San Joaquin Regional Transit District Electric Bus Demonstration

June 3, 2019

Prepared by:
Kevin Leong, Jonathan Norris, Ifeoluwa Dahunsi, and Jasna Tomic
CALSTART

CALSTART

Executive Summary

This report presents the evaluation results of battery-electric buses in revenue service at San Joaquin Regional Transit District (RTD) located in Stockton, California. RTD, committed to becoming a zero-emission all-electric fleet by 2025, demonstrated ten next-generation Proterra battery-electric buses for 12 months. Five electric buses were purchased through a $4 million grant under the Federal Transit Administration's (FTA's) Low and No Emission (LoNo) Program. The remaining five buses were purchased using other grant awards that RTD had received. RTD enlisted CALSTART to conduct an unbiased, third-party evaluation of these electric transit buses. The goal of this demonstration was to evaluate the performance and determine if the electric buses could meet the service requirements of RTD. This was accomplished by comparing the performance and operating costs of the battery-electric buses to that of RTD's conventional diesel-electric hybrid buses. Furthermore, user feedback surveys were administered throughout the demonstration to track how user acceptance of the drivers, maintenance staff, and managers shifted over time.

The ten buses in this demonstration were all battery-electric Catalyst FC transit buses manufactured by Proterra. The 40-foot buses have a nominal range of 62 miles on a single charge and use Proterra's overhead fast charging system. This allows buses to opportunity charge on route at one of Stockton's main transit hubs. There are advantages and drawbacks associated with on-route opportunity charging. A main advantage is that buses can operate indefinitely without long interruptions for charging. Lower vehicle assignment flexibility and dependence on the reliability and functionality of the on-route charging infrastructure is one of the primary disadvantages.

RTD operated the new fleet of electric buses on five routes, including the first all-electric Bus Rapid Transit (BRT) route in California. A summary of the electric bus evaluation is shown in Table ES-1.

Table ES-1: Summary of Evaluation Results

Data Description	Data Value
Number of buses	10
Demonstration period	9/1/2017 – 8/31/2018
Number of months	12
Total days in revenue service	1,038
Total mileage in revenue service (mi)	155,896
Average monthly mileage per bus (mi/month)	1,559
Availability (%)	88
Vehicle efficiency (kWh/mi)	2.13
Vehicle fuel economy (mpdge)	17.7
Vehicle efficiency in revenue service (kWh/mi)	2.00
Vehicle fuel economy in revenue service (mpdge)	18.8
Operational efficiency (kWh/mi)	2.57
Operational fuel economy (mpdge)	14.6
Average moving speed (mph)	14.8

The buses traveled a combined total of 155,896 miles during the 12-moth demonstration, with 1,038 days of revenue service. Performance data was recorded using data loggers installed by the bus supplier as well as through manual mileage and fuel logs provided by RTD. This was supplemented by maintenance records and user acceptance surveys. Using several metrics that were calculated during analysis, CALSTART developed findings and insights that helped inform RTD of the real-world performance and operating costs of electric transit buses.

The electric buses were randomly assigned to one of five service routes but primarily operated on BRT Route 44, which had the highest ridership of the assigned routes. This urban service route spans approximately 14.4 miles in distance and serves passengers from the Downtown Transit Center (DTC) in Central Stockton to as far south as Qantas Lane near Arch-Airport Road. The buses traveled at an average moving speed of 14.8 mph (excluding idle time).

Maintenance data was collected on five electric buses during the demonstration period. The average availability for the electric buses during the data period was 88% compared to 91% for the diesel-electric hybrid baseline bus. There was little variation observed in the availability of electric buses, ranging from a low of 89% to a high of 91%. More importantly, most unscheduled maintenance days were caused by general bus system issues such as HVAC or broken components that were unrelated to the electric drive system of the bus.

Three types of efficiencies were analyzed in the demonstration: overall vehicle efficiency, vehicle efficiency in revenue service, and operational efficiency.

- **Vehicle efficiency**: This is the most common methodology for calculating vehicle efficiency. The ten electric buses had an overall vehicle efficiency of 2.13 kWh/mi.

$$\frac{Total\ energy\ consumed\ (kWh)}{Total\ miles\ (mi)}$$

- **Vehicle efficiency in revenue service**: This efficiency metric uses the same calculation methodology as overall vehicle efficiency but only includes energy consumed and miles traveled during revenue service. A bus was only considered to be active and in revenue service if it traveled at least 10 miles during the day. The ten electric buses had an overall vehicle efficiency of 2.00 kWh per mile when in revenue service.

$$\frac{Total\ energy\ consumed\ in\ revenue\ service\ (kWh)}{Total\ revenue\ service\ miles\ (mi)}$$

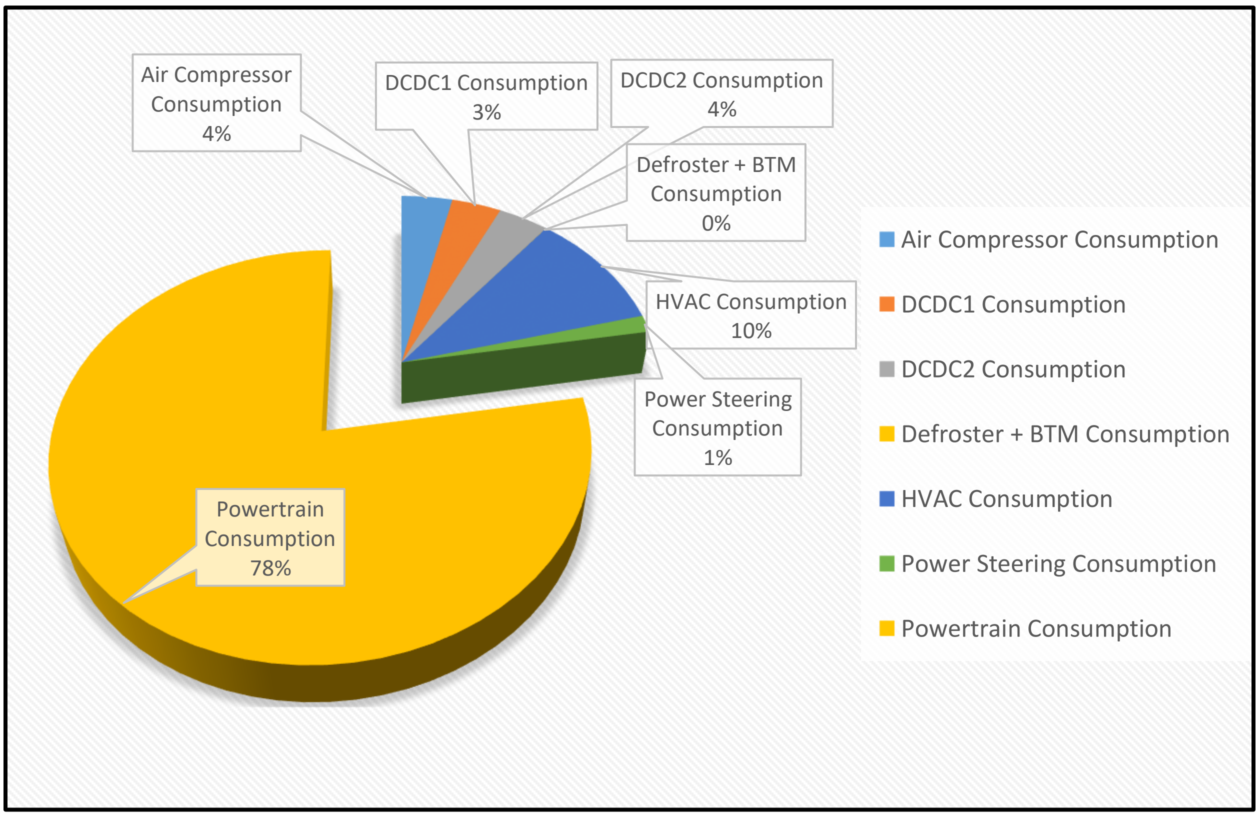
- **Operational efficiency**: Operational efficiency is an efficiency metric based on energy measured at the meter and total miles traveled. Using this methodology, operational efficiency was calculated to be 2.57 kWh/mi. Operational efficiency is not to be compared with vehicle efficiency but rather its purpose is to provide greater insight to the actual energy required to operate electric buses. Due to energy transfer losses between the meter and the bus, the energy measured at the meter will be higher than the energy received by the bus. During the demonstration a 19% loss in energy was observed between the meter and the buses. Since a transit agency is billed for energy measured at the meter, understanding operational efficiency was critical in determining the real-world operating costs of electric transit buses.

$$\frac{Total\ energy\ measured\ at\ the\ meter\ (kWh)}{Total\ miles\ (mi)}$$

Vehicle efficiency based on total miles driven was 2.13 kWh/mi. This equates to 17.7 miles per diesel gallon equivalent (mpdge). In comparison, the diesel-electric hybrid buses had an average efficiency of 5.13 mpdge which is three times less efficient than that of the battery-electric buses. The duty cycle of a vehicle can have a significant impact on its fuel economy. Due to this fact, it is important to note that the battery-electric and diesel-electric hybrid buses did not always operate on the same routes and therefore cannot be considered a direct performance comparison.

To further understand vehicle efficiency, energy consumption of the following bus components was monitored: DC1, DC2, air compressor, HVAC, powertrain, and power steering. The total energy consumed by these components is comprehensive of the total energy consumed by the vehicle and its components during the 12-months of operation. Figure 5.9 shows a percentage breakdown of the energy that each bus component consumed during the demonstration period.

Figure ES-2: Energy Consumption by Vehicle Component



The powertrain consumed the highest amount of energy, accounting for 78% of the total energy drawn by the buses. The powertrain provides the propulsion to move the vehicle and therefore it is expected for this component to have the highest energy draw. Heating, ventilation, and cooling (HVAC) drew the next highest amount of energy, accounting for 10% of the total energy drawn. Stockton has a relatively mild climate, with an average high of 92.1°F in the summer and an average low of 55.5°F in the winter.[1] Though HVAC did not have a significant impact on battery performance in this demonstration, it can become an issue for electric buses in more extreme climates, particularly areas in colder climates.

During the demonstration, RTD's average cost of electricity without demand charges was $0.16/kWh to charge the electric buses. When factoring in customer and peak demand charges, the cost of electricity was $0.49/kWh. In comparison the average cost of diesel during the same period was $2.15/gallon. This is equivalent to $1.28 per mile to power the electric buses compared to $0.42 per mile for the diesel-electric hybrid buses. The cost to power the electric buses does not include credits from the Low Carbon Fuel Standard (LCFS) program which, depending on the LCFS marketing conditions, could offset the total cost of energy by $0.13 to $0.14 per kWh when factored in.

Demand charges can have a significant impact on a transit agency's electricity bill. Demand charges were determined monthly based on the highest average kW measured in a 15-minute interval during the billing period. During RTD's earlier electric bus demonstration, PG&E granted RTD a 2-year demand charge exemption. The exemption expired in 2015 which resulted in RTD incurring peak demand charges during the course of this demonstration. RTD operated two on-route overhead fast chargers (FCrs) with a maximum power rating of 500 kW each. This led to high demand charges and resulted in significantly higher energy costs to operate the electric buses; more than double the operating costs of diesel-electric buses.

At the time of writing this report, PG&E released a proposal that would establish new rates for charging electric vehicles. If approved by the California Public Utilities Commission (CPUC), this would have significant impact on a fleet's operational costs as it would seek to eliminate costly demand charges that RTD faced throughout the demonstration. Though the proposal has not yet been approved, it is likely that some form of this new rate structure will pass. Using the proposed rates that PG&E had released, CALSTART projected that RTD would pay $0.38 per mile to power the electric bus. With LCFS credits factored in, cost per mile would be reduced even further, bringing it to $0.14 per mile. Based on these projections, the new PG&E rate structure could greatly reduce RTD's operating costs for electric buses.

Surveys and interviews were used to capture experiences of RTD personnel – drivers, maintenance staff, and mangers. The surveys provided additional insight into how the vehicles performed during the demonstration. Comparisons were made between the electric bus and the baseline diesel-electric hybrid bus to determine the advantages and disadvantages during normal everyday use. The management team that was surveyed included the fleet manager, supervisors, and directors. In looking at driver acceptance and maintenance issues, RTD management summarized and rated the electric buses based on information from drivers and maintenance staff, respectively. Five of RTD's management staff completed surveys at the beginning of the demonstration and six completed surveys

[1] Stockton, CA Climate & Temperature. http://www.stockton.climatemps.com/ (accessed March 2, 2019)

at the end, in which they compared the electric to the diesel-electric hybrid in terms of 5 performance metrics. Results are shown in Table ES-2 on a scale from one to five.

Table ES-2: Final Manager Survey Scores for the Electric Bus

Metric	Score
Driver Acceptance	2.0
Safety	2.8
Reliability	2.0
Maintenance Issues	1.8
Availability for Service Operation	2.0

The numbers correspond to the following:

1. Much Worse 2. Somewhat Worse 3. Same 4: Somewhat Better 5: Much Better

The ratings depicted in Table ES-2 show final perceptions from six of RTD's management team, all whom had significant experience managing the fleet of electric and diesel-electric hybrid buses. In each category except safety, RTD management rated the bus as somewhat worse in comparison to their conventional buses.

The differences between a battery-electric and diesel-electric hybrid propulsion system limited drivers' ability to get comfortable with the electric buses. Reliability of the charging infrastructure and issues with the docking process, aligning the bus to connect with the charger head, was a primary concern of the drivers. A docking error, caused by the operator or charging system, would delay the charging process and would require operators to drive around the transit center in order to try docking again. This added time caused delays and cut into the break drivers would have between service loops. All performance metrics were rated as worse when compared to their conventional hybrid bus. Rather than getting used to the new vehicle, the drivers' opinions continued to degrade even though 73% of them expressed they had been given sufficient training on how to efficiently drive the electric buses. Therefore, it is reasonable to conclude that the issues with bus performance and charging infrastructure, to some degree, diminished the driver's acceptance of the electric vehicle. The maintenance staff felt that proper training was never implemented which limited their ability to safely maintain and service the bus. Despite the concerns shared by the maintenance staff, they unanimously agreed that the Catalyst electric bus was a substantial improvement over the earlier Proterra EcoRide model that RTD had previously demonstrated in 2013. Finally, when RTD's management team was asked how their perception of electric buses changed over time, most responded positively. The responses included "they are getting better" and "as the technology and experience with the electric buses have matured, we are able to work through many of the operational challenges." While these results are informative, we note that only a sample of the RTD staff were surveyed and the views may not reflect the overall views of the transit agency.

Summary of Findings

This list summarizes the overall takeaways from the study:

- The electric buses had a vehicle efficiency of 2.13 kWh per mile, which equates to 17.7 miles per diesel gallon equivalent (mpdge). In comparison, the diesel-electric hybrid buses had a vehicle efficiency of 5.13 mpdge which is three times less efficient than that of the battery-electric buses.
- The electric buses had an operational efficiency of 2.57 kWh per mile, which equates to 14.6 mpdge. Operational efficiency is an efficiency metric based on energy measured at the meter and total miles traveled. There can be significant loss as energy is transferred between the meter and the bus. RTD had a charging efficiency of 81% which means a 19% loss in energy was observed between the meter and the buses. Since a transit agency is billed for energy measured at the meter, understanding operational efficiency and charging efficiency was critical in determining the real-world operating costs of electric transit buses.
- The average availability for the electric buses during the data period was 88% compared to the 91% for the diesel-electric hybrid baseline bus. Availability is based on the number of days the buses were actually available compared to the days that the buses were scheduled to be available for operation.
- Peak demand charges can significantly impact the operating costs of electric buses, especially in cases where on-route FCrs are required. If the number of electric transit buses using on-route FCrs is optimized, demand charges can be spread among more buses and the overall cost per mile can be greatly reduced. Fifteen buses utilizing two overhead FCrs would bring demand charges down to $0.30 per mile.
- If approved, PG&E’s new rate structure can significantly lower energy costs for electric bus. Based on PG&E’s proposed rates and RTD’s demand profile, cost per mile to charge the electric buses could drop down to $0.42 per mile.
- The LCFS Program can further decrease energy costs by an average of $0.13 to $0.14 per kWh, depending on the LCFS market conditions. In combination with PG&E’s new rate structure, LCFS could reduce charging costs down to $0.09 per mile giving electric buses a significant cost advantage in fuel savings.
- Electric transit buses that require opportunity charging are dependent on the reliability and functionality of the on-route charging infrastructure. If the charging system went down, RTD’s electric transit buses were not able to provide service until the charging system was fixed.
- Overhead fast charging required bus drivers to perform a docking maneuver to properly align and connect the bus with the charging head. Docking errors, caused by either the operator or charging system, delayed the charging process and required operators to drive around the transit center to repeat the process until a successful connection was made. Challenges with docking frustrated operators and sometimes caused delays in service.
- User acceptance was low among RTD staff. Reliability of the on-route FCrs and issues with the in-cab ergonomics were the primary causes of frustrations among the drivers. Maintenance staff expressed they needed more training and feedback from the bus supplier to maintain the buses safely and efficiently.

LIST OF ACRONYMS

BEV	Battery electric vehicle, a vehicle which is solely powered by an onboard battery
CAN bus	Controller Area Network
CARB	California Air Resources Board
CEC	California Energy Commission
CPUC	California Public Utility Commission
DC	direct current
EPA	Environmental Protection Agency
ESS	energy storage system
EV	electric vehicle
FC	Fast Charge
FCr	fast charger
FTA	Federal Transit Agency
GHG	greenhouse gas
GPS	Global Positioning System
GVWR	gross vehicle weight rating
hp	horsepower
HVAC	heating, ventilation, and air conditioning
Hz	hertz
kB/s	kilobyte per second
kW	kilowatt
kWh	kilowatt hours
lb	pounds
LCFS	Low Carbon Fuel Standard
LoNo	Low and No Emission Vehicle Deployment Program
M/HD	Medium-/heavy-duty, refers to vehicles 14,001 – 26,000 lbs GVWR (medium duty) or 26,001 and greater lbs GVWR (heavy duty)
mpdge	miles per diesel gallon equivalent
mph	miles per hour

OBD	on-board diagnostic system
OEM	Original Equipment Manufacturer, also known as truck makers, truck manufacturers
O&M	operations and maintenance
PM	planned maintenance
PMI	preventative maintenance inspection
RTC	Regional Transportation Center
RTD	San Joaquin Regional Transit District
SMA	Stockton Metropolitan Area
XR	Extended Range
ZEB	zero-emission bus
ZEV	zero-emission vehicle, inclusive of all forms of cars, trucks, buses, and off-road vehicles that does not produce any emissions

DEFINITION OF TERMS

Availability: The number of days the buses are actually available compared to the days that the buses were scheduled to be available for operation, expressed as percent availability.

Average moving speed: The average moving speed of the buses while driving, not including stops and idle time. These data are collected using data loggers.

Bus Rapid Transit: Similar to light rail service in terms of frequency and convenience but retains the flexibility of bus service while avoiding the costly infrastructure of rail.

Daily event: A daily event is an average of all the drive events occurring within a 24-hour period. The data is collected using data loggers.

Data scrubbing: A series of validation tests to insure data was good and reliable. If any identified inconsistencies could not be reconciled, the data was discarded during this process.

Demand charge: Peak demand charges are levied by electric utilities on their commercial and industrial customers to recover their capital costs and are calculated based on the maximum amount of electrical power (in kW) the electric transit bus draws from the grid during a charging event. Demand charges are generally charged monthly based on the highest average kW measured in a 15-minute interval during the billing period.

Depot charging: Where the electric transit bus recharges at night or when the vehicle is not in operation. Electric transit buses charging overnight are designed to meet the daily range of a conventional diesel bus. Thus, batteries need to be sized in order to store enough energy to cover over 100 miles.

Docking: Overhead fast charging requires bus drivers to perform a docking procedure to properly align and connect the bus with the charging head.

Drive event: A drive event is defined by the following parameters – speed was greater than 0.1 mph and the bus must not have idled for longer than 10 minutes continuously. If the bus idled for longer than 10 min for any reason, the current drive event would end, and a new drive event would start when the bus exceeded 0.1 mph. These data are collected using data loggers.

Opportunity charging: Where the electric transit bus recharges while the vehicle is operating.

Revenue service: The time when a vehicle is available to the general public while collecting fare from passengers. When vehicles are operated for special events or are providing fare-free service, this is also considered revenue service.

TABLE OF CONTENTS

List of Tables

List of Figures

1. INTRODUCTION

1.1 Background

Greenhouse gases (GHG), climate change and emissions are becoming a prominent concern, both among the public and at public agencies. In addition, the fuel economy of a transit fleet directly affects fleet operating costs. The transit industry, federal, and local agencies have been focusing on new vehicle technologies and alternative fuels as a way to boost fuel economy, reduce operating costs, and reduce emissions. Many promising technologies have emerged, including hybrid, battery electric, and fuel cell buses.

Transit agencies and Original Equipment Manufacturers (OEMs) alike are interested in quantifying fuel reductions in extended field use. Evaluations of fleet vehicles are an effective tool for demonstrating the desired level of performance and reliability. This provides valuable in-use data on component systems and overall maintainability of commercial battery-electric vehicles.

San Joaquin Regional Transit District (RTD) was one of the first transit agencies in California to participate in an electric vehicle (EV) evaluation. RTD first launched its electric bus demonstration program in 2013 with the deployment of two zero-emission battery-electric Proterra buses through a grant from the California Energy Commission.[2] The project included the installation of an on-route FCr to charge the buses between trips. The buses and on-route FCr were monitored in operation for two years – from June 2013 to June 2015. This project demonstrated that electric transit buses can be a one-for-one replacement for diesel, CNG or hybrid buses, with significant operational cost and GHG savings.

1.2 Project Overview

In 2015, RTD was awarded a competitive grant and became one of ten agencies to receive a share of $55 million in funding through the Federal Transit Agency's (FTA) Low and No Emission Vehicle Deployment (LoNo) Program. This award allowed RTD to expand their electric transit fleet by purchasing five 40-foot Proterra Catalyst Fast Charge (FC) battery-electric buses and one additional on-route FCr. RTD purchased a total of ten Proterra Catalyst buses during this time. The remaining five buses were purchased using other grant awards that RTD received. Through the LoNo Program, the FTA was interested in further understanding the performance and reliability of battery-electric transit buses operating in revenue service. By collecting data over the course of 12 months, CALSTART evaluated the benefits of battery-electric transit buses against equivalent baseline vehicles.

During the 12-month demonstration period, CALSTART measured fuel consumption and other performance parameters from the electric buses using data collection equipment installed on the vehicles. CALSTART also monitored the maintenance of the vehicles and conducted driver, maintenance staff, and manager surveys to evaluate the user acceptance. Upon completion of the 12-month demonstration period, CALSTART analyzed the results in order to quantify the environmental, financial,

[2] Hulseman, Sarah. (Proterra). 2015. ***Proterra BE35 EcoRide Electric Transit Bus.*** California Energy Commission. Publication Number: CEC-ARV-11-014

and operational benefits of electric buses which may inform and motivate other transit districts to adopt battery-electric buses.

1.3 Goals of Study

The main goals of the study were:

1. Collect and analyze real-world performance data of five battery electric buses over 12 months of revenue service operation,
2. Assess user fleet acceptance of the electric transit buses,
3. Provide an unbiased evaluation of the costs to operate the electric transit buses.

1.4 Approach

CALSTART designed a Data Collection Test Plan to measure the vehicle's performance during the 12-month demonstration period and then monitored vehicle and engine performance using data logging equipment installed by Proterra, the OEM. All buses were equipped with data recording hardware before delivery to RTD. The data logger captured any data transmitted by the bus's Controller Area Network (CAN bus) through the on-board diagnostic (OBD) port. Additionally, the data logger was also capable of recording Global Positioning System (GPS) data through telemetry monitoring hardware.

Once the data loggers were installed, the buses were able to record and transmit data without further intervention, collecting data when the vehicle was turned on or charging. The data was continuously transmitted through a cellular network and stored on Proterra's online cloud platform called APEX. Data was regularly downloaded from Proterra Connect to monitor progress and to check for any errors that would require further attention. More information on performance data can be found in Section 4.2.

Manual records for operations and maintenance (O&M) were provided by RTD's Operations Superintendent throughout the demonstration period. Maintenance logs were provided in an Excel spreadsheet format and included information on work order type, status, creation date, and description of maintenance work. Using the work order types, maintenance work was divided into two categories – planned and unplanned maintenance. In addition, RTD provided manually collected data on their electricity consumption and cost to charge the buses. This also included fuel consumption and costs to operate the diesel-electric hybrid baseline vehicles. This information was used to study the impacts of peak demand charges. More information can be found in Section 5.4.

Customer feedback surveys were collected from the drivers, maintenance staff, and managers at the beginning and end of the demonstration. The surveys were created by CALSTART and administered by RTD. Surveys were provided in an online format through SurveyMonkey and physical copies were provided to RTD staff who did not have access to a computer. Surveys completed online were immediately made accessible through SurveyMonkey. Surveys completed manually were scanned and provided to CALSTART via email. More information on user acceptance surveys can be found in Section 5.5.

Using this broad data set, CALSTART evaluated the benefits of these electric buses in terms of fuel economy, vehicle usage, reliability, operational costs, and user acceptance. Furthermore, CALSTART examined how operational characteristics, such as opportunity fast-charging, can affect the agency's total cost of ownership.

2. STATE OF ELECTRIC BUS TECHNOLOGY

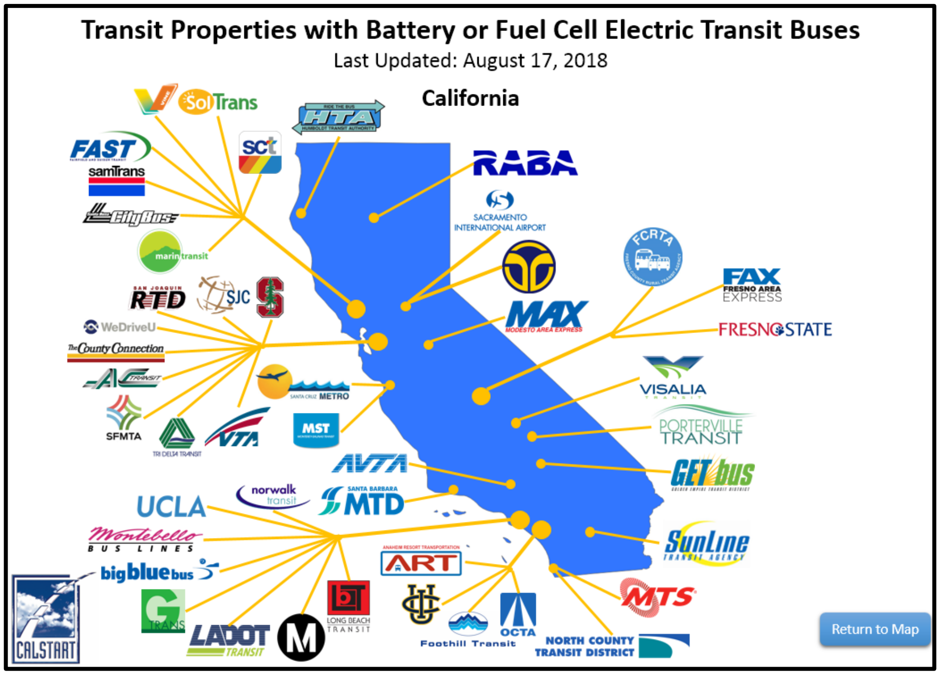
One of the goals of the FTA is to support the research, development and demonstration of low-and zero-emission technology in the realm of transportation. The FTA funds a variety of research projects to encourage the utilization of zero-emission bus (ZEB) technology. These programs include the LoNo Program, a funding opportunity for transit agencies for capital purchases of zero-emission or low emission transit buses that have been proven durable in testing but have not been widely deployed. Some transit agencies that have been beneficiaries of the grants in California are Long Beach Transit, Central Contra Costa Transit Authority and Orange County Transportation Authority with these agencies selecting battery-electric bus suppliers like Proterra, BYD, and New Flyer, amongst others. The total amount of funding that was allocated as part of the LoNo program in 2016 for the purchase of electric buses was $55 million[3]. FTA also works with selected agencies to evaluate the performance of the ZEBs compared to baseline buses operating under similar conditions. The evaluations advance the knowledge of zero-emission technologies to help other fleets that are planning to incrementally introduce the next generation of ZEBs into their operations or learn more about zero-emission vehicles.

California has been a major player in the zero emissions race with 47 transit agencies owning at least one ZEB and over 877 ZEBs in the state, either operating today, on order, or for future purchase through funding programs[4]. Figure 2.1 below highlights the transit agencies in the state of California that have ZEBs deployed or on order.

[3] Federal Transit Authority. https://www.transit.dot.gov/funding/grants/fiscal-year-2016-low-or-no-emission-low-no-bus-program-projects

[4] Popel, E. J. *Breathing Easy: A Survey of Zero Emission Buses Across America, Updated August 17th, 2018*. 23 (CALSTART, 2018). Accessed November 10, 2018

Figure 2.1: California Transit Agencies with Zero-Emission Buses



In 2018, the California Air Resources Board (CARB) approved a first-of-its-kind regulation in the United States that sets a statewide goal for public transit agencies to gradually transition to 100 percent zero-emission bus fleets by 2040. The Innovative Clean Transit regulation is part of a statewide effort to reduce emissions from the transportation sector, which accounts for 40 percent of climate-changing gas emissions and 80-90 percent of smog-forming pollutants. Eight of the 10 largest transit agencies in the state are already operating ZEBs, including battery-electric and hydrogen fuel cell vehicles. Deployment of zero-emission buses is expected to accelerate rapidly in the coming years – from 153 buses today to 1,000 by 2020, based on the number of buses on order or that are otherwise planned for purchase by transit agencies. Altogether, public transit agencies operate about 12,000 buses statewide.[4] University of California Irvine will become the first college campus in the nation to convert its buses to an all-electric fleet by acquiring 20 buses from BYD for $15 million.[5]

Recent reports of technology and fuels assessments indicate that battery and fuel-cell electric buses are commercially available for transit applications. The King County Metro Battery Electric Bus

[4] California transitioning to all-electric public bus fleet by 2040, California Air Resources Board, https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040. (accessed April 7, 2019)

[5] Metro For Transit & Motorcoach Business, UC Irvine is first college in nation to convert to all-electric bus fleet, January 24, 2017, http://www.metro-magazine.com/sustainability/news/719693/uc-irvine-is-first-college-in-nation-to-convert-to-all-electric-bus-fleet (accessed September 7, 2018)

Demonstration received funding from the FTA[6]. King County purchased three Proterra Catalyst battery-electric buses and installed a FCr. The average speed was recorded to be 14.8 mph and accumulated about 100,000 total fleet miles with an average monthly mileage of about 2309. The average availability of the bus was 80.6% with the main reason for decreased availability being general bus maintenance. The fleet averaged about 16.3 miles per charge with an energy consumption of 10,000 kwh to 19,000 kWh. The average energy delivered per charge was about 38.5kWh. The battery-electric fuel economy varied from a high of 17.6 mpdge to a low of 13.3 mpdge. About 183,225 kWh were consumed for a total mileage of 77,563. The battery-electric fleet average fuel cost was about $0.57/mi. The total maintenance cost per mile was $0.26/mile while the overall operations cost, which includes maintenance and fuel cost per mile, was $0.82/mile.

In 2014 Foothill Transit purchased a fleet of electric buses in the Los Angeles county region of California. Twelve Proterra battery-electric buses were purchased with installation of on-route FCrs. The data was collected and analyzed by NREL[7]. The buses averaged 13.9 hours of operational time per day with an average driving speed of 17.7mi/hr. The average efficiency was 2.16 kWh/mi over 399,663 miles with an average monthly mileage of 2,333 miles of use which equates to 17.8 mpdge. The charger transferred about 19.48 kWh energy per charge with an average of 13 charges per day and each charge lasting about 5 minutes. The buses travelled over 500,000 miles during the evaluation period.

The electric transit bus market is constantly evolving. Furthermore, Proterra now offers buses that can do both depot charging and on-route opportunity charging, allowing them to drive longer distances and still take advantage of opportunity charging, enabling greater flexibility for fleets. Lower lithium-ion battery costs and larger scale manufacturing are also making electric transit buses more cost competitive with conventional bus technology. Lastly, with the rapid development of charging technology, the industry is now seeing a shift towards standardized charging.

