

Electric Transit Bus Demonstration Project

Testing Electric Transit Buses in Vermont

EFFICIENCY VERMONT RESEARCH AND DEVELOPMENT REPORT

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Efficiency Vermont
December 2017

Acknowledgements

Jennifer Wallace-Brodeur, Tom McCarran, Ingrid Malgrem, and Justine Sears of VEIC provided technical and research support to this project. Thank you to Advance Transit, Green Mountain Transit (GMT), and the University of Vermont (UVM) in their support as test sites. Build Your Dreams Motors (BYD) generously provided their vehicle for the demonstration project. Finally, the Burlington Electric Department was an active and supportive partner throughout this project providing not only technical support but also their location as a charging site for GMT and UVM.

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Executive Summary

The State of Vermont, Vermont distribution utilities, and Efficiency Vermont have long understood the importance of the transportation sector in creating an efficient, low carbon energy future. While there has been much attention on light duty vehicles, there are other fleets in Vermont that offer opportunities for electrification, including public transit vehicles.

Transit buses transport some of the state's most vulnerable populations, providing equitable access to transportation and creating public health benefits. Transit vehicles (or buses) however, have a disproportionate impact on both energy consumption and vehicle emissions because they tend to be high in mileage and have low fuel economy. As a result, transit is an attractive market for electrification.

To better understand how electric buses would perform in Vermont's operating environment and assess various conditions that would impact energy consumption and efficiency, the Vermont Energy Investment Corporation's (VEIC) Transportation Efficiency team applied for funding from Efficiency Vermont's Research and Development program to sponsor and support an electric transit bus demonstration project.

The Vermont electric transit bus demonstration project was conducted over a seven week period between February, 18 and April 14, 2017. The bus spent four weeks at Advance Transit in Wilder, Vermont, one week at the University of Vermont's (UVM) Burlington campus, and two weeks at Green Mountain Transit (GMT), headquartered in Burlington. This time period was specifically selected so that the bus could be tested during cold weather conditions as well as in snow and ice. As part of the demonstration project, VEIC tracked vehicle performance, fuel efficiency, operating costs and driver perceptions. Taken together, the data suggest a handful of findings about electric transit buses.

1. **The efficiency of an electric transit bus varies by operating environment.** The bus performed best when it operated at moderate speeds with stops spaced at least a half-mile apart. In environments like UVM, where the bus traveled at very slow speeds (0 to 10 miles per hour) and stopped roughly every 1,000 feet, the bus was not able to capture as much energy through regenerative braking, thus reducing energy efficiency. Likewise, the electric bus was less efficient traveling at higher speeds and with fewer stops as recorded by GMT on the commuter runs that traveled on I-89.
2. **Electric transit buses can perform in Vermont's operating conditions.** Prior to the pilot, stakeholders questioned how electric transit buses would perform in Vermont's winters. They were concerned with how well the bus could heat the cabin and how the heater would impact the range. Additionally, there were questions regarding the ability of the vehicle to perform in snow and ice. During the pilot, the vehicle performed well, demonstrating the technology's ability to handle Vermont's harsh winter conditions. While the vehicle had good traction in snow, it improved dramatically when drivers turned off the regenerative braking. Turning off the regenerative braking, however, impacted range.
3. **Drivers generally like electric buses once they have a chance to experience the vehicle.** During the pilot, drivers rated their experience driving the electric bus as compared with a diesel one.

With one exception, drivers rated the electric bus as good or slightly better as compared with the diesel bus. The one exception was driving on snow and ice, prior to turning off the regenerative braking the bus struggled with stopping and accelerating in icy conditions.

Introduction

OVERVIEW

Transportation consumes more energy and is responsible for more greenhouse gas (GHG) emissions than any other sector of Vermont's economy. As of 2017, over 90% of the State's transportation energy is derived from petroleum products used to fuel internal combustion engines. Vermont has one of the cleanest electric grids in the country and it is getting cleaner, which makes transportation electrification an important component of the State's overall strategy to reach its energy goals.

To understand the opportunities of transportation electrification and impacts on electricity use, Efficiency Vermont conducted an electric transit bus demonstration project to learn how the technology would perform in Vermont's operating environment, and assess variables that impact energy consumption and efficiency. The demonstration project was scheduled to occur in the winter of 2017, so buses could be tested in Vermont's harsh operating environment.

BACKGROUND

VEIC has been addressing energy impacts associated with the transportation sector, largely through work with private vehicles, including the effort led by Drive Electric Vermont. Drive Electric Vermont works with stakeholders to strengthen supporting infrastructure for electric vehicles, such as electric vehicle supply equipment (EVSE). The program has also administered incentives, organizes consumer outreach and education activities and provides training for car dealers about electric vehicles.

Drive Electric Vermont's focus is on light duty vehicles, which is the largest fleet in Vermont. However, there are other vehicle fleets in Vermont that offer opportunities for electrification, including public transit vehicles. Transit vehicles (or buses) are an attractive market for electrification because they are high mileage, low fuel economy vehicles, which have a disproportionate impact on both energy consumption and vehicle emissions. Transit buses also transport some of the state's most vulnerable populations, including youths, older adults, and people with disabilities providing equitable access to transportation and creating public health benefits.

Vermont has a robust network of public transportation services. Nearly every region of the state has access to some sort of public transportation service, which are provided by nine agencies¹ located across the state. These nine agencies, plus the University of Vermont, operate a combined fleet of nearly 415 buses statewide.

¹ Addison County Transit Resources; Advance Transit, Green Mountain Transit; Marble Valley Regional Transit District, Rural Community Transportation, Stagecoach Transportation Services, Southeast Vermont Transit, Green Mountain Community Network.

VERMONT TRANSPORTATION EFFICIENCY POLICY GOALS

For Vermont to meet its ambitious energy and emissions goals, the State needs to shift how it powers transportation. The State's statutory greenhouse gas (GHG) reduction goals call for a 50% reduction in emissions from 1990 levels by 2029 and a 75% reduction by 2050.² Energy goals for the state are established in Vermont's Comprehensive Energy Plan (CEP) which challenges Vermont to obtain 90% of its total energy from renewable sources by 2050, including electricity, heating, and transportation. As articulated in the 2011 CEP, "Meeting this goal will require us to virtually eliminate Vermont's reliance on fossil fuels, which we can do through enhanced efficiency and greater use of clean, renewable sources for electricity, heating and transportation."³

Transportation is the largest energy use sector in the state and contributes more GHG emissions than all other sectors in Vermont's economy.⁴ Over 90% of the State's current transportation energy is derived from petroleum products used to fuel internal combustion engines. Given Vermont's development patterns and predominantly rural land use and low population density, the transportation sector will be dominated by private automobile use, at least for the foreseeable future. As a result, Vermont's CEP identifies several strategies for achieving state transportation sector energy goals, including increasing the use of renewable fuels, such as electricity. At the same time Vermont will focus on strategies to reduce the need for travel by private automobile through investments in public transit, transportation demand management and smart growth and land use planning policies.

Vermont has a number of policies in place that promote the adoption and use of electric vehicles. Vermont is one of the original signatories of the Zero Emission Vehicles (ZEV) Memorandum of Understanding indicating that it has adopted California's vehicle emission standards. It has adopted a Vermont ZEV action plan with a number of priorities to boost the electric vehicle market in the state. The state also partially supports Drive Electric Vermont, which is a public-private partnership coordinated by VEIC to promote EV market transformation through stakeholder engagement, consumer outreach, incentives and charging infrastructure development. Finally, Vermont is part of the Transportation Climate Initiative, a collaboration of 11 northeast and Mid-Atlantic States and the District of Columbia committed to developing a clean energy economy, and reducing oil dependence and GHG emissions from the transportation sector.⁵

Other state policies that support deployment of electric vehicles include Vermont's renewable energy standard (RES). This policy makes utilities responsible not only for supplying renewable electricity but also for supporting reductions in customers' fossil fuel use, inclusive of transportation-related fuels. Vermont's Energy Efficiency Resource Standard is one of the more aggressive efficiency standards nationwide. The strength of Vermont's RES combined with the fact that Vermont's electrical generation

² 10 V.S.A. § 578. Greenhouse gas reduction goals

³ http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/State_Plans/Comp_Energy_Plan/2011/CEP%20Overview%20Page_Final%5B1%5D.pdf

⁴ <http://www.eia.gov/environment/emissions/state/analysis/pdf/table3.pdf>

⁵ <http://www.georgetownclimate.org/transportation/transportation-and-climate-initiative.html>

mix is among the cleanest in the nation, means transportation electrification is one of the most viable ways to reduce consumption of fossil fuels and GHG emissions. Indeed, because the Burlington Electric Department (BED) sources 100% of its electricity from renewable sources, the City of Burlington and BED are looking to transportation, including incentives for electric transit buses, as a strategy to meet the RES requirements.

