Lane Transit District
Key Performance Indicator (KPI) Report
Final Report

March 4, 2021

The following report includes a summary of the use and performance of LTD's BYD battery electric bus (BEB) pilot program.

LTD ordered five 40' BYD BEBs with auxiliary diesel-fired heaters and six 80 kW BYD depot chargers in 2016. Two BYD BEBs were put into revenue service in 2019, and their performance was evaluated in LTD's service area.

The results of the pilot program indicated that LTD's service area is well suited to BEB operation, as the buses had low kWh/mi requirements. At the conclusion of the pilot program, the buses and chargers were returned to BYD.

In February 2020, LTD awarded a contract to New Flyer to purchase 11 New Flyer BEBs with a nameplate capacity of 388 kWh and five 150 kW ABB chargers with three dispensers. The New Flyer BEBs will not have fuel-fired heaters. The delivery of the 11 buses was completed in March 2021.

Table 1. Current Equipment Status

Equipment	Delivered to LTD?	In revenue service?
Bus 16101	✓	✗
Bus 16102	✓	✓
Bus 16103	✓	✗
Bus 16104	✓	✗
Bus 16105	✓	✓
6 80kW Chargers	✓	✓

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Fleet Performance Summary

Fleet Performance Summary

Table 2. Current Equipment Status

	Bus 16102 (Cumulative Performance)	Bus 16105 (Cumulative Performance)	Cumulative Performance (February 2019 - March 2020)
Total In-Service Mileage	21,519	18,130	39,649
Total Energy Charged (kWh)	36,521	27,058	63,579
Total Energy Used (kWh)	38,653	30,487	69,140
Average energy consumption – bus energy only (kWh/mi)	1.80	1.72	1.76
Average energy consumption – bus energy + diesel energy (kWh/mi)	2.10	2.21	2.16
Average %SOC/hr	6.33	6.13	6.24
Average diesel consumption (gallons/hr operation)	0.22	0.28	0.25
Total Diesel Consumption (Gallons) February - April 2019, August 2019 - March 2020	207.10	247.00	454.10
Total days in service	231	220	451
Average trip duration (hours)	6.91	6.97	6.94

Figure 1. Monthly Miles and Average kWh/mi (2/3/19 - 3/18/20)

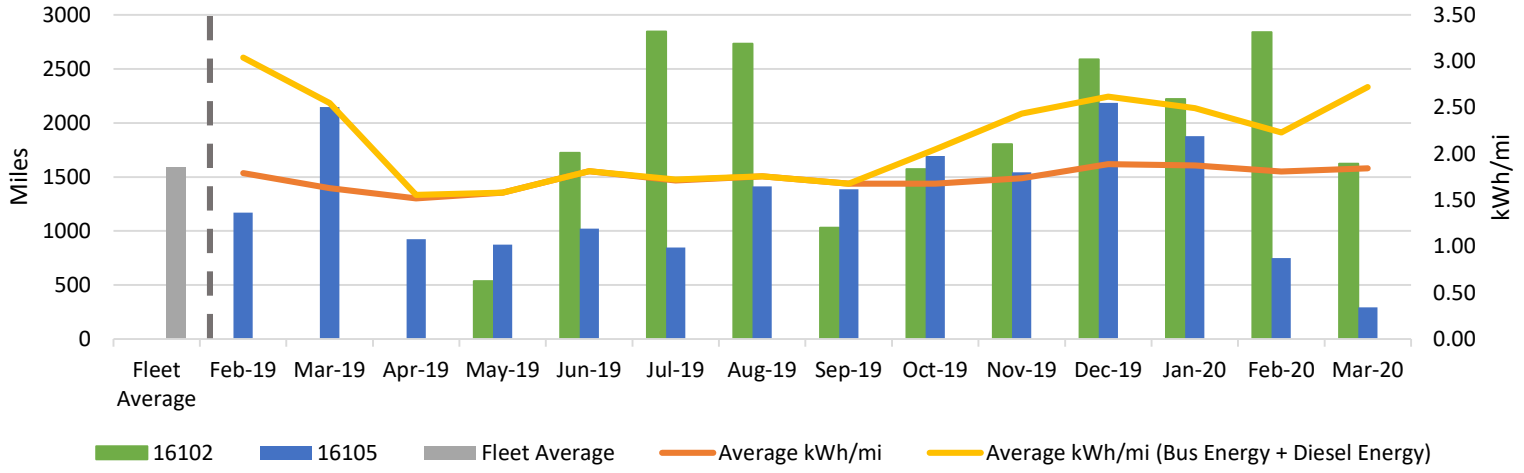

Figure 1 notes: Mileage includes miles driven only when in service and includes deadhead mileage. Lower mileage in April and May due primarily to driver training that prevented the bus from entering service. Average kWh/mi indicates how efficiently the bus is running. "Typical" bus efficiency is about 2 kWh/mi. Average kWh/mi (Bus Energy + Diesel Energy) estimates energy efficiency, taking into account the energy from the diesel consumed from the fuel-fired heater. These values indicate what energy efficiency a BEB without a fuel-fired heater may see in LTD's service area.

