marin transit

711 grand ave, #110
san rafael, ca 94901

ph: 415.226.0855
fax: 415.226.0856
marintransit.org

October 5, 2020

Honorable Board of Directors
Marin County Transit District
3501 Civic Center Drive
San Rafael, CA 94903

SUBJECT: Electric Bus Pilot Project Results and Analysis

Dear Board Members:

RECOMMENDATION: Accept report.

SUMMARY:
On November 21, 2016, your Board approved the purchase of two BYD Battery Electric Buses for a pilot project for Marin Transit staff and contractors to gain experience with this developing technology. Though the buses arrived in late September 2018, the buses were not put in service until July 2019 due to manufacturing issues. This report focuses on the performance of the two electric buses from July 1, 2019 to June 30, 2020 towards meeting the goals of the pilot program. These include performance metrics, reliability, cost, and scalability.

BACKGROUND: The two BYD buses are maintained and operated by Golden Gate Transit. Each vehicle was initially scheduled for no more than 80 miles per day to ensure they operated within the identified maximum vehicle range. Experience quickly indicated that the vehicles could travel farther. The vehicles operated on routes and “work blocks,” or vehicle assignments, as specified by Marin Transit and scheduled by Golden Gate Transit. Generally, they were scheduled during peak hours for a morning and/or an afternoon shift. The vehicles mostly operated on Routes 23X/29 and traveled within Central Marin at relatively low speeds. The vehicles also operated on Routes 17, 23, and 71X, with higher service speeds and longer distances. These routes operate on a relatively flat terrain.

Staff used an onboard monitoring software, Viriciti, to collect the data used in this report. Golden Gate Transit staff provided maintenance and energy cost data.

Route Profiles
The vehicles most frequently operated in service on Routes 23, 23X and 29. These routes have an elevation change of 96 meters. Average speed on these routes is around 16 mph. Staff expected that these routes would support the best performance due to lower speeds, and more stopping that allows for regenerative braking.

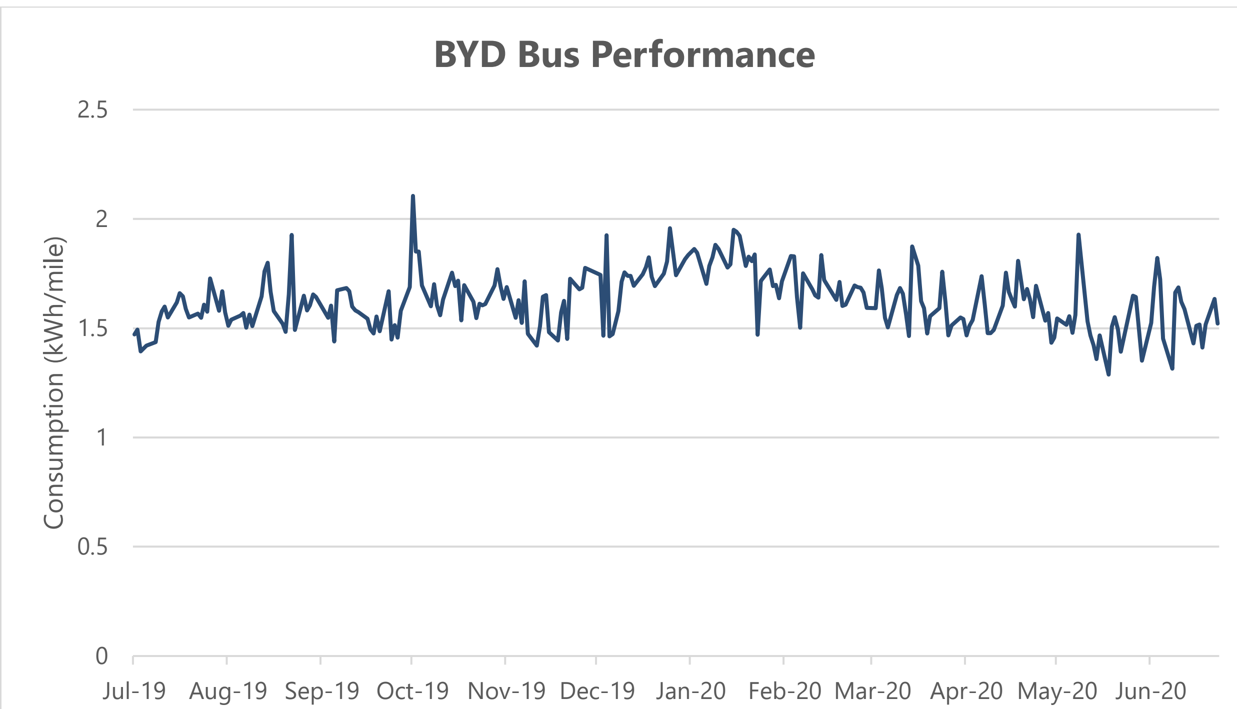
Route 17 extends from San Rafael to Sausalito through Mill Valley. This is the flattest route that the buses travel with an elevation change of 60 meters. Average speed on this route is 19 mph.

Route 71X is an express route that provides service between Novato and Sausalito. This route travels the highest speeds at up to 60 mph on US Highway 101 and averages 30 mph over the course of the trip. The 71X is also relatively flat with a total elevation change of about 80 meters. Staff anticipated that this route would have the worst performance due to the higher speeds and fewer number of stops to recover energy through regenerative braking.

Maps for each of these routes are included as an attachment to this report.

PERFORMANCE: Marin Transit evaluated several factors to identify their impact on the performance of the buses. For this study, performance is measured by the consumption of energy used to travel a mile. Unless specified, staff combined data for both buses for this analysis. The average performance of the buses for the period is shown in Figure 1 below. When the bus consumes less energy, that indicates that is traveling more efficiently. Higher energy consumption indicates less efficiency. The average vehicle performance was 1.63kWh/mile, giving the vehicles a theoretical range of 133 miles assuming usage of 80% of the battery capacity. In comparison, the vehicle manufacture advertised a range for the vehicles of 145 miles.

