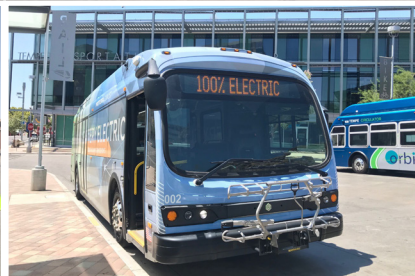


VALLEY METRO

Electric Bus Study Summer 2020



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E EXECUTIVE SUMMARY

During the summer of 2020, Valley Metro tested battery electric buses (BEBs) from three different manufacturers on multiple urban, high density routes. Electric buses bring a number of environmental benefits, but historically, electric buses have been unsuccessful in the Phoenix Metro Area because the vehicles were unable to provide the range necessary for operating existing routes given the technology's adaptation to the region's climate. Battery electric buses use one battery to operate all functions of the bus, and the constant air conditioning demand present in hot climates cause the battery to deplete more quickly than it would in moderate climates. This was seen in 1994 during a pilot program in Phoenix and again in 2016 during an electric bus test in Tempe. Routes in the Phoenix Area span from 30 to 300 miles, with the majority of routes requiring over 100 daily miles per bus. Previous tests showed an electric bus's range to be under 100 miles, which would not support the needs of most routes unless in-route fast charging was used. The low range was an attribute of early electric bus technology and was exacerbated by the extreme heat in this region. In the past five years, electric buses have greatly increased their range and minimized battery impacts during extreme weather. With the improved battery electric bus, these vehicles may now be a viable option for select bus routes in the Phoenix Metro Area.

From August 4 through August 7, during a low of 83°F and a high of 112°F, the 35-foot Proterra Catalyst was tested on a Valley Metro circulator route. This vehicle had an average range of 152 miles under these test conditions, an estimated 185 mile range in 80°F and an estimated 209 mile range in 50°F. From September 22 to September 24, New Flyer tested their 35-foot Xcelsior CHARGE on the same route, with a high of 106°F and a low of 77°F. The New Flyer vehicle had an average range of 180 miles under the test conditions, an estimated range of 184 miles in 80°F and an estimated range of 192 miles in 50°F. Both the Proterra and New Flyer buses demonstrated the ability to operate the circulator

route in all seasons without requiring in-route fast charging. The BYD bus was tested on a local bus route but experienced some operational issues which made it difficult to estimate range in various climates.

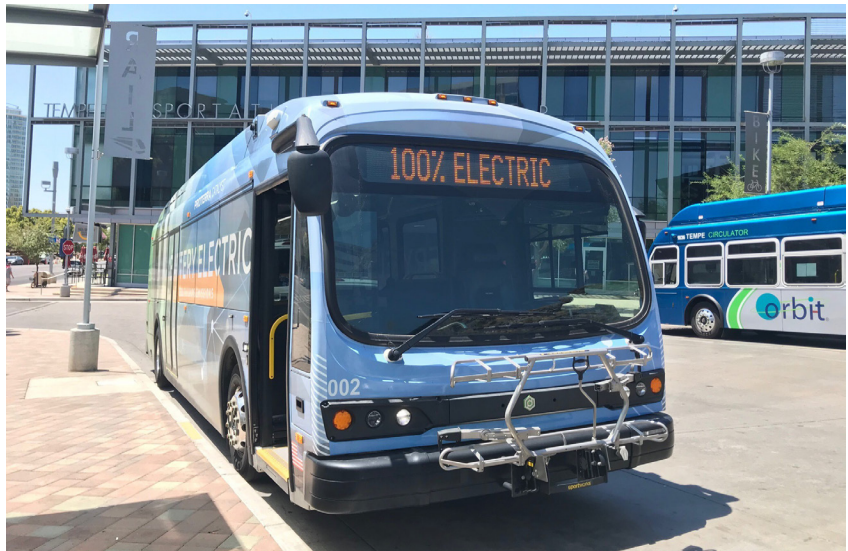
With improved battery technology, there is potential to utilize battery electric buses on some routes throughout the Greater Phoenix Area. The demonstrations and research has led Valley Metro to pursue an initial investment of battery electric buses. There are estimates that show BEBs have a similar or reduced total cost of ownership in comparison to traditional buses. Starting small would allow Valley Metro to gain operational and maintenance experience and help determine lifecycle costs of battery electric buses. Operating electric buses would also increase understanding of battery degradation, help set realistic expectations for BEB performance and contribute to the creation of attainable goals around BEB integration for the region. This report will further discuss the environmental benefits of electric buses in the Phoenix Metro Area, details of each bus demonstration, demonstration results, preliminary cost estimates and next steps.



1 PURPOSE OF REPORT

The purpose of the electric bus demonstrations is to determine if battery electric buses could operate in place of natural gas or diesel buses that currently operate on Valley Metro routes. While Valley Metro is looking at a variety of routes for electric buses, this study focuses on the FLASH circulator and Route 56. See Section 4 for details on these routes and justification for using these routes for demonstration purposes.

To determine if electric buses could be an option for select routes, the project team needed to understand the expected range of an electric bus in hotter months. Battery electric buses currently have a shorter range than traditional buses, but range also varies depending on the following factors: climate, topography on routes, use of heater or HVAC units, number of passengers, and driver behavior. For the Phoenix Metro Area, the most applicable of these factors is air conditioning use in the summer. Because all systems within the bus



1: Proterra Catalyst Bus

are powered through the same battery, higher use of air conditioning will result in a faster battery drain; potential buses need to be tested during extreme temperatures to ensure that they are viable for the area of operation. Section 6 of this report discusses the ranges observed during the bus demonstrations.



2: Interior of BYD bus with water barrels

2 THE CASE FOR BATTERY ELECTRIC BUSES

2.1 Environmental Benefits

Carbon Emissions

One criticism of electric vehicles is that they are only as clean as the energy used to charge them. If an electric vehicle were charged with energy generated by coal power, the electric vehicle would in fact have more negative environmental impacts than a conventional car (Knobloch, 2020). Decades ago, this notion was true in many parts of the country, but as energy becomes increasingly cleaner in the United States, the electric vehicle becomes more sustainable.