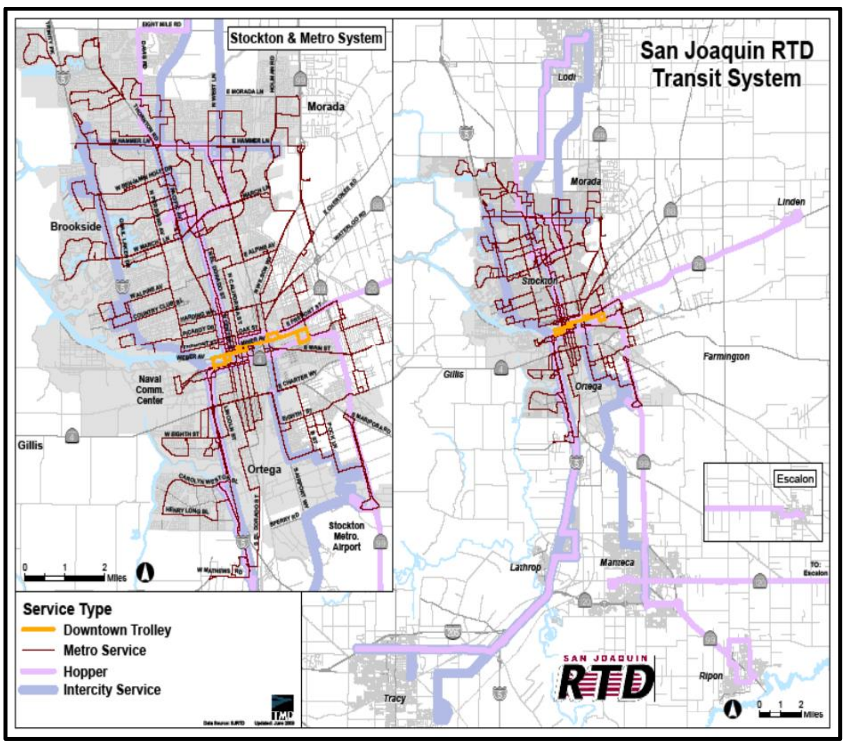
[6] Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses. United States: N. p., 2017. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/115086/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses-fta-report-no-0118.pdf.

[7] Foothill Transit Battery Electric Bus Demonstration Results: Second Report. NREL. https://www.nrel.gov/docs/fy17osti/67698.pdf

3. OVERVIEW OF RTD

RTD currently provides public transit to a growing population within San Joaquin County and the Stockton Metropolitan Area (SMA) as well as intercity, interregional, and rural transit services countywide. RTD serves a 1,426 square mile area with 30 metro routes, 5 Metro Express Bus Rapid Transit (BRT) Routes, 1 intercity fixed route, 9 Metro Hopper Deviated Fixed Routes, 8 County hopper Deviated Fixed Routes and 8 Commuter Routes typically operating between 3:00 AM and 10:20 PM. Of these routes, 21 buses run on the weekends, typically operating between 7:00 AM and 8:00 PM. Metro Express runs between 5:30 AM and 10:00 PM on weekdays. RTD's administrative office is located in Stockton, California and has a total annual ridership of about 3.4 million fixed route and Hopper trips and a commuter ridership of approximately 155,996 trips. Figure 3.1 shows a route map of RTD's transit system.

Figure 3.1: Map of San Joaquin RTD Transit System



The RTD system is solely a bus-based system. The system is linked by four major hubs: Downtown Transit Center (DTC) – found in downtown Stockton, the Mall Transfer Station – near the Weberstown and Sherwood Malls, the Hammer Transfer Station (HTS) located on the northern end of Stockton, and the Union Transfer Station (UTS) located on the southern end of Stockton.

RTD has implemented some key milestones that have shaped the service including, deployment of their first low emission bus in 2004, completion of the DTC in 2006, and the use of their hybrid buses for Stockton's first BRT service developed jointly with the City of Stockton in 2007.

RTD has been proactive in adopting technology that improves the quality of their community and reduces environmental impact. In 2013, RTD completed converting 100% of its SMA fleet to diesel-electric hybrid buses. Hybrids provide significant environmental benefits including lower emissions and reduced fuel consumption. In 2013, RTD launched its first two all-electric 35-foot Proterra buses and installed an on-route FCr with grant funding from the California Energy Commission. This represented the next step in clean, quiet, and economical transportation technology. These buses were monitored in operation for 2 years. In 2015, RTD was awarded a share of FTA's LoNo Program. RTD's grant award funded the purchase of five 40-foot Proterra Catalyst FC battery-electric buses and an on-route FCr. In addition to the LoNo Program, RTD received funding from the California Air Resource Board (CARB), San Joaquin Valley Air Pollution Control District (SJVAPCD), and the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) and purchased five more Proterra buses of the same model. RTD is dedicated to operating clean fuel technologies in its fleet and has committed to converting 100% of its bus fleet serving the city of Stockton to zero-emission electric buses by 2025.

4. DATA COLLECTION

During the 12-month demonstration period CALSTART measured energy consumption, energy efficiency, and other performance parameters from the electric buses using data loggers installed on the test vehicles. Additionally, CALSTART monitored the maintenance and operation of the vehicles through service logs and utility data provided by RTD. Lastly, driver, maintenance staff, and fleet manager surveys were conducted to obtain user acceptance data. The data collected as part of this project provides a comprehensive view into the performance, operation, and maintenance of battery electric buses in revenue service.

Though only five buses were purchased as part of FTA's LoNo Program grant funding, CALSTART collected and analyzed data on a total of ten electric buses deployed during the demonstration period. These ten buses included the additional five buses purchased through other funding sources (see Section 0). Therefore, all analyses conducted in this evaluation references the data collected on ten Proterra Catalyst electric buses that were owned and operated by RTD. This provided a strong sample size to perform the validation and assessment. Table 4.1 provides a summary of the evaluation and data collected during the demonstration period.

Table 4.1: Summary of Evaluation

Data Items	Value
Number of Buses	10
Demonstration period	09/01/17 - 08/31/18
Number of Months	12
Total mileage in revenue service	155,896
Average daily mileage per bus	150
Total operating time (hrs.)	4447

During the demonstration, Proterra transitioned to a new telemetry system that would replace their current system. Proterra made this transition out of necessity to handle the growing number of buses being tracking within their growing fleet. The new system, which was called APEX, made capturing data more reliable and included new tracking features that would provide transit agencies with improved data insights. The transition occurred between October 1, 2017 to November 31, 2017 during which time no data was captured from the electric buses. Therefore only 10 months of in-use performance data was collected during the demonstration.

The next sections will provide background information on the test vehicles, charging infrastructure, and their assigned routes. Both electric and baseline buses are described in detail.

4.1.1 Vehicle Descriptions

RTD deployed and operated ten 40-foot Catalyst Fast Charge (FC) electric buses manufactured by Proterra. This was Proterra's next generation vehicle and like the previous 35-foot EcoRide model, the Catalyst bus had a composite body for low weight and durability. The battery packs are all located under the bus, leaving the interior open for passengers. Figure 4.1 and Figure 4.2 show photographs of the interior and exterior of the electric bus.

Figure 4.1: 40-Foot Proterra Catalyst FC Electric Bus

Figure 4.2: (Top Left) Proterra Dashboard, (Top Right) Bus Interior, (Bottom Left) Driver Side Interior, (Bottom Right) Driver Side Instrument Panel

The bus integrates directly with the existing on-route FCr, allowing RTD to run both bus models (EcoRide and Catalyst) without needing to modify infrastructure. The Catalyst FC model is ideal for predictable transit loops, short-distance, and circulator routes. The 500 kW maximum charge rate allows the bus to fully recharge on-route in 5-13 minutes. See Table 4.2 below for a list of performance specifications for the Catalyst FC electric bus.

Table 4.2: Catalyst FC Model Performance Specifications

Catalyst 40-ft FC Model Electric Bus - Performance	
Projected Altoona Efficiency	1.7 kWh/mile
Top Speed	65 mph
Acceleration	6.8 seconds
Total Energy	79 kWh
Nominal Range	62 miles
Standard Charge Time	13 min
Charging Rate - In Depot	60 kW
Charging Rate - On Route	500 kW

In 2013, RTD converted 100% of its SMA fleet to diesel-electric hybrid buses which used less fuel and significantly reduced emissions than previous diesel buses. Therefore, the comparable baseline bus selected for this study was a 2014 40-foot Gillig diesel-electric hybrid bus with similar duty cycles. The diesel-electric buses were randomly dispatched on all routes whereas the electric buses only operated on a select number of routes (specifics are provided in Section 4.1.3). Table 4.3 provides bus descriptions that compare the electric and diesel-electric hybrid buses that were studied during this evaluation.

Table 4.3: Battery-Electric and Diesel-Electric Hybrid Bus System Descriptions

Vehicle System	Electric	Diesel-Electric Hybrid
Number of buses	10	71 Active[8]
Bus manufacturer/model	Proterra/BE40 Catalyst FC	Gillig
Model year	2016	2006-2014
Length	42.5 FT	29 FT, 35 FT, 40 FT
GVWR/curb weight	38,000 lb / 25,746 lb	39,600 lbs/ 27,300 lbs
Wheelbase	243 in.	279
Passenger capacity	Seated = 40, Standing = 37	Seated = 40, Standing = 29 Varies from MY of bus, due to GVWR rating
Motor or engine	Permanent magnet drive motor	Cummins ISB/ISL/ISXB6.7 280 HP
Rated power	220 kW peak (295 HP)	290-320 HP
Battery size (electric) Fuel capacity (diesel-electric)	79 kWh total energy	75-125 gals ESS with EP 40 Drive
Bus purchase cost	$874,437	$455,000

The buses were put into operation on a number of different routes. Table 4.4 provides a summary of the vehicles evaluated during the demonstration period, providing information on the date of deployment, typical route assignment, and naming convention.

[8] Additional 12 (2018 Gillig Commuter buses) will be active Nov 5, 2018

Table 4.4: Summary of Test and Baseline Vehicles

Vehicle #	Vehicle Name	Model Year	Model	Deployment Dates	Program	Current Routes
16401	EV-3	2016	Catalyst FC	9/1/2017	SMA Fixed Route	578/580
16402	EV-4	2016	Catalyst FC	9/1/2017	SMA Fixed Route	578/580
16403	EV-5	2016	Catalyst FC	9/3/2017	SMA Fixed Route	578/580
16404	EV-6	2016	Catalyst FC	9/3/2017	BRT	44
16405	EV-7	2016	Catalyst FC	9/3/2017	BRT	44
16406	EV-8	2016	Catalyst FC	9/28/2017	BRT	44
16407	EV-9	2016	Catalyst FC	10/26/2017	BRT	44
16408	EV-10	2016	Catalyst FC	10/31/2017	BRT	44
16409	EV-11	2016	Catalyst FC	1/8/2018	BRT	44
16410	EV-12	2016	Catalyst FC	9/3/2017	BRT	44
134240	Baseline	2016	Gillig	8/05/2013	SMA Fixed Route	Varies Daily

4.1.2 Charging Infrastructure

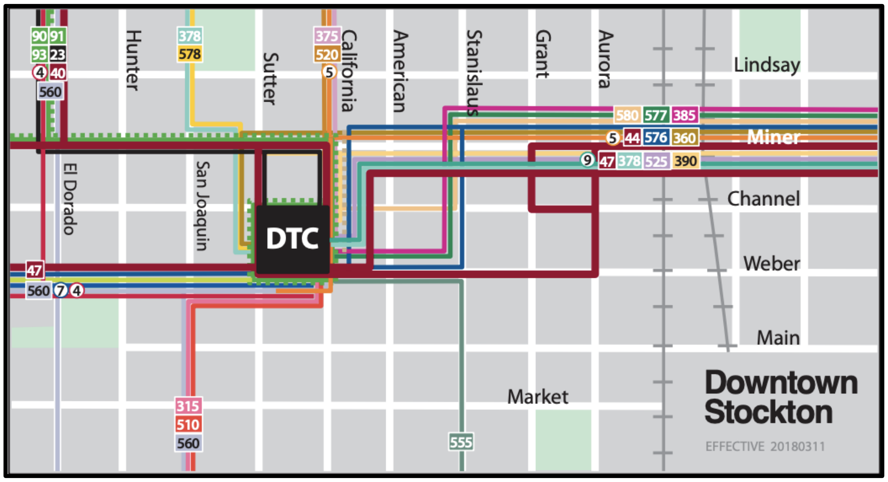
RTD's on-route FCrs are located at the DTC in Stockton. The DTC is Stockton's downtown public transit hub. Nearly all routes connect at the DTC, with 20 sheltered, off-street bus stops on two passenger boarding platforms.[9] The placement of their on-route FCr at a main transit hub allows RTD to have flexibility to dispatch electric buses onto different routes. Figure 4.3 and Figure 4.4 show a street view and system map view of the DTC, respectively.

Figure 4.3: Downtown Transit Center in Stockton, CA

[9] Downtown Transit Center, http://sanjoaquinrtd.com/dtc/default.php

Source: Google Maps Street View

Figure 4.4: RTD System Map of Downtown Transit Center (courtesy of RTD)



The DTC consists of two Eaton 500 kW overhead chargers, with two charge heads located on parallel parking stalls. During the 2013 demonstration, RTD was the fourth location to go through the charger installation process with Proterra, and the first to receive an Eaton charger. For this demonstration, a second on-route FCr was installed at the DTC to expand the service routes of the electric buses. Before the second charger was installed, the first charger was disconnected and also repositioned. Therefore, all electric buses were pulled out of service prior to the start of the demonstration. The first charger was installed at the DTC pickup stall for Route 578/580 and the second charger was installed at the DTC pickup stall for BRT Route 44. Figure 4.5 shows one of the overhead FCrs at the DTC during a charging session.

Figure 4.5: Proterra Bus Receiving On-Route Fast Charging at the Downtown Transit Center

The system is comprised of the charger itself and the docking station manufactured by Proterra. The supply panel equipment is located on the far side of the parking stalls. Figure 4.6 shows the electric supply panel for the charger.

Figure 4.6: On-Route Overhead Charger Supply Panel

The charger provides the electrical energy and the docking station transfers the energy to the bus energy storage system (ESS). The two chargers operate as separate units with a dedicated control system for each. A common communication network serves both units with sensors to detect which charge head a bus is approaching to enable proper bus-to-charger communication for docking. The overhead semi-autonomous system is capable of fully charging the buses in 10 minutes or less when an electric bus pulls into the parking stall below the charge head. For RTD's BRT Route 44, the buses typically have a 10 minutes layover time scheduled to charge before starting the next route. Therefore, issues that prolonged charging events usually caused delays in the operating schedule. Drivers were trained not to leave the charge station unless the bus had sufficient charge for the route.

Each RTD driver assigned to drive an electric bus was provided with additional training. The training materials were provided by Proterra and covered how to safely operate the electric bus during service which includes start-up procedures, description of dashboard controls and gauges, and the approach and docking procedures for on-route FC station. The training materials can be seen in Appendix F: Proterra Training Materials. Figure 4.7 shows the DTC with two electric buses positioned under the charging heads.

Figure 4.7: Two Buses Charging at the DTC On-Route Overhead FCrs

RTD reported that their experience with the overhead chargers has been faced with challenges. These challenges include: maintenance, reliability, and peak demand charges. This will be discussed in more detail later in the report. Even though the DTC had two separate charging heads, each one was dedicated to specific routes and therefore, if a charger required downtime, dispatch typically needed to swap out the electric buses with their conventional diesel-electric hybrid buses.

In addition to the two on-route FCrs, RTD also installed a 60 kW depot charger located at their maintenance facility that was only used for maintenance and diagnostic checks.

4.1.3 Route Assignments

RTD's electric bus fleet operates out of its Regional Transportation Center (RTC). The service consists of five primary routes: The Airport Way Corridor BRT Express Route 44, Stockton Metro Area (SMA) Fixed Route 566, 577, 578, and 580.

RTD primarily assigns its electric bus fleet to BRT Route 44. BRT is similar to light rail service in terms of frequency and convenience but retains the flexibility of bus service while avoiding the costly infrastructure of rail. RTD's BRT service operates on El Dorado and Center Streets and Pacific Avenue, connecting the Downtown Transit Center and Hammer Lane.

Spanning approximately 14.4 miles in distance, BRT Express Route 44 extends to serve passengers from the DTC in Central Stockton to as far south as Qantas Lane near Arch-Airport Road. This route enables people who work or study at locations such as PG&E, Dorfman Pacific, and San Joaquin County Office of Education, to commute rapidly and economically, therefore attracting a high ridership. Between each loop the bus will stop at the DTC for fast charging. Figure 4.8 shows the route map and Table 4.5 describes the duty cycle characteristics of BRT Route 44.

Figure 4.8: Map for BRT Express Route 44 (courtesy of RTD)

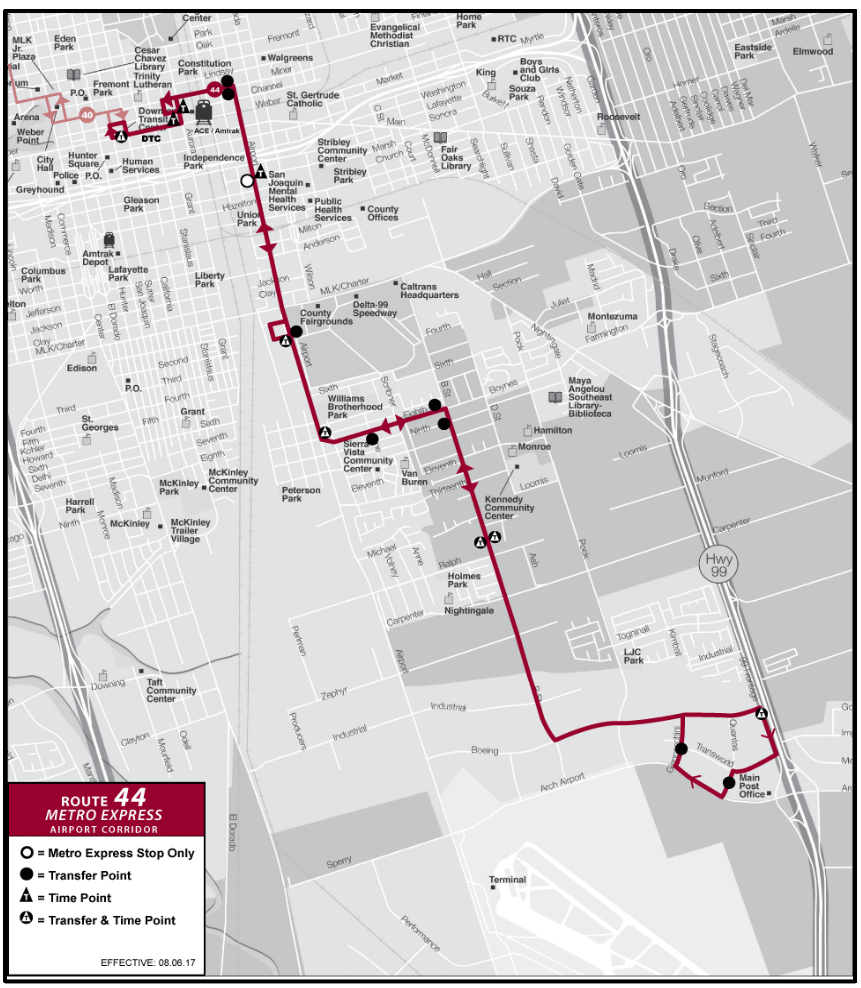


Table 4.5: Characteristics of BRT Express Route 44

Route 44	
No. of Electric Buses on Route	4
Total Time (mins)	48
Loops Per Day	76
Total Length (Miles)	14.4
Number of Stops	22
Number of Passengers Per Day (Weekdays)	881

SMA Route 577 is a shorter 9.7 mile route that transports passengers between the DTC and Waterloo. This route consists of 25 total stops and has the lowest ridership of the electric bus routes. Figure 4.9 shows the route map and

Table 4.6 describes the characteristics of SMA Route 577.

Figure 4.9: Map of SMA Route 577 (courtesy of RTD)

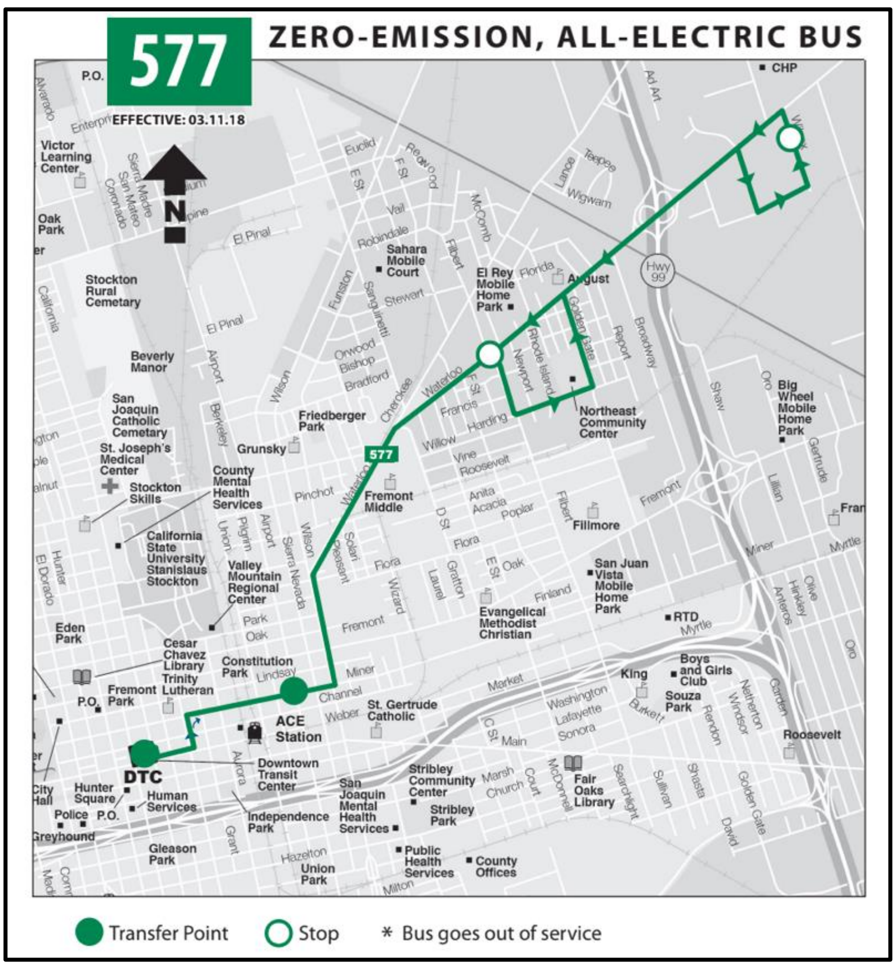


Table 4.6: Route Characteristics of SMA Route 577

Route 577	
No. of Electric Buses on Route	3
Total Time (mins)	30
Loops Per Day	16
Total Length (mi)	9.7
Number of stops	25
Number of Passengers Per Day (Weekdays)	34

Route 578 is 17.7 miles in length and it was the longest route that the electric buses operated on during the demonstration. This route has a total of 77 stops and has a medium to high ridership level. Figure 4.10 shows the route map and Table 4.7 describes the characteristics of SMA Route 578.

Figure 4.10: Map of SMA Route 578 (courtesy of RTD)

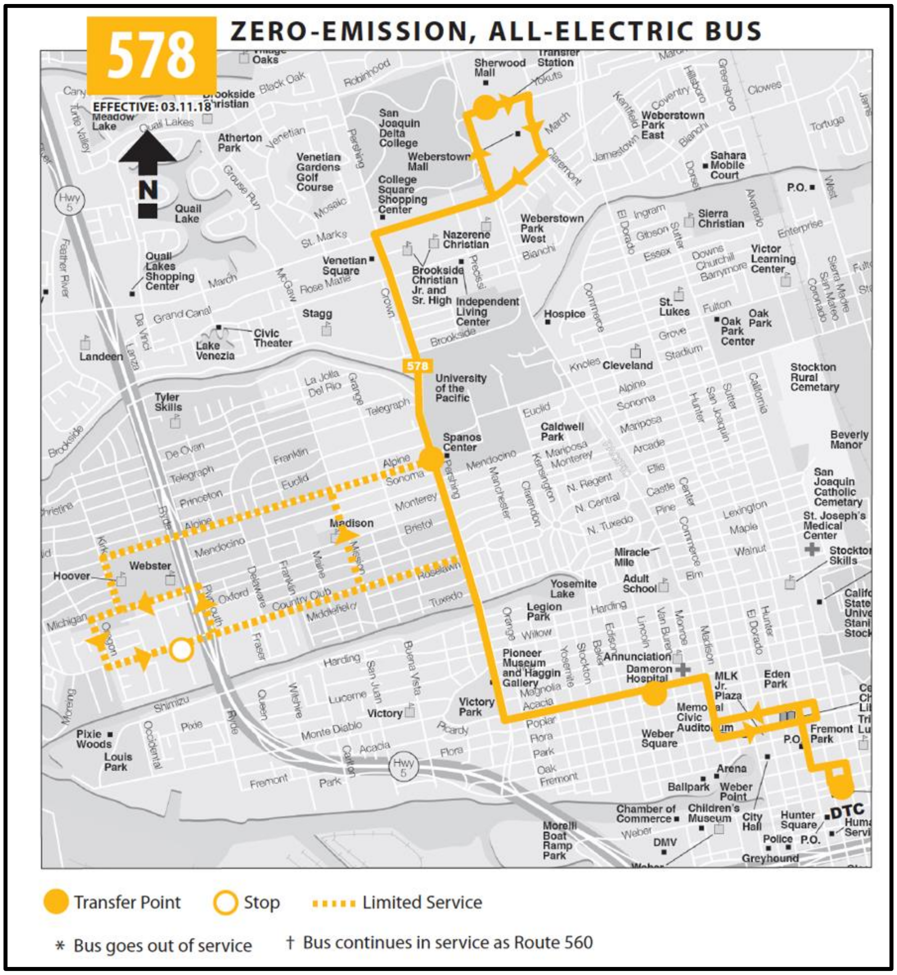


Table 4.7: Route Characteristics of SMA Route 578

Route 578	
No. of Electric Buses on Route	2
Total Time (mins)	68
Loops Per Day	14
Total Length (mi)	17.7
Number of stops	77
Number of Passengers Per Day (Weekdays)	316

The agency also operated the electric buses on SMA Route 560 and 580 which are not discussed in detail in this report. For more information on these routes, please see Appendix D: Route Information.

The electric buses are randomly dispatched on these select routes based on battery range and accessibility to charging. It is important to note that not all electric buses are put into service each day, allowing for reserve in case a bus needs to be pulled out of service for maintenance. Table 4.8 shows a summary of the route assignments, duty cycle, and ridership.

Table 4.8: Route Assignments, Duty Cycles, and Ridership

			Number of Stops		Number of Loops		Route Length (1 loop)	Running time		Number of Passengers per day (FY18, Q3)
Route	Number of buses	Comments	No. Stops Outbound	No. Stops Inbound	Trips-Direction 1	Trips per Direction 2	(Miles)	Running time Direction 1	Running time Direction 2	(Weekdays)
44	4	N/A	10	12	39	37	14.4	24	24	874
560	2	Two buses not operating simultaneously (no service during midday)	27/21	24/17	8	9	6.65	20/14	25/18	72
577	3	Three buses not operating simultaneously (no service during midday)	13	12	7	9	9.7	15	15	31
578	2	Two buses not operating simultaneously (one interlines with other route)	36/18	31/18	13	14	17.7	32/23	36/26	257
580	2	Two buses not operating simultaneously (one interlines with other route)	20	21	13	13	11.5	21	22	108

4.2 Performance Data

Throughout the twelve-month demonstration phase, CALSTART collected detailed data on vehicle performance, fuel savings, and user feedback. Data was collected through a variety of channels, including:

- *Electronic data* collection through data loggers
- *Manual data* collection through service records, fuel logs, and utility bills for both baseline and electric buses.

4.2.1 Data Logger Equipment

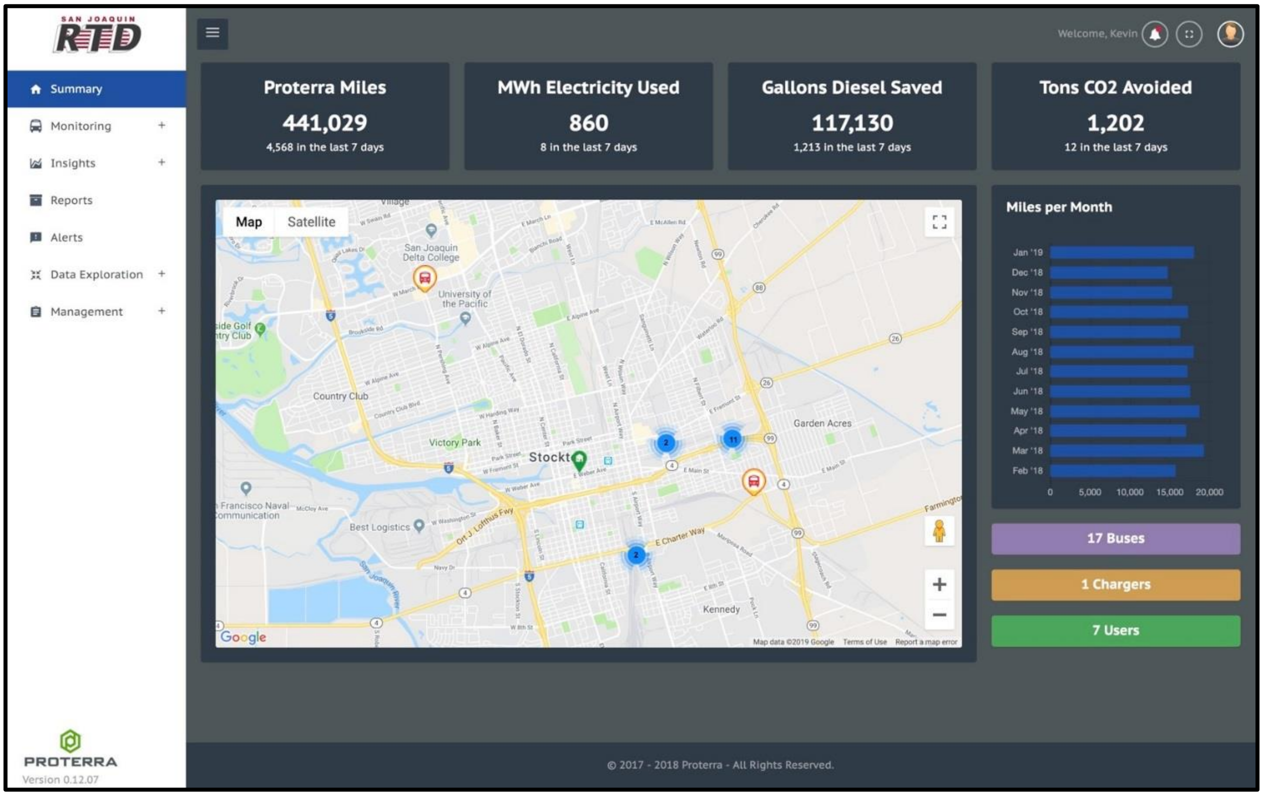
All Proterra buses were equipped with a UniCAN data logger used to track vehicle performance and provide telematics. Proterra installed the data logger hardware that acquires vehicle data from in-vehicle networks and on-board diagnostic sensors. Data was uploaded to secure servers for storage and made available for access through Proterra's cloud-based data platform – APEX. This connected vehicle intelligence system displayed historical and real-time performance on RTD's battery-electric transit buses. The UniCAN data logging system is capable of capturing thousands of messages per minute at a multitude of sample rates per each device. A brief overview is below:

- Datalogger – UniCAN hardware
- PCAN – 250 kB/s
- Raw data with varying sample rates.
- The 2 Hz .csv files, are sampled every 0.5 seconds.

4.2.2 In-use Performance Data

Through Proterra's telematics and data collection hardware, CALSTART was provided with the metrics that were needed to evaluate the in-use performance of the electric buses. In-use performance data from each bus was automatically recorded and transmitted via a cellular network to a secured server. The data became immediately available through Proterra's online portal, APEX. The portal had a user-friendly dashboard and included all recorded data that was available for download. Data within APEX was grouped into different sections based on the information that the data logger relayed to the server. Access to APEX was used periodically throughout the demonstration to validate and spot-check the data for accuracy. Figure 4.11 shows a screenshot of the APEX dashboard when logged in.

Figure 4.11 : APEX Dashboard



APEX gave access to the general information of the buses such as the name of the bus, the gateway serial number, the model, the configuration number and the VIN number. Performance data parameters were categorized by sections within the data platform. The sections included: Environmental Impact, Fleet Usage, Bus Usage, Drive and Charge, and Fleet Efficiency. Data reports could be customized depending on what was needed in the analysis. Customization allowed us to select a specific bus, time period, and reporting format when exporting data.

