CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

GTrans Zero-Emission Repower Bus Project

Prepared for: California Energy Commission

Prepared by: CALSTART, Inc.

Gavin Newsom, Governor

October 2020 | CEC-600-2020-005

California Energy Commission

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ACKNOWLEDGEMENTS

This project would not have been possible without the support of our project partners, GTrans, who continually provided us with data and on the ground updates regarding this deployment. The GTrans staff was very accommodating and helpful in describing their experience with the new technology. The leadership of Ernie Crespo, General Manager, helped make this project a reality. Chuck Barnes and Dale Carson at Complete Coach Works were also very helpful in providing information about their new technology. Finally, we would like to thank the California Energy Commission for the funding to complete this project in support of cleaner transit operations.

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and non-road vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued Solicitation PON-14-605 to cost share the development of truck demonstrations. In response to PON-14-605, the recipient submitted an application which was proposed for funding in the Energy Commission's notice of proposed awards on June 18, 2015, and the agreement was executed as ARV-15-006 on February 4, 2016.

ABSTRACT

GTrans, a public transit agency located in Gardena, California, received grant funds from the California Energy Commission for this project. Seeking to improve the sustainability of their operations, GTrans worked with Complete Coach Works to provide five battery-electric buses to the fleet (4 repowered and remanufactured; 1 new bus). GTrans installed three charging points to power the buses at their facility.

To address workforce training, the Southern California Regional Transit Training Consortium developed a curriculum to help orient both technical staff and operators to these new vehicles. Bus operators in multiple areas noted the expected difficulties of deploying a new technology but the problems were not critical, and their thorough training prepared them well to adapt. Maintenance teams were required to take on additional duties, including charging the buses and monitoring their energy reserves while in service.

Data, including vehicle performance data, operator records, maintenance data, and utility bills, was collected over a period of more than 12 months of normal operations on all five buses beginning with the first deployment in November 2016. The collected data sources were synthesized and analyzed, with conclusions including that the electric buses drove shorter daily distances than their conventional counterparts, there were major improvements in efficiency, and operating costs decreased (fuel costs were roughly one half; maintenance costs were roughly two thirds of standard). The fleet of five electric buses, as run by GTrans during this demonstration project, saved 15,000 pounds of carbon dioxide (CO_2) annually. From an emissions perspective, these savings are equivalent to removing 90 passenger vehicles from the road each year.

The results of this project have inspired GTrans to continue experimenting with electric bus technology. GTrans has a great head start in adopting zero-emission buses and it will be exciting to watch their progress in years to come.

Keywords: Zero-emission bus, repower, battery-electric bus

Please use the following citation for this report:
LeCroy, Chase and Campbell, Scott. 2020. *GTrans Zero-Emission Repower Bus Project*. California Energy Commission. Publication Number: CEC-600-2020-005

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EXECUTIVE SUMMARY

Electric buses have many benefits for the transit agency, the public, and the environment, improved air quality locally and lessening our contribution to climate change due to no tailpipe emissions, less noise pollution due to the buses' near silent operation, simplified maintenance due to fewer moving parts, and cheaper fuel in the form of electricity. This industry has existed for many years, but production levels are still low, and many transit agencies are just beginning to experiment with the technology. GTrans, a public transit agency located in Gardena, California, received grant funds from the California Energy Commission (CEC) for this project. Seeking to improve the sustainability of their operations, GTrans worked with Complete Coach Works to provide five battery-electric buses to the fleet (four remanufactured and one new bus). GTrans installed three charging points to power the buses at their facility.

To help publicize this project, GTrans hosted an event for government officials, transit agencies, media, and other relevant groups to celebrate the electric buses' deployment and explain benefits of zero-emission technology, especially in disadvantaged communities disproportionately affected by vehicle emissions. Ernie Crespo, Director of Transportation at GTrans, Janea Scott, Vice Chair of the CEC, and United States Representative Maxine Waters each spoke.

A workforce adopting new technology needs adequate training before they can be successful. To address this, the Southern California Regional Transit Training Consortium developed a training curriculum to help orient both technical staff and operators to these new vehicles. It is expected that there will be friction whenever an unfamiliar technology comes into a workplace. Problems noted by the operators were wide-ranging but not critical and the thorough training prepared them well to adapt. Maintenance teams were required to take on additional duties including charging the buses and monitoring their energy reserves while in service. Over time, the team will become more comfortable with the new vehicles.

Data, including vehicle performance data, operator records, maintenance data, and utility bills, was collected over a period of more than 12 months of normal operations on all five buses beginning with the first deployment in November 2016. CALSTART synthesized and analyzed collected data sources in order to draw conclusions about the success of the demonstration and the challenges encountered along the way. While it was determined that the electric buses drove shorter daily distances than their conventional counterparts, there were major improvements in efficiency. The electric bus fuel costs were roughly one half those of the conventional buses while maintenance costs were two thirds of standard. The fleet of five electric buses, as run by GTrans during this demonstration project, saved 15,000 pounds of CO_2 annually. From an emissions perspective, running these buses is equivalent to removing 90 passenger vehicles from the road each year.

The results of this project have inspired GTrans to continue experimenting with electric bus technology. GTrans has a great head start in adopting zero-emission buses and it will be exciting to watch their progress in years to come.

CHAPTER 1: Introduction

GTrans is a public transit agency located in the southern California city of Gardena and it serves the 60,000 inhabitants who live in the six square miles that make up the community. Sustainability is a key aspect of GTrans' operations, with state-of-the-art Leadership in Energy and Environmental Design Silver certified headquarters that serve as the transportation and maintenance campus in the City of Gardena. GTrans is continually working to improve their sustainability and the adoption of electric buses is a major component of this. The grant funds from CEC for this project allowed for GTrans to contract with Complete Coach Works (CCW) to remanufacture four of their gasoline-electric hybrid buses, converting them to battery electric buses using their novel Zero Emission Propulsion System (ZEPS). They converted the buses and manufactured the new bus at their Riverside, California facility and provided warranty service throughout the project duration. As opposed to procuring all new buses, GTrans opted to remanufacture older buses, a more sustainable and cost-effective option. GTrans also purchased one new battery electric bus.

Adopting these vehicles helps GTrans work toward their sustainability goals while also recycling key chassis components of buses that were towards the end of their service lives. As battery electric buses, these vehicles save money on fuel and maintenance costs while produce zero tailpipe emissions. Decreasing the emissions of harmful pollutants and greenhouse gases is urgently needed in these regions and the residents of Gardena can be proud that their transit agency is doing its part to help alleviate the problem.

CALSTART collected and analyzed data describing bus performance for this project. Specifically, GTrans' goals were:

- Validating and analyzing the electric buses' performance
- Comparing the operation of electric buses to GTrans' conventional buses
- Quantifying the greenhouse gas savings associated with this deployment
- Assessing the factors that influence bus efficiency

A demonstration period of 12 months of normal operations was designated as the project timeframe. To this end, data was collected on all five buses beginning with the first deployment in November 2016. At the end of the demonstration period, the collected data sources were synthesized and analyzed in order to draw conclusions about the success of the demonstration and the challenges that were encountered along the way.

This report begins with a brief background of the state of the electric bus industry today and progress made in recent years. The details of this project are then described beginning with the procurement of the buses and the installation of the charging infrastructure. The staff training efforts other activities related to the bus demonstration period is described along with any new operational needs and staff responses to the technology. Finally, a conclusion summarizing the main results of this project completes the report.

Background

Electric buses have many benefits for the transit agency, the public, and the environment. The most salient benefits include no tailpipe emissions, leading to better air quality locally and lessening GTrans' contribution to climate change. Many other benefits exist as well, including less noise pollution due to the buses' near silent operation, simplified maintenance due to fewer moving parts, and cheaper fuel in the form of electricity.

While the electric bus industry has existed for many years, production levels are still ramping up and many transit agencies are just beginning to experiment with the technology. In order to facilitate uptake, government agencies are supporting the research, development, and demonstration of zero emission vehicle technology. For example, the CEC has funded this and many other transit bus development projects. Transit agencies that have received grants to deploy electric buses in California include Long Beach Transit, Central Contra Costa Transit Authority, and Orange County Transportation Authority. The Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) program alone allocated $35,000,000 worth of funding specifically for the purchase of zero-emission buses in 2018, showing the scale of the interest the state government has in supporting this industry.[1]

The electric bus market continues to make positive strides. Lower lithium-ion battery costs and larger scale manufacturing are also making electric buses more cost competitive. Globally, China currently dominates the electric bus market with 99 percent of the world's 385,000 total electric buses.[2] In the United States there are currently about 1,500 battery and fuel cell electric transit buses deployed or soon to be deployed; about 650 of these buses are in California.[3]

More than twenty transit agencies have committed to moving away from buying fossil fuel powered buses in the future.[4] These fleets include the Los Angeles Department of Transportation, Los Angeles County Metropolitan Transportation Authority, San Joaquin Regional Transit District, San Francisco Municipal Transportation Agency, Antelope Valley Transit, and others who have committed to converting their entire fleets to zero-emission buses over the next decade or two.

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[1] California Air Resources Board. Proposed Fiscal Year 2017-2018 Funding Plan for Clean Transportation Incentives. November 2017. Clean Transportation Incentives Funding Plan 2017-2018 (https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_1718_funding_plan_final.pdf) Accessed October 2018.

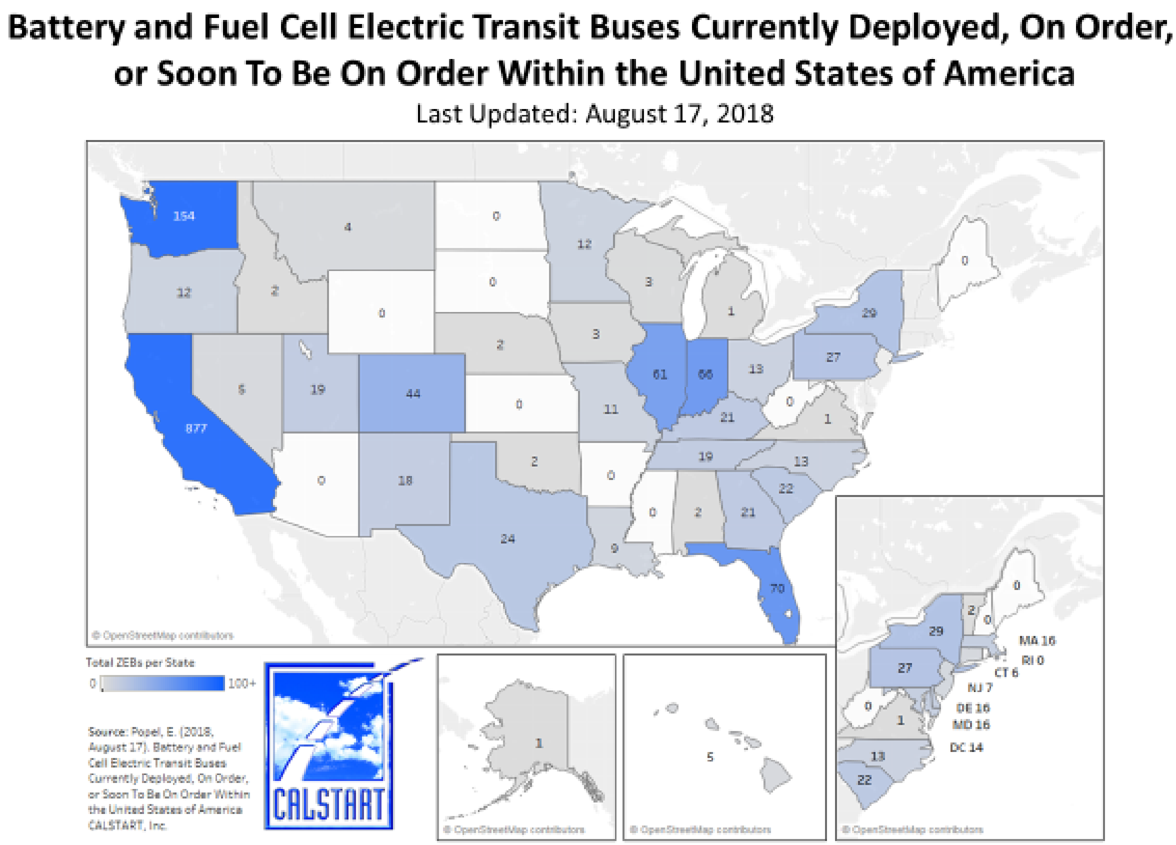
[2] Poon, L. *How China Took Charge of the Electric Bus Revolution*, May 2018. City Lab article on China's electric bus revolution (https://www.citylab.com/transportation/2018/05/how-china-charged-into-the-electric-bus-revolution/559571/) Accessed October 2018.

[3] CALSTART, Internal research soon to be published, 2018.

[4] Aman Atak and Dr. Lorenzo Grande, Li-on Batteries for Electric Buses, 2018-2028, March 2018. Report on market for lithium-ion batteries (https://www.idtechex.com/research/reports/li-ion-batteries-for-electric-buses-2018-2028-000595.asp) Accessed September 7, 2018.

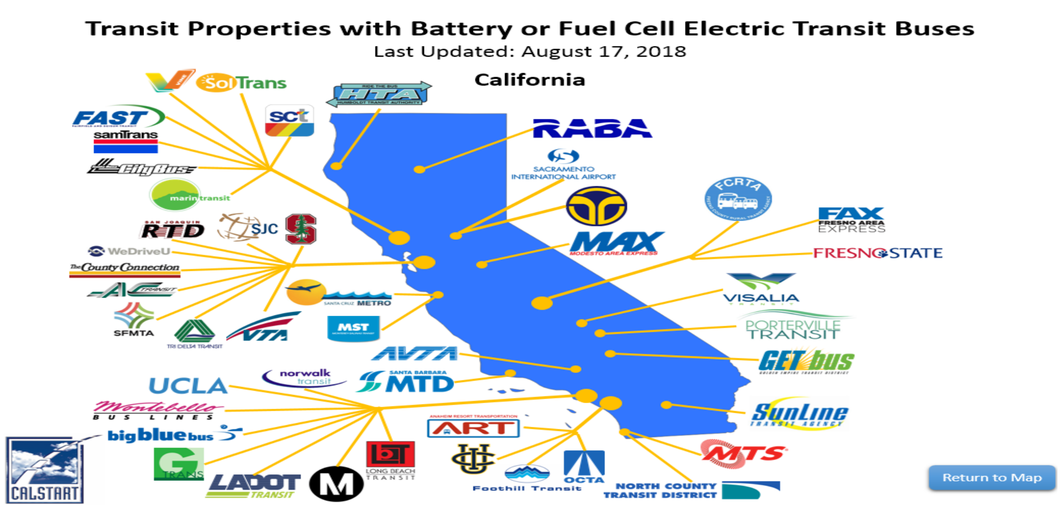
Figure 1 and Figure 2 below highlight the number of zero-emission buses in each state and the variety of transit agencies in California that have zero-emission buses deployed or on order.

Figure 1: Electric Buses Currently or Soon to be Deployed by State



Credit: CALSTART

Figure 2: California Transit Agencies with Zero-Emission Buses



Credit: CALSTART

CHAPTER 2: Bus and Charging Infrastructure Procurement

Bus Procurement

Complete Coach Works (CCW) repowered the GTrans buses using their ZEPS, an all-electric powertrain that provides multiple benefits over a conventional vehicle, including less maintenance, cheaper fuel, and higher torque at low speeds. From a stop, the bus is quicker to accelerate and doesn't need to shift to reach a cruising speed. Operators often report appreciating this improvement to the drivability of their vehicle. The buses are almost silent to operate, reducing the noise pollution that occurs in every city. CCW initially estimated that up to 20 new jobs would result from the work needed for this project. In addition, indirect employment benefits would be felt by the U.S.-based suppliers to CCW. However, per GTrans' staff, this project did not result in job growth for GTrans or increase state revenue.

The approach that CCW used in this project is unique. Instead of building entirely new buses, CCW recycled older hybrid buses belonging to GTrans that would need to be replaced soon. This allowed for usable components to be repaired or remanufactured while only requiring replacement of those parts that were beyond a usable lifetime or unneccessary in a battery electric bus configuration. The engine, gearbox, fuel tank, and transmission were all eliminated while parts such as the chassis frame, differential, and steering and brake systems were able to be remanfactured. Figure 3 below shows two views of one of the buses being remanufactured. The interior was completely stripped and the hybrid gasoline powertrain was removed from the rear of the bus where it usually is located, to be replaced by the electric powertrain.

Figure 3: GTrans ZEPS Bus Being Remanufactured

Credit: CCW

The repowered buses were designed to meet GTrans' requirements in terms of power, durability, and performance, as laid out in the Statement of Work agreed to between the two parties in July 2016. The end product is indistinguishable from a brand new bus, with an updated and modernized exterior and new and improved internal seating. See Figure 4, Figure 5, and Figure 6 below for photographs of the final result.

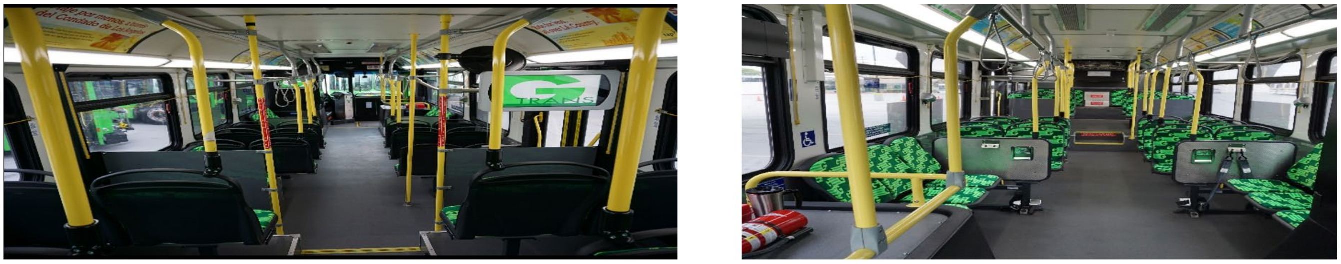
Figure 4: GTrans ZEPS Bus, Front View

Credit: CALSTART

Figure 5: GTrans ZEPS Bus, Side View

Credit: CALSTART

Figure 6: Photos of Bus Interior



Credit: CALSTART

Recycling a portion of the bus allowed for a lower price point as less new material was needed. The converted buses utilized an advanced lithium-ion battery pack with 308 kilowatt hours (kWh) of energy storage capacity and an estimated operating range of 130 miles. These buses were modeled after the 21 remanufactured buses CCW provided to IndyGo Transit in Indianapolis earlier in 2016, but of course molded to GTrans' unique specifications. Please see the full bus specifications in Table 1 below.

Table 1: Specifications for the Buses Repowered by CCW

ZEPS Bus Criteria	ZEPS Bus Specifications
Original model	New Flyer GE40LF
Model year	2005
Tire specifications	Michelin XZU2, 305/70 R22.5
Battery capacity	308 kWh
Usable capacity	250 kWh
Motor	130 kW peak / 90 kW continuous
Battery chemistry	Lithium ion
Battery manufacturer	Samsung
Estimated Range	130 mi
Length	40 ft
Height	102 in
Width	132 in
Wheelbase	293.25 in
Expected operating life	8 years

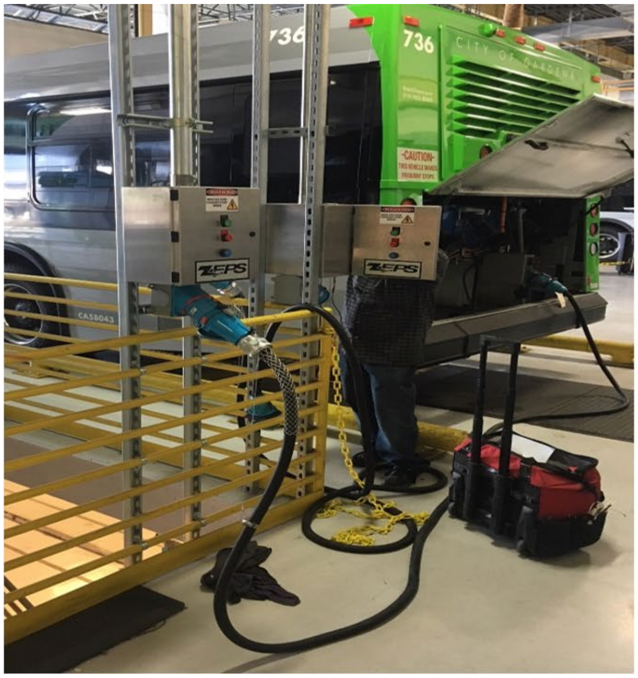
Source: CCW

GTrans received the first of the eventual fleet of five buses in November 2016. By March 2017, all five buses were in GTrans' possession, in service, and recording data.

