Zero Emission Re-Power

Performance and Data Collection Summary Report

Advanced Transportation Technology Evaluation

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List of Acronyms

CCW	Complete Coach Works
CEC	California Energy Commission
BEV	Battery electric vehicle, a vehicle which is solely powered by an onboard battery
CPUC	California Public Utility Commission
EPA	Environmental Protection Agency
EV	Electric vehicle
FTA	Federal Transit Agency
GHG	Greenhouse gas
GVWR	Gross Vehicle Weight Rating
kW	Kilowatt
kWh	Kilowatt hour
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)
OEM	Original Equipment Manufacturer, also known as truck makers, truck manufacturers
VCO	Vehicle Charge Outlet, the control panel that feeds energy to the onboard charger
XO	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
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
ZEPS	Zero-Emission Propulsion System, a remanufactured electric transit bus product produced by Complete Coach Works
ZEV	Zero-Emission Vehicle, inclusive of all forms of cars, trucks, buses, and off-road vehicles that does not produce any emissions

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1 Introduction

GTrans is a public transit agency located in the southern California city of Gardena and serving the 60,000 inhabitants who live in the six square miles that make up the community. GTrans's headquarters are a state-of-the-art LEED Silver certified 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 California Energy Commission (CEC) for this project allowed for GTrans to repower five of their gasoline-electric hybrid buses, converting them to battery electric buses. 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 life. As battery electric buses, these vehicles save money on fuel and 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.

Complete Coach Works (CCW) provides remanufacturing of buses and alternative fuel conversion and was engaged to upgrade the buses using their novel Zero Emission Propulsion System (ZEPS). They converted the five buses at their Riverside, California facility and provided warranty service throughout the project duration.

CALSTART was tasked with the data collection and analysis portions of the project. Specifically, our goals were:

- Validating and analyzing the electric buses' performance
- Comparing the operation of electric buses to GTrans's 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 5 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 that allowed for remote data collection and monitoring via. Performance data was regularly summarized and reported on monthly to follow the progress of each bus throughout the demonstration period. In addition, supplemental data in the form of operator logs, fuel records, maintenance data, and repair information were collected from the various relevant sources in order to have a complete picture of the bus performance. 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 the progress that has been made in recent years. Next, the details of this project are described. The specific bus technology deployed and the various sources of data that were collected and synthesized are explained and listed. The data collection methodology is fully explained along with any caveats or difficulties that were encountered during the data collection phase. Finally, the analysis of the data is presented beginning 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 the electric buses' performance and efficiency is discussed. An analysis of the charging patterns used to power the buses is also reported. Finally, a conclusion summarizing all of the main results ends the report.

2 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 our 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 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% 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. 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.

[1] California Air Resources Board. Proposed Fiscal Year 2017-2018 Funding Plan for Clean Transportation Incentives. November 2017. 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. 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. https://www.idtechex.com/research/reports/li-ion-batteries-for-electric-buses-2018-2028-000595.asp. Accessed September 7, 2018.

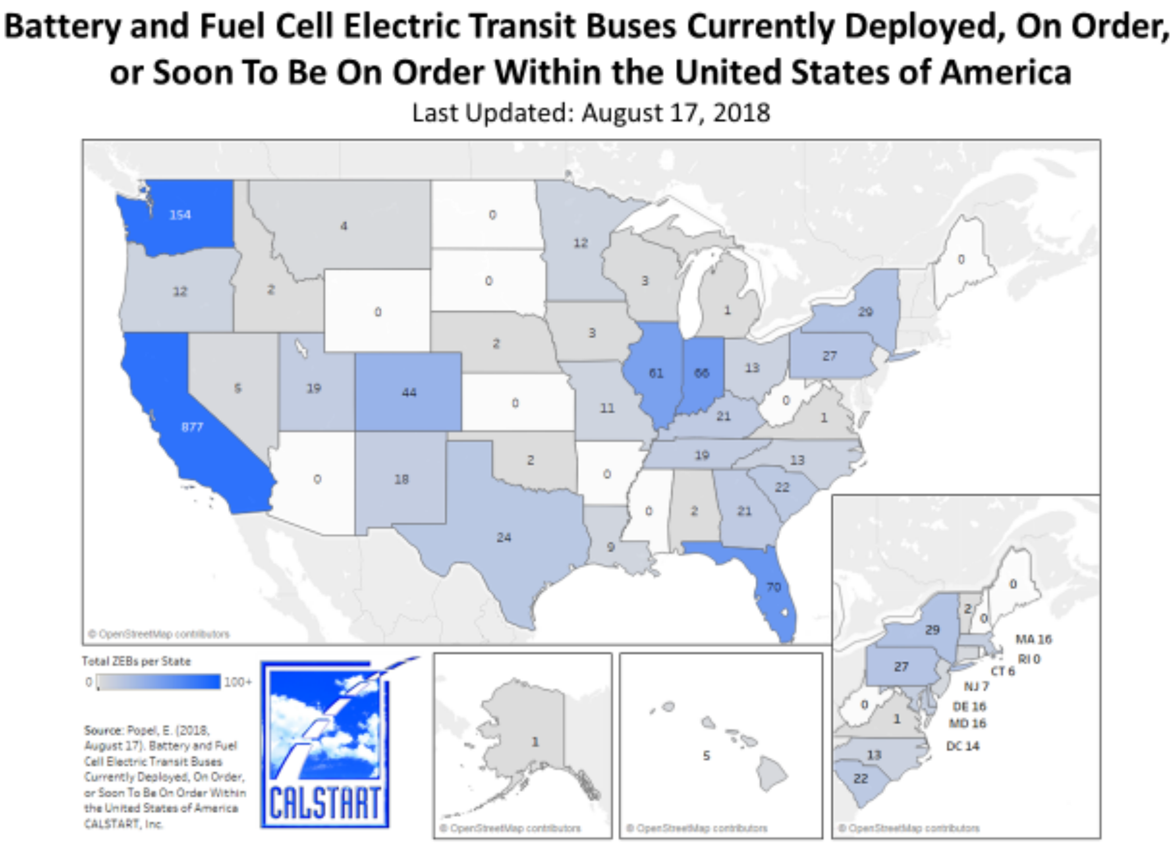

Figure 1 Number of electric buses currently or soon to be deployed in the United States by state

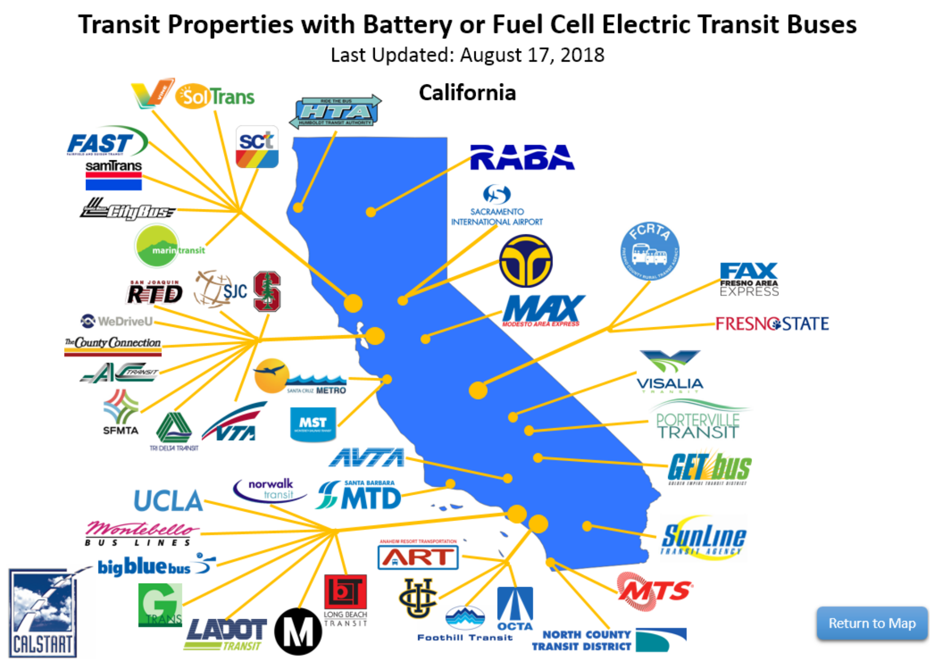

Figure 2 California transit agencies with zero-emission buses

3 Project Specifics

3.1 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% electric buses and 80% conventionally fueled buses (transitioning from the older gasoline-hybrids to 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. Figure 3 shows an overhead view of the facility.

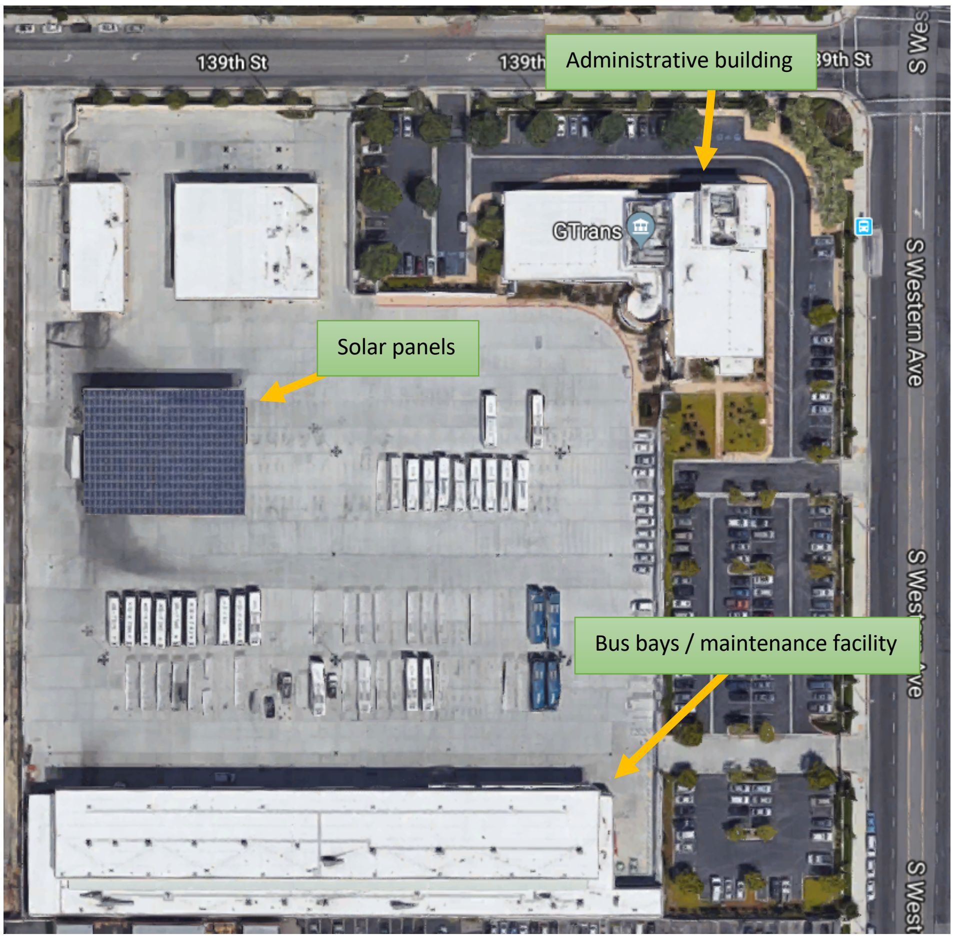

Figure 3 Overhead view of the GTrans facility

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

GTrans serves five primary routes, shown in Figure 4 below.

