of this report is to prepare GTrans to make the most appropriate bus and charger purchase for the City of Gardena. Rather than providing one recommendation, this report presents an estimation model and potential procurement options based on the information currently available. By the time GTrans makes a final recommendation to the Gardena City Council, transit technology may have advanced to make the options compared earlier obsolete.

Still, the estimation model used to provide those options can serve as a foundation for GTrans' final procurement recommendations. As new information arises, GTrans can input those updated numbers to compare bus and charger options. The basic steps of this evaluation model are listed in *Table 5.4* below, along with potential reasons to update the model.

Table 5.4: Basic Steps of Evaluation Model and Reasons for Updates

Steps	Update If…
1. Determine the agency's total daily mileage	Routes change
2. Use BEB range to determine necessary fleet size	New manufacturers or more accurate information on ZEB range are available
3. Calculate cost of the entire fleet per bus type and electricity need	New manufacturers are available, bus price changes, or SCE alters its charge rate
4. Narrow charger options based on bus selection	New manufacturers are available or new charger technology emerges
5. Approach SCE to finalize infrastructure upgrades	FCEB technology becomes more feasible, so GTrans would not be reliant on SCE

While this model includes various factors, GTrans may have additional considerations to add to this evaluation model in the future, which can add depth and accuracy. Nevertheless, GTrans' final recommendations to the Gardena City Council will benefit from relying on this document as a foundation for developing an estimation model. ZEB technology continues to improve at an incredible speed, so this model provides GTrans – and any agency of a similar size and scale – with the necessary tools to adapt and navigate its way to a zero-emission transit future.

APPENDICES

Appendix A: GTrans' Carbon Emissions

Carbon Content for Gasoline (grams/gallon)[80]	GTrans Gasoline Consumption-2019 (gallons)	GTrans carbon produced (grams)	GTrans CO2 produced (grams)	GTrans CO2 produced (metric tons)
2433	**491,195**	**1,195,077,435**	**4,381,950,595**	**4382**

[80] Davis, Stacey and Robert Bundy. *Transportation Energy Data Book*. Ed. 39. U.S. Department of Energy. Accessed March 30, 2021. Retrieved from https://tedb.ornl.gov.

Appendix B: List of Interviews

Organization	Contact(s)	Date	Category
NCTD	Damon Blythe, Chief Operations Officer	12/15/20	Agency
LA Metro	Quintin Sumabat, Deputy Executive Officer of Vehicle Engineering & Acquisition	12/16/20	Agency
Foothill Transit	Doran Barnes, CEO; Ritta Merza, Policy and Programs Manage;r Roland Cordero, Director of Maintenance and Vehicle Technology	12/16/20	Agency
Sunline Transit	Lauren Skiver, CEO	12/18/20	Agency
AC Transit	Mike Hursh, General Manager; Salvador Llamas, Chief Operating Officer	12/21/20	Agency
LADOT	Corinne Ralph, Chief of Transit	1/28/21	Agency
Santa Monica Big Blue Bus	Getty Modica, Transit Vehicle Maintenance Superintendent; Jesus Ocampo, Transit Maintenance Training Coordinator	2/16/21	Agency
Long Beach Transit	Kenneth McDonald, CEO and President	1/6/21	Agency
Proterra	Lauren Scoville, Senior Director of Sales	12/15/20	Bus Manufacturer
New Flyer	Daniel Trujillo, Regional Sales Manager	2/10/21	Bus Manufacturer
Gillig	Sean Solis, Regional Sales Manager	3/5/21	Bus Manufacturer
BTC Power	Christopher McNamara,Regional Sales Manager	3/4/21	Charger Manufacturer
Tritium	Stephen Tok, Director; Mikael Krikorian, Sales Manager	3/2/21	Charger Manufacturer
ABB Chargers	Kendell Whitehead, Sales	3/4/21	Charger Manufacturer
Schaltbau E-Mobility	Jim Tullo, Engineering & Technical Services	3/12/21	Charger Manufacturer

SoCal Edison	John Tierney, Account Management Senior Specialist; Simon Horton, Senior Project Manager; Andrew Papson, Advisor, Transportation Electrification; Mike Kajdasz, Transportation Electrification Advisor	3/12/21	Electric Utility
Ballard Fuel Cell Systems and Clean Energy Fuels	Sydney Krueger, Manufacturer's Representative	3/15/21	Fuel Cell
MOEV, Inc.	Rajit Gadh, Science Advisor; Apurva Chandra, Marketing & New Business Development	2/26/21	Smart Grid

Appendix C: **EV Charging Tariff Rates as Published by SCE**

ELECTRIC VEHICLE CHARGING RATE
TOU-EV-7 TOU-EV-8 AND TOU-EV-9 PRICING
Bundled Service

BUNDLE RATE FACTORS EFFECTIVE FEBRUARY 1, 2021	Customer Charge	Facilities Related Demand (FRD) Charges	Summer Season Energy Charges			Winter Season Energy Charges		
Rate Schedule	$/month	$/kW*	On-Peak kWh	Mid-Peak kWh	Off-Peak kWh	On-Peak kWh	Mid-Peak kWh	Super Off-Peak kWh
Demands 20 kW and below								
TOU-EV-7 (Option E)	45.7 ¢/Day	N/A	$0.46746	$0.35508	$0.17056	$0.37515	$0.16250	$0.10149
TOU-EV-7 (Option D)	45.7 ¢/Day	N/A	$0.46746	$0.35508	$0.17056	$0.37515	$0.16250	$0.10149
Demands between 20 kW to 500 kW								
TOU-EV-8	$158.61	N/A	$0.55168	$0.31622	$0.14805	$0.35668	$0.15774	$0.09350
Demands above 500 kW (Below 2 kV)								
TOU-EV-9	$571.13	N/A	$0.48731	$0.27041	$0.12532	$0.30545	$0.13105	$0.08321
Demands above 500 kW (From 2 kV to 50 kV)								
TOU-EV-9	$303.73	N/A	$0.44856	$0.24495	$0.11549	$0.27895	$0.12009	$0.07882
Demands above 500 kW (Above 50 kV)	Voltage Discount for 220 kV and above are excluded							
TOU-EV-9	$2,102.74	N/A	$0.31932	$0.13598	$0.09082	$0.17156	$0.09456	$0.06833

*No Facility-Related Demand (FRD) charges. Future FRD charges may change pending FERC decision. Please refer to tariff sheet on sce.com

This sheet is meant as a job aid to understanding SCE's pricing schedules. The document does not replace the California Public Utilities Commission-approved tariffs. In the event of a conflict between this job aid and the SCE tariffs, the tariffs control. Please refer to the individual rate schedule of interest for a complete listing of terms and conditions of service, which can be viewed or printed via the Internet at www.sce.com.