Electrifying heavy duty electric transit buses (35' and 40' vehicles) offers a significant opportunity to reduce transportation sector energy use. In anticipation of greater interest and deployment of electric transit buses as a strategy to meet state climate and energy goals, this demonstration provided an initial evaluation of how the vehicles will perform in Vermont's operating environment as well as the conditions that will impact vehicle efficiency and energy use.

STUDY APPROACH

VEIC's Transportation Efficiency team applied for funding from Efficiency Vermont's Research and Development (EVT R+D) Program to sponsor and support an electric transit demonstration project. The goals of the project were to:

- Give transit agencies hands-on experience with electric transit vehicles and charging technology.
- Collect and analyze real world data on electricity use, energy efficiency gains and operating costs.
- Evaluate driver and mechanic experiences and perceptions of all electric transit buses.
- Work with utilities to understand impact of an electric transit bus on the transit agency's electrical infrastructure as well as on the transit agency's electrical usage / billing (consumption, timing, and impact on load).
- Evaluate if – and how – electric transit buses might be incorporated into EVT's efficiency program.

Prior to this project, Vermont's experience with electric transit buses was limited. Advance Transit, a public transit agency operating out of Wilder, VT, operated an electric transit bus in the 1990s. This early generation electric bus proved challenging for Advance Transit in terms of reliability and performance, and was the last time an electric bus was used in regular operations in Vermont. In 2016, Build Your Dreams Motors (BYD) and Proterra, two of the largest electric transit bus manufacturers in the United States brought demonstration vehicles to Vermont in an effort to generate interest in their technology. These vehicles were available for test drives and viewing for a day or two each. In part because of viewing the demonstration vehicles; and in part because of growing interest in the new generation of electric buses nationally, transit providers in Vermont expressed to VEIC a desire to learn more about electric transit technology.

Additionally, several utilities, including Burlington Electric Department (BED) and Green Mountain Power (GMP) expressed their support and interest in bringing electric transit technology to Vermont. Given the interest in electric buses, VEIC's Transportation Efficiency team submitted an application to the EVT R+D program to evaluate the technology, identify variables that impact electricity use and energy efficiency, and evaluate opportunities for incorporating electric transit buses into efficiency programs through a

demonstration project. We designed our project to answer questions about electric buses, mainly their upfront cost, fuel use and efficiency, and their ability to perform in Vermont's climate, topography and operating conditions. We also wanted to examine the impact on drivers' experience.

Once funding was secured, VEIC approached two of the largest electric vehicle manufacturers in the United States, Proterra and BYD to see if they were willing to loan a "demonstration" bus to Vermont during the winter of 2017. Ultimately, only BYD's bus was available for the demonstration project. This bus was deployed in Vermont for seven weeks between February 18 and April, 14, 2017 and was operated by AT, UVM and GMT. During the pilot, VEIC collected data on energy use and the transit operators collected qualitative data on the experience of drivers, mechanics, and other agency staff. This report summarizes and discusses the data and findings collected from experience in this demonstration.

Electric Buses: Technology Overview

ELECTRIC VEHICLE TECHNOLOGY: BATTERIES AND VEHICLE CHARGERS

Electric motors have been around for well over a hundred years. One of the early inventors of electric motors was a Vermonter – Thomas Davenport – a blacksmith who built a vehicle that operated on an electrified track. The challenge with electric vehicles then, and still today, is the ability of an electric motor to access a sustained source of electricity.

Modern vehicles get the electricity by plugging into an electrical source and storing this energy on a battery located on the vehicle. Limitations associated with battery technology together with the cost of the batteries have been - and continue to be - the largest obstacles to accelerating adoption of electric vehicles. A vehicle's battery and battery chemistry determines how much energy can be store on board and in return, how far a vehicle can travel (its range). Battery chemistry determines how well the vehicle can climb hills and power through extreme weather as well as how quickly cells can absorb the electrical charge. Battery systems are also the most costly part of an electric vehicle and are the primary reason why electric buses are more expensive to purchase as compared with other fuel type buses.

The balancing of the different battery attributes has led to development of a handful of slightly different electric transit bus and battery systems. The two primary systems are 1) smaller battery vehicles that can travel for a shorter range (20 to 70 miles) and are designed to charge more often and in the field (i.e., opportunity charging), allowing the bus to stay in service as long as it is needed; and 2) extended range vehicles that have larger batteries and charge less frequently, typically at their base of operations.

SHORT-RANGE / OPPORTUNITY CHARGING TECHNOLOGY

Early models of electric transit buses were built with smaller batteries that travel short distances (between 20 and 70 miles) and relied on in-route or “opportunity” charging to stay in operations. Short-range buses work by connecting to an opportunity charger that uses high powered chargers to replenish batteries in as little as five minutes. The charging systems are located on the top of the bus and connect with an overhead charger to charge the battery (see Figure 1). Fast chargers tend to be located at transit hubs or a central location where multiple buses converge.

Opportunity charging systems worked well in early deployments, because they solved the first problem with electric buses, which was limited range. More recently, however, the industry has started to move away from opportunity charging in part due to the cost of overhead charging systems, but also because of the electricity costs associated with fast, high power charging in the middle of the day. The systems also proved challenging for transit service operations. The high cost of the charging systems meant that transit systems assigned several buses to a single charger. Minor changes in vehicle schedules, therefore, can lead to vehicles waiting to use the charger, which often creates further delays in schedules and operations. The trend of moving away from fast charging system is exemplified by the most recent grant cycle of Federal Transit Administration's Low or No Emission Vehicle Program. This

program is the largest source of funding for alternative fuel vehicles in the United States. In 2017, only 14% of the vehicles funded through the program were for opportunity charge technology vehicles.⁶

Figure 1: Fast Charging System



Source: Protterra

EXTENDED RANGE BUSES

Extended-range electric transit buses are built with larger battery packs that allow buses to travel longer distances of between 150 and 200 miles on a single charge, a distance compatible with many transit agency duty cycles. Although most current vehicle models operate within the 150 and 200 mile range, Protterra recorded extended range buses traveling upwards of 600 miles on a single charge in the fall, 2017⁷. This result was accomplished on a drive track under ideal conditions, but nonetheless provides an indication of potential advances in the near term. As other manufacturers work to achieve this standard, vehicle range will no longer be an obstacle to deploying the technology.

Extended range buses also have the advantage of being somewhat less expensive because they do not require expensive charging equipment. The extended range technology also means that the bus can be deployed into revenue service, in a way that is more consistent with traditionally fueled vehicles. There are, however, downsides to extended range systems:

- **Long charge times:** Extended range buses can take multiple hours to charge and are typically charged at bus depots overnight. Extended ranges of up to 350 miles means the bus can be deployed for a full day of transit service. It also means transit operators must plan three to four hours for the battery to be recharged. This compares with diesel buses that require 10 to 15 minutes to refuel.

⁶ Federal Transit Administration

⁷ <http://www.thedrive.com/new-cars/5151/this-protterra-e2-bus-covered-600-miles-on-an-electric-charge>