Figure 1 – Bus Performance

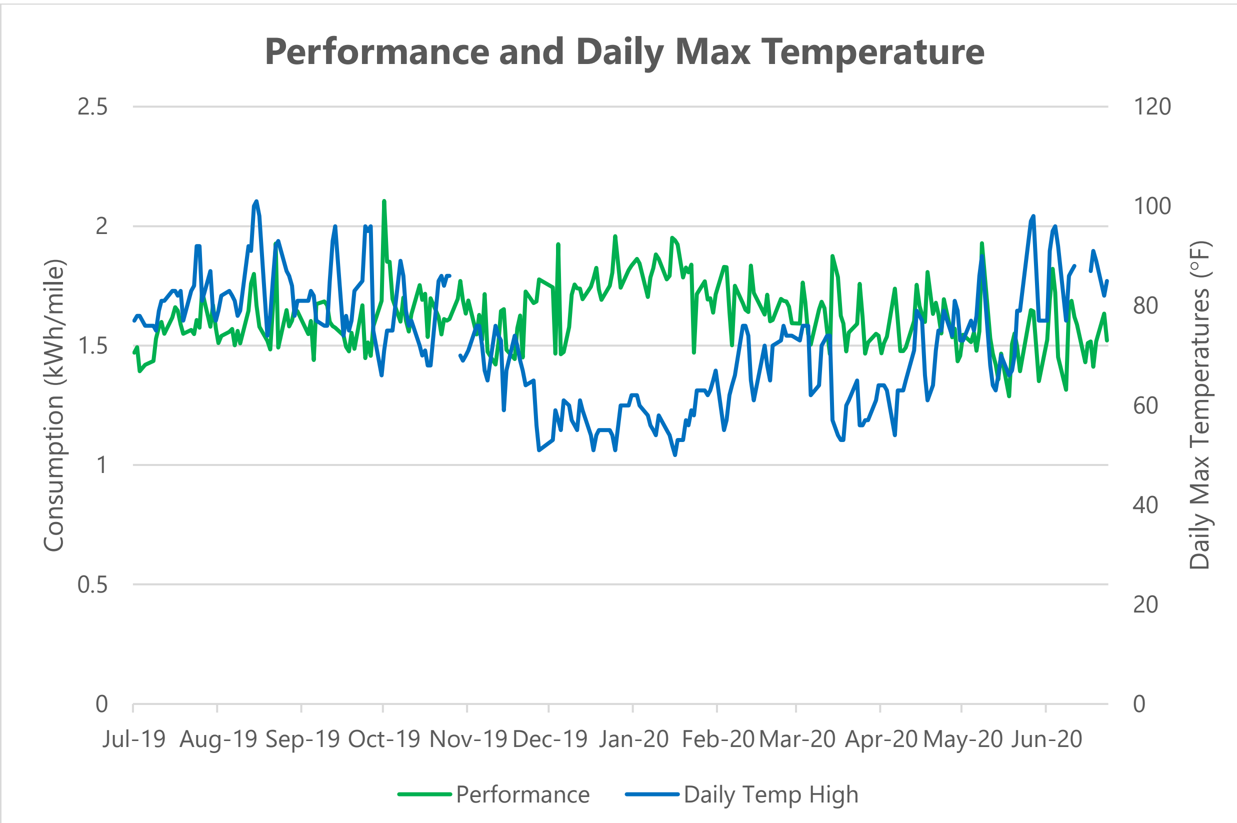


Temperature

HVAC systems such as heating and air conditioning impact the performance of battery electric buses due to the additional energy they require. To analyze HVAC impacts, staff used average daily consumption in kWh per mile compared to daily temperature highs (Figure 2). Staff expected that higher summer temperatures will lower energy consumption and improve performance because the heater would not be in use. When graphed, this result would provide a mirror image of daily temperature highs and consumption per mile. Figure 2 shows this relationship from December 2019 to April 2020, the coldest months of the year. The rest of the year, the opposite appears to be true. This is likely due to the impact of the air conditioner on the battery.

Over the coldest months, heater use appears to reduce efficiency by 0.09kWh or approximately seven miles per charge.

Figure 2 – Performance vs. Daily Max Temperature

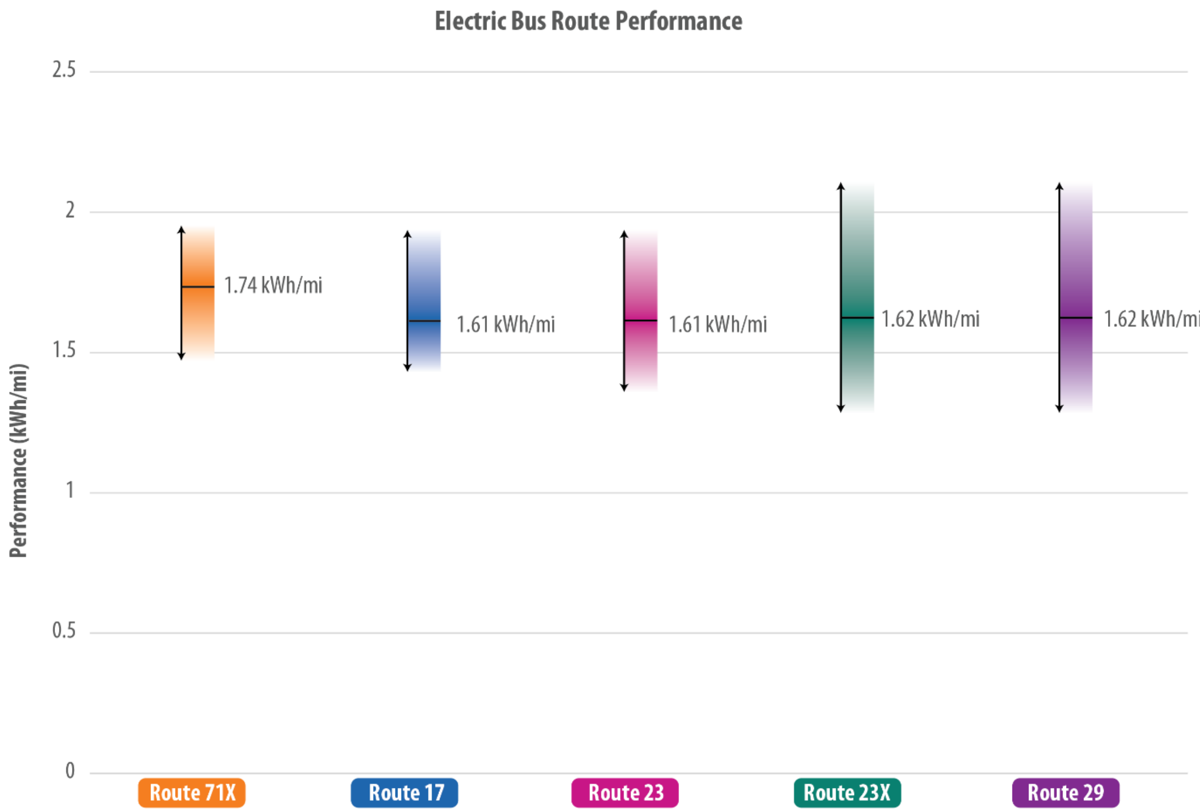


Speed and Elevation
Staff found that speed and elevation do not significantly impact performance. The pilot project included routes with limited elevation changes. Therefore, the pilot was not a good test of elevation impacts on every efficiency. During the pilot, speed did vary between highway and neighborhood operations. However, no relationship was found between average speed and power consumption. Initial findings related to speed and elevation indicate that acceleration and road incline may have more significant impacts on vehicle performance than speed and elevation. Staff need additional data to confirm this finding.

Routing
The black horizontal line in Figure 3 below shows the average performance of the buses on different routes. The arrows extend to the minimum and maximum performance noted during the period of study.

The buses primarily traveled on Routes 23X and 29 in a combined vehicle work block. While the average is very similar to performance on Routes 23 and 17, the 23X and 29 combination resulted in the widest range in vehicle performance. Route 71X has the highest consumption rate average at 1.74 kWh/mile. This matches staff predictions that the vehicles would have the poorest performance on the 71X. However, the wide range of energy consumption patterns on Routes 23X and 29 indicate that there are additional factors influencing performance.

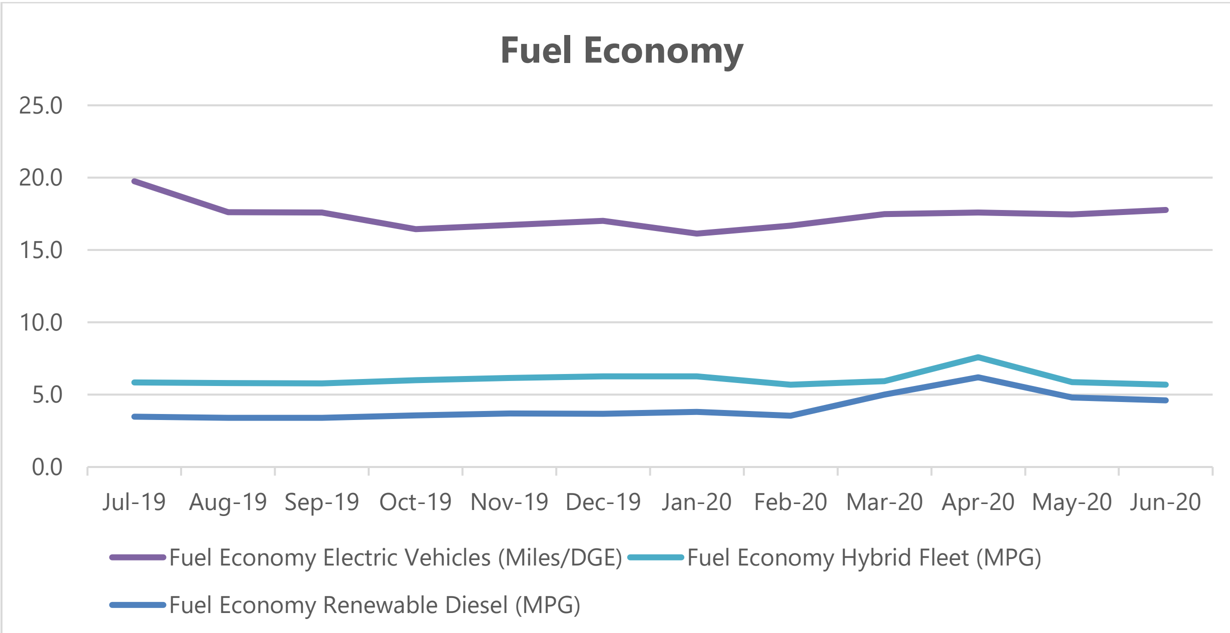
Figure 3 – Performance vs. Vehicle Routing



Vehicle Operator
The bus industry acknowledges that the vehicle operator has an impact on battery electric bus performance. However, Marin Transit was not able to analyze this impact due to the nature of its agreement with Golden Gate Transit. Over time the vehicles had relatively stable consumption rates. This indicates that changes in drivers did not have a noticeable impact on bus performance though staff hopes to track this variable in the future.