As of 2018, battery electric buses have lower global warming emissions than natural gas and diesel-hybrid buses everywhere in the country. Assuming that a bus were charged with the national electricity mix, an electric bus would produce about 50 percent fewer carbon emissions than natural gas or diesel buses (UCSUSA, 2018). In Arizona, the energy sources to generate electricity are cleaner than the national average. The state relies heavily on natural gas and nuclear power, along with some renewables and a small amount of coal power (currently being phased out). With Arizona's current electricity mix, an electric bus produces 58 percent less carbon dioxide (CO₂) emissions than a diesel bus and 52 percent less CO₂ than a natural gas bus (UCSUSA, 2018).

Criteria Air Pollution

Battery electric buses eliminate criteria air pollution, which is a category of air pollutants that cause respiratory damage. Criteria air pollutants include particle pollution, ground-level ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, and lead. The Clean Air Act requires the US Environmental Protection Agency to set National Ambient Air Quality Standards (NAAQS) for these pollutants. The criteria air pollutant that the Phoenix region has the most difficulty controlling is ozone. In Arizona, the primary source of ozone pollution

comes from nitrogen oxides (NO_x). As reported by the MAG Eight-Hour Ozone Moderate Area Plan for the Maricopa Nonattainment Area, there are 127 metric tons of NO_x emitted each day and vehicle travel accounts for 49 percent of emissions. Natural gas and diesel hybrid buses emit fewer criteria air pollutants than diesel or gasoline buses, but BEBs are the only vehicles that produce no criteria pollutants. This makes electric vehicles a part of the solution to reducing the region's criteria air pollution.

Life Cycle Sustainability

The life cycle sustainability of electric buses is almost identical to natural gas or diesel buses. From a mechanical standpoint, electric buses have mostly the same parts as a traditional bus with the only significant difference being a battery to power the engine rather than internal fuel combustion. Most buses can be sold and/or salvaged at the end of life, but there are special considerations for disposing of an electric bus's battery.

Inside an electric bus, a series of lithium-ion batteries are strung together to form a battery pack that stores energy to power the vehicle. There are a few environmental concerns with lithium-ion batteries. The most prominent concern is the sourcing of lithium. While it can be argued that lithium mining is harmful to the developing world, it should be noted that the continued use of carbon emitting fuels has similar effects on international communities. Additionally, there are increasing efforts to increase equity in lithium mining. The other concern with lithium is recycling. Manufacturers are understandably secretive about what goes into their batteries, which makes it harder to recycle them properly. Furthermore, only some recycling facilities have the ability to recycle lithium batteries. For this reason, it has become standard practice for the manufacturers to take the batteries

¹ Energy mix of a country is the specific combination of different energy sources it uses to meet its energy consumption needs

² Life cycle sustainability analyzes the potential overall environmental impacts associated with all the stages of a product or service's life from the extraction of raw materials; the processing of raw materials in order to fabricate a product; the transportation and distribution of the product to the consumer; the use of the product by the consumer; to the disposal of the product's materials after its use.

back at the end of life to dispose of them on behalf of the client or repurpose them for energy storage. While no supply chain is perfect, there are efforts to increase equity in lithium mining, and the disposal of lithium batteries is improving as technology progresses.

Clean Charging

Arizona primarily generates electricity through natural gas and nuclear electric power. Coal was previously a large portion of this mix until Arizona's largest coal plant, the Navajo Generating Station, closed in December 2019. There is still some coal power used, but it is miniscule in comparison to what has been used historically. The remainder of Arizona's coal plants are planned to be phased out. Natural gas, motor gasoline, petroleum, and jet fuel provide most of the energy for the transportation sector (Energy Information Administration, 2018). Renewable energy (solar, wind, and hydropower) makes up about 10 percent of energy in Arizona. In November 2020, the Arizona Corporation Commission passed a proposal requiring utilities to be 100 percent carbon free by 2050 and meet particular benchmarks along the way. According to the commission, carbon free energy includes the following sources: solar, wind, hydroelectric, and nuclear. The following sources will be phased out for energy generation over the coming decades: coal, petroleum, natural gas, oil, and shale.

This is important to transit for three reasons. First, energy is relevant because transportation accounts for the highest energy use in the state. When looking at energy use by sector, transportation uses 36 percent of the state's energy, residential uses 27 percent, the commercial sector uses 23 percent and the industrial sector uses 15 percent (Energy Information Administration, 2018). The second reason that the energy transition is relevant is because a majority of Valley Metro's bus fleet runs on compressed natural gas. If the natural gas supply in Arizona were to significantly decrease or be unavailable, this would affect a large portion of the bus fleet. Lastly, this energy transition is important because it means operating battery electric buses would be more sustainable as time goes on. Given today's sources of electricity generation, electric buses are already more environmentally

friendly than natural gas or diesel buses. As 2050 draws closer and energy from the grid becomes increasingly carbon-free, the electric bus will show tremendous environmental superiority in comparison to the natural gas and diesel bus.

2.2 Operational Benefits

Electric buses are the quietest type of transit bus, with some models being so quiet that they have to be equipped with noise emitters so passengers with visual disabilities can hear them coming. Electric buses are often associated with lower maintenance costs because there are fewer components inside the vehicles that need to be maintained. See Section 7 for more information on BEB maintenance costs.

