In-Use Fleet Evaluation of Fast-Charge Battery Electric Transit Buses

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Background
With support from the U.S. Department of Energy’s Vehicle Technologies Office, the National Renewable Energy Laboratory (NREL) conducts real-world performance evaluations of advanced medium- and heavy-duty fleet vehicles. Evaluation results can help vehicle manufacturers fine-tune their designs and assist fleet managers in selecting fuel-efficient, low-emission vehicles that meet their economic and operational goals.

In 2015, NREL launched an in-service evaluation of 12 battery electric buses (BEBs) compared to conventional compressed natural gas (CNG) buses operated by Foothill Transit in West Covina, California. The study aims to improve understanding of the overall usage and effectiveness of fast-charge BEBs and the associated charging infrastructure in transit operation. To date, NREL researchers have analyzed more than 148,000 km of in-use operational data, including driving and charging events.

Foothill Transit purchased the BEBs with grant funding from the Federal Transit Administration’s Transit Investments for Greenhouse Gas and Energy Reduction Program.

Road Grade Impacts
This typical drive cycle speed trace for a BEB operating on Line 291 shows three separate charge events with an average duration of 5 to 6 minutes. The purple line shows the speed trace of the bus and the blue line shows the battery pack state of charge (SOC); both of these metrics use the left vertical axis. The red line, with the vertical axis on the right, shows cumulative distance. The data in this section is from the battery SOO curve on the portion of the figure labeled “North Loop” shows varying discharge rates, which can be attributed to the modest road grade on Line 291, as the northern end of the loop is 92 m above the Pomona Transit Center.

Foothill Transit’s Line 291
In 2014, Foothill Transit fully electrified one route in its service area—Line 291—and is investigating the feasibility of electrifying other routes as well. The transit agency’s electric buses can fully charge in less than 10 minutes via two 500-kW fast chargers located midway along the 26.8 km route at the Pomona Transit Center. The buses are programmed for easy docking—wireless communications govern the speed and stop locations of the buses, and the overhead charger connects without input from the driver.

Ambient Temperature Impacts
The BEBs demonstrated an overall average efficiency of 1.34 kWh/km, which equates to 7.43 km per diesel liter. The overall BEB fleet efficiency fluctuates relative to average temperature, with efficiency dropping when temperatures are higher and air conditioning is used, and also when temperatures drop and electric heaters are used. The month of highest efficiency have average high temperatures less than 25°C and average low temperatures greater than 11°C, requiring the least amount of energy to maintain passenger thermal comfort.

Drive Cycle Characterization
One metric used to describe the drive cycle of a particular vehicle is kinetic intensity, a relative measure of driving aggressiveness based on the relationship between the energy used for vehicle acceleration versus the amount of energy used to overcome aerodynamic drag. Comparing daily average kinetic intensity to average driving speed, there is very little variation in the data set—99.7% of all the values fall within the orange rectangle representing values within ±3 standard deviations from the mean.

Battery SOC Data
Vehicle-reported SOC for all BEBs over the entire data reporting period. The battery SOC never drops below 50% SOC. The battery pack SOC distribution curve in the graph on the left indicates opportunities to optimize deployment of the BEBs as the buses spend less than 65% of their time at an SOC less than 55%.

Future Work
Future research will compare Line 291, which is serviced exclusively by BEBs, to a broader set of Foothill Transit bus routes using in-use data collected from conventional CNG buses randomly dispatched throughout the Foothill Transit service area. Through modeling and simulation, researchers will identify other routes suitable for electrification. In addition to benchmarking the operational efficiency of BEBs against CNG buses using in-field data, researchers will perform controlled chassis dynamometer testing to characterize efficiency over a range of drive cycles.

NREL also plans to further investigate the impacts of HVAC requirements on energy efficiency and identify areas for improvement.

Optimization Opportunities Based on Battery SOC Data
The BEBs are charged on route at the Pomona Transit Center with an average of 12.5 times per day via overhead conductive chargers, transferring on average 19.48 kWh of energy per charge with an average charging duration of just 4.99 minutes. The average charging energy delivered equates to only 22% of the 88 kWh of total energy storage, indicating possible opportunities for battery pack downsizing, less frequent charging, or longer routes.

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