Fuel Economy
Staff compared the performance of the BYD buses to the District's diesel and hybrid fleet to identify the relative performance and efficiency of the different bus technologies. As shown in Figure 4, staff converted the BYD fleet fuel economy to a miles per diesel gallon equivalent. Staff plotted this against the miles per gallon for the hybrid and diesel fleets. The battery electric bus fleet had a consistently higher fuel economy than the diesel or hybrid fleets. This indicates that BYD electric buses uses energy more efficiently.

Figure 4 – Fuel Economy



Reliability
Reliability is measured by how often the bus is available for service and how many road calls the vehicle required.

Though BYD delivered the two buses in September 2018, it was almost a year before Marin Transit operated the buses in regular service. This was primarily due to manufacturing issues. The buses were missing passenger heating units, and the manufacturer delayed delivery of required training, vehicle manuals, and diagnostic software.

Neither BYD bus required road calls during the year. They were held back from service for regular maintenance, inspections, and for delays in getting a replacement when a mirror was broken on one of the buses. There were a few incidents when the bus pulled out in the morning on one block of work and did not have enough range to do another block of work in the afternoon. This was due to more energy used on the first block than was anticipated.

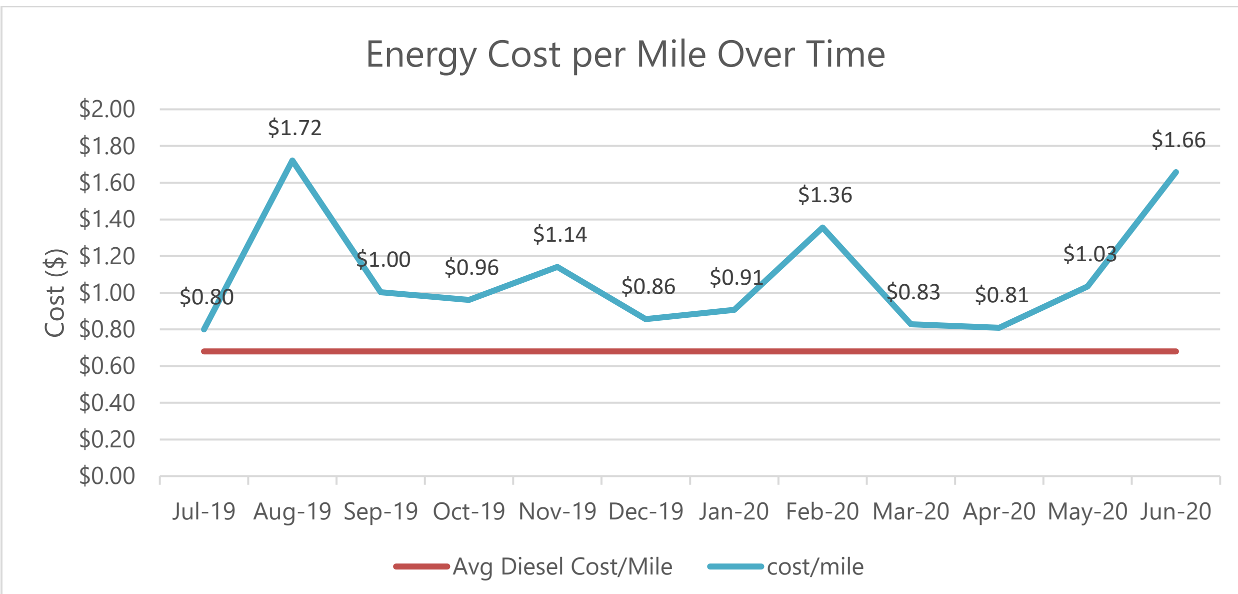
Staff compared the number of days the vehicles operated in service to the number of days they were available i.e., not out of service due to maintenance. The buses were placed into service about 62 percent of the time they were available. This is relatively low and primarily because they are not assigned to operate on weekends due to the length of weekend vehicle operating blocks. Golden Gate Transit also may have kept the buses out of service when they did not have a driver trained to operate the vehicle or comfortable driving it.

Cost
Due to the electric utility rate structure, the BYD bus energy cost per mile is more variable than for traditional diesel fuel buses. Electricity is subject to demand charges. Utility demand charges are incurred based on the highest amount of energy pulled at a given moment during the billing period. If the buses are charged once a month, there is demand charge fee placed on the utility bill no matter how many miles the vehicles traveled during that period. Marin Transit deliberately chose vehicles that can charge slowly overnight when demand charges are lower. Due to this

rate structure, initial energy per mile costs were very high (as much as $8.88 per mile) when the buses were not yet in regular service or traveling long distances. This is the reason for the peak charge at $1.72 per mile in August 2019. As the buses entered regular service, this cost averaged $1.09 per mile over the year compared to the average cost of diesel at $0.68 per mile. Figure 5 shows the cost of energy per mile for the BYD buses compared with the average diesel bus cost per mile.

Marin Transit also benefits from Golden Gate Transit's electricity usage. Marin Transit pays only the difference between peak usage at the Golden Gate Facility and peak usage when the BYD buses are plugged in, up to 160 kW. That is the maximum potential pull from the chargers. Typically, usage ranges between 80kW and 140kW. In June 2020, the difference between Golden Gate Facility peak usage, and peak usage when the buses were plugged did not exceed 160kW. This was due to lower GGT regular power usage at night. As a result, Marin Transit paid a higher demand charge and a significantly higher cost per mile in June. This also represents the full energy cost that Marin Transit would pay if the buses were metered separately from Golden Gate Transit's facility.

Figure 5 – Energy Cost



Emission Reductions

The two BYD buses traveled 30,287 miles from July 2019 to June 2020. During this time, Marin Transit experienced a savings in vehicle emissions of 5,285 kg of CO_2, 127,260 grams of NO_X, and 3,182 grams of particulate matter compared to operating two diesel buses. Combined, this is equivalent to 5.4 metric tons of CO_2 saved, and the amount of carbon sequestered by seven acres of U.S. forests in one year according to the EPA.

Scalability

The buses have performed well and proven reliable despite the limitations of the technology, including range. Marin Transit has learned how to best deploy the buses. Staff is comfortable with recommending a larger investment in this technology. Range will remain a limiting factor that will determine how the buses are deployed. Marin Transit anticipates there will be future technology improvements and will phase the deployment of additional electric buses to mitigate the impact of those limits.

With additional battery electric buses in the fleet, there is an increased possibility of high utility demand charges due to more vehicles plugged in at the same time. Marin Transit will invest in managed charging technology to decrease this cost. Managed charging will ensure that Marin Transit gets the lowest pricing possible for electricity by phasing charging of buses and limiting peak energy pull.

CONCLUSION

The two BYD electric buses performed well during the pilot period. Based on the collected data from the onboard Viriciti system, the buses average performance was 1.63 kW/mile with an effective range of 133 miles per 80 percent charge. This was within ten miles of the advertised 145 mile range. The performance was lower during periods of lower temperatures. The usage of the heater appears to reduce performance about 0.09 kWh/mile, approximately seven miles per charge.

The buses were reliable though not as versatile as diesel vehicles. Golden Gate Transit was able to quickly resolve availability issues, and the most time consuming service incident was unrelated to the electric battery. Range limitations restricted operation of the vehicles weekdays when vehicle work blocks were shorter. Staff initially limited the vehicles to operating 80 miles per day and expanded the range limit to 125 miles per day with sufficient operational experience and performance data showed they could reliably travel farther. A typical 40ft diesel transit bus can be expected to travel over 600 miles per tank and can be easily refueled during the day.

Overall, the electric buses were consistently more expensive to fuel than the District's traditional fleet during the study period. Due to the electrical rate structure, the cost per mile of fueling the vehicles varied significantly based on usage per month. The dominant cost was the monthly electrical demand charge based on the peak electrical draw within a month. This was a known factor and the major reason why overnight charging was used as fees lower at night. In months when the vehicles were consistently in operation, the flat demand charge is spread across more miles. For months with limited operation of the vehicles, the cost per mile quickly doubled. As the District adds electric buses to the fleet, the impact of a bus going out of service will be lessened and energy costs will stabilize. Managed charging will be essential to further limit demand charge costs as the fleet increases over time.

FISCAL/STAFFING IMPACT:

There is no fiscal impact associated with this report.