2.3 Maricopa County Specific Benefits

Operating electric buses are a way for Valley Metro to support multiple city and county wide goals. At the city level, battery electric buses align with the City of Phoenix and City of Tempe's carbon reduction goals. It is anticipated that other cities will develop carbon reduction goals and operating electric buses would help cities move closer to their respective goals. Additionally, the operation of electric buses would improve air quality in a region that urgently needs cleaner air. The Phoenix Metro Area has been in non-attainment for federal air quality standards since 2008 and ranks lower than New York City in terms of air quality (Environment Arizona Research & Policy Center 2018). Additionally, the American Lung Association ranked the Phoenix area in 2011 as the 19th most ozone polluted cities in the U.S., with an unfavorable increase in 2016 to a ranking in the 4th spot (American Lung Association 2016, 2011). Operating electric buses would help the region move toward attainment of federal air quality standards.

3 PEER AGENCY ELECTRIC BUS PROGRAMS

Of the six agencies typically used by Valley Metro for peer comparison, five operate battery electric buses. In Arizona, both Sun Tran in Tucson and Mountain Line in Flagstaff are operating or planning operations for BEBs. Valley Metro conducted peer agency interviews to learn about the programs of each peer city. For the Arizona transit agencies, the information was obtained through informal conversations and publicly available information. This section will provide an outline of each of the agencies' programs.

Regional Transportation District (RTD) – Denver, Colorado

- Fleet of 36 BEBs that operate 3-mile route in eight-hour shifts
- Charging at bus depot
- Planning for addition of 17 BEBs
- First 36 buses were locally funded
- Second phase of project funded through VW Settlement (\$11 million) and a Federal Transit Administration (FTA) grant (\$2.6 million)

Utah Transit Authority (UTA) – Salt Lake City, Utah

- Fleet of seven BEBs that operate a 9-mile route
- Charging at bus depot
- Added BEBs to the fleet to diversify fuel mix and support environmental goals
- Estimated \$9 million project with \$5.4 million of funding from an FTA grant

Dallas Area Rapid Transit (DART) – Dallas, Texas

- Fleet of seven BEBs that operate a 9-mile route in 16-hour shifts
- Utilizes in route fast charging
- \$9 million project with \$7.6 million from an FTA grant

San Diego Metropolitan Transit System (MTS) – San Diego, California

- Fleet of eight BEBs that will be rotated and tested on all routes under 100 miles

- Fast charging at bus depot
- California transit is required to have 100% zero emission buses by 2040
- MTS will be adding more BEBs after testing
- \$12 million project with \$6 million funded through a state grant

TriMet – Portland, Oregon

- Fleet of nine BEBs that operate a 26-mile route and a 30-mile route in 18-hour shifts
- Overhead charging in route and slow charging at bus depot
- Planning to purchase 80 additional BEBs within six years
- Estimated over \$65 million project with \$50 million funded through State of Oregon and \$7.7 million provided through FTA Low/No grants.

Sun Tran – Tucson, Arizona

- Leased one Gillig bus in 2020 to test on different routes and has since purchased five BEBs to begin service in 2021 and five more to begin in 2022
- Slow charging at bus depot
- \$4.8 million project: \$3.76 federal share with \$2.6 million from an FTA grant, \$668,000 local match, \$375,000 in-kind from Tucson Electric Power (TEP)

Mountain Line – Flagstaff, Arizona

- Developing a Zero Emissions Bus Transition Plan, which assesses zero emissions bus technologies specifically in the context of Flagstaff's location and climate and identifies the steps to transition to an all-electric fleet
- Received a grant for \$17.3 million from the FTA for a downtown connection center and electric buses. \$1.6 million of this funding is planned for purchasing two battery electric buses for testing (Arizona Daily Sun, 2019)

4 ABOUT THE DEMONSTRATION ROUTES

The FLASH circulator and Route 56 were used for the battery electric bus demonstrations. The Proterra and New Flyer 35-foot buses were demonstrated on the FLASH and the 40-foot BYD bus was demonstrated on Route 56. For the 35-foot buses, Valley Metro wanted to create similar demonstration conditions for a more accurate comparison between the two buses. The FLASH route was selected because it is a relatively shorter route in comparison to others in the region, its close proximity to the temporary charging stations

set up at the Tempe bus yard, and the route was not operating in the summer of 2020, which made this route ideal for testing. Additionally, due to the COVID-19 pandemic, manufacturers were not allowing passengers to board demonstration buses. Route 56 was used to demonstrate the 40-foot BYD bus. Similarly, this route was selected because it has a shorter range in comparison to other routes in the region and because of the close proximity to temporary charging stations.



3: Proterra bus parked at the East Valley Bus Operations and Maintenance facility

5 BUS MANUFACTURERS AND DEMONSTRATIONS

A total of 10 days of testing were collectively performed between the three manufacturers – Proterra, BYD, and New Flyer, during the summer of 2020. Due to a variety of constraints, including construction impacts, COVID-19 related precautions, varying ambient temperatures and unique stipulations within each demonstration agreement, the parameters for each test varied slightly as noted below. Because of this, the performance of each vehicle should be compared with caution. Nonetheless, the demonstration was successful in ascertaining the general capabilities of each vehicle model to operate within the considered duty cycles.

5.1 BYD USA

About BYD USA

Build Your Dreams (BYD) USA is a battery technology company that manufactures a wide range of electric vehicles from forklifts to double decker buses. The company was founded in 1995 and has about 40,000 electric buses in service worldwide (BYD does not state how many of these operate in the US). One transit agency that operates BYD transit buses is RTD.

Demonstration

BYD provided their K9 model 40-foot bus for this demonstration. The demonstration occurred over a period of three consecutive days: August 26 – August 28. The high temperature during the demo was 113°F and the low was 89°F. The demonstration took place on Route 56 (Priest Drive) (Figure 1). This route was selected due to the variety of all-day and peak-time-only vehicle schedules, combined with the relatively close proximity to the East Valley Bus Operations and Maintenance Facility (EVBOM). Peak-only vehicle schedules were operated on days one and two, and an all-day vehicle schedule was operated on day three. The vehicle was operated only by BYD staff during the demo with no support from agency staff. A static load using 55-gallon water barrels was increasingly applied, between 0 barrels on day one and 14 barrels by day three. Slightly more weight was applied to this bus in



4: BYD demo bus

comparison to the other test buses because BYD’s bus was larger and Route 56 generally has higher ridership than the FLASH.

