New York City Transit Drives Hybrid Electric Buses into the Future

The Metropolitan Transit Authority's New York City Transit (NYCT) is the largest public transportation system in the United States and a leader in the use of clean bus technologies. NYCT launched a pilot fleet of hybrid electric buses in 1998. A larger fleet of next-generation production hybrid electric buses began entering service in 2004. The U.S. Department of Energy's Advanced Vehicle Testing Activity (AVTA) evaluated NYCT's pilot fleet and is evaluating the production buses. This report provides an update on the evaluation of NYCT's production hybrid electric buses and reviews the evolution of hybrid electric bus technologies pioneered by NYCT and other progressive transit agencies.

U.S. DEPARTMENT OF ENERGY HYBRID ELECTRIC TRANSIT BUS EVALUATIONS

The role of AVTA is to bridge the gap between R&D and commercial availability of advanced vehicle technologies that reduce U.S. petroleum use while improving air quality. AVTA supports the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program in moving these technologies from R&D to market deployment by examining market factors and customer requirements, evaluating performance and durability of alternative fuel and advanced technology vehicles, and assessing the performance of these vehicles in fleet applications.

The main objective of AVTA projects is to provide comprehensive, unbiased evaluations of advanced technologies. Data collected and analyzed include the operation, maintenance, performance, safety, cost, and emissions characteristics of advanced technology fleets and comparable conventional technology fleets operating at the same site. By comparing available advanced and conventional technology vehicles, AVTA evaluations help fleet owners and operators make informed purchase decisions.

The Fleet Test & Evaluation team, which is composed of National Renewable Energy Laboratory and Battelle personnel, conducts AVTA medium- and heavy-duty vehicle evaluations. Hybrid electric systems are one of the many medium- and heavy-duty advanced vehicle choices available today. The Fleet Test & Evaluation team is conducting several evaluations of hybrid electric transit buses (Table 1). For information on Fleet Test & Evaluation projects, visit *www.nrel.gov/vehiclesandfuels/fleettest.*

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Table 1. Ongoing AVTA Hybrid Electric Transit Bus Evaluations

Fleet	Location	Vehicle	Technology
IndyGo	Indianapolis, IN	Ebus 22-ft transit bus	Series hybrid, Capstone MicroTurbine™ (diesel)
King County Metro	Seattle, WA	New Flyer 60-ft articulated transit bus	Parallel hybrid, GM-Allison E^{P} 50 SYSTEM™ (diesel)
Knoxville Area Transit	Knoxville, TN	Ebus 22-ft trolley bus	Series hybrid, Capstone MicroTurbine™ (propane)
New York City Transit	Manhattan, Bronx, Queens, NY	Orion VII 40-ft transit bus	Series hybrid, BAE SYSTEMS HybriDrive™ system (diesel)

HYBRID ELECTRIC BUS TECHNOLOGIES

Hybrid electric vehicles typically combine an energy storage device, a power plant, and an electric propulsion system. Energy storage devices are most often batteries, but other possibilities include ultracapacitors and flywheels. Power plant options include internal combustion engines, gas turbines, and fuel cells. The efficiency of a hybrid system depends on a number of factors, such as the combination of subsystems, how the subsystems are integrated, and the control strategy employed.

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SERIES HYBRID: In this configuration, the power plant provides power to the electric motor(s), which drives the wheels. There is no mechanical connection between the power plant and the wheels. An advantage of this configuration is the ability to set the power plant to operate at its maximum efficiency.

PARALLEL HYBRID: This configuration has two power paths. The wheels can be driven by the power plant, the electric motor(s), or both. An advantage of this configuration is the combined power due to the electric motor and power plant driving the wheels simultaneously.

Companies Developing Hybrid Technology for Medium- and Heavy-Duty Applications

BAE SYSTEMS: Series hybrid system for 40-foot transit buses and military applications.

Eaton: Parallel hybrid system for medium- and heavy-duty trucks.

Ebus: Series hybrid system for 22-foot buses using a Capstone MicroTurbine.

GM-Allison: Parallel hybrid system for 40- and 60-foot transit buses.

ISE Research: Series hybrid system for 40-foot transit buses, over-the-road coaches, and military applications (diesel, gasoline, and hydrogen fueled).

Oshkosh: Series hybrid system for heavy-duty trucks such as refuse haulers and military applications.

There are two basic strategies for hybrid propulsion: series and parallel (see sidebar). Hybrid electric vehicles also can use regenerative braking, which converts some of the energy dissipated during braking into electrical energy that can be used to power the vehicle.

Hybrid electric propulsion systems are being developed for a wide range of medium- and heavy-duty vehicle sizes and applications, including transit buses. Hybrid propulsion systems offer several advantages to transit agencies:

- Increased efficiency, potentially lowering fuel cost
- Better acceleration, allowing quick merging into heavy traffic
- Decreased emissions
- Quieter operation.