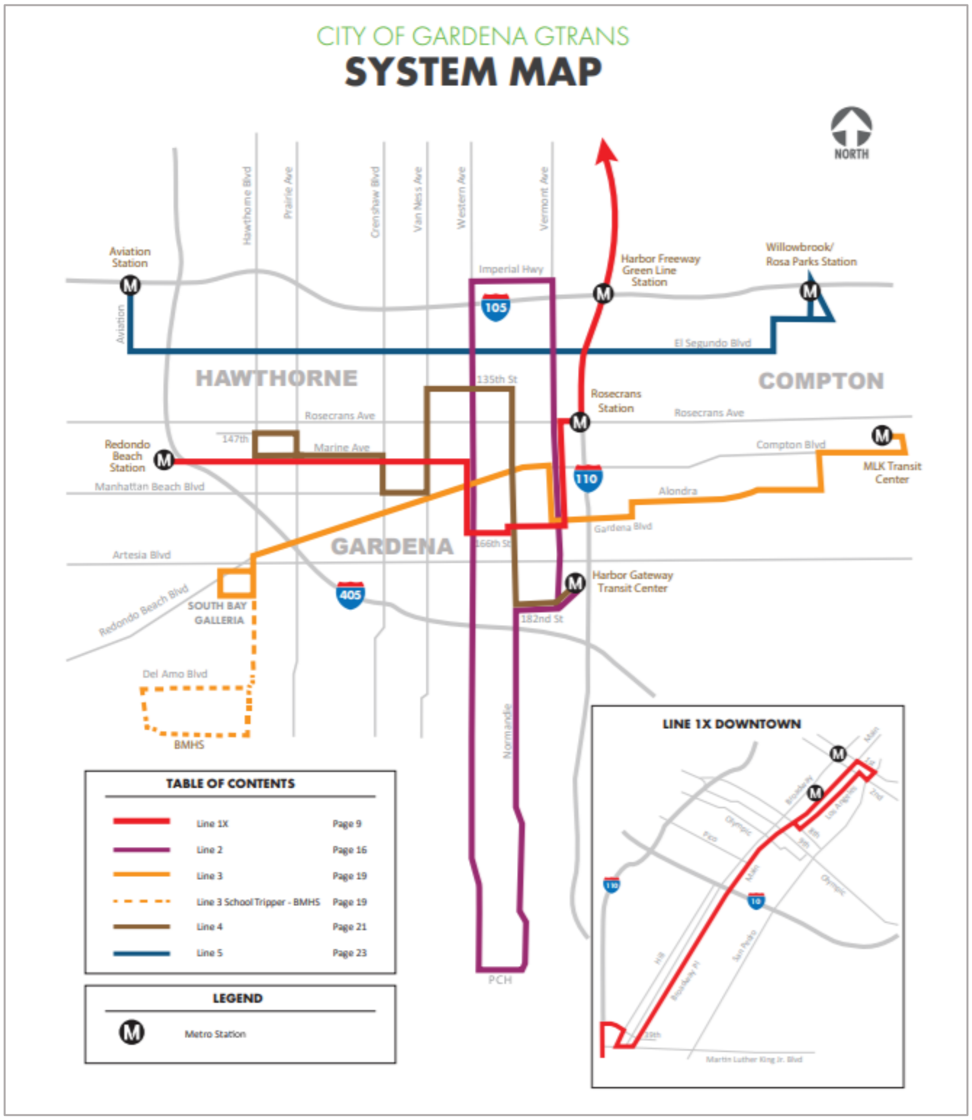

Figure 4 GTrans route map showing the five main routes and one supplemental school route

Line 1X (show 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; and 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% of all trips with data and operator information recorded occurred on Line 3 while 20% occurred on Line 2 (the remaining 3% of trips were on Line 4). Line characteristics are detailed in Table 1.

Table 1 GTrans bus route characteristics

Bus Line	Distance (mi)		Stops		Terrain
	Eastbound	Westbound	Eastbound	Westbound	
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

3.2 Electric Bus Technology

Complete Coach Works (CCW) repowered the GTrans buses using their Zero Emission Propulsion System (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 does 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.

The approach that CCW used in this project is unique. Instead of building entirely new buses, CCW recycled older 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. The repowered buses were designed to meet GTrans's requirements in terms of power, durability, and performance. The end product is indistinguishable from a brand new bus, with an updated and modernized exterior and new and improved internal seating. See Figure 5, Figure 6, and Figure 7 below for photographs of the bus.

Figure 5 GTrans ZEPS bus, front view

Figure 6 GTrans ZEPS bus, side view

Figure 7 Left: GTrans ZEPS bus interior, facing forward, right: GTrans ZEPS bus interior, facing backward

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 kWh of energy storage capacity and an estimated operating range of 130 miles. Please see the full bus specifications in Table 2 below.

Table 2 Specifications for the buses after repowering by CCW

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

3.3 Electric Bus Charging

The ZEPS buses are recharged by three dedicated charging stations installed in three of the bus bays within the GTrans maintenance facility. The vehicle charge outlets supply an onboard charger with power and are rated at 45 kW while usually delivering an effective rate of 40-44 kW, meaning a bus at minimum charge could be completely charged in under 5 hours. Table 3 below shows specifications for the charging equipment.

Table 3 Specifications for the chargers used by the battery electric buses in this project

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

When the data collection period began in November 2016, only one charging point was installed. Only one bus, number 707, had been delivered at this point so the system was sufficient. By March 2017, all five buses had been delivered but there was still only a single vehicle charge outlet installed, meaning the five buses had to share the single charging point. Of course, each bus was limited in the amount it could drive each day because it would have to wait until the vehicle charge outlet was unoccupied to refill its battery. In October 2017, two additional vehicle charge outlets were installed, resulting in three in total. With three options in place, there was less competition for the vehicle charge outlet and keeping each bus's battery full became easier to manage. Figure 8 below shows all three vehicle charge outlets and their locations within the bus maintenance bays.

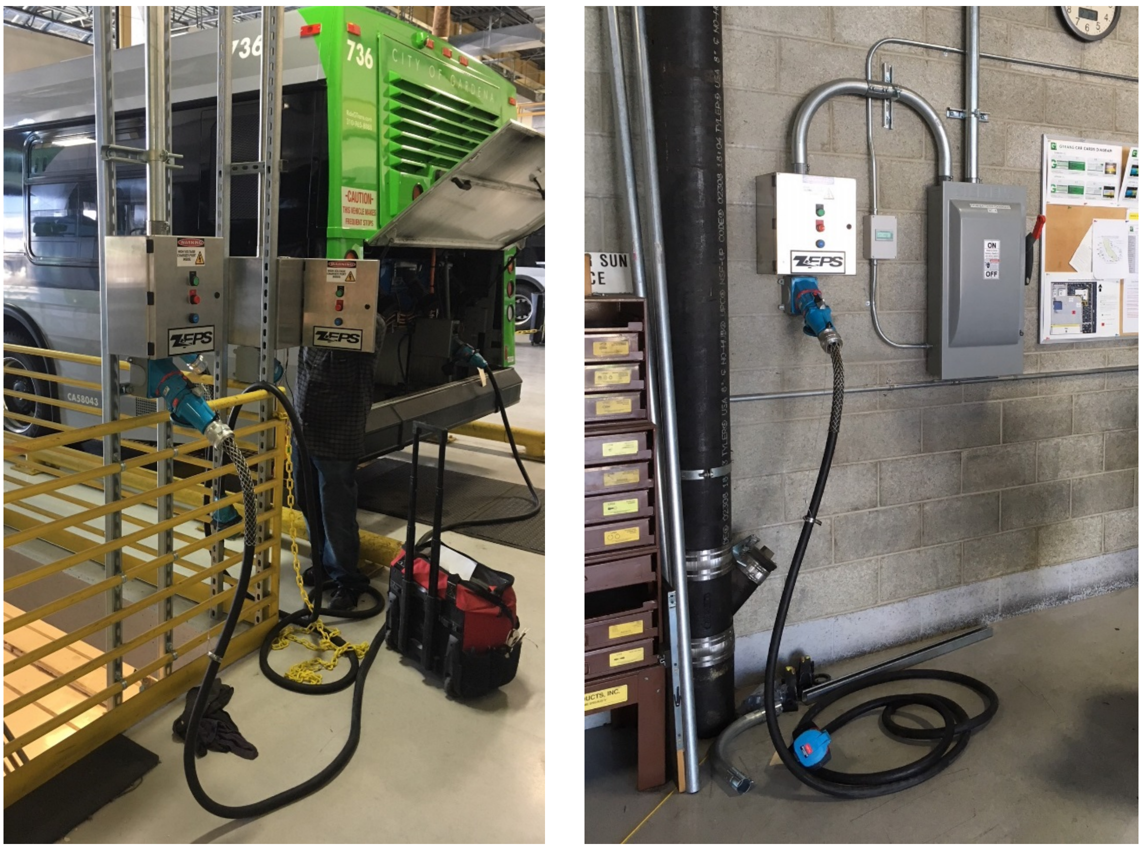

Figure 8 Left – New vehicle charge outlets for the ZEPS buses on the left and the original vehicle charge outlet on the right. Right – The third and final vehicle charge outlet.

