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Analysis of Electric Bus Deployments at Transit Agencies

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List of Acronyms

AFDC	Alternative Fuels Data Center
AVTA	Antelope Valley Transit Authority
BEB	Battery Electric Bus
BYD	Build Your Dreams
CAT	Clemson Area Transit
CNG	Compressed Natural Gas
CPM	Cost per Mile
CTA	Chicago Transit Authority
DART	Dallas Area Rapid Transit
NABI	North American Bus Industries
NREL	National Renewable Energy Lab
PVTA	Pioneer Valley Transit Authority
TRB	Transportation Research Board
TTI	Texas A&M Transportation Institute
WRTA	Worchester Regional Transit Authority

Summary

Transit agencies across the country are turning to zero-emission electric buses at a much faster rate than school districts. This technical memorandum summarizes transit agency experiences with the purchase, operation, and support of electric buses. These experiences can help identify potential concerns for school districts planning for the use of electric buses.

Electric buses have better fuel economy than buses fueled by other sources, but they have reduced range. Transit agencies must be prepared for the reduced range and be proactive in planning which routes the buses will be used on and when charging will be needed. While electricity prices are generally lower than other fuel costs, transit agencies should be mindful of higher demand charges that will be applied when buses are charged during peak periods.

Bus Availability

According to the U.S. Department of Energy's Alternative Fuels Data Center (AFDC), seven bus manufacturers offer a variety of electric bus models available in the United States. Table 1 summarizes the information for the electric buses currently available in the United States (*1*).

DART Evaluation and Peer Comparison

The Texas A&M Transportation Institute (TTI) recently completed a project for Dallas Area Rapid Transit (DART) that included a peer comparison of three other transit agencies' use of zero-emission buses conducted by the National Renewable Energy Lab (NREL).

Foothill Transit in Los Angeles County, California, added twelve 35-ft Proterra battery electric buses (BEBs) to its fleet in 2014. NREL compared the data from the BEBs to those of Foothill's eight 42-ft North American Bus Industries (NABI) compressed natural gas (CNG) buses (*2*).

County Connection in the San Francisco Bay, California, area added four 29-ft Gillig BEBs to its fleet in February 2017 (*3*).

King County Metro in the Seattle, Washington area added three 42.5-ft Proterra BEBs to its fleet in February 2016 (*4*).

DART operates in Dallas, Texas, and in 2018, it added seven 35-ft Proterra BEBs to its fleet.

The data presented in this peer comparison are preliminary results from the evaluation performed by NREL at King County Metro (*4*). Researchers at TTI compared the NREL data to DART's six 30-ft NABI CNG buses that operated on the same route as the Proterra BEBs. Table 2 summarizes the experiences of these transit agencies with zero-emission buses.