Respectfully submitted,

Anna Penoyar

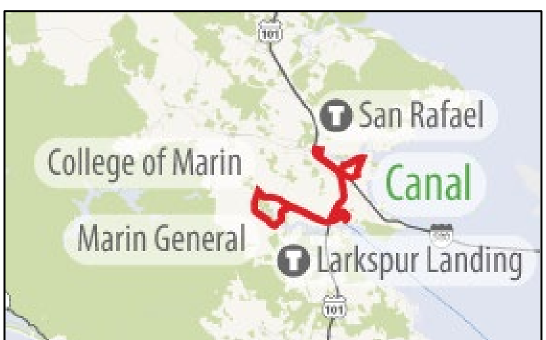
Anna Penoyar
Senior Capital Analyst

Attachment A: Routes operated by BYD Battery Electric Bus

Route 23

Route 23X

Route 17



Route 29

Route 71X

Electric Bus Pilot Project

Board of Director's Meeting

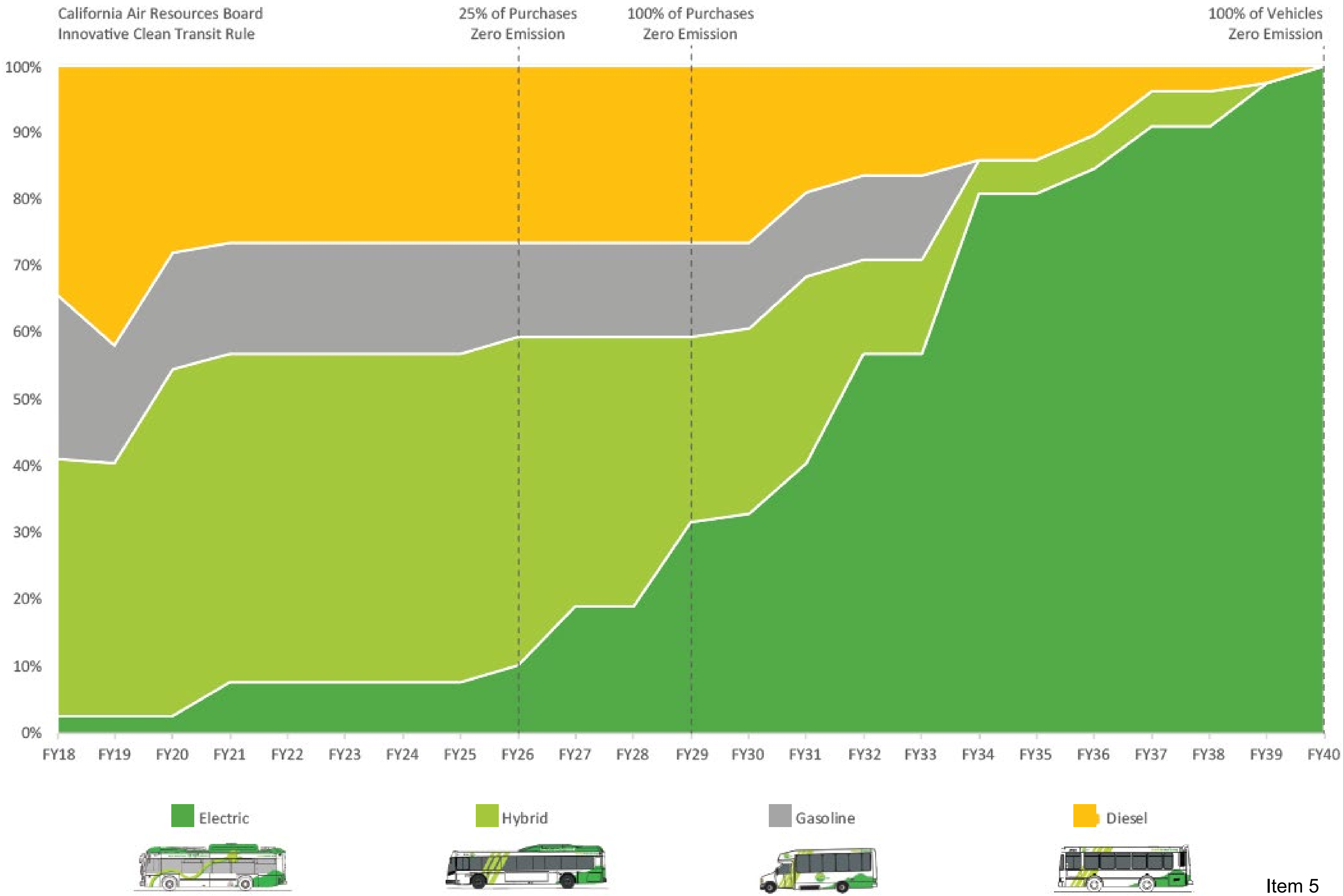
October 5, 2020

Item 5

Overview

- Background
- Performance
- Reliability
- Cost
- Expansion

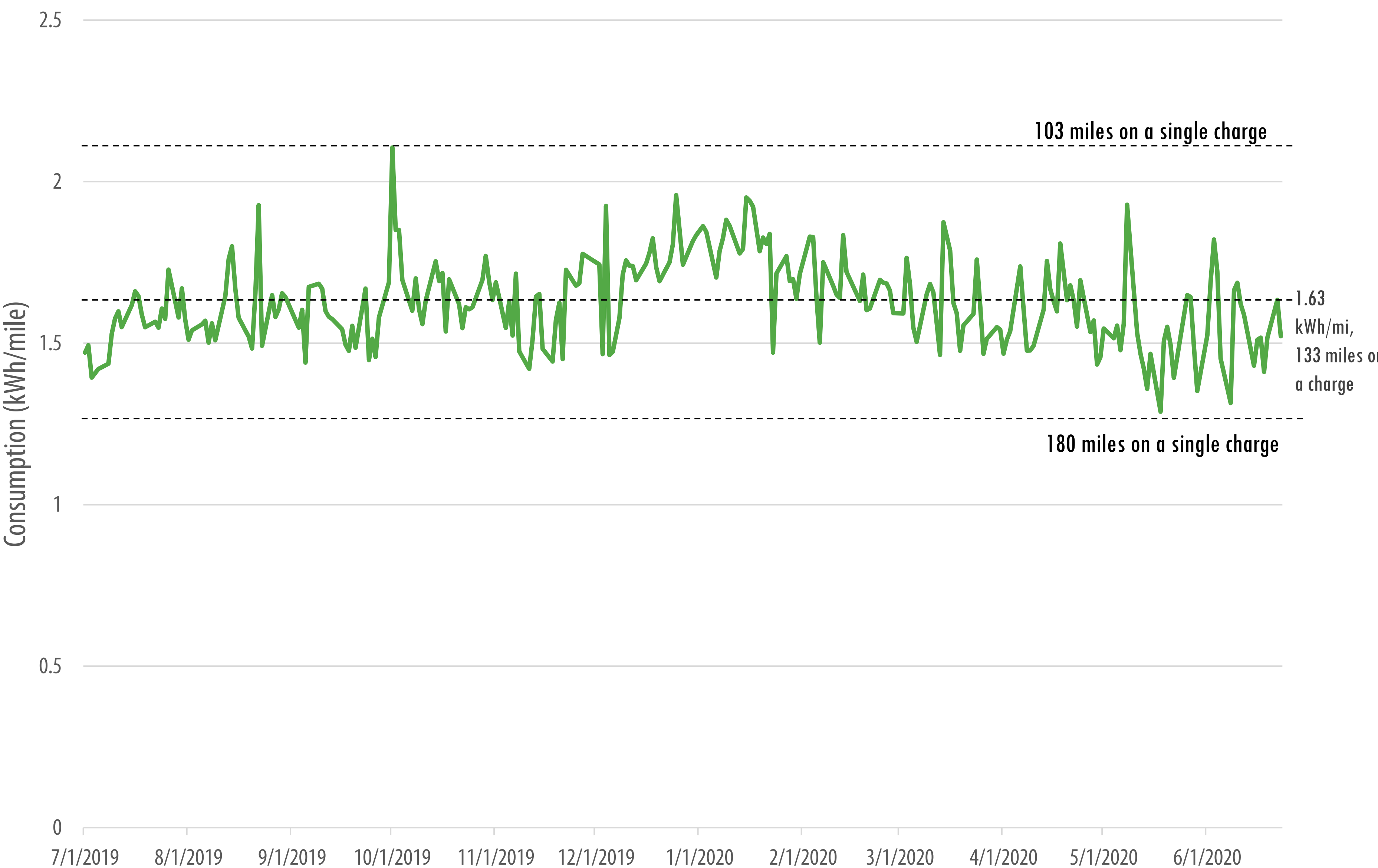
Background – Zero Emission Fleet Plan