The average length of each charge across the entire data collection period was close to 3 hours; just under 100 kWh of energy was delivered per charge on average. Charging generally occurred in two intervals – overnight and during the afternoon. Overnight charges generally ran from 7 PM to 1 or 2 AM. Afternoon charges lasted from roughly 10 AM to 2 PM.

4 Data Collection

4.1 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. The data was collected during the demonstration period, originally defined as 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 we worked with and how it was obtained.

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

4.2 In-use Performance Data

4.2.1 Performance Data Collection

Vehicle performance data was recorded directly from the onboard CAN bus. A data logging system was installed in each electric bus as it was deployed by GTrans. The data logger hardware, known as the DataHub, was provided by ViriCiti and is shown in Figure 9.

Figure 9 The ViriCiti DataHub, which is installed on each bus and connected to the vehicle's internal communication system via the onboard diagnostic port

The DataHub interprets the bus's signals to collect data in real time, on a second-by-second basis. This device features an 800 MHz processor with 1 GB of RAM and 8 GB of on-board memory. In addition to the data signals recorded directly from the vehicle's CAN bus, the DataHub reads GPS 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, or GSM) when needed, where it is stored. All data was protected via 2048-bit encryption to ensure that the information transfer process is safe. The on-board memory serves as back up storage in case data cannot be transmitted due to interference or poor reception. 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 can start being collected. All of the data was made accessible for monitoring the fleet as it moves around the city or for downloading via the online portal. Figure 10 below shows the ViriCiti online platform displaying the bus location and performance information in real time.

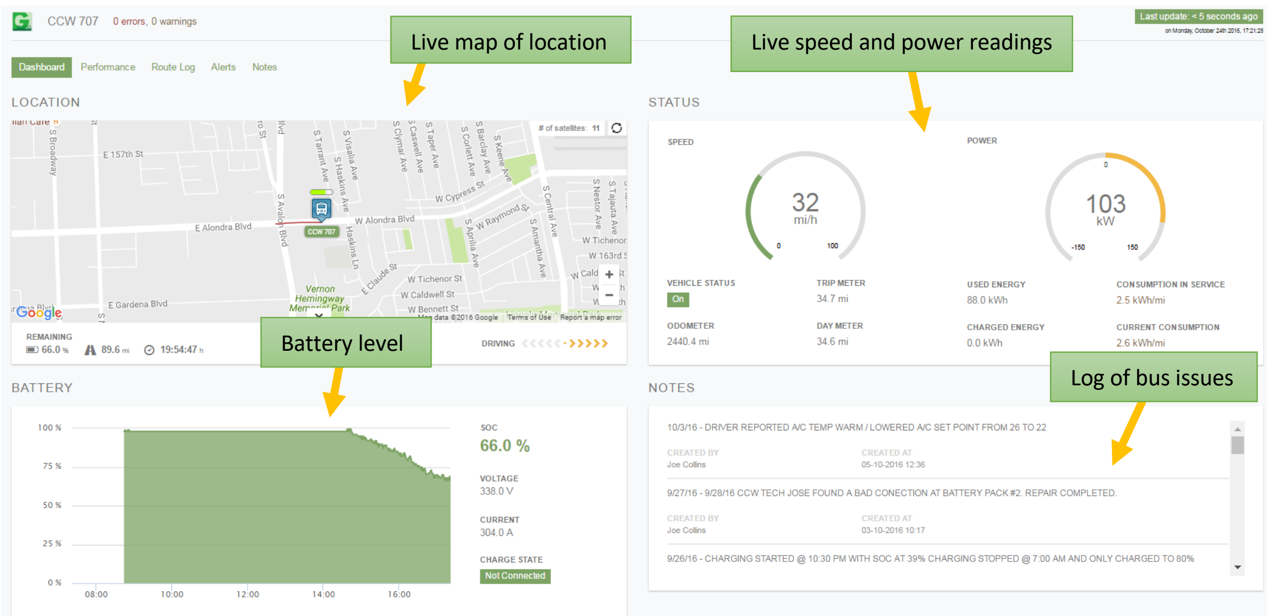

Figure 10 The ViriCiti online platform dashboard

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, SOC remaining, and other parameters. At a glance it is easy to spot any issues that may arise of confirm that operations are running smoothly. On other sections of the portal, data can be graphed and downloaded with user-defined parameter lists and over a variety of user-defined time intervals, 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 11 below shows an example of ViriCiti's charting tool, depicting the state of charge (SOC) used by each of the five battery electric buses over a 12-day period in May 2018.

Figure 11 Example of the data visualization feature of the ViriCiti online data platform showing the SOC used per day by each bus

While ViriCiti records and displays a wealth of information, it was necessary to export large volumes of data to perform our analyses independently and with the flexibility we 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: Parameter Definitions 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 used as 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, mileage data for conventional buses was collected from GTrans's records. 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, we 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's fueling records for comparison purposes as well. Fuel cost data from July 1, 2016 to June 30, 2017 was received and was also provided as total sums across that time frame. Average annual values were used 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.

4.2.2 Performance Data Processing and Challenges

New analysis projects often pose various challenges that must be overcome before a final dataset can be synthesized and analyzed. The data available had some limitations that 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, there were several difficulties that needed to be worked through. The ViriCiti support staff was helpful in addressing these issues as best they could, sometimes even introducing new features to their platform after we identified a need. It seemed that most of the challenges stemmed from the fact that the ViriCiti system was designed with a fleet manager in mind as the primary user. Thus, it is very simple and straightforward to monitor active buses in the field. However, until recently the feature that exports vehicle data was not designed to handle the volume of parameters or the timespan of data that we needed to work with.

It is crucial for the analysis that data be downloaded in tabular form and analyzed independently of the interactive system on the portal. Instead of trusting that the data presented by the portal was correct, we 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, we need to calculate parameters for ourselves so that we can be sure of exactly how the results are generated. Because ViriCiti is continually developing and improving their system, changes may be made in the future that alter how something is calculated or presented in the portal. 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. We also have more flexibility if we can work with the data directly because we can calculate and explore new metrics that are not built into ViriCiti by default. If we could only access the data through the portal, we would not be able to customize graphs and tables freely because we 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.

Whenever data collection is performed on a vehicle, validating the data is a crucial process. 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. Downloaded data was periodically validated 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. Bad or impossible data points were regularly found. When we 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 GPS 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 mi travelled in one day. Going through each parameter for each day of data on all five buses was not practical, so instead a series of filters were developed based on our observations of the data erroneously generated by the system and the buses’ normal behavior. These filters and their justifications are documented in

Table 5 below.

Table 5 Filters applied to the data 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 Driving	Less than 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	
Energy Idled	Less than 500 kWh	
Energy Regenerated	Less than 500 kWh	
Time Charging	Less than 24 hours	There are only 24 hours in a day
Time Driving	Less than 24 hours	
Time Idled	Less than 24 hours	
Time In Service	Less than 24 hours	
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

In addition to incorrect data that need to be removed, there was a fair amount of performance data from ViriCiti that was simply missing. In order to maximize the data we could work with, if a parameter was missing from a bus on a given day, we would label it as NA but still include in our dataset all other parameters that were recorded. Sometimes the reason a given parameter was not recorded is clear: if a bus was plugged in but not driven in a day, we would have data on charging time and energy charged but not distance travelled, for example. When data was missing that should have been recorded, 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 ViriCitit's system was updated and told where to find the new signal.

Another challenge was caused by the extended data collection period. Data collection was originally scheduled from November 1, 2016 to November 1, 2017. However, only one bus was delivered to GTrans by this beginning date. By March 2017, all five buses had been delivered and were beginning to be used daily by GTrans. Data collection began on each bus as it become operational within the GTrans fleet. The data collection timeline was extended to account for these delays, with a new end date of August 1, 2018, meaning the time period for data collection was extended by 9 months.

4.3 Operator and Bus Line Assignment Data

Operator data was provided by GTrans in the form of handwritten logs that recorded which operator was driving each ZEPS bus and what bus line they operated on. Sign in and sign out times were also recorded. This data was digitized and joined to the vehicle performance data. We 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 how many days of operation were recorded for each operator.

Table 6 Number of days for which each operator had a shift recorded and vehicle performance data was also recorded (only operators with 10 or more shifts recorded shown)

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

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. The number of days with data for each of the lines the ZEPS buses operated on is shown below in

Table 7.

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

4.4 Maintenance Data

Maintenance of the ZEPS buses was carried out by CCW as the buses were under warranty during the data collection period. GTrans provided maintenance records for any work that was 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 were completes, 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. These maintenance records were also provided for analysis in a similar format to the other records. New technology is expected 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.

5 Analysis

5.1 Performance Analysis

The large volume of data collected via the data loggers was analyzed to better understand how the electric buses operated as a new technology. In addition, more limited data on the conventional buses was compiled by GTrans so that performance of the electric buses could be compared to GTrans's standard bus, which is a gasoline-electric hybrid model. For the electric buses, we 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, the electric buses are compared to the conventional buses in terms of performance and per mile operating costs. Next, the performance of the electric buses is analyzed on a deeper level including calculating the emissions avoided and how efficiency changed over time and due to different factors. The charging behavior of the buses is analyzed with respect to the daily charging patterns that were recorded.

5.1.1 Comparison of ZEPS and Baseline Buses

The ZEPS buses were compared to the gasoline-hybrid buses that GTrans uses as the core bus in their fleet. First, the average miles driven for each bus was compared. 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's fleet over 2 years, from June 30, 2016 to June 30, 2018.

The average mileage across all of the buses in GTrans's 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). This was compared to the average of miles driven by all the ZEPS buses from March 2017 to July 2018. March 2017 to July 2018 was chosen 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

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

The conventional buses drove more miles per day than the electric buses. This difference could be due to the inclusion of all the conventional buses in the calculation which 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

[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.

pack, they would not all be able to fully charge by the next day's shift. The ZEPS buses are also sent 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, we 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 was used to calculate the result in Table 8. The result using this dataset is very similar Table 8, showing an average miles per day of 43.5.

In talks with GTrans, we 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% 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 the ZEPS buses would be called back to base after a given number of hours in the field. On hotter days, when the buses' HVAC systems were assumed to consume more of the battery pack, the buses were summoned back after a shorter time period in the field.