Table 1. Electric Buses Currently on the Market

Bus Manufacturer	Bus Model	Bus Length	Seating Capacity	Battery Capacity	Bus Range	Charging Time	Max Speed
BYD	K7	30 ft	23	180 kWh iron phosphate*	137 mi*	3–4 hr*	56 mph*
BYD	K9 S	35 ft	33	352 kWh iron phosphate*	145 mi (215 mi for high-capacity model)*	2–3 hr*	62.5 mph*
BYD*	C8MS Double Decker*	35 ft*	51 (47 with restroom)*	313 kWh iron phosphate*	170 mi*	4–4.5 hr*	65 mph*
BYD	K9	40 ft	38*	324 kWh iron phosphate*	156 mi*	2–3 hr*	62.5 mph*
BYD*	C10MS Double Decker*	45 ft*	78*	446 kWh iron phosphate*	230 mi*	2–2.5 hr*	65 mph*
BYD*	K11*	60 ft*	55*	578 kWh iron phosphate*	220 mi*	3–4 hr*	56 mph*
eBus	eBus22	NA	22	130 kWh lithium iron phosphate	125 mi	NA	NA
Gillig	Low Floor Plus	29, 35, or 40 ft	NA	444 kWh	150 mi	NA	NA
GreenPower	EV250	30 ft*	25	210 kWh lithium iron phosphate*	175 mi*	NA	NA
GreenPower	EV300	35 ft*	34	260 kWh lithium iron phosphate*	175 mi*	NA	NA
GreenPower	EV350	40 ft*	40	320 kWh lithium iron phosphate*	185 mi*	NA	NA
GreenPower	EV400	45 ft*	44	320 kWh lithium iron phosphate*	185 mi*	NA	NA
GreenPower	EV550 Double Decker	45 ft*	100	478 kWh lithium iron phosphate*	240 mi*	NA	NA
New Flyer	Xcelsior CHARGE 35′	35 ft	32	388 kWh	225 mi	NA	NA
New Flyer	Xcelsior CHARGE 40′	40 ft	40	466 KWh	225 mi	NA	NA
New Flyer	Xcelsior CHARGE 60′	60 ft	52*	466 kWh	135 mi	NA	NA
Nova Bus	LF Se	NA	41	NA	NA	NA	NA
Nova Bus	LF Se+	NA	41	594 kWh	NA	NA	NA
Proterra	Catalyst 35′ E2	35 ft	28	440 kWh	234 mi	2.7–3.2 hr*	65 mph*
Proterra	Catalyst 35′ XR	35 ft	28	220 kWh	121 mi	2.7–2.8 hr*	65 mph*
Proterra	Catalyst 40′ E2	40 ft	40	440 kWh	230 mi	2.7–3.2 hr*	65 mph*
Proterra	Catalyst 40′ E2 Max	40 ft	40	660 kWh	328 mi	2.8–4.5 hr*	65 mph*
Proterra	Catalyst 40′ XR	40 ft	40	220 kWh	118 mi	2.7–2.8 hr*	65 mph*

Note: BYD = Build Your Dreams; NA = not available.
* Information came from original equipment manufacturer website.
Source: (*1*).

Table 2. Transit Agency Peer Comparison Summary of Zero-Emission Bus Performance

Data	DART	Foothill Transit	County Connections	King County Metro
Number of months in study period	6	33	12	8
Number of buses in study	7	12	4	3
Bus manufacturer	Proterra	Proterra	Gillig	Proterra
Bus model year	2018	2014	2016	2015
Bus length (feet)	35	35	29	42.5
Fleet total mileage	45,020	902,281	51,550	58,391
Average monthly mileage per bus	1,072	2,395	1,074	2,467
Fleet kWh per mile	2.69	2.16	2.84	2.26
Energy cost per kWh	$0.16	$0.17	$0.22	$0.20
Energy cost per mile (CPM)	$0.43	$0.43	$0.73	$0.50
Number of road calls	19	146	11	24
Miles between road calls	2,168	6,180	4,686	2,433
Total parts cost	$73,050.04	$54,932.79	$3,091.45	Not provided
Total maintenance cost	$81,916.87	$137,329.79	$19,963.95	Not provided
Maintenance cost per bus	$11,702.41	$11,444.15	$4,990.99	Not provided
Maintenance CPM	$1.82	$0.19	$0.39	$0.18

The DART BEBs had similar energy costs to the other fleets. Each agency paid about the same amount per kilowatt of energy, ranging from $0.16 to $0.20. The four agencies' BEBs averaged 2.5 kWh per mile and cost an average $0.52 per mile.

DART and Foothill Transit had the same energy CPM, $0.43 per mile, which was similar to King County Metro at $0.50 per mile but much lower than County Connections at $0.73 per mile. The agencies have different contracts in place for calculating energy costs, and each agency has a different type and number of chargers. The time of day can also have an impact on energy costs.

Researchers also compared the energy costs across the different studies. Each agency in this comparison had relatively similar energy costs per kilowatt hour. DART and Foothill Transit paid similar amounts for each kilowatt hour of electricity, at $0.16 per kWh and $0.17 per kWh, respectively, which is about $0.05 per kWh less than what County Connection and King County Metro paid, at $0.22 per kWh and $0.20 per kWh, respectively.