The vehicle operated morning and afternoon peak-time vehicle schedules on day one without incident, however an HVAC system failure was reported on day two and the bus returned to the facility early in the afternoon. The HVAC fault was unresolved by day three when the bus was dispatched to simulate the all-day block. Because the HVAC system was not operating at intended capacity and did not maintain an acceptable internal temperature following the reported failure on day two, the vehicle’s energy efficiency and range data would need to be considered with caution as it is believed the HVAC system may have consumed less energy than typically expected while not operating at full capacity.

Figure 1: Route 56 for BYD Bus Testing



5.2 Proterra

About Proterra

Proterra is an electric bus company founded in 2004 that designs and manufactures transit and school buses. As of October 2020, the company has 650 buses operating in the United States and 400 on order and planned for service. Some transit agencies that operate Proterra buses are DART, UTA, Tri-Met and King County Metro in Washington State.

Demonstration

Proterra provided the first demonstration vehicle – the Proterra Catalyst 35-foot bus. The demonstration occurred over a period of four consecutive days: August 4th – August 7th. The high temperature during the demo was 112°F and the low was 83°F. A combination of Proterra staff and local agency staff operated the bus throughout the demonstration. The intent was to demonstrate the vehicle’s capabilities when assigned to the FLASH service, however due to multiple construction projects along the regular FLASH route, a modified version of the route was developed. See Figure 2 for the route used during the demonstration. It should be noted that the route operated on days one and two was shorter in length than the route operated on days three and four, resulting in additional idle time and fewer



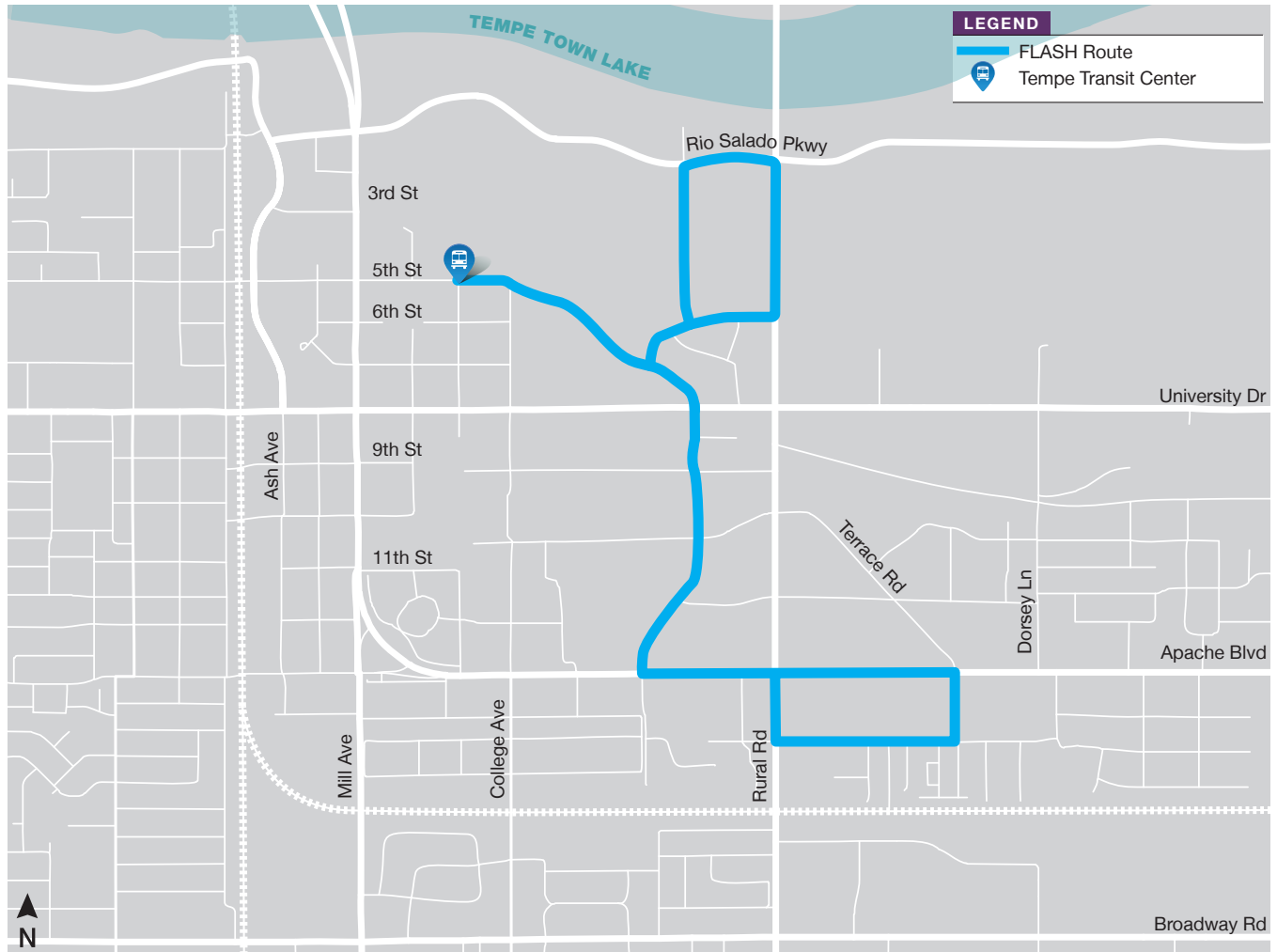
5: Proterra demo bus

miles-per-trip during the first two days compared to the final two days. A static load was applied to the vehicle incrementally throughout the test, using water-filled 55-gallon plastic barrels. On day one the vehicle operated with no load. On days two and three a partial load was applied using four of the barrels (approximately 2,000lbs or 13 passengers). On day four, a full load was applied using ten barrels (approximately 4,800lbs or 32 passengers). The vehicle pulled out of the yard later than expected on days two and four due to a charging issue attributed to the demonstration charger degrading during high ambient temperatures, requiring additional charge time. The vehicle itself performed without any mechanical faults or failures throughout the demonstration. At Proterra’s request and to increase ventilation in response to the pandemic, the HVAC system was programmed to condition only fresh, outside air for the duration of the demonstration and it should be noted the HVAC system would work harder and draw more power when operating in this configuration, especially considering the high ambient summer temperatures.