Figure 2. Daily Average Miles

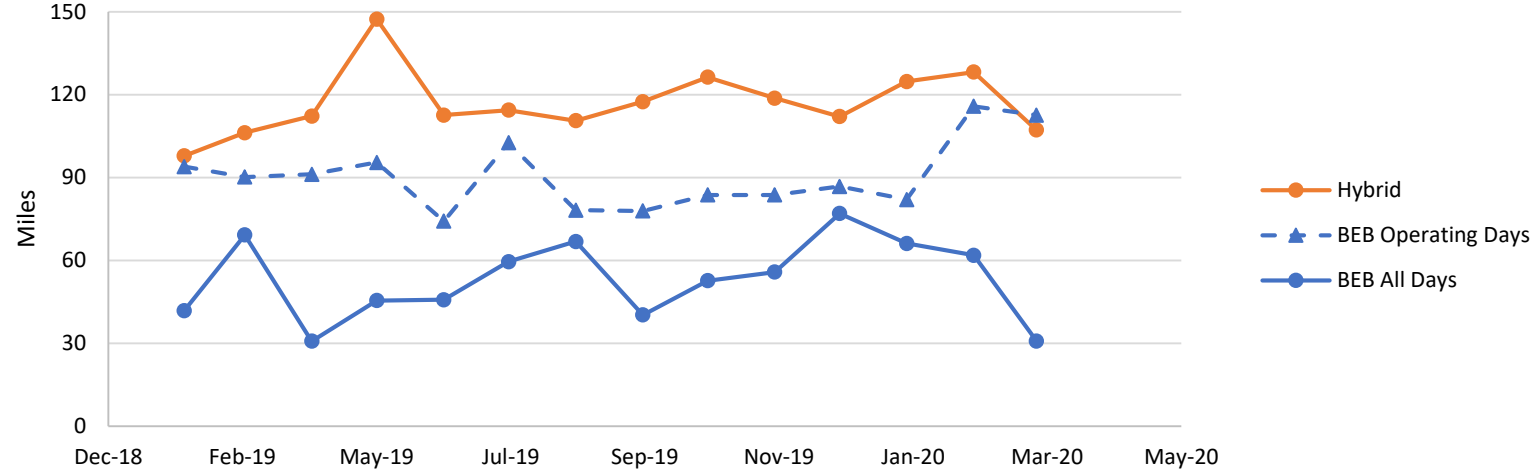

Figure 2 notes: The "Hybrid" and "BEB All Days" data series show the total monthly miles averaged over the total number of days per month and buses in the fleet, regardless of whether a bus was put into service. The "BEB Operating Days" series shows the total monthly BEB miles averaged over the days the bus was in service.

Costs

Fuel Usage and Estimated Costs

Figure 3. Fuel Costs ($/mile)

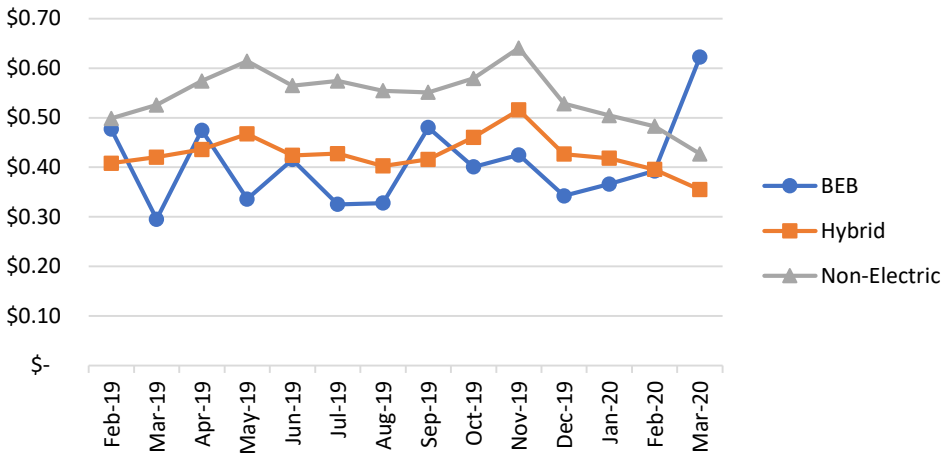

Figure 3 notes: Fuel costs per mile for the 16100 series BEB fleet, 16200 series hybrid fleet, and LTD's entire non-electric fleet are shown. Non-electric fleet fuel costs per mile fluctuate with changing diesel costs.

Figure 4. Fuel Economy

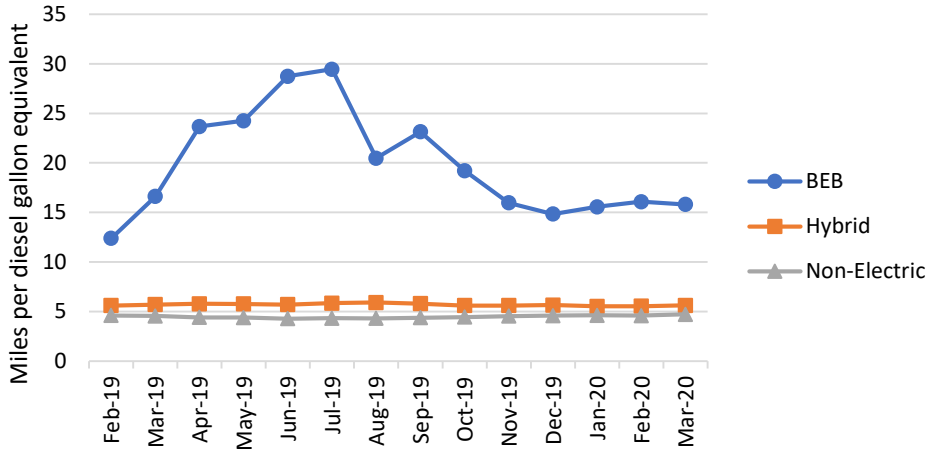

Figure 4 notes: Fuel economy for the 16100 series BEB fleet (miles per diesel gallon equivalent), 16200 series hybrid fleet (in miles per gallon), and non-electric fleet (in miles per gallon) are shown. BEB fuel economy increases in warmer months when the diesel heater is not utilized. Hybrid and non-electric fuel economies remain relatively constant.