Different data streams could easily be downloaded from the Proterra dashboard in a spreadsheet format for further analysis. Data could be exported in either a raw or formatted format. Almost all the data parameters that appear in the dashboard could be downloaded in to order to see the daily breakdown for further analysis. Table 4.9 below outlines the key performance parameters that were collected during the demonstration.

Table 4.9: Performance Parameters to be collected by UniCAN data logger

Parameters Collected	Units
Mileage	mi
Energy Charged	kWh
Operating Time	Hrs
Charging Sessions	-
Charging Time	mins
Daily MPGe	gallons
Speed	mph
Fuel Economy	kWh/mi
Fuel Cost	$
Availability	
Maintenance	$/mile
Maintenance-Propulsion System Only	$/mile
Fuel Economy	kWh/mile
Energy Consumed	kWh
Powertrain Consumption	kWh
Energy Regen	kWh
Power Steering Consumption	kWh
AC consumption	kWh
DC 1 Consumption	kWh
DC 2 consumption	kWh
Defroster Consumption	kWh
Ambient Temp	F or C
Fuel saved	Gallons
CO2 Saved	Metric Tons
Duration	s
Energy Delivered	kWh
Current	A
Power	kW
State of Charge (SOC)	%
Moving Time	s
Non-Moving Time	s
Energy	kWh
Discharged Energy	kWh
PS Consumption	kWh
Longitude	Degrees
Latitude	Degrees

The performance parameters displayed in Table 4.9 contain both primary or raw data collected directly from the CANbus and derived data that is calculated using the raw data. Proterra also generated weekly reports which provided pre-calculated metrics of interest that aided in the overall performance analysis. Weekly reports were provided for each bus at the end of each quarter or when specifically requested. Figure 4.12 shows a sample of one of the weekly reports that were provided during the evaluation.

Figure 4.12: Sample Weekly Report Provided by Proterra

Proterra Weekly Report v05

PROTERRA

CONFIDENTIAL

General Info: STO_EV2, 2017-01-09 to 2017-01-15

Table 1. Operation Overview for VIN 1M9TG16J0CS816016

Distance [mi]	537.3
Average Speed [mph]	11.9
Running Time [hr]	51.3
Max Speed [mph]	55.3
Moving Time [%]	55
Stopped Time [%]	33
Charging Time [%]	12
Average Charge Time [min]	6.6
Number of Charges	43
Total Charge Energy [kWh]	1118.2
Average Efficiency [kWh/mi]	2.08
Avg Efficiency [MPGe] (37.64 kWh/gal)	18.1
Regen Off [%]	0

Table 2. Temperature Data

Temperature	Min [C]	Max [C]	Average [C]
Ambient	3	19	12.8
Coolant	9	28	21
DCDC Controller	5	33	24.6

Table 3. HVAC Operation Modes

Fan Mode [%]	44
Heat Mode [%]	56
Cool Mode [%]	0

Table 4. Auxiliary Loads On Time

Power Steering On [%]	68
Air Compressor On [%]	16
Defroster On [%]	0
HVAC On [%]	49
Radiator Fan On [%]	0
Main Coolant Pump On [%]	100

Table 5. Powertrain Data

Shifts per Mile	6.2
Time in First Gear [%]	29.9
Time in Second Gear [%]	70.1

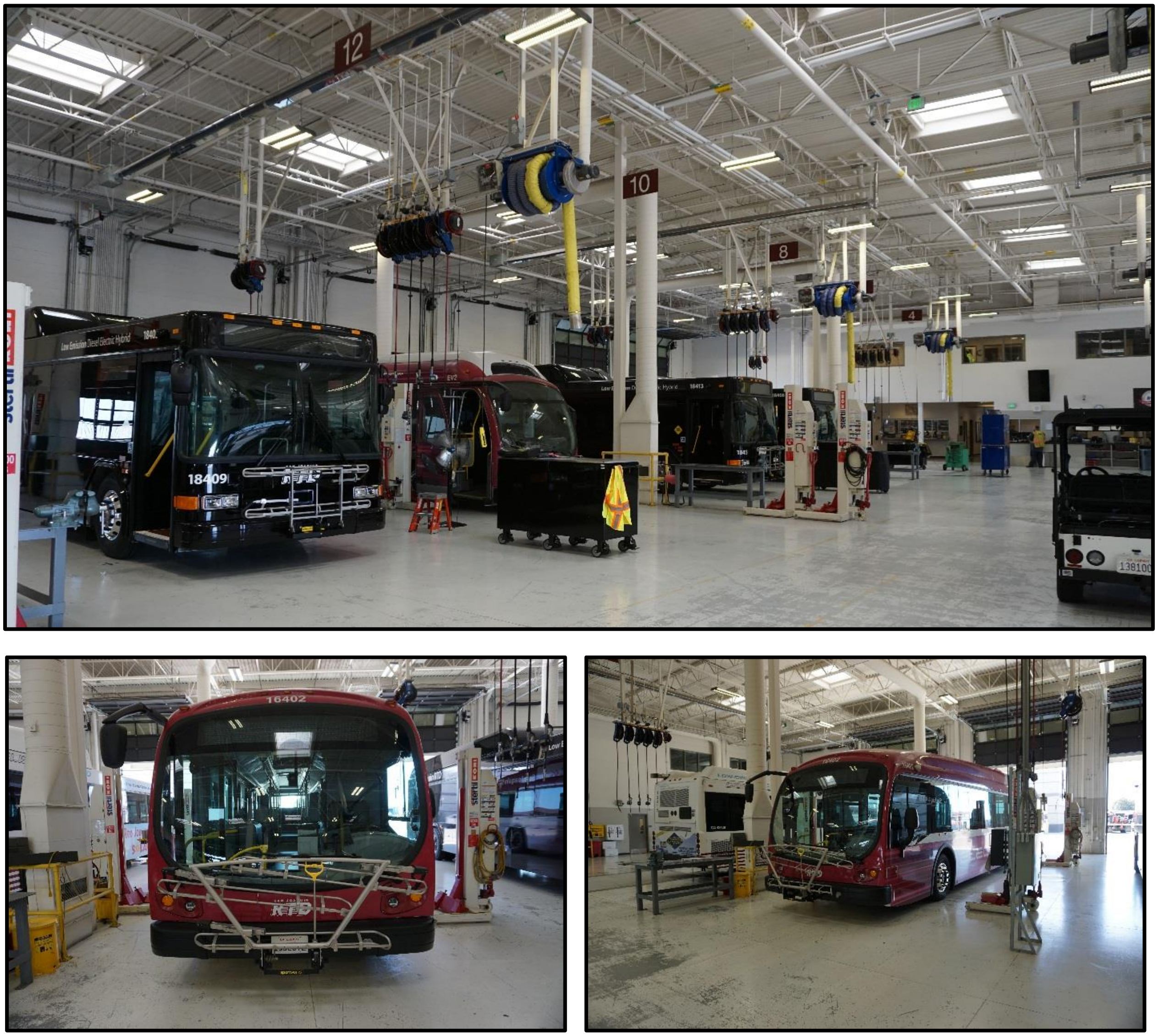
Table 6. Daily Charging Statistics

Date:	Runtime [hr]:	Charges [#]:	Charged Energy[kWh]:	Distance [mi]:
01/09	12	13	258	136.8
01/10	8.7	8	244.4	113.2
01/11	7.8	2	36.7	6.6
01/12	7.9	6	197.2	86.6
01/13	15	14	382	194.1
01/14	0	0	0	0
01/15	0	0	0	0

4.3 Operations and Maintenance Data

RTD's maintenance facility is located at the RTC. The RTC is a 136,000 square-foot centralized facility that consolidates the operations, maintenance, and administrative functions of the San Joaquin Regional Transit District. The maintenance facility within RTC consists of 19 bus bays with two 90-ft pits. The facility can also accommodate small cut-away type vehicles and up to 60-ft articulated buses. Figure 4.13 shows photos of the maintenance facility interior.

Figure 4.13: (Top) RTC Maintenance Facility Interior, (Bottom Left) Bus in Maintenance Dock – Front, (Bottom Right) Bus in Maintenance Dock - Side



A breakdown of their maintenance staff is shown in Table 4.10.

Table 4.10: Maintenance Staff Breakdown

Maintenance Role	Number of Staff
Utility Workers	10
Mechanics	15
Electronics Techs	2
Facility Techs	5

Transit agencies consider expected maintenance costs and vehicle reliability when choosing to invest in a new bus technology. True costs and reliability may not be revealed in a short bus test. In order to better characterize these metrics, CALSTART collected and analyzed costs and reliability data for the full duration of the demonstration. Maintenance records were collected by RTD and comprised of internal service records on both the electric buses and diesel-electric baseline buses also. Additionally, RTD provided operational data that included utility costs, energy rate structures, mileage, and cost per mile comparisons between the electric buses and their hybrid counterparts.

4.3.1 Bus Use and Availability

This section summarizes data collection on bus usage and availability for the electric buses and baseline buses. Bus use and availability are indicators of reliability. Lower bus usage may indicate downtime for maintenance or purposeful reduction of planned work for the buses. Availability of electric buses can be affected by the reliability of the charging infrastructure. Since the electric buses lacked the range to operate throughout the day without access to opportunity charging, downtime of infrastructure had major impacts to bus usage and availability.

RTD manually collected data on maintenance which was split within two categories: planned or preventative maintenance (PM) and unplanned maintenance. The PM evaluated the vehicle state, including brake condition, tire condition, and other review items. RTD scheduled preventative maintenance inspections (PMIs) for the electric buses at the same mileage intervals as the baseline buses. In addition, RTD performed any unplanned service, which included “road calls.” A “road call” is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the problem with the bus could be repaired during a layover and the schedule was kept, this is not considered a road call.

RTD kept a log of the maintenance performed on each of the buses during the evaluation period. The log was sorted into scheduled maintenance and unscheduled maintenance. RTD provided the service logs for five electric buses and one diesel-electric baseline bus. Table 4.11 shows a sample of the maintenance data that was collected and reported by RTD.

Table 4.11: Maintenance Data Captured by RTD

1					2013 40 Ft Gillig Diesel Electric Hybrid						
2											
3	Work Order	WO Create Date		WO Stat	Express Work Or	Equipment Co	Work Order Title	WO Type Code	Created By	WO Maint Type C	Scheduled/Unscheduled
4	1149299	2.01806E+13	6/18/2018	Closed		13420	WC POWER SWITCH LIGHT INOP	Corrective	GFIFITA		Unscheduled
5	1144219	2.01805E+13	6/19/2018	Closed		13420	TRIANGLE BOX MISSING SEAL	Corrective	GFIFITA		Unscheduled
6	1143559	2.01805E+13	6/20/2018	Closed		13420	BODYFLUIDS IN BUS	Corrective	JGONZALEZ	Minor Repair	Unscheduled
7	1141301	2.01804E+13	6/21/2018	Closed	T	13420	AIR DRYER CONSTANT LEAKING	Corrective	GFIFITA		Unscheduled
8	1138942	2.01804E+13	6/22/2018	Closed	T	13420	AIR LEAKS AROUND AIR DRYER AREA	Corrective	GFIFITA		Unscheduled
9	1135181	2.01804E+13	6/23/2018	Closed	T	13420	TRIM WON'T VALIDATING PASSES	Corrective	GFIFITA		Unscheduled
10	1133359	2.01803E+13	6/24/2018	Closed	T	13420	CHECK ENGINE / STOP SYSTEM LIGHT:	Drivers Defect	BMACHADO		Unscheduled
11	1129168	2.01803E+13	6/25/2018	Closed		13420	CANNOT SEE BUS ON DISPATCH MAP	Drivers Defect	DDOMINGUEZ		Unscheduled
12	1127740	2.01803E+13	6/26/2018	Open		13420	C PM DEFECTS	Drivers Defect	WDICKERSOI	Defect	Unscheduled
13	1127739	2.01803E+13	6/27/2018	Open		13420	2013 GILLIG LOW FLOOR "C" INSPECTI	Pit Defect	WDICKERSOI	C Inspection	Scheduled
14	1127679	2.01803E+13	6/28/2018	Closed	T	13420	QC INSPECTION	Pit Defect	WDICKERSON		Scheduled
15	1121759	2.01802E+13	6/29/2018	Closed	T	13420	L/WINDOW #7 FRAME CAME LOOSE	Pit Defect	GFIFITA		Scheduled
16	1119943	2.01802E+13	6/30/2018	Closed		13420	R/SIDE MIRROR NEEDS ADJUSTMENT	Pit Defect	GFIFITA	Minor Repair	Scheduled
17	1118500	2.01802E+13	7/1/2018	Closed	T	13420	RADIATOR FANS RUN CONTINUOUSLY	Pm Defects	GFIFITA		Scheduled
18	1117459	2.01802E+13	7/2/2018	Closed	T	13420	FAN COMES ON HIGH INTERMITTINLEY	Preventative	JVCAMP		Scheduled
19	1115420	2.01802E+13	7/3/2018	Closed		13420	L/SIDE WINDOW #7 FRAME LOOSE	Superintendent QC	GFIFITA		Scheduled
20											
21	Total	Unscheduled	Scheduled	Roadcall							
22	16	9	7	0							

4.4 User Acceptance Data

Drivers, maintenance staff, and managers interact directly with the vehicles, and often have input that would not otherwise be reflected in the above analyses. CALSTART used surveys and interviews to capture these experiences, providing additional insight into how the vehicles performed during the demonstration.

The purpose of the user acceptance evaluation was to assess initial and final impressions of the vehicle from the drivers, mechanics, and managers' point of view. Comparisons were made between the electric bus and the baseline diesel-electric hybrid bus to determine the advantages and disadvantages during normal everyday use. Driver surveys assessed the performance of the electric bus. Maintenance staff surveys (see Appendix B) assessed the serviceability and maintainability of the bus during in-use operations. The fleet manager surveys (see Appendix C) gauged their impressions of the performance of the vehicle as a daily member of the fleet. CALSTART prepared surveys for each group, drivers, maintenance staff, and fleet managers, to best reflect the needs and goals of the project.

The surveys were administered in two rounds. The first round of surveys were distributed in December 2017, at the beginning of the evaluation. The second round of surveys was distributed in August 2018, near the end of the evaluation. This was done to capture whether the transit agency's initial impression of the electric buses shifted over time. Surveys were distributed and collected by RTD using the online survey platform, SurveyMonkey, which allowed for easy distribution and collection. CALSTART also provided RTD with hard copies of each survey in case members of the RTD staff did not have access to a computer during work hours. RTD provided CALSTART with scanned copies of each survey if they were completed manually.

4.4.1 Driver Evaluation Surveys

Drivers were asked to complete a survey by rating the vehicles in key performance areas compared to typical baseline trucks. Due to the subjective nature of driver impressions, a simple, relative rating scheme of “better”, “same”, or “worse” was used to compare performance characteristics to the baseline vehicles. The driver evaluation survey can be found in *Appendix A: Driver Evaluation Survey.*

4.4.2 Maintenance Staff Evaluation Surveys

To evaluate the serviceability and maintainability of the vehicles, maintenance staff were asked to provide subjective feedback on various service and maintenance aspects of the electric bus compared to a similar baseline vehicle. Mechanics were surveyed at the beginning and near the end of the testing period. The mechanic evaluation survey can be found in Appendix B: Maintenance Staff Evaluation Survey.

4.4.3 Management Evaluation Surveys

The managers have a unique position and perspective on the battery electric buses and therefore will be surveyed along with drivers and mechanics at the beginning and end of the testing period. The focus areas for rating the vehicle were driver acceptance, safety, reliability, overall maintenance issues, and perceived fuel economy improvement.

In looking at driver acceptance, maintenance issues, and fuel consumption improvement, the managers essentially summarized information from the drivers, mechanics, and RTD personnel, respectively. Adding safety and reliability to the list speaks to the manager’s capability of comparing the electric buses to the rest of the fleet. The manager evaluation survey can be found in Appendix C: Management Evaluation Survey.

5. ANALYSIS

The large volume of data collected through the data loggers during this project was analyzed to better understand how the electric buses operated. In addition, more limited data on the conventional buses was compiled by RTD so that performance of the electric buses could be compared to conventional ones. For the electric buses, CALSTART focused on how much the buses were utilized, how they consumed energy, how they charged, what factors caused differences in efficiency, and what challenges were encountered during operation.

5.1 Methodology

The electric transit bus demonstration period was from September 1, 2017 to August 31, 2018, during which the combined distance travelled by the ten test vehicles was 155,896 miles over 1,038 active days in revenue service operation. Active days are defined as days when the bus travelled more than 10 miles. This is discussed in more detail in section 5.2.1. As mentioned in Section 0, there was no data collected on the buses between October 1, 2017 to November 31, 2017 as Proterra transitioned to a new telematics platform. The electric buses continued to operate in revenue service during this time period and manual data was still collected through RTD. January 2018 was the first full month that all electric buses were in revenue service and the overhead FCr was fully operational. The following sections will discuss how the buses performed over the course of the 12-month demonstration period.

5.1.1 Drive Events versus Daily Events

Two types of data sets were collected through APEX – Daily Drive Summary and Drive Event data. Both data sets had a combination of raw and process data parameters. Figure 5.1 and Figure 5.2 show snapshots of the daily event and drive event data as seen on the portal.

Figure 5.1: Daily Drive Summary Data on Proterra Connect

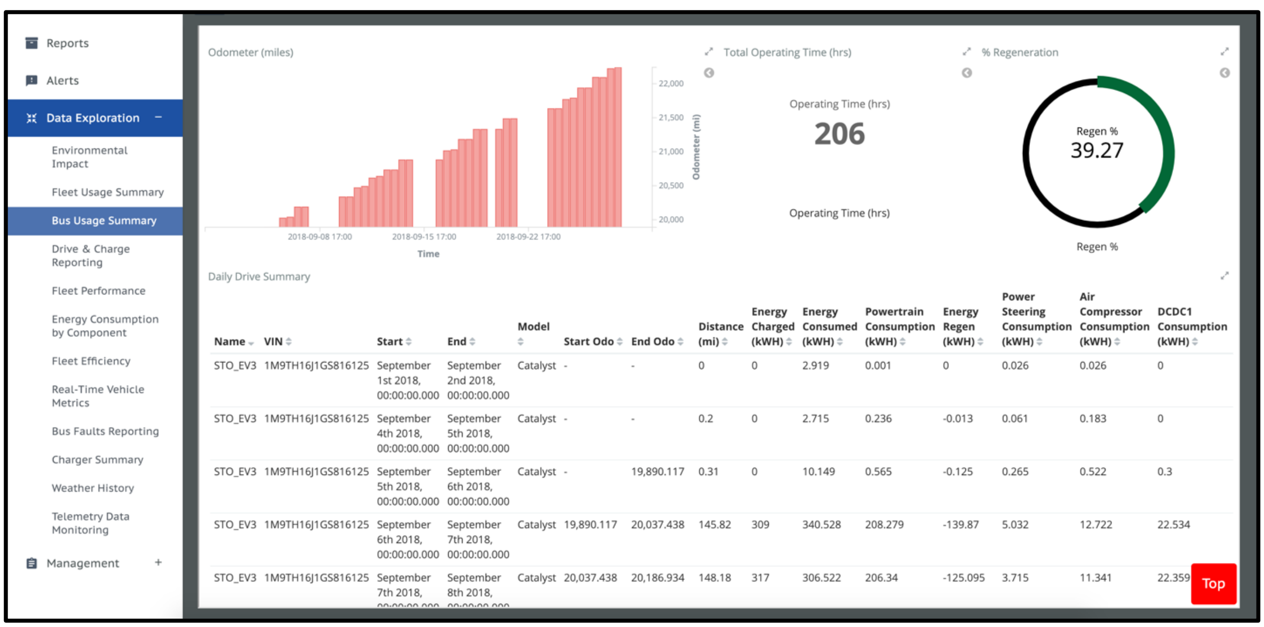
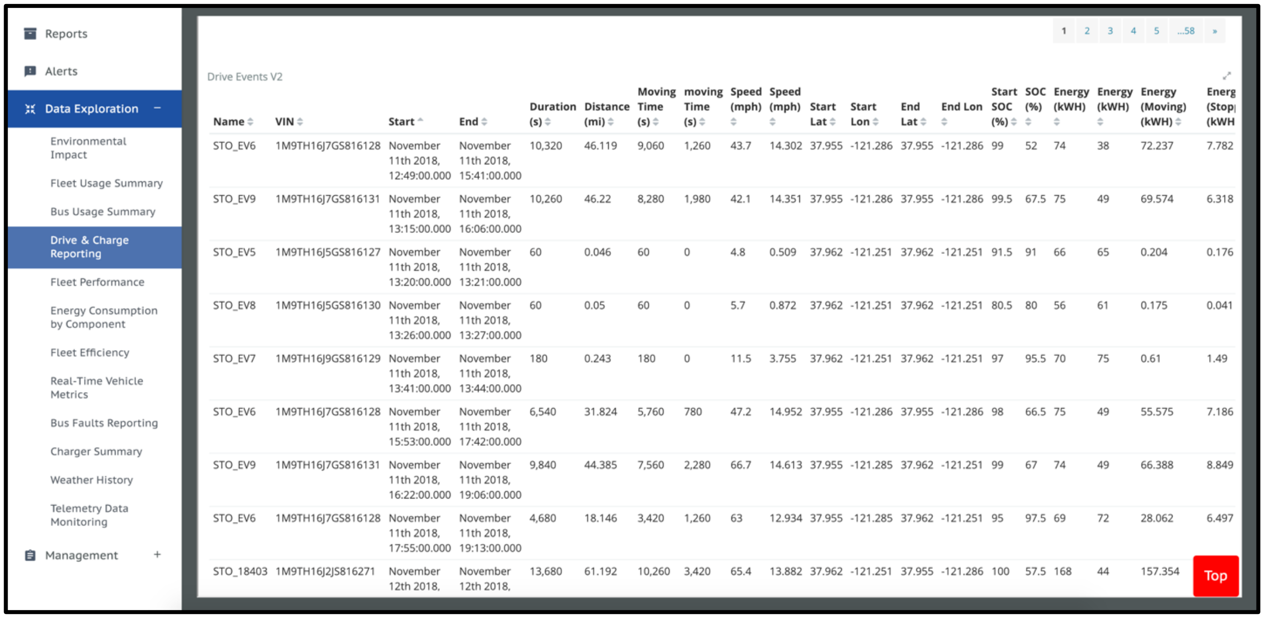


Figure 5.2: Drive Event Data on Proterra Connect



Name	VIN	Start	End	Duration (s)	Distance (mi)	Moving Time (s)	moving Time (s)	Speed (mph)	Speed (mph)	Start Lat	Start Lon	End Lat	End Lon	Start SOC (%)	SOC (%)	Energy (kWH)	Energy (kWH)	Energy (Moving) (kWH)	Energ (Stop (kWH
STO_EV6	1M9TH16J7GS816128	November 11th 2018, 12:49:00.000	November 11th 2018, 15:41:00.000	10,320	46.119	9,060	1,260	43.7	14.302	37.955	-121.286	37.955	-121.286	99	52	74	38	72.237	7.782
STO_EV9	1M9TH16J7GS816131	November 11th 2018, 13:15:00.000	November 11th 2018, 16:06:00.000	10,260	46.22	8,280	1,980	42.1	14.351	37.955	-121.286	37.955	-121.286	99.5	67.5	75	49	69.574	6.318
STO_EV5	1M9TH16J5GS816127	November 11th 2018, 13:20:00.000	November 11th 2018, 13:21:00.000	60	0.046	60	0	4.8	0.509	37.962	-121.251	37.962	-121.251	91.5	91	66	65	0.204	0.176
STO_EV8	1M9TH16J5GS816130	November 11th 2018, 13:26:00.000	November 11th 2018, 13:27:00.000	60	0.05	60	0	5.7	0.872	37.962	-121.251	37.962	-121.251	80.5	80	56	61	0.175	0.041
STO_EV7	1M9TH16J9GS816129	November 11th 2018, 13:41:00.000	November 11th 2018, 13:44:00.000	180	0.243	180	0	11.5	3.755	37.962	-121.251	37.962	-121.251	97	95.5	70	75	0.61	1.49
STO_EV6	1M9TH16J7GS816128	November 11th 2018, 15:53:00.000	November 11th 2018, 17:42:00.000	6,540	31.824	5,760	780	47.2	14.952	37.955	-121.286	37.955	-121.286	98	66.5	75	49	55.575	7.186
STO_EV9	1M9TH16J7GS816131	November 11th 2018, 16:22:00.000	November 11th 2018, 19:06:00.000	9,840	44.385	7,560	2,280	66.7	14.613	37.955	-121.285	37.962	-121.251	99	67	74	49	66.388	8.849
STO_EV6	1M9TH16J7GS816128	November 11th 2018, 17:55:00.000	November 11th 2018, 19:13:00.000	4,680	18.146	3,420	1,260	63	12.934	37.955	-121.285	37.962	-121.251	95	97.5	69	72	28.062	6.497
STO_18403	1M9TH16J2JS816271	November 12th 2018,	November 12th 2018,	13,680	61.192	10,260	3,420	65.4	13.882	37.962	-121.251	37.955	-121.286	100	57.5	168	44	157.354	

A drive event is defined by the following parameters – speed greater than 0.1 MPH and the bus not idling for longer than 10 minutes continuously. If the bus idled for longer than 10 min for any reason, the drive event ended and a new drive event started once the bus exceeded 0.1 MPH. Daily events were averages of all the drive events within a 24-hour reporting period.

5.1.2 Data Scrubbing and Validation

Before the data was analyzed, a series of validation tests were performed to insure the data was accurate and within reasonable limits. During validation testing, CALSTART chose various data parameters and reporting periods to test for consistency between the raw data from APEX and the processed data captured from the weekly summary report, as defined earlier in Section 4.2.2. If a discrepancy between the raw and processed data was identified, CALSTART notified Proterra to determine the source of the discrepancy. If any identified discrepancies could not be reconciled, the data was discarded during a process called “data scrubbing”.

Figure 5.3 and Figure 5.4 shows the daily average efficiency per bus from January 1, 2018 to August 31, 2018 before and after data scrubbing, respectively.

Figure 5.3: Daily Average Efficiency Before Data Scrubbing

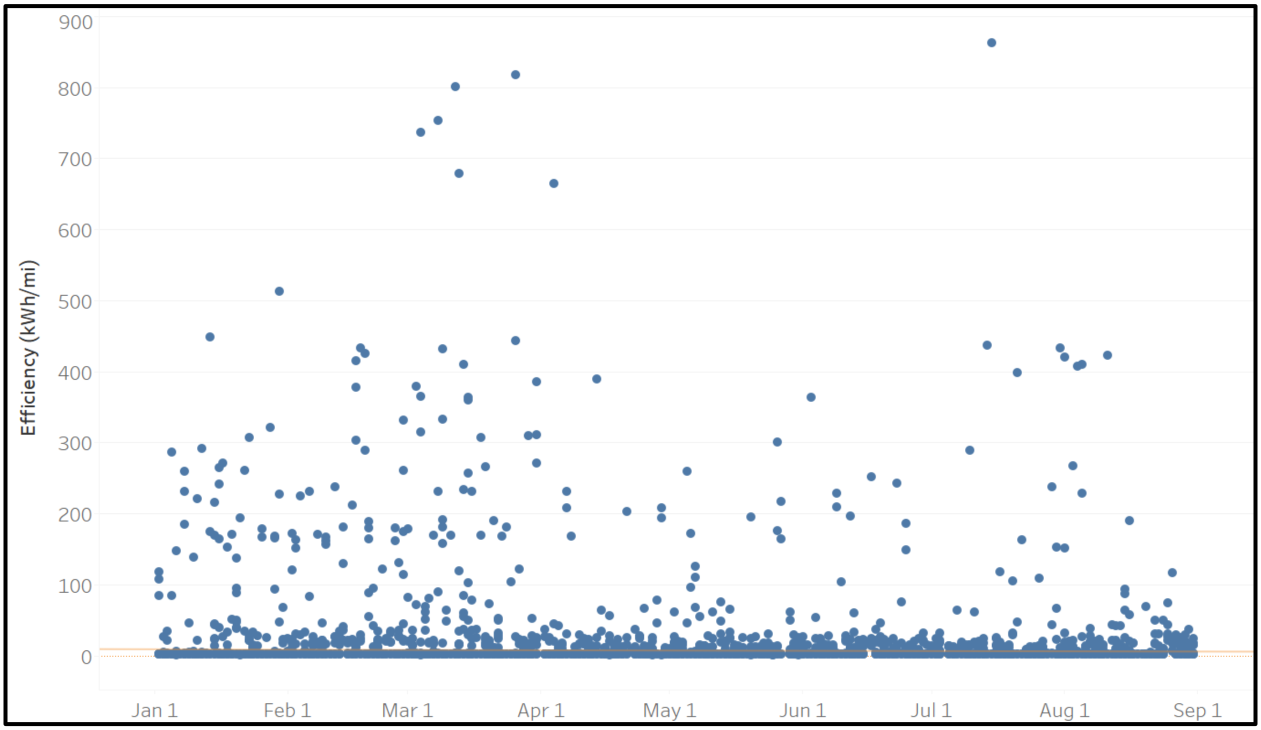
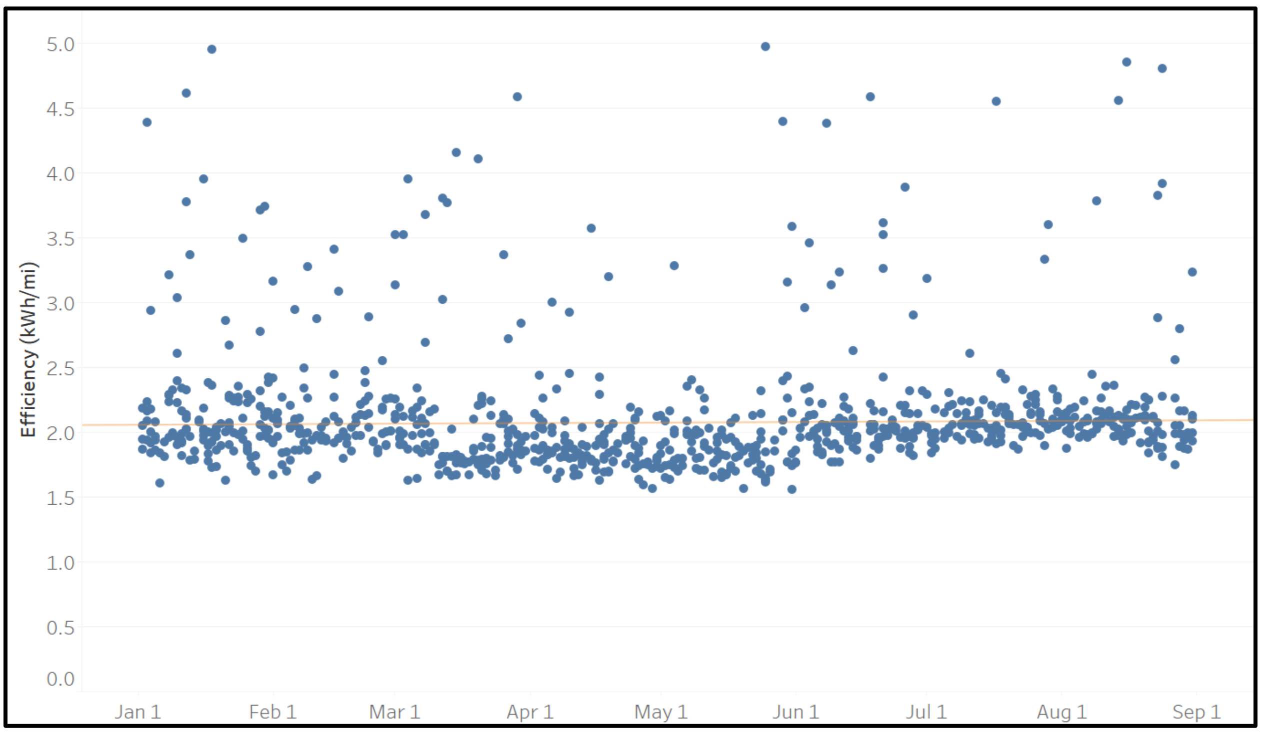


Figure 5.4: Daily Average Efficiency After Data Scrubbing



Daily average efficiency is a calculated parameter and equal to daily energy consumption divided by the daily mileage. In Figure 5.3, we observe daily efficiencies in the range of 1 to 1000 kWh/mi with an average vehicle efficiency of 2.8 kWh/mi. By visually analyzing Figure 5.3, data points were clustered between the ranges of 1.5 – 5 kWh/mi. Based on observations within similar bus demonstrations, a daily efficiency value of 5 kWh/mi or greater is highly unlikely. Visual observations also show that the data points begin to randomly disperse beyond 5 kWh/mi and therefore these points were considered outliers in the data set. Values greater than 5 kWh/mi were suspected to be caused by error in the data collection. In Figure 5.4, a data scrubbing filter is applied to remove all data with a daily average efficiency value of 5 kWh/mi or greater. Data scrubbing had significant impact on daily efficiency , dropping the average from 2.8 kWh/mi to 2.0 kWh/mi.