6: Interior of Proterra bus with water barrels

Figure 2: FLASH Route for Proterra Bus Testing



5.3 New Flyer

About New Flyer

New Flyer is a well-established bus manufacturer with a vast experience using multiple propulsion systems, including alternative fuels, electric and hybrid technology. There are 104 New Flyer electric buses in service in the United States and 237 buses on order to begin service in 2021 (data as of Q4, 2020). Some of the transit agencies that operate New Flyer battery electric buses are UTA, Tri-Met, San Diego Metropolitan Transit System, and LA Metro.

Demonstration

The third and final demonstration was performed in conjunction with bus manufacturer New Flyer, using the Xcelsior CHARGE 35-foot bus. The demonstration occurred over a period of three consecutive days: September 22nd – September 24th. The high temperature during the demo was 106°F and the low was 77°F. The vehicle was operated solely by New Flyer staff during the demo with no support from agency staff. The vehicle was operated on the regular FLASH route (no detours) throughout the duration of the

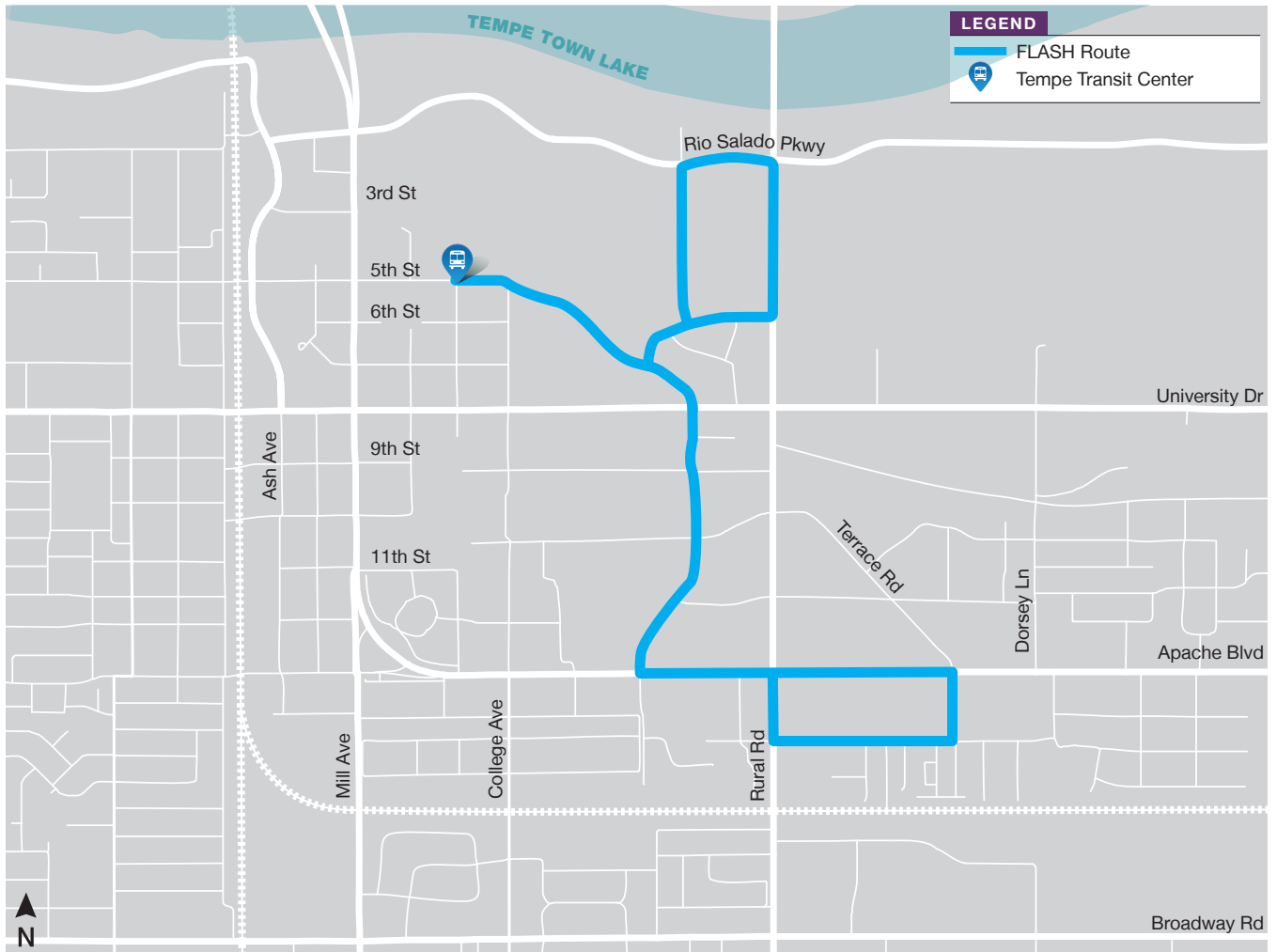
demonstration (Figure 3). A static load was applied to the vehicle prior to day 1 using 10 water-filled barrels (approximately 4,800lbs or 32 passengers), with the intent of removing part of the load for the remaining two days. However, late into the first day of demonstration, the vehicle experienced a battery fault in which one of the five battery strings was not properly connected, causing the bus to deplete the remaining four battery strings

prematurely and without warning. As a result, the 10-barrel load remained on the bus for day two, and prior to beginning the third day of testing, six barrels were removed for a remaining four-barrel load (approximately 2,000lbs or 13 passengers). Aside from the mechanical failure observed on day one, the vehicle completed testing and was able to receive a charge effectively and as intended throughout the duration of the test.