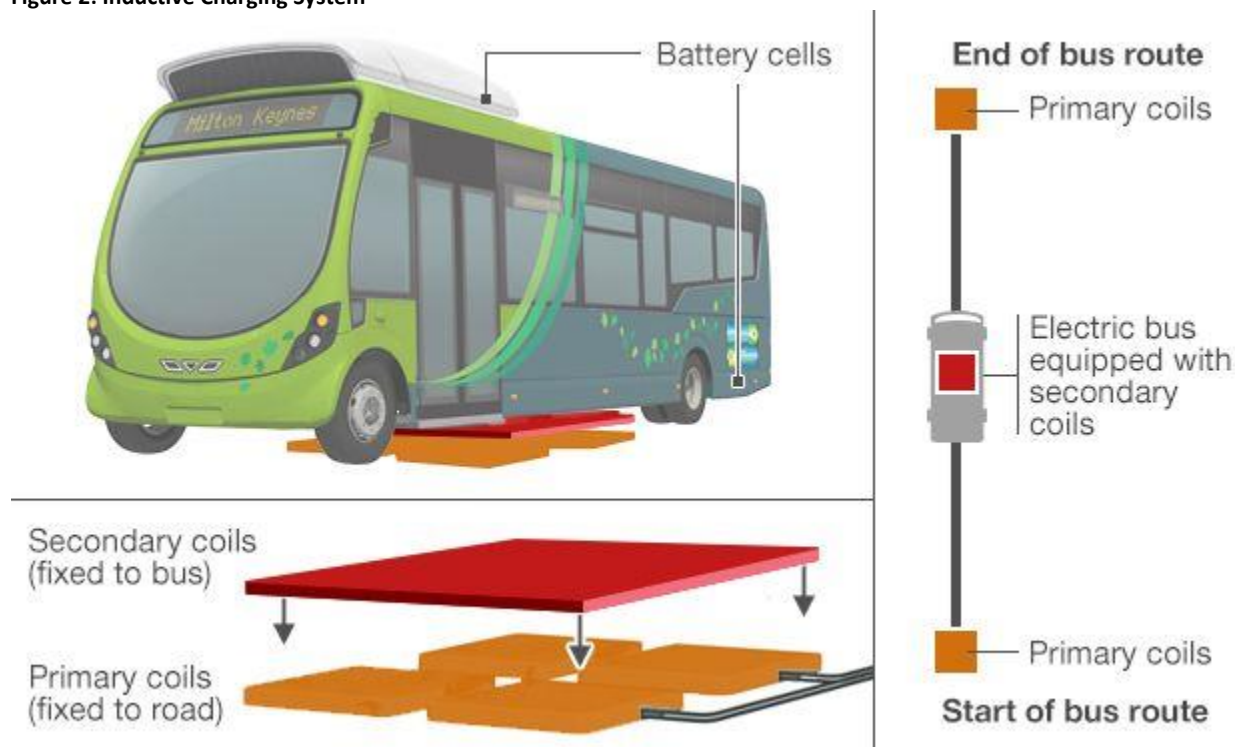
- **Electricity Costs:** Transit agencies can incur demand charges with slow charging as well as fast charging. One slow charger has a charging capacity of about 80kW. When combined with the base load of the depot, slow chargers have the ability to create a peak demand charge, if they are charged during other high use times and/or if multiple buses are plugged in at the same time. As a result, transit agencies are advised to work with their electricity provider to avoid eroding the savings generated at other times.

Inductive Charging

A third emerging technology associated with bus electrification is inductive vehicle charging. Inductive charging offers similar strengths as opportunity charging but instead of deploying an overhead charging system, the technology is buried in the pavement, allowing the bus to park on top of the charger and receive electricity inductively (see Figure 2). The system is currently designed to allow frequent, short charges that can be accomplished in the field.

Currently inductive charging is slower (50kW) than fast chargers and is designed so buses can draw small amounts of power by connecting to the charger for short periods of time. The system allows buses to recharge in the field and extend time in service. Inductive charging is being tested in a handful of locations (Lancaster, California; Wenatchee, Washington and the University of Utah (among others)). Newer systems are designed with faster, more powerful chargers (250 kW).

Figure 2: Inductive Charging System



Source: Planet Custodian

There are a handful of challenges associated with inductive charging. The first is cost: the equipment is expensive – roughly \$350,000 per unit in the ground plus another \$100,000 or so in installation costs. In addition, buses must be equipped with equipment to accept the charge. These plates cost about \$70,000 per bus. Second, the speed of the charging is also limited. The technology is currently deploying charging units with 50kW of power. While powerful, the inefficiency of the technology means it takes 20 minutes of charging time to add 30 miles to the battery. This is longer than most buses have in their schedules.

Finally, another big disadvantage of inductive charging is the efficiency of charging. Existing systems are about 70% efficient meaning roughly 30% of the energy is lost during the charging process. Comparatively, the Build Your Dream (BYD) motors charger's input energy has been estimated to be 91.2% efficient in field testing⁸.

The future of inductive charging technology is unclear. The faster, more powerful charging systems are likely to face similar challenges as overhead charging due to the costs of the equipment and installation; and at 250 kW peak charging is likely to be expensive. If existing vehicle manufacturers are able to reliably offer buses that can travel between 250 and 300 miles, it is unlikely transit operators will opt for inductive charging systems.

ELECTRIC TRANSIT BUS MARKET

According to the American Public Transportation Association (APTA), there are roughly 70,000 buses deployed in public transit operations in the United States plus another 86,000 smaller, medium duty buses, primarily used in dial-a-ride services. The importance of transit vehicles in effort to decarbonize the transportation sector arises because, as discussed, transit buses tend to be higher mileage and lower fuel economy vehicles. They also operate in population centers and serve vulnerable populations so the impact of electrifying buses is disproportionate to the size of the fleet.

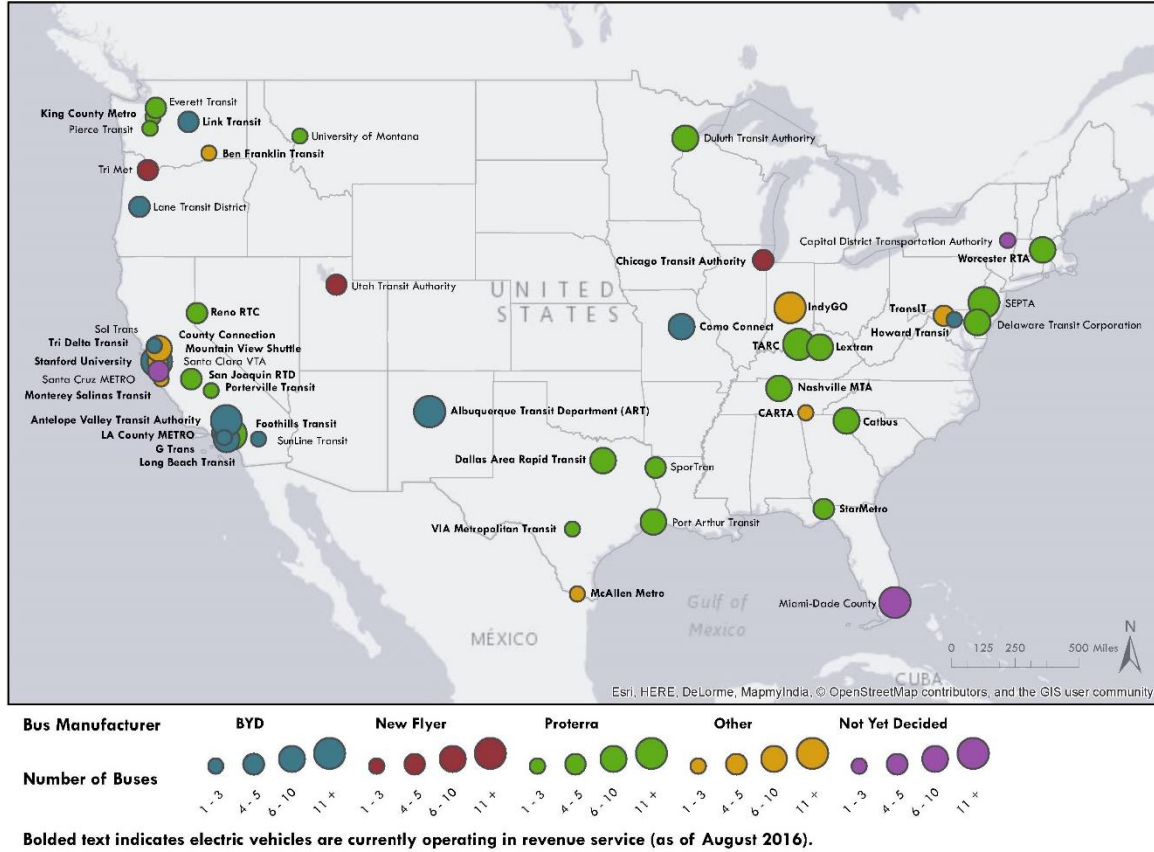
In 2016, VEIC quantified the number of electric transit buses deployed by transit agencies and universities, but not private shuttles (i.e. employer or airport shuttles). We calculated our estimate by talking with vehicle manufacturers and transit operators, using web-based resources and reviewing published reports. VEIC's estimate based on this analysis is that there were approximately 400 electric transit buses deployed in revenue service, awaiting delivery or funded but not ordered in August, 2016 (see Figure 3). These 400 vehicles represent less than 1% of all transit vehicles in the United States. Our analysis suggests that the 400 buses are distributed among 49 transit agencies, which accounts for about two percent of the urban and rural systems in the US. Since our analysis there is reason to believe there will be massive continued growth in the market, a number of large transit agencies including (including LA and King Country Metro) has announced their intentions to go 100% electric.

⁸ The charger's efficiency was measured from data collected at the FTA Altoona Bus Research and Test Facility. The FTA Altoona Bus Research and Test Facility is a national laboratory that test buses on a number of characteristics including safety and efficiency.