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Appendix D: ICT Purchase Requirements by Year[81]

Year	Large Agencies	Small Agencies
2023	25%	-
2024	25%	-
2025	25%	-
2026	50%	25%
2027	50%	25%
2028	50%	25%
2029	100%	100%

[81] California Air Resources Board. Innovative Clean Transit (ICT) Regulation Fact Sheet. May 16, 2019. Retrieved from https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet.

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Appendix F: GTrans 2019 Bus-Blocks

GTrans Bus-Blocks	
Block ID	**Estimated Miles**
1-1	261.2
1-2	218
1-3	259.9
1-4	388.3
1-5	120.3
2-1	176.7
2-2	221.3
2-3	209.1
2-4	229.7
2-5	200.3
2-6	233.7
2-7	176.2
2-8	250.2
2-9	202.2
2-10	176.3
2-11	271.6
2-12	208.8
2-13	189
2-14	201.2
2-15	260.8
3-1	144.1
3-2	147.2
3-3	147.5
3-4	74.5
3-5	65.7
3-6	80.9
3-7	33.5

3-8	51.5
3-9	133.9
4-1	175.3
4-2	188.6
5-1	125.7
5-2	128.2
5-3	158.5
5-4	158.5
School Tripper 1 (M-F)	20.4
School Tripper 2-1 (M-F)	23
School Tripper 2-2 (W &F)	25.4
School Tripper 2-3 (M-THUR)	39.1
School Tripper 2-4 (M-THUR)	20.4
School Tripper 2-5 (M-F)	23
School Tripper 2-6 (M-F)	25.4
School Tripper 2-7 (M-F)	39.1
School Tripper 3-1 (M-F)	21.2
School Tripper 5-1 (M-THU)	20.4
School Tripper 5-2 (M-F)	23
School Tripper 5-3 (M-WED)	25.4
School Tripper 5-4 (M-F)	39.1
TOTAL	6613.3

Appendix G: Projected Number of BEBs by Each Procurement Year[82]

	Proterra		New Flyer					Gillig
Year	440 kW	660 kW	160 kW	213 kW	311 kW	388 kW	466 kW	444 kW
2030	7	7	7	7	7	7	7	7
2031	26	26	26	26	26	26	26	26
2032	26	26	26	26	26	26	26	26
2033	40	30	40	40	40	40	30	40
2034	52	52	149	123	72	58	52	58

[82] Years between 2030 and 2034 are subject to change.

<u>Appendix H</u>: Overview of the Charge Ready Program as Published by SCE

PROGRAM PARTICIPATION

QUICK REFERENCE GUIDE

Charge Ready Transport
Program Handbook Supplement

v2.0 7/10/19

SOUTHERN CALIFORNIA EDISON®
Energy for What's Ahead℠

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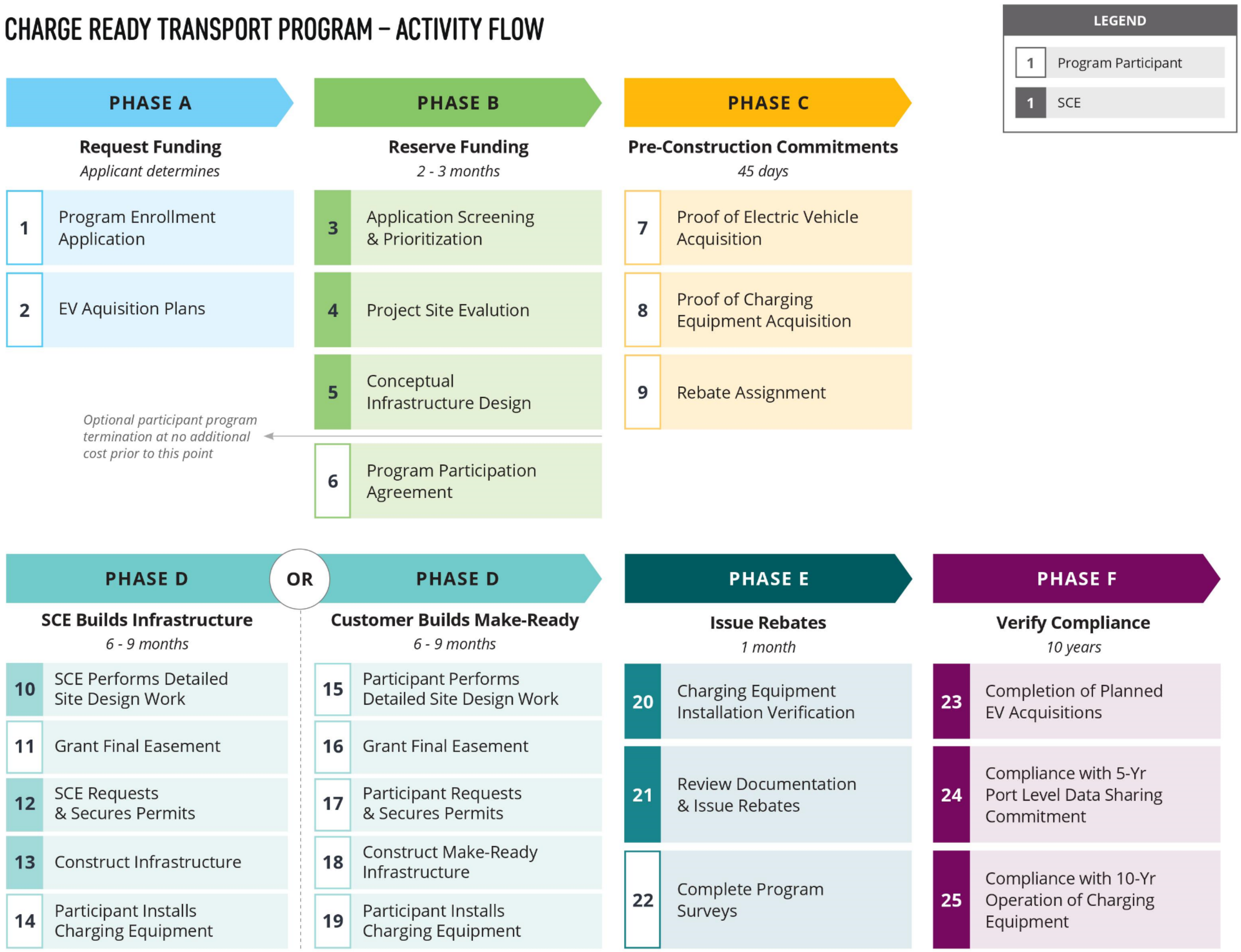
CHARGE READY TRANSPORT PROGRAM – ACTIVITY FLOW



Documents Required:

- The EV Acquisition plan is embedded within the on-line Application.
- Projects for Truck Stop Electrification or Transport Refrigeration Units are required to complete and Upload a copy of the "TRU and TSE Worksheet" to the program enrollment portal.