7: New Flyer demo bus

Figure 3: FLASH Route for New Flyer Bus Testing



6 RESULTS

6.1 BYD USA

During the three-day demo there were multiple HVAC issues. The air conditioning unit inside the vehicle was not emitting cool air on day two or day three. The manufacturer attempted to repair the HVAC unit during the demo but was unable. It was discovered after the testing that the air conditioning unit did not have the proper freon levels and was therefore not able to effectively cool the bus. Because the HVAC issue could provide inaccurate range and efficiency data, the BYD demo results will not be included in this report because.

6.2 Proterra

Energy Consumption

The Proterra bus operated for four days and traveled a total of 406 miles. The average efficiency was 2.61 kilowatt-hours per mile, which is the equivalent of about 14.5 miles per gallon. 42 percent of the energy consumed powered the powertrain, 41 percent powered the HVAC unit, and the remaining energy powered low voltage equipment, the air compressor, and power steering.

Range

The vehicle's maximum range under the test circumstances was 152 miles. Given the air circulation COVID-19 protocols in place, this is a conservative representation of the vehicle's ability to perform. If the air was being recirculated like it is in normal operating conditions, the range would have been greater than 152 miles.

Air Conditioning

The bus maintained an average internal temperature of 74 degrees when outside temperatures averaged 106 degrees and the bus was consistently bringing in outside air. Three different Valley Metro staff rode the bus and assessed the thermal comfort of the vehicle, and all three staff members felt that the air conditioning was adequate. Air conditioning use accounted for 41 percent of battery usage.

Charging

The bus experienced some difficulty charging because of the placement of the temporary charging

infrastructure. The charger used during the demo was a shop charger designed to be used indoors where there is a controlled climate. As such, the charger is not weatherproof, and had only been designed to operate at full output up to 104°F. The charger was placed in full sun at the Tempe bus yard, and the heat caused the charger to degrade and charge the bus slower than expected. If using a permanently installed charger, the bus is estimated to charge in as little as 1.8 hours.

Rider and Operator Feedback:

Below is some of the feedback gathered from Valley Metro staff that rode the Proterra bus:

- "Bus is quieter than others at the Tempe Transit Center"
- "Good acceleration, turning, and braking"
- "Ride quality is about the same as current buses"

One First Transit operator drove this bus during the demonstration. The operator noted that they liked the brakes, acceleration, and that the operator seating area had slightly more room than other buses. The operator enjoyed driving the bus and supports the purchase of this bus.

6.3 New Flyer

Energy Consumption

The New Flyer bus operated for two days and traveled a total of 240 miles. The average efficiency was 2.0 kilowatt-hours per mile, which is the equivalent of about 16.9 miles per gallon. 60 percent of the energy consumed powered the powertrain, 26 percent powered the HVAC unit, and the remaining energy powered low voltage equipment, the air compressor, and power steering.

Range

The vehicle's maximum range under the test circumstances was 181 miles.



8: Proterra bus parked at the East Valley Bus Operations and Maintenance facility

Air Conditioning

This bus was not equipped with the same sensors as the Proterra bus. The HVAC was set to 68 degrees through the duration of the demo but the average temperature inside the bus was not recorded. Three different Valley Metro staff rode the bus and assessed the thermal comfort of the vehicle, and all three staff members felt that the air conditioning was adequate and comparable to the Proterra bus. Air conditioning use accounted for 26 percent of battery usage.

Charging

The bus took two hours to go from a five percent to a 95 percent charge.

Rider and Operator Feedback

Valley Metro staff that rode this bus noted that this was the quietest bus tested. No First Transit operators drove this bus during the demo.

6.4 Comparing Proterra and New Flyer Demonstration Vehicles

HVAC Performance

From a qualitative perspective, the air conditioning on both the Proterra and New Flyer buses were adequate. Multiple staff members rode the buses to assess comfort, and employees noted that the air conditioning inside the vehicles felt comparable to the natural gas buses presently used. The Proterra bus was equipped with a sensor that monitored the internal temperature throughout the service day,

but the New Flyer bus only recorded data on the set point of the HVAC system.

It is difficult to compare the HVAC systems in a BEB and a natural gas or diesel bus because the mechanical design and operating characteristics are significantly different. Comparing output specifications, the rated cooling capacity of the natural gas bus HVAC unit is higher than the rated cooling capacity of the BEB; New Flyer indicates the HVAC cooling capacity of the BEB is 72,000 BTU/hr., whereas the HVAC cooling capacity of the standard natural gas bus is 105,000 BTU/hr. However, this comparison is somewhat misleading because the actual performance of the standard natural gas bus HVAC unit at any given time is dependent on vehicle speed, or more specifically engine speed. The BEB HVAC unit specifically eliminates this problem, by “eliminating the effect of variable engine RPM on load and demand” and provides “Optimum A/C unit capacity at all bus speeds” (Thermo King brochure provided by New Flyer, 11/20). The HVAC system cooling performance as observed during the testing period was effective, and the vehicle remained at a comfortable and acceptable interior temperature when observed by staff.

Battery Performance

Table 1 depicts the performance of the Proterra and New Flyer buses during their demonstrations. It can be seen that the New Flyer bus displayed higher battery efficiency, longer range and longer operation time—however the bus was tested under less difficult conditions than the Proterra bus.

Tables 2-4 show the expected range and efficiencies of the vehicles at different temperatures based on the data collected during the demonstrations. A key takeaway from this data is that the Proterra bus has the potential for a longer range but shows a higher range variability depending on climate. On the other hand, the New Flyer bus shows a lower range in moderate climate conditions, but the bus maintains

a more consistent range as the weather changes. The New Flyer bus also demonstrated a longer range in the summer, however the HVAC differences explained earlier should be taken into consideration. The Proterra bus ranges from 152 miles in 112°F to 209 miles in 50°F, while the New Flyer bus ranges from 160 miles in 112°F and 192 miles in 50°F.