All of the agencies experienced similar fleet kilowatt hour per mile on the BEBs, between 2 and 3 kWh per mile. Both DART and County Connection had slightly better fuel economy on the buses, closer to 3 kWh per mile. Foothill Transit had 2.16 kWh per mile, County Connection had 2.84 kWh per mile, King County Metro had 2.26 kWh per mile, and DART had 2.69 kWh per mile.

Researchers also compared the maintenance and road call data for the different fleets. The DART BEBs experienced higher repair costs, which drove up the maintenance CPM. DART's higher maintenance costs per mile can be attributed to one bus that experienced three high-dollar repairs on motor inverters, as well as the low fleet mileage in the evaluation period compared to peer studies. Other agencies, most notably Foothill Transit, also faced maintenance issues. NREL specifically noted the difficulties and costs associated with needing to train service technicians for the new bus technology. The NREL comparison found that there was also a learning curve for operators in BEB fleet deployments that was similar to DART's experience.

The maintenance CPM was relatively lower for BEB fleets at Foothill Transit and King County Metro, while County Connection's was only slightly higher. The average maintenance CPM for the BEB comparison study was $0.25 per mile, which was much lower than what DART experienced with its BEB fleet: $1.82 per mile. DART's higher maintenance CPM for the BEBs can be explained by multiple high-dollar repairs as well as the lower total mileage in the evaluation period compared to peer studies. In general, BEBs are expected to have lower maintenance CPM than CNG buses.

Other Transit Experiences

According to a 2018 Transportation Research Board (TRB) report entitled *Battery Electric Buses—State of the Practice*, 13 electric bus models were available for purchase in the United States in 2018, and more than 70 transit agencies had implemented electric bus use. The technology for electric buses has advanced over the years, with improvements in battery range, increases in propulsion system reliability, and decreases in purchase price. A survey conducted for the report showed that the majority of respondents planned on purchasing additional electric buses (5).

According to the TRB report, electric buses cost just below $900,000 on average. Also on average, in-depot chargers cost $50,000, while on-route charges cost $500,000. Utility rates vary greatly across the country, but respondents to the survey stated that their electricity cost was between $0.15 and $0.89 per mile. The average electricity cost was $0.36 per mile (5).

In 2013, IndyGo in Indianapolis, Indiana, was awarded a grant to convert 21 buses to battery electric. Complete Coach Works converted 21 Gillig buses that IndyGo already owned. The bus conversions each cost $579,000. IndyGo also installed solar panels on the roof of its garage to help offset higher electricity costs and demand charges. The electric buses accumulated approximately 500 mi each month, with an average route of 90 mi. IndyGo faced challenges with understanding the new technology and has advocated for continuous training for both drivers and mechanics. Drivers experienced challenges with driving performance when they switched between driving diesel and electric buses. IndyGo has recommended that transit agencies manage expectations and research experiences from other transit agencies (5).

In 2013, Worchester Regional Transit Authority (WRTA) in Worchester, Massachusetts, purchased six Proterra electric buses. The buses each cost $1,000,000. Over the course of 4 years, WRTA reported that the CO_2 emissions had been reduced by 780 tons. WRTA analyzed route simulations to determine which routes would work best for the electric buses. WRTA experienced difficulty charging the buses in the winter, especially when there was ice and snow accumulation (6).

In September 2014, Clemson Area Transit (CAT) in Seneca, South Carolina, was the first transit agency to begin using electric buses. CAT chose the Proterra EcoRide buses and received a total of $4.1 million in federal grants. During a comparison of the diesel and electric fleets between 2014 and 2018, the electric buses showed they were cost effective. The electric buses achieved better fuel economy, getting 16.5 miles per gallon (mpg) equivalent, whereas the diesel fleet had 3.8 mpg. The electricity costs were $0.28 per mile and diesel costs were $0.59 per mile. Maintenance costs for the electric buses were $0.55 per mile, compared to $1.53 per mile for the diesel buses. The electric buses were fully charged in only 6 minutes and had a range of more than 40 mi. Battery charging maintained 98–100 percent after 6 years of use. Electric bus brakes showed only 50 percent wear after 100,000 mi (7). CAT has also taken advantage of route modeling software that has been extremely helpful for planning which routes the electric buses should run on. The software allows transit agencies to simulate performance based on different factors, such as route length, weather, and environment (6).