SCE Activities:

- Review Applications for completeness.
- Ensure EV acquisition plan includes a minimum of two EVs to be on-site within 18 months.
- If applicable, ensure TRU and TSE worksheet is complete.

B. FUNDING RESERVATION

Estimated duration: 2-3 months
Steps 3-6

3. Application Screening & Prioritization

A number of factors will help SCE to determine project eligibility & prioritization. These include, but are not limited to: the number and timing of vehicles to be acquired or converted; size of the existing fleet; number of projected previously approved for similar sector; integration with on-site load management such as solar, battery storage, and other; and remaining program funds.

Customer Activities:

- Respond to any application related inquiries received from SCE.

Documents Required:

- None.

SCE Activities:

- SCE will initiate the project feasibility review (TEPFS).
- Determine if application moves to next step.
- If determined the application can move forward to the next step, SCE will schedule a site visit.

4. Project Site Evaluation

After reviewing and evaluating the application, SCE will continue through the evaluation process to schedule and perform a site assessment. This step is necessary for SCE to collect the information needed to develop a conceptual infrastructure design and project cost estimate.

Customer Activities:

- Participate in the on-site visit with SCE.
- Ensure the appropriate individual(s) representing the Customer Applicant, typically the Facility Manager or Yard Manager (someone familiar with the site and the planned installation of the vehicle charging equipment, familiar with how the vehicles are operated, will be parked, etc.), participate in the site walk-through.
- If the customer is already aware of the specific charging equipment they plan to purchase and install, attempt to invite the charging equipment supplier to the site visit.

Documents Required:

- If the customer is already aware of which charging equipment they plan to purchase, email a copy of the charging equipment product specification sheet(s) to **TEPMChargeReadyTransport@sce.com**. Include your application ID number in the subject line, e.g. CRT-2019-xxxx, followed by "STEP 4").

SCE Activities:

- Review Applications for completeness.
- Ensure EV acquisition plan includes a minimum of two EVs to be on-site within 18 months.
- If applicable, ensure TRU and TSE worksheet is complete.

5. Conceptual Infrastructure Design

If during the site assessment the proposed project meets program criteria, and if SCE determines the project can still potentially move forward, SCE will draft a conceptual design and provide a copy to the customer.

Customer Activities:

- If SCE provides the conceptual design, the customer will be requested to accept and approve (verbal will suffice) the design within 10 calendar days of receipt.
- If the customer does not approve the design, customer must then work with SCE to reach agreement on alternate potential lay-out.
- Decide if the make-ready infrastructure will be built by customer or SCE.
- Notify SCE of any other infrastructure projects are planned or underway at the site.
- Review SCE's standard easement language, and if not property owner ensure property owner has reviewed.

Documents Required:

- None. The conceptual design will be included in the Program Participation Agreement.

SCE Activities:

- Develop a conceptual infrastructure design for the site.
- Prepare high level costs estimates for the utility side and customer side infrastructure, including engineering, design and permitting.
- If the proposed project meets program criteria, cost thresholds, and other considerations, SCE will provide the conceptual design exhibit to the customer for approval.
- Receive customer's verbal approval of the conceptual infrastructure design.
- Receive customer's decision on make-ready build (customer or SCE).
- Confirm with customer whether or not there are any other site infrastructure projects planned or underway.

6. Program Participation Agreement

If during the site assessment the proposed project meets program criteria, and if SCE determines the project can still potentially move forward, SCE will draft a conceptual design and provide a copy to the customer.

Customer Activities:

- Customer to provide SCE with decision on specific charging equipment that will be purchased.
- Customer to make any final revisions to the vehicle acquisition plan.
- Receive, review and sign (electronic signature) the Program Participation Agreement that will be available through the program enrollment portal.

Documents Required:

- Signed Program Participation Agreement (via electronic signature – through the program enrollment portal).

SCE Activities:

- Identify the specific charging equipment the customer has chosen.
- Identify any changes to the vehicle acquisition plan.
- Prepare the Program Participation Agreement.
- Upon receipt of customer signature, execute the Agreement and reserve project funds.

A. FUNDING REQUEST

Estimated duration: 45 minutes
Steps 1 & 2

1. Program Enrollment Application

The on-line application can be accessed through the program enrollment portal. A minimum qualification for program participation includes the acquisition or conversion of at least two EV or convert at least two fossil-fueled vehicles to electric to be on-site within 18 months.

Customer Activities:

- Complete on-line application accessible through the program enrollment portal (**www.SCE.com/ChargeReadyTransport**).
- Upload a site plan annotated with preferred location(s) of the charging equipment to the program enrollment portal.
- Upload copy of the civil plan (requested but not required) to the program enrollment portal.

Documents Required:

- Application will be submitted electronically through the program enrollment portal once filled out completely.
- Upload a copy of the site plan annotated with preferred location(s) of the charging equipment in .pdf file format to the the program enrollment portal;
- Upload a copy of the civil plan (requested but not required) to the the program enrollment portal.

SCE Activities:

- Review application for completeness.
- SCE will determine initial eligibility for program participation.

2. EV Acquisition Plans

The acquisition plans are embedded in the Enrollment Application and capture the Applicants EV procurement plans over the next ten years. This information will help to qualify the Applicant for program participation and lay the ground work for understanding the site's charging infrastructure needs.

Customer Activities:

- Ensure the planned EV acquisition portion of the Application is accurate & complete.
- If the project includes truck stop electrification (TSE) or includes Transport Refrigeration Units (TRU's), please fill out and submit the "TRU and TSE Worksheet" which can be downloaded from the the program enrollment portal.

C. PRE-CONSTRUCTION COMMITMENTS

Estimated duration: 45 days
Steps 7-9

7. Proof of Vehicle Acquisition

Within 45 days of the date funds are reserved, customers must provide proof of procurement of at least two EVs or convert at least two fossil-fueled vehicles to electric.

Customer Activities:

- Prepare copy of proof of EV lease or purchase agreement.
- At least two vehicles must be scheduled to arrive on-site within 18 months.

Documents Required:

All documents should be uploaded to the program enrollment portal:

- Copy of itemized lease or purchase contract. The document must include:
  - Execution Date
  - Lease term (if leased)
  - EV dealer(s) name and address
  - Model numbers and quantity of Electric Vehicles purchased, leased or converted.
  - Expected vehicle delivery date(s) – MUST BE WITHIN 18 MONTHS.
  - Payment status (paid or payment terms)

SCE Activities:

- Receive documentation and review for completeness.
- If not complete, follow-up with the customer as may be required.