Charging Infrastructure Procurement and Installation

In advance of any CCW buses arriving at GTrans, CCW installed one electric vehicle supply equipment (EVSE) so that the bus would be able to recharge. There were delays in installing two more EVSEs. Unfortunately, this was a critical bottleneck in the early deployment of the buses because all five had to take turns charging on the single port that was available to them. GTrans has another charging box and cable to install in the future, which would total four chargers on the lot for five buses. This ratio would have reduced any need for buses to queue and ensured more efficient charging. However, the electrical panel at GTrans has a rating of only 1,000 amps and adding a fourth charger would have made the facility exceed this limit. Even with this limited installation, GTrans needed to install added circuit breakers. Down the road, GTrans may be able to install this charger as part of their photovoltaic solar power array and new bus bay that is in the works. Figure 7 shows pictures of the EVSEs.

Figure 7: Vehicle charger stations



Credit: CALSTART

GTrans installed EVSEs in a bus bay in the maintenance garage, so whenever a bus was charging it occupied one of the maintenance bays. After charging was complete, the bus needed to be rotated out and replaced with another bus. This is a less efficient system compared to installing the EVSE in the bus parking lot where, depending on positioning, one EVSE plug could potentially charge four buses parked next to each other by simply unplugging the finished bus and plugging into the next bus. In other words, moving the charging cable to the bus instead of moving the bus to the charging cable. However, this causes other challenges such as trenching to lay conduit from the building's power source to a more remote EVSE in the middle of the parking lot. An EVSE exposed to the elements might need to be replaced sooner than on in doors and would certainly need weatherproofing given amount of exposure to the elements it would see over its service life. The chargers were also not UL certified. As a result, GTrans' application for infrastructure funding through SoCalEdison's ChargeReady program was unsuccessful.

In October 2017, GTrans installed two more EVSEs, bringing the total to three. These new sites were also in the maintenance bays adjacent to the original EVSE. With three options in place, there was less competition for the charge outlets and keeping the batteries full on all five buses became easier to manage. The vehicle charge outlets supply an onboard charger with power and have a rating of 45 kilowatt (kW) while usually delivering an effective rate of 40-44 kW, meaning a bus at minimum state of charge could be completely charged in under 5 hours. Table 2 below shows specifications for the charging equipment.

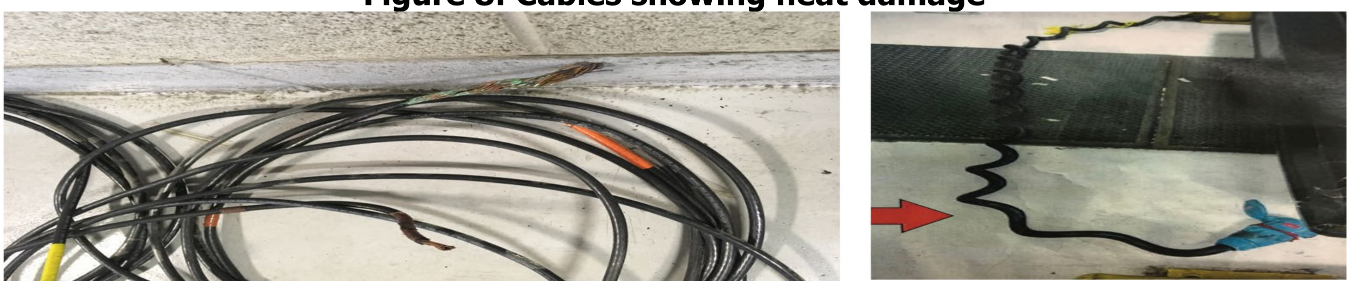
Table 2: Specifications for the Chargers Used in this Project

ZEPS Bus Charging Equipment Type	ZEPS Bus Charging Equipment Information
Connector Type	Meltric 100 Amp 3 Phase, switch rated with last make, first brake contacts
Power Level	45 kW AC
Manufacturer	Complete Coach Works

Source: CCW

Early in the demonstration period, GTrans noticed an issue with the charging equipment. In mid-April 2017, during an inspection of the charging infrastructure, an electrician found that excessive heat was radiating from the charging box. Inside, it was clear that a contactor lug and some high-voltage cabling showed evidence of heat damage. The charging cable that plugs into the bus also showed signs of heat damage, with visible kinking and damage to the wiring and insulation. Figure 8 below shows evidence of the heat damage to interior wiring and the charging cable.

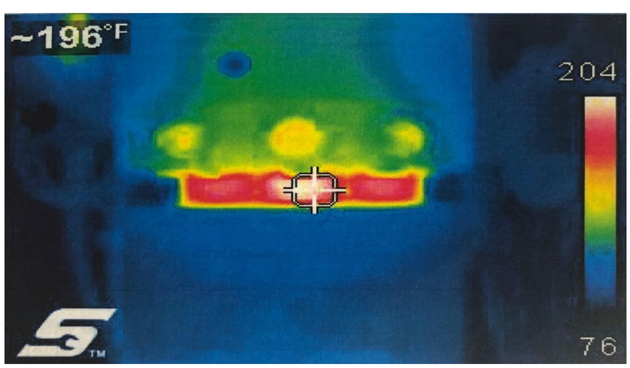
Figure 8: Cables showing heat damage



Credit: CALSTART

Following this issue, GTrans removed the electric buses from service while it addressed the charging situation. GTrans attempted a few solutions over the rest of the month, including lowering the amps at which the buses charged to 55 from 97, but there was still an excessive heat problem. For example, on April 27, 2017, the contacts between the contactor and thermal overload relay were measured at 196°F (see Figure 9 below) while the charge cable coming from the thermal overload relay were measured at 162°F.

Figure 9: Thermal Reading of Charging Box



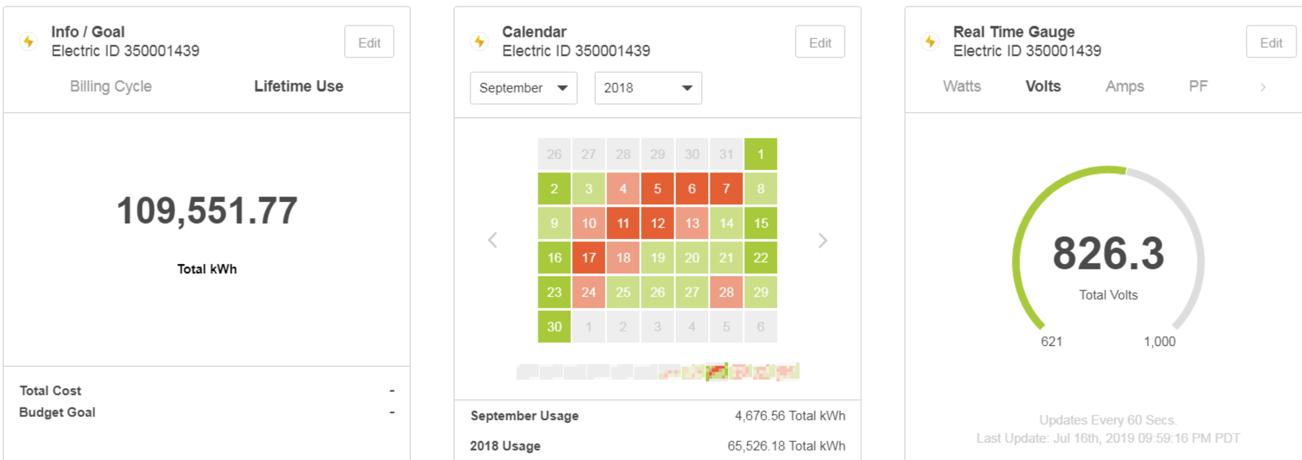
Credit: GTrans

In mid-May 2017, SoCalEdison downloaded and analyzed power data from the charger to investigate what might have been going wrong. They discovered that the power factor of the charger was extremely poor. The power factor is a ratio that reflects how much power is delivered over the maximum power that can be delivered, so a reading of 1.0 would be perfect while anything above 0.90 would be expected for a well-performing charger. The GTrans charger was showing a power factor of only 0.51, causing excessive heat in the charging equipment. It also appeared that the original four-gauge cabling used was not sufficient for the 90-amp electricity that would be flowing through them when the buses charged. The ultimate solution was for CCW to provide modified charging equipment that performed to standards. While in the end this was a minor issue, it still kept the buses out of service for about a month. The heat levels experienced by the charging equipment could have caused a fire if undetected. This is an important reminder that safety needs to be the utmost concern when deploying any technology. Thanks to the diligence of GTrans staff, the only lasting consequence was the need to replace the charger.

GTrans was interested in tracking the amount of electricity used by charger and each bus in order to monitor bus and charger performance. As discussed in Chapter Four, the data loggers on the buses were able to record charging data from the perspective of the bus, but this is not the same as the amount of energy drawn from the grid. When power is fed into the charger from the utility lines, it needs to be converted to direct current electricity before the battery can be charged. There are some conversion losses from this step, so there is more energy consumption than what goes into the battery. It is important that GTrans can track this number in order to receive Low Carbon Fuel Standard credits that help offset the cost of operating electric buses. Initially, a product called the E-Mon D-Mon was installed on the chargers to accomplish the goal of recording the energy consumed. This device is a simple box that was mounted to the wall and wired into the charging hardware. Operationally, the E-Mon D-Mon was not a practical solution because it only shows the total amount of energy used by the charger over its entire existence and this number is simply displayed on the side of the unit (similar to a standard utility meter). Bus operators therefore needed to write down the bus they were charging, the time, and the corresponding reading on the E-Mon D-Mon meter at the moment they unplugged or plugged in to the charger. These numbers were handwritten on clipboards. This process caused issues such as forgetting to write down the information, incorrectly copying numbers, the log pages getting dirty or lost, and the tedious task of ultimately entering the recorded data into Excel by hand to allow for analysis. While the operators did their best to make this system work, it was clear that something more sophisticated would save a lot of effort.

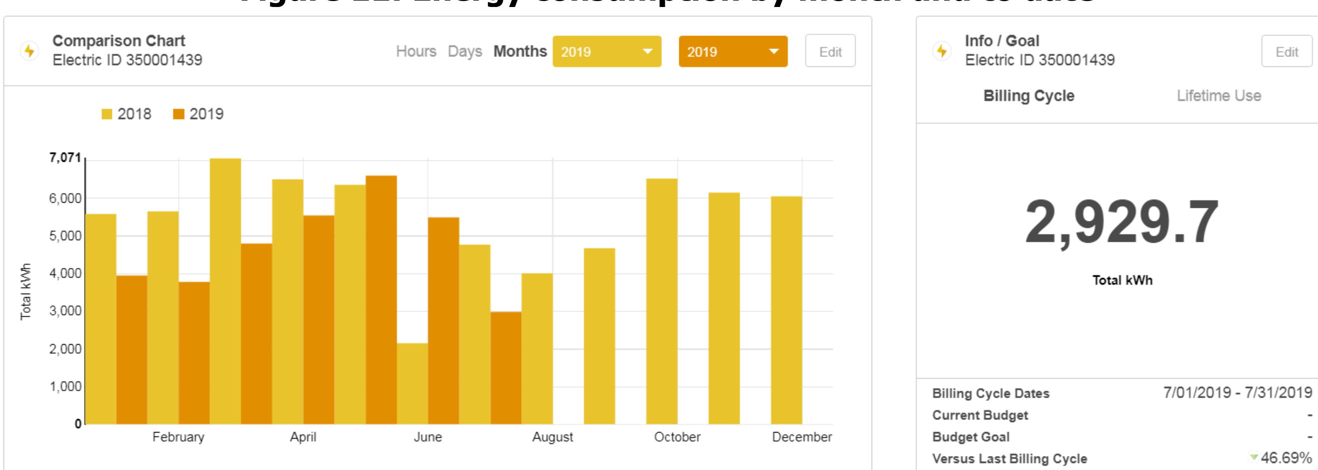
EKM Metering Incorporated meters provided the solution to the issues with the E-Mon D-Mon meter. Similar to the E-Mon D-Mons, these tools allow one to meter the electricity flow through any appliance. In contrast, these devices come with a cloud-based system allowing the data to be stored online and is accessible via a web browser anytime and anywhere. One can export data from this online portal, known as Encompass.IO, in a convenient file format for analysis (and the devices were cheaper in both initial cost and subscription cost). This portal also serves as a highly customizable dashboard, allowing a fleet manager to comprehend the status of their vehicles and chargers at a glance. Different widgets are customizable to show whatever data is most relevant for a specific fleet’s needs including both cumulative and real time data. This tool made it easier to monitor the current status of the buses, provide monthly performance updates, and analyze the demonstration as a whole. Figure 10 shows three widgets displaying (from left to right) total cumulative energy consumption, a calendar heatmap of energy consumption, and a real time gauge of charger wattage. Figure 11 shows a widget on the left comparing total monthly energy consumption in 2018 to 2019 and total energy consumption to date in July 2019.

Figure 10: Energy consumption



Credit: Encompass.IO

Figure 11: Energy consumption by month and to date



Credit: Encompass.IO

Procurement of a new technology, especially one as complicated as a remanufactured battery-electric bus, is bound to present unforeseen challenges. GTrans' experience reflects that reality. While there were some setbacks in obtaining the buses, installing the chargers, and figuring out how to manage this system, the fleet is now well prepared for adding more electric vehicles (EV) to their fleet. GTrans overcame the aforementioned initial barriers and, in the process, GTrans staff added new core competencies to their skillsets that will ease the transition to more sustainable vehicles.

CHAPTER 3: Bus Demonstration

Training

A crucial part in the successful deployment of any new technology is training the individuals who will be the actual users of the technology. In order to effectively and safely demonstrate these electric buses, comprehensive training was emphasized throughout the project. All of those involved with the buses developed new skillsets and greater familiarity with this new technology, enhancing their job retention abilities and widening their exposure to new clean vehicles. Technician trainings generally occurred in eight-hour blocks across two days, with two hours of on-bus training. CCW developed an instructional video that helped orient new users to the buses as well. The Southern California regional transit training consortium (SCRTTC) developed a training curriculum to help orient technical staff to these new vehicles specifically. The technician training course developed by SCRTTC was highly detailed, communicating exactly how the bus subsystems work. SCRTTC instructors emphasized safety, which is important because maintaining an electric bus is very different from maintaining a conventional bus. There are different dangers when dealing with the high voltages used to power these vehicles, so safety should be the top priority. Figure 12 shows the outline of the technician training course.

Figure 12: Schedule of 16-Hour Technician Training

Introduction & Troubleshooting ZEPS

II. Course Agenda

This course is conducted over two 8-hour days. It includes both classroom and practicum instruction.

Agenda

DAY 1	
15 min	**Introduction** • Introductions and Ice Breaker • Course Overview and Objectives • Review of Course Agenda
1 hr 45 min	**Electrical Safety** • Safety equipment • High-voltage Safety • Low-voltage Safety • Ground Isolation
15 min	**Break**
1 Hr 45 min	**Vehicle Systems Overview** • High-voltage Power Distribution • Low-voltage Power Distribution
1 hour	**Lunch**
2 Hr 15 min	**Vehicle Systems Overview (Continued)** • Electric Power Steering System • Electric Air Compressor • Drive Motor • Electronics Cooling System
15 min	**Break**
1 hr 30 min	**First Responder** • Bus Shutdown • Energy Storage Isolation • Fire Procedures (battery / electric fire)
	Adjourn

Introduction & Troubleshooting ZEPS

DAY 2	
15 min	**Review and Q&A**
1 hr	**Software Training** • Overview of Software ○ Opto 22 ○ Canbus (Bussmaster) ○ VCU Communication • Appropriate Contacts
45 min	**Vehicle Maintenance and Operation**
15 min	**Break**
1 Hr 45 min	**Vehicle Maintenance and Operation (continued)**
1 hour	**Lunch**
2 Hr	**Vehicle Maintenance (continued)**
15 min	**Break**
1 hr 45 min	**Vehicle Maintenance (continued)**

Credit: SCRTTC

Internal instructors led teams of operators in training sessions developed with CCW. All operators at GTrans received training on the electric buses, including a behind the wheel test, but GTrans chose a subset of experienced operators to be the first team to put the buses into service. Some trainings continued on a rolling basis to make sure staff knowledge of these new vehicles remains strong. Figure 13 below shows a sign-in sheet that documented one of these trainings at GTrans; Figure 14 shows a checklist used to ensure each operator receives training on all relevant aspects of driving an electric bus.

Figure 13: Sign-in Sheet for Operator Training at GTrans

SCRTTC

www.scrttc.com

Confirmed Training Registration Form

Registration Information:

"The project was made possible with funding provided to GTrans by the California Energy Commission (CEC)"

Attention Registrant:

1) Please verify your name and spelling is correct on the list below and sign – in.
2) If class is a two-day class – please Initial Day 2 Attendance below on second day.
3) We'd like to use your name/photo in our testimonial files for publications and website.
   a. Please check **YES** or **NO** below.

Today's Date: 11/11/2018	Course Name: GTrans/CEC/CCW ZEP – CCW Bus	Course Number: Beta
Date of Course: November 14, 2018 Time of Course: 8 am to 4 pm	Location of Course: GTrans Ballenger Room 13999 S. Western Ave. Gardena CA 90249	Instructor:

Registrant Name & Organization	Sign-In Signature	Attendance Initial	Use of name and photo? YES	Use of name and photo? NO	Evaluation Form Completed
Nolberto Acosta/GTrans	[signature]	NA	✓		✓
Than Dinh/GTrans	[signature]	TD	✓		✓
Osvaldo Arechiga/GTrans	[signature]	OA	✓		✓
Chuck Barnes/CCW					
Wayne Nelson/CCW	[signature]	WN	✓		✓
Jason Glueck/CCW	[signature]	JG	✓		✓
Jose Melendez/Montebello Bus Lines (MBL)	[signature]	JM	X		✓
CARLOS ROJAS	[signature]	C.R	X		

Credit: SCRTTC

Figure 14: GTrans Checklist Used to Verify Operators Successfully Trained on Electric Buses

ZEPS –Emission Propulsion System
CCW Electric Bus

Training Verification Form

I, (Print Name) ______________________ DATE__________

I.D. # __________ have been trained on the coach in the following areas listed below:

- ☐ Pre-trip inspection and inspection of the vehicle airbrake system.
- ☐ Fundamental of vehicle operation/ Control your acceleration (at take-off).
- ☐ Regenerative Braking explained, demonstrated and performed.
- ☐ Starting Procedure / Verify State of Charge Bar Graph (Energy Level).
- ☐ Door Operation Vapor Door Electric- Knee/ Wheelchair Ramp Stow Button Location.
- ☐ Wheelchair securement device operation.
- ☐ Wheelchair Ramp Manual Operation.
- ☐ Discuss waiting for passengers to be seated to ensure safety if near center of coach.
- ☐ Seat release mechanism for wheelchair restraint area.
- ☐ Operation of front and rear door exits: opening, closing, emergency release.
- ☐ Explanation of all emergency exits operation.
- ☐ Basic vehicle operation; left turns, right turns, and transmission shift selector.
- ☐ Pedestrian Awareness Alert System
- ☐ Using caution pulling away from bus stops and lights.
- ☐ Monitoring the interior and exterior rear section using mirrors.
- ☐ Driver's booster blower operation and seat adjustment.
- ☐ Driver Foot Controls Turn Signals.
- ☐ Adjustable foot pedal
- ☐ Operator Display Keyboard (Head sign).
- ☐ Vehicle Specifications (Dimensions, Brake System).
- ☐ Instrumental panel & controls and gauges.
- ☐ Heat, A/C, control switches.
- ☐ Electric Power steering
- ☐ Seat Adjustment, Seatbelt.