From the observations in Figure 5.4 and **Error! Reference source not found.**, a series of data filters were developed and applied to scrub the data, removing any erroneous data points generated by either the bus or data loggers. Additionally, data scrubbing was used to identify days that the buses were in revenue service. The applied filters and their justifications are documented in Table 5.1.

Table 5.1: Filters Applied to Scrub the Data

Parameter	Filter	Justification
Distance	Greater than 10 mi	Travelling under 10 miles in one day is too short for a bus to be considered in revenue service
Daily Vehicle Efficiency	Less than 5 kWh/mi	Efficiency metrics average 2 kWh/mi, with data between 5.0 and 1.5 kWh/mi
	Value	**Description**
Total Days -Pre-Scrub	1,678	Total days before data scrub
Total Days -Post-Scrub	900	Total days after data scrub

As an additional validation step, energy consumed versus distance traveled was analyzed to insure there was a positive correlation between these parameters. Figure 5.5 shows energy consumed and distance traveled for each bus, displayed on a dual-axis graph.

Figure 5.5: Energy Consumed versus Distance Traveled

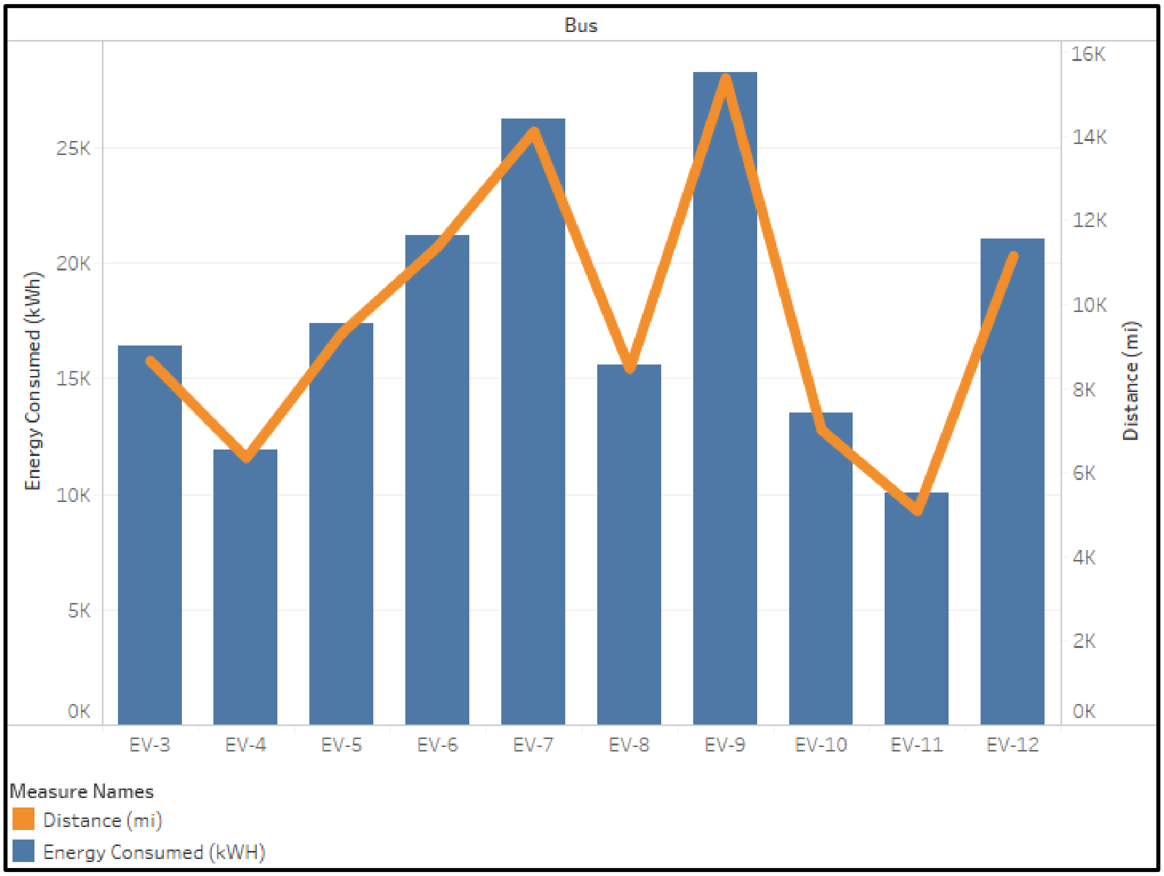


Figure 5.5 reveals a strong correlation between energy consumption and miles traveled, affirming that the buses were reporting good data.

5.2 Bus Performance

5.2.1 Total Days Driven and Total Days Driven in Revenue Service

While the analysis of this report focuses on the performance of electric buses in revenue service, it was also important to understand how the buses were utilized outside of revenue service based on the needs of the transit agency. Therefore, this section looks at the differences between total days driven and total days driven in revenue service over the course of the demonstration.

A revenue service day is defined as a day when the bus travelled greater than 10 miles. Ten miles was used as the cutoff because it is the minimum distance required for a bus to complete a single loop on most routes. Hence, if the bus did not travel further than 10 miles in a single day, then it was not considered in revenue service for that day. If the bus was not in revenue service, it may have still been driven a shorter distance based on the operational needs of RTD. Therefore, Table 5.2 and Table 5.3 compare the difference between total days and total days in revenue service observed among the ten buses.

Table 5.2 shows the total days and the total mileage driven for each electric bus over the demonstration period. A bus was considered driven if it traveled any distance during the day. The information included in this table was downloaded from the "Bus Usage Summary" section of the APEX dashboard and filtered.

Table 5.2: Total Days Compared to Total Mileage

Bus	Total Days	Total Mileage	Average In-use Daily Mileage
EV-3	274	14,221	52
EV-4	230	8,936	39
EV-5	168	12,367	74
EV-6	235	19,764	84
EV-7	283	27,575	97
EV-8	204	15,478	76
EV-9	253	19,225	76
EV-10	164	10,236	62
EV-11	211	6,552	31
EV-12	251	22,276	89
Total	**2,273**	**156,631**	**69***

**Average active day mileage across all twelve buses*

Table 5.3 shows the days and the mileage each electric bus drove in revenue service. A bus was considered to be in revenue service if driven farther than 10 miles during the day. The information included in this table was downloaded from the "Bus Usage Summary" section of the APEX dashboard and trips and days where the buses drove less than 10 miles were filtered.

Table 5.3: Days in Revenue Service Compared to Mileage in Revenue Service

Bus	Days in Revenue Service	Mileage in Revenue Service	Average Daily Mileage in Revenue Service
EV-3	104	14,117	136
EV-4	68	8,794	129
EV-5	80	12,285	154
EV-6	125	19,705	158
EV-7	171	27,511	161
EV-8	102	15,537	152
EV-9	124	19,141	154
EV-10	70	10,167	145
EV-11	54	6,449	119
EV-12	140	22,192	159
Total	**1,038**	**155,896**	**150***

**Average active day mileage across all twelve buses*

Significant variance can be observed between the total number of driven and number of days driven in revenue service. Bus EV-3 was driven a total of 274 days but was only considered to be in revenue service for 104 days. Therefore, EV-3 was in revenue service just 38% of the total days it was driven. This trend was observed across all buses. Of the 2,273 total days that the buses driven, only 45% of those days were days that the buses were considered to be in revenue service. Even though there was a significant difference between days driven and days driven in revenue service, the difference in total mileage was small. The primary reason for this being that days the buses were driven and not in revenue service were usually days when the buses traveled no further than one mile. Additionally, this is why daily average mileage between total days and days in revenue service show a large variance as well.

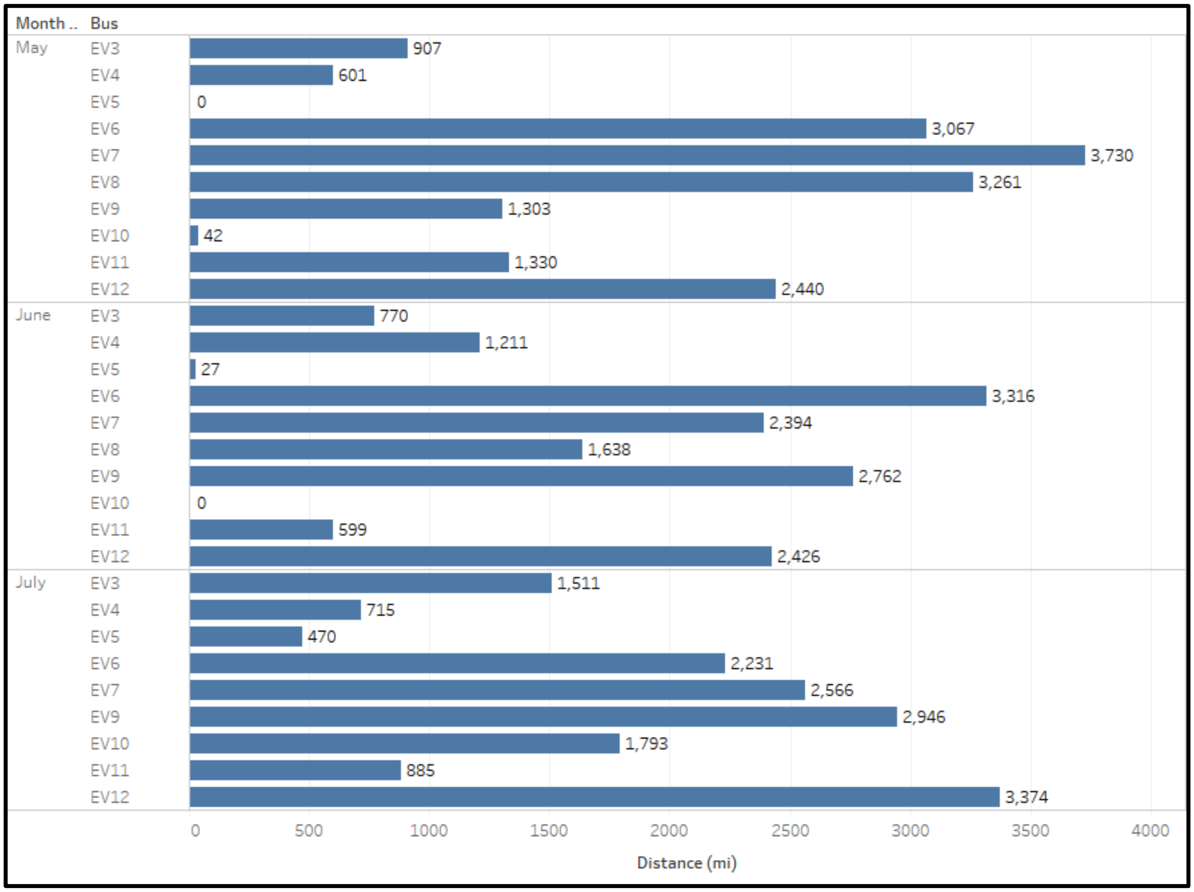
There was also a significant variance observed in usage across buses. Table 5.3 shows that EV-11 had only 54 active days with 6,449 miles driven while EV-7 had 171 active days with 27,511 miles driven, a difference of 117 active days and 21,062 miles. The difference in usage was attributed to the random assignments of buses at RTD. This is explained in more detail in the next section.

5.2.2 Daily and Monthly Mileage

Depending on the route assignment and number of loops driven per day, as shown in Table 4.8, buses typically drove between 100 - 200 miles during a full day of service. The average mileage a bus traveled during an active day is 122 miles. If placed on the BRT Route 44, the bus could potentially travel up to 227 miles in a single day of service.

In order to show how monthly mileage varied between buses, provides a sample of monthly mileage by bus between May 2018 and July 2018.

Figure 5.6: Monthly Mileage per Bus, May 2018 – July 2018



Each vehicle was used differently, depending on the operational needs of RTD. RTD randomly selected which vehicles were put into service and selection did not always consider previous usage. Therefore, some vehicles were driven significantly more than others as observed in this figure. There were months when not all buses were put into service either due to maintenance or not being selected for service.

5.2.3 Energy Charge Events and Charging Efficiency

The average time taken to charge each bus was also examined. Due to the smaller battery size and shorter range, each electric bus was required to charge every time it stopped at the DTC, as seen in Figure 2.1. Each bus only had 10 minutes to charge between service loops, therefore it was important that the buses charged within the allotted time to stay on schedule. The information was available under the "Drive & Charge" section of the APEX dashboard and is summarized in Table 5.4 together with the number of charging events and average charge time that CALSTART calculated.

Table 5.4: Energy Charged and Average Charge Time by Bus

Bus	Energy Charged (kWh)	Number of Charging Events	Average Charge Time (min)
EV-3	29,974	13,236	8.3
EV-4	18,707	724	7.9
EV-5	26,189	935	8.6
EV-6	40,049	1,410	7.7
EV-7	55,699	1,977	7.6
EV-8	32,391	1,179	8.3
EV-9	39,716	1,444	8.4
EV-10	22,116	779	8.6
EV-11	14,467	592	9.5
EV-12	46,460	1,662	7.8
Total	**325,715**	**23,938**	**8.3***

*Average charge time across all buses

Table 5.4 shows the total energy charged and the average charge time for the electric buses during the evaluation period. Data was captured from the vehicle CAN bus through the data loggers. The average charge time ranged between 7.7 - 9.5 minutes with an average charge time of 8.3 minutes per charging event. During the evaluation period, each electric bus consumed an average of 3,257 kWh per month with a total energy amount of 325,715 kWh being charged across all ten buses.

In order to understand real-world costs of operating electric buses, energy measured at the meter was compared to energy received by the buses. The DTC overhead chargers were connected to a dedicated meter allowing RTD to track the actually energy required to operate the electric buses. The difference between total energy measured at the meter and total energy received by the bused was suspected to primarily caused by losses in the conversion process as energy was transferred from the meter to the buses. Therefore, calculating fuel costs based solely on energy being consumed by the buses, in most cases, will fail to capture the total costs incurred to the transit agency by their electric utility. This is important for transit agencies to consider as they determine the operating costs of electric transit buses.

Table 5.5 compares energy measured at the meter to energy received by the buses. Energy measured at the meter was tracked by RTD through their utility bills. RTD documented their monthly energy consumption, as reported by PG&E, and summarized this information in a spreadsheet (Appendix X). This information was provided to CALSTART each quarter of the demonstration. The energy received by the buses was tracked through the data loggers. Since the older EcoRide buses were still in revenue service during the demonstration, energy used to charge the EcoRide buses needed to first be removed before comparing energy consumed at the meter to energy charged for the Catalyst buses. Based on one year of utility data collected from July 2016 – June 2017, the EcoRide buses had an average vehicle efficiency of 2.29 kWh/mi. Using average efficiency and total miles driven during the demonstration, energy consumption of the EcoRide buses was calculated and then removed from the total energy consumed by the facility.

Table 5.5: Charging Efficiency by Month

Month	Energy Measured - Meter (kWh)	Energy Received – Buses (kWh)	Charging Efficiency (%)
September	30,218	21,607	72%
October	43,292	-	-
November	41,058	-	-
December	53,986	34,362	64%
January	47,005	40,573	86%
February	35,134	29,113	83%
March	40,549	33,018	81%
April	35,514	31,415	88%
May	37,356	32,138	86%
June	36,878	30,693	83%
July	40,309	34,880	87%
August	45,589	37,916	83%
Total	**402,538**	**325,715**	**81%***

*Average charging efficiency from January 1, 2018 to August 31, 2018

In January, RTD's utility bill showed that the DTC overhead chargers consumed 47,005 kWh of energy even though buses only received 40,573 kWh of usable energy through charging. This means that only 86% of the energy that RTD was billed for became usable energy in the buses. The percentage of the energy consumed at the meter versus energy received by the buses was called charging efficiency. The months of September and December showed a low charging efficiency compared to the overall average observed in the demonstration. This was most likely caused by data inconsistencies stemming from Proterra's transition to the APEX platform. Proterra cautioned that data reported during the pre and post-transition period could contain errors. Therefore, September and December were not included in the overall average. Overall, charging efficiency was 81% averaged across January 1, 2018 to August 31, 2018. Using a high-power overhead charging system like the one installed at RTD, it is expected for charging efficiency to be lower when compared to level 2 depot chargers. When trying to understand how charging efficiency of this demonstration compared to others, a similar demonstration with a comparable data source or metric could not be found. Additionally, factors that have the greatest impact on charging efficiency could not be concluded from this study. Therefore, understanding charging efficiency is a critical step that transit agencies must consider during the process of fleet electrification.

5.2.4 Vehicle Efficiency and Operational Efficiency

Three types of efficiencies were analyzed in the demonstration: vehicle efficiency, vehicle efficiency in revenue service, and operational efficiency.

- **Vehicle efficiency**: The most common methodology for calculating vehicle efficiency. The ten electric buses had an overall vehicle efficiency of 2.13 kWh/mi.

$$\frac{Total\ energy\ consumed\ (kWh)}{Total\ miles\ (mi)}$$

Figure 5.7: Vehicle Efficiency Summary

Bus	Mileage (mi)	Energy Consumed (kWh)	Vehicle Efficiency (kWh/mi)	Average Miles Per Diesel Gallon Equivalent (mpdge)
Baseline				5.1
EV-3	14,221	30,564	2.15	17.5
EV-4	8,936	20,954	2.34	16.1
EV-5	12,367	27,119	2.19	17.2
EV-6	19,764	40,084	2.03	18.6
EV-7	27,575	55,525	2.01	18.7
EV-8	15,627	33,968	2.17	17.3
EV-9	19,225	39,716	2.07	18.2
EV-10	10,236	23,635	2.31	16.3
EV-11	6,552	15,959	2.44	15.5
EV-12	22,276	46,483	2.09	18.0
Total	**156,780**	**334,007**	**2.13**	**17.7**

Note: Data for this table was taken from the Drive summary sheet

This table shows a summary of the electric bus efficiency compared to the baseline bus. The average efficiency is 2.13 kWh/mi, which equates to 17.7 mpdge. The kWh/mile was converted to mpdge by dividing 37.64 kWh/gal diesel by the average kWh/mi value. Energy consumption values were downloaded from the "Fleet Efficiency" section of the APEX dashboard.

2) **Vehicle efficiency in revenue service**: This efficiency metric uses the same calculation methodology as vehicle efficiency but only includes energy consumed and miles traveled during revenue service. A bus was considered active and in revenue service when traveling greater than 10 miles during the day. The ten electric buses had an average vehicle efficiency of 2.00 kWh per mile when in revenue service.

$$\frac{Total\ energy\ consumed\ in\ revenue\ service\ (kWh)}{Total\ revenue\ service\ miles\ (mi)}$$

- **Operational efficiency**: Operational efficiency is an efficiency metric based on energy measured at the meter and total miles traveled. Using this methodology, operational efficiency was calculated to be 2.57 kWh/mi. Operational efficiency is not to be compared with vehicle efficiency but rather its purpose is to provide greater insight to the actual energy required to operate electric buses. Due to energy transfer losses between the meter and the bus, the energy measured at the meter will be higher than the energy received by the bus. During the demonstration a 19% loss in energy was observed between the meter and the buses. Since a transit agency is billed for energy measured at the meter, understanding operational efficiency was critical in determining the real-world operating costs of electric transit buses.

$$\frac{Total\ energy\ measured\ at\ the\ meter\ (kWh)}{Total\ miles\ (mi)}$$

5.2.5 Vehicle Speed Profile

Vehicle speed is both a route characteristic and an important variable that affects a vehicle's fuel economy. Therefore, in order to understand vehicle efficiency within the appropriate context, it was important to observe the vehicle's speed profile. Using the drive event data set, Figure 5.8 shows a histogram of all ten buses and displays their average speed using vehicle speed distribution bins, wherein each bin represents a 1 MPH range.

Figure 5.8: Vehicle Speed Histogram

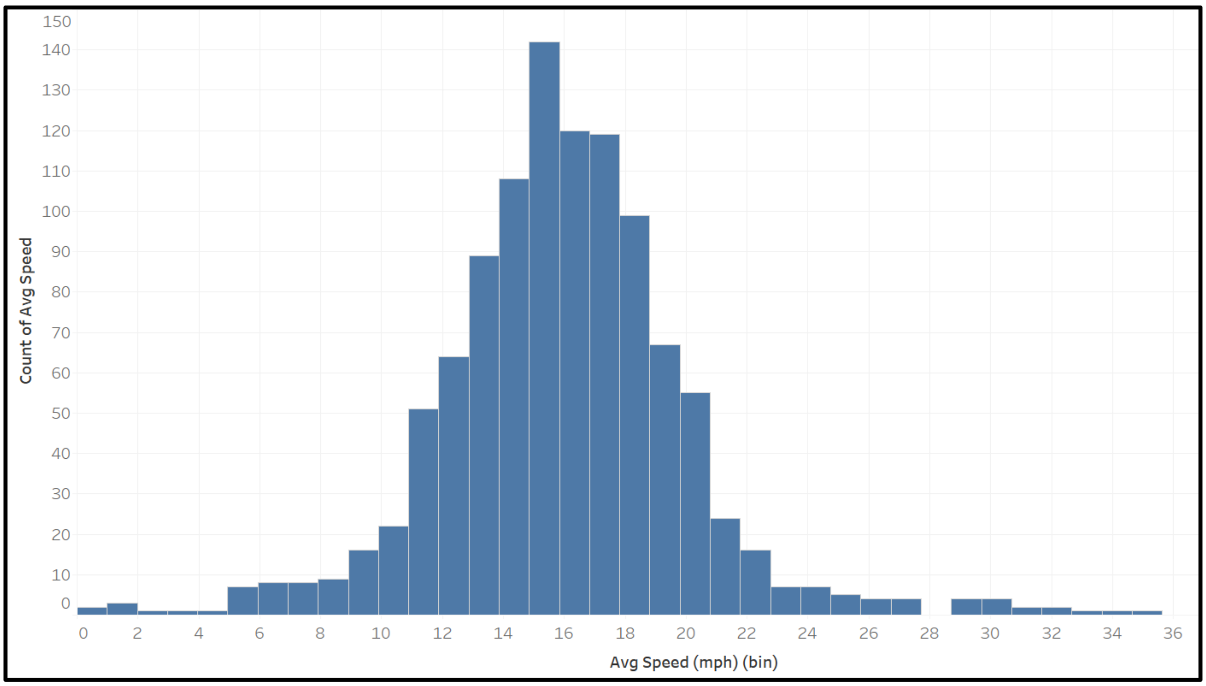


Figure 5.8 reveals that, when in operation, buses spent the most time traveling between the 14 - 18 MPH, never exceeded 39 MPH. This is a typical speed profile for buses operating on urban routes that have frequent stop-and-go travel. The average speed among all buses within the full 12-month demonstration period was 14.8 MPH.

5.2.6 Energy Consumption by Component

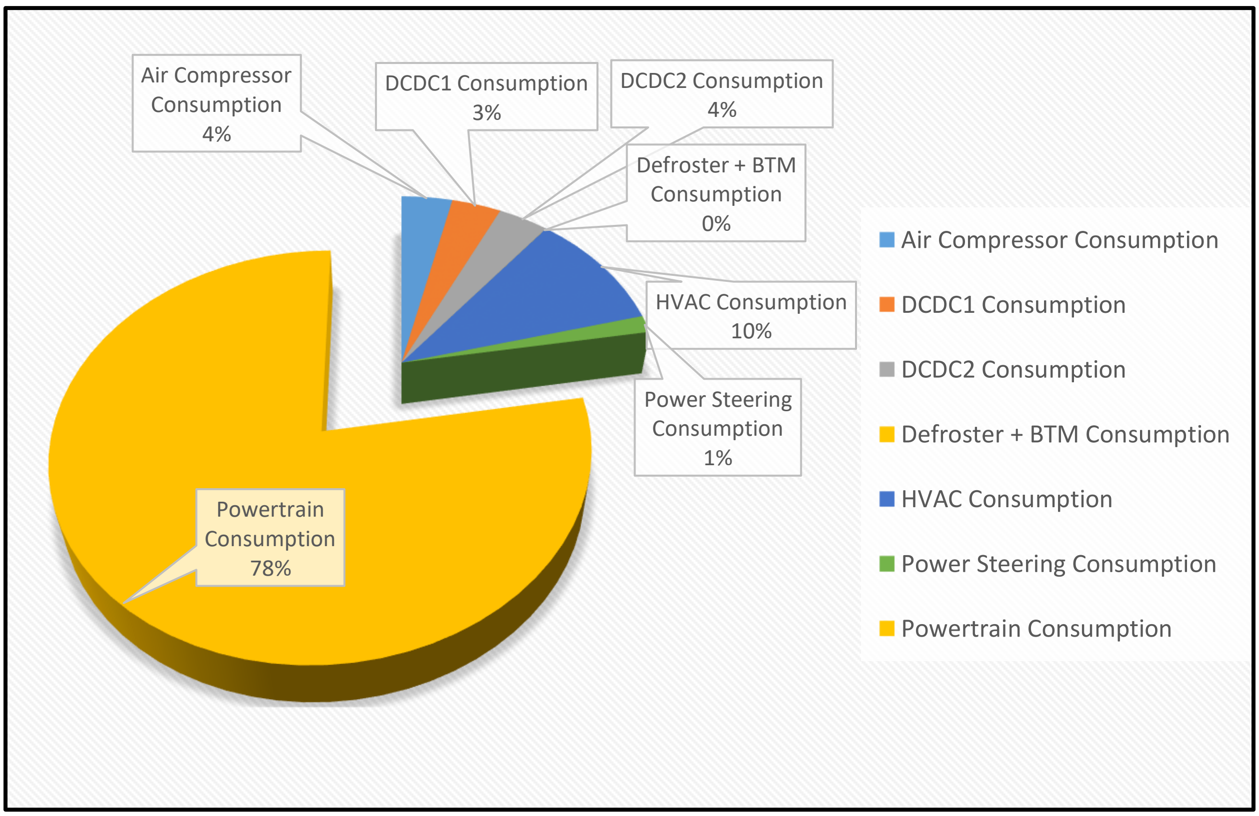
In order to further understand vehicle efficiency, Table 5.6 looks at the energy consumption of the following bus components: DC1, DC2, air compressor, HVAC, powertrain, and power steering. The total energy consumed by these components is comprehensive of the total energy consumed by the vehicle and its components during the 12-months of operation.

Table 5.6: Component Level Description and Total Energy Consumed

Component	Energy Consumed, kWh	Energy Consumed per Mile, kWh/mi	Description
DC1 and DC2	18,507	0.12	Energy used for on-board low voltage DC components such as cabin lights
Air Compressor	9,418	0.07	Energy used to power vehicle's air brake systems
HVAC	27,179	0.20	Energy used to provide interior cooling, heating, and air
Powertrain	205,410	1.48	Energy consumed to provide vehicle propulsion
Power Steering	3,833	0.03	Energy consumed to provide power steering

Figure 5.9 shows a percentage breakdown of the energy that each bus component consumed during the demonstration period.

Figure 5.9: Energy Consumption by Vehicle Component



The powertrain was the largest energy consumer, accounting for 78% of the total energy drawn by the buses. The powertrain provides the propulsion to move the vehicle and therefore we expect this component to have the highest energy draw. The HVAC component had the second highest energy consumption, showing 10% of the total energy drawn. Stockton has a relatively mild climate, with an average high of 92.1°F in the summer and an average low of 55.5°F in the winter.[10] Though HVAC did not have a significant impact on battery performance in this demonstration, it does have the potential of affecting transit agencies in more extreme climates, particularly those in colder climates.

5.3 Operation and Maintenance

A large component of total vehicle lifecycle cost is the ongoing cost of maintenance activities, both regular servicing and repairs when a component fails. This study's 12-month demonstration period offered an opportunity to measure and quantify the maintenance cost of the electric transit buses. The 12-month duration was too short to capture rare events that may occur every two or three years, or mid-life replacements with large costs, so the findings in this chapter should be considered a low bound for total maintenance costs over the lifetime of the vehicle.

5.3.1 Preventative Maintenance

A PMI was performed on each bus at 6,000-mile intervals. Based on the mileage driven during the demonstration, each bus required an estimated total of 2 PMIs. Each 6,000-mile PMI took approximately 7 hours to perform. Table 5.7 summarizes the preventative maintenance parts and associated costs for the buses.

Table 5.7: Bus PMI Parts and Cost

Part	Cost Per PMI	PMI Interval
Labor ($50/ hour)	$350	6,000 Miles
HVAC Filter	$92	48,000 Miles
Air compressor filters	$143	48,000 Miles
Component fluids	$117	48,000 Miles
Coolant	$35	6,000 Miles
Lubricant	$5	6,000 Miles
Total Cost	$742	

The labor rate is assumed to be $50 per hour and the total cost assumes that all parts are replaced during each inspection. During the demonstration, RTD inspected the electric transit buses at the same mileage intervals as their baseline buses. The PMI intervals for electric buses have the potential to change once RTD has adequate time to assess the longer-term performance and reliability of the electric buses.

In addition to preventative maintenance performance on the buses, a PMI was also performed on the on-route FCrs about once every month. Each charger PMI took an estimated 2 hours to perform. Table 5.8 summarizes the preventative maintenance parts and associated costs for the charger.

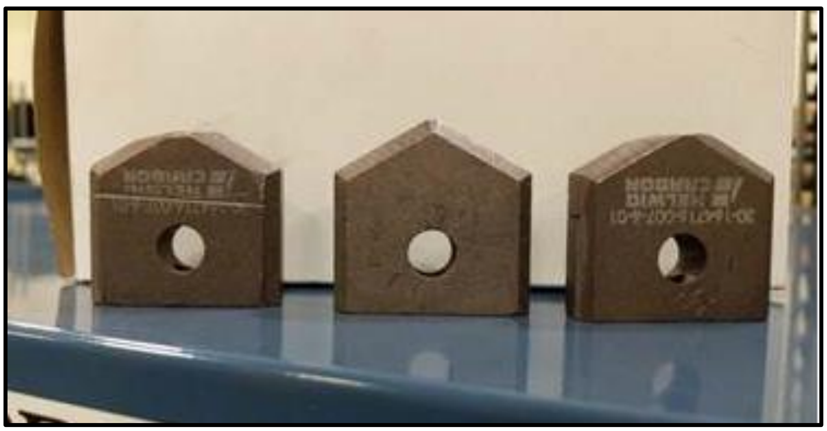
[10] http://www.stockton.climatemps.com/

Table 5.8: Charger PMI Parts and Costs

Part	Cost Per PMI	PMI Interval
Charger air filters	$30	4 Weeks
Charge pilot brush	$20	2 Weeks
Air compressor oil	$20	4 Weeks
Air compressor desiccant	$70	4 Weeks
Labor ($50/ hour)	$100	4 Weeks
Total Cost	$260	

Labor rate is assumed to be $50 per hour. During the demonstration, RTD discovered that accelerated wear on the charger pilot brush was causing docking issues with the bus that required them to replace the brush every 2 weeks instead of 4 weeks. Proterra addressed this issue and acknowledged that a design flaw was causing the charger brush to wear down quicker than anticipated. Figure 5.10 shows a visual comparison between a new and used pilot brush.

Figure 5.10: New and Used Charger Pilot Brushes (Middle) New (Left and Right) Used



In Figure 5.10, we can observe significant wear in both used pilot brushes after just a few weeks of use. Near the end of the demonstration, Proterra announced they were producing new charger heads that utilized a different type of electric delivery, eliminating the need for pilot brushes. The new overhead chargers that Proterra is adopting will be located at the front of the bus for improved alignment and in compliance with the SAE J3105 standards. RTD was scheduled to have the charger heads replaced by Proterra but at the time of writing this report, the current charger heads were still being used.

5.3.1 Vehicle Availability

Vehicle availability data was collected and defined as the percentage of days that the bus was available for use during the evaluation period, regardless of whether the vehicle was actually used in operation. This did not include scheduled days that the bus was pulled out of service for PMIs.

Vehicle availability data was recorded and provided for five test vehicles by RTD's maintenance staff using manual service logs. The service logs were used to keep a record of all maintenance and service actions associated with a particular vehicle. Unscheduled maintenance days were identified by the following work order codes listed in the service logs.

