

Evaluation of Orion/BAE Hybrid Buses and Orion CNG Buses at New York City Transit

Preprint

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*To be presented at the American Public Transportation
Association Bus and Paratransit Conference
Columbus, Ohio
May 15-18, 2005*

Conference Paper
NREL/CP-540-37751
May 2005



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ABSTRACT

The National Renewable Energy Laboratory (NREL) is evaluating the Orion VII/BAE SYSTEMS hybrid buses at New York City Transit (NYCT). This evaluation is part of an ongoing U.S. Department of Energy (DOE) evaluation program, the Advanced Vehicle Testing Activity (AVTA). The current AVTA evaluation activities at NREL are shown at www.nrel.gov/vehiclesandfuels/fleettest/avta.html. The NREL AVTA project is conducting evaluations of medium- and heavy-duty transit buses and trucks, including the hybrid and compressed natural gas (CNG) buses at NYCT.

NREL's evaluation of the NYCT hybrid buses follows an evaluation of 10 prototype Orion/BAE hybrid buses completed in 2002. The evaluation of the newest generation hybrid buses began in 2004 and will cover one year of operation in revenue service. Detailed data will be collected on two hybrid configurations, the natural gas version of the same bus platform, and similar conventional buses for comparison. Information being collected and analyzed includes operational data such as vehicle use, fuel consumption, and maintenance performed, as well as descriptions of NYCT's experience implementing this new technology. The objective of the evaluation is to provide credible data and results that show the progress of hybrid electric technologies toward widespread commercialization. This will provide vital information to transit agencies considering the use of hybrid buses.

The yearlong evaluation is in progress and will not be complete until later in 2005. This paper describes the background and start-up experience with the hybrid buses at NYCT and details the evaluation plans. Early results of the evaluation—including vehicle use, fuel economy, and

maintenance costs—should be available for presentation at the APTA 2005 Bus and Paratransit Conference.

INTRODUCTION

The National Renewable Energy Laboratory (NREL) Fleet Test & Evaluation (FT&E) team was formed to accomplish the objectives of the U.S. Department of Energy (DOE) to reduce our nation's dependence on imported petroleum by developing advanced vehicle technologies. The FT&E team looks specifically at real-world experience encountered by fleets as they incorporate these new vehicles into their operations. Composed of NREL and Battelle personnel, the team leads vehicle evaluation projects supported by DOE's Office of FreedomCAR and Vehicle Technologies and Office of Hydrogen, Fuel Cells and Infrastructure Technologies.

FT&E projects help inform the purchase decisions of fleet owners and operators by providing them with comprehensive laboratory and fleet test data on viable alternative fuel and advanced technology vehicles. Advanced technologies of interest include hybrid electric and fuel cell vehicles. The evaluations typically cover one year of operational data and include economic, technical, emissions, and safety factors. Data are collected on the operation, maintenance, performance, and, sometimes, emissions characteristics of advanced technology fleets and comparable diesel fleets (if available) operating at the same site. Operators considering the use of these advanced technology vehicles are the primary audience for this information.

The FT&E team has evaluated various technologies in use by transit fleets around the country, including the early hybrid buses in service at New York City Transit (NYCT). The team continues to work with NYCT to evaluate the latest hybrid technology developed by BAE

SYSTEMS in the Orion VII bus platform. The following sections describe the project team, the technology, and the plans for evaluation.

PROJECT PARTNERS

NYCT is the largest public transportation system in the United States. It currently has more than 4,500 buses operating from 18 depots and serving more than 2,100 miles of routes daily. More than 2 million passengers use its 219 bus routes every day. Since 1992, NYCT has displayed its commitment to cleaner vehicles by testing and evaluating a variety of clean fuel buses in revenue service. NYCT's Clean Fuel Bus Program is a continuing effort to lower bus fleet emissions, reduce traffic congestion, and improve air quality. The plan includes using new clean diesel engines with particulate filters and ultra-low sulfur (30 parts per million sulfur content) diesel fuel for the entire diesel fleet (starting in 1998), as well as purchasing compressed natural gas (CNG) and hybrid electric buses.

NYCT's hybrid electric buses (Figure 1) are built by Orion Bus Industries (DaimlerChrysler Commercial Buses North America) and use the BAE SYSTEMS HybriDrive™ propulsion system. In this series hybrid electric system, a relatively small diesel engine running at controlled speed is connected to a generator that produces electricity for the electric drive motor and batteries. The electric motor drives the vehicle and acts as a generator to capture energy during regenerative braking. The batteries supply additional power during acceleration and hill climbing and store energy recovered during regenerative braking and idling. The battery optimization subsystem monitors and maintains the charge of each individual battery. The propulsion control subsystem manages the entire system and optimizes performance for emissions, fuel economy, and power.