Total Training Hours: ______

Operator's Signature ______________ **D.O.T. Certified Trainer** ______________

This operator is capable of operating the vehicle proficiently in compliance with 13CCR1234 (b).

Credit: GTrans

Publicity Event

On May 31, 2017, GTrans hosted an event celebrating the deployment of these electric buses. GTrans invited government officials, transit agencies, media, and other relevant groups to hear about the early successes of the demonstration and how this project was made possible through the work of many organizations and dedicated individuals. The benefits of zero-emission technology, especially in disadvantaged communities disproportionately affected by vehicle emissions, was explained and praised. Attendance to the event was very positive. Some of the speakers during the event were Ernie Crespo, Director of Transportation at GTrans, Janea Scott, Vice Chair of the CEC, and Representative Maxine Waters, whose district in the U.S. House of Representatives includes Gardena. The event was a great success in raising awareness of the project, educating about the emissions issues the project seeks to address, and introducing people to in-service electric buses. Figure 15 shows Ernie Crespo and Representative Waters speaking at the event along with the crowd eagerly examining and touring the CCW buses.

Figure 15: Photos from publicity event

Credit: CALSTART

Operators

Bus operators are obviously a key contributor to the success of projects introducing new bus technology. Their cooperation or antagonism can make or break a demonstration project. Overall, the GTrans operators are very open to change and willing to learn new ways of doing things without much push back. The relationship with management is very positive and it feels as if everyone is a real team. Nonetheless, there was a definite learning curve to driving these vehicles. The different driving style was immediately noticeable. Electric vehicles have higher torque than conventional vehicles at low speed, resulting in a faster acceleration from a stopped position. On the old vehicles, the accelerator had to be depressed forcefully to put the bus in motion whereas on the electric buses require a much lighter touch. Otherwise, the ride would feel very jerky and uneven to passengers. Likewise, coasting is also different. The regenerative braking engages once the operator removes their foot from the accelerator, slowing the bus. The operators must use a very light touch on the accelerator to keep it running smoothly without slowing down.

Problems noted by the operators were wide-ranging but not critical. These issues were largely in the category of annoyances rather than failures. The electric power steering had a different feel to conventional buses, and on one occasion seemed to fail, leaving the operator unable to turn unless moving at very slow speeds. On the plus side, operators felt that the air conditioning system on the bus worked better than on previous bus models. One aspect of the electric buses that operators and passengers valued and appreciated was their near silent operation. While passengers didn’t necessarily realize they were travelling on an electric bus, they did comment on the quietness. The lack of engine noise can be a hazard to pedestrians who might not hear the vehicle coming. To counteract this, the bus emits a verbal warning each time it is turning right or left. This warning sound was initially far too loud and disturbed passenger and operators. The volume was eventually set lower, but the bus warning still triggers too frequently. For example, when the operators slightly turn the steering wheel to change lanes, the warning might sound.

The new electrically-powered doors presented a challenge as well. Most buses have an interlock on the rear door to prevent the bus from taking off while it is open. The CCW buses have an interlock on the front door as well. To release the interlock, the operator must depress the brake firmly two times and this procedure reportedly hurt their knees. Addressing this from an ergonomics perspective could alleviate this problem. Operators felt that the front door closed too slowly, and since the bus cannot drive until it is fully closed, the operators felt that the door issue was causing delays on their bus schedules. In contrast, operators stated that the rear doors closed too hard and fast. This may also be a passenger safety concern.

Surprisingly, the dashboard on the buses did not have an indicator of the exact state of charge. Instead, the dashboard used a color gauge from green to red to show the remaining energy. This imprecise system makes it difficult for operators to assess when they need to arrange for a replacement bus to meet them on route. The dispatch and maintenance teams can monitor the state of charge precisely from GTrans headquarters, but it would be better if operators had the autonomy to manage this aspect of the electric buses themselves. In general, dispatch and maintenance teams called the buses back to base when they reached 25 percent state of charge, but it is hard for bus operators to know when this occurs. Eventually, a miscommunication or simple mistake will lead to an operator misjudging and having the bus die while in service.

Although there were expectations of some dislike of an unfamiliar technology coming into the operators’ workplace, the solid training they received prepared them well to adapt. Over time, the team will become more comfortable with the new vehicles. The operators indicated that they preferred the even older compressed natural gas (CNG) buses to these electric models, but the electric models were preferred to the current hybrid models used at GTrans. However, the optimism of the operators is such that they wouldn’t complain if required to go all-electric at some point on the future.

Maintenance

The GTrans maintenance team had to adapt to the operational and mechanical differences in electric vehicles during the course of this demonstration. From an operations perspective, the maintenance team had to assume obligations beyond their normal duties to make this demonstration a success. Maintenance was responsible for plugging in and unplugging the buses in, rotating them to ensure they all are charged, and monitoring the status of the bus's energy reserves while in service. They estimated that charging the buses alone required 2.5 labor hours per day.

As far as maintaining the buses and keeping them in service, there were never any real powertrain issues. However, the maintenance staff had much trouble with the proprietary nature of CCW's diagnostic system. They were frustrated that the Opto diagnostic tool used to read error codes from the vehicles kept them in the dark as to the problems a vehicle might be having. They could read a diagnostic code but have no idea what the code meant. Meanwhile, CCW could remotely monitor the same codes and understand them. This system required the maintenance staff to contact CCW whenever something went wrong. Initially this was not a serious problem. CCW would ship the bus to their headquarters and fix it for free under the two-year warranty. Now that the warranty period has expired, GTrans must pay out of pocket to ship a bus with a problem, which can cost $750 plus $350 per hour. The need to send the bus out for repairs ensures that any maintenance will take longer on this bus than a conventional bus.

Delays in getting the bus back in service leave the maintenance technicians feeling somewhat helpless. Other bus companies do release their diagnostic code systems, allowing for more internal control over maintenance. The GTrans technicians can still do routine preventative maintenance, including the brakes, wheelchair ramp issues, tires, and other components not related to the electrical system for propulsion.

CHAPTER 4: Bus Data and Performance

In the data collection section, there are discussions of the specific bus technology as well as the various sources of data collected and synthesized for analysis. It also includes the data collection methodology along with any caveats or difficulties encountered during the data collection phase. The final section is the data analysis. It begins with a comparison between the performance of the electric buses and the fleet's standard buses. The emissions reduction benefits are calculated and contextualized before discussions of the electric buses' performance and efficiency. There is also an analysis of the charging patterns used to power the buses.

CALSTART worked on the data collection and analysis portions of the project. Specifically, its goals were:

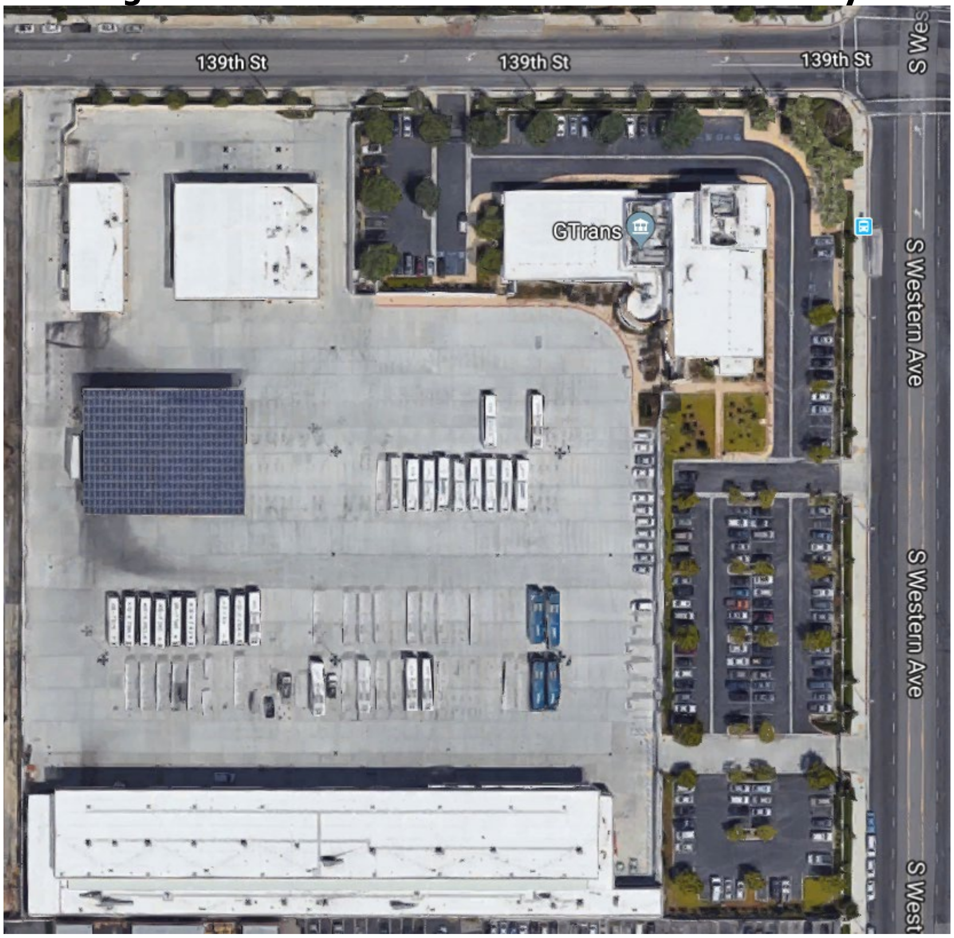
- Validating and analyzing the electric buses' performance
- Comparing the operation of electric buses to GTrans' conventional buses
- Quantifying the greenhouse gas savings associated with this deployment
- Assessing the factors that influence bus efficiency

The project timeframe designated a 12-month demonstration period. To this end, there was data collection on all five buses beginning with the first deployment in November 2016. As the remainder of the buses were delivered and deployed into service, each one was equipped with a data logger allowing for remote data collection and monitoring via. CALSTART regularly summarized and reported performance data on monthly to follow the progress of each bus throughout the demonstration period. In addition, CALSTART collected supplemental data in the form of operator logs, fuel records, maintenance data, and repair information from the various relevant sources in order to have a complete picture of the bus performance. At the end of the demonstration period, CALSTART synthesized and analyzed collected data sources in order to draw conclusions about the success of the demonstration and the challenges encountered along the way.

GTrans Facility and Bus Routes

GTrans bus routes provide transportation options throughout the city limits and beyond. Their bus fleet consists of 57 gasoline-electric hybrid buses. Over time, GTrans plans to convert its fleet to 20 percent electric buses and 80 percent conventionally fueled buses (transitioning from the older gasoline-hybrids to compressed natural gas (CNG). This fleet mix will allow GTrans to balance their sustainability goals while still providing comprehensive and reliable service. The GTrans facility is equipped with solar panels, energy efficient lighting, heating and air conditioning systems, a 14-bay bus garage, fueling stations, and a bus wash. The solar panels and Leadership in Energy and Environmental Design Silver certification of the facility likely exceed Title 24 standards for building efficiency. Figure 16 shows an overhead view of the facility.

Figure 16: Overhead View of the GTrans Facility

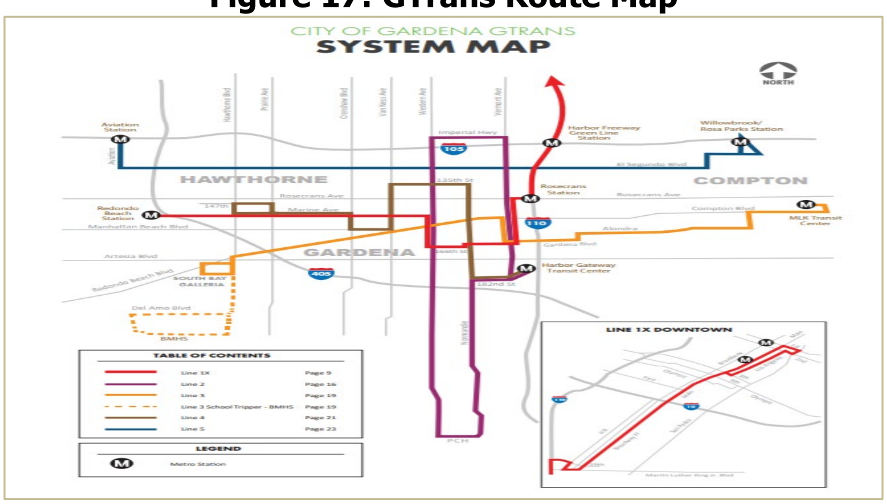


Credit: Google Earth

Future plans include expansion of the existing 130 kW solar array to 380 kW as well as installing a 1 megawatt hour energy storage system to power their current and potential future battery electric buses.

GTrans serves five primary routes, and Figure 17 below shows a route map displaying the main routes and one supplemental school route

Figure 17: GTrans Route Map



Credit: GTrans

Line 1X (shown in red) connects Gardena and the surrounding communities to downtown Los Angeles. Line 2 (shown in purple) runs as a loop between Gardena and Carson to the south. Line 3 (shown in orange) runs roughly from Compton in the east to Redondo Beach in the west. Line 4 (shown in brown) is a compact route connecting Hawthorne, Torrance, and Gardena. Line 5 (shown in blue) runs parallel to the 105 freeway on Hawthorne Boulevard. The ZEPS buses operated on Lines 2, 3, and 4 exclusively. 77 percent of all trips with data and operator information recorded occurred on Line 3 while 20 percent occurred on Line 2. The remaining 3 percent of trips were on Line 4. Table 3 shows line characteristics.

Table 3: GTrans Bus Route Characteristics

Bus Line	Eastbound Distance (mi)	Westbound Distance (mi)	Eastbound Stops	Westbound Stops	Terrain
Line 2	17.4	14.4	87	91	Flat
Line 3	9.2	11.7	43	46	Flat
Line 4	9.0	8.9	47	49	Flat

Source: GTrans

Data Collection

Methodology

To evaluate the performance of the buses and achieve the project goals, CALSTART managed multiple data streams in order to have a complete picture of the early stages of zero-emission bus use at GTrans. The main data source was in-use performance data collected through an on-board data logger. Data collection occurred during the demonstration period, which was originally 12 months, but later extended to 20. In addition, GTrans provided operational data, including preventive maintenance records, repair records, charging data, route data, and operator driving logs. CALSTART then analyzed the performance and operational data in order to draw conclusions about the successes and issues associated with deploying this new technology. Table 4 below lists the different data CALSTART worked with and their sources.

Table 4: List of Different Data Streams Analyzed for this Project and their Sources

Data Stream	Data Source
In-use Performance Data	On-board data logger
Operator Information	GTrans records
Bus Line Assignment	GTrans records
Maintenance Records	CCW and GTrans records

Source: CALSTART

In-Use Performance Data

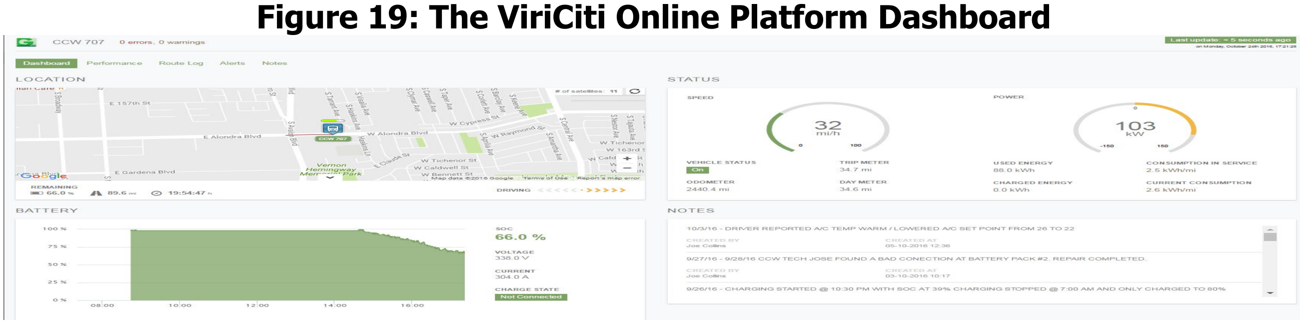
ViriCiti provided the data logger hardware, known as the DataHub, and assisted GTrans with installing them on each electric bus. These devices recorded vehicle performance data and connect to vehicle's internal communication system via the onboard diagnostic port. Figure 18 shows the DataHub.

Figure 18: The ViriCiti Data Hub

Source: ViriCiti

The DataHub interprets the bus's signals to collect data in real time, on a second-by-second basis. This device features an 800 megahertz processor with 1 gigabyte of random access memory and 8 gigabytes of on-board memory. In addition to the data signals recorded directly from the vehicle's controller area network (CAN) bus, the DataHub reads global positioning system signals through its own connection. A three-axis accelerometer measures where the vehicle is in space and how it is moving while a barometric sensor measures altitude. The data was wirelessly transmitted to ViriCiti's servers, using WiFi when available or a cell phone network (known as the Global System for Mobile communications) when needed, where it is stored. A 2048-bit encryption protected data to ensure that the information transfer process is safe. The on-board memory serves as back up storage in case interference or poor reception prevents data transmittal. The DataHub is quite compact. Its plug-and-play design means that the maintenance staff simply needs to locate the diagnostics port, plug in the device, and secure the device to the bus before data collection begins. All of the data was accessible for monitoring the fleet as it moves around the city or for downloading via the online portal. Figure 19 below shows the ViriCiti online platform displaying the bus location and performance information in real time.

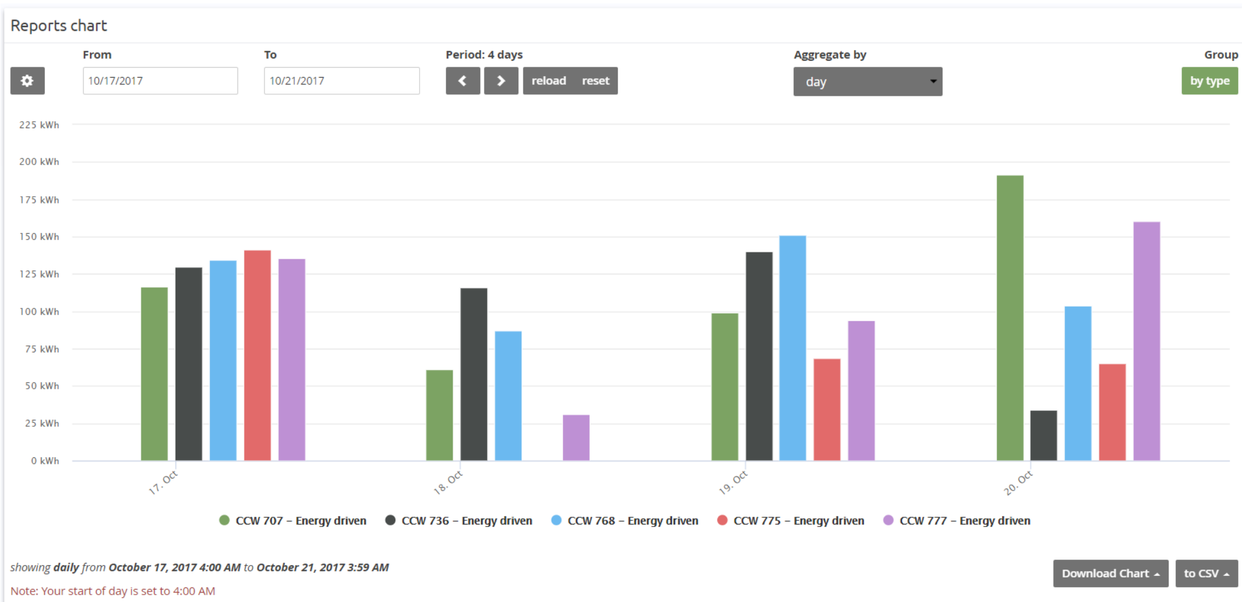
Figure 19: The ViriCiti Online Platform Dashboard



Credit: ViriCiti

The online platform makes vehicle data readily available to fleet managers and other users, via customizable dashboards, charts, and statistics, any time a web browser is accessible. The fleet can use this platform to easily identify problem areas or confirm that everything is running smoothly. For example, the landing page of the website depicts all of the buses, active and inactive, and information about their current conditions such as speed, energy used, state of charge (SOC) remaining, and other parameters. At a glance, it is easy to detect any issues that may arise or confirm that operations are running smoothly. Other sections of the portal allow for the graphing and downloading of data with user-defined parameter lists and over a variety of user-defined time intervals, thereby allowing for analytical flexibility. It is very intuitive for a user to produce a simple chart displaying information about a bus in the system and its past performance. Figure 20 below shows an example of ViriCiti's charting tool, depicting the state of charge used by each of the five battery electric buses over a 12-day period in May 2018.