8. Proof of Charging Equipment Acquisition

Within 45 days of the date funds are reserved for the project, customers must provide proof of procurement ALL vehicle charging equipment designated for the project.

Customer Activities:

- Submit copy of the purchase order, paid invoice, or sales receipt for charging equipment (separately listed purchase price from any EVITP certified installer costs).
- If applicable, submit a copy of the Network Service Agreement (required for charging equipment fueling on-road EVs).
- For non-standard equipment, submit a copy of the NRTL Safety Performance Evaluation Test Report & complete and submit copy of

ELECTRIC VEHICLE CHARGING RATE
TOU-EV-7 TOU-EV-8 AND TOU-EV-9 PRICING
Bundled Service

BUNDLE RATE FACTORS EFFECTIVE FEBRUARY 1, 2021	Customer Charge	Facilities Related Demand (FRD) Charges	Summer Season Energy Charges			Winter Season Energy Charges		
Rate Schedule	$/month	$/kW*	On-Peak kWh	Mid-Peak kWh	Off-Peak kWh	On-Peak kWh	Mid-Peak kWh	Super Off-Peak kWh
Demands 20 kW and below								
TOU-EV-7 (Option E)	45.7 ¢/Day	N/A	$0.46746	$0.35508	$0.17056	$0.37515	$0.16250	$0.10149
TOU-EV-7 (Option D)	45.7 ¢/Day	N/A	$0.46746	$0.35508	$0.17056	$0.37515	$0.16250	$0.10149
Demands between 20 kW to 500 kW								
TOU-EV-8	$158.61	N/A	$0.55168	$0.31622	$0.14805	$0.35668	$0.15774	$0.09350
Demands above 500 kW (Below 2 kV)								
TOU-EV-9	$571.13	N/A	$0.48731	$0.27041	$0.12532	$0.30545	$0.13105	$0.08321
Demands above 500 kW (From 2 kV to 50 kV)								
TOU-EV-9	$303.73	N/A	$0.44856	$0.24495	$0.11549	$0.27895	$0.12009	$0.07882
Demands above 500 kW (Above 50 kV)	Voltage Discount for 220 kV and above are excluded							
TOU-EV-9	$2,102.74	N/A	$0.31932	$0.13598	$0.09082	$0.17156	$0.09456	$0.06833

*No Facility-Related Demand (FRD) charges. Future FRD charges may change pending FERC decision. Please refer to tariff sheet on sce.com

This sheet is meant as a job aid to understanding SCE's pricing schedules. The document does not replace the California Public Utilities Commission-approved tariffs. In the event of a conflict between this job aid and the SCE tariffs, the tariffs control. Please refer to the individual rate schedule of interest for a complete listing of terms and conditions of service, which can be viewed or printed via the Internet at www.sce.com.

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the Testament of Compliance with SCE's Non-Standard Equipment Technical Requirements.

- A limited extension of this procurement period may be granted by submitting an extension request in writing prior to the expiration of the initial 45 day period. SCE may, at its discretion, provide an extension, if, in SCE's sole judgment, the Participant is actively seeking to complete the procurement.

Documents Required:

All documents relating to Step 8 should be uploaded to the program enrollment portal:

- Proof of purchase including purchase date, the make, model and serial #'s of the charging equipment, expected delivery date and individual unit pricing;
- If applicable, a copy of Network Services Agreement;
- For non-standard equipment – copy of NRTL Safety Test Report;
- For non-standard equipment, a signed copy of the Technical Requirements for Non-Standard Charging Equipment.

SCE Activities:

- Receive documents and review for completeness.
- If not complete, follow-up with the customer as may be necessary.

9. Rebate Assignment

This form is used to collect the necessary information for SCE to process and remit applicable rebates.

Customer Activities:

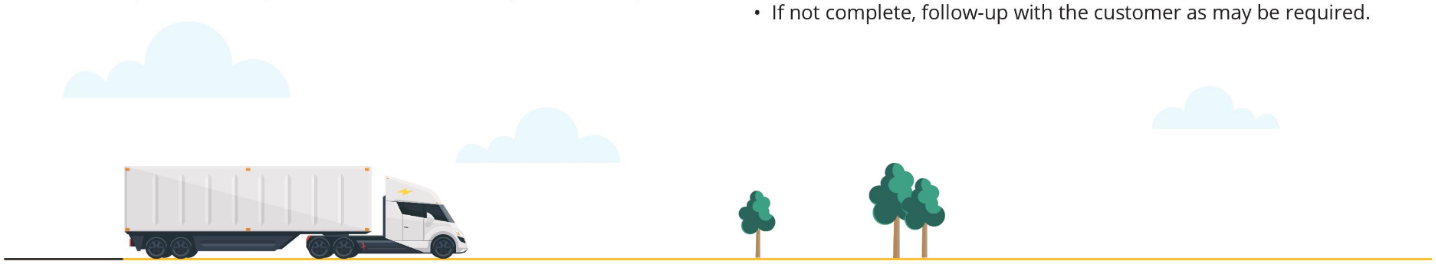
- If Participant is eligible for the Charging Equipment Rebate or the Make-Ready Rebate, within 45 days of the date funds are reserved for the project, complete the on-line Rebate Assignment Form.
- Submit completed copy of W-9 for tax purposes.
- Submit completed copy of the CA 590 form, if applicable.

Documents Required:

- If rebate eligible, complete the on-line Rebate Assignment Form located on the program enrollment portal;
- If rebate eligible, upload a copy of a completed and signed copy of IRS Form W-9;
- If applicable, upload a signed copy of a completed CA form 590.

SCE Activities:

- Receive documents and review for completeness.
- If not complete, follow-up with the customer as may be required.



D. DESIGN AND BUILD PHASE

SCE BUILDS INFRASTRUCTURE

Estimated duration: 6-9 months
Steps 10-19

10. SCE Performs Detailed Site Design Work

Following the execution of an Agreement, and upon receipt of all required Pre-Construction documentation, SCE will commence with drafting detailed design plans and developing final infrastructure cost estimates.

Customer Activities:

- Approve SCE's site visit request to collect information which will help with developing the detailed design work & cost estimates.
- The customer will be presented with the detailed design, and is requested to complete their review and approval within 10 calendar days.

Documents Required:

- Email approval of the Preliminary design to **TEPMChargeReadyTransport@sce.com** (include your application number in the subject line, e.g. CRT-2019-xxxx, followed by "STEP 10").

SCE Activities:

- The design and build phase will commence following completion of the Pre-Construction Commitments outlined in Steps 7-9.
- SCE will schedule/coordinate the site visit to start the detailed design work.
- Develop Preliminary design & present to customer.
- Receive Preliminary design approval from customer.

11. Grant Final Easement

The customer is required to execute and notarize the easement, or facilitate its execution (for non-owned sites).

