

Interim Evaluation Results from New Flyer/Allison Hybrid Buses at King County Metro

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ABSTRACT

The National Renewable Energy Laboratory (NREL) is evaluating hybrid buses at King County Metro (KC Metro) in Seattle, Washington. The buses are diesel hybrid electric articulated buses from New Flyer, equipped with the Allison parallel hybrid propulsion system. The evaluation will compare the performance of 20 hybrid buses and 10 diesel buses from the same order. This evaluation also will include a comparison of the hybrid and diesel buses to the Breda dual-mode buses that are being replaced by this new order of buses at KC Metro.

INTRODUCTION

The U.S. Department of Energy (DOE) has been evaluating heavy-duty advanced propulsion and alternative fuel vehicles for many years through the National Renewable Energy Laboratory (NREL). Current advanced heavy vehicle propulsion evaluations are being accomplished as part of DOE's Advanced Vehicle Testing Activity (AVTA) in the FreedomCAR and Vehicle Technologies Program [1]. The primary goal of AVTA is to benchmark and validate the performance of light-, medium-, and heavy-duty vehicles that feature one or more advanced technologies, including the following:

- Internal combustion engines burning advanced fuels such as 100% hydrogen and hydrogen/compressed natural gas-blended fuels
- Hybrid electric, pure electric, and hydraulic drive systems
- Advanced batteries and engines
- Advanced climate control, power electronic, and other ancillary systems.

By benchmarking the performance and capabilities of advanced technologies, AVTA supports the development of industry and DOE technology targets. The testing results are also leveraged as input to component, system, and vehicle models, as well as hardware-in-the-loop testing.

AVTA produces information resources that support the decisions fleet managers and the public make when acquiring advanced technology vehicles. The testing results are presented in easy-to-understand formats that allow users to compare the performance of different types of vehicles.

EVALUATION AT KING COUNTY METRO

The Fleet Test & Evaluation team at NREL, which includes NREL and Battelle staff, is conducting the AVTA evaluation of diesel hybrid electric articulated buses at King County Metro (KC Metro) in Seattle, Washington. Objectives of this evaluation include the following:

- Provide credible data and evaluation results that show progress and experience for hybrid electric bus and infrastructure operation in transit service
- Add to the body of information about performance of advanced vehicles at different transit agencies and in different operating conditions.

This information is important for estimating what the future technology and costs of operation may be based on the experiences of these operations and expected advances in systems integration and development.

KING COUNTY METRO TRANSIT

KC Metro [2] operates transit service in the Seattle/King County, Washington area (2,134 square-miles), including approximately 1,300 standard and articulated buses, electric trolleys, dual-powered buses, and streetcars. Annual ridership is approximately 100 million trips. KC Metro has committed to supplying environmentally sound and energy efficient transportation through several initiatives, including the following:

- Retrofit of existing bus fleet with diesel particulate filters and use of ultra low sulfur diesel (ULSD) fuel. ULSD is a specially refined fuel with much lower sulfur content than regular highway diesel. The sulfur content ranges from 15 to 30 parts per million.
- Continuing use of zero-emission electric trolley buses to supply clean and quiet transportation on some of the busiest routes.
- Using re-refined engine oil and special formulation transmission oil to increase recycling and decrease waste oil disposal.
- Continuing use of the 1.3-mile electric bus tunnel underneath downtown Seattle (Figure 1). Only very low emission and electric buses are used in the tunnel.

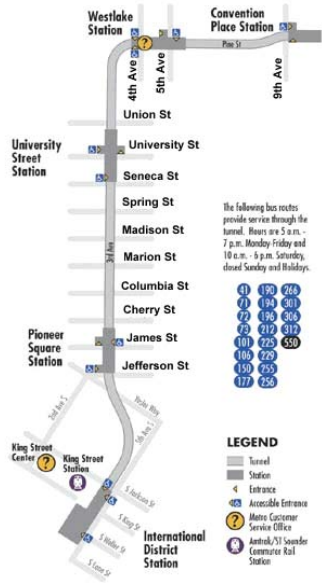


Figure 1. Seattle Downtown Metro Bus Tunnel

The latest transit improvement at KC Metro is the use of new hybrid electric articulated buses, which replace dual-mode Breda buses (Figure 2). The Breda buses, which have been used in the Metro Bus Tunnel since its opening in 1990, allow for electric propulsion in the tunnel and diesel engine propulsion outside the tunnel or when off the electric catenary. These buses were developed especially for this tunnel application, but they have been expensive to operate and, at 14 years old, have exceeded their expected useful operating life. The technology in the new hybrid electric buses reduces emissions compared with the Breda buses by converting energy that is normally wasted in braking into electricity used to help the bus accelerate (i.e., regenerative braking).