Figure 20: Data Visualization Feature of ViriCiti Online Data Platform



Credit: ViriCiti

While ViriCiti records and displays a wealth of information, it was necessary to export large volumes of data to perform analyses independently and with the flexibility CALSTART needed. Certain parameters were more important than others for this analysis and those became the focus of the project, including distance, speed, efficiency, charging, and time measurements. Appendix A contains this subset of parameters and their definitions. The parameters of interest were regularly exported, summarized, reported on, and became central to the analysis performed for this project. Each of the parameters are recorded by ViriCiti on a per second basis but can be viewed or exported over this or a variety of time intervals (e.g. per hour, per day, per week, or per month). In general, daily summary data was the primary data source for this project. Focusing on daily data offers a balance between high resolution, high volume data (for example measuring parameters every second) that is more challenging to work with and low resolution, low volume data (such as using monthly summaries) that over simplify the data.

For the purposes of comparison, GTrans' collected mileage data from existing records and provided this data for analysis. The conventional bus data comes from the period June 30, 2016 to June 30, 2018, and it was provided as sum totals per asset per year. That is, CALSTART received total mileage for each conventional bus from 2016 to 2017 and again from 2017 to 2018. Fuel costs for conventional buses were collected from GTrans' fueling records for comparison purposes as well. Fuel cost data from July 1, 2016 to June 30, 2017, was received and provided as total sums across that time frame. CALSTART used average annual values for comparison in most cases. Using averages helped minimize any discrepancies since the conventional data could not be disaggregated into values over shorter time periods.

In-Use Performance Data Challenges

New analysis projects often pose various challenges. These issues need to be resolved before a final dataset can be synthesized and analyzed. The data available had some limitations. These limitations had to be managed during the analysis and comparison of conventional versus ZEPS buses.

Although the ViriCiti system made monitoring the buses straightforward and allowed for downloading data at will, several difficulties needed to be resolved. The ViriCiti support staff helped address these issues as best they could, sometimes even introducing new features to their platform after CALSTART identified a need. It seemed that most of the challenges stemmed from the fact that the ViriCiti system's design envisioned fleet manager's as the primary users. Thus, monitoring active buses in the field feels very straightforward. However, until recently, the data export feature could not accommodate the volume of parameters or the timespan of data that CALSTART needed to work with.

It is crucial for the analysis to download data in tabular form and analyze it independently of the interactive system on the portal. Instead of trusting that the data presented by the portal was correct, CALSTART worked with the data directly ourselves. The portal is somewhat a "black box" in that it is not clear how exactly each parameter is calculated or what data sources are being used. In order to be confident in the results, CALSTART needed to recalculate parameters to ensure the accuracy of the background calculations. Because ViriCiti is continually developing and improving their system, there is the possibility of future changes to the calculation and presentation of data. Downloading data and analyzing it independently also ensures that the results are static and reproducible in the future - anyone with the final dataset and the processing script will get identical results. CALSTART also would have more flexibility if it could work with the data directly. This is because it could calculate and explore new metrics not built into ViriCiti by default. If CALSTART could only access the data through the portal, it would not be able to customize graphs and tables freely because it would be limited to the predefined options. The new export feature recently added to the site has made the data download process more direct and efficient, although during this project it was not available to us.

Data validation is a critical process that must occur during data collection. Data validation can encompass many different tasks, but, in general, it refers to scrutinizing the data for internal consistency and to be confident that all reported values are accurate and reliable. Validation of downloaded data occurred through exploring the data by producing a series of ad hoc graphs and charts to see if there were outliers or other suspicious data points. Raw data was spot checked and then systematically analyzed to identify any issues with the data. CALSTART staff regularly found bad or impossible data points. When CALSTART pointed out the errors to ViriCiti, it was not clear what the cause was, but the possibilities include poor communication between the data collection device and the bus, bad reception on the global positioning system or cellular network, or other unidentified glitches in the system. For example, occasionally daily mileage numbers would exceed what is physically possible such as over 300 miles travelled in one day. Going through each parameter for each day of data on all five buses was not practical, so instead CALSTART developed a series of filters based on its observations of the data erroneously generated by the system and the buses' normal behavior. Table 5 shows these filters and their justifications.

Table 5: Filters Applied to ViriCiti to Remove Outliers or Impossible Data points

Parameter	Filter	Justification
Average Speed	Less than 20 MPH	Average speed of buses is between 10 – 15 MPH during revenue service
Distance	Greater than 3 mi or less than 300 mi	Travelling under 3 miles in one day is too short for the bus to be on a bus route; 300 miles in one day is not possible for the ZEPS buses
Efficiency In Service	Less than 5 kWh/mi	Efficiency metrics average 2.3 kWh/mi, with most data between 3.0 and 1.5 kWh/mi
Efficiency Overall	Less than 5 kWh/mi	Efficiency metrics average 2.3 kWh/mi, with most data between 3.0 and 1.5 kWh/mi
Efficiency Driving	Less than 5 kWh/mi	Efficiency metrics average 2.3 kWh/mi, with most data between 3.0 and 1.5 kWh/mi
Energy Charged	Less than 500 kWh	Battery capacity is only 308 kWh; it is highly unlikely that a bus could charge or use almost double its full capacity in one day
Energy Consumed Driving	Less than 500 kWh	Battery capacity is only 308 kWh; it is highly unlikely that a bus could charge or use almost double its full capacity in one day
Energy Idled	Less than 500 kWh	Battery capacity is only 308 kWh; it is highly unlikely that a bus could charge or use almost double its full capacity in one day
Energy Regenerated	Less than 500 kWh	Battery capacity is only 308 kWh; it is highly unlikely that a bus could charge or use almost double its full capacity in one day
Time Charging	Less than 24 hours	There are only 24 hours in a day
Time Driving	Less than 24 hours	There are only 24 hours in a day
Time Idled	Less than 24 hours	There are only 24 hours in a day
Time In Service	Less than 24 hours	There are only 24 hours in a day
State of Charge Used	Less than 100%	It is highly unlikely that the battery would be depleted by more than its full capacity in a single day

Source: CALSTART

In addition to incorrect data, there was some missing performance data from ViriCiti. In order to maximize the data CALSTART could work with, if a parameter was missing from a bus on a given day, CALSTART would label it as NA but still include in its dataset all other recorded parameters. Sometimes the reason given for an unrecorded parameter is clear: if a bus was plugged in but not driven in a day, CALSTART would have data on charging time and energy charged but not distance travelled, for example. When data was missing, it is not clear why there is no data. One possible cause is miscommunication between CCW's CAN bus configuration and what the ViriCiti DataHub was reading. Towards the end of the project, CCW's CAN bus changed how it was reporting distance travelled, so the DataHub could not record the signal for distance until ViriCiti updated its system and told it where to find the new signal.

The extended data collection period caused another challenge. Originally, the data collection period was from November 1, 2016 to November 1, 2017. However, GTrans only had one bus to demonstrate at the beginning of the demonstration period. By March 2017, all five buses were ready for demonstration. Data collection began on each bus as it become operational within the GTrans fleet. GTrans and the CEC extended the data collection timeline to account for these delays, with a new end date of August 1, 2018, meaning the data collection period increased by 9 months.

Operator and Bus Line Assignment Data

GTrans provided operator data in the form of handwritten logs that recorded which operator was driving each ZEPS bus and what bus line they operated on. Other data included sign in and sign out times. CALSTART digitized and joined this data to the vehicle performance data. CALSTART analyzed this data together in order to estimate whether operator efficiency improved over the course of the data collection period. Electric vehicles have a different driving style than internal combustion engine vehicles and it is possible that increased familiarity with the bus and how it runs could lead to more efficient operations. Table 6 below shows the number of recorded operation days for each operator.

Table 6: Number of Shifts with Data by Operators with 10 or more shifts recorded

Operator	Number of Days with Data
Operator 1	96
Operator 2	52
Operator 3	26
Operator 4	19
Operator 5	19
Operator 6	17
Operator 7	16
Operator 8	15
Operator 9	12
Operator 10	10

Source: CALSTART

The bus line data is important because different routes may be more or less demanding of the bus, leading to less or more efficient operation. For example, a line with many steep hills could cause a bus to operate inefficiently while a flat route may yield more efficient operation. Table 7 shows the number of days with data for each of the lines on which the ZEPS buses operated.

Table 7: Number of Days with Data for Each Bus Line that the ZEPS were operated on

Line	Number of Days with Data
2	75
3	296
4	13

Source: CALSTART

Maintenance Data

CCW carried out ZEPS bus maintenance as the buses were under warranty during the data collection period. GTrans provided maintenance records for any work performed on the buses under warranty in the form of tables listing the bus in question, what repair needed to be done, the dates repairs started and finished, and what the cost of service would have been in terms of parts and labor. GTrans also carried out regular preventive maintenance according to their standard schedule for upkeeping their buses, which consists of periodic maintenance inspections every 6,000 miles. GTrans provided these maintenance records for analysis in a similar format to the other records. New technology is likely to have hurdles on the path to adoption, and these records allow for analyzing how successful or difficult deploying these buses was.

Maintenance costs for all buses, conventional and ZEPS, rely on data spanning February 1, 2016 through September 30, 2018. This maintenance data consists of total costs divided into the categories of parts, labor, and sublet (sublet is defined as any outside expense such as towing, body work, or repaired components). In the data, each GTrans asset had its total costs summed over the whole time period. Thus, maintenance costs cannot be disaggregated by any other time frame such as cost per month or per day. Additionally, because this time frame covers dates before and after the start of the ZEPS bus demonstration, the total maintenance costs include costs for the ZEPS buses before and after they were re-powered.

CHAPTER 5: Analysis

CALSTART analyzed a large volume of data collected via the data loggers to better understand how the electric buses operated as a new technology. In addition, GTrans compiled limited data on the conventional buses to allow for interpretation of the buses' data in context with GTrans' standard bus, which is a gasoline-electric hybrid model. For the electric buses, CALSTART focused on how much the electric buses were utilized, how they used and consumed energy, how they charged, what factors caused differences in efficiency, and what challenges were overcome. First, CALSTART compared the electric buses to the conventional buses in terms of performance and per mile operating costs. Next, CALSTART analyzed the performance of the electric buses on a deeper level, including calculating the emissions avoided and how efficiency changed over time and due to different factors. CALSTART analyzed the charging behavior of the buses with respect to the daily patterns observed.

CALSTART compared the ZEPS buses to the gasoline-hybrid buses that GTrans uses as the core bus in their fleet. It first compared the average miles driven for each bus. Data on mileage for the conventional bus came from fleet mileage summaries provided by GTrans. This data included total miles driven by each asset in GTrans' fleet over 2 years, from June 30, 2016 to June 30, 2018.

The average mileage across all of the buses in GTrans' fleet was calculated (except 707, 736, 768, 775, and 777 which were in service as gasoline-hybrids for part of the time period and as ZEPS buses after they were repowered by CCW). CALSTART compared this to the average of miles driven by all the ZEPS buses from March 2017 to July 2018. CALSTART chose March 2017 to July 2018, as it was the longest span of time for which data was available for all ZEPS buses concurrently.
Table 8 below shows the results of these calculations.

Table 8: Average Performance of ZEPS Bus Compared to Conventional Bus

Parameters Compared	Conventional Bus	ZEPS Bus
Average miles per day (mi)	86.3 [5]	48.5
Average speed (mph)	11.6 [6]	11.6
Average overall efficiency (kWh/mi)	10.0 [7]	2.3

Source: CALSTART

[5] Buses assumed to operate 365 days per year.
[6] Assumed to be the same as what was recorded for the ZEPS buses.
[7] Gallons per mile is converted to kilowatt-hours per mile by multiplying gallons per mile by 33.7 kWh/gal.

Major Finding 1: The ZEPS buses drove shorter distances per day on average.

The table above shows that two different bus types operated on different duty cycles. While they both averaged the same speed, the conventional buses drove much further per day on average. The longer range of these buses simply allows them to drive further. The staff also operated the electric buses more conservatively because the technology is new to them. No data was collected on the conventional buses so the duty cycles cannot be compared on a more detailed level.

The difference in daily mileage observed could be due to the inclusion of all the conventional buses in the calculation. These buses drive multiple routes of different lengths, compared to the ZEPS buses, which mostly drove on a single route. However, it is more likely due to charging limitations and the lower mileage capabilities of the ZEPS buses. With only three vehicle charge outlets available to be used by five buses, if each bus uses a significant portion of its battery pack, they would not all be able to fully charge by the next day's shift. GTrans also sends ZEPS buses out on shorter shifts in the interest of caution. If a bus's SOC runs to zero in the field, it is costly and disruptive to the fleet. As a check on mileage, CALSTART verified the average miles per day for the ZEPS buses by using mileage data provided by Gardena Transit for the year 2017-2018, as opposed to ViriCiti data, which CALSTART used to calculate the result in Table 8. The result using this dataset is very similar to Table 8, showing average miles per day of 43.5.

In talks with GTrans, CALSTART learned that the max range of the conventional buses is over 225 miles while they typically run 80 to 225 miles per day. GTrans estimated that the ZEPS buses are able to run 70 to 120 miles per day maximum. However, as mentioned, GTrans tended to call the ZEPS buses back at lower mileage as a way to ensure that the buses did not run out of charge while on route. For the first couple months of the data collection period the ZEPS buses' SOC was closely monitored, with the buses being called back to base once they had reached 20 percent SOC or less. This required focused attention throughout the day and was difficult to maintain. No employee had this as part of their job description, so it placed extra burden on an already busy staff. Over time, operations evolved such that GTrans called the ZEPS buses back to base after a given number of hours in the field. On hotter days, when GTrans believed that buses' HVAC systems consume more of the battery pack, it summoned the buses back after a shorter amount of time in the field.

Major Finding 2: The average overall efficiency of the ZEPS buses is much better than the conventional GTrans bus.

CALSTART calculated the average overall efficiency for both the conventional bus and the ZEPS Bus. CALSTART used fueling data logged by GTrans for the conventional bus. Like average miles driven per day, CALSTART used averages for fuel consumed across all 700-series buses in GTrans' fleet. CALSTART calculated the average overall efficiency for the ZEPS bus using averages across all ZEPS buses from March 2017 to July 2018. One will notice in

Table 8 that the average overall efficiency of the ZEPS Buses is much better than the conventional bus when compared in terms of kWh/mi. This is consistent with recent estimates of electric bus fuel efficiency compared to conventional buses.[8,9]

Table 9 shows a comparison of average fuel and maintenance costs per mile between conventional buses and ZEPS buses.

Table 9: Average Cost per Mile Comparison of ZEPS Bus and Conventional Bus

Parameters Compared ($/mi)	Conventional Bus	ZEPS Bus
Fuel Cost	$0.61	$0.30
Maintenance Cost	$0.68	$0.47
Total Cost	$1.29	$0.77

Source: CALSTART

Major Finding 3: The fuel cost and maintenance cost per mile for the ZEPS buses was well below that of the conventional GTrans buses.

For the conventional buses, CALSTART averaged fuel costs across all similar GTrans buses from July 1, 2016 through June 30, 2017. CALSTART obtained electricity cost data for the ZEPS buses from GTrans' utility data. CALSTART calculated the fuel cost per mile using the average electricity rate per kWh from October 2016 to September 2018. The total cost per mile is 40 percent lower for ZEPS buses than conventional buses.

Maintenance costs for the conventional buses consisted of averages for total maintenance costs (parts, labor, and sublet (sublet is defined as any outside expense such as towing, body work, or repaired components)) across all similar buses from February 1, 2016 to September 30, 2018. Maintenance costs for the ZEPS buses come from the same source as for the conventional buses (GTrans' records) but only for the data collection period when the ZEPS buses were active. The ZEPS buses' maintenance costs were also lower, about 31 percent less than the conventional buses. These savings may be partially due to the time when GTrans took ZEPS buses out of operation to be re-powered. Because GTrans took ZEPS buses out of operation for re-powering, they had less time for maintenance costs to accrue compared to conventional buses. Their maintenance costs may therefore be underestimated. A past electric bus report in Seattle, Washington found a maintenance cost of only $0.26 per mile, but a fuel cost of $0.57, leading to an overall cost of $0.83 per mile which is slightly higher than what

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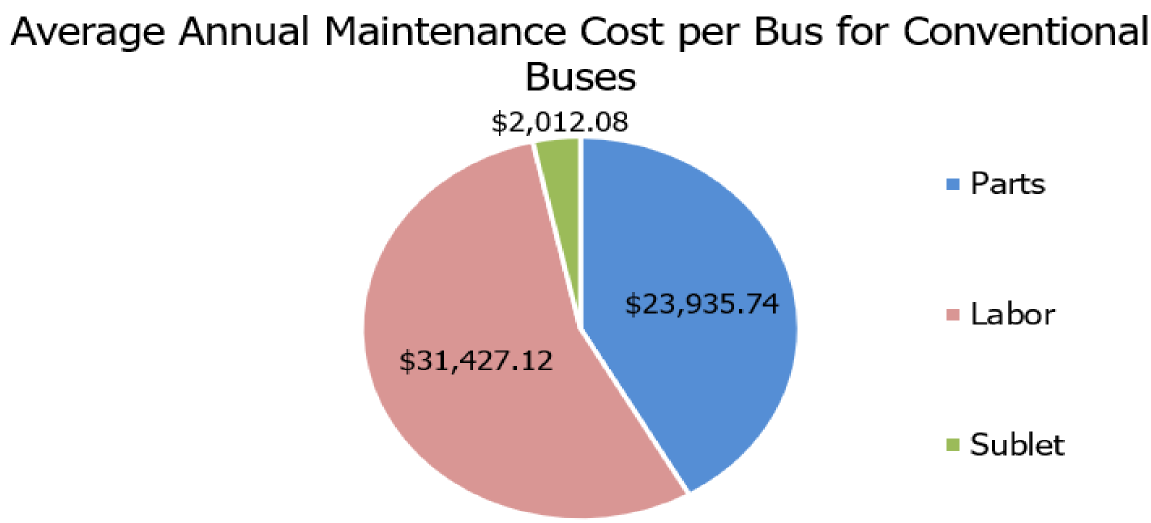
[8] Eudy, L., Prohaska, R., Kelly, K., & Post, M. *Foothill Transit Battery Electric Bus Demonstration Results*. January 2016. Report discussing results of Foothill transit battery electric bus demonstration (https://www.nrel.gov/docs/fy16osti/65274.pdf.) Accessed October 12, 2018.

[9] U.S. Department of Energy Alternative Fuels Data Center. *Average Fuel Economy of Major Vehicle Categories*. June 2015. Average fuel economy chart consisting of major vehicle categories (https://www.afdc.energy.gov/data/10310) Accessed October 12, 2018.

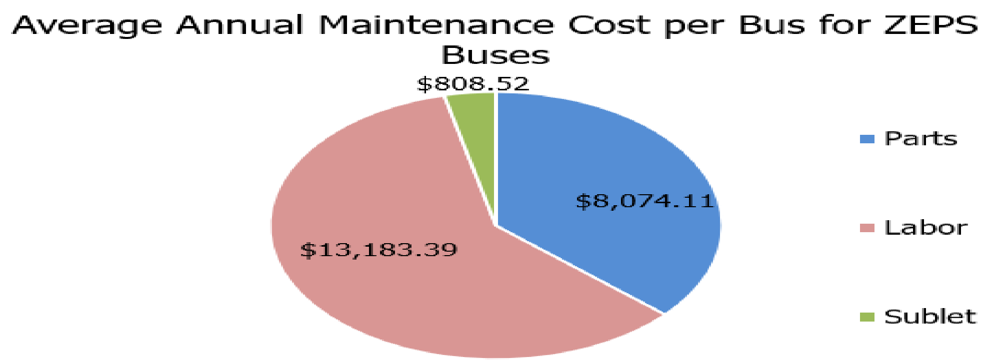
was calculated for this project[10]. In that same report, the conventional baseline maintenance cost for the diesel fleet was $0.46 per mile while the fuel cost was $0.30 per mile, for a total cost of $0.76 per mile. This result is almost identical to its result for the ZEPS buses but significantly cheaper than GTrans' conventional buses. See Figure 21 and Figure 22 below for a breakdown of average maintenance costs per bus.