Customer Activities:

- Sign and notarize easement documents.
- Email a copy of the document to SCE.
- Return the original signed and notarized easement to SCE within 30 calendar days from the date of receipt.
- If customer is not the site owner, have the owner of property sign and notarize easement documents

Documents Required:

- Email copy of notarized easement to **TEPMChargeReadyTransport@sce.com** (include your application number in the subject line, e.g. Ex CRT-2019-xxxx, followed by "STEP 11");
- Return original signed and notarized easement to SCE following the mailing instructions that will be provided.

SCE Activities:

- SCE prepares easement documents and provide to customer for execution.
- SCE ensures notarized copy is received.

12. SCE to Request & Secure Permits

SCE will submit its construction plans to the relevant AHJ to secure all necessary reviews, approvals and permits.

Customer Activities:

- Sign permit application documents as may be requested by SCE.

Documents Required:

- Upon request from AHJ, as may be required.

SCE Activities:

- SCE submits designs to the AHJ for plan check and permitting.
- Send customer any required documents requiring signature.
- Provide customer the necessary information to establish a new Service Account (address for service).

13. Construct Infrastructure

SCE will design, procure, construct and maintain the necessary equipment on both the utility side and customer side of the meter up to the first point of interconnection with the planned location of the customer's charging equipment.

Customer Activities:

- Within 15 days of the completed make-ready construction, customers are required to provide SCE with approval of the work performed.
- Work with SCE Account Representative to select TOU rate plan and request service turn-on (performed before meter is set).

Documents Required:

- Email a signed copy of the "Infrastructure Approval and Acceptance Certificate" to **TEPMChargeReadyTransport@sce.com** within 15 days. Include your application number in the subject line, e.g. CRT-2019-xxxx, followed by "STEP 13".

SCE Activities:

- After securing permits, initiate construction phase.
- Complete the construction phase.
- Confirm receipt of infrastructure form.
- Activate new Service Account upon Participant's request.

14. Participant Installs Charging Equipment

Customers will always be required to install the vehicle charging equipment following the completion of the utility side and customer side of the meter infrastructure work. Post charging equipment installation, and within 10 calendar days, relevant documentation to be submitted to SCE.

Customer Activities:

- Ensure compliance with the CPUC TE Safety Checklist.
- Obtain final invoices for charging equipment installation and notify SCE the work is complete.
- Secure permits for charging equipment Installation.
- Install equipment within 20 calendar days and have final inspections performed.
- Obtain "EVSE Commissioning" Report.
- Submit a completed "Charging Equipment Registration Form".
- If charging equipment is not listed on SCE's APL, obtain copy of the Field Listing Inspection Report.
- If charging equipment is not listed on SCE's APL, work with SCE to schedule (possible) equipment commissioning test.
- Any publicly-accessible charging equipment must be reported to the US Department of Energy's EV Charging Station Locations mapping tool at: **https://www.afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC**

Documents Required:

All documents specified should be scanned for upload to the program enrollment portal.

- A copy of the installation permit & evidence of final inspection;
- A copy of the final charging equipment purchase invoice;
- A copy of the charging equipment installation invoice (in all cases the equipment purchase price should be broken out from the installation costs);
- A copy of the completed "Charging Equipment Registration Form";
- A copy of the "EVSE Commissioning Report";
- If the charging equipment was not listed on SCE's APL, submit copy of the Field Listing Inspection Report.

SCE Activities:

- Receive notification work is complete, receive documents and review for completeness.
- Follow up with customer as may be required for missing information.
- Determine if SCE will be performing equipment commissioning test and schedule if needed.

D. DESIGN AND BUILD PHASE

CUSTOMER BUILDS MAKE-READY

Estimated duration: 6-9 months
Steps 10-19

15. Participant Performs Detailed Site Design Work

Customers choosing to perform their own make-ready infrastructure installation are responsible for its design, procurement, construction and maintenance.

Customer Activities:

- Complete the make-ready infrastructure design.
- Create a base map and civil plan map, for location of the make-ready and charging equipment (see Appendix of Program Handbook for civil plan sample) and provide copy to SCE.
- Submit a copy of estimated construction costs to SCE.
- Provide approval for SCE utility side infrastructure design.

Documents Required:

- All documents required for this step should be aggregated into a single email and submit to **TEPMChargeReadyTransport@sce.com**. Include your application number in the subject line, e.g. CRT-2019-xxxx, followed by "STEP 15").
- A copy of the base map detailing the make-ready Infrastructure design (include E-sheet and load calculations) following the "CAD File Requirements" included in the Appendix of the Program Handbook;
- A copy of the civil plan in .pdf file format;
- A copy of the estimated construction costs broken out by design and engineering costs; permitting costs; and construction costs. A template is provided in the Appendix of the Program Handbook;
- A copy of the approval of SCE's utility side infrastructure design (sign design before sending a .PDF copy).

SCE Activities:

- After receiving customer's plans, design utility side infrastructure.
- SCE to draft and share utility side infrastructure design with the customer via email for approval.
- Draft the legal description for the utility side infrastructure easements.
- Receive documentation from customer and ensure completeness.

16. Grant Final Easement

The SCE team will draft the legal description to be used for the utility side infrastructure easement.

Customer Activities:

- Once SCE provides the final easement language for the utility side infrastructure, the customer is required to grant, or facilitate the

- granting of new easements for the utility side infrastructure work.
- Sign and notarize easement documents.
- Email a copy of the document to SCE.
- Return the original signed and notarized easement to SCE within 30 calendar days from the date of receipt.
- If customer is not the site owner, have the owner of property sign and notarize easement documents.

Documents Required:

- Email a copy of notarized easement to **TEPMChargeReadyTransport@sce.com**. Include your application number in the subject line, e.g. CRT-2019-xxxx, followed by "STEP 16";
- Return original signed and notarized easement to SCE following the mailing instructions that will be provided.

SCE Activities:

- Provide customer with final utility side easement language.
- Once copy of final easement is obtained, SCE will initiate recording of the easement.

17. Participant Requests & Secures Permits

Customer is required to submit its construction plans to the relevant AHJ to secure all reviews, approvals and permits.

Customer Activities:

- Initiate permitting process.
- Obtain necessary permits.
- SCE will provide customer with the necessary information to establish a new Service Account.

Documents Required:

- Any required by AHJ.

SCE Activities:

- Provide customer with support as may be necessary.
- SCE will secure any permits relevant to the construction of the utility side infrastructure.
- Provide customer the necessary information to establish a new Service Account (address for service).

18. Construct Infrastructure

Customers will be responsible for managing and coordinating all related infrastructure design and installation work and complying with labor and safety requirements.

Customer Activities:

- Schedule a preconstruction meeting with SCE and provide a detailed construction schedule.
- Procure equipment & manage all infrastructure work.
- Ensure installation contractor is state licensed and insured, using IBEW signatory labor for all work performed.