Table 3. Estimated Fuel Costs Comparison for 16100 Series BEB fleet, 16200 Series Hybrid Fleet, and Non-Electric Fleet

Month	16100 Series BEB $/mi	16200 Series Hybrid $/mi	Non-Electric Fleet $/mi
Feb-19	$ 0.48	$ 0.41	$ 0.50
Mar-19	$ 0.30	$ 0.42	$ 0.53
Apr-19	$ 0.47	$ 0.44	$ 0.57
May-19	$ 0.34	$ 0.47	$ 0.61
Jun-19	$ 0.42	$ 0.42	$ 0.56
Jul-19	$ 0.33	$ 0.43	$ 0.57
Aug-19	$ 0.33	$ 0.42	$ 0.55
Sep-19	$ 0.48	$ 0.43	$ 0.55
Oct-19	$ 0.40	$ 0.45	$ 0.58
Nov-19	$ 0.43	$ 0.49	$ 0.64
Dec-19	$ 0.34	$ 0.41	$ 0.53
Jan-20	$ 0.37	$ 0.39	$ 0.50
Feb-20	$ 0.39	$ 0.40	$ 0.48
Mar-20	$ 0.62	$ 0.35	$ 0.43

Table 3 notes: Monthly fuel costs per mile for the 16100 series BEB fleet, 16200 series hybrid fleet, and non-electric fleet are shown.

Table 4. Estimated Fuel Economy Comparison for 16100 Series BEB fleet, 16200 Series Hybrid Fleet, and Non-Electric Fleet

Month	16100 Series BEB Fuel economy (mpDGE)	16200 Series Hybrid Fuel economy (mpg)	Non-Electric Fleet Fuel Economy (mpg)
Feb-19	12.3	5.6	4.6
Mar-19	16.6	5.7	4.6
Apr-19	23.7	5.8	4.4
May-19	24.0	5.8	4.4
Jun-19	28.7	5.7	4.3
Jul-19	29.4	5.8	4.3
Aug-19	20.5	5.9	4.3
Sep-19	23.1	5.8	4.4
Oct-19	19.2	5.6	4.4
Nov-19	16.0	5.6	4.5
Dec-19	14.8	5.6	4.6
Jan-20	15.6	5.5	4.6
Feb-20	16.1	5.5	4.6
Mar-20	15.8	5.6	4.7

Table 4 notes: Fuel economy for the 16100 series BEB fleet (miles per diesel gallon equivalent), 16200 series hybrid fleet (in miles per gallon), and non-electric fleet (in miles per gallon) are shown.

Fuel Usage and Estimated Costs

Table 5. Estimated Fuel Costs per mile for the 16100 Series BEB Fleet

Estimated Fuel Costs per mile – 16100 Class BEB Fleet												
Month	Miles	kWh Consumed	Demand kW	Demand Charge	Energy Charge	Basic Customer Charge*	Diesel Gallons	Total Diesel Cost	Total Electricity Costs	Total Fuel Cost	$/kWh	$/Mile
Feb-19	1,128	2,140	88	$ 356.69	$ 108.33	$ 82.20	39.8	$ 91.55	$ 465.02	$ 558.64	$ 0.21	$ 0.48
Mar-19	2,148	3,548	88	$ 356.69	$ 172.42	$ 82.20	43.6	$ 104.44	$ 529.11	$ 633.55	$ 0.15	$ 0.30
Apr-19	923	1,375	88	$ 356.69	$ 66.83	$ 82.20	5.8	$ 14.62	$ 423.52	$ 438.14	$ 0.31	$ 0.47
May-19	1,410	2,431	88	$ 356.69	$ 116.98	$ 82.20	0	$ -	$ 473.67	$ 473.67	$ 0.20	$ 0.34
Jun-19	2,795	4,113	176	$ 948.93	$ 192.27	$ 82.20	0	$ -	$ 1,141.20	$ 1,141.20	$ 0.29	$ 0.42
Jul-19	3,695	5,195	176	$ 948.93	$ 252.45	$ 82.20	0	$ -	$ 1,201.38	$ 1,201.38	$ 0.23	$ 0.33
Aug-19	4,147	8,044	176	$ 948.93	$ 390.93	$ 82.20	8.2	$ 19.62	$ 1,339.86	$ 1,359.48	$ 0.17	$ 0.33
Sep-19	2,416	4,179	176	$ 948.93	$ 203.12	$ 82.20	3.5	$ 8.45	$ 1,152.05	$ 1,160.49	$ 0.28	$ 0.48
Oct-19	3,265	5,767	176	$ 948.93	$ 280.29	$ 82.20	30.6	$ 79.05	$ 1,229.22	$ 1,308.27	$ 0.21	$ 0.40
Nov-19	3,349	6,290	176	$ 948.93	$ 305.68	$ 82.20	57.9	$ 168.66	$ 1,254.61	$ 1,423.27	$ 0.20	$ 0.43
Dec-19	4,773	9,458	176	$ 948.93	$ 459.68	$ 82.20	93.4	$ 224.79	$ 1,408.61	$ 1,633.40	$ 0.15	$ 0.34
Jan-20	4,102	7,819	176	$ 948.93	$ 380.02	$ 82.20	74.7	$ 172.35	$ 1,328.95	$ 1,501.30	$ 0.17	$ 0.37
Feb-20	3,591	6,499	176	$ 948.93	$ 315.86	$ 82.20	66.4	$ 145.42	$ 1,264.79	$ 1,410.21	$ 0.19	$ 0.39
Mar-20	1,915	3,217	176	$ 948.93	$ 156.34	$ 82.20	43.4	$ 86.58	$ 1,105.27	$ 1,191.85	$ 0.34	$ 0.62

Table 5 Notes: Fuel cost per mile for the BEB fleet is estimated using available mileage and kWh consumption data from HAMS. 10% is added to "Energy Charged" in HAMS to account for estimated efficiency losses. Demand kW is estimated as the rated power of the number of chargers used for the buses in service, with 10% added to account for estimated efficiency losses. Cost of diesel is provided by LTD. The more miles operated by the BEBs each month will result in lower $/mi. At 40,000 miles per year, fuel costs per mile are estimated to be lower than diesel and diesel hybrid buses.

*Basic Customer Charge was not included in the Total Electricity Costs because the chargers are on the same meter as other LTD facilities and LTD is responsible for paying the fee regardless of BEB charging.