Figure 21: Average Annual Maintenance Cost per Bus Breakdown for Conventional Buses



Credit: CALSTART

Figure 22: Average Maintenance Cost per Bus Breakdown for ZEPS Buses



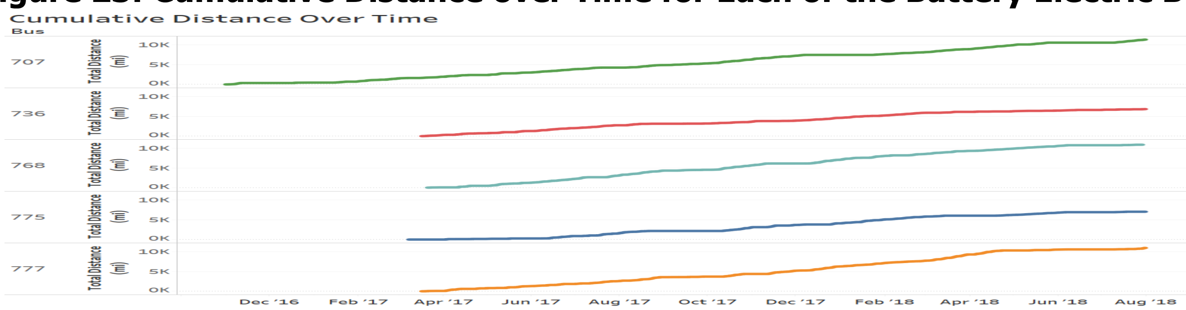
Credit: CALSTART

[10] U.S. Federal Transit Administration, *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses,* February 2018. King County Metro bus evaluation results 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. Accessed October 2018.

Performance Data Comparison

Comparing the performance of the ZEPS buses to the conventional buses is useful to help understand the performance of the electric buses in context. Because they are fundamentally different technologies and have different performance metrics, it is also important to take a closer look at the ZEPS buses in isolation. In this section, CALSTART analyzed the ZEPS buses in terms of distance travelled, active days, and efficiency, per bus line and operator. CALSTART was unable to analyze the idling time of the buses or the energy spent idling, because the buses were typically left on all the time, even when parked or charging, to ensure there would be no gap in data collection or transmission if a bus was completely shut down. Unfortunately, this practice makes the data related to idling not very useful for analysis. Figure 23 below shows the cumulative mileage for each bus over the course of the data collection period.

Figure 23: Cumulative Distance over Time for Each of the Battery Electric Bus



Credit: CALSTART

In general, mileage was lower for the ZEPS buses than their conventional counterparts. This is likely due to charging limitations and the lower range capabilities of the ZEPS buses. In Figure 23, the earlier start of bus 707 is apparent – note the gap in start date between November 2016 for bus 707 and March 2017 for the other buses. Bus 707 was the first delivered bus and was put into service in November 2016. CCW delivered the other four ZEPS buses in March 2017. This figure also shows where there was little bus activity in terms of mileage, due to missing data or bus servicing: when the lines flatten, the bus was not recording much data. Bus 707 logged very few miles in December and January of 2018, leading to a flattening of the cumulative mileage curve during those time periods. The curves for buses 736 and 775 are likewise flat around March and April 2018. Buses 768 and 777 show little activity towards the end of the data collection period. All buses besides 707 had low mileage in September 2017.

Table 10: Mileage, Number of Active Days, and Miles per Active Day for Each Bus

Bus No.	Total Mileage (mi)	Active Days	Miles per Active Day(mi)
707	11,309.1	251	45.1
736	6,819.6	167	40.8
768	10,881.1	217	50.1
775	7,022.8	159	44.2

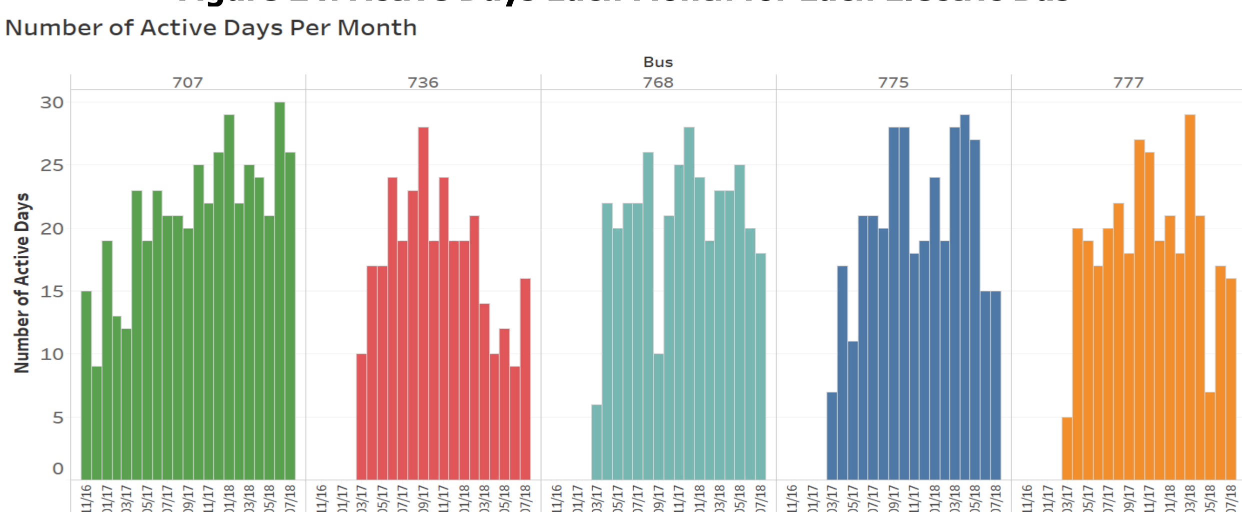
Bus No.	Total Mileage (mi)	Active Days	Miles per Active Day(mi)
777	10,941.0	179	61.1

Source: CALSTART

Major Finding 4: The total project mileage varied by over 65 percent and the average daily mileage varied by over 35 percent between individual ZEPS buses.

By the end of the data collection period, 707, 768, and 777 were very close in total mileage with about 11,000 miles each, while operators drove buses 736 and 775 less, with total mileage closer to 7,000 miles each. These figures likely underestimate the actual mileage because there were gaps in data collection. For reference, the GTrans conventional buses travel 31,485.8 miles annually on average. Buses 768 and 777 were able to match bus 707 because it appears that operators used these buses more intensively, with 50.1 and 61.1 miles per day, respectively, compared with 45.1 miles per day from bus 707. Figure 24 below shows the number of active days per month for each bus; active days are days when the bus drove more than 3 miles and data recording occurred for the bus.

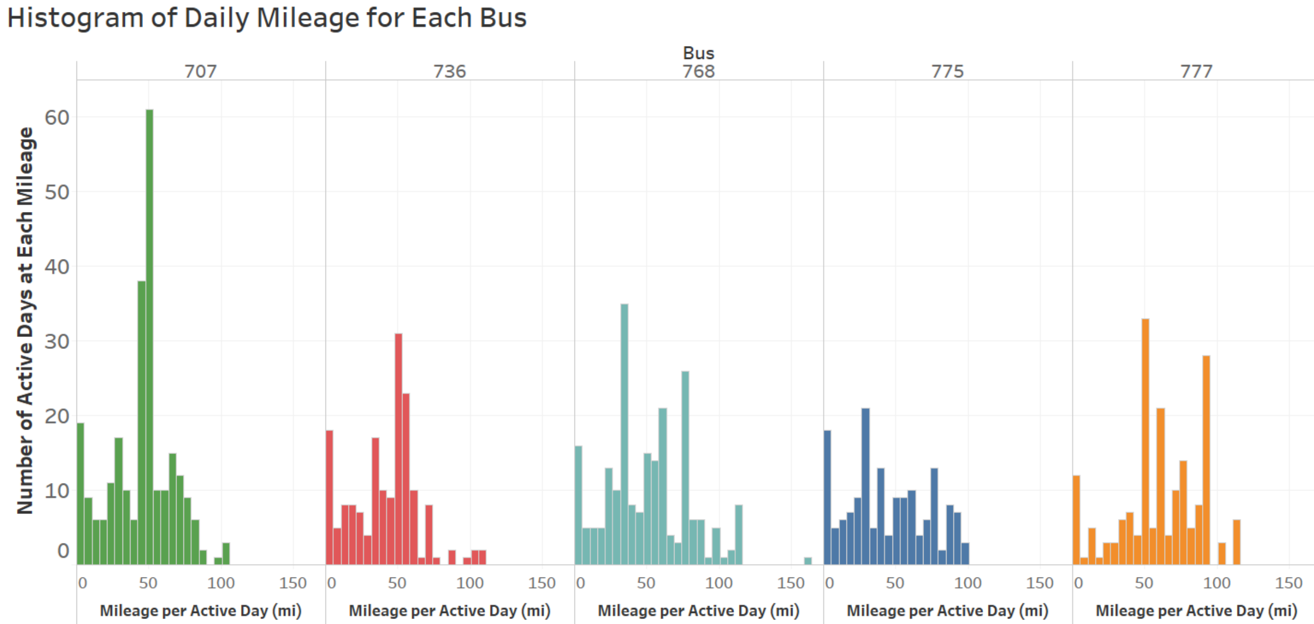
Figure 24: Active Days Each Month for Each Electric Bus



Credit: CALSTART

In general, the number of active days each month seems to strongly relate to the mileage in a given month, with dips in Figure 24 corresponding to flattening of the curves in Figure 23. Figure 25 below shows the frequency distribution of miles per day for each bus.

Figure 25: Histogram Showing the Number of Active Days for Each Bus by Mileage



Credit: CALSTART

The maximum miles per day tops out around 120 miles. Given the overall average of 2.3 kWh/mi, 120 miles would expend 276 kWh. This range would be pushing the maximum for the electric buses considering that their usable battery capacity is reportedly 250 miles. These extremely long-range days were rare; much more frequently were trips in the 40-60 miles range. Bus 707 most frequently drove 45-50 miles per day. Bus 768 and 775 had lower mileages as their most frequent range, with about 32 and 27 miles respectively being their most common daily mileages. Bus 777 had an unusually high number of days with 90 miles travelled, close to its maximum theoretical range. It appears that on the majority of active days, operators drove the buses conservatively and finished their days after using less than half of their potential range. Given the high cost and inconvenience of completely losing charge in service, and the fact that this technology is new to GTrans, this operational strategy is understandable.

Fuel Use and Emissions

Use of the ZEPS buses also resulted in a significant displacement of fuel for GTrans. Table 11 shows the estimated average annual fuel displaced (in gallons) from replacing a conventional bus with a ZEPS bus.

Table 11: Average Annual Fuel Displaced by ZEPS Buses

Average Annual Fuel Consumption per Bus (gal)	Average Gasoline Cost ($/gal)	Average Annual Fuel Cost Avoidance per Bus ($)	Average Annual Fuel Cost Avoidance for 5 Buses ($)	Equivalent Passenger Cars Removed from Road for Operating 5 Electric Buses
9,352.3	$2.10	$19,639.83	$98,199.15	90

Source: CALSTART

To calculate the displaced fuel, CALSTART averaged total fuel consumption for all the buses in GTrans' fleet using the same data as in Table 13. Then, it calculated daily gallons by first assuming that the buses operate 365 days per year. CALSTART assumes that average annual gallons of fuel displaced to be equal to the average annual gallons consumed across all these buses. Multiplying the average by five to account for the five ZEPS buses demonstrated that, in this project, the ZEPS buses displaced an average of 46,761.5 gallons of gasoline annually. This magnitude of avoided fuel use is equivalent to taking just under 90 average passenger vehicles off the road for each year these five buses remain in operation.[11]

According to the fuel cost data provided on GTrans' buses, the average cost paid per one gallon of gasoline during this time was $2.10. GTrans calculated this value by dividing the annual cost reported for unleaded gasoline by the annual gallons of gasoline purchased for each bus in the fleet, and then taking the average across all buses. Given this, CALSTART estimates that the average annual fuel cost avoidance for one bus would be $19,639.83. The fleet saves $98,199.15 in fuel costs per year.

Use of the ZEPS buses over the conventional gasoline-hybrid buses resulted in significant reductions of greenhouse gases and criteria pollutants by displacing the conventional hybrid buses. Table 12 shows estimates for the average annual emissions avoided in kilograms by deploying ZEPS buses instead of conventional buses. CALSTART was unable to calculate carbon intensity but has data on emissions reductions below.

Table 12: Average Annual Emissions Avoided by Replacing One Conventional Bus with One ZEPS Bus

Pollutant	Average Mileage per Year (mi)	Emission Factor (g/mile)[12]	Average Annual Emissions (kg)
CO	31,485.8	36.24591	1141.23
NO_x	31,485.8	7.02561	221.21
VOC Exhaust	31,485.8	1.68671	53.11
VOC Evaporation	31,485.8	0.11613	3.66

[11] U.S. Environmental Protection Agency, *Greenhouse Gas Emissions from a Typical Passenger Vehicle,* United States Environmental Protection Agency report on typical passenger vehicle emissions (https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle), Accessed October 2018.

[12] Cai, Burnham, and Wang. Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET Using Moves. September 2013. Accessed October 2018.

Pollutant	Average Mileage per Year (mi)	Emission Factor (g/mile)[12]	Average Annual Emissions (kg)
SO_2	31,485.8	0.02050	0.65
PM_{10} Exhaust	31,485.8	0.01301	0.41
PM_{10} OC	31,485.8	0.00968	0.30
PM_{10} BC	31,485.8	0.00215	0.07
PM_{10} Sulfate	31,485.8	0.00019	0.01

Source: CALSTART

Emission factors in Table 12 come from Cai, Burnham, and Wang (2013) who included lifetime mileage-weighted average air pollutant emission factors for gasoline transit buses by model year in their paper.[12] This research informs the widely cited and commonly accepted Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model emissions model developed by the US Environmental Protection Agency. According to GTrans, the model year for each bus in their fleet ranges from 2005 to 2010. Thus, CALSTART calculated the average annual emissions avoided for each year from 2005 to 2010 and then CALSTART took the average of those model years for its analysis. The emission factors above are the averages of emission factors for each model year from 2005 to 2010, and so the results represent the average annual emissions avoided for one bus using those chosen factors. CALSTART calculated average mileage per year for one busby averaging the total miles driven from June 30, 2016 through June 30, 2018 for each bus in GTrans' fleet. This was the case in the performance analysis. CALSTART calculated the CO_2 emissions in the same way. Table 13 below shows the average annual emissions of CO_2 avoided, but as the conversion factor is based on fuel consumption rather than mileage, it is shown in pounds.

Table 13: Average Annual Emissions of CO_2 Avoided Per Bus

Pollutant	Emission Factor (lbs/gal of gasoline)[13]	Average Annual Gallons Consumed (gal)	Average Annual Emissions (lbs)
CO_2	18.9	9,352.3	176,758.7

Source: CALSTART

Major Finding 5: The ZEPS buses had major emissions and fuel savings for the fleet relative to the conventional buses.

The results show that, by using a ZEPS bus over a conventional gasoline bus, an estimated 1,421 kilograms of total emissions avoided per year per bus on average, equal to about 3,133 pounds. The emission factor used for CO_2 in Table 13 comes from the Energy Information

Administration (EIA).[13] Average annual gallons of gasoline consumed comes from GTrans-provided data on fuel consumption, consisting of total volumes of unleaded gasoline consumed by each bus from July 1, 2016 through June 30, 2017. When added with total results from Table 12 total estimated average annual emissions avoided for one bus equal about 179,892 lbs or 81,597 kg.

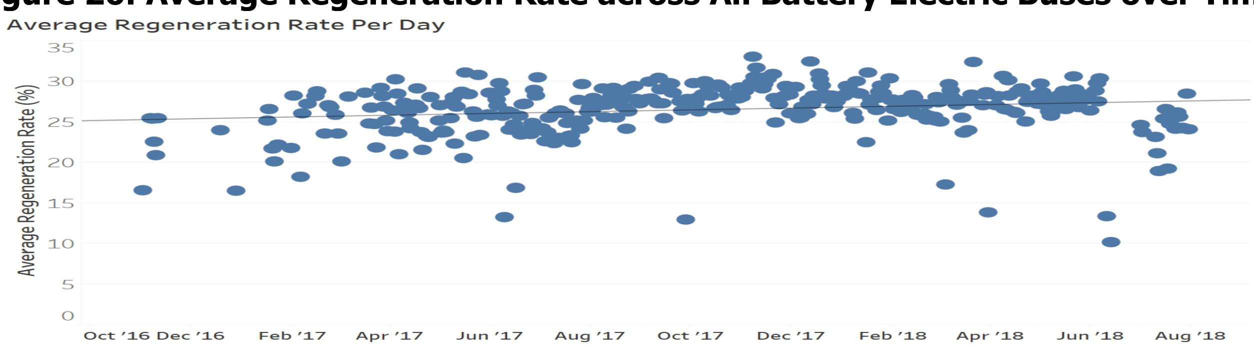
Efficiency Analysis

This project was interested in determining how operator training may affect the performance of the electric buses. Electric vehicles drive differently than conventional vehicles; accelerating and braking have a different feel. During braking, the bus regenerates energy and feeds it back to the battery, so how an operator applies the brakes will affect the amount of energy that is recycled. At the start of this project, there were speculations that there might be a learning curve for the operators as they became more familiar with the new vehicles. This is part of the motivation for developing the training course for electric bus operators. If this were true, CALSTART would expect to see evidence of improvement in two key efficiency metrics over time: regeneration rate and efficiency overall. Regeneration rate is the amount of energy recovered by regenerative braking divided by the sum of the total amount of energy expended by the bus while driving and the amount of energy regenerated (see the equation below).

$$\text{Regeneration Rate} = \frac{\text{Energy Regenerated}}{\text{Energy Driving} + \text{Energy Regenerated}}$$

A higher regeneration rate means more efficient braking and therefore more efficient operation. If there is indeed improvement over time, regeneration rate and efficiency overall should both increase over the course of the data collection period. In fact, regeneration rate shows a slight increase over time (Figure 26 below).

Figure 26: Average Regeneration Rate across All Battery Electric Buses over Time



Credit: CALSTART

Major Finding 6: The average regeneration rate across all ZEPS buses improved over the course of the project.

Over the whole data collection period, there was a slight improvement in regeneration rate from an average of 21.9 percent in the first three months to 25.8 percent in the last three

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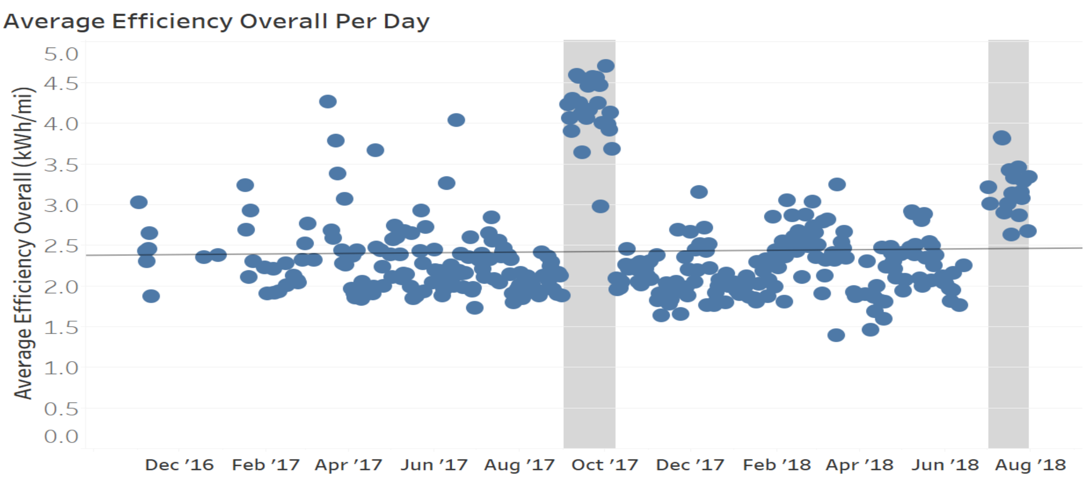
[13] U.S. Energy Information Administration. *How much carbon dioxide is produced from burning gasoline and diesel fuel?* April 25, 2017. U.S. Energy Information Administration frequently asked questions (https://www.eia.gov/tools/faqs/faq.php?id=307&t=11) Accessed October 2018.

months, an improvement of 3.9 percent. Most of the improvement seems to take place in the first several months, as the cluster of points appears to rise until about June 2017 when the trend seems to level off. In July 2018, there were some particularly low regeneration rates, which will have a disproportionate effect on the trend line, pulling the slope of improvement downward. Regeneration rate has not been regularly reported in past electric bus studies so it is not possible to put these results in a larger context outside of this project.