- Ensure compliance with Contractor training certification (EVITP) and obtain copies of certificates in advance of work being performed.
- Review and ensure compliance with the CPUC's Transportation Electrification Safety Requirements Checklist.
- Post installation, ensure final inspection process is complete.
- Work with SCE Account Representative to select TOU rate plan and request service turn-on (new account activation).

Documents Required:

- Email a copy of the detailed construction schedule in advance of work to be performed to **TEPMChargeReadyTransport@sce.com**. For all emailed documents, please include your application ID number in the subject line, e.g. CRT-2019-xxxx, followed by "STEP 18").
- Following construction, email copies of:
  - Evidence of final inspection;
  - A copy of the final as-built map; and
  - A signed copy of the Testament of Compliance with the Safety Requirements Checklist.

SCE Activities:

- Notify customer when utility side infrastructure work is complete.
- Attend the customer's scheduled pre-construction meeting.
- Energize site once customer has completed construction and received all necessary AHJ approvals.
- Activate new Service Account upon Participant's request.

19. Participant Installs Charging Equipment

Customers will be required to install the vehicle charging equipment following the completion of the utility side and customer side of the meter infrastructure work. Within ten calendar days of completion of the installation, the required documents should be submitted to SCE.

Customer Activities:

- Ensure compliance with the CPUC TE Safety Checklist.
- Obtain final invoices for charging equipment installation and notify SCE the work is complete.
- Secure permits for charging equipment Installation.
- Install equipment within 20 calendar days and have final inspections performed.
- Obtain "EVSE Commissioning Report".
- Submit completed copy of the "Charging Equipment Registration Form".
- Work with SCE to schedule (possible) equipment commissioning test.
- If charging equipment is not listed on APL, obtain copy of the Field Listing Inspection Report.
- Any publicly-accessible charging equipment must be reported to the US Department of Energy's EV Charging Station Locations mapping tool at: **https://www.afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC**

Documents Required:

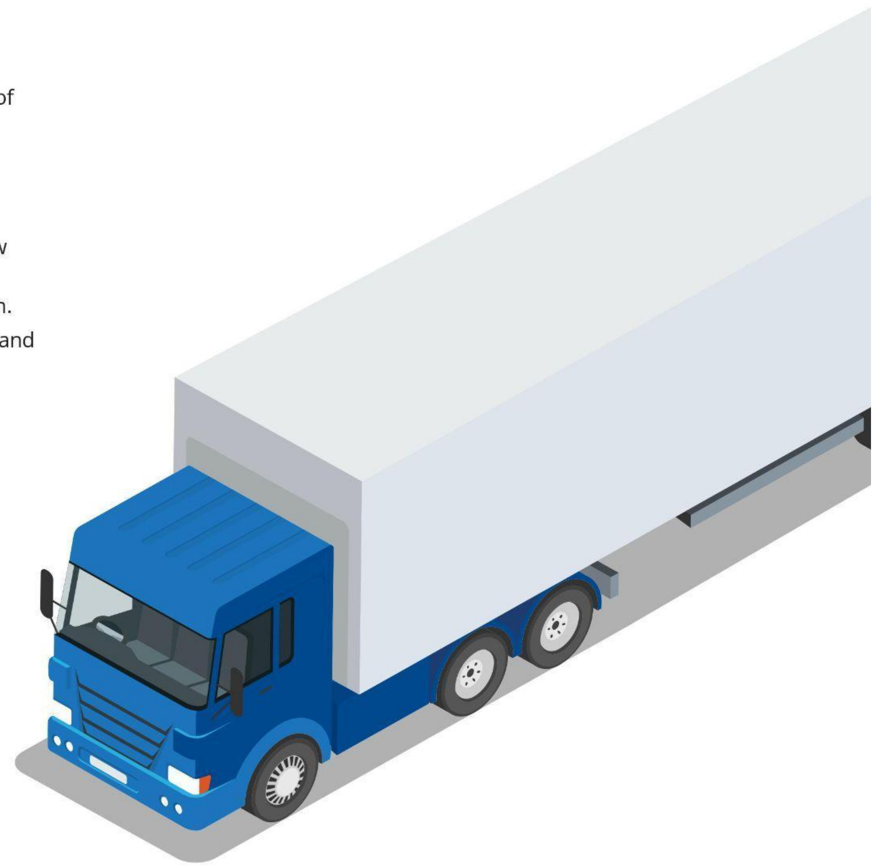
All documents specified should be scanned for upload to the program enrollment portal:

- A copy of the installation permit & evidence of final inspection;
- A copy of the final charging equipment purchase invoice;

- A copy of the charging equipment installation invoice (in all cases the equipment purchase price should be broken out from the installation costs);
- A copy of the completed "Charging Equipment Registration Form";
- A copy of the "EVSE Commissioning Report";
- If the charging equipment was not listed on SCE's APL, submit copy of the Field Listing Inspection Report.

SCE Activities:

- Receive notification work is complete, receive documents and review for completeness.
- Follow up with customer as may be required for missing information.
- Determine if SCE will be performing equipment commissioning test and schedule if needed.



E. ISSUE REBATES

Estimated duration: 1 month
Steps 20-22

20. Charging Equipment Installation Verification

After SCE is notified the work is complete, the required documentation has been received, and the new service account was activated, SCE will perform final site inspection.

Customer Activities:

- Notify SCE when installation of charging equipment is complete.

Documents Required:

- None

SCE Activities:

- After notification received from customer, perform final site inspection.
- Once inspection complete, initiate rebate process.

21. Review Documentation & Issue Rebates

Following site visit and review of ALL required documentation, SCE will move forward with processing the rebate for remittance to the assigned designee.

Customer Activities:

- No further action required for Charging Equipment Rebate processing.
- For the Make-Ready Rebate, if applicable, the documentation outlined below will be required within 10 calendar days after charging equipment is installed.

Documents Required:

All documents for the Make-Ready Rebate should be scanned for upload to the program enrollment portal:

- A copy of the "Participant Installed Make-Ready Cost Breakdown worksheet";
- A copy of the final "As-Built" for the make-ready infrastructure work;
- A copy of the final inspection for the make-ready Infrastructure work.

SCE Activities:

- Review documentation for completeness.
- Initiate processing of rebates.
- Issue rebate check.

22. Complete Program Surveys

Customers may be provided with program related information request(s) and/or surveys at various times throughout the duration of the program.

Customer Activities:

- Respond to survey requests in a timely manner.

Documents Required:

- Provide responses as requested (may be received in electronic or paper format).

SCE Activities:

- Develop surveys, distribute, process responses and follow-up as may be necessary.