Fuel Usage and Estimated Costs

Table 6. Estimated Fuel Costs per mile for the 16200 Series Hybrid Fleet

Estimated Fuel Costs per mile – 16200 Class Hybrid Fleet				
Month	Total Fleet Miles	Diesel gallons used	Total Fuel Costs	$/mile
Feb-19	13,702	2,431	$ 5,592.00	$ 0.41
Mar-19	16,468	2,890	$ 6,923.00	$ 0.42
Apr-19	16,843	2,914	$ 7,343.28	$ 0.44
May-19	22,838	3,954	$ 10,670.10	$ 0.47
Jun-19	17,457	3,045	$ 7,399.83	$ 0.42
Jul-19	17,738	3,045	$ 7,583.53	$ 0.43
Aug-19	22,946	3,862	$ 9,241.00	$ 0.40
Sep-19	15,891	2,739	$ 6,609.00	$ 0.42
Oct-19	15,295	2,727	$ 7,045.00	$ 0.46
Nov-19	13,171	2,332	$ 6,793.00	$ 0.52
Dec-19	14,163	2,510	$ 6,041.00	$ 0.43
Jan-20	16,933	3,069	$ 7,081.00	$ 0.42
Feb-20	16,374	2,957	$ 6,476.00	$ 0.40
Mar-20	16,546	2,944	$ 5,873.00	$ 0.35

Table 6 Notes: Fuel cost per mile for the 16200 Hybrid series is provided as a comparison.

Table 7. Estimated Fuel Costs per mile for the Non-Electric Fleet

Estimated Fuel Costs per mile – Non-Electric Fleet				
Month	Total Fleet Miles	Diesel gallons used	Total Fuel Costs	$/mile
Feb-19	268,411	58,414	$ 133,798	$ 0.50
Mar-19	324,949	71,389	$ 170,789	$ 0.53
Apr-19	324,706	73,668	$ 186,455	$ 0.57
May-19	333,477	76,154	$ 204,824	$ 0.61
Jun-19	310,971	72,748	$ 175,627	$ 0.56
Jul-19	330,899	76,427	$ 189,960	$ 0.57
Aug-19	323,056	74,988	$ 179,084	$ 0.55
Sep-19	309,801	70,799	$ 170,755	$ 0.55
Oct-19	344,450	77,555	$ 199,586	$ 0.58
Nov-19	309,514	68,235	$ 198,352	$ 0.64
Dec-19	312,697	68,153	$ 165,221	$ 0.53
Jan-20	332,152	71,928	$ 167,542	$ 0.50
Feb-20	315,528	68,797	$ 152,319	$ 0.48
Mar-20	292,552	62,098	$ 124,885	$ 0.43

Table 7 Notes: Fuel cost per mile for the non-electric fleet is provided as a comparison.

Energy Consumption and Range Analysis

Energy Consumption Analysis

Figure 5. Daily kWh/mi (Bus Energy Only) for BEB Fleet (2/3/19 - 3/18/20)

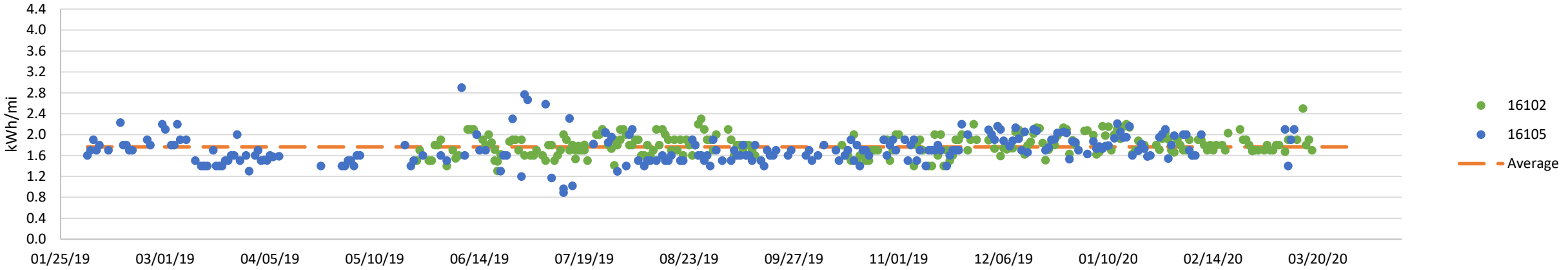

Figure 5 notes: Daily energy consumption (kWh/mi) by bus is shown, along with the overall average. HVAC consumption, driver style, and route conditions can impact energy efficiency.

Figure 6. Estimated Daily kWh/mi (Bus Energy + Diesel Energy) for BEB Fleet (2/3/19 - 3/18/20)

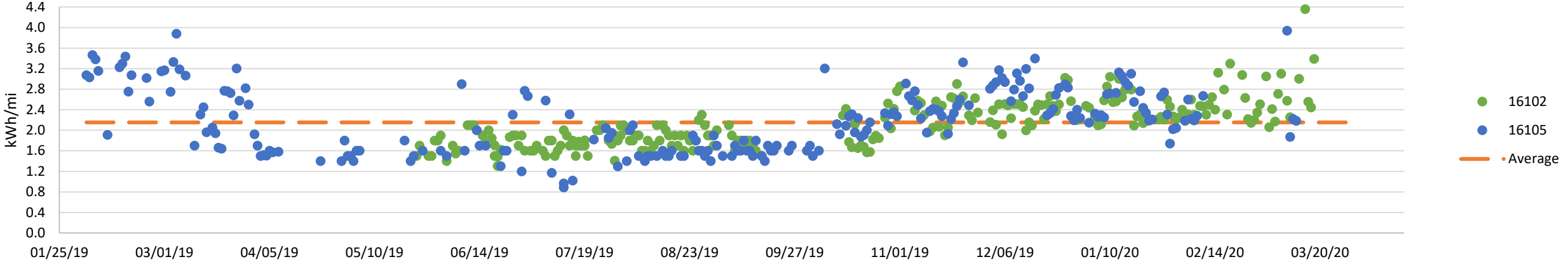

Figure 6 notes: An estimated daily energy consumption (kWh/mi) by bus is shown, taking into account the energy from the diesel consumed from the fuel-fired heater. These values indicate what energy efficiency a BEB without a fuel-fired heater may see in LTD's service area. Diesel usage data was only measured via refueling data, and daily kWh/mile data points may reflect multiple days of diesel fuel use. The daily kWh/mi values may reflect higher estimated daily energy consumption than would be realized in practice.