Average efficiency overall measures efficiency directly, by adding energy spent driving and energy spent idling divided by the total mileage driven, as shown in the following equation and Figure 27.

$$\text{Average Efficiency Overall} = \frac{\text{Energy Driving} + \text{Energy Idling}}{\text{Mileage}}$$

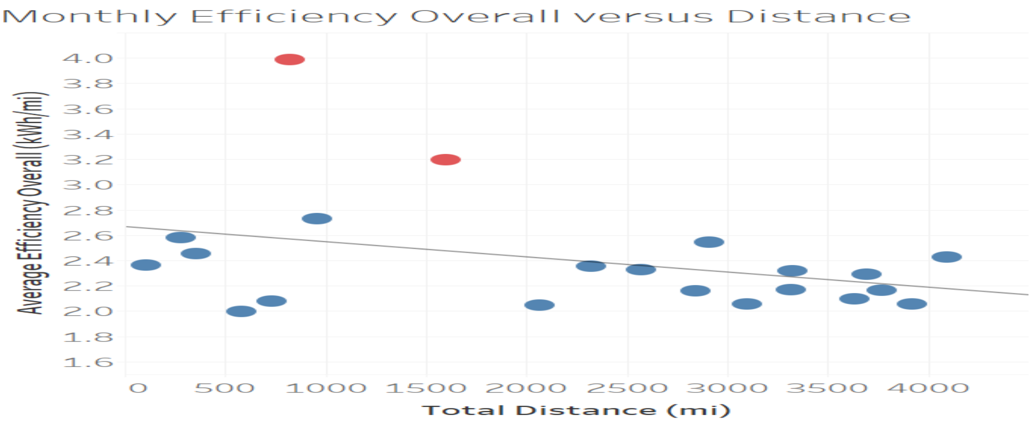
Figure 27: Average Efficiency Overall per Day during the Data Collection Period



Credit: CALSTART

Average efficiency overall shows little to no change over time: the linear regression trendline is almost completely flat. However, there are two unexplained regions of very poor efficiency in September 2017 and to a lesser extent in July 2018 (both periods highlighted in Figure 27). The underlying parameters all seem correct i.e. these results are not the result of a calculation error but could possibly have been an error at the point of data collection by the bus. The September efficiency numbers were higher by 3.0 kWh per mile and in July by 2.0 kWh per mile. Interestingly, CALSTART saw no evidence of this in the regeneration rate even those these two parameters are directly correlated. The other efficiency parameters, which are of less importance because they do not reflect how the buses actually drive, also show these same irregularities. As shown below in Figure 28, efficiency tends to improve with increased distance; the two months in question have relatively low mileage and are outliers when compared with the rest of the months (the trendline is a linear regression; the two red points represent September 2017 and July 2018).

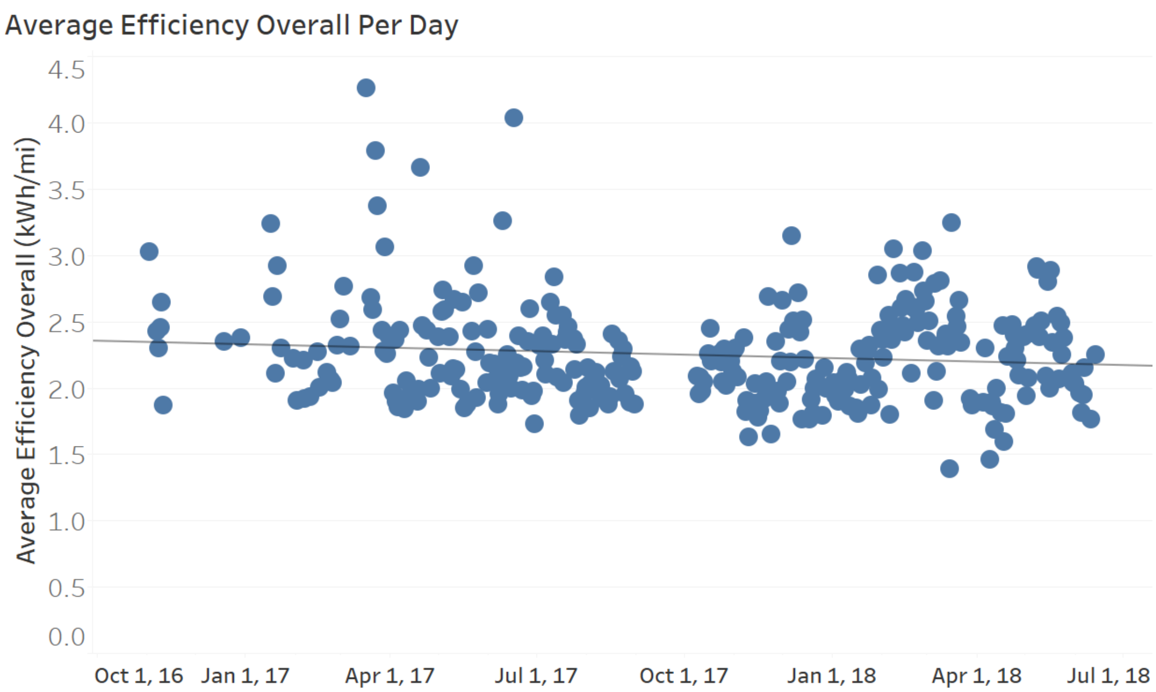
Figure 28 Average Efficiency Overall Versus Total Distance for Each Month



Credit: CALSTART

When CALSTART removed the data from September 2017 and July 2018 from the chart of overall efficiency over time, a distinct trend of improving efficiency over time emerges as shown in Figure 29.

Figure 29: Average Efficiency Overall per Day during the Data Collection Period



Credit: CALSTART

Major Finding 7: The average efficiency overall across all ZEPS buses improved over the course of the project once two different time periods with uncertain data removed.

With the suspect data removed, the average overall efficiency improves from 2.5 kWh per mile to 2.2 kWh per mile from the first three months to the last three months of data collection. This modest improvement of 12 percent could be evidence of a learning curve as operators became more familiar with the new electric buses. To put these results in context, past reports from Europe have reported efficiencies as poor as 3.86 kWh per mile and as good as 2.05 kWh per mile.[14] These results do not clarify whether the efficiencies cited are from test operations or actual in-use service as studied here, so they are likely not directly comparable. One study that took place in Seattle, Washington in February 2018 cited an overall in-use efficiency of 2.36 kWh per mile, which is slightly less efficient than the range of efficiencies exhibited by the buses in this report. A similar study with in-use data from the Foothill Transit Agency in Los Angeles County reported an overall efficiency of 2.16 kWh per mile, which also aligns with what CALSTART calculated for the ZEPS buses.

To further examine the factors that influence efficiency, usage metrics for the different configurations of bus line and operator that were recorded and analyzed. In Table 14 below, there seems to be a maximum difference of 0.3 kWh per mile or 13 percent in overall efficiency and 0.2 percent in regeneration rate between different routes.

Table 14: Bus Usage and Efficiency by Line

Bus Line	Total Service Days	Total Distance (mi)	Average Efficiency Driving (kWh/mi)	Average Efficiency Overall (kWh/mi)	Average Regeneration Rate (%)
2	75	3,499.1	2.0	2.3	27.3
3	296	16,859.4	1.9	2.2	27.4
4	13	1,046.8	1.8	2.0	27.5

Source: CALSTART

Bus Line 4 is slightly more efficient than the other two, but it has very few service days – thereby making it underrepresented. So, the metrics are not as definitive for this route. Table 15 shows efficiency by operator.

[14] ZeEUS Consortium, *ZeEUS eBus Report: An overview of electric buses in Europe*, 2016. Report on electric bus use in Europe (http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-internet.pdf.) Accessed October 2018.

Table 15: Bus Usage and Efficiency by Operator

Operator Code	Total Service Days	Total Distance (mi)	Average Efficiency Driving (kWh/mi)	Average Efficiency Overall (kWh/mi)	Average Regeneration Rate (%)	Days Bus Line 2	Days Bus Line 3	Days Bus Line 4
1	96	5,090.6	2.1	2.3	27.1	0	96	0
2	52	3,694.0	1.7	2.0	27.5	1	51	0
3	26	1,382.2	1.9	2.2	27.8	0	26	0
4	19	1,182.0	1.7	2.1	28.2	0	19	0
5	19	815.1	2.0	2.3	27.0	3	16	0
6	17	1,305.8	1.7	2.0	27.1	17	0	0
7	16	1,023.7	1.6	1.9	30.3	0	15	1
8	15	709.2	2.2	2.7	26.9	9	6	0
9	12	793.6	1.8	2.2	26.4	0	12	0
10	10	688.0	1.8	2.1	25.1	0	10	0

Source: CALSTART

Major Finding 8: It is not possible to determine if any specific route or operator is more efficient than any other at this time.

The table above shows all operators with more than 10 service days of data. Using GTrans operator records dating from March 2017 onward, CALSTART was able to match 384 operator shifts to days where it had complete bus data. It appears there is a moderate range in operator performance in terms of efficiency. However, CALSTART could only compare operators who drove the same route. Factors unique to each line could influence efficiency and CALSTART wanted to be sure that it is holding other variables constant and only comparing operators. Unfortunately, this limits CALSTART's comparison to operators who primarily drove line 3 because operators spent few days on the other two routes. Comparing operators 1-5, 7, 9, and 10, average overall efficiency differs by about 17 percent or 0.4 kWh per mile in terms of average overall efficiency. There is not enough data to compare operators who primarily drive on the other two lines. In the future, GTrans must designate a test to specifically measure the effect of operators on efficiency in order to reach results that are more conclusive.

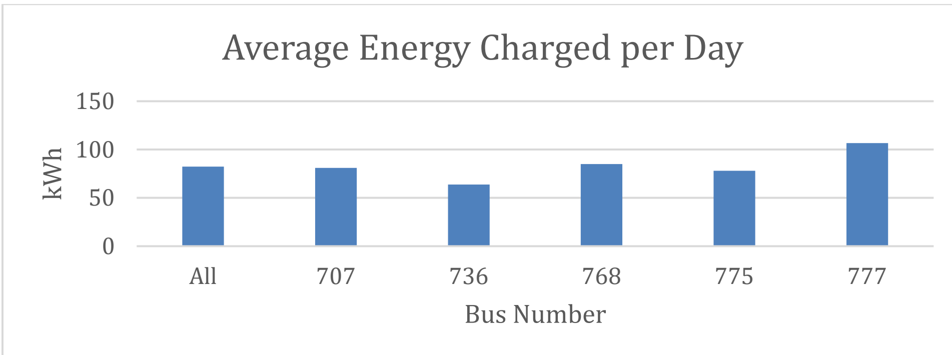
Charging Data Analysis

ZEPS bus. To understand how the buses charged and how this affected GTrans' operations, this section shows results for various charging metrics across all ZEPS buses.

Energy Charged

In this demonstration, each bus on average per day charged 82.4 kWh, plugged into a vehicle charge outlet for 2.8 hours, used 35.7 percent of its battery charge while driving, and regenerated 35.2 kWh. In general, the buses tended to charge mostly overnight and mid-day. As GTrans' only had three depot vehicle charge outlets for five electric buses, GTrans cycled charging as needed to meet daily operational requirements. Figure 30 shows the average energy charged per day for each ZEPS bus. Note that Figure 30 through Figure 35 use data from only days when a distance was logged using the ViriCiti datalogger. This ensures that the results shown display only data from when the buses were in operation.

Figure 30: Average Energy Charged per Day for Each Electric Bus in kWh



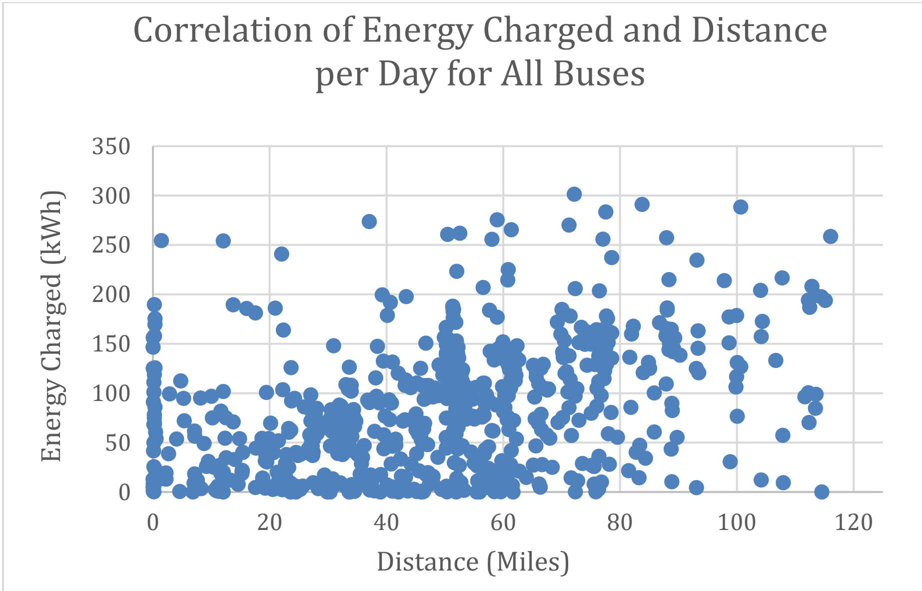
Source: CALSTART

Major Finding 9: The amount of energy charged per day varied widely between different ZEPS buses.

Bus 777 charged the most per day on average, followed by 768, 707, 775, and 736, with an overall average of 82.4 kWh per day. While most buses have consistent results around 80 kWh per day, the difference between bus 736 and bus 777 is significant. From the data, it appears that operators used bus 777 more often and to a larger extent than bus 736. Bus 777 traveled almost 20 miles more per day than 736 on average, it regenerated about 8 kWh more from regenerative braking per day than 736, and it spent about 1 more hour in service per day than bus 736. This could be due to differences in the way GTrans dispatched the buses and which routes they traversed. The difference between these two buses in results on charging is consistent throughout this section of the report.

As a check, CALSTART also correlated the amount of energy charged per day with the number of miles driven per day across all buses and for each bus independently (not shown in the interest of space). Figure 31 shows how the correlations compare.

Figure 31: Correlation of Energy Charged and Distance per Day for All Buses

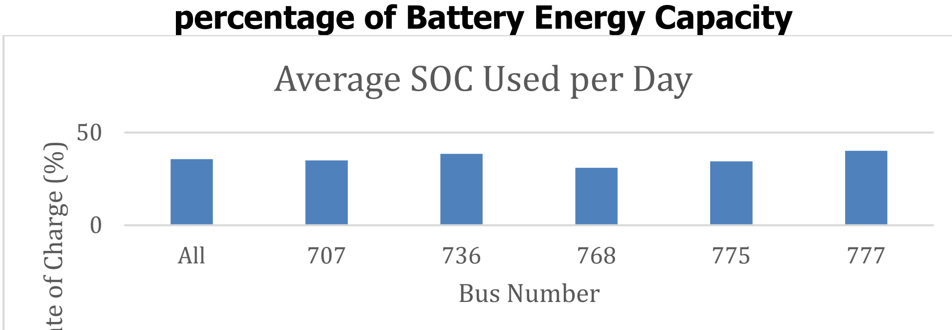


Credit: CALSTART

Across all buses, there is a weak positive correlation between the amount of energy charged per day and the number of miles driven per day. Each bus shows a similar relationship independently, except for 775, which shows a slightly stronger, moderately positive relationship between the two parameters. Generally, this data shows that the more miles the buses travelled, the more they charged. CALSTART expects that the relationship may not be very strong because a bus may spend a long time charging one day and go into service the next or could have a long service day and undergo charging after midnight.

Figure 32 shows the average SOC used per day for each bus, and while 736 charged the least per day on average, it consumed a disproportionately large portion of its battery charge per day on average relative to its rank in energy charged per day. This could result from the inverse relationship between driving time and charging time: more time spent driving (and consuming SOC) leaves less time for charging (and increasing SOC).

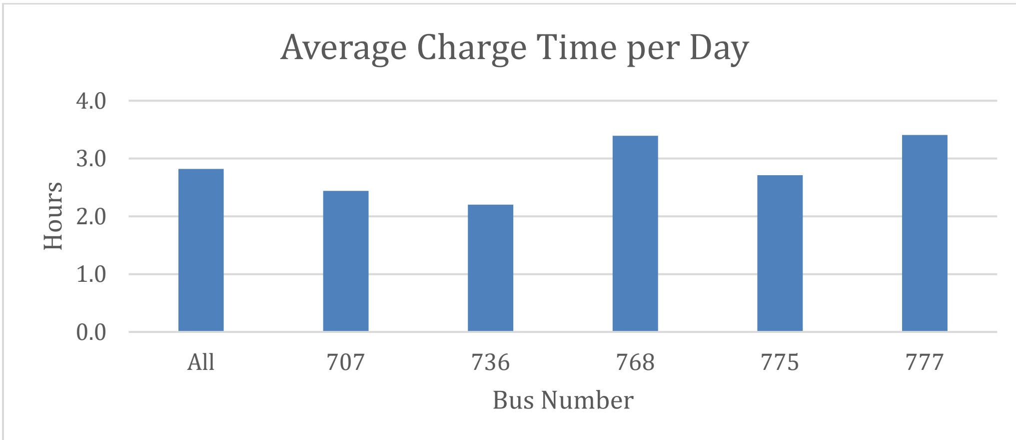
Figure 32: Average State of Charge Used per Day for Each Electric Bus in percentage of Battery Energy Capacity



Credit: CALSTART

All buses' use of SOC per day ranges in between 30 percent of battery capacity and 40 percent of battery capacity with 777 using the most and 768 using the least. The average state of charge used per day across all buses was 35.7 percent. This data gives a sense of the consumption of energy during operation of the bus on a daily basis, with emphasis on the battery. Taking regeneration of energy into account, the buses used 35.7 percent of their battery while driving per day on average. When taken along with the average daily mileage of the ZEPS buses shown in Table 8 this data indicates that operators drove buses in a highly conservative manner, and could potentially drive more per day as, on average, about 64 percent of the battery's charge remained at the end of service each day. Figure 33 shows the average charge time per day in hours for each bus.

Figure 33: Average Charge Time per Day for Each Electric Bus in Hours

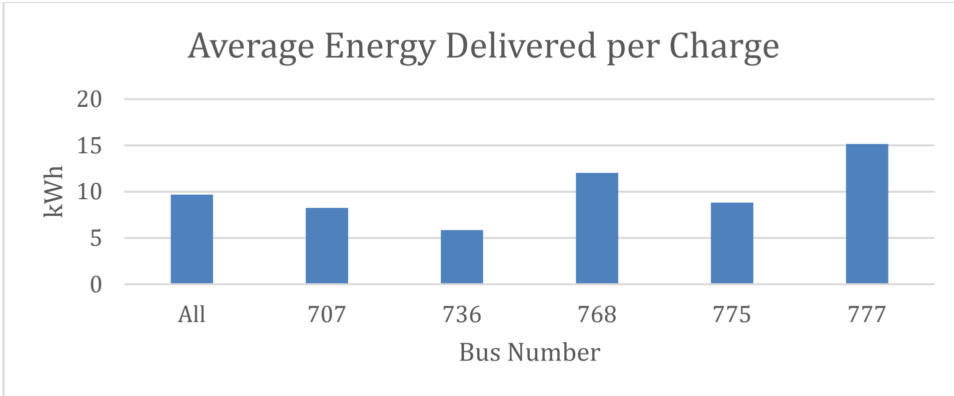


Credit: CALSTART

The longest average time spent charging per day was 3.4 hours (buses 768 and 777) while the average charging time across all busses was 2.8 hours. These results are almost exactly in line with Figure 30. This makes sense, as one would expect a strong correlation between the amount of energy charged and the amount of charge time. These results are important when estimating potential EV charging costs, especially with demand charges. As demand charges can vary throughout the day depending on peak loads, transit authorities like GTrans must be cognizant of the timing of their EV charging.

