

Transit Bus Technology Feasibility Study

Prepared by Advanced Energy

December 2010

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Executive Summary

National security concerns, environmental impacts and rising fuel prices are driving an evolution of our nation's transportation sector. The early stages of a transition to electrified transportation are underway. However, as new technologies emerge, it can be difficult to identify which technologies hold the most promise and warrant performance verification testing or demonstration. One area of particular interest for electric transportation considerations is mass transit buses.

City bus routes typically consist of frequent starts and stops and a defined route, which make them an ideal application for plug-in electric vehicles. As such, Advanced Energy investigated the capabilities of 11 plug-in transit buses currently offered by seven manufacturers. In addition to comparing make, model and design, Advanced Energy also compared:

- Power Source;
- Battery Electric Range;
- Rapid Charging Availability;
- Range Between Charges; and
- Recharge Time.

Research conducted for this project showed that plug-in transit buses are not widely used in the United States. There is a concentration of use in areas of California, along with several transit agencies on the East Coast, but high initial costs and infrastructure requirements hinder their widespread use. Developments in battery technology, reducing size and cost, are required before plug-in transit buses will be widely applicable. In cases where plug-in transit buses have worked well, they are nearly always used on short, repeatable routes with time available for recharging. Route selection has been found to be essential in maximizing bus performance. In addition, driver and maintenance training are important aspects of a successful plug-in transit bus program.

Introduction

Mass transit buses exhibit several characteristics which make this mode of transportation a promising candidate for plug-in (hybrid and all-electric) vehicle technology, such as frequent starts and stops, defined routes, centralized vehicle management, and numerous chances for recharging. Primary charging can occur at bus stations during driver breaks and overnight, and there is the potential to extend vehicle range through opportunity charging at designated bus stops.

Approximately 32% of transit buses in the United States utilize an alternative power source. A number of transit authorities utilize battery powered or other types of all-electric buses, including:

- Alabama: Mobile
- California: Anaheim, Los Angeles, Santa Barbara and San Francisco
- Colorado: Colorado Springs
- Connecticut: New Haven
- Florida: Miami Beach
- Georgia: Atlanta, specifically at Emory University
- Tennessee: Chattanooga
- Virginia: Hampton

In Los Angeles, San Francisco, and Santa Barbara, California electric buses are already commonplace on many routes. A 2008 San Francisco passenger survey conducted by AC Transit, the Center for Transportation and the Environment, and Breakthrough Technologies Institute found that more than:

- 74% of passengers were aware they were riding on an alternative fuel vehicle;
- 50% of passengers responded that their opinion of AC Transit's service improved as a result of the agency using alternative fuel buses;
- 70% reported an improved opinion of the city because of the use of emission-free transportation technology;
- 63% felt the ride was smoother;
- 90% responded developing alternatives to petroleum was important; and
- 81% had positive feelings toward large-scale adoption of alternative fuel buses in their city.

The San Francisco passenger survey also found that electric buses are considerably more popular amongst passengers than standard diesel buses. Internationally, electric buses have more widespread acceptance and use. For example, Montreal, Canada's bus fleet will be entirely electric by 2025 and there is a current European Union directive that mandates the purchase of electric buses for public services.

Plug-in transit buses offer an environmental benefit over standard diesel buses. While a conventional diesel bus uses approximately 15,500 gallons of diesel fuel in a year and emits approximately 153 tons of CO₂, an all-electric bus uses the equivalent of approximately 1,800 gallons of fuel per year and emits approximately 13 tons of CO₂. In addition to the environmental impact of electric buses, there are advantages for both fleet operators and passengers:

Advantages for Fleet Owners/Operators:

- No idling fuel and energy losses;
- Lower and more predictable operating and maintenance costs;
- Regenerative braking adds energy savings of approximately 30%.

Advantages for Passengers:

- Lowest possible noise levels and reduced vibration provides a faster, more comfortable riding experience.