Background - Timeline

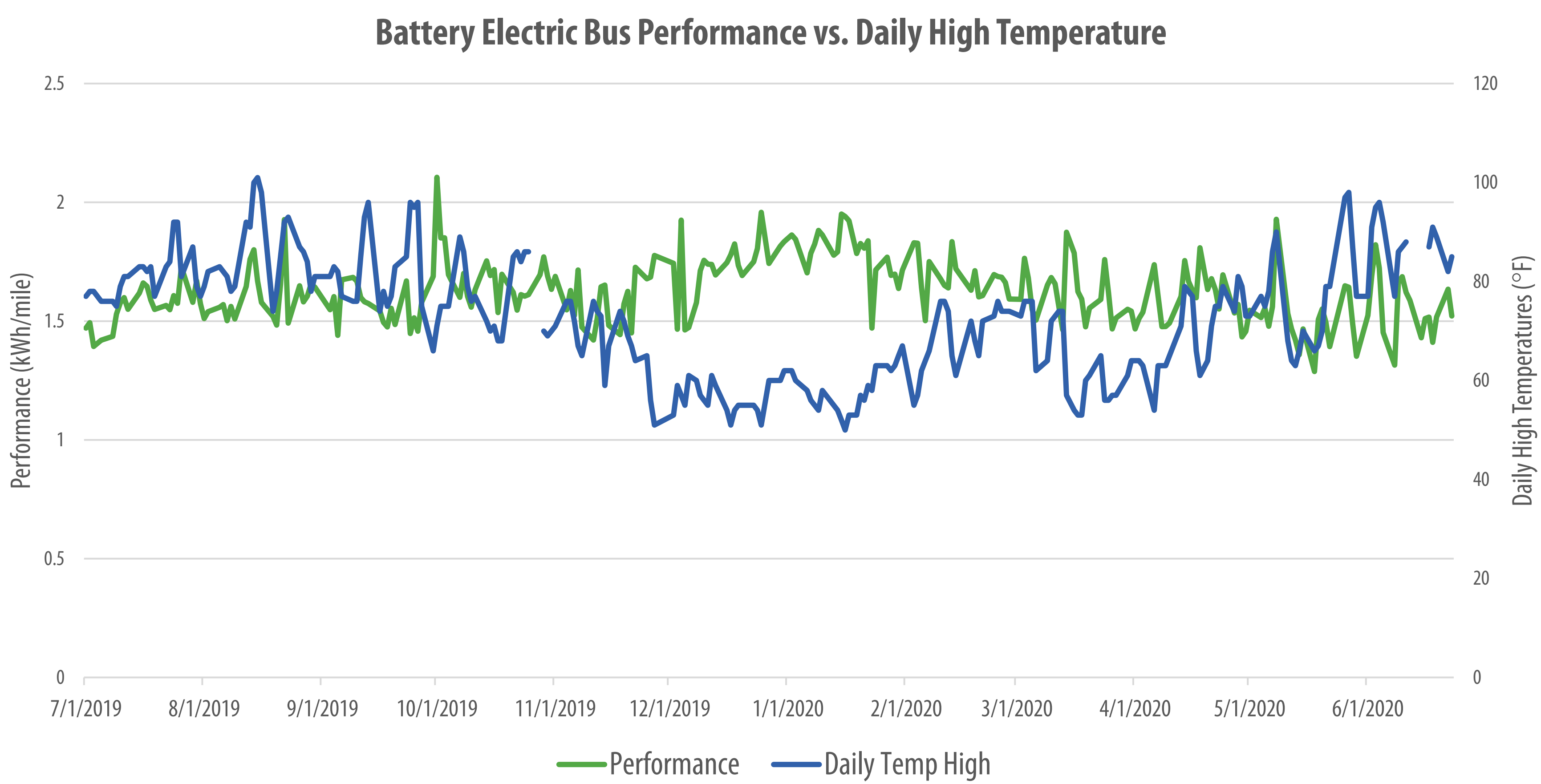
2014-2016	Established Partnership with MCE, GGT
2016	Purchase Approved by Board
2018	Vehicles delivered
2018-2019	Mechanical Issues Delayed Service
2019	Both entered service in 2019
7/2019 – 6/2020	Observation period, data collection with Viriciti software

Vehicle Performance over Time



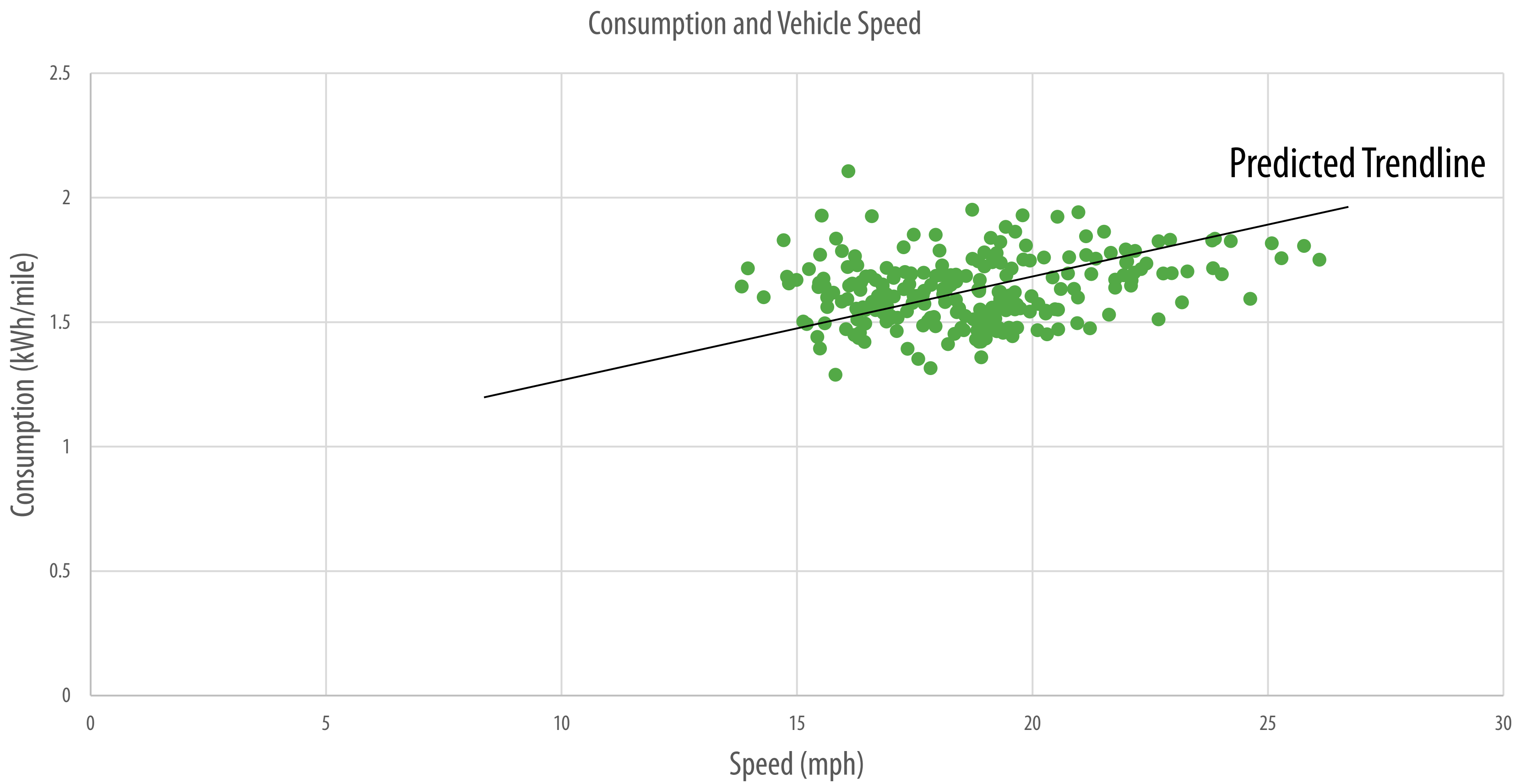
Vehicle Performance and Temperature

Predicted that lower temperatures would correlate with worse performance because of heater use