- **Driver's defects** – defects drivers find wrong with the bus, during a pre-trip or post-trip inspection and/or during the operation of the bus.
- **Corrective** – defects anyone finds wrong with the bus, at any time.
- **PM Defect** – defects found during the PM Inspection.
- **Campaign** – Scheduled maintenance to correct a defect found on several vehicles or a sub-fleet of vehicles.
- **Pit Defect** – defects found during the weekly Pit Safety Inspection.

Table 5.9 summarizes the days the electric buses were pulled out of service for maintenance and presents the vehicle availability.

Table 5.9: Summary of Bus Maintenance and Availability

Bus	Total Days	Preventative Maintenance Days	Unscheduled Maintenance Days	Planned Service Days	Days Available	Percent Availability
Baseline	365	6	33	359	326	91%
EV-3	365	4	45	361	316	88%
EV-4	365	2	49	363	314	87%
EV-6	365	4	48	361	313	87%
EV-7	365	5	40	361	321	89%
EV-11	365	3	40	362	322	89%

An available day was defined as a day when the bus was not undergoing any type of planned or unplanned maintenance. The bus is available if it can be driven at any time if needed. The total days are the entire number of days during the evaluation period. The planned service days are the days when the bus was not supposed to undergo any type of planned maintenance. The unscheduled maintenance days are the days when the bus was pulled out of service because of an impromptu maintenance issue with the bus or a road call. The percent availability was calculated by dividing the available days by the planned service days of the bus.

The average availability for the electric buses during the data period was 88% compared to the 91% for the diesel-electric hybrid baseline bus. There was little variation observed in the availability of electric buses, ranging from a low of 89% to a high of 91%. Majority of the unscheduled maintenance was caused by general bus system issues such as HVAC or broken components that were unrelated to the electric drive system of the electric buses.

5.4 Impacts of Peak Demand Charges

At the time of writing this report, the Pacific Gas and Electric Company (PG&E) released a proposal that would establish new rates for charging electric vehicles. If approved by the California Public Utilities Commission (CPUC), this would have significant impact on a fleet's operational costs as it would seek to eliminate costly demand charges that RTD faced throughout this demonstration. Though the proposal has not yet been approved, it is likely that some form of this new rate structure will pass.

Using the proposed rates that PG&E released, CALSTART performed a series of analyses to understand what RTD's energy costs would be under the new structure. These analyses can be found in Section 5.4.4. The following sections were written prior to PG&E's announced proposal and using current rate structure and demand charge rates. Even though they may no longer be applicable in the future, we believe it is still important to understand the impacts of the demand charges that were applicable during the course of this demonstration.

Public transit agencies deploying electric transit buses around the county are bound to experience the impact of peak demand charges. In 2009, RTD purchased two on-route opportunity charging electric transit buses to provide BRT service in their operating fleet. The first electric transit bus deployment led to an additional purchase of ten more buses to fully electrify BRT Express Route 44, making it the first all-electric BRT route in the nation. During RTD's earlier electric bus deployment, PG&E granted a 2-year demand charge exemption. During this deployment, the exemption on demand charges had expired and as a result, peak demand chargers were incurred. This section evaluates the major impacts peak demand charges can have on the operation of electric buses.

5.4.1 What Are Peak Demand Charges?

Peak demand charges are levied by electric utilities on their commercial and industrial customers to recover their capital costs and are calculated based on the maximum amount of electrical power (in kW) the electric transit bus draws from the grid during a charging event. While each utility has different rules for implementing demand charges, generally they are charged monthly based on the highest average kW measured in a 15-minute interval during the billing period. For more detailed background on peak demand charges see CALSTART's white paper.[11]

Some electric utilities do not apply demand charges on commercial and industrial customers whose peak demand remains under a certain threshold. However, the demand threshold varies considerably between electric utilities and in the case of RTD, peak demand charges were incurred monthly. As a result, demand charges had a significant impact on the transit agency's electricity bill.

5.4.2 Charging Electric Transit Buses

There are two primary ways of charging electric transit buses:

- **On-route** opportunity charging - the electric transit bus recharges while the vehicle is operating.
- **Overnight/depot charging** - the electric transit bus recharges at night, or when the vehicle is not in operation. Electric transit buses charging overnight are designed to meet the daily range of a conventional diesel bus. Thus, batteries need to be sized to store enough energy to cover over 100 miles.

[11] Peak Demand Charges and Electric Transit Buses, Gallo, Block-Rubin, and Tomic, 2014. Available at: http://calstart.org/libraries-publications-peak_demand_charges_and_electric_transit_buses_white_paper-sflb-ashx/

These two different ways of recharging electric transit buses each have their place in the electric transit bus market. In most cases, both options will be impacted by peak demand charges. Table 5.10 below presents the main advantages and drawbacks associated with on-route opportunity charging.

Table 5.10: Advantages and Drawbacks of On-Route Opportunity Charging

Advantages	Drawbacks
▪ Smaller battery size can reduce vehicle curb weight, potentially increasing vehicle efficienc ies and can take less space	▪ Lower vehicle assignment flexibility as buses a re dedicated to on-route charging infrastructure
▪ Possibility to operate indefinitely without long interruption for charging	▪ Demand charges can be high without energy storage
▪ Smaller battery may be easier and cheaper to service and replace	▪ Charging infrastructure costs can be high and grid connection

A major advantage of electric transit buses designed for on-route charging is the reduction in weight. With identical battery energy densities, the electric transit bus charging on-route has a much lighter and smaller battery pack compared to the electric transit bus capable of operating all day on a single charge. However, as battery technology improves they become lighter and capable of higher energy densities, therefore this advantage may become less significant.

Due to the smaller battery pack and therefore shorter range, RTD's electric buses must use on-route overhead FC between each loop, as specified in Section 4.1.2. On-route charging is generally done at a high-power rate to minimize dwell time between routes. There are two on-route FCrs installed at the DTC and each has a maximum input power of 500 kW and nominal power of 450 kW. If the bus is charged continuously for all 15 minutes, it would generate a peak demand of 450 kW $(450\ kW\ x\ \frac{15\ minutes}{15\ minutes})$.

In addition, electric transit buses charging on-route have smaller batteries that will limit the amount of energy transferred when charging, and thus, limit the peak demand from the grid. For instance, while the overhead FC system is capable of replenishing 112.5 kWh in a 15-minute window, in the absolute worst-case, the Proterra Catalyst FC only needs 79 kWh. At a nominal power of 450 kW, it would take about 10.5 minutes to transfer 79 kWh. This would result in a maximum peak demand of 315 kW per charger $(450\ kW\ \times \frac{10.5\ minutes}{15\ minutes})$.

Lastly, in real-world transit operation, it is unlikely that an electric transit bus charging on-route would use 80% or more of its total battery capacity. BRT route 44 is approximately 15 miles long. With an efficiency of 1.93 kWh/mi, this translates into about 29 kWh $(15\ mi\ \times\ 1.93\ \frac{kWh}{mi})$ of energy used between charges. At a nominal power of 450 kW, it would take about 3.9 minutes to transfer 29 kWh. This would result in an average peak demand of 117 kW $(450\ kW\ \times\ \frac{3.9\ minutes}{15\ minutes})$. Route 578 is 18 miles long and with approximately 35 kWh of energy used between charges, resulting in an average peak demand of 140 kW ($450\ kW \times \frac{4.7\ minutes}{15\ minutes}$). Table 5.11 shows the peak demand and average peak demand power levels required from the grid during charging events.

Table 5.11: On-Route Charging Power Levels

	Maximum Input Power	Nominal Power	Maximum Peak Demand	Average Peak Demand
Power from the grid	500 kW	450 kW	316 kW	140 kW

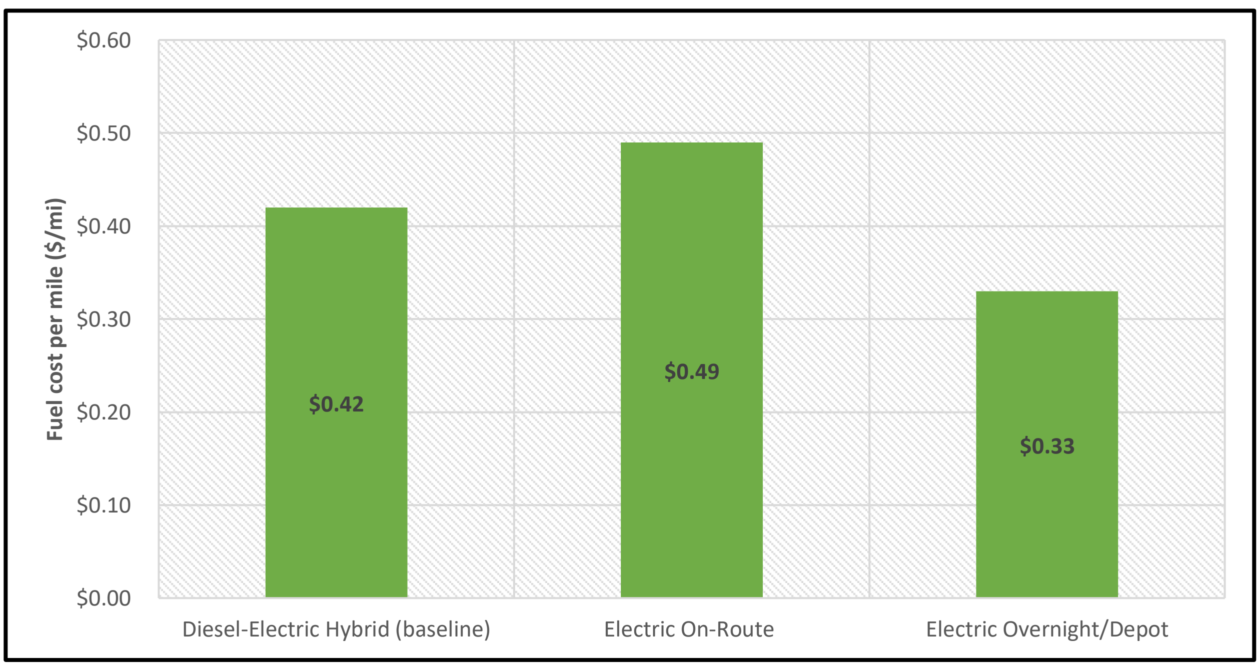
RTD's demand charges vary by season. During peak season, May through October, RTD paid $19.52 per KW in demand charges. During non-peak season, November through April, they paid between $10.95 and $11.76 per KW. For this analysis, an average demand charge of $15 per kW was applied. This is summarized in Table 5.12.

Table 5.12: Demand Charges Based on Season

	Peak Season	Non-peak Season	Average
Months	May - October	November - April	
Demand Charges	$19.52	$10.95	$15.00

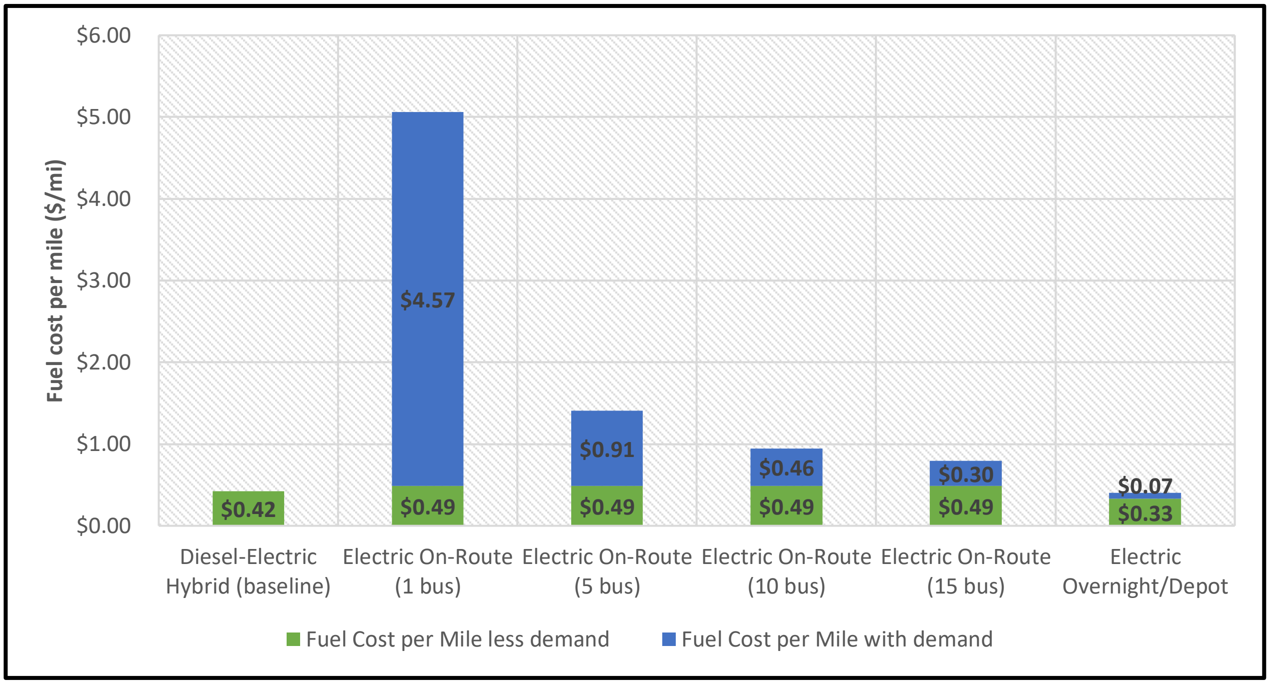
The figures below compare the fuel costs of RTD's diesel-electric hybrid and two types of electric transit buses: charging on-route (current bus) and overnight depot charging. In Figure 5.11 no demand charges were included and in Figure 5.12, demand charges at $15 per kW were included.

Figure 5.11: Fuel Cost per Mile for Diesel/Hybrid and Electric Transit Buses (Less Demand Charges)



When no demand charges were included, electric transit buses cost more to fuel than the diesel-electric hybrid transit buses. However, if the electric transit buses were charged overnight during off-peak hours when electricity rates are lowest, fuel costs would drop below that of the hybrid buses. High power chargers are generally very expensive and require significant and costly utility infrastructure upgrades. Demand charges will have a greater impact on small pilot deployments of electric transit buses charging on-route. Since demand charges are calculated based on the maximum power demand on the grid, greater utilization of a FCr will not increase demand charges. That is why optimizing the number of electric transit buses using a single FCr can maximize charger usage and spread demand charges over more electric transit buses as shown in Figure 5.12.

Figure 5.12: Fuel Cost per Mile for Diesel/Hybrid and Electric Transit Buses (With Demand Charges)



When demand charges were included, fuel cost increased by $0.07 per mile for one electric bus charging overnight and by $4.57 per mile for one electric bus charging on-route. However, if the number of electric transit buses using on-route FCrs is optimized (up to 15 buses using two FCrs), demand charges can be spread over more buses and greatly reduced. Despite the optimization of on-route FCrs through deployment of additional electric buses, without additional incentives like the Low Carbon Fuel Standard (LCFS) program, there appears to be no real cost benefit. Rather there is a cost disadvantage until the cost of diesel increases to $3 per gallon and demand charges are either reduced or eliminated.

Demand charges can have a significant impact on a transit agency's electricity bill. For example, Table 5.13 shows the impact of peak demand charges on RTD's monthly billing cycle with two scenarios presented: a) on-route charging, b) overnight charging. Depot charging assumes that buses will be plugged in between the hours of 11:00pm and 5:00am each night, allowing 6 hours to fully charge. Additionally, since the Proterra FC buses do not have the battery capacity to operate a full day on a single charge, the depot charging calculation uses Proterra's Catalyst extended-range (XR) electric bus which has a 440 kWh battery and an operating range of up to 200 miles per charge. All other assumptions remain the same. Each bus is assumed to consume 40,000 kWh and travel 18,800 miles per month.

Table 5.13: Impact of Demand Charges on Monthly Billing Cycle

	On-Route Charging (1 bus)	Overnight/Depot Charging (1 bus)	On-Route Charging (10 buses)	Overnight/Depot Charging (10 buses)
Peak Demand	*316 kW x 1 on-route FCr = 316 kW*	*40 kW x 1 depot charger = 40 kW*	*316 kW x 2 on-route FCrs = 632 kW*	*40 kW x 10 depot chargers = 400 kW*
Demand Charge	*316 kW x $15.00/kW = $4,740*	*40 kW x $15.00/kW = $600*	*632 kW x $15.00/kW = $9,480*	*400 kW x $15.00/kW = $6000*
Energy Cost	*40,000 kWh x $0.18/kWh = $7,200*	*40,000 kWh x $0.13/kWh = $5,200*	*400,000 kWh x $0.18/kWh = $72,000*	*400,000 kWh x $0.13/kWh = $52,000*
Total Energy Cost w/ Demand	$11,940	$5,800	$81,480	$58,000
Energy Cost per Mile	**$0.64**	**$0.31**	**$0.43**	**$0.31**

Table calculations assume an average off-peak energy rate of $0.13/kWh for depot charging and a blended energy rate of $0.18 for on-route charging.

In order to calculate the demand charge for depot charging, the 80% of the bus's total battery capacity was divided by the 6 hours available to charge at night. At minimum, a 40 kW charger would be needed to fully charge the XR buses overnight. For on-route charging, as the number of electric buses in a fleet increases, cost per mile to charge the buses will decrease. The monthly energy cost for 10 buses charging on-route is 25% higher than costs for 10 buses that utilize depot charging. Actual cost differences will vary depending on the power rating of depot chargers, energy costs, and how many buses are charged overnight.

In this assessment, it is very important to consider the associated cost of purchasing and installing charging infrastructure. This will impact the overall business case for a transit agency. Charging infrastructure can have significant capital costs and these vary greatly from site to site. Before selecting which charging methodology to use, transit agencies should assess their needs and understand all the associated costs of charging infrastructure, including hardware, software, and installation.

5.4.3 Mitigating Impact of Peak Demand Charges

This section discusses potential options that could mitigate the impact of peak demand charges on the operation of electric transit buses for RTD. While we did not look at every option available on the market today, we considered several options that RTD could implement in their current operations.

- Increase Number of Charging Stops
- Energy Storage
- Solar
- Depot Charging with Load Management System

Increase Number of Charging Stops

On-route opportunity charging is based on providing just enough energy during charging to reach the next charging stop. As transit buses frequently stop to pick-up and drop-off passengers, they can charge frequently at lower power rates instead of charging only once between each route at high power rates.

Charging stops should be located on-route to ensure bus operation and minimize peak demand charges. Electric transit buses should also recharge anytime it is possible even if they have enough energy to get to the next charging stop.

Energy Storage System

Energy storage systems (such as batteries, ultracapacitors or flywheels) can be used as buffers between the grid and FCrs to smooth out peak load.

Ultracapacitors integrated into the charging stations are recharged from the grid for a duration of minutes at 40 kW. When the bus is connected to the charging station, the ultracapacitors can transfer their stored energy in about 15 seconds at a 400 kW charging power.

The use of ultracapacitors decreases the maximum charging power from 400 kW to 40 kW while maintaining the benefits of on-route opportunity charging. In addition, lower charging power allows for easier siting of the charging infrastructure as it may not require complex and expensive upgrades to the electric infrastructure.

Adding an energy storage system will increase the cost and complexity of the charging infrastructure and decrease the overall efficiency of the system as it adds energy conversion losses but it represents an interesting option to implement on-route opportunity charging of electric transit buses without the high-power demand that can be associated with fast charging.

Overnight Depot Charging with Load Management System

As discussed earlier in the section, overnight depot charging can be very effective in reducing peak demand charges if the buses can meet the needed duty cycle requirements on a single charge. Transit agencies implementing electric transit buses in their fleet could use load management systems to accommodate some or all of the added demand from electric transit bus charging. A load management system would typically be used for depot charging but could also be applied to on-route fast charging.

Charging electric vehicles right upon returning to the facility can mean adding electrical load to a facility already drawing a large amount of power from the grid. In the worst-case scenario, electric vehicles charging can increase the peak load of the facility and thus increase peak demand charges. On the other hand, electric vehicles could easily be charged at night (between 11pm and 6am) without increasing the maximum demand of the facility. Load management systems could automate the process, by choosing to allow charging at the most favorable time or by staggering charging between several buses while still ensuring that the vehicles will be charged when needed.

Peak demand charges have a significant impact on the business case of electric transit buses charging on-route and overnight. In areas where demand charges are high, fuel cost is more than doubled although it still stays below the fuel cost of a diesel-powered bus and remains competitive with a CNG-powered bus.

Demand charges will have a greater impact on small pilot deployments of electric transit buses charging on-route than on small pilot deployments of electric transit buses charging overnight. However, for bus deployments of 6 to 8 buses (the optimum number of buses that can use a single FCr in the conditions), demand charges can be spread over more buses and greatly reduced.

The price of the electricity used to recharge an electric transit bus is an important component of its fuel costs. Charging off peak when electricity prices are low can lead to significant savings. On the other hand, charging on peak when electricity prices are high can dramatically increase fuel costs per mile.

5.4.4 Potential Energy Costs under PG&E's Proposed Commercial EV Rate Structure

On November 05, 2018 Pacific Gas and Electric Company (PG&E) submitted a proposal to the California Public Utilities Commission (CPUC) to establish new rates for charging electric vehicles[12]. This proposed rate seeks to eliminate costly demand charges and to make charging EVs more affordable. At the time of writing this report, the proposal was active at the CPUC and a final decision on it has not yet been made. There was a prehearing conference on the matter scheduled for January 22, 2019[13].

To estimate what RTD might pay per month to charge their electric buses under PG&E's proposed new EV rate structure, CALSTART used actual energy use bus data and applied the new rate structure to it. RTD provided a Microsoft Excel document containing energy usage (in kWh) in 15-minute intervals from October 22, 2015 through October 20, 2018. Additionally, PG&E provided a PDF file containing their Commercial EV Rate Proposal. In this proposal, PG&E designed two rates, one for charging installations up to 100 kW (CEV-Small) and another for installations over 100 kW (CEV-Large). As RTD currently has two overhead FCrs rated at 500 kW each, CALSTART applied CEV-Large to the energy use patterns to estimate costs under this new rate structure.

In the CEV-Large rate, customers would pay two separate monthly charges: A Subscription Charge and an Energy Charge. The Subscription Charge is a monthly flat rate based on the amount of charging capacity connected to the grid. This charge increases by $184 for every 50 kW of charging capacity

[12] Pacific Gas and Electric Company. (2018, November 5). PG&E Proposes to Establish New Commercial Electric Vehicle Rate Class. In *PG&E*. Retrieved from https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20181105_pge_proposes_to_establish_new_commercial_electric_vehicle_rate_class

[13] California Public Utilities Commission. (2018, December 07). *Administrative law judge's ruling setting prehearing conference*. Retrieved December 13, 2018, from http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M246/K138/246138373.PDF

connected. So, with 1000 kW installed RTD would pay a $3,679.00 Subscription Charge per month. However, if RTD believes it can manage its energy usage to a level below 1000 kW they can opt for a lower Subscription Charge. For example, if they believe they can limit energy demand from the chargers to 750 kW they could opt to pay $2,759.00 per month. If they do this and exceed 750 kW in a month, however, they must pay an overage fee. The proposed overage fee is twice the subscription rate for any incremental demand above the elected level. So, if RTD used 800 kW instead of 750 they would pay their normal subscription of $2,759.00 for that month plus an additional $368 for the extra 50 kW used ($184 X 2 for every 50 kW).

Table 5.14 CEV-Large Rate Structure

Subscription Charge	Energy Charge
$184 / 50 kW connected charging	$X.XX / kWh consumed per time of day (see Time-of-Day Pricing Table)

The second charge, the Energy Charge, is based upon the amount of energy consumed per month and it is billed on time-of-day pricing. Table 5.15: shows the three time-of-day prices proposed.

Table 5.15: Proposed Time-of-Day Pricing

Type	Time-of-Day	Price
Off-Peak	12:00 AM – 9:00 AM, 2:00 PM – 4:00 PM, 10:00 PM – 12:00 AM	$0.11 / kWh
Super-Off-Peak	9:00 AM – 2:00 PM	$0.09 / kWh
Peak	4:00 PM – 10:00 PM	$0.30 / kWh

To apply this rate structure to RTD's energy usage in charging their electric buses, CALSTART took the file they shared, and color coded each 15-minute interval to the corresponding proposed time-of-day pricing ranges. Then, energy use in each time-of-day pricing range was summed and the dollar amount charged for energy used in each of those ranges was calculated, per day. Next, CALSTART calculated the cost of energy use per day by summing all time-of-day price range costs for each day recorded. Finally, monthly energy charges were calculated by summing each daily cost, month by month.

With these data CALSTART calculated maximum, minimum, average, and median values for monthly costs. While this was performed twice, once with all data from 2015 to 2018 and again with only data from July 2017 and on, in this report we show only results using energy data from July 2017 to October 2018 since the electric buses were not deployed prior to July 2017. The following tables show estimates for what RTD would pay to charge the buses per month under the proposed rate structure, including both Subscription Charges and Energy Charges. These estimates were also compared to actual costs incurred to charge electric buses under PG&E's current rate structure. It is important to note that all the following estimates in this section of the report analyze only operating costs associated with fueling and charging the buses. None of the estimates in this section include the costs of infrastructure or any other capital costs. Additionally, none of the estimates using the proposed rate structure include taxes or fees.

Table 5.16: shows the estimated monthly energy costs under various Subscription Charges and using the average, median, and maximum amount of energy used by RTD from July 2017 to October 2018.

Table 5.16: Estimated Monthly Energy Costs

Estimated Energy Costs Under Proposed PG&E EV Electricity Rate (Using Energy Usage Data from July 01, 2017 to October 20, 2018)			
kW Installed	**Subscription Price**	**Note:** Subscription Price starts at $184 for 50 kW and increases by $184 for every 50kW installed.	
300	$1,103		
500	$1,839		
1000	$3,679		
kW Installed	**Subscription Price**	**Average Monthly Energy Price**	**Total Monthly Cost (using Average Energy Price)**
300	$1,103	$5,532	$6,635
500	$1,839	$5,532	$7,371
1000	$3,679	$5,532	$9,211
kW Installed	**Subscription Price**	**Median Monthly Energy Price**	**Total Monthly Cost (using Median Energy Price)**
300	$1,103	$5,958	$7,061
500	$1,839	$5,958	$7,797
1000	$3,679	$5,958	$9,637
kW Installed	**Subscription Price**	**Maximum Monthly Energy Price**	**Monthly Cost (using Maximum Energy Price)**
300	$1,103	$7,799	$8,902
500	$1,839	$7,799	$9,638
1000	$3,679	$7,799	$11,478

At the 1000 kW Subscription Charge level, the lowest monthly cost estimate would by $9,211 and the highest is $11,478. Both are lower than the average monthly cost currently incurred by RTD to charge their buses with lowest monthly fuel cost for electricity being $10,111 as seen in Table 5.17: . Of course, if RTD opts for a lower Subscription Charge, their total monthly costs will drop.

Table 5.16: Estimated Monthly Energy Costs shows how the monthly costs compare between the proposed rate structure and what costs were actually incurred as shown in Table 5.17: Actual Monthly Energy Costs Incurred. Using 1000 kW as the amount of charging capacity installed under the new proposed rate structure, RTD would save an estimated $4,330 per month at average energy use. Even the maximum monthly cost estimate of $11,478 with the new rate structure would save RTD $2,063 per month when compared to the current average monthly cost incurred of $13,541.

Table 5.17: Actual Monthly Energy Costs Incurred

Actual Monthly Energy Information: September 2017 – September 2018[14] (including taxes and fees)				
Month	Total Fuel Cost (Electric)	Fleet Mileage, mi (Electric)	Cost per Mile, $/mi (Electric)	Cost per Mile, $/mi (Diesel Hybrid)
09/17	$13,274	12,434	1.07	0.33
10/17	$14,330	18,664	0.77	0.31
11/17	$11,877	22,058	0.54	0.30
12/17	$15,044	16,402	0.92	0.40
01/18	$12,830	18,706	0.69	0.40
02/18	$10,111	11,810	0.86	0.36
03/18	$10,867	16,171	0.67	0.38
04/18	$10,387	17,750	0.59	0.38
05/18	$14,012	16,945	0.83	0.40
06/18	$15,018	12,760	1.18	0.42
07/18	$18,526	13,807	1.34	0.49
08/18	$15,984	14,869	1.07	0.50
09/18	$13,770	13,254	1.04	0.49
Max	$18,526	22,058	1.34	0.50
Min	$10,111	11,810	0.54	0.30
Average	$13,541	15,818	0.89	0.40
Median	$13,770	16,171	0.86	0.40

[14] July 2018 and August 2018 are omitted due to outlier values. Fuel costs and mileage during those months are not in line with typical results for the other months shown and are not representative of actual monthly results.

Table 5.18: Comparison of Energy Costs – Estimated and Actual

Installed	Total Monthly Energy Cost - Proposed Rates, $	Total Monthly Energy Cost - Current Rates, $
kW	With Average Energy Price	Average
300	$6,635	$13,541
500	$7,371	$13,541
1000	$9,211	$13,541
kW	With Median Energy Price	Median
300	$7,061	$13,770
500	$7,797	$13,770
1000	$9,637	$13,770
kW	With Maximum Energy Price	Maximum
300	$8,902	$18,526
500	$9,638	$18,526
1000	$11,478	$18,526

While the proposed rate structure would save RTD money in their monthly energy bill, the per mile cost of charging electric buses is still higher than the current per mile cost of fueling diesel hybrid buses. Table 5.19: shows the estimated cost per mile to charge electric buses under the proposed rate structure. At a 1000 kW Subscription Charge level and average energy usage the per mile cost is $0.58. This drops if the Subscription Charge drops and if monthly mileage rises. In one of the lowest cases, a 500 kW Subscription Charge level and maximum monthly mileage of 22,058 miles, the cost per mile is estimated at $0.44, still higher than the average cost per mile of fueling diesel hybrid buses at $0.40.

Table 5.19: Estimated Electric Fuel Costs per Mile

	Total Monthly Cost, $	Actual Monthly Mileage, mi	Cost per Mile, $/mi
kW Installed	With Using Average Energy Price	Average	Using Average Energy Price and Mileage
300	$6,635	15,818	$0.42
500	$7,371	15,818	$0.47
1000	$9,211	15,818	$0.58
kW Installed	Using Median Energy Price	Median	Using Median Energy Price and Mileage
300	$7,061	16,171	$0.44
500	$7,797	16,171	$0.48
1000	$9,637	16,171	$0.60
kW Installed	Using Maximum Energy Price	Maximum	Using Maximum Energy Price and Mileage
300	$8,902	22,058	$0.40
500	$9,638	22,058	$0.44
1000	$11,478	22,058	$0.52

Currently RTD operates two overhead FCrs. Another charging option is overnight depot charging. If RTD used this option, they could take advantage of charging during only off-peak hours at a lower rate. Table 5.20 shows estimated monthly costs and per mile costs using this option. CALSTART used energy data from July 2017 to October 2018 and applied only the $0.11/kWh Off-Peak rate.

