Fuel Cell Electric Buses: A Business Case for Clean Transportation in Connecticut

Connecticut Center for Advanced Technology
Joel M. Rinebold
Paul Aresta
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Introduction:

Government and industry are now investigating the use of hydrogen and renewable energy as a replacement of hydrocarbon fuels in the transportation sector, which accounts for 30.1 percent of Connecticut's total energy consumption. There are approximately 921 transit buses that provide public transportation services in Connecticut. Fuel cell electric vehicles (FCEVs) and fuel cell electric buses (FCEBs) have several advantages, including:

- Zero emissions with high efficiency operation;
- Energy security with fuel produced using domestic and/or renewable resources;
- Quiet operations with electric motor drive and no internal combustion;
- Economic operation with competitive price and hedge against fossil fuel price volatility; and
- Long range with short duration refueling compared to conventional vehicles.

Zero Emission Operation and High Efficiency:

FCEBs operate on hydrogen fuel with use of a fuel cell to convert hydrogen with oxygen from the atmosphere into electricity. The by product is water with zero emission tailpipe operation. The emissions that result from the production and transport of the hydrogen are dependent on the production technology, feedstock, and mode of distribution. Use of solar photovoltaic and electrolysis technologies that are currently in commercial use would result in zero or near zero emissions to produce the hydrogen. Use of biofuel feedstock and anaerobic digestion could produce hydrogen with low emissions and net zero carbon emissions. A transit bus powered by fuel cell technology, operated on hydrogen from renewable sources, would produce zero emissions and could displace approximately 89.3 metric tons of CO_2 emissions and approximately 44 pounds of NOx emissions annually, compared to a conventional diesel bus.

Potential annual reductions for 4 to 8 FCEBs compared to conventional diesel bus operations:

- CO2 emissions = 357 – 714 metric tons;
- NOx emissions = 176 – 352 pounds; and
- Diesel Fuel = 35,200 – 70,400 gallons.

Hydrogen is well suited for transit operations

- *Hydrogen contributes to energy independence*
- *Hydrogen provides operational flexibility*
- *Hydrogen is ideal for centralized fueling of large fleets*

Although the efficiency of conventional diesel buses has increased, buses have the greatest potential for energy savings by using electric motor drive technology. FCEBs have an average fuel economy of approximately 7 to 8 miles per diesel gallon equivalent (DGE) while the average fuel efficiency of conventional diesel transit buses is approximately 4 to 5 miles per gallon. The use of hydrogen and fuel cell technology has the potential to reduce diesel fuel use by approximately 8,800 gallons per vehicle annually, compared to a conventional diesel bus. Battery electric buses (BEBs) have the highest efficiency, exceeding 17 miles DGE; however, these buses are not One-for-one replace nets for conventional buses and require overnight or in-route recharging, possibly several times per day. In addition, the fuel efficiency for the BEBs is significantly affected by cold weather, which limits the range and customer comfort.

Energy Security

Production of hydrogen as an energy carrier can be done by using natural gas, renewable electricity, or hydrogen rich compounds such as ammonia. It is unlikely that the production of hydrogen will be tied to the import of liquid petroleum crude oil or diesel fuel. While the price of diesel fuel has stabilized, diesel fuel derived from crude oil is not renewable and subject to price and supply volatility. Hydrogen as an energy carrier has value for regional energy security through a variety of feedstocks including use of renewable and biofuel energy.

Quiet Operations:

FCEBs and BEBs both use electric motor drives without internal combustion and are comparatively quiet. This application is of high value for urban operations and other locations with sensitive sound receptors. The noise level of electric drive buses is about 52 dB, compared to internal combustion diesel buses with noise levels of about 80 dB.

Economics:

The current capital cost of FCEBs is approximately $1.2 million, which represents a significant reduction in costs since 2010. Ultimately, the DOE and FTA have established a target of $600,000 for the capital cost of FCEBs with a 12 year, 500,000 mile life, bus availability of 90 percent, and a fuel economy of eight (8) miles per DGE. It is expected that a small fleet of FCEBs at $600,000 each, with an 80 percent subsidy could achieve simple parity with (high volume) BEBs and diesel hybrid buses (capital and operating costs) if the cost of dispensed hydrogen is equal to or less than approximately $4.45 DGE and $7.23 DDE, respectively.

Range and Refueling

Although battery electric buses produce zero emissions and have low capital and operating costs, vehicle range is limited and they are subject to long duration or multiple recharging per day; major factors for the provision of service in transit operations. Buses fueled with hydrogen also offer zero emissions, but have a range of 300 miles or more per fill. Consequently, commercialized FCEBs would have capital cost, operating costs, and range similar to diesel hybrid buses, but with zero emissions. Drawbacks with both FCEBs and BEBs include requirements for dedicated recharging and/or hydrogen refueling. FCEBs will require dedicated hydrogen refueling infrastructure with on-site storage. On-route recharging for BEBs will require multiple chargers in various locations to cover the route/service area, which requires cooperation from other organizations/cities for areas where the transit agency does not own the land and significant infrastructure costs. In-depot charging will require plug-in infrastructure for numerous buses, which may take up space and affect electric demand costs, which will decrease the cost effectiveness of the BEBs. Furthermore, as BEB manufacturers add battery packs to increase range, the weight of the bus increases which reduces transport efficiency and challenges weight restrictions for legal operation of public roadways.