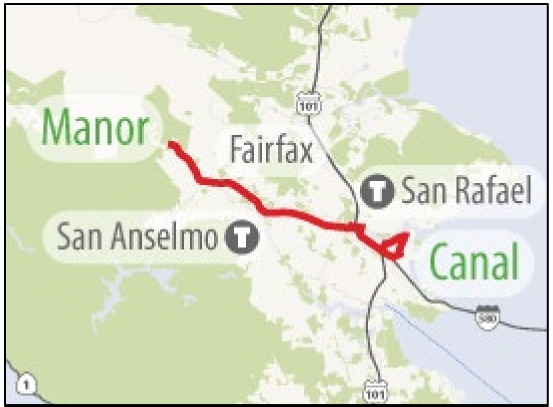


Vehicle Performance and Speed

- Predicted that at higher speeds, performance would be worse
- No relationship seen



Vehicle Routing



Route 23X

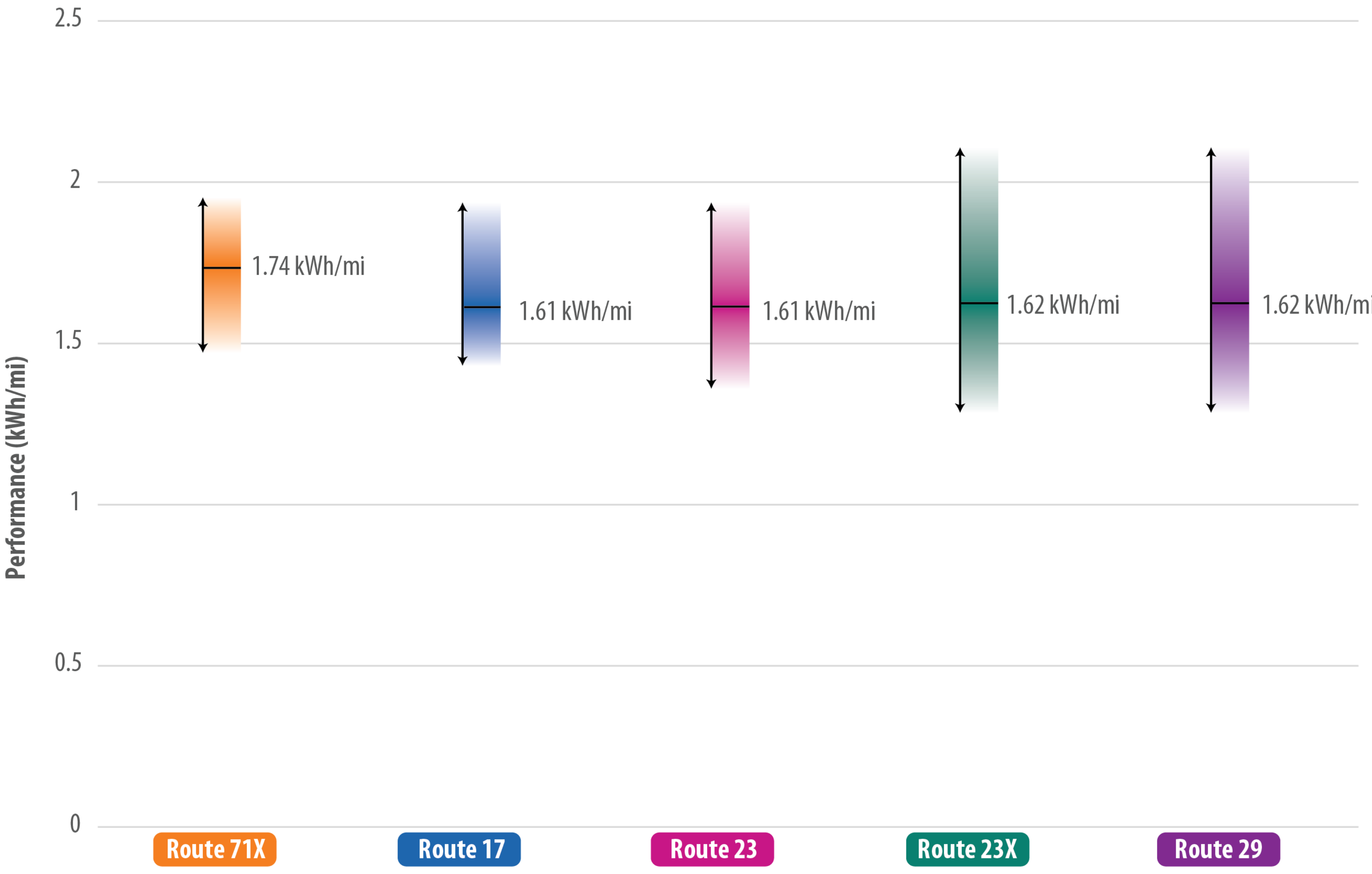
Route 23

Route 71X

Route 29

Route 17

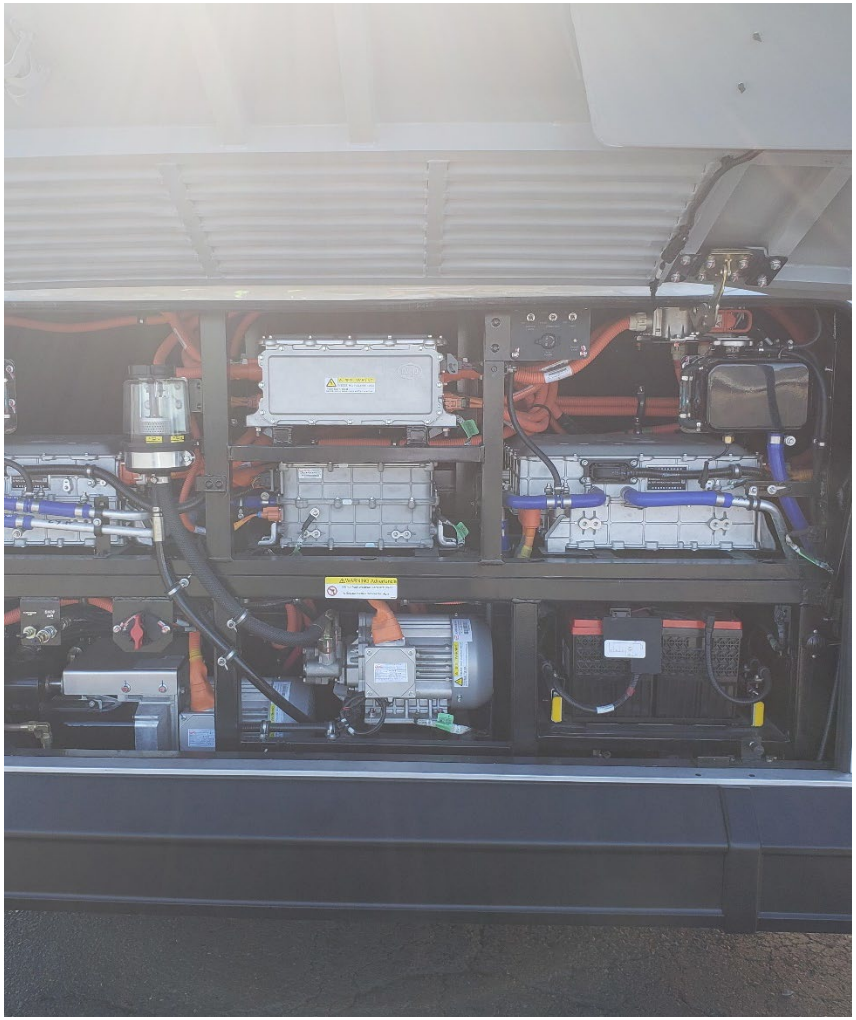
Vehicle Performance and Routing