Testing Electric Transit Buses in Vermont

Electric transit buses, therefore, are not at the cutting edge of industry deployment, but are still in the early stages of development. In addition, the majority of the transit sector’s experience with electric transit buses has been in flatter, warmer and more urban environments. At the time of our demonstration, electric transit bus technology had less experience in operating environments that included cold weather, hilly terrain and longer routings, like Vermont.

Figure 3: Deployment of Electric Transit Vehicles in the United States (2016)



Electric Transit Vehicles: Demonstration Experience

VEIC's Transportation Efficiency team conducted the electric transit bus demonstration project over a seven week period between February 18 and April 14, 2017. The bus spent four weeks at Advance Transit in Wilder, Vermont, one week at UVM's Burlington campus, and two weeks at Green Mountain Transit, headquartered in Burlington. This time period was specifically selected so that the bus could be tested during cold weather conditions as well as in snow and ice.

VEIC worked with the transit operators through three major project stages:

- **Preparations / Planning** – VEIC worked with the transit operators and BYD to make sure each site was prepared to host the bus. This involved securing insurance certifications required by BYD and understanding electrical capabilities to determine if the bus could be charged on-site.
- **Deployment** – During the pilot, VEIC staff worked with the transit agency to support their deployment of the vehicle. We helped with press information, developed and executed data collection systems and coordinated with BYD, as needed.
- **Data Analysis and Reporting** – At the end of the pilot, VEIC analyzed data on the vehicle performance, including mileage, energy efficiency and consumption, and operational assessments. We also collected qualitative data from the drivers on their experience operating the bus.

Our experience and findings from each of these stages is described in the following sections.

PREPARATIONS AND PLANNING

VEIC's Transportation Efficiency staff led the preparations and planning with both the electric bus manufacturer and the individual transit agencies. VEIC staff worked with Vermont's public transit operators through the Vermont Public Transit Association (VPTA), which is the state association of public transportation operators. We approached this group to ask for agencies interested in demonstrating electric vehicle technology. Advance Transit (AT) and Green Mountain Transit (GMT) both expressed an interest in participating in a pilot project. The University of Vermont, which is not part of VPTA, expressed an interest in the pilot as part of other conversations on electrification.

After confirming interest, VEIC worked with AT, GMT and UVM to prepare their facilities to host the electric transit vehicle. This involved meeting with transit agency general managers as well as the facility and maintenance directors to discuss and confirm facility needs to host an electric vehicle and how the bus would be deployed.

VEIC led negotiations between the operators and BYD; these negotiations primarily focused on the dates of the pilot and insurance requirements. VEIC also made sure that each operator had access to the BYD demonstration vehicle specifications (vehicle length, passenger capacity, expected range, etc.) and

charging systems requirements (see Appendix A) so they could plan how best to deploy the vehicle in passenger (revenue) service.

The power and energy needs of the vehicle charging system guided the evaluation of the facility to determine if the transit agencies could set up temporary charging systems. VEIC worked with the appropriate utilities (Green Mountain Power for AT and BED for GMT and UVM) to evaluate the electrical infrastructure at each site to determine if it could host an electric bus.

In each case, all three of the host facilities would have needed upgrades to their electrical service to host a vehicle charger. For example, in the case of AT, the cost of upgrading their electrical infrastructure and installing electric vehicle charging equipment (EVSE) was estimated at \$15,500; \$12,000 to cover the cost of a three-phase transformer and its installation cost⁹, \$2,500 for the equipment and \$1,000 for the installation¹⁰. The electrical upgrades at GMP and UVM were less expensive but were still determined too cost prohibitive for a short demonstration.

As a result of the cost associated with installing a charger, Advance Transit charged the bus using a diesel generator (loaned to them by BYD). Burlington Electric Department, however, was interested in collecting and recording data on charging consumption, so BED agreed to install EVSE at their offices on Pine Street in Burlington for UVM and GMT to use for the pilot. This installation of this charger cost roughly \$8,000 including a meter cabinet and aerial drop wire (see Figure 4). Both the drivers at UVM and GMT picked up and dropped off the bus daily from BED.

Figure 4: Installation of the EVSE at Burlington Electric



Source: BED

⁹ Estimated by VEIC based on fieldwork and discussions with Advance Transit.

DEPLOYMENT OVERVIEW

The BYD 40-foot electric bus was on site from February 18, 2017 until April 14, 2017 (see Table 1). BYD dispatched staff to each transit property on the day the bus arrived on site. BYD provided a high level training to the staff at each agency on vehicle operations and maintenance. Additionally a BYD driver stayed with the bus, accompanying the transit drivers at each facility.

Table 1: Electric Transit Bus Demonstration Deployment Schedule

Agency	Time Period
Advance Transit	February 18 – March 24, 2017
University of Vermont	March 27 – March 31, 2017
Green Mountain Transit	April 3 – April 14, 2017

Advance Transit (AT)

Advance Transit provides rural transit services in Vermont and New Hampshire’s Upper Valley communities. AT operates on weekdays with the majority of service oriented around the region’s major employers and employment centers, including the Dartmouth Hitchcock Medical Center (DHMC), downtown Hanover, NH, and downtown Lebanon, NH.

The electric transit bus was deployed at AT for four weeks. Due to a variety of challenges associated with getting started and confirming documentation, the bus was deployed for 14 days of operations between February 18 and March 24. The bus was assigned to a combination of routes, including shuttle services that bring passengers from remote parking to DHMC and rural routes that connect the Upper Valley communities. The shuttle routes travel short distances over relatively flat terrain and passenger loads can be significant. Shuttle routes travel short distances but generally do not stop in between passenger pick up and drop off. The rural routes tend to be longer routes with more varied terrain, few stops and lower passenger loads.

AT’s experience with the BYD vehicle was generally positive. The deployment went smoothly and the bus was used in operations for 14 days and was used on 25 driver assignments for a total of 1,890 miles (see Table 2). The electric bus consumed 3,160 kWh and achieved an energy efficiency of about 0.60 miles per kWh. VEIC estimates that AT would have spent \$0.15 per kWh, or roughly \$600 worth of electricity. This translates to a cost per mile of about \$0.25. A diesel bus that has a fuel economy of 4.26 miles per gallon would have consumed 444 gallons of diesel to travel the same distance, costing about \$0.53 per mile. Operating 30,000 miles per year is expected to result in annual fuel cost savings of about \$6,300 (see Table 2).

Table 2: Advance Transit Estimates

Advance Transit	Electric	Diesel
Total Miles Driven	1890	1890
Total kWh consumed	3160	--
Fuel cost (\$ / kWh)	\$0.156	\$2.25
Total fuel cost	\$474	\$998
Efficiency (miles / kWh)	0.60	4.26
Average fuel cost (\$ / mile)	\$0.25	\$0.53

Source: Data provided by Advance Transit; adapted by VEIC

A major winter storm hit the Upper Valley during the pilot project. One of AT’s most experienced drivers took the electric bus out in service on this day to test operations in the snow and ice. The driver initially reported sliding on the snow and ice and in particular, noted a swinging of the rear end of the bus. After consulting with BYD, the driver turned off the regenerative braking, which improved vehicle traction. Removing regenerative braking, however, reduced vehicle fuel efficiency and range.

University of Vermont

The University of Vermont (UVM) operates transit routes for its students. The services consist of on-campus routes that provide connection between campus buildings and off-campus routes that connect UVM with downtown Burlington. Generally speaking UVM’s campus routes travel on relatively flat terrain, carry high passenger loads and stop frequently. The off-campus routes travel more hilly terrain, carry high passenger loads and stop frequently. This operating environment impacted the use of regenerative braking and, as a result, the bus was considerably less efficient driving on the UVM campus (see below).

UVM was scheduled to operate the electric bus for five full days of service (3/27 to 3/31), but due to technical issues with the EVSE installed at BED, the bus was only available for three days. Once the issues with the EVSE were resolved, operation of the vehicle was smooth. In total, UVM drove the bus 220 miles. The bus consumed 729 kWh of electricity, for a vehicle efficiency of .30 miles per kWh, which was roughly half of the efficiency achieved by AT. The lower efficiency means that the fuel costs associated with an electric bus were higher per mile as compared with the diesel bus (see Table 3).