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

The average overall efficiency was calculated for both the conventional bus and the ZEPS Bus. We used fueling data logged by GTrans for the conventional bus. Like average miles driven per day, averages for fuel consumed were used across all 700-series buses in GTrans's fleet. The average overall efficiency for the ZEPS bus was calculated using averages across all ZEPS buses from March 2017 to July 2018. You 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	Conventional Bus	ZEPS Bus
Fuel Cost ($/mi)	$0.61	$0.30
Maintenance Cost ($/mi)	$0.68	$0.47
Total Cost ($/mi)	$1.29	$0.77

[8] Eudy, L., Prohaska, R., Kelly, K., & Post, M. *Foothill Transit Battery Electric Bus Demonstration Results*. January 2016. 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. https://www.afdc.energy.gov/data/10310. Accessed October 12, 2018.

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, fuel costs were averaged across all similar GTrans buses from July 1, 2016 through June 30, 2017. Electricity cost data for the ZEPS buses was obtained from utility data provided by GTrans. The fuel cost per mile was calculated using the average electricity rate per kWh from October 2016 to September 2018. The total cost per mile is 40% 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's records) but only for the data collection period when the ZEPS buses were active. The ZEPS buses' maintenance costs were also lower, about 31% less than the conventional buses. These savings may be partially due to the time when ZEPS buses were taken out of operation to be re-powered. Because the ZEPS buses were taken out of operation to be re-powered for some time, 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/mile, but a fuel cost of $0.57, leading to an overall cost of $0.83/mile which is slightly higher than what was calculated for this project[10]. In that same report, the conventional baseline maintenance cost for the diesel fleet was $0.46/mile while the fuel cost was $0.30/mile, for a total cost of $0.76 per mile. This result is almost identical to our result for the ZEPS buses but significantly cheaper than GTrans's conventional buses. See Figure 12 and Figure 13 below for a breakdown of average maintenance costs per bus.

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

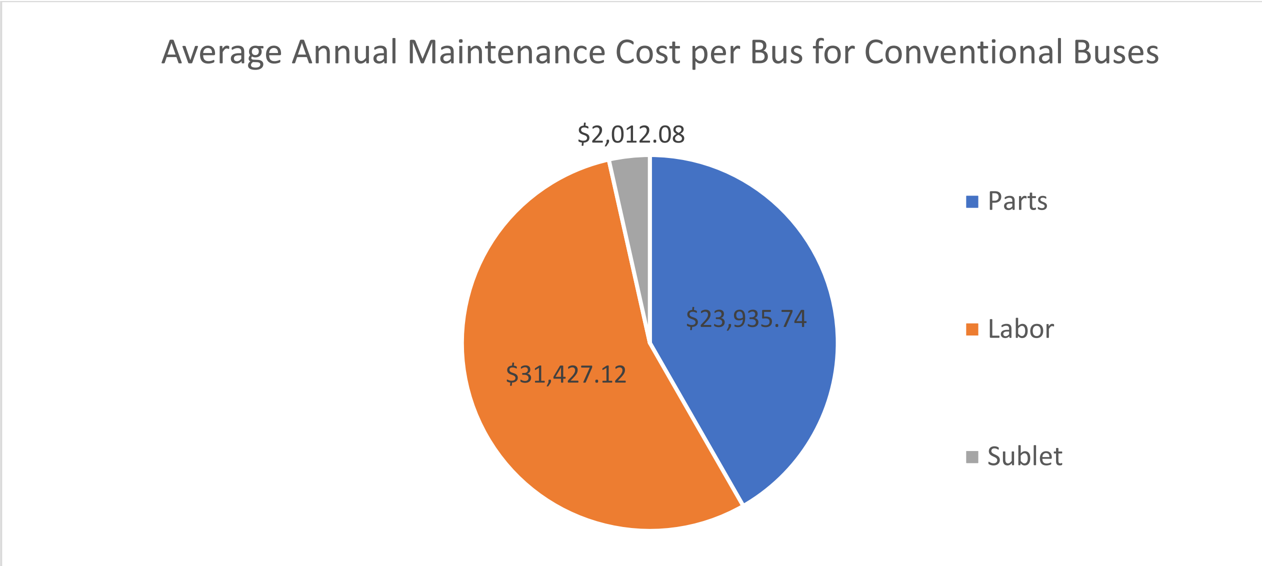

Figure 12 Average maintenance cost per bus breakdown for conventional buses

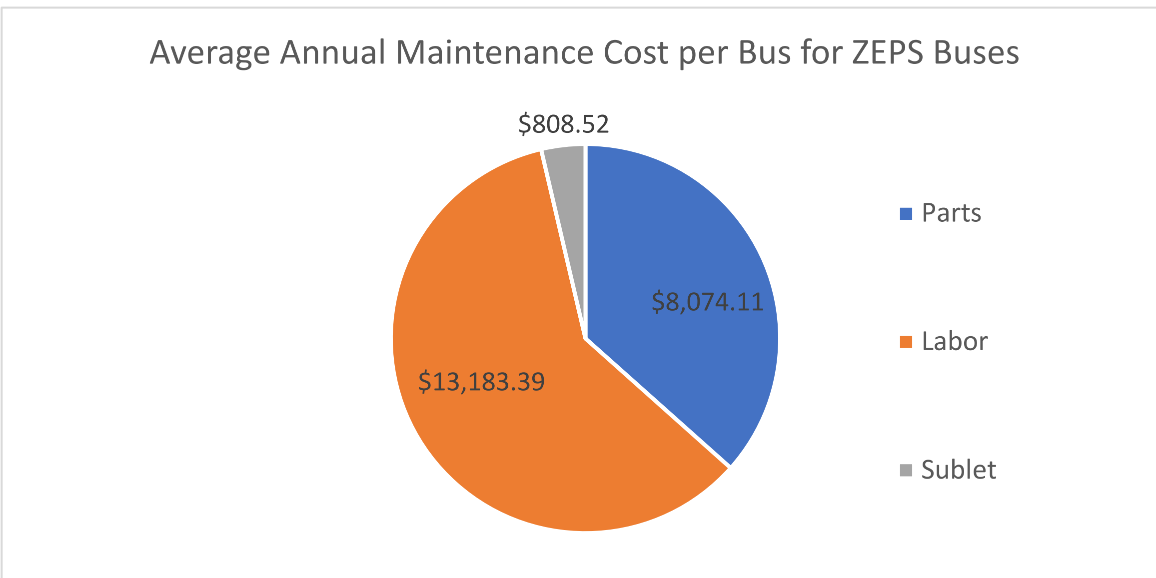

Figure 13 Average maintenance cost per bus breakdown for ZEPS buses

5.1.2 ZEB Performance Analysis

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 we analyzed the ZEPS buses in terms of distance travelled, active days, and efficiency, per bus line and operator. We were 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 14 below shows the cumulative mileage for each bus over the course of the data collection period.

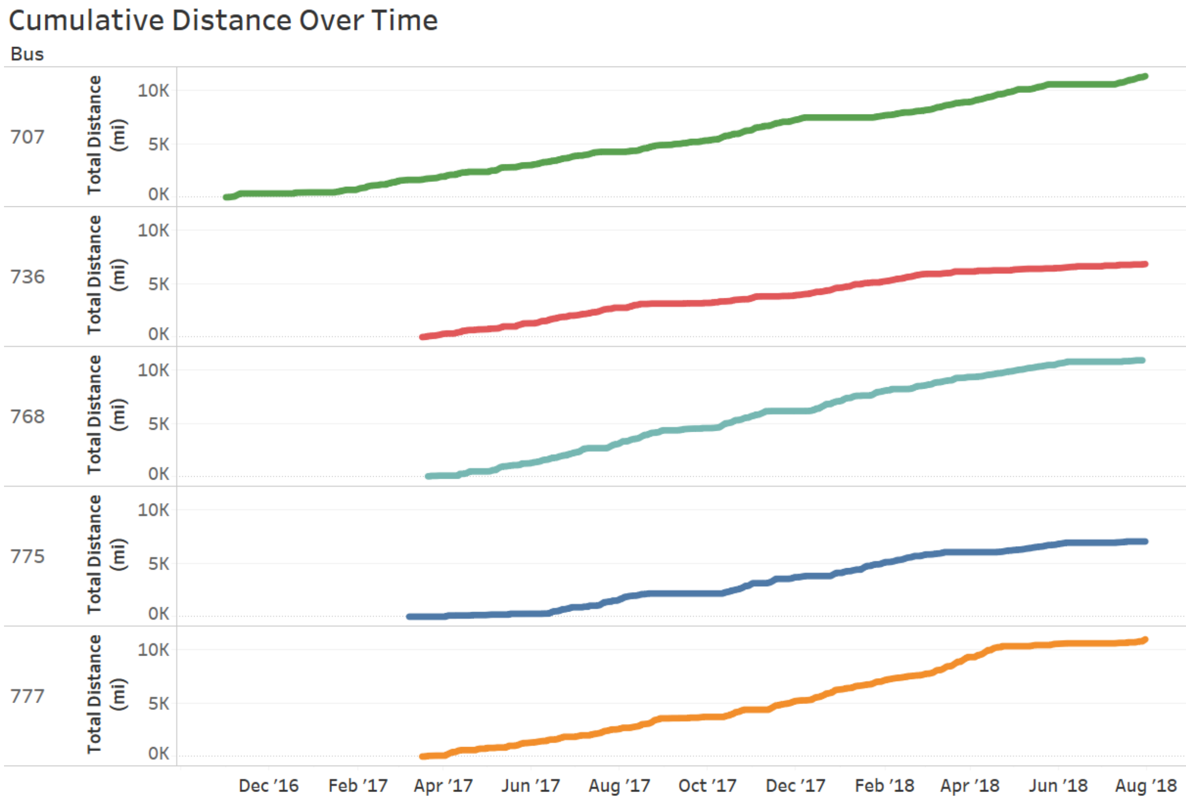

Figure 14 Cumulative distance over time for each of the battery electric buses

In Figure 14, 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 to be delivered and was put into service in November 2016. The other four ZEPS buses were delivered 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 reports the total mileage for each bus and the mileage per day with recorded data.

Table 10 Total 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
777	10,941.0	179	61.1

Major Finding 4: The total project mileage varied by over 65% and the average daily mileage varied by over 35% 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 buses 736 and 775 were driven 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 they seem to have been used more intensively, with 50.1 and 61.1 miles per day respectively compared with 45.1 miles per day from bus 707.