Further, comparing average charge time per day to average energy charged per day can show the average energy charged per hour for each bus. This enables CALSTART to identify any inconsistencies in charging infrastructure or bus manufacture, which may play a role in the buses receiving electricity at a constant rate. Figure 30 and Figure 33 clearly show that the charging rate varied slightly by bus. Figure 34 shows the average amount of energy delivered per charge for each bus, calculated by multiplying the average energy charged per bus per day with the average charge time as a fraction of twenty-four hours per bus per day.

Figure 34: Average Energy Delivered Per Charge for Each Bus

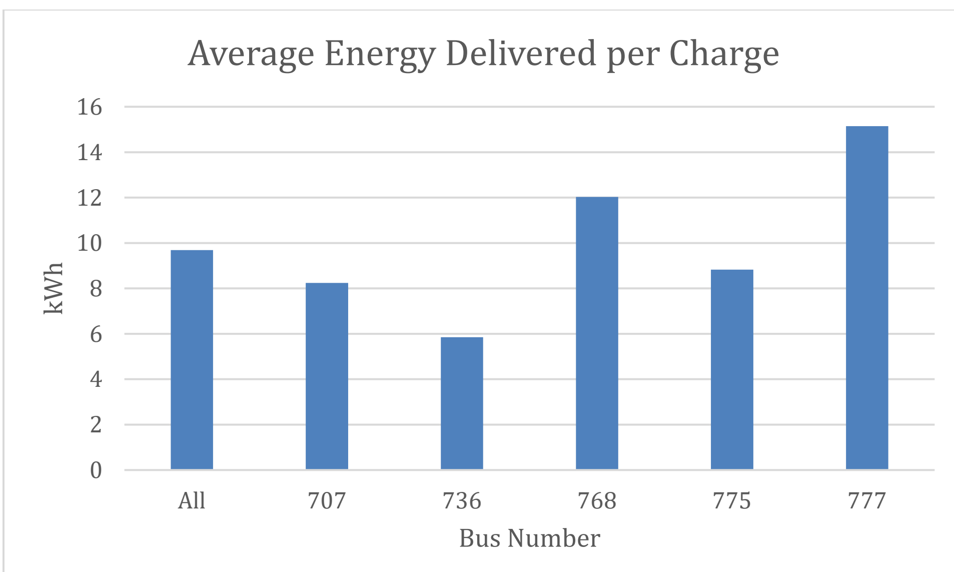


Credit: CALSTART

The average energy delivered across all buses is 9.7 kWh with a range from 15.1 kWh to 5.9 kWh. The difference between each bus in energy delivered per charge is largely due to charge time, which can vary greatly between bus and between each charge event. Notice that the order of buses in terms of magnitude matches Figure 33 highlighting the strong dependency of energy delivered per charge with charge time.

Another way the ZEPS buses generate a charge is regenerative braking, the process of cycling energy that would otherwise be lost back into the vehicle while braking. Figure 35 shows the average energy regenerated per day for each bus and as an average across all buses.

Figure 35: Average Energy Regenerated Per Day



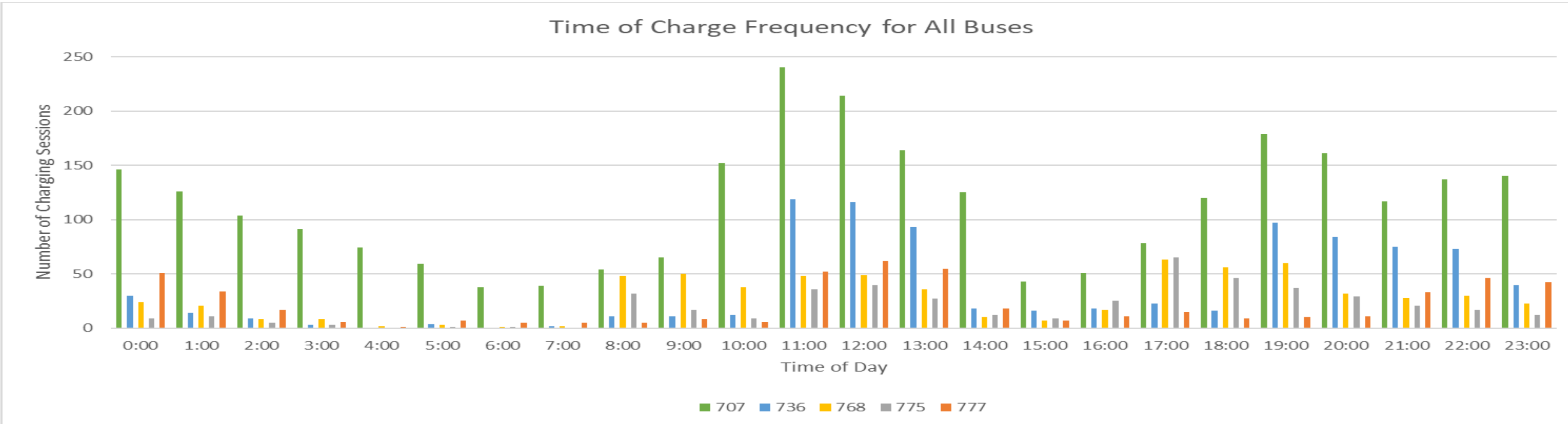
Credit: CALSTART

Charging Frequency

As GTrans plans charging logistics, it is useful to know when each bus charged throughout the day. Demand charges are fees levied by utilities based on the maximum power demanded throughout a billing period. These charges are in addition to the typical cost that utility customers pay per kWh. Demand charges penalize higher rates of charging or plugging in more electric vehicles at once. These demand charges can be very high especially in projects involving high-powered chargers. GTrans has not experienced excessive demand charges during the course of this project. However, keeping demand charges and electricity pricing in mind would be very prudent as the fleet adopts more electric buses.

CALSTART calculated the frequency of charging in each hour by first exporting hourly data from ViriCiti and then identifying when the State of Charge reported by ViriCiti increased in one hour compared to the previous hour. For example, if State of Charge was 70 percent at the tenth hour and 71 percent at the eleventh hour, then the vehicle was considered to be charging. Figure 36 below shows the frequency of charging for each hour throughout the day across the timespan of the demonstration.

Figure 36: Frequency of Charging Times for All Buses



Credit: CALSTART

Major Finding 10: All buses charged most often during the afternoon and late night to early morning.

All buses had similar charging patterns, charging most frequently mid-day and at night. For ease of viewing, Figure 36 aggregates these patterns for all buses. While GTrans may have some constraints in when they are able to charge their buses, one recommendation here is to stagger the use of vehicle charge outlets when possible. Charging multiple buses at the same time places more demand on the grid and can lead to large demand charges that significantly increase cost.

The charging results show that bus operation varied. Buses 777 and 736 were consistently the highest rank and lowest rank in many of these metrics, respectively. This means that operators drove bus 777 more intensively and 736 less intensively. The cause of this discrepancy is not clear from the data available at this time. Relatedly, the average charge delivered per hour, while close, also varied across buses, indicating some inconsistency in the rate that each bus received charges. This and the similar patterns in frequency of charging by hour each day leads us to recommend that GTrans stagger charging of each bus to minimize costs, if possible.

CONCLUSION

The results of this project should be instructive to other fleets seeking to adopt electric buses. Successfully adopting electric buses requires increased operational efforts in addition to detailed planning to ensure success. Managing the electric buses in real time on a day-to-day basis required a lot of work on behalf of the fleet maintenance manager and dispatch team. As a result, operators did not push the electric buses to their operating limits. At first, the buses' operating status and SOC were closely scrutinized minute by minute in order to make sure they drove the most miles possible each day while still being able to return to base and not get stranded on the road with a dead battery. However, this extra work required additional effort on top of an already busy staff's workload. Eventually, more broad guidelines were required to reduce this effort to a more manageable effort. This included recalling buses to base depending on the number of hours they had already driven in service that day. Using number of service hours over a metric more closely related to the buses' remaining range, such as SOC, likely limited the daily operating range experienced by the buses.

As GTrans adds more electric buses to its fleet, it will need to also add more charging infrastructure. Currently, the fleet operates at a 3:5 ratio of vehicle charge outlet to buses. While a 1:1 ratio would ensure all buses are able to charge to their full potential, maintaining the current ratio would require the addition of three electric buses to the facility's infrastructure in order for GTrans to meet its goal of a 20 percent electric fleet. Improving the vehicle charge outlet to bus ratio would likely decrease charging delays and increase utilization. Increasing the cumulative miles driven by the buses increases savings to the fleet. However, it will remain important to closely watch these numbers as more buses potentially charging at once would increase the instantaneous power demand, resulting in higher demand charges to be levied by the utility provider. Going forward, and as GTrans adds to their electric bus fleet, having an employee dedicated to managing the electric buses in operation may be useful for increasing the number of active days per month and number of miles driven per month while keeping costs low.

Even though operators did not drive the buses at their maximum potential range, the fleet still gained multiple benefits. The fuel and maintenance savings experienced by the buses were significant. Over the limited data collection period, both categories of per mile costs (fuel and maintenance) were shown to be cheaper than the current baseline conventionally-fueled buses. Adopting more electric buses within their fleet while working up to the goal of 20 percent electric would increase the value of these benefits to a savings of 102,875 gallons of gasoline and $216,038 annually. If other trends CALSTART observed continue, regeneration rate and efficiency will keep improving. Once the operator training course being developed by the SCRTTC is prepared and delivered to the operators, there may even greater improvements in these categories.

Recommendations stemming from the learnings gathered during this project revolve around changeable operational practices to increase bus usage performance and verify operator performance. As GTrans continues to expand zero-emission bus operation, they should consider hiring staff dedicated to managing and monitoring the electric buses. Their usage is just too different from current bus management practices at GTrans, so employees who are solely responsible for the new technology buses would help maximize their usage. The operator training course should continue to be refined and when ready presented to the operators. If the variation in operator efficiency remains of interest to GTrans, they should develop a specific testing protocol in order to measure operator performance. It was difficult to discern any real differences between operators under the operating paradigm in place throughout the course of this project, but it would be possible to measure the variation if conditions are controlled.

The results of this project have inspired GTrans to continue experimenting with electric bus technology. The electric buses represent an improvement in both sustainability and operability over the gasoline-hybrid buses that make up the majority of GTrans' fleet. GTrans had to get special permission from the federal transit administration (FTA) to retire some of those buses earlier than their planned lifespan because of numerous issues. Although the current electric buses on the market cannot meet the full range requirements of the fleet, GTrans is committed to pursuing this path toward sustainability. To this end, the fleet replacement plan recently approved by the city council of Gardena guides the fleet towards accumulating two more electric buses next year followed by four more the following year. Eventually, the fleet composition will be 80 percent CNG and 20 percent electric. Aside from the range requirements, the electric buses have too high of a cost. The remanufactured buses cost about as much as a brand new CNG bus but come with a longer operating life and more proven track record. GTrans has a great head start in adopting zero-emission buses and it will be exciting to watch their progress in years to come. Table 16 below summarizes the major findings of this project.

Table 16: Major Findings from the GTrans ZEPS Bus Project

Major Findings
The ZEPS buses drove shorter distances than conventional buses per day on average.
The average overall efficiency of the ZEPS Buses is much better than the conventional GTrans bus.
The fuel cost and maintenance cost per mile for the ZEPS buses was well below that of the conventional GTrans buses.
The total project mileage varied by over 65 percent and the average daily mileage varied by over 35 percent between individual ZEPS buses.
The ZEPS buses had major emissions and fuel savings for the fleet relative to the conventional buses.
The average regeneration rate across all ZEPS buses improved over the course of the project.
The average efficiency overall across all ZEPS buses improved over the course of the project once two different time periods with uncertain data are removed.
Due to the predominance of route 3 in the data and the pattern of each operator generally only driving one route it is not possible to determine if any specific route or operator is more efficient than any other at this time.
The amount of energy charged per day varied widely between different ZEPS buses.
All buses charged most often during the afternoon and late night to early morning.

Source: CALSTART

GLOSSARY

BATTERY ELECTRIC VEHICLE (BEV) – Also known as an "All-electric" vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

CALIFORNIA ENERGY COMMISSION (CEC) – The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

- Forecasting future statewide energy needs
- Licensing power plants sufficient to meet those needs
- Promoting energy conservation and efficiency measures
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
- Planning for and directing state response to energy emergencies

Funding for the Commission's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account and other sources.

CALIFORNIA PUBLIC UTILITIES COMMISSION (CPUC) – A state agency created by constitutional amendment in 1911 to regulate the rates and services of more than 1,500 privately owned utilities and 20,000 transportation companies. The CPUC is an administrative agency that exercises both legislative and judicial powers; its decisions and orders may be appealed only to the California Supreme Court. The major duties of the CPUC are to regulate privately owned utilities, securing adequate service to the public at rates that are just and reasonable both to customers and shareholders of the utilities; including rates, electricity transmission lines and natural gas pipelines. The CPUC also provides electricity and natural gas forecasting, and analysis and planning of energy supply and resources. Its main headquarters are in San Francisco.

CALSTART – A nonprofit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions. CALSTART is a network that connects companies and government agencies and helps them do their jobs better. CALSTART is located in Pasadena, California.[15]

CARBON DIOXIDE (CO2) – A colorless, odorless, nonpoisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent).

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[15] CALSTART (https://calstart.org/)

COMPLETE COACH WORKS (CCW) – CCW is a family-owned and operated organization headquartered in Riverside, California that provides services to the North American transportation industry.[16]

COMPRESSED NATURAL GAS (CNG) – Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

CONTROLLER AREA NETWORK (CAN) – A serial network technology that was originally designed for the automotive industry, especially for European cars, but has also become a popular bus in industrial automation as well as other applications. The CAN bus is primarily used in embedded systems, and as its name implies, is a network technology that provides fast communication among microcontrollers up to real-time requirements.[17]

ELECTRIC VEHICLE (EV) – A broad category that includes all vehicles that are fully powered by electricity or an electric motor.

ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE) – Infrastructure designed to supply power to EVs. EVSE can charge a wide variety of EVs, including BEVs and PHEVs.

Extended Operations (EO) – Extended operations, refers to an off-road vehicle with a secondary power source (e.g. a conventional engine) that provides power once the battery is depleted, allowing for longer use times.

Extended Range (XR) – Extended range, refers to an on-road vehicle with a secondary power source (e.g. a conventional engine) that provides power once the battery is depleted, allowing for greater range.

FEDERAL TRANSIT ADMINISTRATION (FTA) – An agency within the U.S. Department of Transportation, the Federal Transit Administration (FTA) provides financial and technical assistance to local public transit systems, including buses, subways, light rail, commuter rail, trolleys and ferries. FTA also oversees safety measures and helps develop next-generation technology research.

GREENHOUSE GASES (GHG) – Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

GROSS VEHICLE WEIGHT RATING (GVWR) – The maximum weight of the vehicle as specified by the manufacturer. Includes total vehicle weight plus fluids, passengers, and cargo.[18]

HYBRID AND ZERO-EMISSION TRUCK AND BUS VOUCHER INCENTIVE PROJECT (HVIP) – A project launched in 2009 by the ARB in partnership with CALSTART to accelerate the purchase of cleaner, more efficient trucks and buses in California.

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[16] Complete Coach Works (https://completecoach.com/about-1/)
[17] Copperhill Technologies (https://copperhilltech.com/a-brief-introduction-to-controller-area-network/)
[18] U.S. Department of Energy (https://afdc.energy.gov/data/10380)

KILOWATT (kW) – One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home—with central air conditioning and other equipment in use—might have a demand of 4 kW each hour.

KILOWATT-HOUR (kWh) – The most commonly used unit of measure telling the amount of electricity consumed over time, means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumed 534 kWh in an average month.

MEDIUM/HEAVY DUTY (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).

ORIGINAL EQUIPMENT MANUFACTURER (OEM) – Makes equipment or components that are then marketed by its client, another manufacturer, or a reseller, usually under that reseller's own name.

SOUTHERN CALIFORNIA REGIONAL TRANSIT TRAINING CONSORTIUM (SCRTTC) –The SCRTTC is a leading provider of training for the public transit industry. The SCRTTC is comprised of public transportation agencies and academic members located in Southern California.[19]

STATE OF CHARGE (SOC) – Available capacity expressed as a percentage of its rated capacity.[20]

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) – A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting, and enforcement activities.

VEHICLE CHARGE OUTLET (VCO) – The control panel that feeds energy to the onboard charger.

ZERO EMISSION PROPULSION SYSTEM (ZEPS) – Zero-Emission Propulsion System, a remanufactured electric transit bus product produced by Complete Coach Works

ZERO EMISSION VEHICLE (ZEV) – Vehicles that produce no emissions from the on-board source of power (e.g., an electric vehicle).

[19] Southern California Regional Transit Training Consortium (http://scrttc.com/)
[20] State of Charge Definition (https://www.mpoweruk.com/soc.html)

APPENDIX A: Parameter Definitions

Table 17: Parameters Collected for Data Analysis

Parameters Collected	Units	Definition
Date	Year-Month-Day	Date the data was recorded
Average Speed	MPH	Total distance recorded for the day divided by time spent driving
Distance	Miles	Total distance recorded
Efficiency Driving	kWh/mi	Efficiency of the vehicle measured only during driving (speed > 0)
Efficiency Overall	kWh/mi	Efficiency of the vehicle including idling (speed ≥ 0)
Efficiency In Service	kWh/mi	Efficiency of the vehicle including the amount of energy used during driving and idling (speed ≥ 0) plus an additional 10 minutes after the vehicle stops
Energy Charged	kWh	The total energy charged
Energy Consumed Driving	kWh	The total energy consumed to drive the vehicle (speed > 0), excluding recovered energy
Energy Driven	kWh	The total energy consumed to drive the vehicle (speed > 0), including recovered energy
Energy Idled	kWh	The total energy consumed while the vehicle stands still (speed = 0)
Energy Regenerated	kWh	The total energy recovered by regenerative breaking
Energy Used	kWh	The total energy used while the vehicle is on
Regeneration Rate	%	Ratio between recovered energy and consumed energy
SOC Used	%	The percentage of the battery's total capacity used while the vehicle is turned on
Time Charging	HH:MM:SS	Total amount of time the vehicle was charging
Time Driving	HH:MM:SS	Total amount of time the vehicle was driving (speed > 0)
Time Idling	HH:MM:SS	Total amount of time the vehicle was on but not driving (speed = 0)
Time in Service	HH:MM:SS	Total amount of time the vehicle was driving plus an additional 10 minutes after the vehicle stops

Source: CALSTART

APPENDIX B: Bus Summary Data Tables

Table 18: Vehicle Usage Parameters, Bus 707

Month	Time in Service	Time Driving	Time Idled	Mileage	Miles per Day (in service)	Days in Service	Average Speed
Unit	HH:MM:SS	HH:MM:SS	HH:MM:SS	mi	mi	Days	MPH
Nov. ‘16	24:29:48	18:47:24	21:11:58	351.7	39.1	9	14.8
Dec. ‘16	7:41:34	5:26:04	3:03:59	103.2	25.8	4	14.4
Jan. ‘17	19:29:05	14:17:46	27:23:57	282.4	40.3	7	14.8
Feb. ‘17	48:30:58	37:21:32	11:35:27	732.0	73.2	10	15.1
Mar. ‘17	29:48:11	22:46:05	13:22:07	459.1	57.4	8	15.4
Apr. ‘17	36:10:08	22:19:04	10:55:45	444.1	49.3	9	15.6
May ‘17	40:21:53	30:02:01	11:04:45	594.5	39.6	15	14.9
June ‘17	56:40:30	43:16:54	14:22:02	873.3	46.0	19	15.3
July ‘17	26:15:06	19:48:38	23:54:46	402.1	50.3	8	15.3
Aug. ‘17	39:18:45	30:27:15	14:14:40	627.9	44.9	14	15.8
Sep. ‘17	42:28:10	32:02:36	10:36:31	425.0	25.0	17	8.2
Oct. ‘17	72:59:12	7:07:42	18:16:00	957.9	47.9	20	14.2
Nov. ‘17	64:40:59	49:40:05	15:30:36	948.3	52.7	18	14.8
Dec. ‘17	60:29:05	12:40:05	29:07:53	244.8	61.2	4	13.1
Jan. ‘18	9:11:36	7:07:42	9:21:45	192.1	38.4	5	15.0
Feb. ‘18	NA[21]	NA[21]	35:52:45	463.0	30.9	15	NA[21]
Mar. ‘18	NA[21]	NA[21]	58:35:34	782.3	41.2	19	NA[21]
Apr. ‘18	25:57:24	20:12:52	61:43:57	988.2	47.1	21	14.8
May ‘18	41:23:54	30:48:09	32:07:45	671.2	48.0	14	13.2
June ‘18	NA[21]	NA[21]	NA[21]	NA[21]	NA[21]	NA[21]	NA[21]
July ‘18	109:57:14	59:39:17	339:03:02	766.2	51.1	15	7.0

Source: CALSTART

[21] No data recorded this month.