Table 3: University of Vermont Estimates (as provided by BED)

University of Vermont	Electric	Diesel
Total Miles Driven	220	220
Total kWh consumed	729	--
Fuel cost (\$ / kWh)	\$0.10	\$2.25
Total fuel cost	\$73	\$117
Efficiency (miles / kWh)	0.30	4.26
Average fuel cost (\$ / mile)	\$0.33	\$0.53

Source: Data provided by UVM; adapted by VEIC

Green Mountain Transit (GMT)

Green Mountain Transit (GMT) is the largest operator of three agencies participating in the electric bus demonstration project. GMT provides transit service throughout northern and central Vermont, including Chittenden County, Franklin and Grand Isle counties, plus in the Capital District, Mad River Valley and Stowe. Given the diversity of the land uses, GMT’s services range from commuter routes, inter-county regional services, and urban services. GMT also operates dial-a-ride service, both as part of its rural services and in conjunction with federal requirements associated with the Americans with Disabilities Act (ADA), which requires transit operators to provide complementary paratransit service for individuals unable to use fixed-route services.

GMT piloted the electric transit bus for roughly two weeks and deployed the bus on a number of routes mostly on service within Chittenden County, but also commuter service between Burlington and Montpelier. In between the UVM and GMT deployment, BYD swapped out the electric bus and replaced the vehicle used by AT and UVM with a newer vehicle. This vehicle, however, had a mechanical failure and had to be pulled out of service after just a few days of operation. BYD returned the original bus to GMT and this bus remained in operation until the end of the pilot period.

GMT had a positive experience operating the bus on routes serving downtown Burlington and the urban parts of Chittenden County. The bus performed less successfully on the commuter routes, traveling on the interstate with full passenger loads. Drivers using the electric bus on these trips reported the bus as having challenges maintaining high speeds while traveling uphill with passengers on board.

In total, GMT drove the bus 786 miles and consumed 1,719 kWh of electricity for a fuel economy of 0.46 miles per kWh. The cost of electricity was \$0.22 per mile, less than half of the per mile fuel cost of their diesel buses (\$0.53) (see Table 4).

Table 4: Green Mountain Transit Estimates

Green Mountain Transit	Electric	Diesel
Total Miles Driven	786	786
Total kWh consumed	1,719	--
Fuel cost (\$ / kWh)	\$0.10	\$2.25
Total fuel cost	\$172	\$415
Efficiency (miles / kWh)	0.46	4.26
Average fuel cost (\$ / mile)	\$0.22	\$0.53

Source: Data provided by UVM and BED; adapted by VEIC

Data Analysis, Findings and Implications

VEIC collected a variety of data during the demonstration project, including data on energy consumption, vehicle efficiency and driver perception of the vehicles. Data was collected both manually and automatically. Because the bus was a demonstration project, the vehicle was not set up or programmed to record data on vehicle movements or energy consumption. As a result, drivers' manually logged information at the beginning and end of each trip, including the odometer reading and battery state of charge (see Appendix B for Driver's Log Example). The VEIC team used this data to understand fuel efficiency and average daily mileage. When the BYD bus was in Burlington, the EVSE recorded energy consumption, but trip data was also recorded by UVM and GMT drivers.

ENERGY CONSUMPTION AND FUEL COSTS

VEIC compared data on fuel consumption, efficiency and costs across the three demonstrations sites (see Figure 5). This data shows a range of experiences among the three operators. AT drove the bus the most, logging more than twice the amount of miles as compared with GMT, and nearly 9 times as many miles as UVM. Difference in miles reflects both the amount of time operators had access to the bus, and the type of service provided at each site.

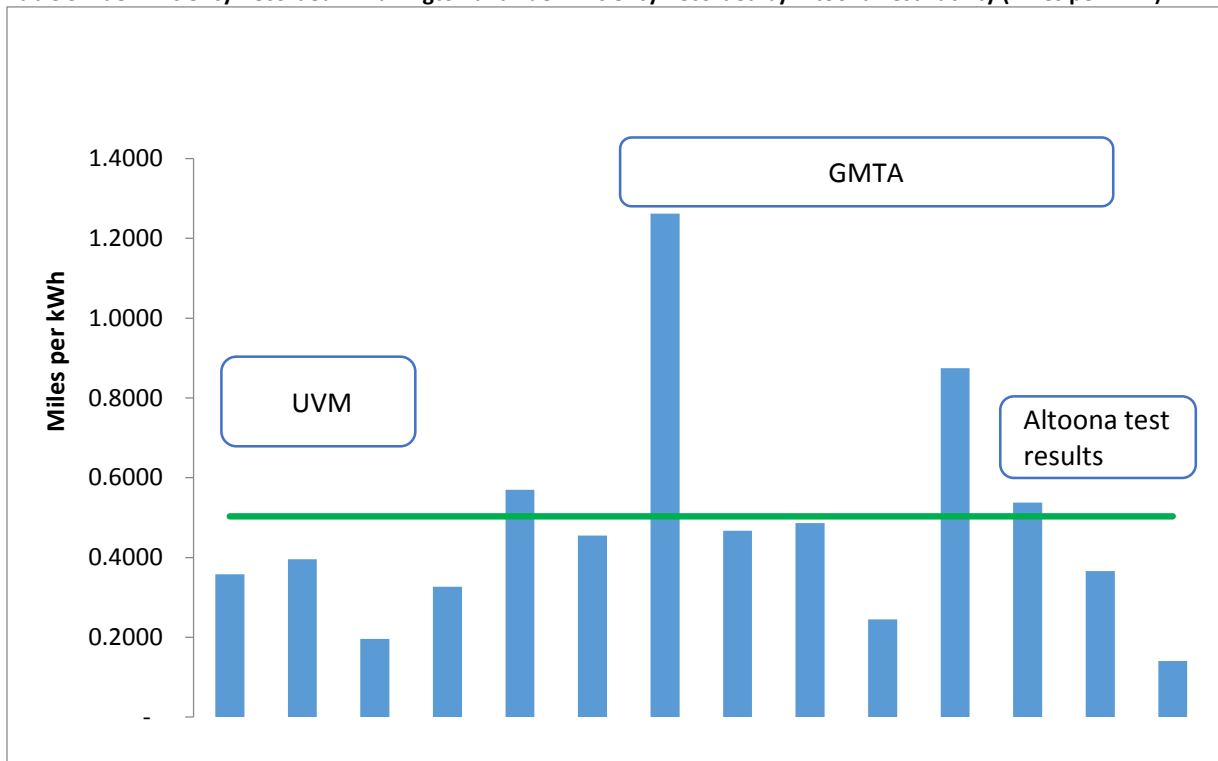
Another key difference in the experience of each operator is with regard to fuel efficiency. AT recorded a significantly higher fuel efficiency (more fuel efficient) as compared with either GMT or UVM. VEIC compared the experience in Vermont with data measured at the FTA Altoona Bus Testing Facility¹¹. The Altoona Bus Testing facility is a national lab that tests buses for safety and crash-worthiness as well as other characteristics, such as fuel economy.

As compared with the Altoona tests (which recorded an efficiency of 0.47 miles per kWh), the fuel efficiency recorded during the AT demonstration was higher (0.60). AT's recording, therefore, may reflect errors in data collection or in the process associated with converting diesel fuel to electricity. GMT's recorded vehicle efficiency is nearly exactly the same as reported in the Altoona test. UVM, on the other hand, experienced significantly lower fuel efficiency (see Figure 5).

The poor efficiency UVM experienced during the pilot most likely reflects the operating environment at UVM, with low speed and stop and go travel, which limits the productivity of the regenerative braking system. Other factors that could impact the bus's efficiency include weather, passenger loads, and driver behavior but more research, over a longer span of time, would be needed to determine the impact of these factors on the bus's efficiency.

¹¹ The Bus Testing Program of the [Federal Transit Administration](#) was established in response to the requirements of the Surface Transportation and Uniform Relocation Assistance Act (STURAA) of 1987. Under the program, testing is required on all new model buses before they can be purchased with federal funds. The testing mandated by STURAA and the vehicle categories included were expanded by the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. A history of the implementation and changes to the bus testing law are highlighted under the [Governing Law](#) tab. See also: <http://altoonabustest.psu.edu/about>

Table 5: Fuel Efficiency Recorded in Burlington and Fuel Efficiency Recorded by Altoona Test Facility (Miles per kWh)



Source: Burlington Electric Department

Despite variances, VEIC’s analysis suggests that the fuel cost per mile of an electric bus is lower than the fuel cost per mile of a diesel bus. AT and GMT benefitted from a high vehicle fuel efficiency. While UVM did not realize an improved fuel efficiency, the low per unit cost of electricity (\$0.10) meant that the fuel cost per electric bus mile was still advantageous relative to one of their diesel buses (see Table 6).