Figure 15 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 was recorded.

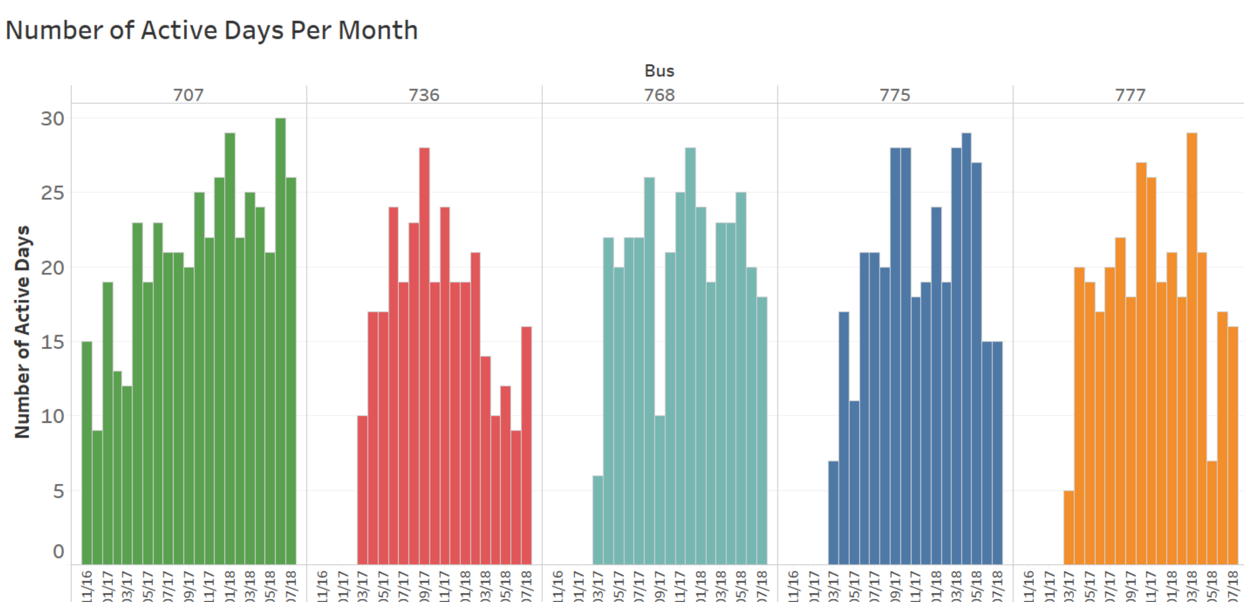

Figure 15 Active days each month for each electric bus

In general, the number of active days each month seems to strongly relate to the mileage in a given month, with dips in Figure 15 corresponding to flattening of the curves in Figure 14. Figure 16 below shows the frequency distribution of miles per day for each bus.

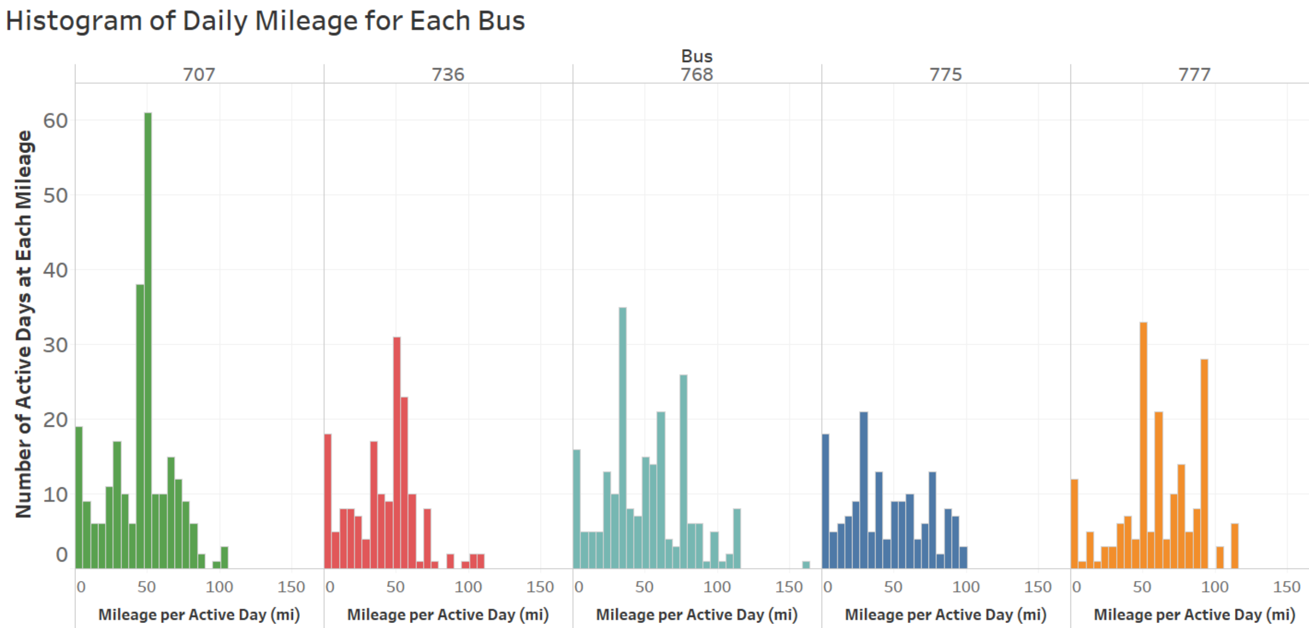

Figure 16 Histogram showing the number of active days for each bus by mileage

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 defined as 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, the buses were operated 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.

5.1.3 Fuel Use and Emissions Reductions

Use of the ZEPS buses also resulted in a significant displacement of fuel for GTrans. . Average annual gallons of fuel displaced was assumed 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, an average of 46,761.5 gallons of gasoline were displaced annually. This magnitude of avoided fuel use is equivalent to taking just under 90 average passenger vehicles off the road for each year these 5 buses remain in operation.

According to the fuel cost data provided on GTrans's buses, the average cost paid per one gallon of gasoline during this time period was $2.10. This value was calculated 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, it is estimated that the average annual fuel cost avoidance for one bus would be $19,639.83; when all ZEPS buses are aggregated, $98,199.15 are saved by the fleet in fuel costs per year.

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 replacing one conventional bus with one ZEPS bus

Average Fuel Consumption (gal)	Average Gasoline Cost ($/gal)	Average Annual Fuel Cost Avoidance per Bus ($)	Average Annual Fuel Cost Avoidance for 5 Buses ($)
9,352.3	$2.10	$19,639.83	$98,199.15

To calculate the displaced fuel, total fuel consumption for all of the buses in GTrans's fleet was averaged using the same data as in Table 13. Then, daily gallons were calculated by assuming that the buses operate 365 days per year. Average annual gallons of fuel displaced was assumed 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, an average of 46,761.5 gallons of gasoline were displaced annually. This magnitude of avoided fuel use is equivalent to taking just under 90 average passenger vehicles off the road for each year these 5 buses remain in operation[11].

According to the fuel cost data provided on GTrans's buses, the average cost paid per one gallon of gasoline during this time period was $2.10. This value was calculated 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, it is estimated that the average annual fuel cost avoidance for one bus would be $19,639.83; when all ZEPS buses are aggregated, $98,199.15 are saved by the fleet 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.

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		7.02561	221.21
VOC Exhaust		1.68671	53.11
VOC Evaporation		0.11613	3.66

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

SO_2		0.02050	0.65
PM_{10} Exhaust		0.01301	0.41
PM_{10} OC		0.00968	0.30
PM_{10} BC		0.00215	0.07
PM_{10} Sulfate		0.00019	0.01

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]. According to GTrans, the model year for each bus in their fleet ranges from 2005 to 2010. Thus, we calculated the average annual emissions avoided for each year from 2005 to 2010 and then we took the average of those model years for our 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. Average mileage per year for one bus was calculated by averaging the total miles driven from June 30, 2016 through June 30, 2018 for each bus in GTrans's fleet, as was the case in the performance analysis. The CO_2 emissions were calculated 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 by 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

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 are 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 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.

5.1.4 Efficiency Analysis

This project was interested in determining how operator training may affect the performance of the electric buses. A training program is being developed by the Southern California Regional Transit Training Consortium (SCRTTC), but the operators have not yet received this training. Nevertheless, there

[12] Cai, Burnham, and Wang. *Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET Using Moves*. September 2013. Accessed October 2018.
[13] U.S. Energy Information Administration. *How much carbon dioxide is produced from burning gasoline and diesel fuel?* April 25, 2017. https://www.eia.gov/tools/faqs/faq.php?id=307&t=11. Accessed October 2018.

could still be evidence of operator improvement over the course of the project. Electric vehicles drive differently than conventional vehicles; accelerating and braking have a different feel. During braking, energy is being regenerated and fed 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 it was speculated that there may 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, we would expect to see evidence of improvement in two key efficiency metrics over time: regeneration rate and efficiency overall. Regeneration rate is defined as the amount of energy that is 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).

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

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 17 below).

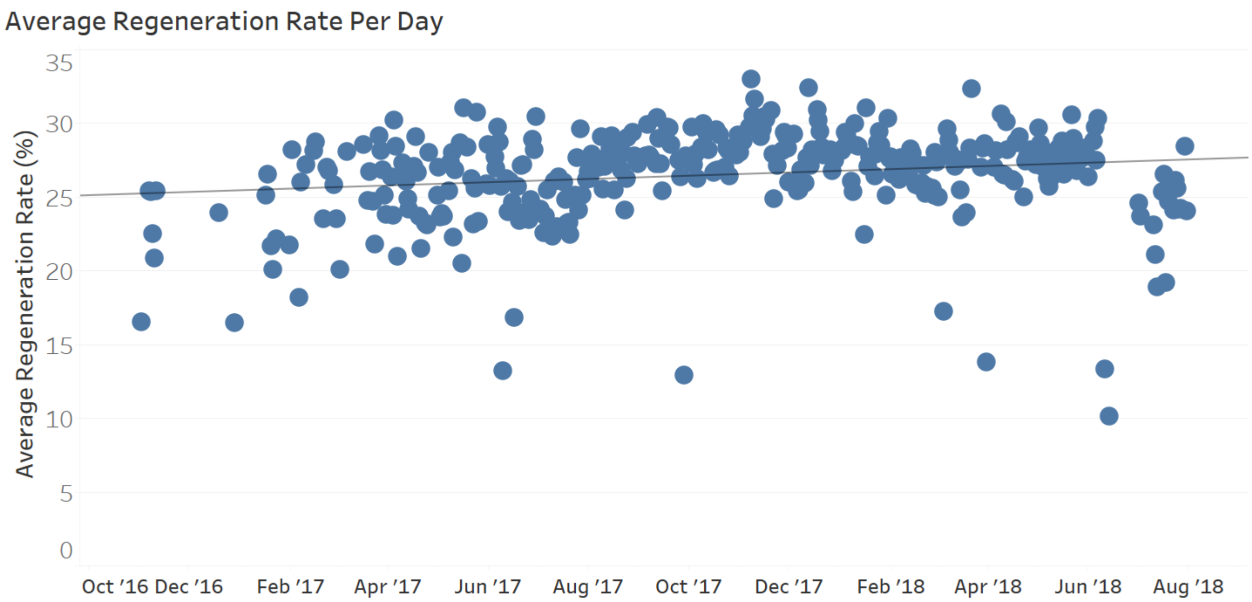

Figure 17 Average regeneration across all battery electric buses over time

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% in the first three months to 25.8% in the last three months, an improvement of 3.9%. 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 recorded 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 18.