Fuel cell electric buses can replace diesel buses without significant changes to operational requirements

- *No need to adapt routes and schedule*
- *No roadside infrastructure*
- *1:1 replacement of conventional buses*

Summary and Conclusion

Electric drive bus operations appear to be the technology of the future offering high efficiency, and quiet and clean operations. Without the use of zero emission vehicles, urban areas may be challenged to achieve compliance with air quality standards. Hydrogen FCEBs offer quiet operation, zero emissions, long range, and a conventional refueling experience. BEBs offer quiet operations and zero emissions, but have limited range and a need to recharge frequently or over long durations. Both electric drive technologies require dedicated recharging and/or refueling. Hydrogen FCEBs may be best suited for a broad range of transit operations where hydrogen refueling is available and convenient. While there is a place in transit operations for both FCEBs and BEBs and each has its own challenges, FCEBs currently provide the best one-to-one replacement for conventional diesel or hybrid diesel transit buses.

Table 1: Analysis of Simple Payback for Various Bus Technologies[1]

Fuel Cell Fleet Vehicle Economic Model

Transit Bus	Current FCEB	Current Conventional Diesel (40 ft)	Diesel Hybrid (40 ft)	Commercialized FCEB	Battery Electric Bus (High Volume)	CNG Bus
Capital Cost	$1,200,000	$445,000	$650,000	$600,000	$600,000	$495,000
% Federal Reimbursement	80%	80%	80%	80%	80%	80%
Federal Reimbursement	$960,000	$356,000	$520,000	$480,000	$480,000	$396,000
VW Funding						
Net Capital Cost	$240,000	$89,000	$130,000	$120,000	$120,000	$99,000
Target: Useful Vehicle Life (Miles) 12 years at 34,000 per yr	408,000	408,000	408,000	408,000	408,000	408,000
Fuel Efficiency (Miles/DGE)	7.01	3.87	4.84	8.00	17.35	2.91
Fuel Cost ($/DGE)	$8.93	$2.90	$2.90	$4.45	$6.14	$2.76
Maintenance ($ / Vehicle Mile Travelled)	$1.00	$0.79	$0.68	$0.40	$0.60	$0.85
Fuel Cost	$519,749	$305,736	$244,463	$226,950	$144,387	$386,969
Maintenance Cost	$408,000	$322,320	$277,440	$163,200	$244,800	$346,800
Total Operational Costs	$927,749	$628,056	$521,903	$390,150	$389,187	$733,769
Net Capital + Operational Costs	$1,167,749	$717,056	$651,903	$510,150	$509,187	$832,769

Notes: Does not include value of avoided environmental, energy security, and budgetary related price volatility control benefits

[1] Costs and purchase terms are for illustrative purposes only and subject to change. Please consult with an authorized dealer for specific details and restrictions.

Resources

Bus and Maintenance Costs; Fuel Efficiency:

https://www.arb.ca.gov/msprog/bus/maintenance_cost.pdf

https://www.nrel.gov/docs/fy18osti/70075.pdf

https://arb.ca.gov/msprog/ict/meeting/mt170626/170626costdatasources.xlsx

https://www.afdc.energy.gov/uploads/publication/foothill_transit_beb_demo_results_2nd_rpt.pdf

https://www.afdc.energy.gov/uploads/publication/fc_bus_project_eval_3rd_rpt.pdf

Personal communications with FCEB operator

Fuel Prices

For current diesel prices: (12-5-17); https://www.eia.gov/petroleum/gasdiesel/

DGE Conversion factors:
https://cleancities.energy.gov/blog/measuring-fuels-understanding-and-using-gasoline-gallon-equivalents

Electricity costs (Connecticut: $16.33/kWh Commercial rate as of July 2017:
https://www.eia.gov/state/data.php?sid=CT

Fuel Prices CNG + Hydrogen: Clean Cities Alternative Fuel Price Report, October 2017
https://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_oct_2017.pdf

Hydrogen costs
https://cafcp.org/sites/default/files/Fuel-Cell-Bus-Fact-Sheet-final.pdf

Bus Noise Measurements
Altoona Bus Research and Testing, (EV Transit Bus), DGMR Consulting Engineers BV, 2012, “Noise Emissions of Light Rail”, Staiano Engineering, Inc., 2007, “A comparison of conventional diesel bus noise levels”

Other
Nicolas Pocard, Ballard, Presentation at the 2017 North American Fuel Cell Bus Conference; November 2, 2017.