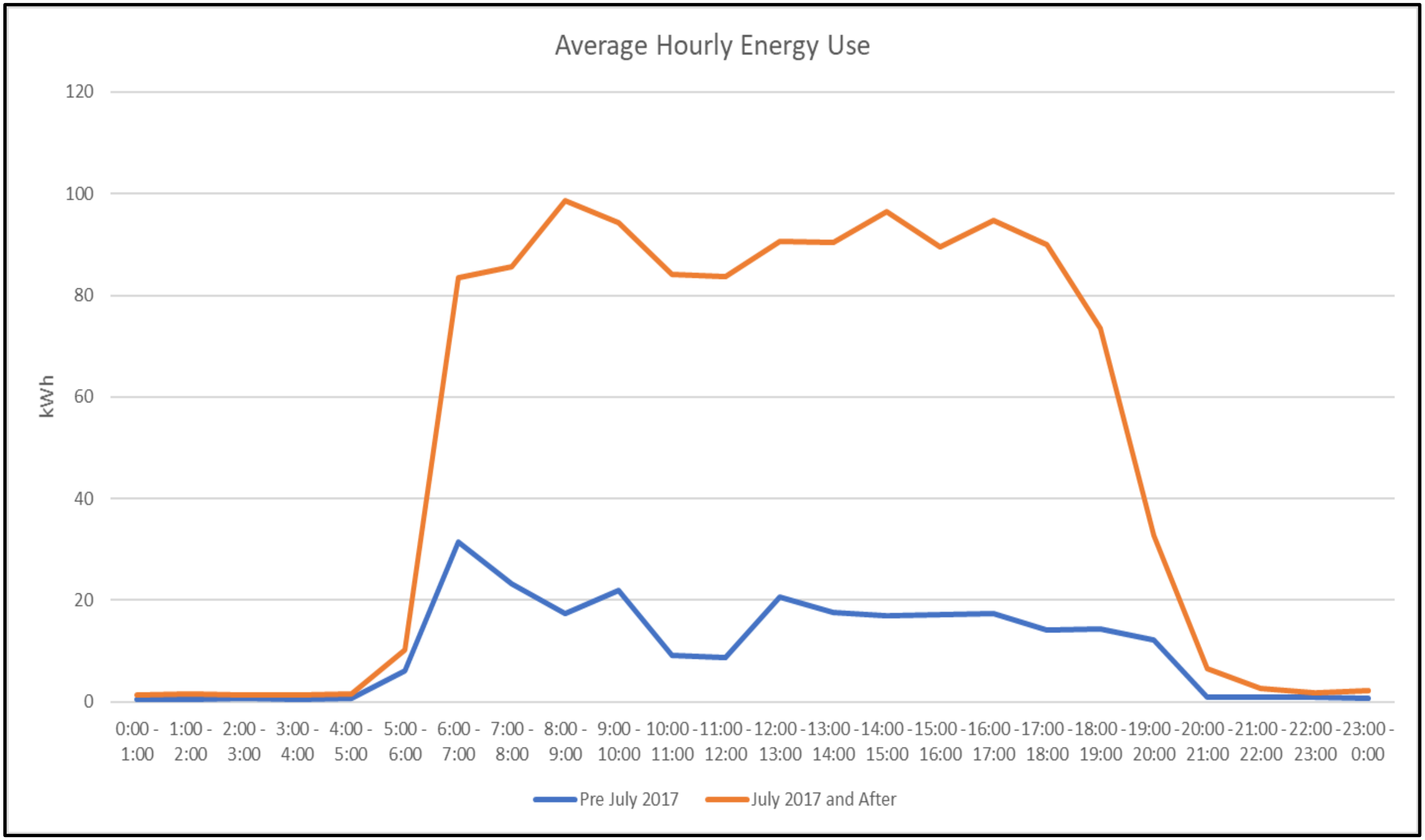
Table 5.20: Charging Cost Estimates if RTD Used ONLY Overnight Depot Charging

	Total Monthly Cost, $	Actual Monthly Mileage, mi	Cost per Mile, $/mi
kW Installed	Using Average Energy Price	Average	Using Average Energy Price and Mileage
300	$5,170	15,818	$0.33
500	$5,906	15,818	$0.37
1000	$7,746	15,818	$0.49
kW Installed	Using Median Energy Price	Median	Using Median Energy Price and Mileage
300	$5,480	16,171	$0.34
500	$6,216	16,171	$0.38
1000	$8,056	16,171	$0.50
kW Installed	Using Maximum Energy Price	Maximum	Using Maximum Energy Price and Mileage
300	$6,790	22,058	$0.31
500	$7,526	22,058	$0.34
1000	$9,366	22,058	$0.42

The per mile costs drop as you would expect, from $0.58 to $0.49 at a 1000 kW Subscription Level and average energy prices, for example. With overnight depot charging only during off-peak hours, RTD could reach parity with average diesel hybrid per mile costs at a subscription charge level of 500 kW or below.

In this case, if RTD switched to overnight depot charging, the average hourly demand for charging the electric buses would change from the current pattern as shown in Table 5.20.

Figure 5.13: Average Hourly Energy Use



5.4.5 Potential Impact of Low Carbon Fuel Standard on Energy Costs

The Low Carbon Fuel Standard (LCFS) is a state policy in California that aims to reduce carbon emissions by incentivizing use of low-carbon fuels. This policy established a market-based cap and trade system with a goal to reduce the carbon intensity (CI) of fuels used in the transportation sector by at least 10% by 2020. Under the LCFS, producers of fuels based on petroleum must reduce the CI of their fuels through the design of new products or they can purchase LCFS credits from low-carbon fuel users. Transit agencies like RTD stand to benefit from the LCFS by earning LCFS credits through operating buses that use low-carbon fuels, like electricity. We were curious to know how RTD's potential use of the LCFS might lower the costs of charging electric buses at RTD, and the remainder of this section addresses that question.

Before explaining the results of this analysis, it is important to note a few things about the LCFS program and RTD's use of it. While RTD is currently accruing LCFS credits, they have not yet sold any credits. As such, RTD has not realized any LCFS revenue at the time of writing this report. As the amount of credits that RTD can accrue depends on the amount of electricity they consume to charge their buses, it takes time for RTD to accrue enough credits to significantly offset their charging costs. Additionally, the LCFS program is market-based, so credit prices fluctuate depending on market conditions. As of March 15th, 2019, the price for one LCFS credit was $197.00/MT[15]. On a yearly basis, from 2016 to 2018, the average credit price was $116.67/MT[16], but for simplicity we assume a $100.00/MT credit price for our calculations. As the credit price increases, the amount of revenue that could be collected increases. Finally, the LCFS program was developed pursuant to California Assembly Bill AB 32 and Executive Order S-01-07[17]. As such, the program was originally set to end in 2020. However, the California Air Resources Board (CARB) recently approved an amendment that extends the program through 2030[18]. It should be noted that while the LCFS program provides an opportunity to lower the costs of fueling near-zero and zero-emission vehicles for fleets, it is a temporary program.

To help participants of the LCFS program, CARB released a LCFS Credit Price Calculator[19]. Using this calculator, it appears that, if they made use of the LCFS program, RTD could receive a subsidy ranging

[15] See https://www.arb.ca.gov/fuels/lcfs/credit/lrtweeklycreditreports.htm
[16] See https://www.arb.ca.gov/fuels/lcfs/credit/20190212_jancreditreport.pdf
[17] See https://www.arb.ca.gov/fuels/lcfs/ab32.pdf and https://www.arb.ca.gov/fuels/lcfs/eos0107.pdf
[18] See https://ww2.arb.ca.gov/news/carb-amends-low-carbon-fuel-standard-wider-impact
[19] https://www.arb.ca.gov/fuels/lcfs/dashboard/creditpricecalculator.xlsx

from $0.13/kWh to $0.14/kWh for electricity used to charge the buses, depending on LCFS market conditions[20][21][22][23]. This credit can be used to offset the total energy costs to charge the buses.

Table 5.21: Cost Estimates Including Low Carbon Fuel Standard (Low Credit)the total monthly cost of charging the buses including the low end of the LCFS subsidy ($0.13/kWh).

Table 5.21: Cost Estimates Including Low Carbon Fuel Standard (Low Credit)

Estimates with Low Carbon Fuel Standard Credit Revenue (Low Credit: $0.13/kWh)			
kW Installed	Total Monthly Cost	LCFS Low Credit Revenue	Total Monthly Cost with LCFS Low
kW	Using Average Energy Price	Using Average Energy Use	Using Average Energy Use and Energy Price
300	$6,635	$4,807	$1,828
500	$7,371	$4,807	$2,564
1000	$9,211	$4,807	$4,404
kW	Using Median Energy Price	Using Median Energy Use	Using Median Energy Use and Energy Price
300	$7,061	$5,172	$1,889
500	$7,797	$5,172	$2,625
1000	$9,637	$5,172	$4,465
kW	Using Maximum Energy Price	Using Maximum Energy Use	Using Maximum Energy Use and Energy Price
300	$8,902	$6,721	$2,181
500	$9,638	$6,721	$2,917
1000	$11,478	$6,721	$4,757

At this rate, the LCFS would generate an estimated average of $4,807 in credit for RTD per month, $5,172 at the median, and a maximum of $6,721 (assuming they use the maximum amount of energy per month as was used since July 2017). The credit decreases the total monthly cost of charging the buses significantly, cutting it almost in half at a 1000 kW Subscription Price level with average energy use. In turn, this would lower RTD's estimated per mile costs of charging the electric buses.

Table 5.22: Per Mile Cost Estimates Including Low Carbon Fuel Standard (Low Credit: $0.13/kWh) shows the per mile cost estimates using the low LCFS subsidy. At a 1000 kW Subscription Price level, average

[20] As the LCFS is a market-based system, credit prices fluctuate.
[21] We assume a compliance year of 2018, a Vehicle-Fuel Energy Economy Ratio (EER) of 4.2 comparing battery electric buses and diesel-fueled buses, a CI Value ranging from 10 to 40 gCO2e/MJ, and a Credit Price of $100.
[22] One of the factors in determining this subsidy is Vehicle-Fuel Energy Economy Ratio (EER). This ratio is the distance an alternative-fueled vehicle travels divided by the distance a conventional engine vehicle travels using the same amount of energy.
[23] One factor in determining this subsidy is Carbon Intensity (CI) of the fuel used. CI Value represents the emissions generated from the use of alternative fuel per megajoules of conventional fuel displaced, and it varies by fuel. Electricity has a CI Value ranging from just above 0 to about 40 gCO2e/MJ. See: https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm

energy use, and average mileage, RTD is likely to see a per mile cost of $0.28, well below the average per mile cost of fueling the diesel hybrid buses.

Table 5.22: Per Mile Cost Estimates Including Low Carbon Fuel Standard (Low Credit: $0.13/kWh)

kW Installed	Total Monthly Cost with LCFS Low	Actual Monthly Mileage	Cost per Mile with LCFS Low
kW	**Using Average Energy Use and Energy Price**	**Average**	**Using Average Monthly Cost and Mileage**
300	$1,828	15,818	$0.12
500	$2,564	15,818	$0.16
1000	$4,404	15,818	$0.28
kW	**Using Median Energy Use and Energy Price**	**Median**	**Using Median Monthly Cost and Mileage**
300	$1,889	16,171	$0.12
500	$2,625	16,171	$0.16
1000	$4,465	16,171	$0.28
kW	**Using Maximum Energy Use and Energy Price**	**Maximum**	**Using Maximum Monthly Cost and Mileage**
300	$2,181	22,058	$0.10
500	$2,917	22,058	$0.13
1000	$4,757	22,058	$0.22

Applying the high LCFS estimate ($0.14/kWh), the total monthly costs decreases more. Table 5.23: Cost Estimates Including Low Carbon Fuel Standard (High Credit: $0.14/kWh) lists the estimated cost at a 1000 kW Subscription Price level and average energy use. The total monthly cost would decrease over 40% to $4,035 per month. That translates to a $0.26 per mile cost for charging the buses at average energy usage and average mileage.

Table 5.23: Cost Estimates Including Low Carbon Fuel Standard (High Credit: $0.14/kWh)

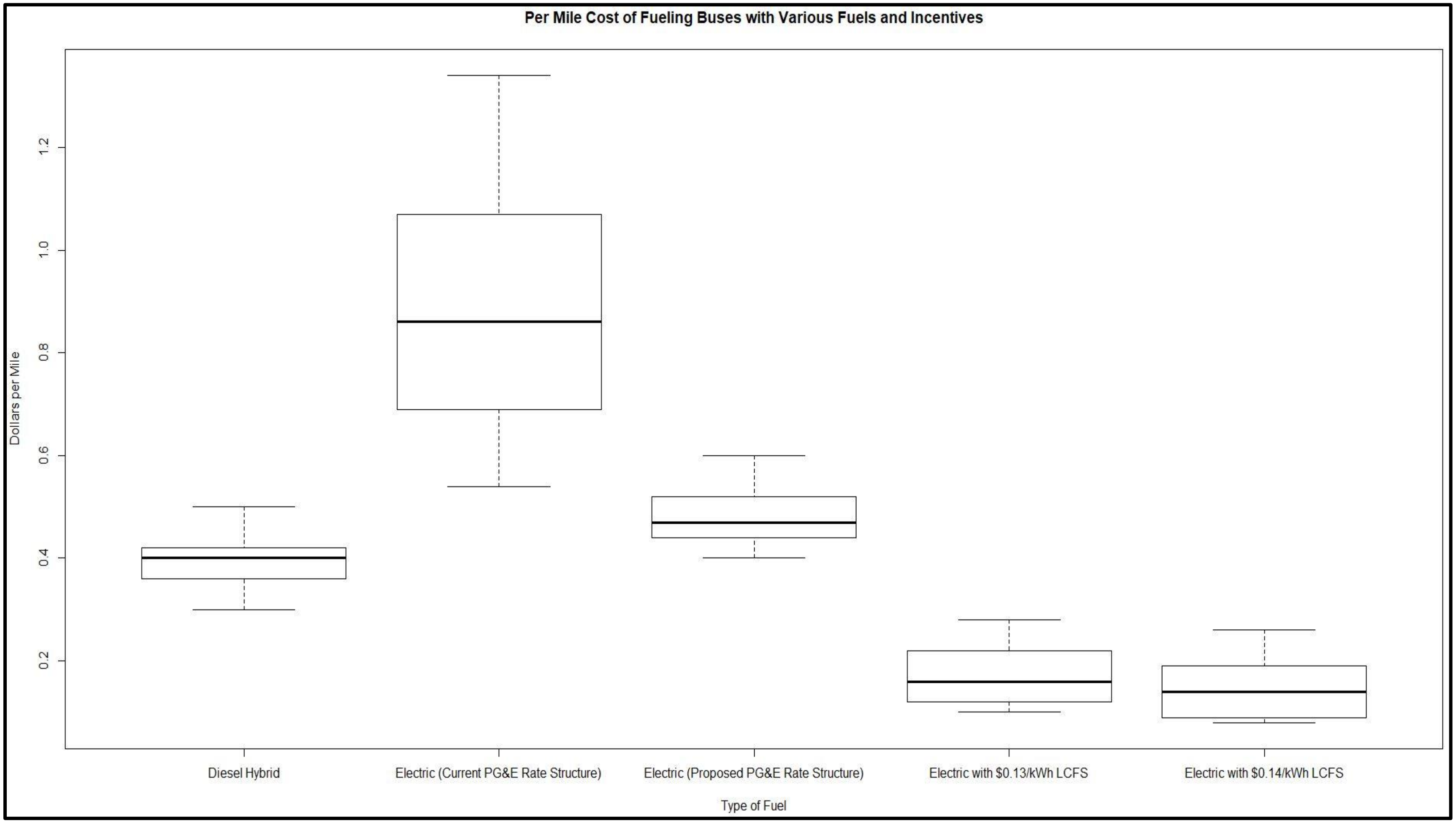
kW Installed	Total Monthly Cost	LCFS High Credit Revenue	Total Monthly Cost with LCFS High
kW	**Using Average Energy Price**	**Using Average Energy Use**	**Using Average Energy Use and Energy Price**
300	$6,635	$5,176	$1,459
500	$7,371	$5,176	$2,195
1000	$9,211	$5,176	$4,035
kW	**Using Median Energy Price**	**Using Median Energy Use**	**Using Median Energy Use and Energy Price**
300	$7,061	$5,570	$1,491
500	$7,797	$5,570	$2,227
1000	$9,637	$5,570	$4,067
kW	**Using Maximum Energy Price**	**Using Maximum Energy Use**	**Using Maximum Energy Use and Energy Price**
300	$8,902	$7,238	$1,664
500	$9,638	$7,238	$2,400
1000	$11,478	$7,238	$4,240

Table 5.24: Per Mile Cost Estimates Including Low Carbon Fuel Standard (High Credit: $0.14/kWh)

kW Installed	Total Monthly Cost with LCFS High	Actual Monthly Mileage	Cost per Mile with LCFS High
kW	**Using Average Energy Use and Energy Price**	**Average**	**Using Average Monthly Cost and Mileage**
300	$1,459	15,818	$0.09
500	$2,195	15,818	$0.14
1000	$4,035	15,818	$0.26
kW	**Using Median Energy Use and Energy Price**	**Median**	**Using Median Monthly Cost and Mileage**
300	$1,491	16,171	$0.09
500	$2,227	16,171	$0.14
1000	$4,067	16,171	$0.25
kW	**Using Maximum Energy Use and Energy Price**	**Maximum**	**Using Maximum Monthly Cost and Mileage**
300	$1,664	22,058	$0.08
500	$2,400	22,058	$0.11
1000	$4,240	22,058	$0.19

To sum the per mile costs of all fuels, Figure 5.14 shows a boxplot with each fuel and incentive represented. For each fuel, the box represents the range from the 25th and 75th percentiles, the whiskers represent the maximum and minimum results, and the dark solid line in the box represents the median value. As you can see in the figure, RTD currently pays more per mile to charge the electric buses than to fuel the diesel hybrid buses, and while PG&E's proposed rate structure would bring the per mile costs down significantly, it isn't likely to bring them down enough to reach parity with the diesel hybrids, especially with RTD's current on-route overhead charging pattern during daytime hours. However, if PG&E's rate structure goes into effect, RTD could use it in tandem with LCFS revenue to bring the per mile costs of charging the electric buses well below the cost of fueling the diesel hybrid buses.

Figure 5.14: Per Mile Cost of Fueling Buses with Various Fuels and Incentives



5.5 User Feedback Surveys

The purpose of evaluating user feedback is to assess impressions of the vehicle from the drivers, maintenance staff, and fleet managers' points of view. Comparisons were made between the electric and diesel-electric hybrid vehicles during normal everyday use.

To obtain user acceptance data, the three different groups of individuals were targeted with different survey questions and methodologies. Drivers who operated the electric bus were asked to fill out either an on-line or hard-copy survey at the beginning and upon completion of the demonstration period. The survey focused on collecting perception of vehicle performance, and overall impressions of the electric drive system and the buses. The driver evaluation survey is available in Appendix A: Driver Evaluation Survey.

A similar survey was distributed to the maintenance staff. The questions highlighted the perceptions of the vehicle performance while providing a ranking of maintenance metrics such as reliability, safety, and design for serviceability. This survey was distributed at the beginning and upon completion of the demonstration period to look for any improvement or deterioration of bus components. The maintenance staff evaluation survey is available in Appendix B: Maintenance Staff Evaluation Survey.

The fleet managers were the final group surveyed at the beginning and end of the demonstration through interviews focused on obtaining a high-level view of how the vehicles fit into the fleet from an operational perspective. The fleet manager survey is available in Appendix C: Management Evaluation Survey.

In addition to using the surveys, CALSTART also interviewed the RTD drivers, maintenance staff, and fleet managers in person during an on-site visit towards the end of the demonstration. Table 5.25 shows a breakdown of survey responses from the different groups of RTD staff.

Table 5.25:Survey Distribution and Response Breakdown

Type of Survey Given	Role	Surveys Collected
First Round of Surveys – December 2017		
Driver Evaluation	Drivers	11
Maintenance Staff	Mechanic	10
Management	Fleet Manager, Supervisors, Directors	4
Second Round of Surveys - August 2018		
Driver Evaluation	Drivers	4
Maintenance Staff	Mechanic	10
Management	Fleet Manager, Supervisors, Directors	5

5.5.1 Driver Evaluation Survey Results

Driver surveys were aimed at establishing performance and operational ratings, along with any additional thoughts regarding the electric drive system that differentiates it from a conventional bus. Due to the subjective nature of driver impressions, a simple, relative rating scheme of "better", "same" or "worse" was used to compare electric bus performance characteristics to those of their conventional diesel-electric hybrid bus. RTD was responsible for distributing, coordinating, and collecting completed driver forms. Surveys were distributed via the fleet manager at the beginning and end of the demonstration period to as many drivers as possible.

There were six performance metrics to compare to a conventional bus that drivers ranked on a scale from "Much Worse" to "Much Better":

1. **Initial Launch from Standstill**: A major advantage of the electric drive system is in the torque provided from start-up when the conventional bus engine is typically most inefficient. This metric aims to capture drivers' perceptions of the effectiveness of the launch with the electric drive system.
2. **Maneuverability at Slow Speeds**: Since most routes travel through neighborhoods it is important to gauge the agility of the vehicle at realistic speeds.
3. **Acceleration**: Comparable to the initial launch, this metric refers to acceleration throughout the power band to gauge boost effectiveness at all speeds.
4. **Coasting/Deceleration**: The electric drive system uses regenerative braking to convert the vehicle's kinetic energy into energy stored in the battery. This extends driving range, improves brake efficiency, and reduces break wear. This metric aims to obtain driver perception on the effectiveness and feel of this new form of coasting in the electric vehicle.
5. **Overall Braking Behavior**: This metric captures overall braking performance by incorporating brake feel as well as the effectiveness of the new coasting and regenerative braking scheme.
6. **Productivity**: The electric buses needed opportunity charging after each service loop. This metric evaluated whether this and other electric vehicle characteristics affected drivers' ability to cover their routes any quicker.

Due to the much smaller sample size of drivers captured in the final round of surveys, the results from the final round of driver surveys were deemed as inconclusive and may not accurately reflect the overall views of the RTD staff. If you wish to see the results of the final round of driver surveys, it can be found in Appendix E: Final Survey Tables - Drivers. To summarize, in every performance category that drivers were asked to rank, the driver impressions of the electric vehicle diminished over time. Typically, we expect performance ratings to improve as drivers become more familiar with features of the new vehicle but in this case, continuous frustration with the charging infrastructure may have caused drivers to develop more negative impressions over time. Drivers most commonly complained about the reliability of the overhead FCrs, specifically about issues with docking the bus for charging. Drivers shared that the overhead charging would often have connection errors, charge too slowly, or would not be available to due maintenance issues. Furthermore, nagging ergonomics issues such as placement of the phone, sensitivity of the foot pedals, and blind spots on the curbside mirror due to its positioning also was a probable cause of low user acceptance. Drivers are highly in-tune with vehicle problems that affect proper functionality and driver comfort, underscoring the importance of in-cab ergonomics and overall acceptance.

5.5.2 Maintenance Staff Evaluation Survey Results

Maintenance staff surveys were aimed at establishing the serviceability and maintainability of the electric transit bus, along with any additional thoughts regarding maintenance of the electric drive system that differentiates it from a conventional bus. The maintenance staff were asked to provide feedback on various service and maintenance aspects, generally comparing to their convention diesel-electric hybrid vehicle.

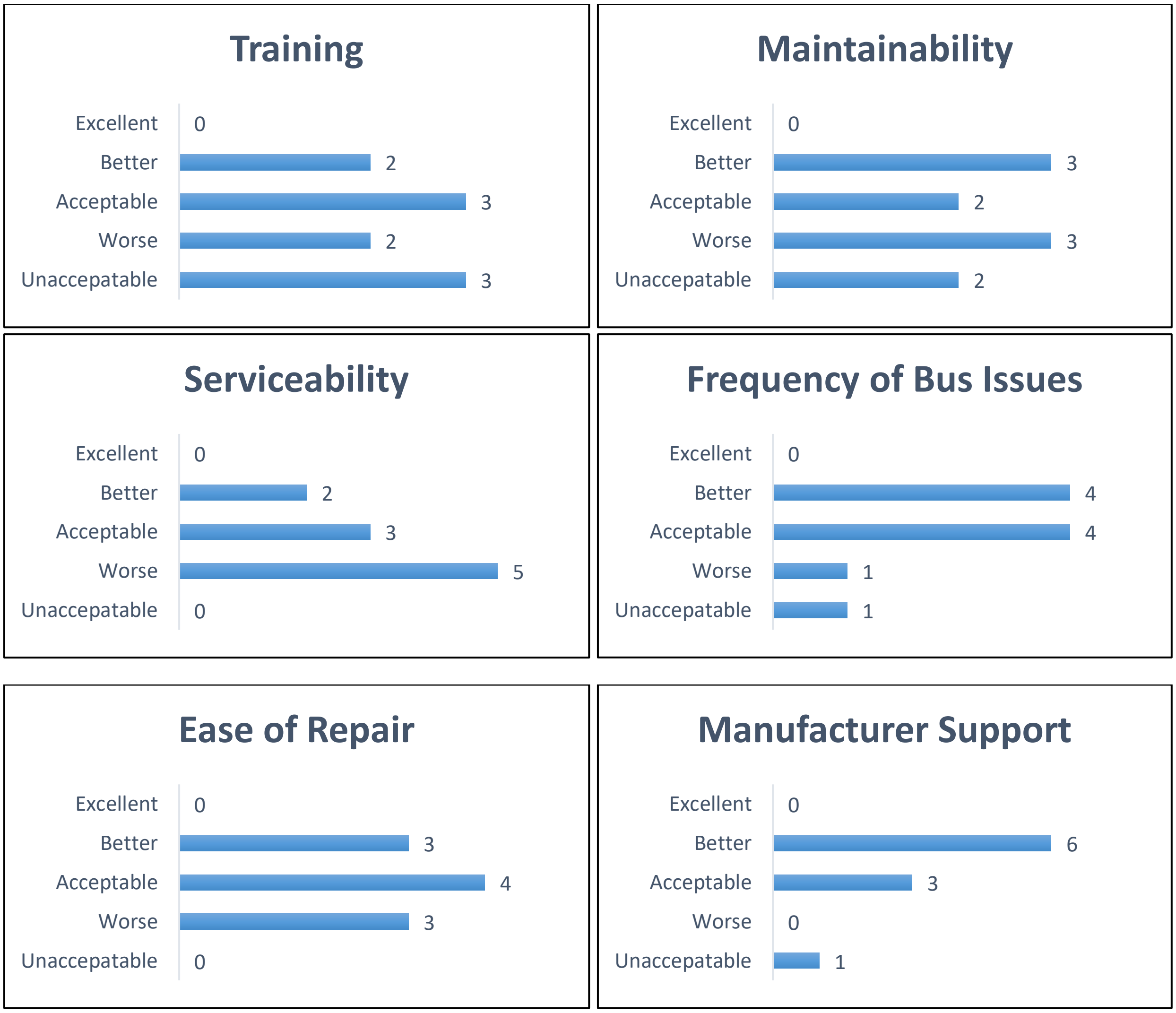
Due to the subjective nature of maintenance staff impressions, a simple, relative rating scheme of “excellent”, “acceptable” or “unacceptable” was used to gauge the overall maintainability of the electric buses. RTD was responsible for distributing, coordinating, and collecting completed driver forms. Surveys were distributed via the fleet manager at the beginning and end of the demonstration period to as many drivers as possible.

There were six performance metrics that maintenance staff ranked on a scale from “Unacceptable” to “Excellent”:

1. **Battery System and Component Training**: This metric aims to capture the maintenance staff’s perceptions on whether adequate training was provided on maintaining and servicing the electric bus.
2. **Design for Maintainability**: In order to maximize bus availability, it is important to gauge whether the design of the electric bus can be easily maintained to minimize down time.
3. **Design for Serviceability**: This metric refers to the ease with which the design of the electric drive components and integration within the vehicle system can be serviced.
4. **Overall Frequency of Electric Bus Related Issues**: This metric aims to obtain the maintenance staff’s perception on how frequently the electric bus is pulled out of service for unscheduled maintenance or road calls.
5. **Ease of Repair of Electric Bus Related Issues**: This metric captures the overall ease of repair of any electric bus related issues.
6. **Electric Bus Manufacturer Support**: Assessing the reliability of manufacturer support is very important, especially when adopting a new vehicle technology. This metric aims to gauge whether the manufacturer provided adequate support during the demonstration period.

The following results from the final round of surveys display the combined ratings of all maintenance staff surveyed and indicate their perceptions after 11 months with the test vehicles.

Figure 5.15: Final Electric Bus Performance Ratings by Maintenance Staff



The ratings depicted in Figure 5.15 above show the final perceptions from ten maintenance staff, all of whom had significant experience maintaining both the electric and conventional diesel-electric hybrid vehicles. Overall, it appears that most of the maintenance staff either thought the electric bus maintained acceptably or better than acceptable. Training and Design for Maintenance received slightly lower ratings, indicating that better training and maintainability could help improve the user experience from a maintenance perspective.

The maintenance staff listed a variety of issues observed during the demonstration period, some of which were repaired in-house, others were corrected by Proterra. HVAC issues were one of the primary concerns expressed by RTD maintenance, sharing that the bus often lacked sufficient airflow to passengers, the heating did not work well, and placement of the HVAC module was located in an area that was difficult to reach. Another common complaint observed was the positioning and design of the curbside mirror arm. Lastly, most maintenance staff expressed that they needed more training and feedback from the bus supplier to maintain the buses safely and efficiently.

Despite the concerns shared by the maintenance staff, they unanimously agreed that the Catalyst electric bus was a substantial improvement over the previous EcoRide model. Additionally, most concerns focused on the physical bus design and components unrelated to the electric drive system. As the bus supplier continues to receive feedback, we believe that over time improvements will continue to be made on the overall bus design and its components.

We investigated how the maintenance staff responses changed from the beginning to the end of the demonstration period. A total of ten staff participated in the first round of surveys. Assigning a quantitative scale from 1 to 5 for “Unacceptable” to “Excellent,” the average ratings of all maintenance staff responses were calculated at each survey event. These trends are shown below in Figure 5.16, where the averaged response to each question is shown for the initial and final surveys.

Figure 5.16: Historical Trends of Electric Bus Performance Ratings by Maintenance Staff

In the Manufacturer Support category, maintenance staff impressions improved over time. This is a positive sign which indicated that staff felt their feedback was being heard by the bus manufacturer. Ease of Repair and Frequency of Electric Bus Related Issues remained relatively neutral over the demonstration period, with staff rating these categories as "Acceptable". Impressions on Training, Design of Maintainability, and Design of Serviceability diminished over time. As with the driver surveys, we would typically expect for these ratings to improve as staff become more familiar with the components of the vehicle and electric drive system. Continued frustration with some of the vehicle components may have caused impressions to become more negative over time.

Though the survey aimed to capture maintenance impressions of the electric vehicle itself, the charging infrastructure is an integral part of the bus reliability and maintainability of the overhead FCr was a commonly addressed issue in the survey. Due to a design flaw, pilot brushes on the overhead FCrs needed to be changed every 2-4 weeks. Accelerated wear on the pilot brushes caused continuous docking and connection issues between the bus and the charger throughout the demonstration. Proterra was made aware of this issue and communicated to RTD that a retrofit was coming that would reduce the frequency in which pilot brushes needed replacement.

5.5.3 Management Survey Results

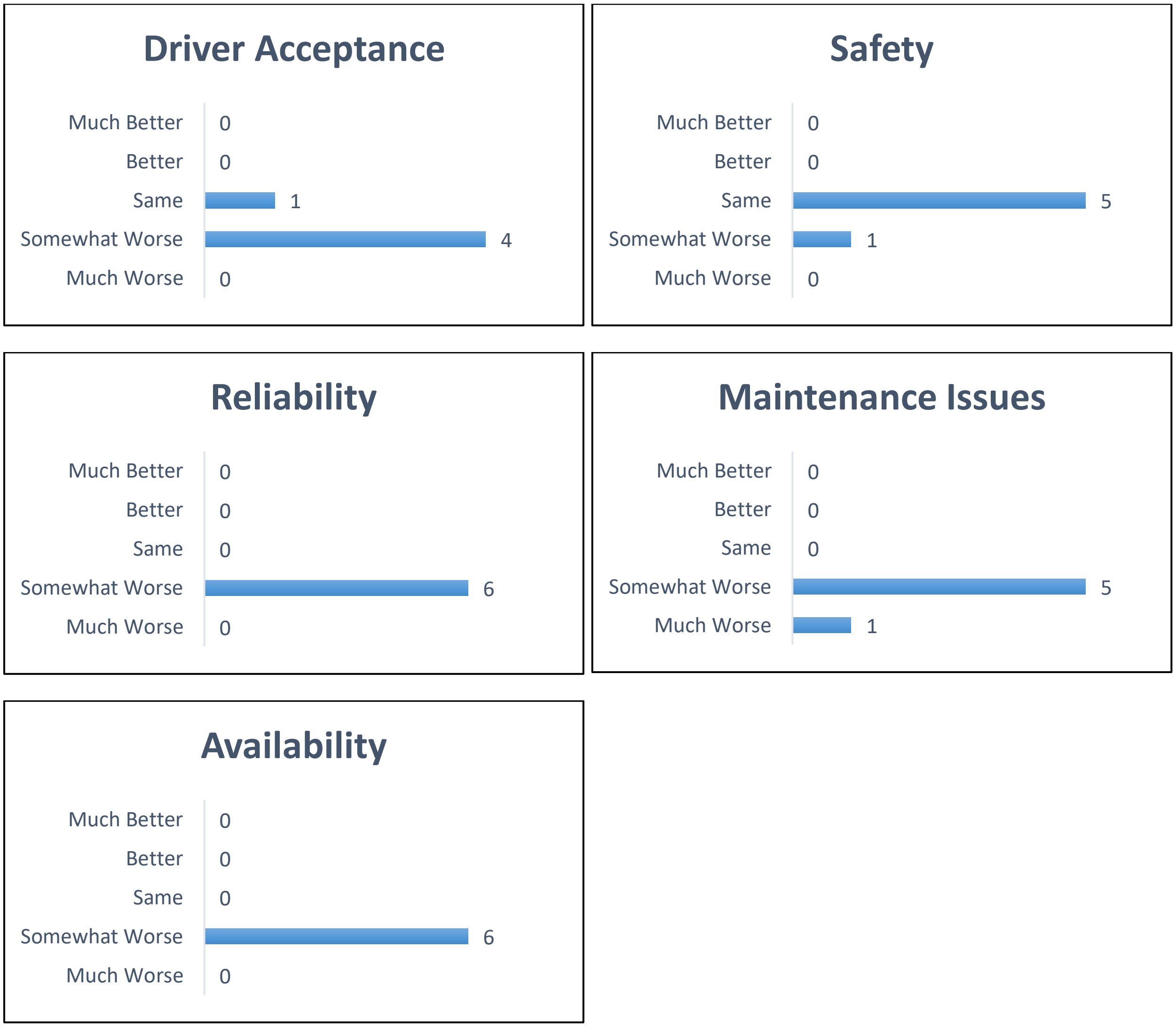
Following the same format as the driver and maintenance surveys, the management questionnaire focused on driver acceptance, safety, reliability, overall maintenance issues, and perceived fuel economy improvement. The management team that was surveyed included the fleet manager, supervisors, and directors. In looking at driver acceptance and maintenance issues, RTD management summarized and rated the electric buses based on information from drivers and maintenance staff, respectively. Adding safety and reliability to the list speaks to the manager's capability of comparing the electric vehicle to the rest of his fleet.