Table 19: Electrical Vehicle Usage Parameters, Bus 707

Month	Total Energy Driving	Total Energy Idled	Total Energy Regenerated	Total Energy Used	Total Energy Charged	Average Efficiency Driving	Average Efficiency Overall	Total Charging Time	Regen Rate
Unit	kWh	kWh	kWh	kWh	kWh	kWh/mi	kWh/mi	HH:MM:SS	%
Nov. ‘16	672.4	955.8	206.9	826.9	1,401.9	1.9	2.4	22:00:26	23.8
Dec. ‘16	204.3	45.5	57.5	244.7	437.4	2.0	2.4	16:21:44	27
Jan. ‘17	553.7	1237.8	165.6	639.4	1,637.4	2.0	2.5	30:08:12	24
Feb. ‘17	1319.3	187.6	460.8	1,499.4	1,300.2	1.8	2.1	61:29:41	25.6
Mar. ‘17	902.3	482.8	317.0	1,023.6	1,282.3	2.0	2.4	32:31:46	26
Apr. ‘17	820.2	334.0	277.3	1,003.8	954.3	1.8	2.1	44:53:38	26.2
May ‘17	1209.4	218.3	450.0	1,411.1	1,137.7	2.0	2.4	73:34:34	27.3
June ‘17	1699.1	296.0	620.0	1,982.3	989.3	2.0	2.3	70:33:32	26.8
July ‘17	835.8	1164.5	281.7	1,005.4	1,452.2	2.1	2.5	39:44:00	24.7
Aug. ‘17	1155.3	461.9	456.2	1,330.3	878.0	1.9	2.2	43:46:55	28.5
Sep. ‘17	1231.9	164.7	488.7	1,394.1	718.2	2.6	3.0	22:37:06	21.1
Oct. ‘17	2068.1	330.7	841.9	2,385.6	1,547.7	2.1	2.4	85:08:57	29.5
Nov. ‘17	1705.2	228.6	731.2	1,928.6	1,259.5	1.8	2.0	121:52:01	30.2
Dec. ‘17	460.2	1465.0	181.5	1,203.1	1,022.5	1.9	2.6	30:12:53	28.0
Jan. ‘18	255.5	464.7	92.3	292.1	371.0	1.9	2.1	11:36:50	26.5
Feb. ‘18	NA[2]	1,974.5	NA[22]	NA[22]	1,106.2	NA[22]	NA[22]	34:35:24	NA[22]
Mar. ‘18	NA[22]	3,221.6	NA[22]	NA[22]	1,901.3	NA[22]	NA[22]	64:54:29	NA[22]
Apr. ‘18	698.2	3,054.7	276.6	3,752.9	2,005.8	1.8	2.1	83:02:24	28.4
May ‘18	1,081.8	1,282.8	436.0	2,364.6	1,019.1	2.0	2.2	41:41:01	28.6
June ‘18	NA[22]	NA[22]	NA[22]	NA[22]	NA[22]	NA[22]	NA[22]	NA[22]	NA[22]
July ‘18	2,182.6	1,024.8	732.9	2,487.2	3,500.0	2.8	3.3	88:03:46	25.2

Source: CALSTART

[22] No distance recorded, so parameter could not be calculated.

Table 20: Vehicle Usage Parameters, Bus 736

Month	Time in Service	Time Driving	Time Idled	Mileage	Miles per Day (in service)	Days in Service	Average Speed
Unit	HH:MM:SS	HH:MM:SS	HH:MM:SS	mi	mi	Days	MPH
Mar. '17	29:19:17	16:42:42	50:45:50	290.4	36.3	8	10.6
Apr. '17	31:18:02	19:24:12	48:37:25	424.9	53.1	8	13.6
May '17	57:38:37	30:36:37	213:27:22	571.8	47.7	12	11.5
June '17	63:26:27	32:38:45	438:33:51	716.9	42.2	17	11.6
July '17	58:39:18	39:40:10	223:40:39	734.0	52.4	14	12.9
Aug. '17	31:54:49	17:01:51	200:57:25	388.4	43.2	9	12.5
Sep. '17	10:25:57	7:37:14	2:52:09	59.3	19.8	3	8.2
Oct. '17	47:40:43	35:09:39	43:55:42	452.6	34.8	13	9.6
Nov. '17	22:38:14	19:24:42	3:35:24	236.7	33.8	7	10.5
Dec. '17	71:28:33	54:27:40	50:51:18	713.4	51.0	14	10.0
Jan. '18	62:15:27	44:06:25	66:25:52	606.9	46.7	13	10.2
Feb. '18	64:28:56	54:09:52	10:49:52	682.2	40.1	17	10.6
Mar. '18	24:34:35	20:05:23	4:55:43	244.2	27.1	9	10.1
Apr. '18	13:03:40	8:05:03	65:36:05	106.7	21.3	5	8.8
May '18	25:22:55	15:16:08	126:42:18	212.6	35.4	6	8.9
June '18	14:17:58	9:25:49	103:58:31	165.0	41.2	4	14.1
July '18	22:26:21	13:25:53	245:27:05	213.5	26.7	8	11.3

Source: CALSTART

Table 21: Electrical Vehicle Usage Parameters, Bus 736

Month	Total Energy Driving	Total Energy Idled	Total Energy Regenerated	Total Energy Used	Total Energy Charged	Average Efficiency Driving	Average Efficiency Overall	Total Charging Time	Regen Rate
Unit	kWh	kWh	kWh	kWh	kWh	kWh/mi	kWh/mi	HH:MM:SS	%
Mar. '17	641.7	177.3	200.8	735.8	723.9	2.2	2.7	22:37:46	23.9
Apr. '17	717.9	151.6	235.9	798.0	781.7	1.7	1.9	24:45:57	24.8
May '17	1327.8	287.3	385.7	1,572.4	1,151.1	2.0	2.4	56:36:20	23.2
June '17	1453.2	376.0	406.7	1,727.1	1,963.5	2.0	2.5	97:43:04	22.0
July '17	1456.5	504.6	349.0	1,766.8	1,836.6	2.0	2.6	92:52:14	19.6
Aug. '17	666.6	373.8	220.6	765.6	809.9	1.8	2.1	35:52:09	24.9
Sep. '17	291.4	37.6	101.8	328.3	10.2	3.323	3.7[23]	00:10:05	25.9
Oct. '17	1258.8	165.8	401.9	1,408.2	289.1	2.8	3.2	5:18:19	24.2
Nov. '17	645.6	58.3	207.1	699.7	43.1	2.7	3.0	00:25:47	24.3
Dec. '17	1908.9	184.4	609.6	2,066.4	607.3	2.7	2.9	13:28:02	24.3
Jan. '18	1539.8	139.6	492.4	1,650.8	694.8	2.5	2.8	15:59:07	23.7
Feb. '18	1920.5	158.1	631.2	2,037.3	257.7	2.8	3.0	3:14:38	24.8
Mar. '18	699.7	68.7	222.6	755.0	60.2	2.9	3.1	00:45:48	24.2
Apr. '18	275.5	43.4	102.9	298.4	280.1	2.6	2.8	6:47:50	27.4
May '18	542.0	95.2	213.8	579.6	485.3	2.5	2.8	11:35:26	28.3
June '18	359.8	62.6	101.8	376.9	471.4	2.2	2.3	11:03:32	19.9
July '18	554.2	182.3	139.1	620.4	639.5	2.6	3.2	16:07:48	19.0

Source: CALSTART

[23] Only 3 dates had the data necessary to calculate this parameter, so it is likely to be inaccurate as an average.

Table 22: Vehicle Usage Parameters, Bus 768

Month	Time in Service	Time Driving	Time Idled	Mileage	Miles per Day (in service)	Days in Service	Average Speed
Unit	HH:MM:SS	HH:MM:SS	HH:MM:SS	mi	mi	Days	MPH
Mar. '17	13:27:23	7:37:57	9:29:26	118.2	23.64	5	8.9
Apr. '17	29:07:34	17:42:12	15:05:31	394.9	65.8	6	14.6
May '17	64:55:22	34:42:12	239:04:28	761.1	63.4	12	11.9
June '17	79:54:40	43:18:42	379:13:43	987.9	58.1	17	12.5
July '17	68:42:13	36:34:03	362:16:55	826.6	63.6	13	12.2
Aug. '17	104:12:59	55:49:45	399:31:10	1,260.0	57.3	22	12.1
Sep. '17	NA	NA	17:59:54	201.3	33.5	6	NA **Error! Bookmark not defined.**
Oct. '17	91:19:20	48:53:37	316:19:42	1,122.0	66.0	17	12.4
Nov. '17	40:57:54	22:03:40	520:17:54	477.3	53.0	9	12.0
Dec. '17	74:36:31	40:43:54	558:38:03	904.2	75.4	12	12.4
Jan. '18	80:32:51	53:18:19	311:31:46	983.3	54.6	18	13.3
Feb. '18	39:37:42	33:10:49	6:54:25	499.0	41.6	12	13.9
Mar. '18	61:15:40	51:49:52	9:20:27	785.9	37.4	21	14.6
Apr. '18	57:13:01	35:10:00	208:22:58	547.2	30.4	18	14.3
May '18	78:48:59	41:05:15	336:38:28	671.5	32.0	21	12.1
June '18	28:56:29	8:31:57	397:45:00	214.9	43.0	5	7.8
July '18	182:21:37	8:31:19	378:33:17	125.8	42.0	3	8.7

Source: CALSTART

Table 23: Electric Vehicle Usage Parameter, Bus 768

Month	Total Energy Driving	Total Energy Idled	Total Energy Regenerated	Total Energy Used	Total Energy Charged	Average Efficiency Driving	Average Efficiency Overall	Total Charging Time	Regen Rate
Unit	kWh	kWh	kWh	kWh	kWh	kWh/mi	kWh/mi	HH:MM:SS	%
Mar. '17	257.8	46.0	100.2	296.2	276.6	2.2	2.6	8:12:23	28.0
Apr. '17	613.2	84.9	261.7	688.7	996.9	1.5	1.7	30:57:58	NA
May '17	1154.4	190.8	505.3	1,326.1	1,831.8	1.5	1.8	83:06:57	30.5
June '17	1498.2	227.8	635.6	1,699.1	1,680.7	1.5	1.7	76:57:44	29.8
July '17	1372.9	329.7	530.2	1,626.0	1,882.9	1.7	2.0	88:07:17	27.9
Aug. '17	2019.1	445.0	788.9	2,392.2	2,247.6	1.6	2.0	108:13:35	28.1
Sep. '17	NA[24]	925.6	NA[24]	NA[24]	354.8	NA[24]	4.6[25]	9:17:02	NA[24]
Oct. '17	1777.6	377.1	762.3	2,055.7	2,382.7	1.6	1.9	115:30:21	30.0
Nov. '17	732.7	118.8	339.9	838.1	1,204.1	1.5	1.8	60:30:04	31.8
Dec. '17	1331.3	206.5	605.4	1,509.1	1,925.9	1.5	1.7	46:03:41	31.3
Jan. '18	1692.9	196.0	743.1	1,849.6	1,141.8	1.6	1.8	25:21:52	30.6
Feb. '18	1066.0	94.9	413.6	1,150.9	77.6	2.0	2.2	1:01:12	28.0
Mar. '18	1637.7	131.1	668.2	1,717.9	230.2	1.9	2.1	2:54:06	29.0
Apr. '18	1357.6	128.5	526.9	1,462.5	829.1	1.7	1.8	31:32:19	28.0
May '18	1542.4	186.8	628.5	1,698.5	1,327.1	1.7	1.9	55:25:11	29.0
June '18	340.4	1448.2	139.2	395.6	1,911.3	1.6	1.9	72:33:42	29.0
July '18	313.5	622.1	110.2	450.3	1,028.6	2.5	3.0	35:33:10	26.0

Source: CALSTART

[24] No data recorded this month.
[25] Only 6 dates had the data necessary to calculate this parameter, so it is likely to be inaccurate as an average.

Table 24: Electrical Vehicle Usage Parameters, Bus 775

Month	Total Energy Driving	Total Energy Idled	Total Energy Regenerated	Total Energy Used	Total Energy Charged	Average Efficiency Driving	Average Efficiency Overall	Total Charging Time	Regen Rate
Unit	kWh	kWh	kWh	kWh	kWh	kWh/mi	kWh/mi	HH:MM:SS	%
Mar. '17	6.9	24.1	2.7	8.2	168.0	6.9	24.1	2:42:02	NA[26]
Apr. '17	433.7	97.0	150.7	488.3	521.4	1.7	2.2	16:50:05	25.2
May '17	241.2	75.7	100.4	276.1	159.8	1.6	2.1	7:15:48	29.2
June '17	1108.6	188.8	406.5	1,273.3	1,236.5	1.6	1.9	55:54:42	26.8
July '17	1085.5	238.8	409.0	1249.4	1,378.8	1.6	1.9	62:38:32	27.4
Aug. '17	1002.7	189.5	374.0	1,161.0	1,404.0	1.6	2.0	65:07:20	27.2
Sep. '17	NA[26]	NA[26]	NA[26]	NA[26]	722.0	NA[26]	4.6[27]	30:39:49	NA[26]
Oct. '17	1458.4	294.8	541.2	1,695.6	1,737.6	1.6	2.0	80:46:04	27.2
Nov. '17	1013.1	177.2	415.9	1,140.0	1,535.2	1.6	1.8	70:58:42	29.2
Dec. '17	704.3	89.8	271.5	791.9	855.3	1.5	1.7	27:03:52	27.5
Jan. '18	1804.2	194.8	714.1	1,979.0	1,066.9	1.9	2.1	22:28:31	28.4
Feb. '18	1799.3	133.2	678.5	1,931.1	194.6	2.5	2.7	2:02:11	27.4
Mar. '18	600.5	43.5	227.2	634.1	159.7	2.5	2.7	1:49:29	27.5
Apr. '18	480.1	48.1	170.3	519.0	307.9	2.7	2.9	7:30:34	26.2
May '18	1396.8	167.2	486.9	1,536.5	1,282.7	2.5	2.8	31:00:15	25.9
June '18	239.1	1179.1	86.0	278.3	1,549.9	1.7	2.0	35:54:47	26.4
July '18	251.3	1120.6	64.3	359.1	1,491.4	2.2	2.6	34:31:32	19.1

Source: CALSTART

[26] No data recorded this month.
[27] Only 6 dates had the data necessary to calculate this parameter, so it is likely to be inaccurate as an average.

Table 25: Vehicle Usage Parameters, Bus 777

Month	Time in Service	Time Driving	Time Idled	Mileage	Miles per Day (in service)	Days in Service	Average Speed
Unit	HH:MM:SS	HH:MM:SS	HH:MM:SS	mi	mi	Days	MPH
Mar. '17	8:39:05	4:35:59	7:31:05	83.4	27.8	3	10.1
Apr. '17	53:05:30	31:34:54	31:29:01	647.5	64.8	10	13.3
May '17	41:43:23	23:23:31	185:14:08	523.6	52.4	10	12.6
June '17	50:24:43	26:47:13	247:59:54	586.0	58.6	10	11.7
July '17	55:59:04	30:11:23	308:16:22	684.8	62.3	11	12.1
Aug. '17	79:30:53	43:41:13	215:49:07	1,036.1	69.1	15	12.6
Sep. '17	NA[28]	NA[28]	11:36:41	138.1	23.0	6	NA[28]
Oct. '17	54:34:32	30:17:41	146:29:41	672.1	67.2	10	12.2
Nov. '17	67:38:32	37:18:50	285:22:58	800.3	72.8	11	12.0
Dec. '17	84:57:54	50:04:06	274:04:13	1,053.0	70.2	15	12.2
Jan. '18	74:58:24	51:08:43	286:43:12	880.0	51.8	17	14.4
Feb. '18	38:02:11	30:35:53	08:07:29	535.1	41.2	13	16.7
Mar. '18	NA[28]	NA[28]	NA[28]	1,645.5	74.8	22	NA[28]
Apr. '18	NA[28]	NA[28]	10:22:31	1,017.4	78.3	13	NA[28]
May '18	19:44:49	11:18:46	285:09:48	202.5	50.6	4	13.4
June '18	6:48:42	2:37:01	290:19:01	61.5	61.5	1	9.1
July '18	41:42:17	30:00:55	219:25:05	374.1	46.8	8	8.2

Source: CALSTART

[28] No data recorded this month.

Table 26: Electrical Vehicle Usage Parameters, Bus 777

Month	Total Energy Driving	Total Energy Idled	Total Energy Regenerated	Total Energy Used	Total Energy Charged	Average Efficiency Driving	Average Efficiency Driving	Total Charging Time	Regen Rate
Unit	kWh	kWh	kWh	kWh	kWh	kWh/mi	kWh/mi	HH:MM:SS	%
Mar. '17	165.3	41.0	66.6	193.9	334.3	2.0	2.4	9:55:26	28.9
Apr. '17	1,214.2	279.6	428.7	1,434.8	847.4	1.7	2.1	27:02:00	25.9
May '17	977.8	201.3	336.8	1,146.0	1,051.5	1.9	2.3	33:41:38	25.7
June '17	1,083.7	256.0	325.7	1,293.2	1,032.3	1.8	2.3	31:45:40	23.1
July '17	1,252.7	424.2	377.0	1,532.3	982.4	1.9	2.4	30:12:20	23.5
Aug. '17	1,637.6	278.3	646.3	1,881.0	1,631.6	1.6	1.9	52:01:01	28.3
Sep. '17	NA[29]	641.2	NA[29]	NA[29]	484.3	NA[29]	NA[29]	9:56:42	NA[29]
Oct. '17	1,075.8	230.1	416.5	1,264.8	1,049.5	1.6	2.0	36:28:35	27.9
Nov. '17	1,242.1	186.3	533.6	1,411.1	1,590.0	1.6	1.8	59:30:19	30.0
Dec. '17	1,606.2	275.4	657.9	1,830.8	2,018.5	1.6	1.8	90:30:31	29.1
Jan. '18	1,718.6	193.8	705.1	1,685.2	1,305.1	1.6	1.8	23:58:12	29.0
Feb. '18	1,060.9	101.9	407.3	1,028.1	534.4	1.7	1.9	00:00:00	27.7
Mar. '18	15.7	0.0	0.4	22.0	6.3	0.2	0.1	15.7	2.7
Apr. '18	NA[29]	NA[29]	NA[29]	NA[29]	NA[29]	NA[29]	NA[29]	NA[29]	NA[29]
May '18	416.5	50.6	175.4	460.3	425.1	1.7	1.8	9:50:22	29.7
June '18	101.4	4,305.6	48.9	115.6	4,600.3	1.6	1.9	102:32:31	32.5
July '18	244.5	1,087.8	84.3	446.2	1,096.8	2.5	3.0	24:35:16	25.7

Source: CALSTART

[29] No data recorded this month.