Figure 1. NYCT Hybrid Bus

NYCT'S EARLY EXPERIENCE WITH HYBRID BUSES

NYCT's experience with hybrid electric buses began in 1998 with the purchase of a pilot fleet of 10 Orion VI buses with the BAE SYSTEMS HybriDrive propulsion system. At the time these buses were ordered, a hybrid configuration was not a typical option for transit buses. BAE SYSTEMS, Orion, and NYCT collaborated to design and build this technology and implement it into transit service. Understanding that this was an investment in unproven technology, the partnership set specific goals for the project to measure success. The goals included reducing emissions, significantly increasing fuel economy, and demonstrating that hybrid buses could operate in regular service with no restrictions and perform as well as or better than conventional buses.

All 10 prototype buses were in service by mid-2000. The FT&E team conducted a yearlong evaluation of this fleet in operation [1]. The prototype hybrid electric buses met or exceeded the project goals. The evaluation also helped establish a benchmark for hybrid electric technology and assessed the progress of commercialization to that point. The results of the pilot fleet demonstration were very positive, leading NYCT to continue its commitment to hybrid technology.

NYCT's early experience with the pilot bus fleet helped the project team improve and optimize the system to increase efficiency and maximize the potential benefits to the agency. Compared with the Orion VI hybrid electric buses, the next generation Orion VII buses are expected to be optimized more fully for fuel economy and emissions. Modifications included the following:

- The bus platform was updated to the Orion VII model, a step-up low-floor bus; the Orion VII features a removable engine cradle for ease of maintenance.
- The change to a rear step-up design (as opposed to a true low floor) allowed more seats and use of a standard rear axle configuration, which should reduce brake repair costs.
- The engine-generator connection was modified to a "T" configuration to allow easier placement in the bus and better access for maintenance.

- The power plant was switched to a Cummins ISB engine with an Engelhard DPX™ diesel particulate filter.
- All hybrid components were improved for better performance, reliability, availability, and serviceability.

NYCT is purchasing 325 production Orion VII hybrid electric buses in two orders, the first for 125 buses and the second for 200 buses. These large orders mark the continued progress of this hybrid electric technology from a demonstration toward commercialization.

STATUS OF NYCT HYBRID FLEET

As of early January 2005, 117 of NYCT's first 125 Orion VII hybrid electric buses have been delivered and are being integrated into fleet operations. Mother Clara Hale Depot in Manhattan has 65; staff at this depot have experience with hybrid electric buses from operating the pilot Orion VI buses. Queens Village Depot in Queens has 52 Orion VII hybrid electric buses and is scheduled to receive 8 more. Complete delivery of the 125 buses is scheduled for early 2005. To date, NYCT's experience with the hybrid electric buses has been positive. Drivers like the quick acceleration of the buses, which makes it easier to merge into heavy traffic situations typical in New York City.

In addition to the order of 125 Orion VII hybrid electric buses, NYCT has agreed to purchase 200 similar, but slightly upgraded, hybrid electric buses. According to BAE SYSTEMS, four subsystems on this order of buses have been improved, including the engine, generator, propulsion control, and cooling and packaging. The company expects these refinements to result in improved emissions, improved power, quieter operation, and improved reliability, durability, maintainability and performance. Table 1 lists the specifications of the hybrid buses at NYCT.

Delivery of the 200-bus order is scheduled to begin in early 2005, and the buses will be split between three NYCT depots. Once delivery is complete, NYCT will have 325 hybrid electric buses, about 7% of its entire fleet. NYCT also expects to be operating 476 CNG buses by 2005, bringing its combined clean fuel fleet to 801 buses, about 18% of its entire fleet.

Table 1. NYCT Hybrid Electric Bus Specifications

Description	NYCT Orion/BAE SYSTEMS Buses
Buses	2002, 2004 Orion VII
Length/Width/Height	40 ft/102 in/132 in
GVWR/Curb Weight	42,540/31,840 lb
Seated Passenger Capacity	38-44 passengers
Engine	Cummins ISB, 5.9L (2004 equipped with EGR)
Engine Rating	270 hp @ 2,500 rpm 660 ft-lb @ 1,600 rpm
Fuel Storage	100 gal (ultra-low sulfur diesel)
Propulsion	BAE SYSTEMS HybriDrive™
Motor and Internal Gear Reduction	Type: AC Induction, high-power density Horsepower: 250 hp continuous (320 hp peak) Torque: 2,700 ft-lb @ 0 rpm
Generator	Type: Permanent magnet Horsepower: 160 hp continuous
Controls	Type: Integrated power electronics and controls Horsepower: 250 hp continuous (320 hp peak), J1939 CAN interface
Energy Storage	Type: Sealed lead acid Voltage: 520-700 VDC
Regenerative Braking	Yes
Emissions Equipment	Catalyzed diesel particulate filter

EVALUATION PLANS

The evaluation of NYCT's Orion VII hybrid electric buses will include collecting operation, maintenance, and performance data from a selection of hybrid buses from the 125-bus order and the 200-bus order. Detailed data will be collected from a total of 20 hybrid and 20 conventional diesel buses.