Energy Consumption Analysis (cont.)

Figure 7. Energy Consumption (kWh/mi) vs. Daily Average Temperature (2/3/19-3/18/20)

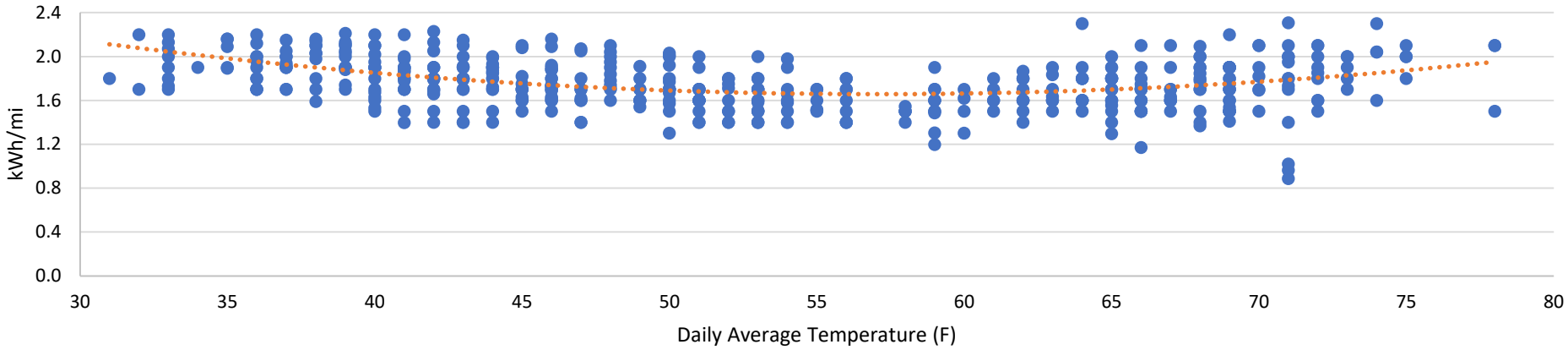

Figure 7 notes: Daily energy consumption (kWh/mi) by daily average temperature. In general, higher energy consumption is seen at very cold temperatures. Higher HVAC use in winter and summer months will most likely see the highest energy consumption.

Figure 8. Energy Consumption (kWh/mi) vs. Daily High Temperature (2/3/19-3/18/20)

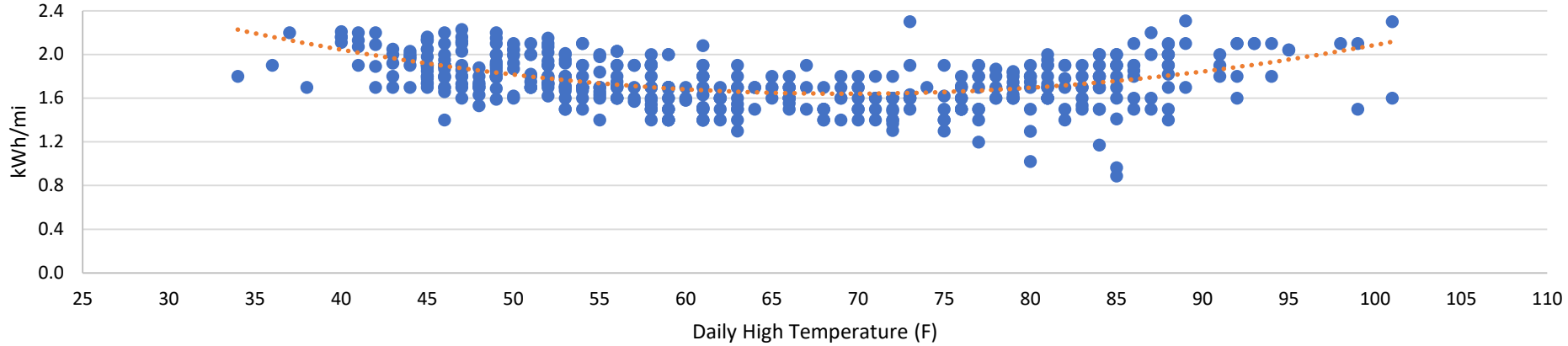

Figure 8 notes: Daily energy consumption (kWh/mi) by daily high temperature. In general, higher energy consumption is seen at very cold temperatures. Higher HVAC use in winter and summer months will most likely see the highest energy consumption.

Range Analysis

Figure 9. Estimated Usable Battery Capacity (kWh)