Technology Overview

Hybrid-Electric versus All-Electric Buses

Hybrid-electric buses are similar to hybrid-electric vehicles. Both combine a conventional internal combustion engine propulsion system with an electric propulsion system, utilizing electric power as an energy source (though hydraulic power is being explored as an alternative). Additionally, hybrid-electric buses typically use a diesel-electric power train, using the engine to expand the drive range and charge the battery, with the expanded option to obtain power from the electric grid. All-electric buses are powered solely by electricity, either from onboard stored electricity or external power sources.

Onboard Stored Electricity

Batteries are the common standard for onboard stored electricity; however, battery size and cost are the principal challenges to widespread use of electric transit buses. Recent developments in battery technology with regards to transit buses include a GE dual battery demonstration on a hybrid transit bus. The bus uses both a lithium-ion and a sodium metal halide battery for power, resulting in a less expensive battery system that offers the same range and power commonly used in a 40-ft standard diesel and a 60-ft articulated diesel bus. Additionally, recent focus has been placed on the idea of making electric buses capable of battery swapping – employing a “one size fits all” battery that can easily be charged and replaced as needed within the fleet. Mitsubishi Heavy Industries recently announced that they are developing electric buses with battery swapping capabilities for use in Japan in 2011.

Off-Board Electricity

Buses utilizing off-board electricity obtain power in one of two ways – through overhead electric wires (such as a trolley bus) or the power is supplied over a gap from a power line embedded in the ground. In the latter example, buses can share the road with other vehicles.

Charging Infrastructure

According to the Department of Energy’s Alternative Fueling Stations report in 2009, only 15 states currently have battery recharging stations, only some of which are for transit vehicles. The lack of sufficient charging infrastructure has limited wider adoption of electric buses across the U.S. Additionally, manufacturing costs remain significantly higher for hybrid and electric buses versus their diesel counterparts.

Model Comparisons

Advanced Energy investigated currently available plug-in electric transit buses in order to document their specifications and capabilities. The results are shown in Table 1.

Use of plug-in transit buses in the United States is not widespread due to high upfront costs and high infrastructure costs compared with that of standard diesel buses. Initial cost for a plug-in transit bus can be in the range of \$600,000-\$700,000 higher than that of a diesel transit bus. Fast charging systems add additional cost, depending on the type and size of the batteries in the bus.

Table 1. Currently Available Plug-in Transit Buses

Manufacturer	Model	Type	Battery Type	Battery Capacity (kWh)	Electric Range (miles)	Charging Time	Charging Specifications	Seating Capacity (seats/max)
Astonbus*	E-City 12.0	Electric	Iron Phosphate Lithium	360	approx. 310	6 to 8 hours	400V/100A	30/41
	E-City 10.0	Electric	Iron Phosphate Lithium	230	approx. 310	6 to 8 hours	400V/100A	30/41
	City DD.0	Electric	not specified	330	not specified	not specified	not specified	72 (double decker bus)
DesignLine	Eco Smart 1	Electric	not specified	not specified	100+	not specified	not specified	42
Ebus	Ebus 22	Electric	Nickel Cadmium Liquid Cooled	not specified	not specified	30 minutes with fast charger	90 kW fast charger (cost: \$58,000)	22/32
	Series Hybrid	Electric Range Extended	Nickel Cadmium Liquid Cooled	not specified	not specified	overnight with standard charger	25 kW standard charger; 90 kW fast charger (cost \$58,000)	22
Fisher Coachworks	GTB-40e	Electric	Sodium Nickel Chloride; evaluating Lithium Ion, Lithium Phosphate and Titanium Oxide for future use	210	120	not specified	not specified	44/80

Manufacturer	Model	Type	Battery Type	Battery Capacity (kWh)	Electric Range (miles)	Charging Time	Charging Specifications	Seating Capacity (seats/max)
Fisher Coachworks	GTB-40ex	Electric Range Extended	Sodium Nickel Chloride; evaluating Lithium Ion, Lithium Phosphate and Titanium Oxide for future use	70	300+	not specified	not specified	44/80
Pioneer Bus	eBus-40	Electric	Lithium Iron	not specified	125	6 hours standard; less than 30 minutes with rapid charger	not specified	33/80
Proterra	EcoRide BE35	Electric	Proprietary TerraVolt Energy Storage System	55	24-30	FastFill charging station: 6 to 10 minutes	440V, 1200A (500KW)	38/72
Sinautec	Ultracap Bus	Electric	5.9 kWh ultracapacitors		3.5 - 6	30 seconds at bus stops; 5 to 10 minutes at terminal stops	not specified	41

* Astonbus also has E-City bus models 8.1 and 11.0, but specifications for these buses were not available.