Table 1: Performance Results of Summer 2020 Bus Testing

BUS	AVG TEMPERATURE DURING SERVICE DAY (°F)	AVG EFFICIENCY IN KWH/MI	MPG EQUIVALENT DESCRIPTION	MAXIMUM RANGE	MAXIMUM TIME OF OPERATION
Proterra 35-foot E2	105.5	2.6	15	152	19:43
New Flyer 35-foot Xcelsior CHARGE	98.7	2.0	19	181	20:30

Table 2: Modeled Bus Performance in 112°F

BUS	AVG EFFICIENCY IN KWH/MI	MPG EQUIVALENT	MAXIMUM RANGE
Proterra 35-foot E2	2.6	15	152
New Flyer 35-foot Xcelsior CHARGE	2.4	16	160

Table 3: Modeled Bus Performance in 80°F

BUS	AVG EFFICIENCY IN KWH/MI	MPG EQUIVALENT	MAXIMUM RANGE
Proterra 35-foot E2	2.2	17	185
New Flyer 35-foot Xcelsior CHARGE	2.1	18	184

Table 4: Modeled Bus Performance in 50°F

BUS	AVG EFFICIENCY IN KWH/MI	MPG EQUIVALENT	MAXIMUM RANGE
Proterra 35-foot E2	2.0	19	209
New Flyer 35-foot Xcelsior CHARGE	2.0	19	192

Planning for Battery Degradation

During the New Flyer demonstration, the electric bus demonstrated an energy efficiency of 2.0 kilowatt-hours per mile. The 35-foot New Flyer electric bus is available with a 437kWh battery capacity in comparison to the 400 kWh bus demonstrated during the summer (New Flyer, 2020). In new condition, the 437kWh vehicle would be expected to operate up to 219 miles during the summer. New Flyer considers the end-of-life capacity to be 70 percent, or 306 kWh. 70 percent of battery capacity would bring the expected range to 153 miles. The standard New Flyer warranty that is included with the purchase of each vehicle guarantees 70 percent for six years. Purchasing the extended warranty would guarantee 70 percent for 12 years or 500,000 miles.

During the Proterra demonstration, the electric bus demonstrated an energy efficiency of 2.6 kilowatt-hours per mile. The Proterra electric bus is available with a 440 kWh battery capacity (Proterra, 2020).

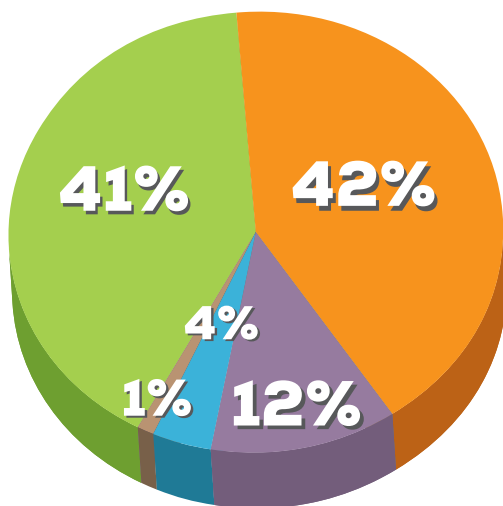
In new condition, the vehicle would be expected to operate up to 152 miles during the summer. Proterra warrants their batteries for 12 years and guarantees 70 kWh per every 110 kWh, or 64 percent of usable battery power. Proterra also offers an extended warranty on the battery that guarantees 80 percent of battery capacity for 12 years. At the end-of-life with no extended warranty, the expected range would be 97 miles; with the extended warranty, the range would be 122 miles. When looking at this end of life range, it is important to note the harsher conditions that the Proterra vehicle was tested in and consider this range as a worst-case-scenario. Another aspect to consider is the differences between how New Flyer and Proterra advertise battery capacity. Proterra indicated that 90 percent of their advertised battery capacity is usable, whereas New Flyer simply indicates that the batteries have a usable capacity of 440 kWh. With this in mind, the Proterra numbers are lower and New Flyer has a new battery with a higher capacity rating.

Figure 4 compares the battery usage between the Proterra and New Flyer buses during their respective demonstrations. The biggest difference between the two buses can be seen in the energy used to power

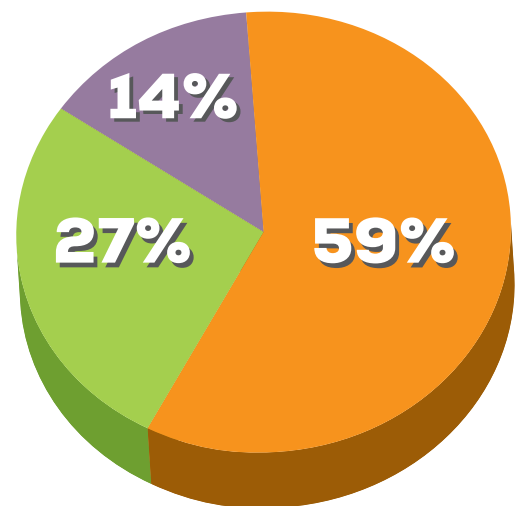
the HVAC system. The Proterra bus used 41 percent of the battery to power the HVAC system while the New Flyer bus used 27 percent of its battery power.

Figure 4: Battery Consumption by Category

Proterra Energy Consumption Summary



New Flyer Consumption Summary



- HVAC
- Powertrain
- HVAC
- Low Voltage
- Air Compressor
- Other
- Power Steering

7 BATTERY ELECTRIC BUS COST ESTIMATES

Vehicle

Battery electric buses have a higher upfront cost when compared to natural gas or diesel buses. Depending on specifications, a New Flyer electric bus ranges from \$800,000 to \$850,000 (as of Q4 2020). Similarly, a Proterra bus ranges from \$739,000 to \$850,000 (as of Q4 2020). In comparison, a standard 35-foot natural gas bus costs approximately \$560,000 in 2020 dollars.