Figure 2. Breda Dual-Mode Bus in Yard

NEW FLYER/ALLISON HYBRID BUSES

At around the same time KC Metro began investigating replacements for the Breda buses, it was making plans to add light rail to the downtown tunnel operation. The light rail requires 1,500 VDC, and the dual-mode bus catenary is 700 VDC. For the light rail and dual-mode buses to operate in the tunnel at the same time, both catenary systems would need to coexist in the tunnel, which KC Metro did not find desirable. The agency wanted a replacement bus technology that met the following objectives:

1. Be capable of operating in the tunnel with low tailpipe and noise emissions, preferably without the catenary system
2. Be capable of significantly reduced operations and maintenance costs compared with the Breda dual-mode buses
3. Be capable of operating on routes other than those in the tunnel.

The search for a replacement bus technology occurred at the start of 2000, around the same time that Allison Transmission (a division of General Motors)

began investigating potential test fleets for their new hybrid bus drive system. Based on a conference presentation by Allison, a discussion between Allison and KC Metro began. Allison demonstrated its technology at KC Metro using a 40-foot bus with a trailer. After this testing, KC Metro demonstrated the technology by purchasing one hybrid bus, which was manufactured by New Flyer.

The demonstration bus was received in October 2002 and was immediately put into test service, shadowing another in-service bus. The goal was to put a year's worth of operation on the bus as quickly as possible. The bus was loaded to 130% seated load weight and operated in mock revenue service (shadow service) from November 2002 through February 2003, 7 days a week, from noon to 8:00 am the next morning. The bus was serviced between 8:00 am and noon. The bus was operated for 37,000 miles during this testing. Allison documented this test in a video [3].

This first hybrid bus used a Cummins ISL engine (330 hp). In December 2002, Cummins notified KC Metro that it could not meet 2004 bus emissions standards with its 330 hp engine and withdrew from the project. Soon after, Caterpillar expressed interest in providing high horsepower engines for the bus industry. The project team switched to Caterpillar's C9 diesel engine, which was certified for emissions at 330 hp. New Flyer reengineered the demonstration bus; the changes added 7 inches to the rear of the bus to accommodate the Caterpillar engine.

In April 2003, KC Metro released a request for proposals (RFP) for 265 buses, including 213 60-foot articulated hybrid buses for KC Metro, 22 60-foot articulated hybrid buses for nearby Sound Transit, and 30 conventional diesel 60-foot articulated buses for KC Metro. The RFP included only standard performance criteria—KC Metro wanted to give the manufacturer design flexibility—and the Caterpillar engine was added to the RFP. The contract was signed in October 2003, with New Flyer including the Allison electric drive and Caterpillar C9 engine. The hybrid articulated buses cost \$645,000 each. This new order had minor changes from the original demonstration bus, including the change to the C9 engine and the change of the drive axle from ArvinMeritor to MAN.

CURRENT STATUS

As of March 2005, all the new hybrid and diesel articulated buses (Figure 3 and 4) had been received and were in service. Table 1 shows the bus specifications. The buses are operating from five locations at KC Metro:

1. South Base – 75 hybrid buses
2. Ryerson Base – 30 diesel buses
3. East Base – 38 hybrid buses
4. North Base – 48 hybrid buses
5. Atlantic Base – 52 hybrid buses