Mangers were asked to rate the electric buses on five performance metrics ranked on a scale from "Much Worse" to "Much Better":

1. **Driver Acceptance**: This metric evaluates driver acceptance of the electric buses, an important consideration for transit agencies looking to adopt a new vehicle technology.
2. **Safety**: A transit agency's primary concern is the safety of its drivers, maintenance staff, and passengers. This metric measures the safety of the electric bus compared to that of its conventional counterpart.
3. **Reliability**: This metric addresses the overall reliability of the electric bus.
4. **Maintenance Issues**: This metric aims to obtain the fleet manager's perception on the maintainability of the electric bus.
5. **Availability for Service Operation**: Bus use and availability are indicators of reliability. Lower bus availability may indicate greater downtime for maintenance. This metric captures the availability of electric buses for service operation

The following results from the final round of surveys display the combined ratings of six fleet managers and indicate their perceptions after significant experience with the vehicle.

Figure 5.17: Final Electric Bus Performance Ratings by Management



The ratings depicted in Figure 5.17 above show final perceptions from six managers, all whom had significant experience managing the fleet of electric and diesel-electric hybrid buses. In each category except safety, the RTD managers rated the bus as somewhat worse in comparison to their conventional buses. Safety was rated as comparable by all fleet managers except one.

Next, we investigated how the manager's responses changed from the beginning to the end of the demonstration period. A total of five managers participated in the first round of surveys. Assigning a quantitative scale from 1 to 5 for "Much Worse" to "Much Better," the average ratings of all fleet managers responses were calculated at each survey event. These trends are shown below in Figure 5.18, where the averaged response to each question is shown for the initial and final surveys.

Figure 5.18: Historical Trends of Electric Bus Performance Ratings by Management

Some of the issues that arose with the charging infrastructure may have impacted the driver acceptance, maintenance, and availability of the vehicles. One of the managers explained how these issues, along with adding to the expense per mile, alter the image of the vehicle, particularly when a malfunctioning component causes the charger to go offline, as was the case with the charger's pilot brushes. Their direct statement was, "It is very expensive to operate due to electric cost and constant man hours servicing and or repairing the charging station." When asked how their perception of electric buses changed over time, most fleet managers responded positively. The responses included "they are getting better" and "as the technology and experience with the electric buses have matured, we are able to work through many of the operational challenges."

5.5.4 Lessons Learned

The irrevocable differences between a battery-electric and diesel-electric hybrid propulsion system limited drivers' ability to get comfortable with the electric buses. Reliability of the charging infrastructure and issues with the docking process were the primary concerns of the drivers. At the time of writing, Proterra was working with RTD to make the docking easier by painting a lane on the approach to the charger to provide a visual aid that would help drivers line up the vehicle with the charger more easily. All performance categories were rated as worse when compared to their conventional hybrid bus. Rather than getting used to the new vehicle, their opinions continued to degrade even though 73% of drivers expressed they had been given sufficient training on how to efficiently drive the electric buses. Therefore, it is reasonable to conclude that the issues with bus performance and charging infrastructure diminished their acceptance of the electric vehicle. The maintenance staff, however, felt that proper training was never implemented which limited their ability to safely maintain and service the bus. Proper training for this group would increase serviceability of the vehicle, improving overall acceptance and integration into the fleet.

Improving the perception of the vehicle is also important to the fleet and could be accomplished by upgrading individual components that are currently being replaced far too frequently, namely charger pilot brushes. Another tool for improving perception could be to improve the overall comfortability of the vehicle for the passengers and drivers. This could be improved by addressing the issues with the HVAC system and vehicle ergonomics. As electric vehicle technology matures, and future generations of electric buses are developed, RTD and CALSTART are optimistic that these early issues will be addressed over time.

6. CONCLUSION AND LESSONS LEARNED

- The electric buses had a vehicle efficiency of 2.13 kWh per mile, which equates to 17.7 miles per diesel gallon equivalent (mpdge). In comparison, the diesel-electric hybrid buses had a vehicle efficiency of 5.13 mpdge which is three times less efficient than that of the battery-electric buses.
- The electric buses had an operational efficiency of 2.57 kWh per mile, which equates to 14.6 mpdge. Operational efficiency is an efficiency metric based on energy measured at the meter and total miles traveled. There can be significant loss as energy is transferred between the meter and the bus. RTD had a charging efficiency of 81% which means a 19% loss in energy was observed between the meter and the buses. Since a transit agency is billed for energy measured at the meter, understanding operational efficiency and charging efficiency was critical in determining the real-world operating costs of electric transit buses.
- The average availability for the electric buses during the data period was 88% compared to the 91% for the diesel-electric hybrid baseline bus. Availability is based on the number of days the buses were actually available compared to the days that the buses were scheduled to be available for operation.
- Peak demand charges can significantly impact the operating costs of electric buses, especially in cases where on-route FCrs are required. If the number of electric transit buses using on-route FCrs is optimized, demand charges can be spread among more buses and the overall cost per mile can be greatly reduced. Fifteen buses utilizing two overhead FCrs would bring demand charges down to $0.30 per mile.

- If approved, PG&E's new rate structure can significantly lower energy costs for electric bus. Based on PG&E's proposed rates and RTD's demand profile, cost per mile to charge the electric buses could drop down to $0.42 per mile.
- The LCFS Program can further decrease energy costs by an average of $0.13 to $0.14 per kWh, depending on the LCFS market conditions. In combination with PG&E's new rate structure, LCFS could reduce charging costs down to $0.09 per mile giving electric buses a significant cost advantage in fuel savings.
- Electric transit buses that require opportunity charging are dependent on the reliability and functionality of the on-route charging infrastructure. If the charging system went down, RTD's electric transit buses were not able to provide service until the charging system was fixed.
- Overhead fast charging required bus drivers to perform a docking maneuver to properly align and connect the bus with the charging head. Docking errors, caused by either the operator or charging system, delayed the charging process and required operators to drive around the transit center to repeat the process until a successful connection was made. Challenges with docking frustrated operators and sometimes caused delays in service.
- User acceptance was low among RTD staff. Reliability of the on-route FCrs and issues with the in-cab ergonomics were the primary causes of frustrations among the drivers. Maintenance staff expressed they needed more training and feedback from the bus supplier to maintain the buses safely and efficiently.

Appendix A: Driver Evaluation Survey

Bus Driver Evaluation Survey - San Joaquin RTD

Bus Driver Operation Evaluation Survey

As part of the zero-emission battery electric bus deployment and testing period we would like to hear your input and evaluation of the electric bus. It will help us evaluate the performance of the vehicle and identify areas that need improvement. Please take 15 minutes to provide your evaluation of the electric bus by answering the following questions.

We appreciate your time and assistance with this evaluation. If you have any questions about the content of this survey, please contact Kevin Leong at (626)744-5606 or at kleong@calstart.org.

Your responses to this survey will be kept confidential and anonymous.

1. Please fill in the following information:

First Name

Last Name

Job Title:

Contact Information (phone or email)

*** 2. Please provide the Route # on which you operate the electric bus:**

*** 3. Do you feel sufficient training was given on properly operating the EV buses?**

- ◯ Yes
- ◯ No (please explain why)

The following questions will ask to compare your experience with an electric bus to that of a conventional RTD bus:

1

*** 4. Please describe the conventional bus that you drive when not operating an electric bus:**

Make	
Model	
Fuel Type	

*** 5. Performance of the electric bus compared to a conventional bus:**

	Much worse	Somewhat worse	Same	Better	Much better
Initial launch from stand still	○	○	○	○	○
Maneuverability at slow speeds	○	○	○	○	○
Acceleration	○	○	○	○	○
Coasting / Deceleration	○	○	○	○	○
Overall braking behavior	○	○	○	○	○
Productivity (able to cover routes quicker)	○	○	○	○	○

*** 6. Operation of the electric bus compared to a conventional bus:**

	Much worse	Somewhat worse	Same	Better	Much better
Reliability	○	○	○	○	○
Inside noise level	○	○	○	○	○
Outside noise level	○	○	○	○	○
In-cab ergonomics (driver interface)	○	○	○	○	○

The following questions are specific to your experience with the electric buses:

2

*** 7. Did you have any customer complaints related to the electric drive system (noise, vibrations, uncomfortable ride...)?**

- ◯ No
- ◯ If yes, please explain:

*** 8. Did you receive any customer compliments related to the electric bus?**

- ◯ No
- ◯ If yes, please explain:

*** 9. Did you have any issues at low speed (noise, vibrations, system unresponsive...)?**

- ◯ No
- ◯ If yes, please explain:

*** 10. Did you have any issues with the regenerative braking?**

- ◯ No
- ◯ If yes, please explain:

*** 11. Did you encounter issues with docking the bus for overhead charging?**

- ◯ No
- ◯ If yes, please explain:

3

*** 12. Have you experienced or noticed any changes in performance on very hot or cold days?**

- ◯ No
- ◯ If yes, please explain:

*** 13. Please provide an overall rating of the electric bus:**

Very Poor	Poor	Good	Very good	Excellent
☆	☆	☆	☆	☆

*** 14. Please list 3 things you like about the electric bus:**

Like #1

Like #2

Like #3

*** 15. Please list 3 things you dislike about the electric bus:**

Dislike #1

Dislike #2

Dislike #3

16. Please provide suggestions or recommendations of performance areas that need improvements in the electric bus:

17. Please share any additional comments you have concerning the electric bus:

(Thank you for your participation!)

4

Appendix B: Maintenance Staff Evaluation Survey

Maintenance Technician Evaluation Survey - San Joaquin RTD

Maintenance Technician Evaluation Survey

As part of the zero-emission battery electric bus deployment and testing period we would like to hear your input and evaluation of the electric bus. It will help us evaluate the performance of the vehicle and identify areas that need improvement. Please take 15 minutes to provide your evaluation of the electric bus by answering the following questions.

We appreciate your time and assistance with this evaluation. If you have any questions about the content of this survey, please contact Kevin Leong at (626)744-5606 or at kleong@calstart.org.

Your responses to this survey will be kept confidential and anonymous.

1. Please fill in the following information:

First Name

Last Name

Job Title

Contact Information (phone or email)

*** 2. Do you feel that sufficient training was given on properly maintaining the electric buses?**

- Yes
- No (please explain why)

The following questions relate specifically to electric bus components - i.e. electric drivetrain, charging, etc.

1

*** 3. Did you observe any electric bus issues during the early part of the demonstration period?**

- ◯ No
- ◯ Yes (please specify issue and whether it was corrected by the manufacturer)

*** 4. Please rate the following issues related to electric bus maintenance on a scale of 1 to 5, where 1 means unacceptable and 5 means excellent.**

	1 (Unacceptable)	2	3	4	5 (Excellent)
Battery system and component training:	◯	◯	◯	◯	◯
Design for Maintainability:	◯	◯	◯	◯	◯
Design for Serviceability:	◯	◯	◯	◯	◯
Overall frequency of electric bus related problems:	◯	◯	◯	◯	◯
Ease of repair of electric bus related problems:	◯	◯	◯	◯	◯
Electric bus system manufacturer support:	◯	◯	◯	◯	◯

*** 5. Please provide an overall rating of the electric bus:**

Very Poor	Poor	Good	Very good	Excellent
☆	☆	☆	☆	☆

2

*** 6. Please list 3 things you like about the electric bus:**

Like #1

Like #2

Like #3

*** 7. Please list 3 things you dislike about the electric bus:**

Dislike #1

Dislike #2

Dislike #3

8. Please provide suggestions or recommendations of maintenance areas that need improvements in the electric bus:

9. Please share any additional comments you have concerning the electric bus:

(Thank you for your participation!)

3

Appendix C: Management Evaluation Survey

Leadership Evaluation Survey - San Joaquin RTD

Leadership Evaluation Survey

As part of the zero-emission battery electric bus deployment and testing period we would like to hear your input and evaluation of the electric bus. It will help us evaluate the performance of the vehicle and identify areas that need improvement. Please take 15 minutes to provide your evaluation of the electric bus by answering the following questions.

We appreciate your time and assistance with this evaluation. If you have any questions about the content of this survey, please contact Kevin Leong at (626)744-5606 or at kleong@calstart.org.

Your responses to this survey will be kept confidential and anonymous.

1. Please fill in the following information:

First Name

Last Name

Job Title

Contact Information (phone or email)

The following questions are specific to your experience with the electric buses:

*** 2. Performance of the electric bus compared to a similar conventional bus:**

	Much worse	Somewhat worse	Same	Better	Much better
Driver Acceptance	○	○	○	○	○
Safety	○	○	○	○	○
Reliability	○	○	○	○	○
Maintenance Issues	○	○	○	○	○
Availability for Service Operation	○	○	○	○	○

1

*** 3. Please provide an overall rating of the electric bus:**

Very Poor	Poor	Good	Very good	Excellent
☆	☆	☆	☆	☆

*** 4. Please list 3 things you like about the electric bus:**

Like #1	
Like #2	
Like #3	

*** 5. Please list 3 things you dislike about the electric bus:**

Dislike #1	
Dislike #2	
Dislike #3	

6. Please provide suggestions or recommendations of performance areas that need improvements in the electric bus:

7. Please share any additional comments you have concerning the electric bus:

(Thank you for your participation!)

2

Appendix D: Route Information

Route 44

Express 44 to Downtown Transit Center (DTC)	To PG&E Express 44
Hwy 99 Frontage @ Boeing Way SB	DTC Dep A
Qantas & Transworld SB	Aurora St & Channel St NB
Giannecchini Ln & Transworld Dr NB	Miner Ave & Airport Way EB
B Street Industrial Dr NB	Airport Way & Sonora St SB
B & Ralph NB	Airport Way & 2nd SB Arr
8th St & B Street WB	Airport Way & 8th SB
Airport Way & 8th St Arr NB	Ralph & Airport EB
Airport Way & 2nd NB	Ralph & B EB
Airport Way & Sonora St NB	"B" St & Industrial SB
Miner Ave & Airport Way WB	Hwy 99 Frontage @ Boeing Way SB
DTC Dep A	

Route 578

Mall Transfer Station (MTS) to Downtown Transit Center (DTC)	To Mall Transfer Station (MTS)
Mall Transfer Arr (South)	DTC Dep C
March Ln & Pacific Ave WB	San Joaquin St & Oak St NB
March Ln & Precissi Ln WB	Park St & Center St WB
Pershing Ave & March Lane SB	Madison St & Flora St NB
Pershing Ave & Rose Marie Ln SB	Acacia & Madison WB
Pershing Ave & Brookside Rd SB	Acacia & Lincoln WB
Pershing Ave & Alpine SB	Acacia & Stockton WB
Alpine & Pershing Ave WB	Pershing Ave & Vine St NB
Alpine & Grange Ave WB	Pershing Ave & Elm St NB
Alpine & Mission Rd WB	Country Club Blvd & Pershing WB
Alpine & Franklin Ave WB	Country Club Blvd & Grange Ave WB
Oregon Ave & Michigan Ave SB	Country Club Blvd & Mission Rd WB
Country Club Blvd & Oregon Ave EB	Country Club Blvd & Franklin Ave WB
Country Club & Fontana Arr EB	Country Club Blvd & Delaware Ave WB
Country Club Blvd & Plymouth Rd EB	Country Club Blvd & Plymouth Rd WB
Country Club Blvd & Clipper Ln EB	Michigan Ave & Ryde WB
Country Club Blvd & Carlton Ave EB	Michigan Ave & Kirk WB
Country Club Blvd & Mission Rd EB	Oregon Ave & Michigan Ave SB
Country Club Blvd & Grange Ave EB	Country Club Blvd & Oregon Ave EB

Country Club Blvd & Pershing EB	Country Club Blvd & Fontana Arr EB
Pershing Ave & Elm St SB	Country Club Blvd & Plymouth Rd EB
Pershing Ave & Rose SB	Country Club Blvd & Clipper Ln EB
Acacia & Yosemite EB	Country Club Blvd & Carlton Ave EB
Acacia & Yosemite EB	Country Club Blvd & Mission Rd EB
Acacia & Lincoln EB	Mission Rd & Bristol Ave
Acacia & Madison EB	Alpine & Mission Rd EB
Madison St & Flora St SB	Alpine & Grange Ave EB
Oak St & El Dorado St EB	Alpine & Pershing Ave EB
San Joaquin St & Park St SB	Pershing Ave & Larry Heller NB
San Joaquin St & Lindsay St SB	Pershing Ave & Brookside Rd NB
DTC Dep C	Pershing Ave & Rosemarie NB
	Pershing Ave & Monaco St NB
	March Ln & Pershing Ave EB
	Pacific Ave & March Ln NB
	Pacific Ave & Weberstown Ent NB
	Mall Transfer Arr (South)

Route 577

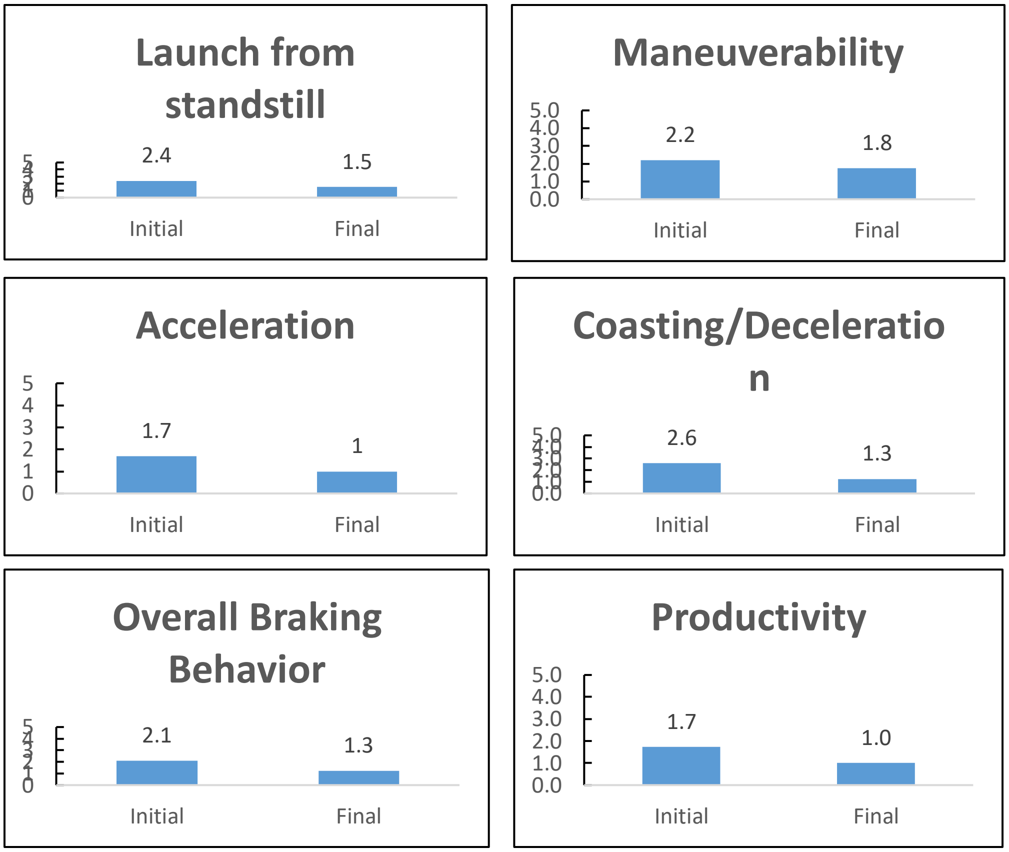
Wilcox & Waterloo to Downtown Transit Center (DTC)	**Downtown Transit Center (DTC) To Waterloo Rd**
Wilcox & Waterloo NB	DTC Dep C
Waterloo Rd & Report Ave WB	Stanislaus & Miner NB
Waterloo Rd & Golden Gate WB	Miner Ave & Airport Way EB
Waterloo Rd & Sunset Ave WB	Wilson Way & Lindsay NB
Waterloo Rd & Filbert St WB	Wilson Way & Park NB
Wilson Way & Lindsay St SB	Wilson Way & Poplar St NB
Miner Ave & Sierra Nevada WB	Waterloo & Sycamore EB
Miner Ave & Airport Way WB	Filbert St & Waterloo SB
Stanislaus & Miner Ave SB	Harding Way & Rhode Island EB
Weber & Stanislaus WB	Harding Way & Golden Gate Ave EB
DTC Dep C	Golden Gate & John St NB
	Waterloo Rd & Report Ave EB

Route 560

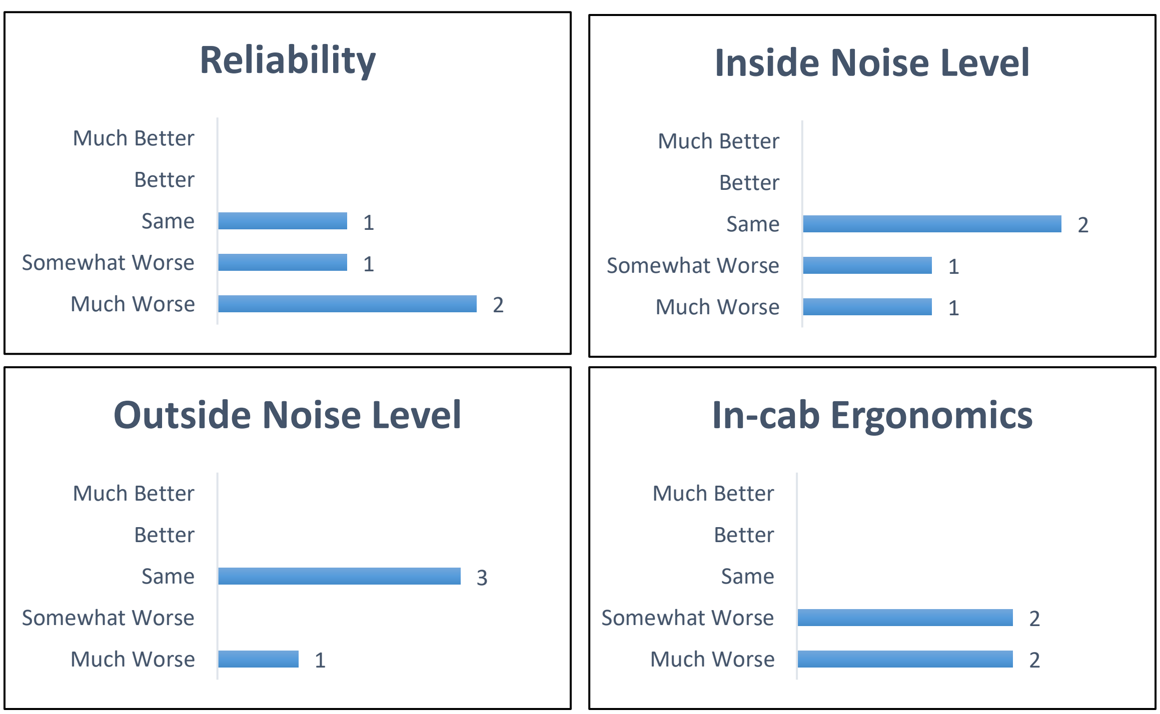
Mt Diablo Ave & Ryde Ave to Downtown Transit Center (DTC)	**Downtown Transit Center (DTC) To Mt Diablo Ave & Pixie Woods**
Mt Diablo Ave & Ryde Ave EB	DTC Dep C
Mt Diablo Ave & Wilshire Ave EB	San Joaquin St & Weber Ave SB
Mt Diablo Ave & Carlton Ave EB	San Joaquin St & Market St SB
Mt Diablo Ave & San Juan Ave EB	San Joaquin St & Lafayette SB
Mt Diablo Ave & Buena Vista Ave EB	San Joaquin St & Hazelton SB
Picardy Dr & Acacia St EB	San Joaquin St & Taylor St SB
Picardy Dr & Pershing Ave EB	San Joaquin St & Anderson SB
Fremont St & Pershing Ave EB	Fremont St & Center St WB
Fremont St & Argonaut St EB	Fremont St & Madison St WB
Fremont St & Yosemite St EB	Fremont St & Van Buren WB
Fremont St & Baker St EB	Fremont St & Harrison St WB
Fremont St & Harrison St EB	Fremont St & Baker St WB
Fremont St & Van Buren St EB	Fremont St & Yosemite St WB
Fremont St & Commerce St EB	Fremont St & Argonaut St WB
Center St & Weber Point SB	Pershing Ave & Fremont St NB
Weber @ Courthouse EB	Picardy Dr & Pershing Ave EB
San Joaquin St & Weber Ave SB	Picardy Dr & Argonne Dr WB
San Joaquin St & Market St SB	Mt Diablo Ave & Buena Vista St WB
San Joaquin St & Lafayette SB	Mt Diablo Ave & San Juan Ave WB
San Joaquin St & Hazelton SB	Mt Diablo Ave & Carlton Ave WB
San Joaquin St & Taylor St SB	Mt Diablo Ave & I-5 WB
San Joaquin St & Anderson SB	Mt Diablo Ave & Ryde WB
Weber @ Courthouse EB	Mt Diablo Ave & Kingsley Ave WB
DTC Dep C	Occidental Ave & Mt Diablo Ave NB
	Occidental Ave & Toyon Dr NB
	Mt Diablo Ave & Pixie Woods
Total Time (mins)[24]	**68/49**
Loops Per Day	**17**
Total Length (Mi)	**13.30**
Number of Passengers Per Day (Weekdays)	**65**

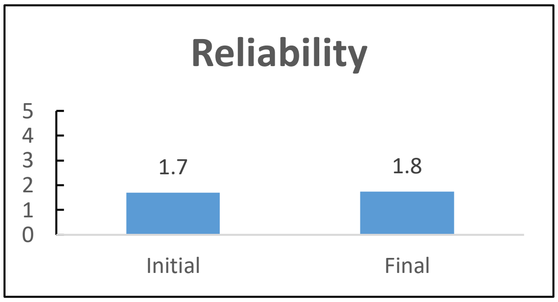
24

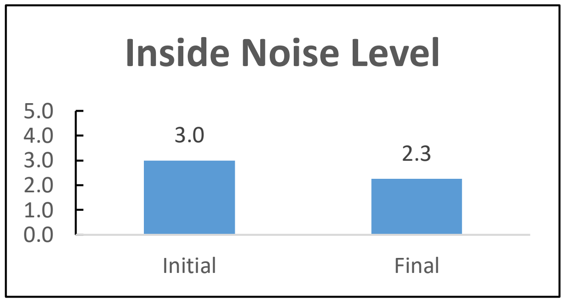
Appendix E: Final Survey Tables - Drivers

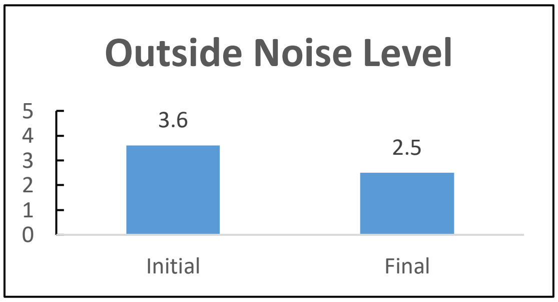


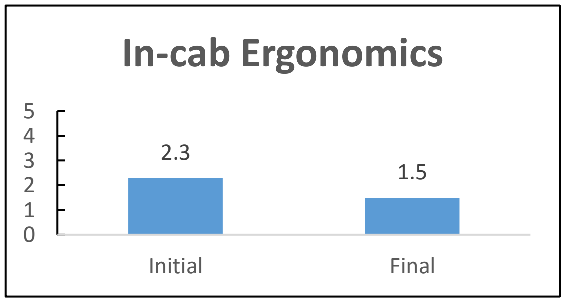
Final Electric Bus Operational Ratings by Drivers




Reliability
5
4
3
2
1
0
1.7
1.8
Initial
Final


Inside Noise Level
5.0
4.0
3.0
2.0
1.0
0.0
3.0
2.3
Initial
Final


Outside Noise Level
5
4
3
2
1
0
3.6
2.5
Initial
Final

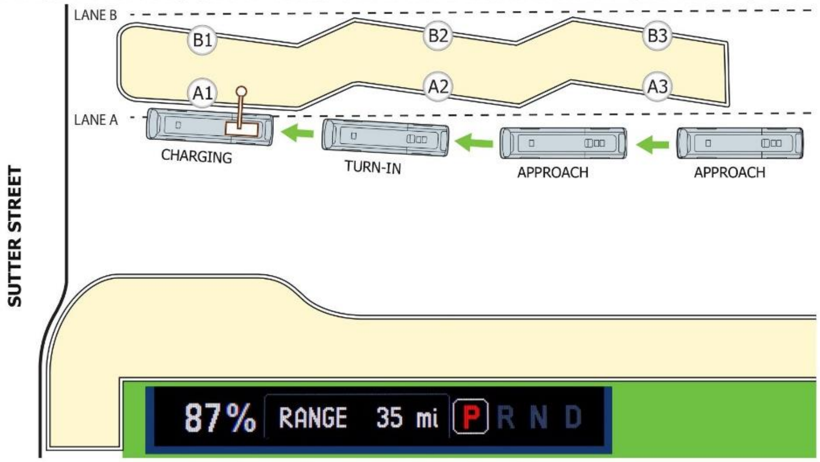

In-cab Ergonomics
5
4
3
2
1
0
2.3
1.5
Initial
Final

Appendix F: Proterra Training Materials

Proterra Inc. Revision 1.0

Approaching and Docking with the Fast Charge Station

IMPORTANT!: DO NOT LEAVE THE CHARGE STATION UNLESS THE CHARGE IS SUFFICIENT FOR THE ROUTE. THIS WILL BE INDICATED ON THE SCREEN.

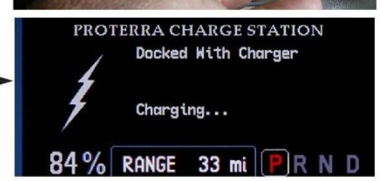


- Within 5 feet of the charge head you should hear a BEEP indicating the charge process is beginning and press the Accelerator Pedal to the floor as the bus speed will be limited. IF NO BEEP is heard, stop the bus within 5 feet of the charge head and drive slowly and/or stop before pole until BEEPs begin (up to 10 seconds).
  WARNING!: You must continue to look and steer the bus straight, and to within 0-12" from the curb. If anyone or anything comes in front of the bus, RELEASE the Accelerator pedal and DEPRESS the Brake Pedal, as necessary.
  Note: For training purposes, you can observe on the display the 1-4 stages of the docking process.

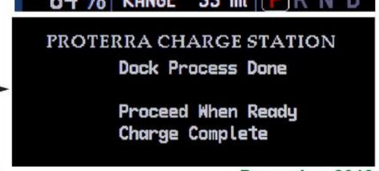
- The bus will automatically brake and stop 2/3 through the docking process while the charge head lands on top of the bus, continue to press the accelerator pedal during the stop (You will hear a THUNK). The bus will then release the brakes and continue through to the final docking location.

- When the bus stops again, release the accelerator pedal and pull the parking brake to begin charging. After 30 seconds you will begin to see the ECO meter drop in the blue and the SOC % will rise.

- Within 10 minutes the bus will have a sufficient charge for the next route.
  Note: The SOC % may change slightly within the first few hundred feet of driving.



- When the bus has enough energy to run the route it will be displayed on the screen. At this point you may depart, but the bus will continue charging if you have additional time and remain at the charger. Release the Parking Brake to retract the Charge Head.
  Note: The bus may not charge to 100%.