Charging Infrastructure

The initial electric bus investment would utilize slow charging at the bus depot to charge buses overnight, with one charging station for each bus. The total charging infrastructure costs per vehicle is estimated to be \$200,000. The charging station itself is estimated at \$75,000 per charger and engineering, design and installation are estimated at \$125,000 per charging station.

Charging Costs

Charging costs could vary depending on the location used for charging the buses. In order to determine more accurate costs, Valley Metro would need to pick a facility for charging station installation and start working with the respective utility provider. It is difficult to give an accurate estimate at this time.



Maintenance Costs

Valley Metro's current internal combustion circulators have a per vehicle average maintenance cost of \$0.39/mi and a maintenance cost range of \$0.20/mi to \$0.71/mi. The per vehicle estimated maintenance cost for the Proterra and New Flyer BEB's is between \$0.20 and \$0.40 per mile (Proterra and New Flyer estimates as of Q4, 2020). The electric bus cost per mile estimate does not include replacing the battery. While replacing a battery is the most

expensive potential maintenance, depending on the duty cycle of the bus it is not always necessary. If a route similar to the test route were run with electric buses, it is not expected that Valley Metro would need to replace the battery. The cost to replace the battery is estimated to be \$200,000. This cost can be covered by purchasing an extended warranty from the electric bus manufacturer. The likelihood of batter replacement and its impact maintenance costs would need to be evaluated on a route by route basis.

Training

Both Proterra and New Flyer include some mechanic training for electric buses. Special tools and training (including ongoing recertification training) would be required for the maintenance of high-voltage systems present on all electric buses demonstrated to-date. Valley Metro has historically acquired special equipment/tooling as part of the bus procurement (which is beneficial due to the availability of federal funding for bus purchases) and some initial training hours. However, the service contractor would be ultimately responsible for ensuring all staff maintaining the electric buses are trained and certified to work on the equipment. Training would also be required to coordinate vehicle charging as needed, including oversight of nightly charging as part of an optimized charging strategy.

Warranties

Proterra and New Flyer electric buses have standard and extended warranty options available for various components of the buses. Proterra's standard warranty that is included in the base price covers the following components outlined in Table 5. In addition to the standard warranty, Proterra offers extended warranty options for their buses. Considering Valley Metro's routes, the 12 Year Energy Storage System Warranty is recommended. This would ensure that 80 percent of the battery capacity would be usable for the lifetime of the vehicle, in comparison to just 64 percent from the standard warranty. This extended warranty is estimated to cost \$75,000 per bus. It is not anticipated that the other warranty options would be necessary.

Table 5: Proterra Base Warranty Standard Terms

COMPONENT	YEARS	MILES
Complete bus	1	50,000
Main composite monocoque structure	12	500,000
Structural system	3	150,000
Major components	2	100,000
Energy storage systems	6	300,000
Charging systems	2	N/A

Like Proterra, New Flyer has a standard warranty that is included with each bus and extended warranty options that can be purchased for different

components of the vehicle. **Table 6** shows the standard terms of the base warranty.

Table 6: New Flyer Base Warranty Standard Terms

MAJOR COMPONENT DESCRIPTION	YEARS	MILES
Base Bus Warranty	1	50,000
Basic Bus Structure	3	150,000
Chassis Structure (Integrity)	12	500,000
Chassis Structure (Corrosion)	12	500,000
Propulsion System	6	300,000
Energy Storage System	6	300,000
Axle (front and rear)	5	300,000
A/C	2	Unlimited
Brake System	1	50,000
Destination Signs	6	Unlimited
Door Systems	3	150,000
Wheelchair Ramp	2	Unlimited
Electrical System	3	150,000
Tires	2	24,000
LED Headlights	6	Unlimited
Air Compressor	1	Unlimited
New Flyer Connect System	2	Unlimited
Paint	5	Unlimited

While extended warranties can be purchased for a variety of components, the project team anticipates that the battery storage system warranty would be the only extended warranty needed. This warranty will ensure the bus will maintain 70 percent of battery capacity through the 12-year life of the

bus. Purchasing this warranty is estimated to cost \$55,000 per bus.

Table 7 summarizes the cost estimates listed above to show the anticipated initial cost for procuring a battery electric bus. The estimate assumes the higher warranty cost of \$75,000.

Table 7: Battery Electric Bus Initial Cost Estimate

ITEM	QUANTITY	COST PER UNIT	TOTAL
Bus	1	\$800,000	\$800,000
Charger	1	\$125,000	\$125,000
Charger Installation	1	\$75,000	\$75,000
Warranty	1	\$75,000	\$75,000
		Total Initial Cost	\$1,075,000

8 NEXT STEPS

After multiple electric bus demonstrations during the summer of 2020, it is apparent that electric bus technology is rapidly evolving and is becoming a more viable option for regions with hot climates. An initial investment of battery electric buses would further knowledge of the technology in our region and bring numerous environmental benefits to the community. There is also the potential for cost savings through the life of the bus. In order to bring electric buses into service in the region, the project team has identified the following as critical next steps.

- Coordinate with Utility Providers. The cost to charge the vehicles has a large impact in the overall cost to operate electric buses. When transit agencies work closely with their electric providers, they are able to create charging schedules that benefit both the utility and the transit agency.
- Determine Battery Electric Bus Manufacturer. New Flyer and Proterra demonstrated the ability to be able to operate shorter range routes during peak climatic conditions. Some additional research should be done to determine which bus would best suit Valley Metro's needs and determine the exact costs associated with each bus manufacturer. Makes and models of electric buses that entered the market after the summer 2020 testing should also be considered.
- Seek Funding Opportunities. There are a variety of grant programs that support transitions to electric vehicles. Valley Metro should begin researching and applying for funding opportunities to support the upfront cost of electric buses and the electric charging infrastructure.

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