The Chicago Transit Authority (CTA) began using two electric buses in 2014 and plans to have its entire fleet fully electric by 2040. CTA chose New Flyer buses and received a total of $2.5 million in federal grants. CTA stated that its electric buses have saved more than $24,000 per year in fuel costs and $30,000 per year in maintenance costs compared to costs per year for diesel buses also purchased in 2014. CTA continues to operate its electric buses, with the additional purchase of 20 Proterra electric buses in 2018 (7).

In November 2014, Antelope Valley Transit Authority (AVTA), located in northern Los Angeles County, purchased two electric buses from the Chinese bus manufacturer Build Your Dreams (BYD) for $770,000. The electric buses accumulated more than 11,500 mi each month, with an average route of 21 mi. AVTA determined that driver performance can have critical impacts on bus performance, especially regarding regenerative braking. To mitigate this inconsistency, AVTA implemented a training program to help drivers learn the importance of gradual braking and efficient driving practices. AVTA has recommended that transit agencies should develop a strong partnership with different stakeholders, such as the local utility company and bus manufacturers (*5*).

In 2016, Pioneer Valley Transit Authority (PVTA) in western Massachusetts purchased three Proterra electric buses. The buses each cost $749,000. PVTA experienced longer charging times when the weather was colder, and heating the bus further reduced the range. The buses undergo scheduled maintenance after accumulating 6,000 mi. PVTA reported that each bus removes 122 tons of CO_2 each year (*6*).

Albuquerque Rapid Transit purchased 18 electric buses from BYD in 2016 and was faced with challenges from the onset of operation. The buses had an expected range of 275 mi, but the agency only achieved 177 mi between charges. Other operating issues with the buses included doors opening suddenly, faulty brakes, overheating batteries, and other safety concerns. The electric buses had not been approved by the Federal Transit Administration, and officials in Albuquerque decided to end the contract with BYD and pull the buses from service due to unmet contractual agreements on bus performance. In 2019, Albuquerque announced that it would attempt to incorporate electric buses again, with the planned purchase of five new vehicles (*7*).

Conclusion

Implementing new vehicle technology can present challenges and opportunities for transit agencies. The implementation of the Proterra BEBs at DART was no exception. The potential for lower operating cost per mile for BEBs would increase BEB favorability as fleet miles and time accumulate. The emissions benefits from BEBs would also accumulate with increasing time and miles.

With the deployment of BEBs, more awareness exists on the impact of electrical energy costs on BEB operation. Electrical energy cost is affected by demand charges, and to achieve the available electric charging capacity during peak hours, a premium must be paid. This impact of demand charges on BEB operating cost has been experienced by most of the transit agencies implementing BEBs.

Agency Considerations

Following are the suggestions for agency consideration based on the analysis of electric bus deployments by transit agencies:

- **Utilize funding opportunities.** Grant opportunities are often available and could be used to help offset the costs of electric buses.
- **Plan for training for drivers and technicians.** Drivers and technicians will need enhanced training to understand the new technology. Agencies may want to consider this training to be a high priority.
- **Optimize charging strategies.** Transit agencies have faced challenges with charging infrastructure. By finding a way to optimize charging strategies, transit agencies can see benefits and financial savings.
- **Utilize a high-mileage route.** To see cost benefits from their investment, transit agencies could allow electric buses to accumulate high route mileage. The higher the route mileage, the better the cost per mile.
- **Continually evaluate electric bus performance.** Agencies might consider robust data collection on all aspects of electric bus use in their fleets. This practice allows agencies to monitor cost benefits, help ensure best use of this new asset, and inform future decision-making.

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