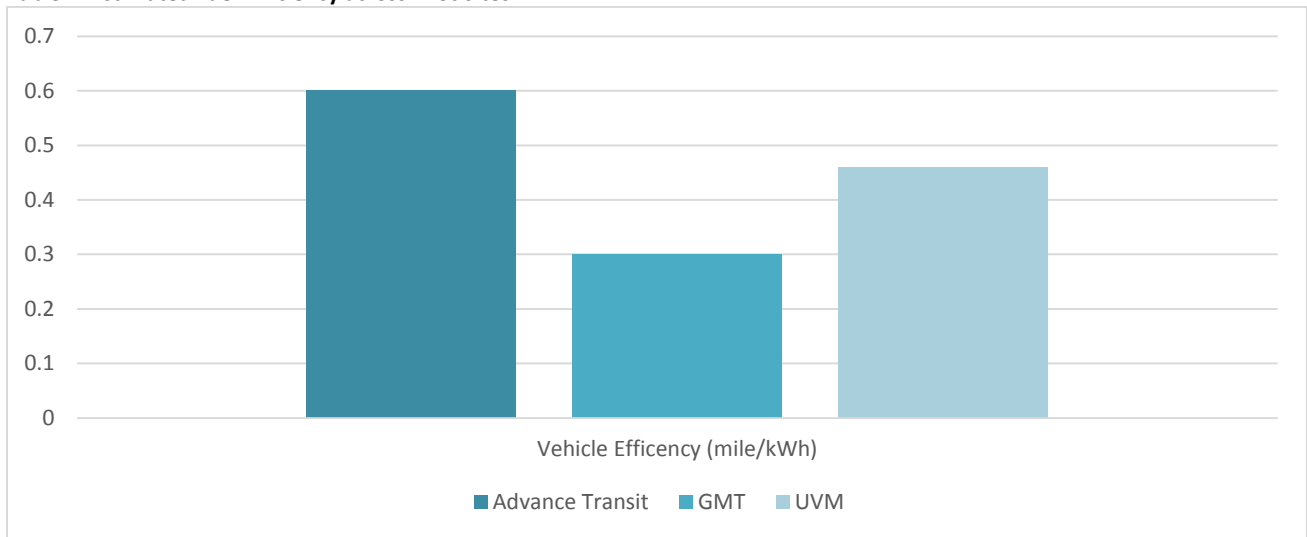
The demonstration project confirmed this finding and also showed that fuel efficiency varied by temperature, terrain, passenger loads and operating environment. This particularly was evident when comparing the efficiency across the three transit agencies (see Figure 6).

Table 6: Fuel Consumption, Efficiency and Costs, All Demonstration Sites

	Advance Transit	UVM	GMT
Miles Traveled	1,890	220	786
Fuel Consumed (kWh)	3,160	729	1719
Fuel Efficiency (miles / kWh)	0.60	0.30	0.46
Fuel Cost per Unit	\$0.156/ kWh	\$0.10/ kWh	\$0.10/ kWh
Fuel Cost (\$ per mile)	\$0.25	\$0.33	\$0.22

Source: Data provided by Advance Transit UVM and BED; adapted by VEIC

Table 7: Estimated Fuel Efficiency across Pilot Sites



TRAVEL RANGE

The BYD bus had a battery capacity of 365 kWh. Data collected during the demonstration showed that the buses were deployed between 60 and 100 miles each day, without charging. For some operators, like UVM and AT, the deployment was roughly equivalent with diesel vehicles. For GMT, a deployment of 60 miles is on the low end of a typical duty cycle. The fuel efficiency recordings suggest that each bus would consume about 140 – 220 kWh of electricity per day to travel between 60 and 100 miles. At the high end (100 miles and 200 kWh), transit operators were using about 60% of the battery capacity. With experience and confidence, transit operators may be able to drive the bus to 80% of the battery capacity or about 125 – 130 miles.

With a charging capacity of 80 kW, this requires charging buses two to three hours per day. In Burlington, the cost per kWh (off-peak) is \$0.10, which means the daily cost of charging would be \$14.00 or \$22.00.

DRIVER PERCEPTION

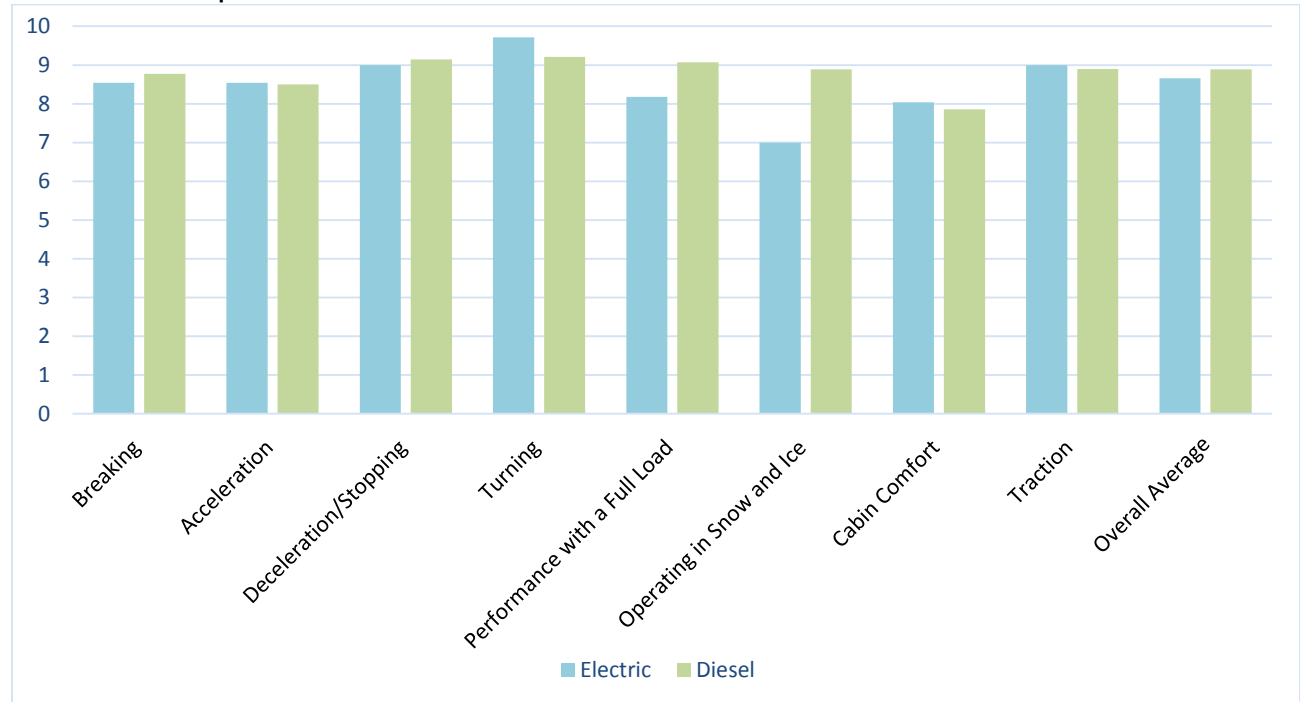
VEIC also asked transit operators (drivers) about their perceptions and experience driving an electric bus. Data was collected by asking the drivers to complete a short survey; asking about the diesel bus before the demonstration began and again after they had experience driving the electric bus. In both cases, drivers were asked to rank a regular diesel vehicles from 1-10 and justify their rating when possible in the following categories:

- Breaking
- Acceleration
- Deceleration/stopping
- Turning
- Performance with a full load

- Operating in snow and ice
- Cabin Comfort
- Traction

VEIC compared the results of driver scoring (see **Error! Reference source not found.**). While qualitative, the data suggests that drivers generally had similar perceptions and feelings about electric transit buses as they did about diesel ones. A couple of exceptions to this overall experience were 1) operating in the snow and ice; and 2) performance with a full load. In both of these cases, drivers felt that diesel buses outperformed electric ones.

Table 8: Driver Perceptions of Diesel and Electric Buses



Source: VEIC

SUMMARY OF FINDINGS

Taken together, the data suggest a handful of findings about electric transit buses.

1. **The efficiency of an electric transit bus varies by operating environment.** The bus performed best when it operated at moderate speeds with stops spaced at least a half-mile apart. In environments like UVM, where the bus traveled at very slow speeds (0 to 10 miles per hour) and stopped roughly every 1,000 feet, the bus was not able to capture as much energy through regenerative braking, thus reducing energy efficiency. Likewise, the electric bus was less efficient traveling at higher speeds and with fewer stops as recorded by GMT on the commuter runs that traveled on I-89.
2. **Electric transit buses can perform in Vermont's operating conditions.** Prior to the pilot, stakeholders questioned how electric transit buses would perform in Vermont's winters. They

were concerned with how well the bus could heat the cabin and how the heater would impact the range. Additionally, there were questions regarding the ability of the vehicle to perform in snow and ice. During the pilot, the vehicle performed well, demonstrating the technologies ability to handle Vermont's harsh winter conditions. While the vehicle had good traction in snow, it improved dramatically when drivers turned off the regenerative braking. Turning off the regenerative braking, however, did impact range.