Contact: service@proterra.com or 864-438-0000 December 2016

Proterra Inc. Revision 1.0

Docking Process Errors
What To Do If Things Go Wrong

If any docking errors occur, the driver screen will indicate **"Docking Aborted"**. The screen will also indicate if you are to try docking again, or if you should call dispatch. In addition, there will be a fault code number and a word (or a couple of numbers) displayed in the lower right corner of the docking screen. These numbers are helpful when reporting issues with docking. Record the number that appears during a failed dock attempt and report this number to dispatch. This number only appears for 1 second every 10 seconds because multiple numbers may exist. Some of the docking errors are listed in the table below.

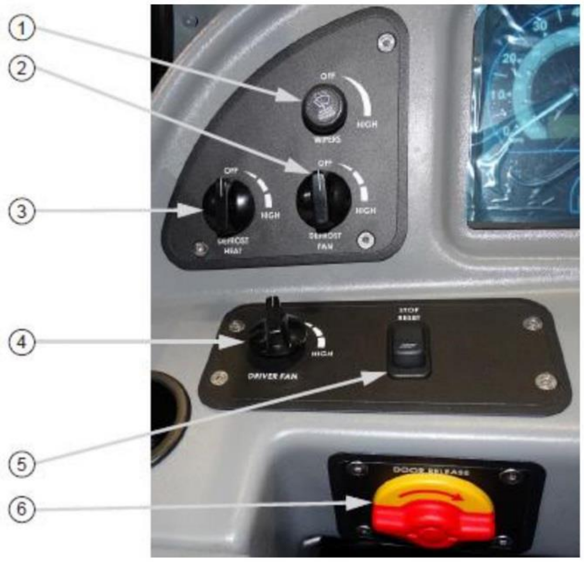
IMPORTANT: As soon as the bus begins to move, the fault code numbers will clear.

Symptom / Message Displayed	Probable Cause	Corrective Action
Screen displays: **"No Land .... 25"** If head appears to land (THUNK is heard when screen initially reports "Head Landing", but screen then shows message above.	Operator pulled in too far from the curb.	Try the docking process again and ensure that the bus is parallel to the curb and located 6-18 inches from the curb.
Screen displays: **"Ultra .... 23"**	Operator did not pull in parallel to the curb or operator pulled in too far from the curb.	Try the docking process again and ensure that the bus is parallel to the curb and located 6-18 inches from the curb.
Docking BEEP noise exists all of the time or starts happening when out on the route.	The roof-mounted Emergency Exit is not closed properly.	Open and re-close the roof-mounted Emergency Exit.
Bus fails to start the docking process.	Bus was not identified by the on-board computer before the docking process started.	• Try docking again, but slow down and stop before the front of the bus goes under the overhead docking arm. • Wait up to 10 seconds for BEEP. Proceed to the other charging station if BEEP doesn't start. • If neither station responds, turn the bus OFF and then cycle the Main Power switch located near the rear of the bus. Try docking again. Call dispatch if its still not working.
Screen displays: **"Pilot .... 24"**	The cause of this error is NOT the Operator's fault.	Try docking again. Contact dispatch if the problem continues to occur.
Screen displays: **"Comm .... 21"**	The cause of this error is NOT the Operator's fault.	Try docking again. Contact dispatch if the problem continues to occur.
Docking is aborted, but fault code is different from those listed above.	The message and fault code will give a clue. This could happen for many reasons.	Record the message and fault code and attempt docking again. Contact dispatch if the problem continues to occur.

- In all fault cases when the bus aborts the docking process:
  - STAY CALM. Be patient and watch the bottom of the screen for a fault code.
  - Remember or record the fault code displayed.
  - While applying the brake, press N, then D, then N, then D to allow the bus to start driving again.
  - If "**Contact Dispatch**" is displayed, park the bus, contact dispatch, and report the error code.
  - Attempt to dock again if State of Charge (SOC) is not sufficient to run the route.

Contact: service@proterra.com or 864-438-0000 December 2016

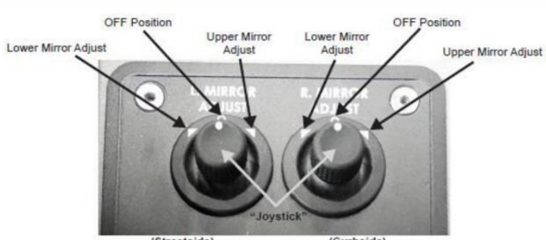
Dashboard Controls



Callout	Control	Operation
1	WIPERS	TURN clockwise to engage wipers (interval, low, high). PRESS to wash windshield.
2	DEFROST FAN	TURN clockwise to desired speed setting. Note: Turn fan ON before turning heat ON.
3	DEFROST HEAT	TURN clockwise to desired heat setting. Note: Turn fan ON before turning heat ON.
4	DRIVER FAN	TURN clockwise to desired speed setting.
5	STOP RESET	PRESS to clear a passenger stop request.
6	DOOR RELEASE	TURN clockwise to dump air to front passenger door.

Callout	Control	Operation
7	RIDE HEIGHT	PRESS and HOLD up (top) to increase ride height. PRESS once down (bottom) to return to normal ride height.
8	RAMP ENABLE	PRESS up (top) to unlock ADA ramp for manual deployment. PRESS down (bottom) to enable normal ADA ramp operation.
9	ADA RAMP	PRESS and HOLD right to deploy ramp. PRESS and HOLD left to retract ramp.
10	KNEEL	PRESS and HOLD right to kneel the bus. PRESS once left to un-kneel the bus.
11	HAZARD	PRESS down (bottom) to turn ON hazard flashers. PRESS up (top) to turn OFF hazard flashers.

Mirror Controls



LEFT MIRROR ADJUST	"O" = locked Right ▶ adjusts bottom mirror. Left ▶ adjusts top mirror.
RIGHT MIRROR ADJUST	"O" = locked Right ▶ adjusts bottom mirror. Left ▶ adjusts top mirror.

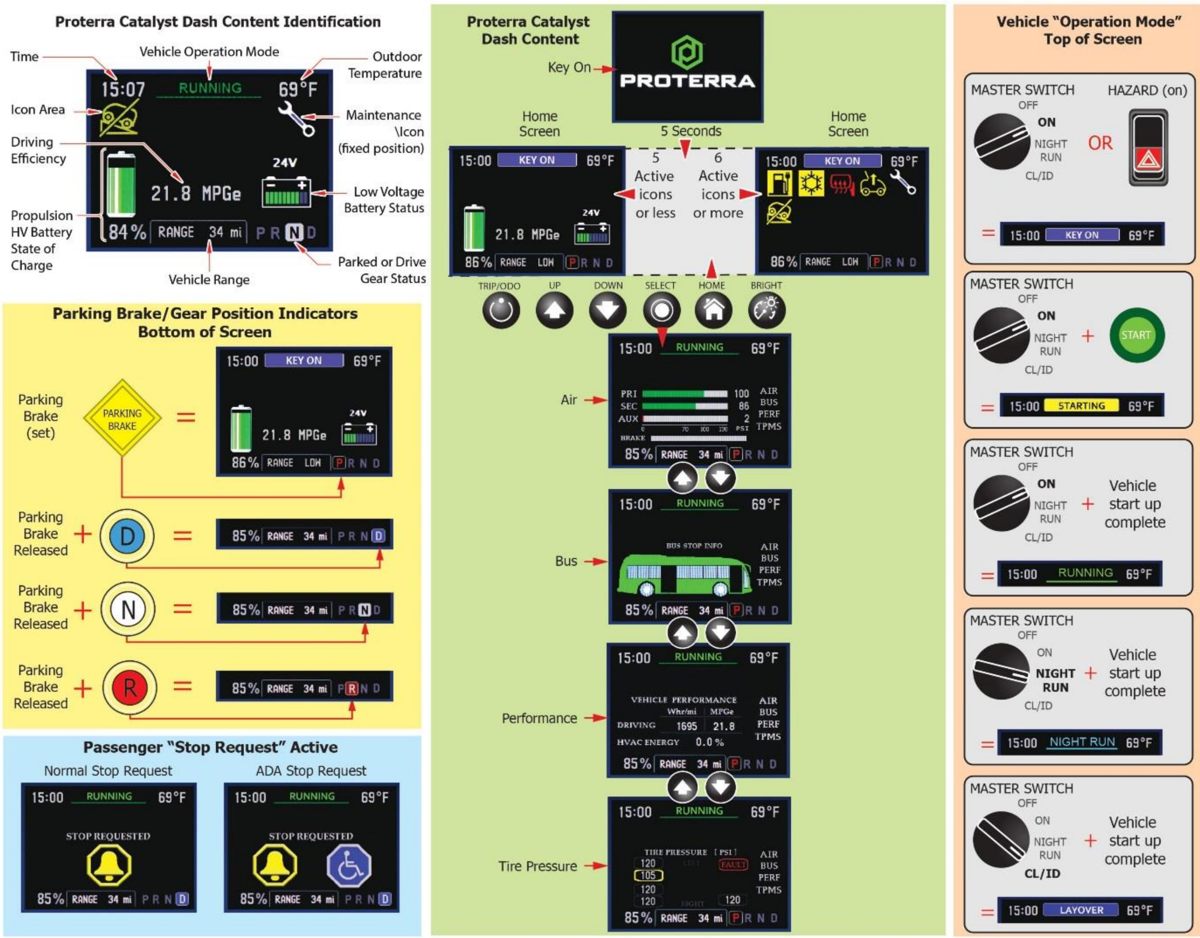
PROTERRA | Proterra Catalyst

Left Panel Controls

Callout	Control	Operation
12	MIRROR CONTROLS	TURN and MOVE "Joystick" to select and adjust mirror.
13	MASTER SWITCH	TURN clockwise to turn bus power ON: ON - day mode ON - night run mode (high beam switch active) ON - layover mode (CL/ID lights on); powertrain disabled
14	START	PRESS to activate high-voltage.
15	SPEAKER SELECT	PRESS down for external speaker only. MIDDLE = both internal and external speakers active PRESS up for internal speaker only.
16	FARE BOX LIGHT	PRESS down to turn ON. PRESS up to turn OFF.
17	INTERIOR LIGHT	PRESS down for dim lighting (option). MIDDLE = OFF PRESS up for bright lighting (option).
18	DRIVER LIGHT	PRESS down to turn ON. PRESS up to turn OFF.
19	DRIVE CONTROLS	PRESS to engage desired drive control: Drive, Neutral, Reverse
20	FRONT DOOR	PUSH to open. PUSH to close.
21	REAR DOOR	PUSH to open. PUSH to close.

Callout	Control	Operation
22	INTERLOCK OVERRIDE	LIFT red cover and MOVE toggle switch forward to activate the vehicle interlock override (door interlocks, etc.).
23	HVAC CONTROLS	Turn the HVAC system ON/OFF or adjust temperature UP/DOWN.
24	HEATED SCOOP	PRESS down to turn ON the heater for the charge scoop and blade.
25	MIRROR HEAT	PRESS down to turn ON timed mirror heat.
26	COVERT EVENT SWITCH	PRESS button to activate the recording function of the DVR, cameras, and microphone.

Callout	Control	Operation
27	PANIC BUTTON / SILENT ALARM	PRESS button to activate exterior emergency flashers, show emergency message on destination signs, and notify dispatch.
28	SHUTDOWN OVERRIDE	PRESS and HOLD 2 seconds to activate the override of a vehicle fault condition or a vehicle shutdown condition. PRESS again to deactivate.
29	BRAKE RELEASE	PRESS and HOLD to override (release) the parking brake.
30	PARKING BRAKE	PULL UP to engage Parking Brake. PRESS DOWN to release the Parking Brake.


Proterra Catalyst Dash Content Identification
Time
Vehicle Operation Mode
Outdoor Temperature
Icon Area
Maintenance \Icon (fixed position)
Driving Efficiency
Low Voltage Battery Status
Propulsion HV Battery State of Charge
Vehicle Range
Parked or Drive Gear Status
15:07 RUNNING 69°F
21.8 MPGe
24V
84% RANGE 34 mi P R N D
Parking Brake/Gear Position Indicators Bottom of Screen
Parking Brake (set)
PARKING BRAKE
Parking Brake Released
Passenger "Stop Request" Active
Normal Stop Request
ADA Stop Request
STOP REQUESTED
Proterra Catalyst Dash Content
Key On
PROTERRA
Home Screen
5 Seconds
5 Active icons or less
6 Active icons or more
KEY ON
TRIP/ODO
UP
DOWN
SELECT
HOME
BRIGHT
Air
Bus
Performance
Tire Pressure
BUS STOP INFO
VEHICLE PERFORMANCE
TIRE PRESSURE
AIR
BUS
PERF
TPMS
Vehicle "Operation Mode" Top of Screen
MASTER SWITCH
OFF
ON
NIGHT RUN
CL/ID
HAZARD (on)
OR
START
STARTING
Vehicle start up complete
RUNNING
NIGHT RUN
LAYOVER


Dash Screen Progression During
Docking Process
15:00 RUNNING 69°F
PROTERRA CHARGE STATION
Docking In Progress
Proceed Slowly
Speed Limit Level 1
84% RANGE 33 mi P R N D
Speed Limit Level 2
Speed Limit Level 3
Wait One Moment
Head Landing
Speed Limit Level 4
Dash Screen Progression During
Charging Process
Charging
Complete
Exiting
Charging Process
Docked With Charger
Set Parking Brake
Head In Position
CHARGING
Charging...
Dock Process Done
Proceed When Ready
Charge Complete
21.8 MPGe
24V
85% RANGE 34 mi
Docking Aborted
Operator Cancelled
If Operator
Cancelled
Aborted
If
Fault
Try Docking Again
Resp 18
Contact Dispatch
Charge Station Error
87% RANGE 35 mi
Charging
Not Charging
Manual Charging Screens
MANUAL CHARGING
Charger Connected
Unplug to Drive
81% RANGE 31 mi

Proterra, Inc. PROTERRA

Driver's Quick Start Procedures – Catalyst

1. Conduct an exterior "walk-around" to ensure all access panels are secured and that there is no exterior damage to the bus.
2. Open the curbside rear access panel and turn the 12/24V Master Disconnect switch ON.

Curbside Rear Access Panel

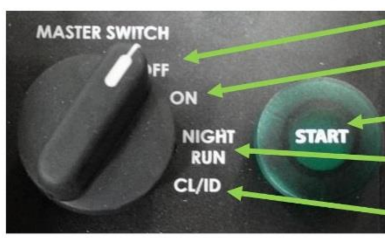
12/24V Master Disconnect (shown in ON position)

3. Open the front passenger door by pressing the button, located behind the streetside access panel. You must press and HOLD the door switch for several seconds until the door activates.

Streetside Front Access Panel

Front Passenger Door Open Button (PRESS and HOLD)

4. Turn bus power ON by turning the Master Switch to the ON position. The START button will illuminate green. Press the START button to start the high voltage connection sequence.



Power OFF

Power ON (Day-Run Mode)

START button (High Voltage)

Power ON (Night-Run Mode)

Power ON (CL/ID) (Standby Mode)

5. The Power ON process may take up to 1 minute, during which the bus cannot be driven.
6. Ensure that air pressure is above 110 psi before driving and that the driver display shows the "OK" icon.
7. Use the drive control buttons to move the bus forward or backward.
   - To change from Neutral to Drive or Reverse, you must press the brake pedal.
   - The bus automatically shifts to "N" when the Parking Brake is applied.

D = Forward

N – Neutral

R = Reverse

Proterra, Inc. PROTERRA

Driver's Shut Down Procedures – Catalyst

1. Stop the bus in a safe location.
2. Deboard all passengers and close the rear passenger door. Leave the front passenger door open for driver exit.
3. Set the Parking Brake by pulling the **yellow knob** on the driver's lower left panel.

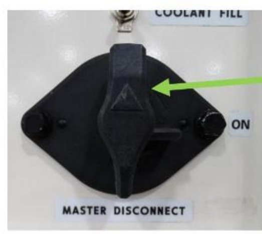
Parking Brake

4. Turn the Master Switch to the OFF position.

OFF Position (shown)

5. Open the curbside rear access panel and turn the 12/24V Master Disconnect switch OFF.

Curbside Rear Access Panel



12/24V Master Disconnect (shown in OFF position)

6. Close the front passenger door by pressing the button, located behind the streetside access panel.

Streetside Front Access Panel

Front Passenger Door Close Button (PRESS and HOLD)

CATALYST PROTERRA

Operator Icon/Diagnostic Description

RED – High level fault present, accompanied with the blinking red light in the center of the instrument panel and an alarm. Driver should pull to the side of the road and call for maintenance support, as the bus performance may be severely limited and shutdown may occur. Examples: Fire detected, critical battery temperature exceeded or transmission failure.

DESCRIPTION	ICON
High Voltage Battery System – State of Charge	
Power Derate Active - Loss of Performance	
High Voltage Connection	
High Voltage Battery System	
General Fault	
Pedal Fault	

DESCRIPTION	ICON
Traction Motor	
Transmission	
Cooling System Temperature	
High Voltage System Isolation	
12/24V Battery System and Charging System	
HVIL Open	

DESCRIPTION	ICON
Air Compressor Motor Temperature	
Fire Detection System Warning	
Complete High-Voltage Shutoff	
Power Steering	
Air System Fault	

AMBER – Low level fault present, accompanied with the constant yellow light in the center of the instrument panel. The vehicle will still be drivable. Driver should be aware and discuss with dispatch at end of shift or convenient time. Examples: Headlight failure, door sensor failure or ADA ramp sensor failure.

DESCRIPTION	ICON
High Voltage Battery System – State of Charge	
Power Derate Active - Loss of Performance	
High Voltage Connection	
High Voltage Battery System	
General Fault	
Traction Motor	
Transmission	
Cooling System	
High Voltage Isolation	

DESCRIPTION	ICON
12/24V Battery System and Charging System	
Air Compressor Motor Temp	
Ride Height and Kneel Control System	
ADA Ramp	
Stop Request System	
Coolant Level	
Door System	
HVAC System	
Air System Fault	

DESCRIPTION	ICON
Power Steering Fluid Level	
Windshield Washer Fluid Level	
Tire Pressure	
Exterior Lights	
Brake Interlock Disabled	
Manual Charger Connected	
ABS System	
Traction Control System	

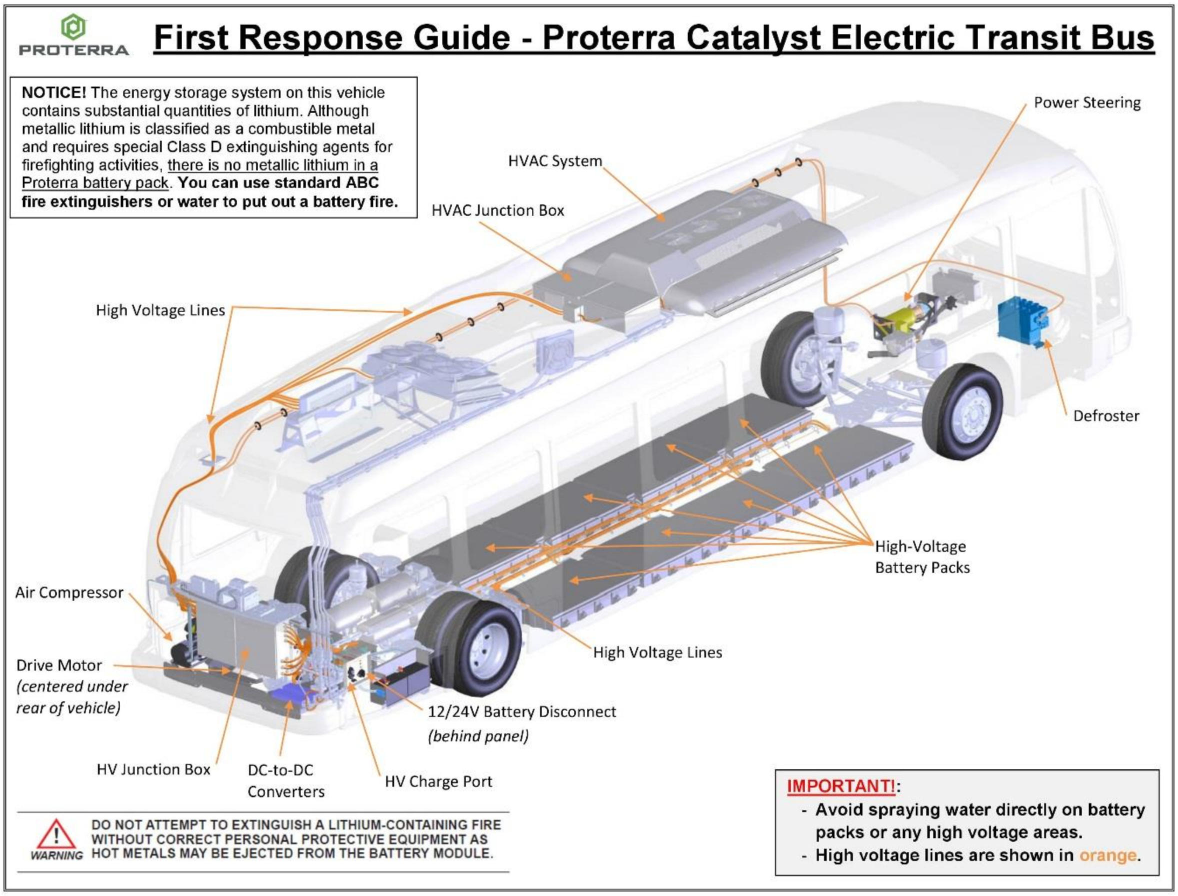
CATALYST PROTERRA

BLACK – Operator information icon. These icons are only used to indicate the state of the vehicle to the driver and are NOT a vehicle fault. Icon is stored in diagnostic system for future troubleshooting. Examples: ADA Ramp Extended.

DESCRIPTION	ICON
High Voltage Battery System – State of Charge	
Power Derate Active - Loss of Performance	
High Voltage Connection	
Ride Height and Kneel Control System	
ADA Ramp Extended	
Door Sensitive Edge Active	
Heated Scoop System Active	
Mirror Heat Active	
12/24V Battery System and Charging System	
Driver Pedal Release	
Pedestrian Warning	
Forward Collision Alert	

DESCRIPTION	ICON
Brake Interlock Active Indication	
Brake Interlock Disabled	
Bike Rack Extended	
Roof Hatch Open	
Service Brake Active	
Regenerative Braking Active	
Regenerative Braking Disabled	
Exterior Lights	
Steady: Seat Belt Flashing: Driver not seated Flashing + Alarm: Driver not seated and Parking Brake not set	
Lane Departure Left	
Following Distance Alert	
Maintenance Wrench (indicates service required at end of shift)	

DESCRIPTION	ICON
Hill Hold Engaged	
Hill Hold Disabled	
ECO Driving Indicator	
Parking Brake Not Applied on Key Off	
Traction Control Engaged	
Traction Control Disabled	
Air System Alert	
Trailer Mode Active	
Propulsion Disabled (by Service Switch)	
Speed Limit Warning	
Lane Departure Right	


PROTERRA
First Response Guide - Proterra Catalyst Electric Transit Bus
NOTICE! The energy storage system on this vehicle contains substantial quantities of lithium. Although metallic lithium is classified as a combustible metal and requires special Class D extinguishing agents for firefighting activities, there is no metallic lithium in a Proterra battery pack. You can use standard ABC fire extinguishers or water to put out a battery fire.
Power Steering
HVAC System
HVAC Junction Box
High Voltage Lines
Defroster
High-Voltage Battery Packs
Air Compressor
Drive Motor (centered under rear of vehicle)
High Voltage Lines
12/24V Battery Disconnect (behind panel)
HV Junction Box
DC-to-DC Converters
HV Charge Port
WARNING DO NOT ATTEMPT TO EXTINGUISH A LITHIUM-CONTAINING FIRE WITHOUT CORRECT PERSONAL PROTECTIVE EQUIPMENT AS HOT METALS MAY BE EJECTED FROM THE BATTERY MODULE.
IMPORTANT!:
- Avoid spraying water directly on battery packs or any high voltage areas.
- High voltage lines are shown in orange.

PROTERRA

Proterra Catalyst Electric Transit Bus - Manual Shutdown

Important: The following actions will shut down the electrical systems on the bus.

1. Set the Parking Brake by pulling the **yellow knob** on the driver's lower left panel:

2. Turn the Master Power switch, which controls the electrical systems, located on the upper left panel, to the OFF position:

3. Open the curbside rear access panel and turn the 12/24V Master Disconnect switch to the OFF position:

Appendix G: RTD Fuel Cost Matrix

Electric Bus Energy Cost Per Mile 2018

	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
	Winter	Winter	Winter	Winter	Winter/Summer	Summer	Summer	Summer	Summer
Customer charge	$137.99	$128.79	$147.19	$133.39	$142.59	$142.59	$137.99	$156.39	$124.19
Demand charge	$5,242.86	$4,467.60	$4,515.84	$4,431.17	$7,308.29	$7,050.62	$7,823.62	$8,405.27	$7,598.58
Demand charge (@ $15/kW)	$7,182.00	$6,120.00	$5,760.00	$5,652.00	$5,616.00	$5,418.00	$6,012.00	$9,756.00	$5,742.00
Energy charge peak 5/1-10/31 (12P-6A) M-F	n/a	n/a	n/a	na	$3,579.93	$3,474.45	$3,872.10	$4,095.44	$3,371.91
Energy charge part peak 5/1-10/31 (8:30a-12P & 6P-9:30P) M-F 11/1-4/30 (8:30A-9:30P) M-F	$4,859.06	$3,225.23	$3,383.27	$3,655.89	$1,810.63	$1,833.55	$1,929.60	$2,087.27	$1,696.74
Energy charge Off Peak Year round 9:30P-8:30A M-F & S-S, Holidays	$1,849.34	$1,707.03	$2,194.07	$1,567.58	$1,821.86	$1,837.25	$1,853.29	$1,992.50	$1,667.15
Total Energy Charge	$7,586.73	$5,643.89	$6,351.08	$5,955.37	$4,579.09	$4,674.28	$4,981.02	$5,153.19	$4,277.58
PDP Program detail total	n/a	n/a	n/a	na	-$1,455.42	-$181.38	$1,849.21	-$1,670.17	-$1,477.77
Adjustments total	n/a	n/a	n/a	na	na	na	na	na	na
Taxes total	$740.34	$582.84	$626.55	$598.51	$804.01	$860.89	$1,060.14	$917.03	$789.50
Total fuel cost **	**$20,416.32**	**$15,755.38**	**$17,218.00**	**$16,341.91**	**$18,590.98**	**$19,692.25**	**$23,506.97**	**$21,136.92**	**$18,047.88**
Total fuel cost per bus (avg)	**$1,701.36**	**$1,312.95**	**$1,434.83**	**$1,361.83**	**$1,549.25**	**$1,641.02**	**$1,958.91**	**$1,761.41**	**$1,503.99**
Total fuel cost less demand	**$15,173.46**	**$11,287.78**	**$12,702.16**	**$11,910.74**	**$11,282.69**	**$12,641.63**	**$15,683.35**	**$12,731.65**	**$10,449.30**
Total fuel cost per bus less demand (avg)	**$1,264.46**	**$940.65**	**$1,058.51**	**$992.56**	**$940.22**	**$1,053.47**	**$1,306.95**		
EV1 mileage	1223	977	615	549	422	982	925	0	0
EV2 mileage	982	609	118	1011	803	347	0	0	0
16401 mileage	2678	492	786	1496	887	486	1266	1806	2039
16402 mileage	873	171	461	1510	604	1232	716	136	494
16403 mileage	1718	188	1140	787	1349	604	905	1312	113
16404 mileage	1082	881	2908	2373	3008	3259	2204	2595	1683
16405 mileage	2161	1260	2468	2893	3267	1955	2417	2575	1726
16406 mileage	2949	1909	1099	2118	3294	1523	0	1109	2352
16407 mileage	1488	1596	2150	2355	1085	0	0	0	0
16408 mileage	2027	1826	1549	0	0	0	1803	1134	1786
16409 mileage	56	0	1530	0	0	124	505	1264	1414
16410 mileage	1469	1901	1347	2658	2226	2248	3066	2938	1647
Total electric fleet mileage	**18,706**	**11,810**	**16,171**	**17,750**	**16,945**	**12,760**	**13,807**	**14,869**	**13,254**
Total electric bus mileage (avg)	**1,559**	**984**	**1,348**	**1,479**	**1,412**	**1,063**	**1,151**	**1,239**	**1,105**
Total cost per mile (Electric)	**$1.09**	**$1.33**	**$1.06**	**$0.92**	**$1.10**	**$1.54**	**$1.70**	**$1.42**	**$1.36**
Total cost per mile (Electric) less demand	**$0.81**	**$0.96**	**$0.79**	**$0.67**	**$0.67**	**$0.99**	**$1.14**	**$0.86**	**$0.79**
KW demand charge	478.8	408.0	384	376.8	374.4	361.2	400.8	650.4	382.8
KWH peak 5/1-10/31(12P-6P) M-F	n/a	n/a	n/a	na	16026.9	15554.7	17334.9	18334.8	14985.6
KWH part-peak 5/1-10/31 (8:30a-12P & 6P-9:30P) M-F 11/1-4/30 (8:30A-9:30P) M-F	35,897.7	23,887.05	24073.35	26013.2	10762.2	10898.4	11469.3	12406.5	9987.9
KWH off-peak Year round 9:30P-8:30A M-F & S-S, Holidays	15,677.7	14,471.25	17770.05	12696.0	12997.5	13107.3	13221.75	14197.5	11756.25
Total KWH	52,054.20	38,766.30	42,227.40	39,085.95	40,161.00	39,921.60	42,426.75	45,589.20	37,112.55
Efficiency (kWh/mi)	47,071	35,182	40,571	35,560	37,393	36,918	40,336	45,589	37,113
Customer charge rate	30 days @ $4.59959	28 days @ $4.59959	32 days @ $4.59959	29 days @ $4.59959	31 days @ 4.59959	31 days @ 4.59959	30 days @ $4.59959	34 days @ $4.59959	27 days @ $4.5959
Demand charge rate	KW @ $10.95000	KW @ 10.95000	KW @ $11.76000	KW @ $11.76000	KW @ 19.52000	KW @ 19.52000	kW @ $19.52000	ays kW @ $19.85000	kW @ $19.85000
	$10.95	$10.95	$11.76	$11.76	$19.52	$19.52	$19.52	$19.52	$19.52
Peak rate	n/a	n/a	n/a	n/a	kWh @ 0.22337	kWh @ 0.22337	kWh @ $0.22337	kWh @ $0.22337	kWh @ $0.22501
Part-peak rate	KWH @ $0.13502	KWH @ $0.13502	KWH @ $0.14054	KWH @ $0.14054	kWh @ 0.16824	kWh @ 0.16824	kWh @ $0.168.24	kWh @ $0.16824	kWh @ $0.16988
Off-peak rate	KWH @ $0.11796	KWH @ $0.11796	KWH @ $0.12347	KWH @ $0.12347	kWh @ 0.14017	kWh @ 0.14017	kWh @ $0.14017;	@ kWh @ $0.14181	kWh @ $0.14181
	$0.12	$0.12	$0.12	$0.12	$0.14	$0.14	$0.14	$0.14	$0.14
Diesel monthly cost average (per gallon)	**$2.03**	**$2.05**	**$2.06**	**$2.08**	**$2.11**	**$2.13**	**$2.45**	**$2.46**	**$2.48**
SMA hybrid fleet diesel consupmtion	22,239	22,469	23,747	22,260	24,156	24,060	24,754	29,440	24,958
Total fuel cost **	$45,145.17	$46,061.45	$48,918.82	$46,300.80	$50,969.16	$51,247.80	$60,647.30	$72,422.40	$61,895.84
SMA hybrid fleet mileage	112,174	126,581	128,785	120,465	128,814	123,219	123,049	145,579	126,827
Total cost per mile (Diesel Hybrid)	**$0.40**	**$0.36**	**$0.38**	**$0.38**	**$0.40**	**$0.42**	**$0.49**	**$0.50**	**$0.49**
Monthly Comments:	Diesel fuel price is slightly higher than last month. Also, Electric buses are not being utilized as planned due to Prop 65 issue.	Electric bus usage down due to Operator Prop 65 issue and radio conerns. Effected the SMA electric fleet primarily. Diesel fuel prices still climbing.		Diesel prices increasing since December 2017.	Diesel fuel is 0.39 higher than May 2017. Charging issues caused a decrease in mileage over the last month. First month of Peak charges this calendar year.	Diesel prices continue to rise. This months demand charges are high. Electric buses are not being used to full capacity due to routes and UTS	Dramatic price increase in diesel per gallon, this month over last month. Also, saw an increase in electricity charges.	Diesel price slightly higher than last month. Electricity usage and charges are higher than last month, but given a deduction on PDP.	Diesel prices rising in junction with the price of oil.