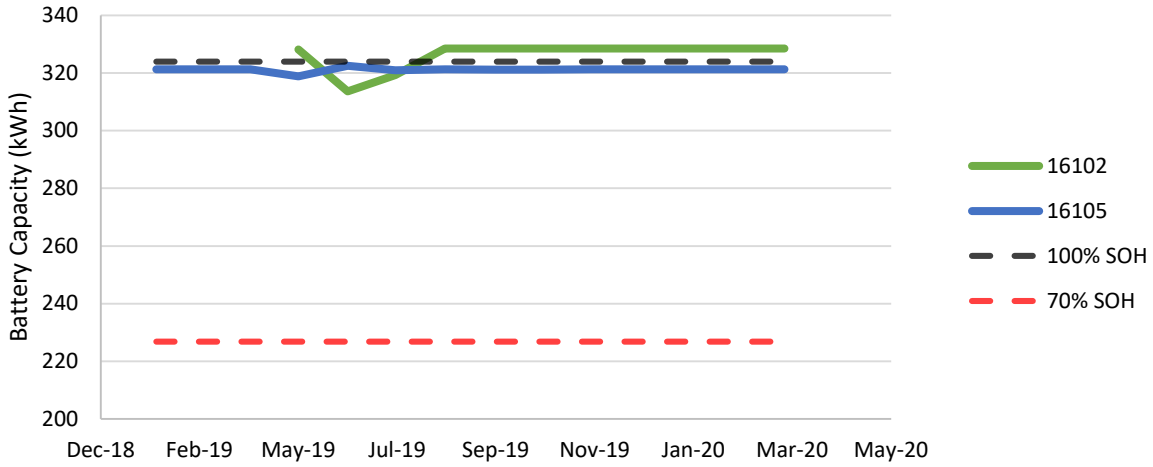

Figure 9 notes: Estimated usable battery capacity as reported as the average "Battery Energy" value in HAMS when the bus is at 100% SOC. The values are abounded by 100% state of health (SOH) (324 kWh, or the nameplate capacity of the battery) and 70% SOH (226.8 kWh, or the warranted capacity of the battery). The methodology for calculating "Battery Energy" in HAMS is not known and has not been validated. A gradual decline in usable battery capacity is expected throughout the life of the buses.

Figure 10. Estimated Range vs. Daily Average Temperature (F) (2/3/19 - 3/18/20)

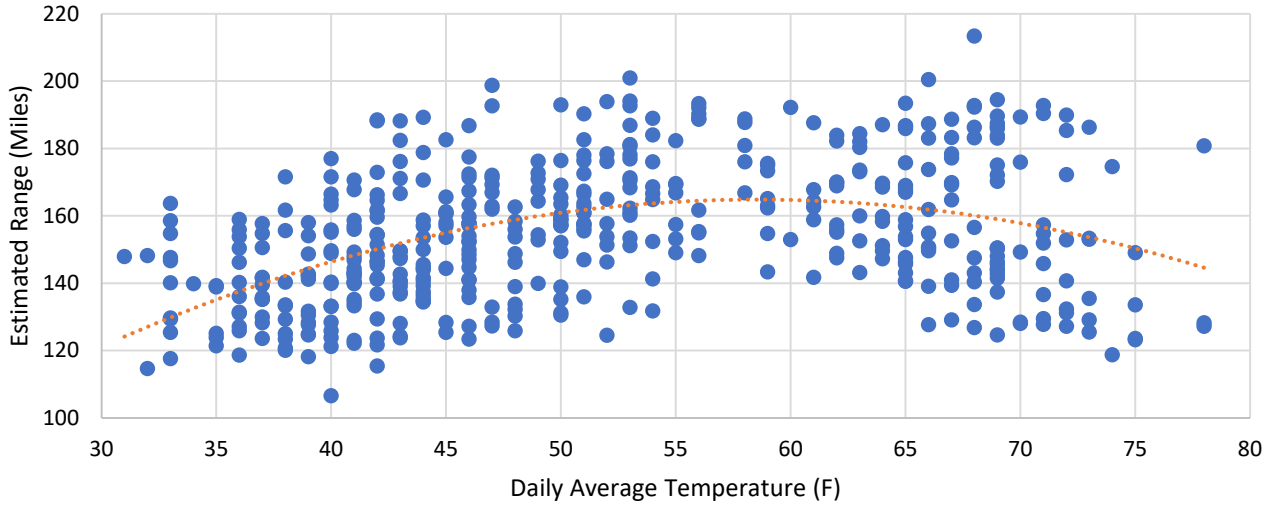

Figure 10 notes: Estimated vehicle range was calculated based off the %SOC per mile for each trip. The values represent the total estimated range if the bus is operated from 100% to 20% SOC.

Figure 11. Estimated Range vs. Daily High Temperature (F) (2/3/19 - 3/18/20)

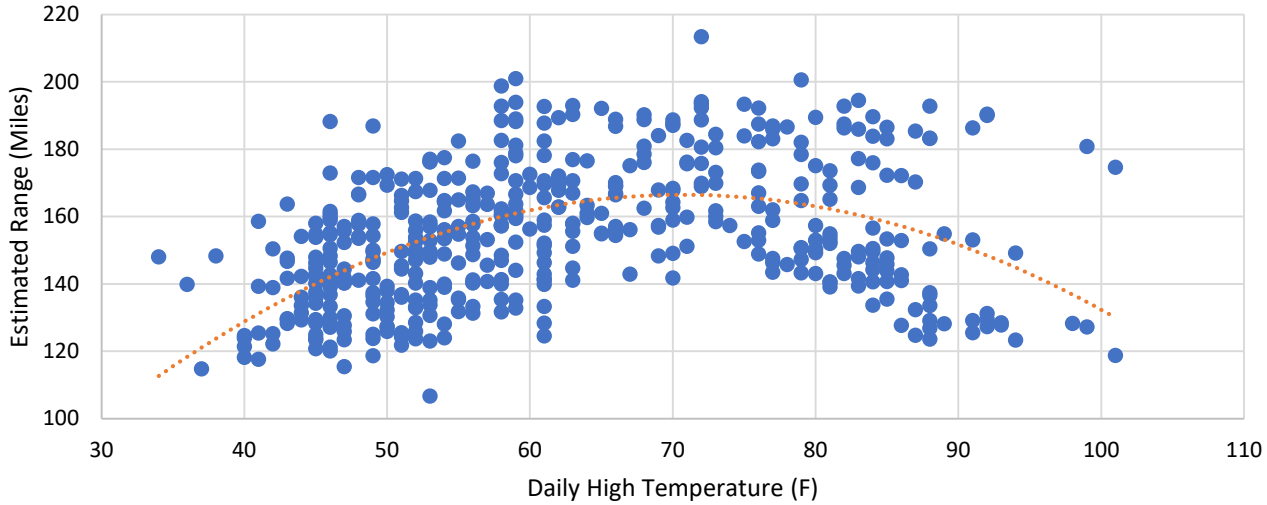

Figure 11 notes: Estimated vehicle range was calculated based off the %SOC per mile for each trip. The values represent the total estimated range if the bus is operated from 100% to 20% SOC.