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

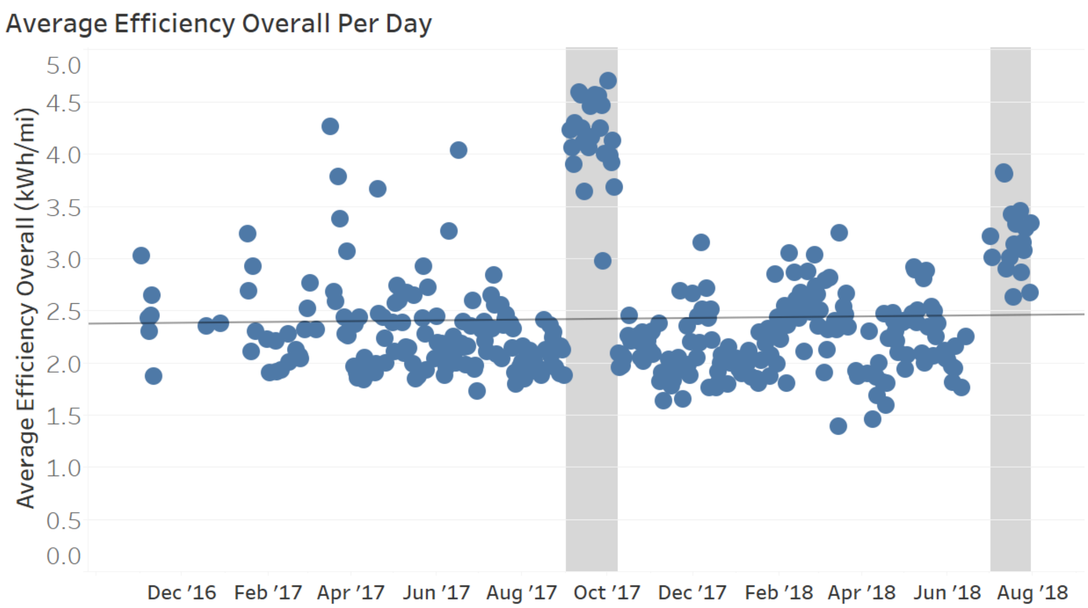

Figure 18 Average efficiency overall per day during the data collection period.

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 18). 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/mi and in July by 2.0 kWh/mi. Interestingly, we see 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 19, 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).

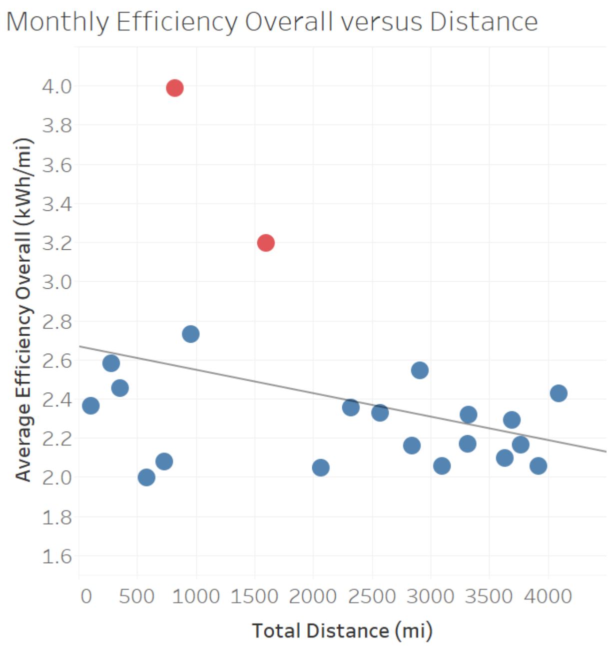

Figure 19 Average efficiency overall versus total distance for each month.

When the data from September 2017 and July 2018 is removed from the chart of overall efficiency over time, a distinct trend of improving efficiency over time emerges as shown in Figure 20.

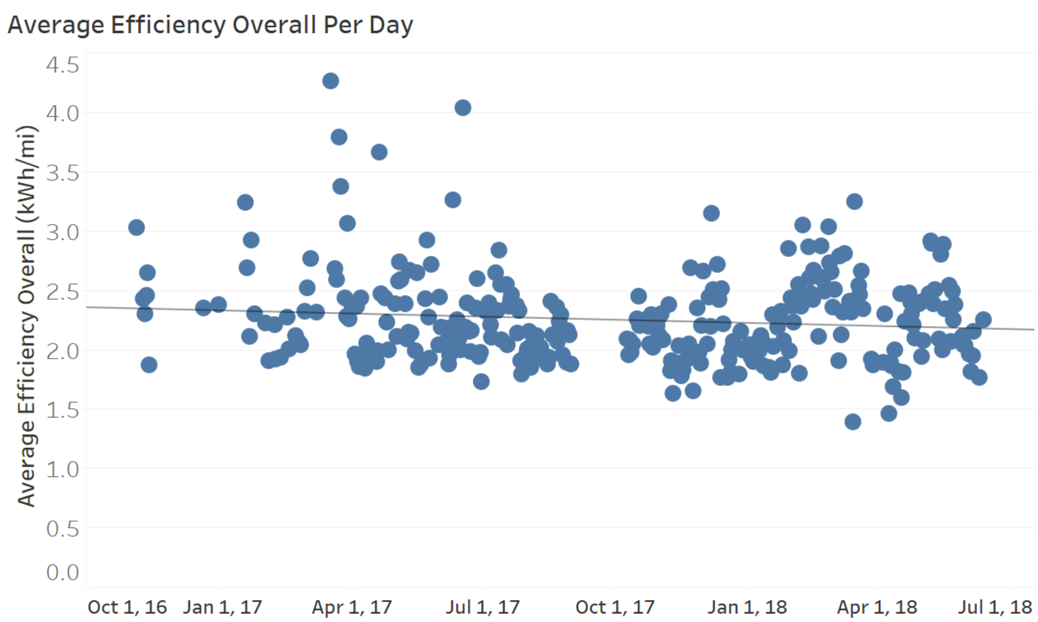

Figure 20 Average efficiency overall per day during the data collection period with outlying data from September 2017 and July 2018 removed. The trendline shows a linear regression.

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 are removed.

With the suspect data removed, the average overall efficiency improves from 2.5 kWh/mi to 2.2 kWh/mi from the first three months to the last three months of data collection. This modest improvement of 12% 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/mi and as good as 2.05 kWh/mi[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/mi which is slightly less efficient the range of efficiencies exhibited by the buses in this report.[10] A similar study with in-use data from the Foothill Transit Agency in Los Angeles County reported an overall efficiency of 2.16 kWh/mi, which also aligns with what we calculated for the ZEPS buses[8].

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, we see that there seems to be a maximum difference of 0.3 kWh per mile or 13% in overall efficiency and 0.2% 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

Bus Line 4 is slightly more efficient than the other two, but it is also underrepresented with very few service days so the metrics should not be thought of as definitive for this route. Efficiency by operator is shown in Table 15 below.

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

Table 15 Bus use 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

Major Finding 8: 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.

All operators with more than 10 service days of data are shown. Using GTrans operator records dating from March 2017 onward, we were able to match 384 operator shifts to days where we had complete bus data. It appears there is a moderate range in operator performance in terms of efficiency. However, we can only compare operators who drove the same route. Factors unique to each line could influence efficiency and we want to be sure that to the best of our abilities we are holding other variables constant and only comparing operators. Unfortunately, this limits our comparison to operators who primarily drove line 3 because so few days were spent on the other two routes. Comparing operators 1-5, 7, 9, and 10, average overall efficiency differs by about 17% or 0.4 kWh/mi 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, a test must be designed to specifically measure the effect of operators on efficiency in order to reach more conclusive results.

5.2 Charging Analysis

Along with performance and efficiency, it is also important to understand charging patterns for the ZEPS bus. To understand how the buses charged and how this impacted GTrans's operations, this section shows results for various charging metrics across all ZEPS buses.

5.2.1 Energy Charged

In this demonstration each bus on average charged 82.4 kWh per day, was plugged into a vehicle charge outlet for 2.8 hours per day, used 35.7% of its battery charge while driving per day, and regenerated

35.2 kWh per day. In general, the buses tended to charge most overnight and mid-day. As GTrans's only had three depot vehicle charge outlets for five electric buses, charging was cycled as needed to meet daily operational requirements. Figure 21 shows the average energy charged per day for each ZEPS bus. Note that Figure 21 through Figure 26 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.