NYCT considers the hybrid electric buses to be commercial products and plans no special treatment for their operation. The depots will not have additional spare buses and will be responsible for maintaining bus availability at 85% or better, the same as required for conventional diesel and CNG buses. Recovery time for troubleshooting and repair of the hybrid electric buses is extremely important to NYCT. The ability of the maintainers to fully integrate the hybrid buses into the fleet will be a measure of the success of these bus orders.

NYCT is also receiving Orion VII CNG buses, which will be included as part of this evaluation. The CNG buses will be operated out of West Farms Depot in the Bronx and Jackie Gleason Depot in Brooklyn. Detailed data will be collected on a selection of CNG and conventional diesel buses operating from West Farms

Depot. Table 2 outlines the evaluation plan by bus type and fleet location.

Table 2. Buses Included in the NYCT Evaluation

Depot/ Location	Bus Chassis	Propulsion Technology	Number of Buses
Mother Clara Hale/ Manhattan	Orion V	Conventional diesel	10
	Orion VII	BAE SYSTEMS hybrid (125-bus order)	10
Fresh Pond/ Queens	Orion V	Conventional diesel	10
	Orion VII	BAE SYSTEMS hybrid (200-bus order)	10
West Farms/ Bronx	Orion V	Conventional diesel	10
	Orion VII	CNG	10

The detailed data being collected on each of the 60 study buses include the following:

- Fuel Consumption - amount of fuel, odometer reading, date, price
- Mileage and route information - miles in service per day and month with consideration of duty cycle
- Availability
- Engine oil additions and oil/filter changes - amount of oil, odometer reading, date
- Preventive maintenance action records - date of repair, labor hours, number of days out of service, odometer reading, parts replaced, parts cost, descriptions of problems and repair
- Records of unscheduled maintenance - road calls and warranty repairs.

In addition, specific road call data will be collected on all hybrids at Fresh Pond and Mother Clara Hale Depots and on all the CNG buses at West Farms Depot. Analysis of these additional data will indicate reliability for each order.

WHAT WILL BE IN THE PRESENTATION

The presentation at the APTA 2005 Bus and Paratransit Conference is intended to provide background and hybrid bus introduction experience from NYCT. The background information will include a thorough description of the buses and the hybrid propulsion system as well as a description of the implementation experience at NYCT. The introduction experience will include early data and evaluation results at the fleet with fuel economy and operating costs.

ACKNOWLEDGEMENTS

We would like to thank DOE’s Office of Energy Efficiency and Renewable Energy, Office of FreedomCAR and Vehicle Technologies, and Lee Slezak, Manager of the Advanced Vehicle Testing Activity, for their support. We would also like to thank the project partners, including Gary LaBouff, Doug Zupo, and Gordon Coor at NYCT; Thomas Webb at BAE SYSTEMS; and Mark Brager at Orion Bus Industries.

ENDNOTES

1. *Hybrid Electric Transit Buses—New York City Transit (NYCT) Diesel Hybrid Electric Buses: Final Results*. Golden, CO: National Renewable Energy Laboratory. Report no. NREL/BR-540-32427, 2002.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY) May 2005		2. REPORT TYPE Conference Paper		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Evaluation of Orion/BAE Hybrid Buses and Orion CNG Buses at New York City Transit: Preprint				5a. CONTRACT NUMBER DE-AC36-99-GO10337	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) L. Eudy, R. Barnitt, and K. Chandler				5d. PROJECT NUMBER NREL/CP-540-37751	
				5e. TASK NUMBER FC05.3000	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393				8. PERFORMING ORGANIZATION REPORT NUMBER NREL/CP-540-37751	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S) NREL	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT (Maximum 200 Words) The National Renewable Energy Laboratory (NREL) is evaluating the Orion VII/BAE SYSTEMS hybrid buses at New York City Transit (NYCT). NREL's evaluation of the NYCT hybrid buses follows an evaluation of 10 prototype Orion/BAE hybrid buses completed in 2002. The evaluation of the newest generation hybrid buses began in 2004 and will cover one year of operation in revenue service. Detailed data will be collected on two hybrid configurations, the natural gas version of the same bus platform, and similar conventional buses for comparison. Information being analyzed includes operational data such as vehicle use, fuel consumption, and maintenance performed, as well as descriptions of NYCT's experience implementing this new technology. The evaluation is in progress and will not be complete until later in 2005. This paper describes the background and start-up experience with the hybrid buses at NYCT and details the evaluation plans.					
15. SUBJECT TERMS nrel; doe; advanced vehicle testing activity; hybrid electric; bae systems; buses; public transit; new york city transit					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code)