Energy Consumption

Figure 12. Gallons of diesel used/hour of operation vs. Temperature (2/3/19 - 3/18/20)

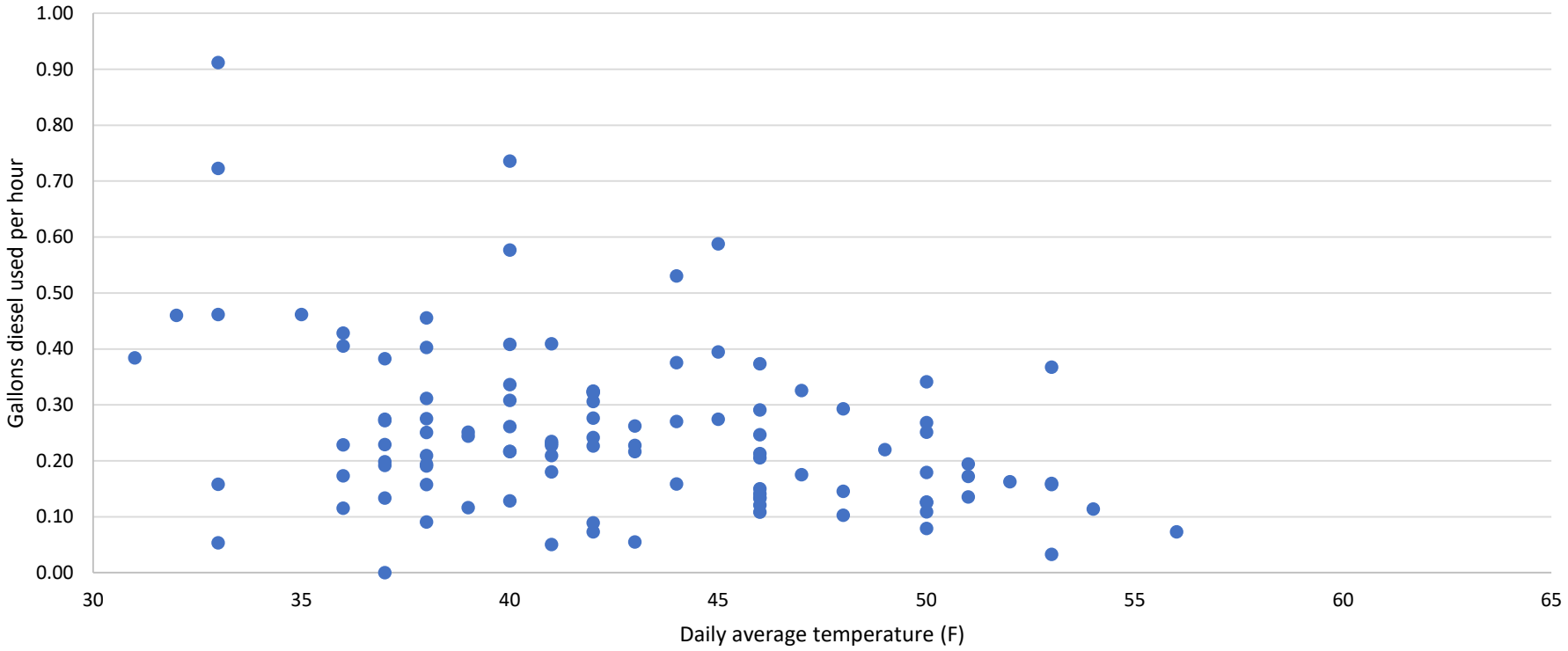

Figure 12 notes: Gallons of diesel used by the diesel heater per hour of operation was calculated for the fueling data provided by LTD. Operating hours for days where the bus was put into service but not fueled were added to the operating hours for the next day when the bus was fueled. Daily average temperature for the day the bus was fueled is used in the chart.

Fleet Availability and Maintenance Costs

Fleet Availability and Maintenance Costs

Table 8. Fleet Availability Summary

Availability Summary						
Description	**Bus 16102 (Cumulative)**		**Bus 16105 (Cumulative)**		**Overall (Cumulative)**	
	Days	**%**	**Days**	**%**	**Days**	**%**
In service	231	73%	220	57%	451	61%
Not available to be put into service	0	0%	35	8%	35	5%
Road call, did not complete service	0	0%	0	0%	0	0%
Available, not in service (Operational issue)	85	27%	168	40%	253	34%
OVERALL AVAILABILITY	**100%**		**92%**		**95%**	
OVERALL UTILIZATION	**73%**		**52%**		**61%**	

Table 9. BEB Fleet Maintenance $/mile

Total Maintenance Costs	Total Miles	Maintenance $/mile
$3,386.81	39,649	$0.09

Table 9 notes: Overall maintenance costs for the BEB fleet.

Table 8 notes: Availability is the percentage of time a bus is categorized as "In Service" (Green), "Road Call" (Orange), or "Available, not in service" (Blue). Utilization is the percentage of time a bus is categorized as "In Service" (Green) or "Road Call" (Orange), and represents when a bus was put into service when it was available to do so.