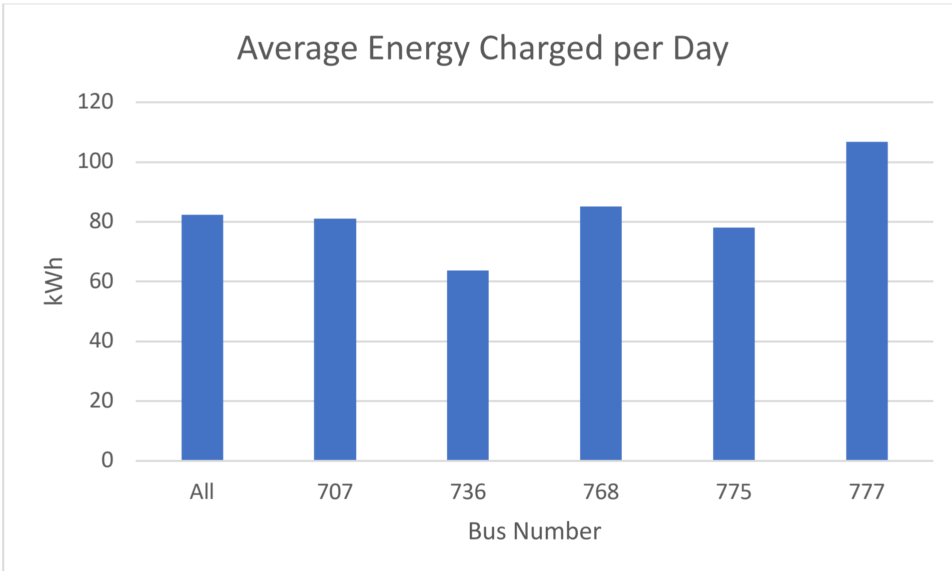

Figure 21 Average energy charged per day for each electric bus in kWh

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 bus 777 was utilized 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 the buses were dispatched 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, we 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 22 shows how the correlations compare.

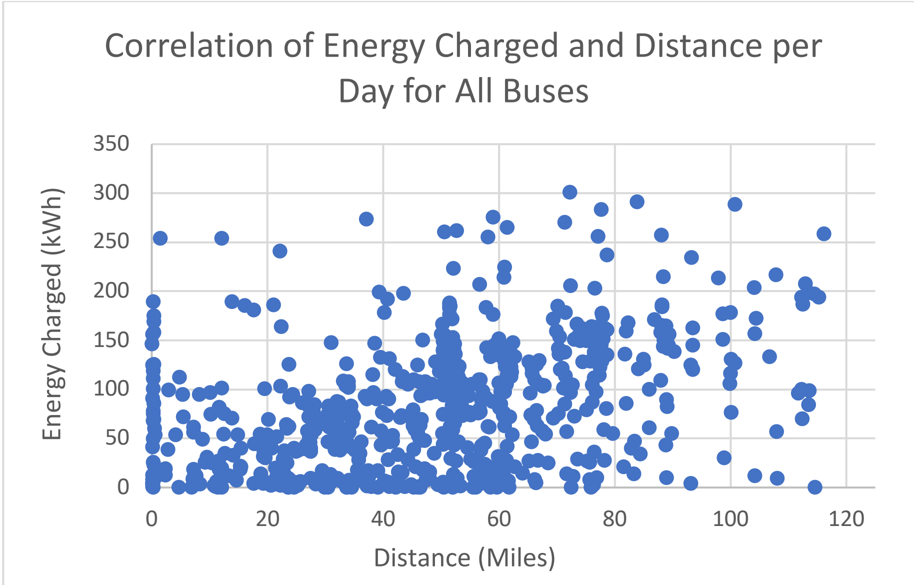

Figure 22 Correlation of energy charged and distance per day for all buses

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. It is expected 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 only be plugged in to charge after midnight.

Figure 23 shows the average state-of-charge (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.

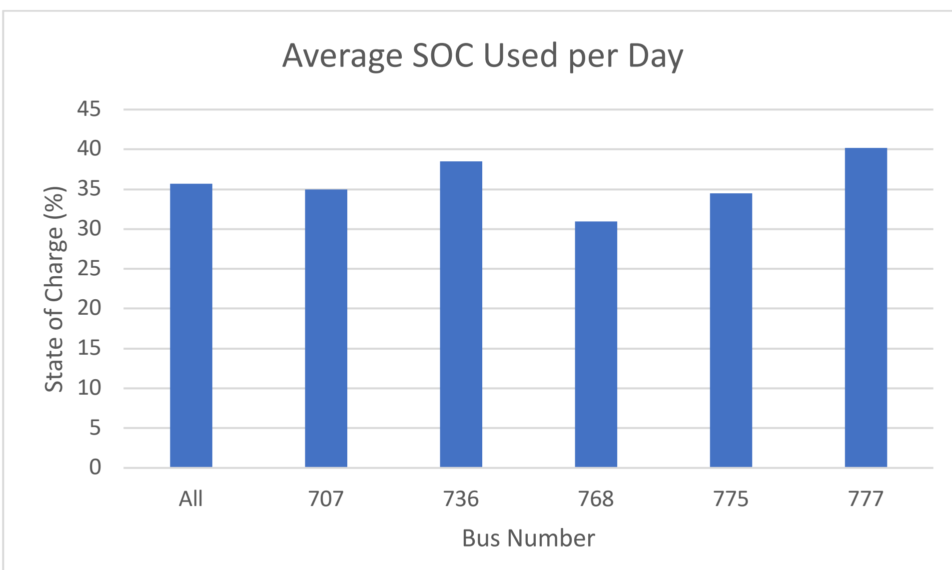

Figure 23 Average state-of-charge used per day for each electric bus in % of battery energy capacity

All buses' use of SOC per day ranges in between 30% of battery capacity and 40% 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%. 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% 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 the buses were driven in a highly conservative manner, and could be driven more per day as, on average, about 64% of the battery's charge remained at the end of service each day.

Figure 24 shows the average charge time per day in hours for each bus.

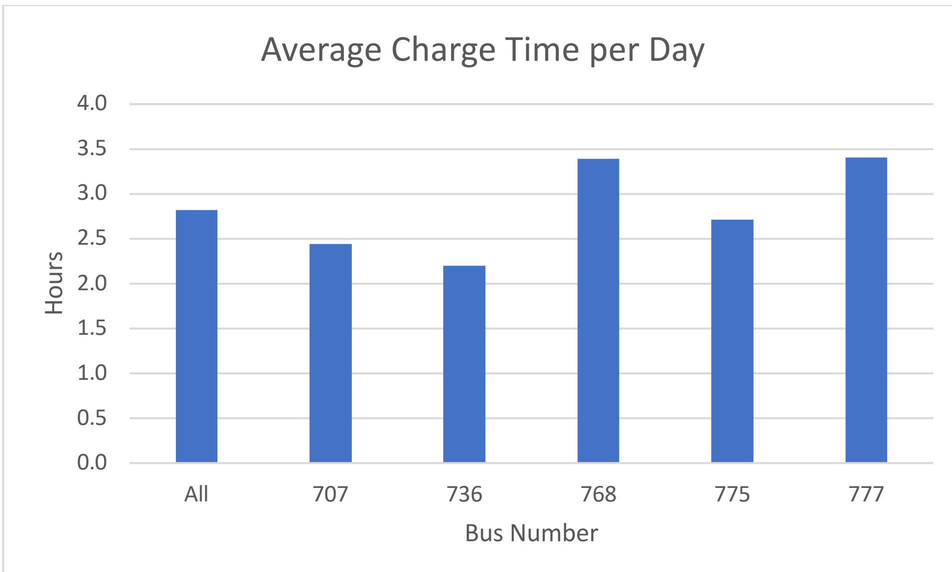

Figure 24 Average charge time per day for each electric bus in hours

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 21. This makes sense as you 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 us to identify any inconsistencies in charging infrastructure or bus manufacture which may play a role in the buses receiving more or less electricity at a constant rate. Using values from Figure 21 and Figure 24 it is clear that the charging rate varied slightly by bus.

Figure 25 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.

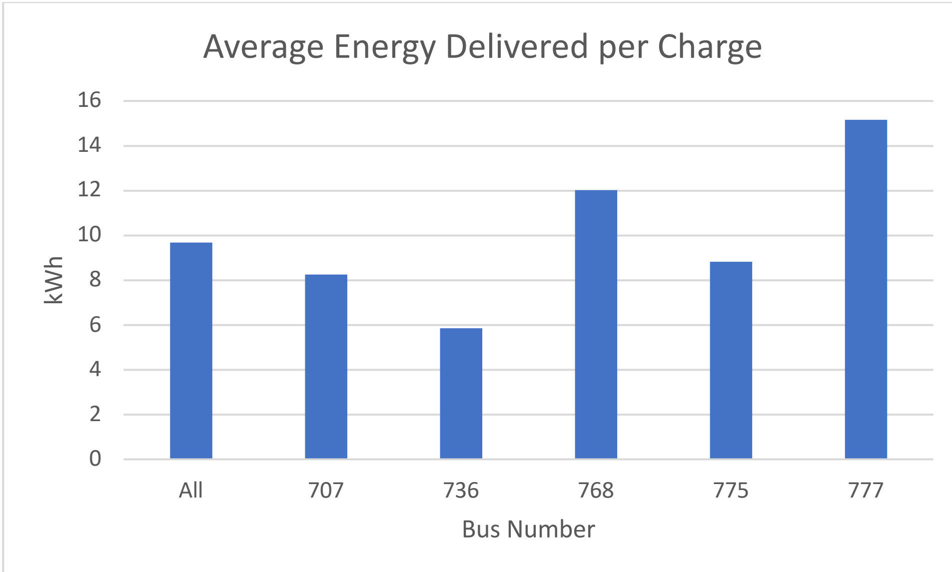

Figure 25 Average energy delivered per charge for each bus

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 24, 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 26 shows the average energy regenerated per day for each bus and as an average across all buses.

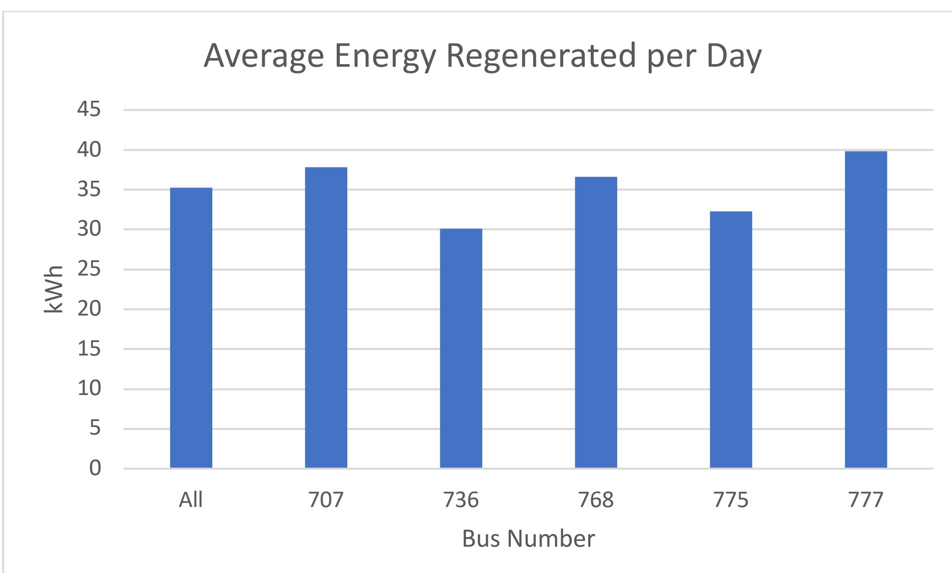

Figure 26 Average energy regenerated per day

Energy regenerated is expressed in kilowatt-hours. The average energy regenerated per day is fairly consistent across all the buses, with 777 regenerating the most at 39.8 kWh and 736 the least at 30.1 kWh. The average across all buses is 35.2 kWh.