3. **Drivers generally like electric buses once they have a chance to experience the vehicle.** During the pilot, drivers' rated their experience driving the electric bus as compared with a diesel one. With one exception, drivers rated the electric bus as good or slightly better as compared with the diesel bus. The one exception was driving on snow and ice, prior to turning off the regenerative braking the bus struggled with stopping and accelerating in icy conditions.

Conclusion

MEASURES OF SUCCESS

VEIC conducted the Vermont electric transit bus demonstration project with a handful of goals in mind and identified the most important measures of success as:

- Helping transit operators gain confidence with electric transit vehicle technology.
- Identifying variables that impact vehicle efficiency.
- Evaluating potential for incorporating electric transit buses into Vermont's energy efficiency framework.

VEIC was successful in helping the transit operators who participated in the pilot gain confidence with electric transit technology. In particular two of the agencies, Green Mountain Transit (GMT) and Advance Transit (AT), pursued funding to purchase electric transit buses. GMT was successful in their pursuit and will be purchasing four all electric transit buses in the next year.

This project was also a good first step in identifying variables that impact vehicle efficiency. During the pilot VEIC was able to identify some general operating conditions where the bus performed more efficiently and others that reduced efficiency. However, more research is needed to validate these findings and understand all the factors that impact an electric transit bus's energy consumption and efficiency. In particular it would be helpful to track a vehicle's efficiency over a longer period of time across multiple seasons. It would also be helpful to evaluate vehicles from more than one manufacturer.

The final measure of success, evaluating the potential for incorporating electric transit buses into Vermont's energy efficiency framework, is the focus of the following section.

Electrified transit and energy efficiency

There are a lot of reasons why electric transit buses offer promise for energy efficiency programs. Electric buses are a rapidly maturing technology, which is moving to near parity with diesel in terms of performance. Buses are typically high mileage, low fuel economy vehicles making their impact significant. Impacts are also significant for the vulnerable populations served by transit, including low income individuals, who are often left out of energy efficiency programming.

There are challenges to deploying electric transit buses, the largest of which is cost. Despite offering ongoing cost savings associated with increased fuel efficiency, lower fuel costs and reduced maintenance costs, depending on the make and model there is a \$250,000 to \$300,000 premium to purchase an electric bus as compared with a diesel one, and there is little variability in price among manufacturers. Transit agencies almost always make capital investments, such as buses, through a combination of federal (FTA) and state (VTrans) grants, plus local funding, which in Vermont is largely raised through a combination of fares and municipal and institutional (colleges, ski resorts, large employers) contributions. Each of these funding sources is constrained, so purchasing a more expensive vehicle means that transit agencies would be able to buy fewer vehicles. Another factor is the

breakdown of funding; the FTA pays 80% of the cost of the vehicle, with state and local resources accounting for 10% each. The funding structure is relevant because a transit agency interested in purchasing a more expensive vehicle must be sure all funding sources are able to absorb increased costs.

Range is another persistent challenge. While electric transit bus manufacturers have been steadily increasing the travel distances on a full state of battery charge, travel ranges are still lower as compared with a diesel vehicle. Refueling times are also longer. In addition, the transit industry's experience with the largest electric vehicle manufacturers (Proterra and BYD) is limited to a handful of years. This means some operators are concerned about the long term performance of the vehicle and technology.

Potential EVT ROLE

Currently, transportation efficiency programming is outside Efficiency Vermont's scope. However, under the current EVT framework there are ways in which Efficiency Vermont as one of the state's efficiency utilities can help transit agencies adopt energy efficient vehicle technologies and ensure deployment maximizes energy efficiency.

- **Leading the Conversation** – the EVT R+D demonstration project played a critical role in encouraging GMT to purchase four electric transit buses. Further, GMT was able to purchase electric buses by combining a variety of funding, including funding from more traditional federal transportation funding programs (Low or No Emission Vehicles) with energy funding (Burlington Electric's RES programming and VLITE – see also next steps). It was the combination of resources and assistance from the transportation and energy stakeholders that made this collaboration successful. EVT could offer help convene stakeholders to support other transit agencies in purchasing electric transit buses.
- **Technical assistance** – another lesson from the demonstration project is the importance of a diversity of technical assistance. The pilot project convened utilities, energy efficiency specialists and transportation professionals to execute and study the demonstration project and the combined perspective ensured success. Utilities helped transit operators understand electrical infrastructure needs, electricity rate structures and potential charging costs. VTrans provided insights into transportation funding. VEIC facilitated conversations between these stakeholders, and brought an energy efficiency perspective to the conversation. VEIC also helped link transportation and energy sector funding. The combined technical assistance supported the transit providers and electric utilities and gave them the confidence needed to advance the technology. EVT's ability to provide technical assistance and in particular, ensure implementation is as efficient and cost effective as possible will be critical to creating opportunities in this sector. EVT could also play an ongoing role helping to select efficient systems (vehicles and charging technologies) and ensure efficient operations (managed charging, efficient driving).
- **Couple energy efficiency measures with electrifying vehicles** – When a transit agency adopts any electric vehicle (light or heavy duty) they will increase their electrical load. As a result, a transit agency investing in electric transit vehicles will have an added motivation to consider site

efficiency measures. Coupling electric vehicle with efficiency measures transforms a vehicle project into a total energy perspective that could help increase energy efficiency, potentially even as additional load is added.

Renewable Energy Standard – Transformative Energy Projects (Tier III)

As discussed, Vermont’s Renewable Energy Standard includes a provision for transformative energy projects. These projects known as Tier III in reference to being the third tier of the standard’s implementation, require distribution utilities to invest in projects that reduce fossil fuel consumption.

The Burlington Electric Department sources more than 99% of its energy production from renewable energy. As a result, it is looking to transportation to meet its Tier III requirements. In 2017, BED offered a \$65,500 (approved by Vermont Public Service Board) incentive to purchase and operate an electric bus. The incentive is designed to be performance based, so GMT receives half (\$35,000) upfront and half after the bus is driven 30,000 miles. The amount of the incentive is set to match the next best option for BED to meet the RES requirements. In 2018, Green Mountain Transit will take advantage of this incentive to purchase four electric transit buses. While this incentive has been critical to GMT’s ability to purchase buses, it is important to note that the incentive amount is not enough on its own to make up the difference in cost between a diesel and electric bus.

DISSEMINATION OF RESULTS

The results of this research should be shared with stakeholders internal and external to EVT. VEIC staff has already begun disseminating the results of this project with external stakeholders including transit providers throughout the state. We have presented the findings to the participating agencies as well as the Vermont Public Transit Association. Within EVT, presentations as well as deeper discussions with leadership is needed to gain a deeper understanding of whether and how the organization can further support greater adoption of electric transit vehicles.

FURTHER RESEARCH

While this research project was a good first step to demonstrate electric transit vehicles in Vermont and evaluate the opportunities for electric efficiency, more research is needed to understand the factors that impact electric transit buses energy consumption and efficiency. This project has directly resulted in GMT adopting four electric transit buses. Once these buses are on the road they should be monitored for their energy consumption, maintenance costs, and performance to give a larger, more detailed understanding of their impact.

In addition, this project was limited as it only tested one make and model of an electric transit bus. Testing multiple types of electric transit vehicles and chargers could result in a better understanding of the different factors that can impact the vehicles efficiency.

Electric Cutaway Vehicles

This research project was focused on 40-foot electric transit buses but currently only four out of the ten transit agencies in the state use this size bus. Instead, smaller cutaway buses are used in the state’s rural

areas, where routes tend to be long and serve a relatively small number of people. Every transit agency in the state includes cutaways in its fleet. There are currently approximately 333 cutaways on the road in Vermont owned by public transit agencies. This includes about 250 medium-sized light-duty buses and 83 medium-sized medium-duty buses.

Currently, the electric cutaway market is not as mature as the electric full size bus market (please see Appendix D for more information on the electric cutaway market). More research is needed to understand how the operating environment for these vehicles may impact efficiency and to better understand opportunities for efficiency.