Figure 13. Monthly Availability and Utilization

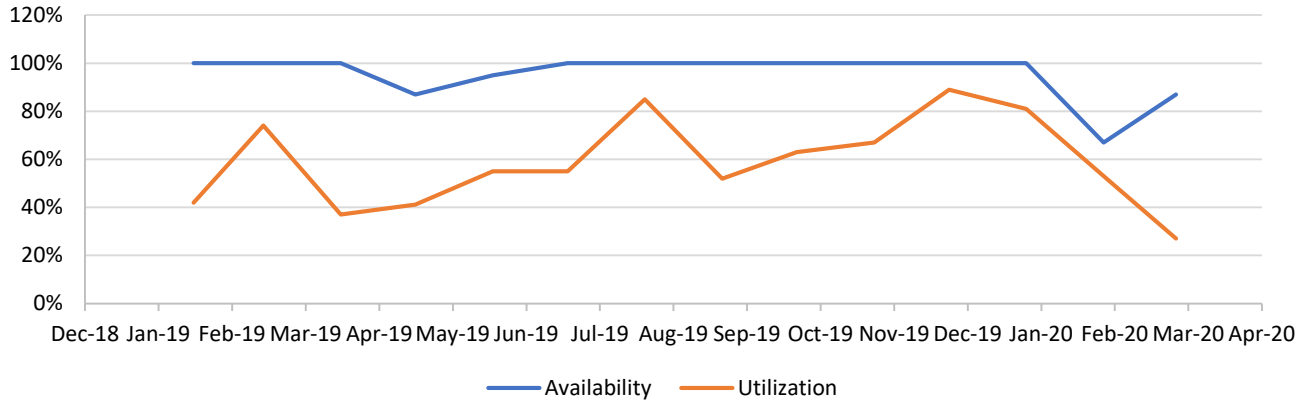

Figure 13 notes: Availability is the percentage of time a bus is categorized as "In Service" (Green), "Road Call" (Orange), or "Available, not in service" (Blue). Utilization is the percentage of time a bus is categorized as "In Service" (Green) or "Road Call" (Orange), and represents when a bus was put into service when it was available to do so.

Greenhouse Gas Emissions

Emission Reductions

Table 10. Avoided Emissions from BEB Fleet Operation

Avoided Emissions from BEB Fleet Operations (2/3/19-3/18/20)	
Avoided Diesel Gallons	9,448
Avoided GHG (MT)	85
Avoided CO_2 (MT)	83
Avoided CO (lb)	38
Avoided NOx (lb)	72
Avoided VOC (lb)	3.58
Avoided PM2.5 (lb)	1.57
Avoided PM10 (lb)	1.75

Table 10 Notes: Cumulative emission reductions from the operation of the BEB fleet is shown, taking into account GHG and CO2 emissions produced from the electrical grid and diesel heater used for cabin heating.

Table 11. Avoided Emissions from BEB Fleet Operation

Emissions from BEB Fleet Operations (2/3/19-3/18/20)	
Grid Emissions – BEB Charging (CO_2) (MT)	8.78
Diesel Emissions – BEB Heating (CO_2) (MT)	4.61

Table 11 Notes: Estimated emissions LTD BEBs. LTD BEB calculations use the emissions factor for the Springfield Utility Board as reported to the Oregon Clean Fuels Program.

Figure 14. CO_2 Produced per Bus (Pilot Deployment Period: 2/2019 - 3/2020)

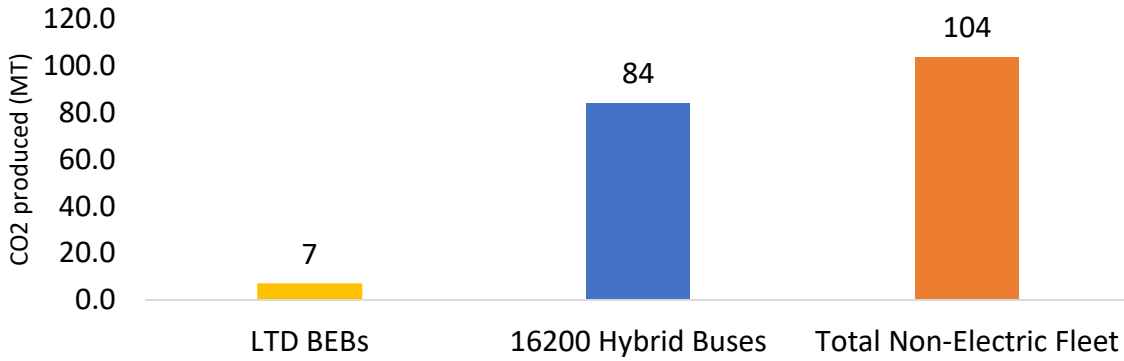

Figure 14 notes: Comparison of estimated CO2 emissions from various propulsion types during the pilot deployment period for the BEBs.

Table 12. Estimated Avoided Emissions from New Flyer BEB Fleet Operation

Estimated Avoided Emissions from New Flyer BEB Operations (Annual)	
Avoided Diesel Gallons	97,778
Avoided GHG (MT)	1,018
Avoided CO_2 (MT)	867
Avoided CO (lb)	425
Avoided NOx (lb)	743
Avoided VOC (lb)	39.77
Avoided PM2.5 (lb)	17.46
Avoided PM10 (lb)	19.40
Grid Emissions – BEB Charging (CO2) (MT)	125.7

Table 12 Notes: Estimated emission reductions from the projected operation of the 11-New Flyer BEBs is shown, taking into account GHG and CO2 emissions produced from the electrical grid. Averaged vehicle efficiency of 2.25 kWh/mile and 40,000 miles annually per bus used for BEBs. Average efficiency of 4.5 mpg used to estimate avoided diesel gallons.

Emission Reductions – Data Sources and Assumptions for Calculations

Data Sources	
Source 1	https://greet.es.anl.gov/afleet
Source 2	https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
Source 3	Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA 2017)
Source 4	EIA, Emission Factors for Greenhouse Gas Inventories as of April 25, 2014
Source 5	https://www.eia.gov/electricity/state/oregon/index.php
Source 6	SUB emissions factor reported in Oregon Clean Fuels Program

Assumptions		
Calculated	22.95	lbs GHG (weighted combination of CO2, methane, & N2O) produced per gallon diesel consumed
From Source 4:	22.38	lbs CO2 produced per gallon diesel consumed
From Source 1:	0.0076	lbs NOx produced per gallon diesel consumed
From Source 1:	0.438	g CO produced per mile driven
From Source 1:	0.041	g VOC produced per mile driven
From Source 1:	0.018	g PM2.5 produced per mile driven
From Source 1:	0.020	g PM10 produced per mile driven
From Source 5:	280	lbs CO2 per MWh generated in OR (2017)
From Source 5:	.280	lbs CO2 per kWh generated in OR (2017)
From Source 3:	0.975	lbs CO2 per lb GHG (CO2eq) total for medium-heavy duty diesel trucks and buses
From Source 6:	5.08	g CO2 per MJ