5.2.2 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 kilowatt-hour. 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.

Figure 27 show the frequency of times when each bus was undergoing a charge event each day.

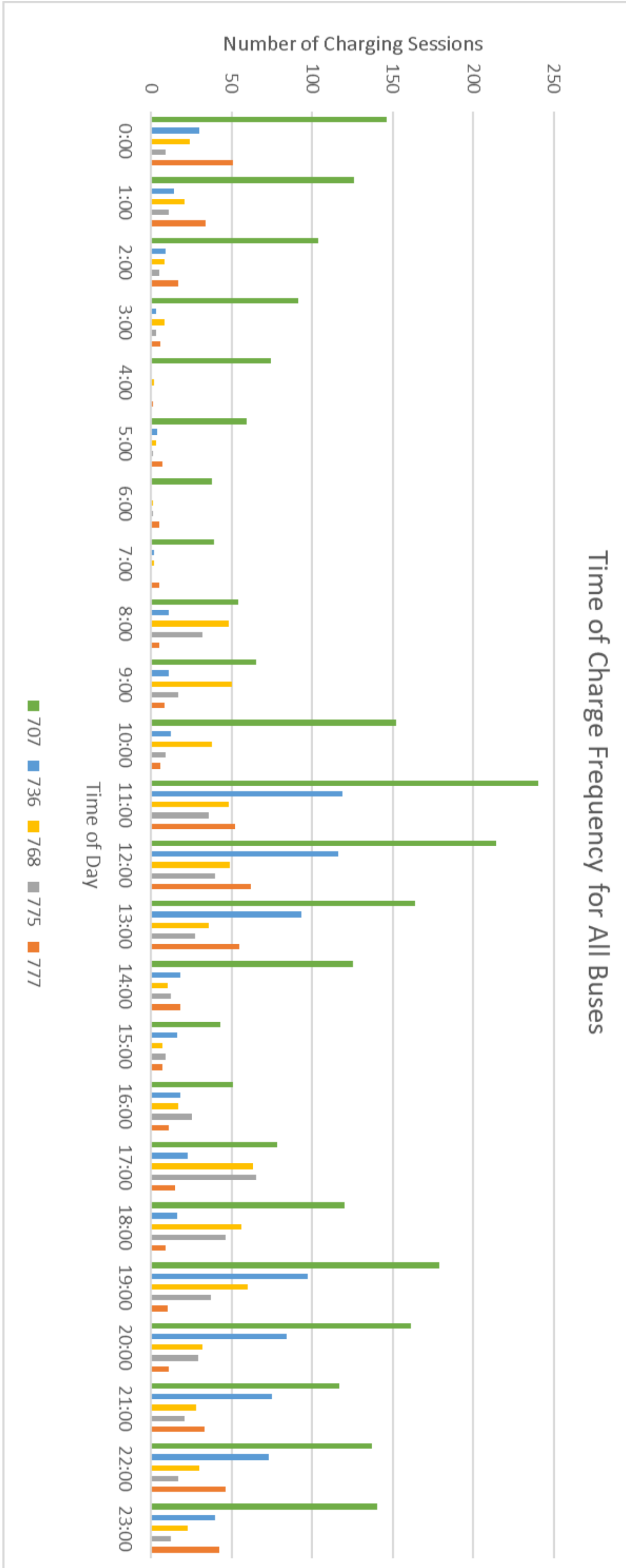

Figure 27 Frequency of charging times for all buses

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

The frequency of charging in each hour was calculated 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% at 10:00 and 71% at 11:00, then the vehicle was considered to be charging. The frequency of charging by hour was counted and displayed in the figures below, showing how often each vehicle was charging at each hour throughout the day across the timespan of the demonstration.

All buses had similar charging patterns, charging most frequently mid-day and at night. For ease of viewing, Figure 27 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 the way each bus was operated varied. Buses 777 and 736 were consistently the highest rank and lowest rank in many of these metrics, respectively. This means that bus 777 tended to be operated more intensively while 736 was operated 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.

6 Summary and Conclusions

Maximizing the mileage of newly adopted electric buses requires increased operational efforts in addition to detailed planning to ensure success. The results of this project should be instructive. 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, the electric buses were not pushed 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 needed to be placed on the buses 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.

Charging infrastructure will need to be added as more electric buses are acquired. 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 mean at least three more were added to the facility's infrastructure before the goal of a 20% electric fleet was reached. 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, 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 if the buses in this project were not operated at their maximum potential range, there were multiple benefits experienced by the fleet. The fuel and maintenance savings experienced by the buses were significant. Over our 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% electric would increase the value of these benefits to a savings of 102,875 gallons of gasoline and $216,038 annually. If other trends we 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 operational practices that could be changed 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 how buses are currently managed 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 driver performance. It was difficult to discern any real differences bet ween drivers 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. 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 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% and the average daily mileage varied by over 35% between individual ZEPS buses.
The ZEPS buses drove shorter distances per day on average.
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.

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

Appendix B: Bus Summary Data Tables

Table 18 Vehicle usage parameters, bus 707

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			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[15]	NA[15]	35:52:45	463.0	30.9	15	NA[15]
Mar. '18	NA[15]	NA[15]	58:35:34	782.3	41.2	19	NA[15]
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[15]	NA[15]	NA[15]	NA[15]	NA[15]	NA[15]	NA[15]
July '18	109:57:14	59:39:17	339:03:02	766.2	51.1	15	7.0

[15] No data recorded this month.

Table 19 Electrical vehicle usage parameters, bus 707

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/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[16]	NA[16]	1,106.2	NA[16]	NA[16]	34:35:24	NA[16]
Mar. '18	NA[16]	3,221.6	NA[16]	NA[16]	1,901.3	NA[16]	NA[16]	64:54:29	NA[16]
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[16]	NA[16]	NA[16]	NA[16]	NA[16]	NA[16]	NA[16]	NA[16]	NA[16]
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

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

Table 20 Vehicle usage parameters, bus 736

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			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

Table 21 Electrical vehicle usage parameters, bus 736

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/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	3.317	3.717	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

[17] 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

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**			**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[18]	NA[18]	17:59:54	201.3	33.5	6	NA[18]
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

[18] No data recorded this month.

Table 23 Electrical vehicle usage parameters, bus 768

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/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[19]	925.6	NA[19]	NA[19]	354.8	NA[19]	4.6[20]	9:17:02	NA[19]
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

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

Table 24 Vehicle usage parameters, bus 775

Bus 775							
Month	Time in Service	Time Driving	Time Idled	Mileage	Miles per Day (in service)	Days in Service	Average Speed
Unit	HH:MM:SS			mi		Days	MPH
Mar. ‘17	1:14:34	00:21:11	9:58:04	3.3	1.7	2	8.6
Apr. ‘17	19:14:36	11:10:23	24:10:43	150.5	25.1	6	13.8
May ‘17	12:36:22	6:59:50	89:10:17	122.8	30.7	4	13.2
June ‘17	55:06:38	29:41:40	314:20:58	605.9	50.5	12	12.8
July ‘17	52:03:30	28:16:47	275:37:28	674.7	67.5	10	13.3
Aug. ‘17	48:07:51	25:37:55	230:18:47	608.8	67.6	9	13.0
Sep. ‘17	NA[21]	NA[21]	NA[21]	NA[21]	NA[21]	NA[21]	NA[21]
Oct. ‘17	75:19:49	40:08:06	280:06:33	889.2	63.5	14	12.0
Nov. ‘17	54:31:09	28:47:48	266:47:14	634.5	52.9	12	11.9
Dec. ‘17	38:31:47	21:32:05	234:44:53	403.3	50.4	8	12.1
Jan. ‘18	81:55:25	55:29:51	204:14:08	968.9	57.0	17	11.9
Feb. ‘18	63:19:27	53:24:51	10:36:08	728.5	42.9	17	11.6
Mar. ‘18	20:32:00	17:08:32	3:28:49	236.6	23.7	10	11.6
Apr. ‘18	20:23:44	12:10:42	95:12:57	180.2	25.7	7	8.8
May ‘18	68:54:46	35:35:51	390:22:17	561.4	25.5	22	8.5
June ‘18	18:09:06	5:58:03	317:14:53	139.6	34.9	4	7.7
July ‘18	105:54:49	6:03:41	317:15:60	114.6	22.9	5	12.4

[21] No data recorded this month.

Table 25 Electrical vehicle usage parameters, bus 775

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/mi		HH:MM:SS	%
Mar. '17	6.9	24.1	2.7	8.2	168.0	6.9	24.1	2:42:02	NA[22]
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[22]	NA[22]	NA[22]	NA[22]	722.0	NA[22]	4.6[23]	30:39:49	NA[22]
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

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

Table 26 Vehicle usage parameters, bus 777

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**			**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[24]	NA[24]	11:36:41	138.1	23.0	6	NA[24]
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[24]	NA[24]	NA[24]	1,645.5	74.8	22	NA[24]
Apr. '18	NA[24]	NA[24]	10:22:31	1,017.4	78.3	13	NA[24]
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

[24] No data recorded this month.

Table 27 Electrical vehicle usage parameters, bus 777

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/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[25]	641.2	NA[25]	NA[25]	484.3	NA[25]	NA[25]	9:56:42	NA[25]
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[25]	NA[25]	NA[25]	NA[25]	NA[25]	NA[25]	NA[25]	NA[25]	NA[25]
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

[25] No data recorded this month.