Figure 3. New Flyer 60-Foot Articulated Diesel Bus at Ryerson Base



Figure 4. New Flyer 60-Foot Articulated Hybrid Bus Awaiting Prep for Service

Table 1. New Flyer/Allison Bus Descriptions

Description	KC Metro New Flyer/Allison Buses
Buses	2004 New Flyer DE60LF
Length/Width/Height	60.7 ft/102 in/132 in
GVWR/Curb Weight	66,790/44,600 lb
Seated Passenger Capacity	58 (or 50 and 2 wheelchairs)
Engine	Caterpillar C9, 8.8L
Engine Rating	330 hp @ 2,100 rpm 1,150 ft-lb @ 1,300 rpm
Emissions Certification (with DPF)	2.5 g/bhp-hr NOx + HC 0.5 g/bhp-hr PM
Fuel Storage	125 gal (ULSD)
Propulsion	Allison E ^P 50 Parallel Hybrid System
Motor/Generator	15 kW nominal, 150 kW peak
Drive Unit	E ^V 50 Drive: 246 kW input rating, 1,050 ft-lb torque
Controls	Allison (proprietary)
Energy Storage	Nickel metal hydride batteries, 600 VDC
Regenerative Braking	Yes

EVALUATION PLANS

The evaluation at KC Metro is intended to be a Full Evaluation as defined in the DOE/NREL General Evaluation Plan [4]. This type of evaluation is concentrated on commercial or nearly commercial technology vehicles and generally includes at least five of the advanced technology propulsion vehicles and three or more conventional propulsion vehicles matched as closely as possible in operation and vehicle type. The data collection period is intended to be at least 12 months.

Plans for the KC Metro evaluation include selecting 10 diesel and 20 hybrid buses for detailed study. The diesel buses are exactly the same bus and engine as in the hybrid buses but do not have the Allison hybrid propulsion system. The evaluation also includes a study of two specific routes for the diesel and hybrid buses that are closely matched in operation, to yield a detailed fuel economy comparison:

- Diesel buses: 10 buses from Ryerson Base

- Hybrid buses: 10 buses from South Base and 10 buses from Atlantic Base.

The evaluation also will compare the introduction and operation of the diesel hybrid buses with the Breda dual-mode buses, which should demonstrate the business case for purchasing the hybrid buses. The evaluation includes several levels of data collection:

1. Experience implementing the hybrid electric articulated buses and infrastructure
2. Detailed descriptions of the vehicles used in the evaluation
3. Public awareness materials and public perception of the projects
4. Vehicle performance testing as made available from the manufacturers and transit agencies
5. Facilities built or used specifically for this demonstration, including fueling and modifications to existing structures to accommodate hybrid electric buses
6. Capital costs for vehicles, facilities, and training
7. Safety and training at each site
8. Descriptions of baseline operations for standard buses at the site using the newest available and appropriate standard bus operations for diesel buses
9. Operations data collection: vehicle and fueling infrastructure, duty cycle/assignment, fueling, maintenance, and configuration/design changes.

REPORTING

Three reports will be produced from this evaluation:

- Start-up report: two-page description of KC Metro, the hybrid bus technology, and the evaluation plans [5]
- Interim report: eight- to twelve-page description of interim results such as performance, fuel economy, maintenance issues, implementation experience, and status of the technology development; planned for availability in late summer 2005

- Final report: 16- to 24-page description of full final results; planned for availability in early 2006.

WHAT WILL BE IN THE PRESENTATION

The presentation at the APTA 2005 Bus and Paratransit Conference will give background information, including a thorough description of the buses and the hybrid propulsion system. It will also give KC Metro's introduction experience, including early data and evaluation results such as fuel economy and operating costs.

ACKNOWLEDGEMENTS

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ENDNOTES

1. U.S. Department of Energy FreedomCAR & Vehicle Technologies Web site: www.eere.energy.gov/vehiclesandfuels/.
2. King County Metro Transit Web site: <http://transit.metrokc.gov/>.
3. Allison Transmission: *Allison Electric Drives King County Seattle Phases 1 & 2 Test*. CD3713EN, 2003. Visit www.allisontransmission.com/publications/index.jsp to obtain.
4. National Renewable Energy Laboratory: *General Evaluation Plan, Fleet Test & Evaluation Projects*. Golden, CO: National Renewable Energy Laboratory. Report no. NREL/BR-540-32392, 2002. Visit www.eere.energy.gov/afdc to obtain.
5. National Renewable Energy Laboratory: *King County Metro Transit. Advanced Technology Vehicles in Service: Diesel Hybrid Electric Buses*. Golden, CO: National Renewable Energy Laboratory. Report no. DOE/GO-102004-2026, 2004. Visit www.eere.energy.gov/afdc to obtain.

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