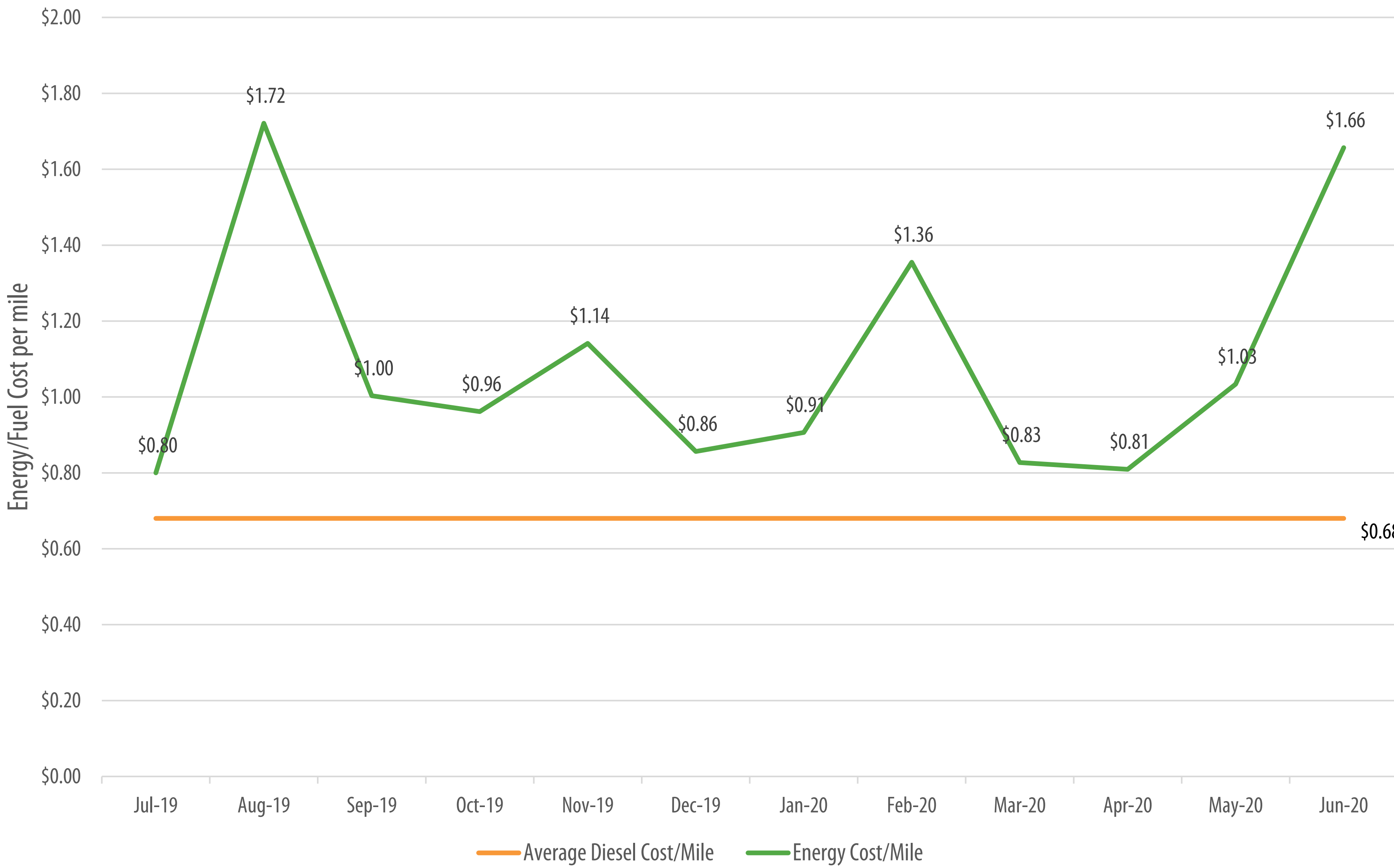
Vehicle Reliability and Availability

- Range: 120 miles!
- No Roadcalls
- In service 62% of the time that they were available
- Availability: Vehicles are operable

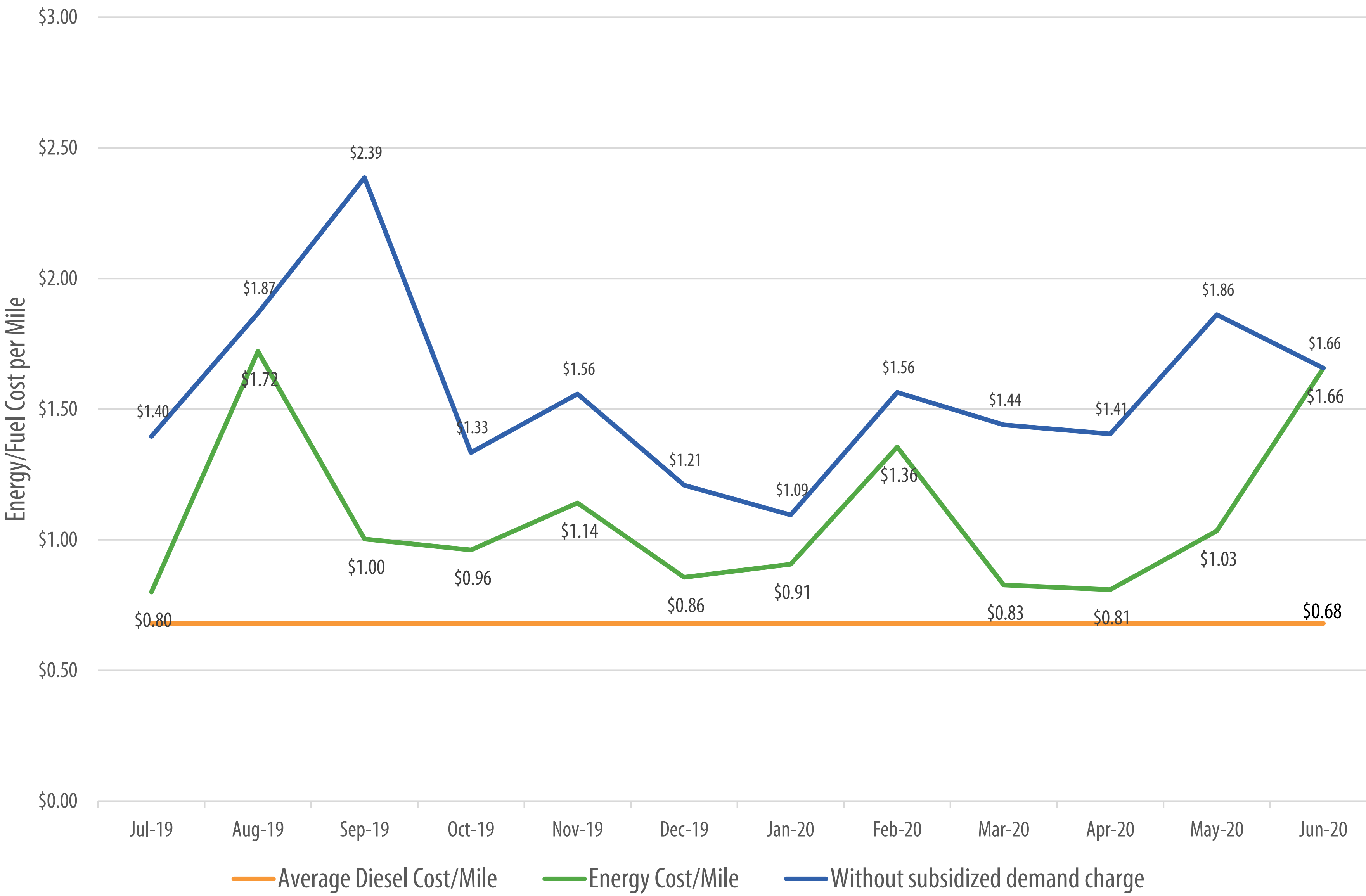
Vehicle	1801	1802
Days Used in Service:	216	210
Days Available:	338	352
Days Unavailable:	27	13