F. COMPLIANCE VERIFICATION

Estimated duration: 10 years
Steps 23-25

23. Completion of Planned EV Acquisitions

SCE will monitor project related EV acquisitions to ensure those reflected in the Agreement materialize.

Customer Activities:

- Acquire EVs as outlined in the Agreement (adhere to volume and timing of vehicle delivery).
- If for any reason, the volume or timing of delivery deviates from the Agreement, promptly notify SCE.

Documents Required:

- On-going response to SCE's annual EV acquisition survey. Participants will be asked to provide the Make and Model of vehicles acquired during that calendar year, and for information relating to the retirement of any EV during that calendar year.

SCE Activities:

- Ongoing monitoring for each participating site.
- SCE may follow-up with customers to monitor compliance with planned vehicle acquisitions.

24. Compliance with 10-Yr Operation of Charging Equipment

The customer is required, at its own expense, to operate and maintain the equipment in good working order at the originally installed location for 10 years.

Customer Activities:

- Maintain the charging equipment in good working order for 10 years.
- Replace or repair charging equipment, if required, as set forth in the Agreement and Handbook.

Documents Required:

- None.

SCE Activities:

- Ongoing monitoring for each site.
- Aggregate usage data available for all EV load.
- Follow up with customer as may be necessary.

25. Compliance with 5-Yr Port Level Data Sharing Commitment

Customers must provide EV charging usage data for a period of 5 years.

Customer Activities:

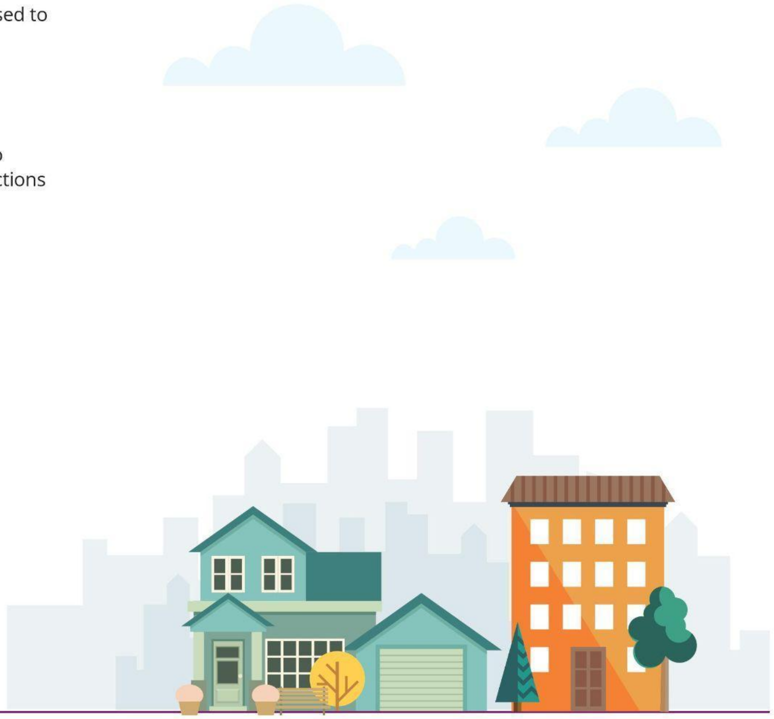
- Maintain 5 year contract with Network Service Provider to capture and share port level usage data with SCE for charging equipment used to fuel on-road vehicles.

Documents Required:

- Must provide monthly electronic usage data files conforming to SCE's "Charging Equipment Usage Data Monthly Report" instructions included in Appendix of the Handbook.

SCE Activities:

- Ongoing monitoring for each site.
- Follow up with customer as may be necessary.



ELECTRIFICATION PROJECT ESTIMATE

RATE ANALYSIS REQUEST FORM

This form is meant to be used in providing an annual cost estimate based on anticipated charging stations, operating in the manner as depicted, using requirements in this form.

Select Service Type: ☐Charge Ready ☐School Bus ☐Transit Bus ☐Fleet ☐Workplace ☐MUD ☐Public Charging

Customer Name:

1. What is the site address for the charging stations? (Leave blank if still unknown)

2. How many charging stations does the customer expect will be installed? (whole number only please - no number range) Indicate the total number of charging stations.

3. What is the estimated maximum kW of the charging stations?

4. * In order to capture and build the estimated charge load, please indicate the timeframe you anticipate the charging stations being used with the hours based on each day of the week (e.g., 7am-11am 12pm-4pm, 10 pm-2am).

   For your convenience you have the option to enter an additional charge pattern scenario showing different anticipated charging hours/days to gain a second annual cost estimate. Please refer to the optional Charging Pattern #2 table to add those new hours/days.

Charging Pattern #1 - Required						
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Charging Pattern #2 - Optional (Additional Scenario)						
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**

Additional information/comments to include that is pertinent to building the estimated charge load

5. *Will the charging pattern(s) of questions 4 occur every day, 365 days a year?
   - ☐ Yes
   - ☐ No

   a. Specify specific dates outside of weekdays/weekends that charging will not occur (e.g., Labor Day, Christmas Day, Spring Break-1 week in April, June) for each charge pattern

*The charging pattern information provided in question 4 above will be applied to the total number of charging stations identified in questions 2, which assumes that all charging stations will operate in the same manner. If the customer does not intend to follow the same pattern for each charging station they will need to provide the answers for questions 4 through 5 for each charging station separately.

FOR INTERNAL USE – DO NOT DISTRIBUTE

SOUTHERN CALIFORNIA EDISON®
Energy for What's Ahead®

Time-of-Use Rate: TOU-D-PRIME

A NEW RATE OPTION — PRIME FOR CLEAN ENERGY HOUSEHOLDS.

Learn more about our new TOU-D-PRIME rate to see if it's the best fit for your home and the clean energy technologies you use.

RATE PLAN HIGHLIGHTS

Designed exclusively for high-energy-use households with an electric or plug-in hybrid vehicle, residential battery, or heat pump.

TOU-D-PRIME offers our lowest off-peak rates. A fixed daily basic charge allows for lower Super Off-Peak and Off-Peak rates.

Details

- Lowest rates: 8 a.m. – 4 p.m. and 9 p.m. – 8 a.m.
- Highest rates: All year 4 - 9 p.m.

Go electric with a great rate plan.

Get more value for your electric or plug-in hybrid vehicle and other clean energy technologies with **TOU-D-PRIME**. This Time-Of-Use (TOU) rate plan has the same periods as our TOU-D-4-9PM rate plan option, but offers the lowest off-peak rates of all TOU rate plans. In lieu of a minimum daily basic charge and baseline credit, TOU-D-PRIME has a fixed daily basic charge equivalent to approximately $12 per month — which allows for lower Super Off-Peak and Off-Peak rates.