Appendix A: Build Your Dream (BYD) Bus and Charging Specifications

Table A 1: BYD 40-ft Electric Bus Specs

Length	40 Ft
Width	100 in
Gross Weight	40
Seats	Up to 40
Top Speed	55 mph
Expected Range	155 miles
Battery Type	Lithium Iron Phosphate

Table A 2: BYD Vehicle Charger

Input Ratings	
Phase/Voltage	480V, 3 Phase
Amperage	96 Amps
Output Rates	
Phase/Voltage	80 kVA
Amperage	126 A ac

Appendix C: Estimated Cost to Upgrade Advance Transit Maintenance Facility

- **Option 1: One EVSE**
 - Uses existing electric service. Limited to one charging station, pending capacity approval from GMP. No possibility for further charging stations with this method.
 - Total Costs: **\$15,500**
 - \$2,500 EVSE
 - \$1,000 EVSE installation
 - \$12,000 three-phase transformer + installation
 - Unit cost: **\$15,500 per EVSE**
- **Option 2: Five EVSEs**
 - New 500kVA transformer and line extension from GMP to allow up to 5 EVSEs eventually.
 - Total Costs: **\$47,500** (\$35,000 + \$2,500 per EVSE)
 - \$25,000 New 500kVA transformer and line extension from GMP
 - \$2,000 precast vault for transformer
 - \$4,000 Site work (**Very** dependent on the nature of the site. Not knowing the layout of the lot, this is a very rough estimate)
 - \$4,000 EVSE wiring installation (depends heavily on whether wires will be buried or can be run along a wall)
 - \$12,500 EVSEs (\$2,500 per EVSE. Could be bought one at a time as busses are acquired)
 - Unit cost: **\$9,500 per EVSE**
- **Option 3: 10 EVSEs**
 - New 1000kVA transformer and line extension from GMP to allow up to 10 EVSEs eventually.
 - Total Costs: **\$74,500** (\$49,500 + \$2,500 per EVSE)
 - \$35,000 New 500kVA transformer and line extension from GMP
 - \$2,500 precast vault for transformer
 - \$6,000 Site work (**Very** dependent on the nature of the site. Not knowing the layout of the lot, this is a very rough estimate)
 - \$6,000 EVSE wiring installation (depends heavily on whether wires will be buried or can be run along a wall)
 - \$25,000 EVSEs (\$2,500 per EVSE. Could be bought one at a time as busses are acquired)
 - Unit cost: **\$7,450 per EVSE**

Appendix D: Electric Cutaways for Vermont

Due to Vermont's rural landscape, many of the state's transit agencies do not use the full size 40 foot buses common in more densely populated urbanized areas. Instead, smaller cutaway buses are used in the state's rural areas, where routes tend to be long and serve a relatively small number of people. Every transit agency in the state includes cutaways in its fleet. Vermont transit agencies employ approximately 333 cutaways on the road, including about 250 medium-sized light-duty buses and 83 medium-sized medium-duty buses. In Vermont, cutaways drive an average of 12,000 miles annually. Collectively, we estimate that these vehicles are using 588,200 gallons of diesel each year and emitting 7,760 tons of GHG. Although the technology is still developing, there are electric cutaway options. Like any all-electric vehicle, plug-in cutaways have zero tailpipe emissions, as well as lower maintenance and fueling costs. Because cutaways are used throughout Vermont, unlike full size transit buses, which are only used by three transit agencies in the state's larger cities, electrification of this vehicle type holds great promise as a viable option.

ELECTRIC CUTAWAY OPTIONS

There are currently four all-electric small transit vehicle options in production and available to Vermont transit operators. A few states and larger cities (New York, California, and Chicago) now offer truck voucher incentive programs to offset the higher purchase price of electric and other alternative-fuel vehicles. Although, Vermont does not offer incentives for vehicles, the VW settlement and Diesel Emissions Reduction Act (DERA) do offer funds when replacing an older vehicle with an all-electric vehicle. The shuttle buses described below would be eligible for these funds, but the van would not be large enough to qualify for this funding.

The largest of these vehicles is the 23 foot **Build Your Dreams (BYD) C6 Electric Motor Coach**¹². This bus is a motor coach style bus and would best fit into the type of role currently filled by the Middlebury Link or the Montpelier Express Link. Charging capacity for this vehicle is listed at 100kW and requires a DC fast charger and three-phase power. Charging time for this vehicle is listed is 1.5 – 2 hours. BYD is a Chinese company that is the market leader for large transit buses. In the last few years, BYD has produced about 100,000¹³ all-electric transit buses globally per year. There are currently 15 BYD C6 motor coaches in service in the U.S. (with five more on order).

Motiv power systems¹⁴, of Foster City California develops all-electric powertrains for medium and heavy duty vehicles. To build its shuttlebus (or cutaway), Motiv partners with Ameritrans bus and installs batteries and an electric motor on an E450 Champion bus chassis. The powertrain components are modular and scalable allowing transit operators to choose from a number of battery pack and range options. Motiv is a Ford Electric Qualified Vehicle Modifier meaning that Ford honors its vehicle warranty on vehicles that have a Motiv electric powertrain installed. Motiv has over 30 all-electric vehicles on the road today and expects to double that number by the end of January 2018. Google has

¹² <http://www.byd.com/usa/bus/c6-electric-motor-coach/>

¹³ <https://www.trucks.com/2017/10/26/byd-chief-future-electric-trucks/>

¹⁴ <https://motivps.com/portfolio/electric-shuttle-bus/>

funded free Mountain View Community Shuttle¹⁵ service using Motiv all-electric cutaways. Over the last two years, the shuttles run seven days a week and have logged over 197,000 miles. University of California Los Angeles just ordered an all-electric shuttle bus powered by a Motiv power system.

Phoenix Motorcars' (Zero Emissions Utility Shuttle) **ZEUS 305**¹⁶ has recently been deployed in South Pasadena, CA as part of the City's Dial-a-Ride program for senior citizens. The wheelchair-lift equipped shuttle is used to transport seniors to medical appointments, and leisure activities such as shopping excursions and exercise classes.¹⁷ Earlier this year, Los Angeles International Airport deployed 16 all-electric ZEUS shuttle buses to service off-airport parking facilities. ZEUS all-electric buses have also been deployed in the United Arab Emirates and by NASA's jet propulsion laboratory in Pasadena, CA. Phoenix Motorcars is located in Ontario, California.

Zenith Motors in Wilder, KY offers both electric cargo and passenger vans. Zenith began designing, developing and testing prototype units between 2011 and 2014. The all-electric vans went into production in 2014. DHL Express and Fed Ex use the all-electric cargo vans for urban delivery purposes. The passenger shuttle vans, which seat up to 16, are currently used by airport parking companies, hotels, and for community transportation. These shuttle vans may be a good option for rural routes in Vermont because they offer front wheel drive which may be more suitable to Vermont's winter driving conditions. In addition, they weigh less, which may increase their ability to drive on Vermont's dirt roads, particularly during mud season. They are also less expensive than cutaways, overall and per passenger seat.

¹⁵ <https://mvcommunityshuttle.com/about/>

¹⁶ <http://www.phoenixmotorcars.com/shuttle-bus/>

¹⁷ <http://www.metro-magazine.com/sustainability/news/726364/calif-city-adds-phoenix-motorcars-zeus-305-electric-vehicle-to-fleet>

Testing Electric Transit Buses in Vermont



Manufacturer	BYD	Motiv Powertrains	Phoenix Motorcars	Zenith Electric
Model	C6	Ford E450 Cutaway Shuttle	ZEUS	Electric Shuttle Van
GVWR	18,331	14,500	14,500	10,500
Seating	Up to 20	15-20	20	16
Range	124 miles	90 miles	Up to 100 miles	80-135 miles*
Battery Capacity	135 kWh	106 kWh/127 kWh	105 kWh	51.8kWh/62.1 kWh/ 70 kWh
Vehicle Cost	\$250,000 inc. charger	\$200,000/\$250,000	\$189,950	\$109,000/\$115,000*
Conventional Vehicle Cost	\$100,000	\$80,000	\$80,000	\$37,204
Incremental Cost	\$150,000	\$120,000/\$170,000	\$109,950	\$71,769/\$77,769*
Chassis	BYD	Ford E450	Ford E450	Dodge ProMaster
Drive Train	All-Electric AC Synchronous Motor	All-electric	All-Electric RWD	All-Electric FWD
Regenerative Braking	Yes	Yes	Dual-mode	Yes
Top Speed (governed)	62.1 mph	60 mph	70 mph	55 mph
Required Electric Service	160 amp	80 amp	80 amp	30 amp-70 amp
Charge Time (level 2)	N/A	8 hours	9 hours	8-10 hours
Charge Time (DC Fast)	1.5-2 hours		3 hours	3 hours
Wheelchair lift	\$25,000	\$3,500	\$5,999	\$12,000

*Depending on the number of battery packs.