Best Practices for Fleet Adoption

Through the research conducted for this project, Advanced Energy noted reoccurring themes presented in papers and discussions and has identified the following best practices for fleet adoption of plug-in transit buses:

- Route Selection
- Training
 - Operator (Driving Style)
 - Maintenance
 - Emergency Responders
- Education and Outreach

Route Selection

While electric and hybrid buses can show a significant improvement in fuel economy over diesel buses, they need to be matched to a route that allows for maximum gain from the system. A proper route is critical to success. Advanced Energy has performed fuel economy tests in a variety of conditions with other plug-in vehicles in an effort to determine the characteristics of an ideal bus route. The following key parameters were found to have a significant impact on fuel economy for both electric and plug-in hybrid buses:

- Shorter distances
- Lower speeds
- Frequent stops

Routes that incorporate these parameters have shown significant fuel economy improvements over a conventional diesel bus on the same route. A 2006 National Renewable Energy Laboratory study demonstrating in-use applications of electric transit buses found that downtown circular routes were best suited for this technology. In this particular study, new routes were created for the electric buses to maximize their capabilities and performance. Matching the vehicle to the application proved to offer significant performance benefits for the vehicles in the study.

Training

Key to overall success is proper training for operators, maintenance technicians and emergency responders. Operators not only need to know how to drive the bus, but must realize the impact their driving style will have on bus performance. While directly influencing

and modifying a driver's operating style is extremely difficult and ongoing training will take time and resources, this will be time and money well spent. As such, fleet owners should develop education and outreach campaigns designed specifically around teaching drivers how driving style directly impacts fuel economy. Since driving more efficiently typically equates to less aggressive driving, there is a potential that driver safety will improve. Thus, vehicle insurance companies may have a vested interest in offsetting some of the associated costs. Additionally, some automotive manufacturers have been attempting to influence driver behavior with plug-in electric vehicles by the addition of visual cues that help the driver gauge how efficiently they are driving. For example, many vehicles come equipped with instantaneous and average fuel economy readings.

Maintenance technicians will need to be aware of how to efficiently and correctly service the buses as needed. Creating programs through local technical schools could be one means of achieving this. Whatever the program, technicians will need to be made aware of the program and it must be accessible to anyone interested.

In addition to operator and maintenance technician training, emergency responders should be provided with training classes and hands-on instruction on how to respond in an emergency.

Education and Outreach

Encouraging riders to utilize greener public transportation requires a commitment to public education, which helps governing bodies, consumers and fleet managers understand the benefits of electric and hybrid buses and overcome concerns that hinder their use. The media must be engaged to report on infrastructure development and public support from influential leaders in the community is critical. It is vital for initial adopters to have a positive consumer experience that will contribute to widespread acceptance.

To help make the public more familiar with electric and hybrid buses and to gauge their interest, education and outreach programs are essential. These programs typically include activities such as press announcements, local events showcasing new vehicles, test drives, websites/blogs, workshops and conferences. The more education and outreach programs, or plans for programs, the more likely that the community will be ready to accept this newer technology.

Resources

Fuel Cell Buses in U.S. Transit Fleets: Current Status. National Renewable Energy Laboratory. 2009.

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National Fuel Bus Cell Program: Accelerated Testing Evaluation Report. Alameda-Contra Costa Transit District (AC Transit). 2009

Transit Cooperative Research Program Report 132: Assessment of Hybrid-Electric Transit Bus Technology. Federal Transit Administration. 2009.