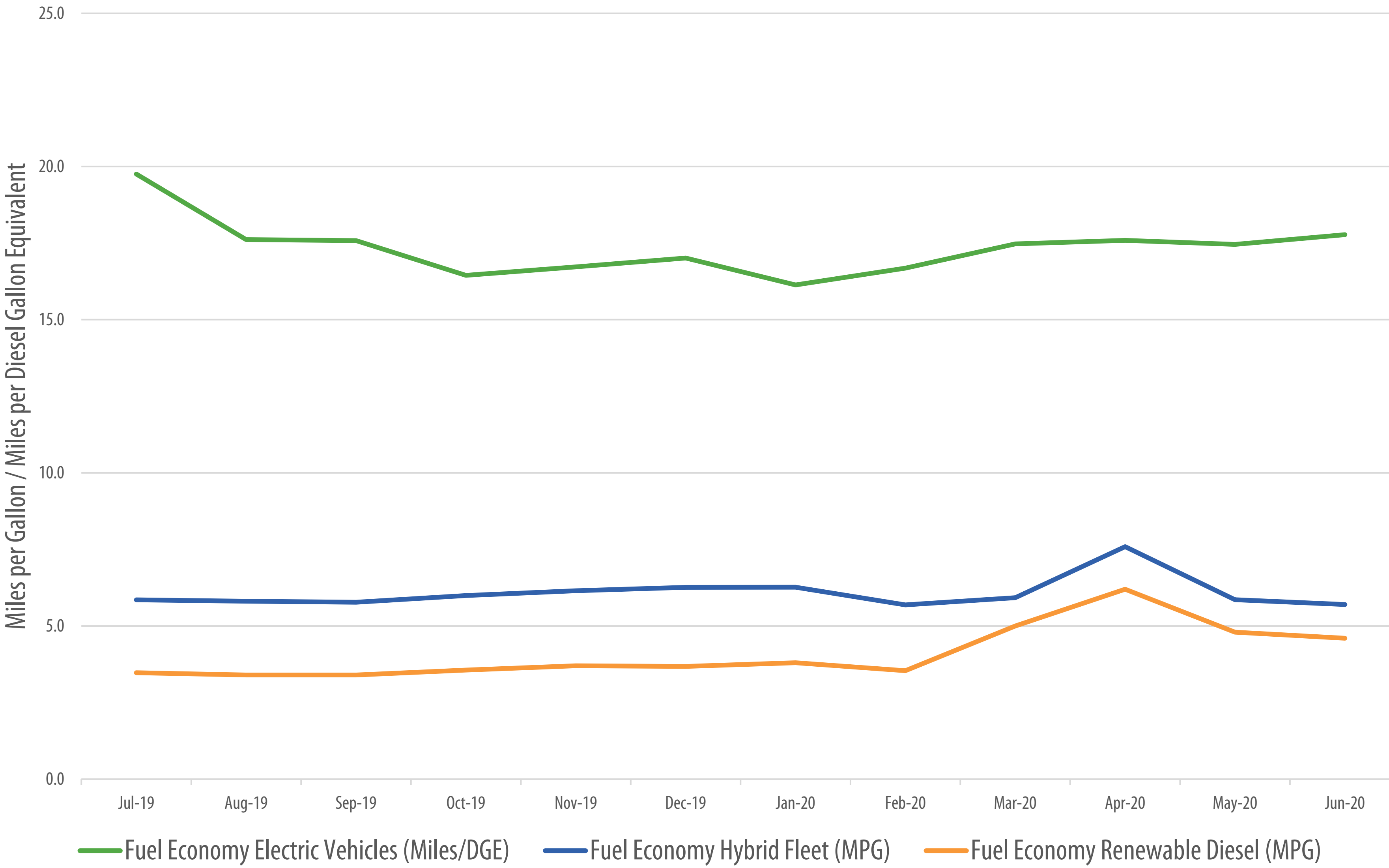
Fuel Cost per Mile



Fuel Cost per Mile without Subsidized Demand Charge



Fuel Economy



Emissions Savings – 1 year of service

5,285 kg of CO_2

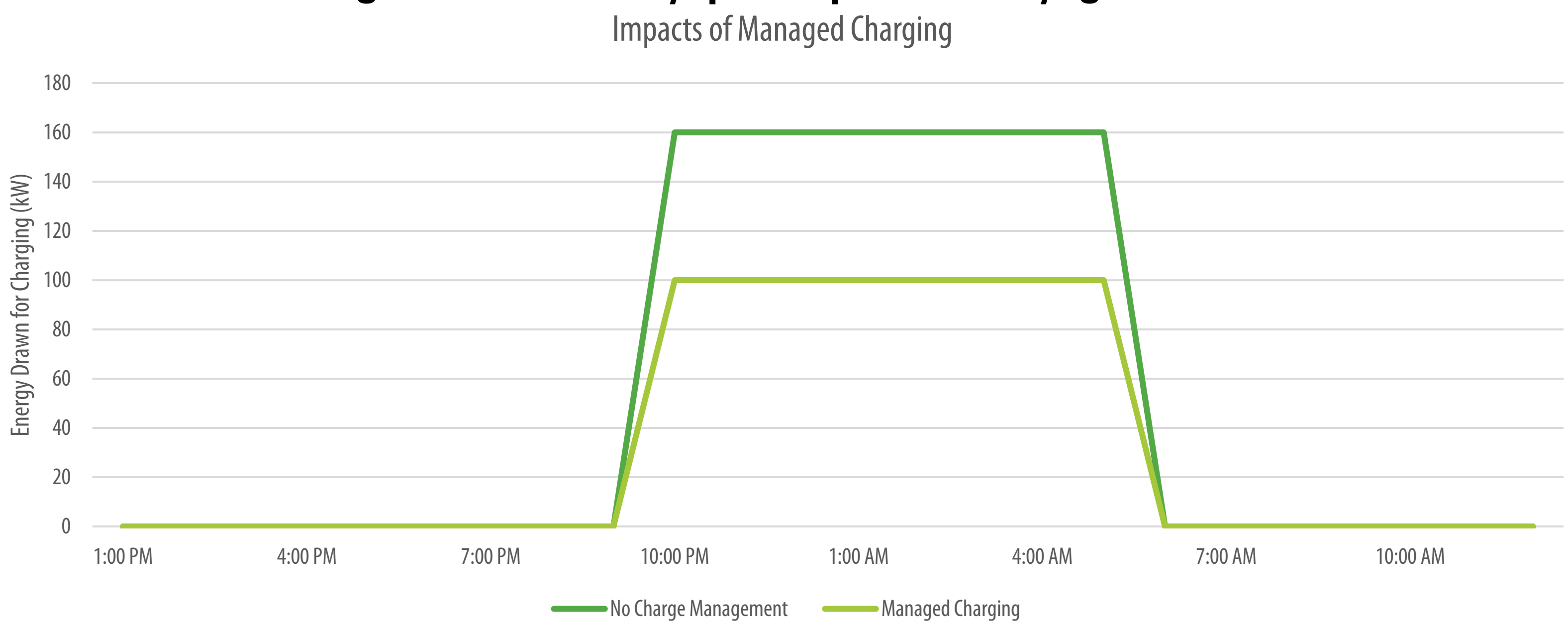
127,000 g of NO_X

3,182 g of Particulate Matter

Yearly carbon sequestration of **7 acres** of forest

Expansion

- Technology has proven reliable, and suggests additional investment is prudent.
- Charging management system for additional buses
  – Can plug buses in, but charging is regulated by a system
  – Demand charges incurred by peak pull at any given time

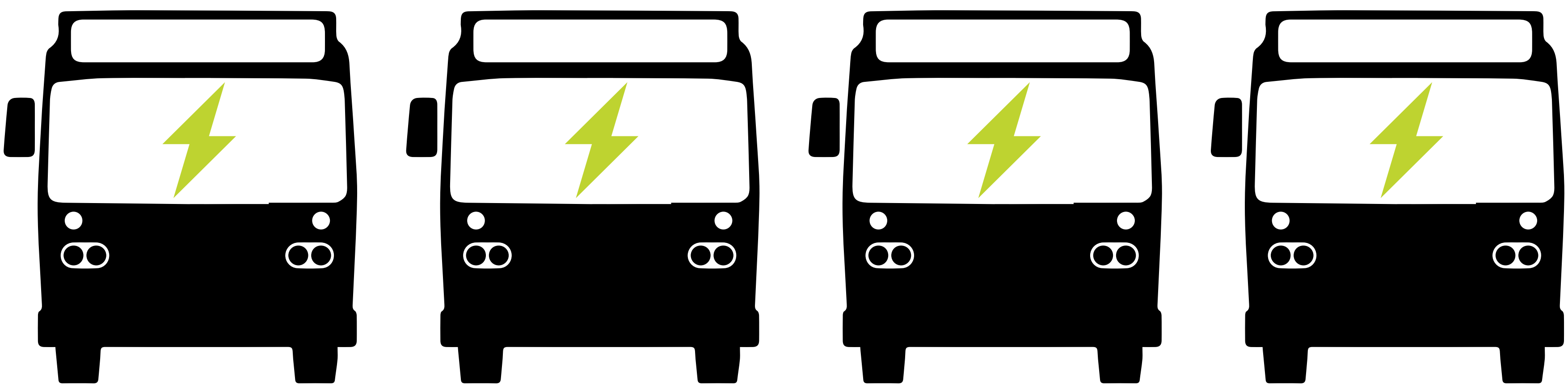


Battery Electric Bus Pilot Project Conclusions

- Buses can travel 120 miles on a single charge
- The technology is reliable
- The buses use energy more efficiently than traditional fuel buses
- Buses reduce emissions
- Fuel costs are higher
- More analysis is needed

Next Steps

- Continue to monitor performance
- Test on routes with different profiles
- Expand to more routes
- Invest in more battery electric buses
- Purchase additional land for bus charging



Discussion and Questions

Anna Penoyar

Senior Capital Analyst