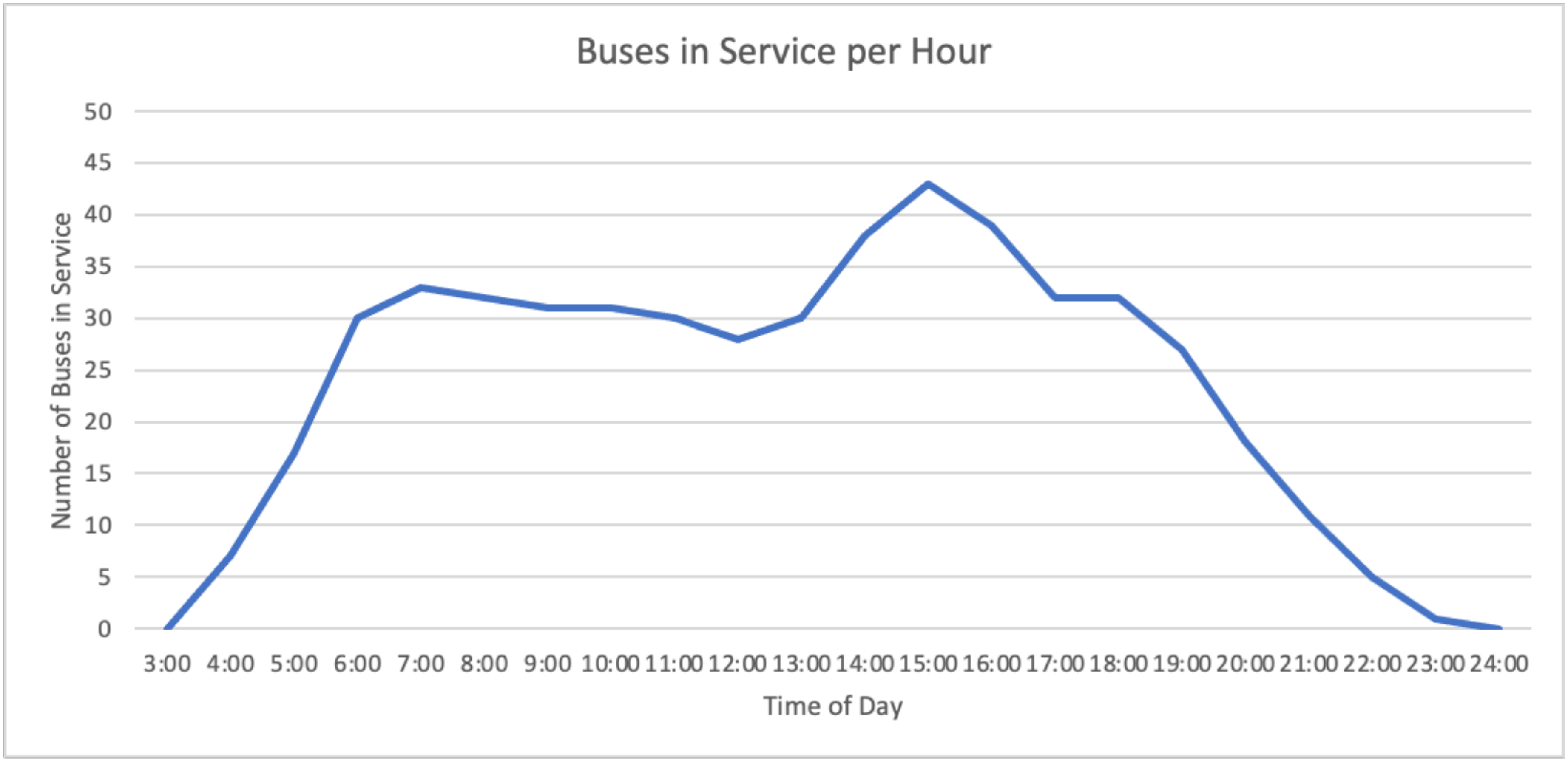
Would TOU-D-PRIME be a good fit for me?

Your home, your family size, your schedule, and your lifestyle all play a part in determining your electricity needs. If you have a large household or are considered a high-energy user, TOU-D-PRIME may be the best rate for you, if you also own or lease one or more of the following clean energy technologies:

- Electric or plug-in hybrid vehicle
- Residential battery
- Electric heat pump for water or space heating

To be eligible to enroll in this rate plan option, you must have one or more of the clean energy technologies listed above, unless you are currently enrolled in TOU-D-A, TOU-D-B, or TOU-D-T rate plans.

<u>Appendix I:</u> Buses in Service per Hour



Appendix J: Foothill Transit Charger Evaluation Matrix

		Specifications			Warranty					Reliability and Standards					Network			Additional information/ services provided	Pricing
Vendor	Greenlots Overall rating	Variations in Connector Types	Procurement (lead time, production capacities)	Buy America compliance	Standard/Extended Warranty offers	SLAs	Local support (manufacturing, US support, California locations for parts or service)	Customer Support services	Maintenance	Lifetime, efficiency rating guarantee	UL approval	Standards implementation including OCPP, OpenADR	Bus Fleet usage	Obselescence	Connectivity methods (wifi, cellular, etc.)	Existing partnership with CPOs	Remote Monitoring capabilities	Battery back up inclusion/pricing	
BTC	4.53	3	4	5	5	5	5	4	5	4	5	5	3	4	5	5	5		5
ABB	4.82	5	3	5	5	5	5	5	5	4	5	5	5	5	5	5	5		5
Momentum Dynamics	4.35	3	4	5	5	5	5	4	5	4	3	5	4	5	5	3	5		4
Schaltbau Emobility	4.12	4	5	5	5	4	4	5	1	5	4	5	5	4	5	3	3		3
Signet	3.94	5	5	1	3	5	3	5	3	4	4	5	4	3	4	5	5		3
Wave Inc.	4.00	3	5	5	3	4	5	3	5	5	5	4	4	3	4	3	4		3
Tritium	4.35	3	5	3	3	3	5	5	5	4	4	5	5	4	5	5	5		5
Siemens	4.33	5	3	3	5	4	5	4	5	4	4	5	5	3	5	4	5	5	4
Chargepoint	4.44	3	5	5	3	5	5	5	5	4	4	5	5	4	5	3	5	5	4
Heliox	4.89	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	5	5	5
Proterra	4.47	4	4	5	5	5	5	5	2	4	5	4	5	4	5	4	5		5
GE																			

<u>**Appendix K:**</u> **GTrans Path to Zero Emissions - Fleet Planning**

Purchase Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
2019	18-CNG												18-Electric			
2021			14-CNG												14-Electric	
			2-Electric													
2022				13-CNG												13-Electric
				4-Electric												
2027									1-Electric							
															Zero Emission Fleet in 2034:	52