More than 30 organizations in the United States are currently operating hybrid electric bus technologies. Promising results from early projects have led several agencies to place large orders for hybrid buses. More than 600 hybrid buses could be placed into service across the United States in the next several years. NYCT is one of the fleets that have made a commitment to hybrid technology.

THE BAE SYSTEMS HYBRIDRIVE™ SYSTEM

NYCT's hybrid electric buses are built by Orion Bus Industries (DaimlerChrysler Commercial Buses North America) and use the BAE SYSTEMS HybriDrive™ propulsion system (Figure 1).

In this series hybrid electric system, a relatively small diesel engine running at an optimal 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.

NYCT'S CLEAN FLEET COMMITMENT

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.

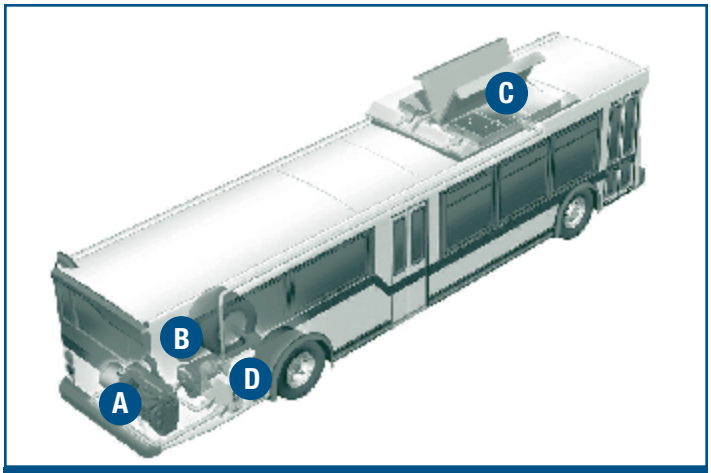

Figure 1. The BAE SYSTEMS HybriDrive™ System

A: A 5.9-liter diesel engine runs at an optimal controlled speed and is connected to a generator to produce electrical power for the drive motor and batteries.

B: The electric motor drives the vehicle and acts as a generator to capture energy during braking.

C: The batteries supply power during acceleration and hill climbing and store energy recovered during regenerative braking.

D: The propulsion control system manages the entire system and optimizes performance for emissions, fuel economy, and power.

NYCT'S FIRST-GENERATION PILOT HYBRID ELECTRIC 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 an 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, including the following:

- Reduce emissions
- Significantly increase fuel economy
- Show hybrid buses can operate in regular service with no restrictions and perform as well as or better than conventional buses
- Significantly increase brake life
- Demonstrate positive perception of hybrid electric buses by drivers and passengers
- Improve the hybrid electric bus design to promote development and aid in commercializing the technology.

All 10 prototype buses were in service by mid-2000. The AVTA Fleet Test & Evaluation team conducted a yearlong evaluation of this fleet in operation*. The prototype hybrid electric buses met or exceeded the project goals. The evaluation also established a benchmark for hybrid electric technology and assessed the progress of commercialization to that point.

NYCT'S NEXT-GENERATION PRODUCTION HYBRID ELECTRIC BUSES

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 more fully optimized for fuel economy and emissions. Table 2 shows the Orion VII specifications. 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 increased its commitment to hybrid electric technology by 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'S NEXT-GENERATION HYBRID ELECTRIC BUSES

As of early March 2005, all 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 60 Orion VII hybrid electric buses. To date, NYCT's experience with the hybrid electric buses has been positive. Drivers like the quick

Table 2. Orion VII Bus Specifications

Buses: Orion VII	
Model Years	2002, 2004
Length/Width/Height	40 ft/102 in/132 in
GVWR/Curb Weight	42,540/31,840 lb
Seats	38-44 passengers
Service	Manhattan, Queens, Bronx, NY
Engine: Cummins ISB 5.9 liter*	
Rating	270 bhp @ 2,500 rpm 660 lb-ft @ 1,600 rpm
Fuel Storage: Diesel	100 gal
Fuel	Ultra-low sulfur diesel (less than 30-ppm sulfur content)
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 lb-ft @ 0 rpm
Generator	Type: Permanent magnet Horsepower: 160 hp continuous
Energy Storage	Type: Sealed lead acid Voltage: 520-700 VDC
Controls	Type: Integrated power electronics and controls Traction motor/generator horsepower: 410 hp continuous (480 hp peak), J1939 CAN interface
Regenerative Braking	Yes
Auxiliary Power	Diesel engine
Emissions Equipment	
Catalyzed Diesel Particulate Filter	Engelhard DPX™ (on MY 2002 buses) Johnson Matthey CRT™ (on MY 2004 buses)

* Engines in MY 2004 (200-bus order) buses equipped with exhaust gas recirculation (EGR).

* To obtain publications related to this evaluation, visit the Alternative Fuels Data Center at *www.eere.energy.gov/afdc* or call the National Alternative Fuels Hotline at 1-800-423-1363. Related publications include *NYCT Diesel Hybrid Electric Buses: Final Results, NYCT Diesel Hybrid Electric Buses: Final Data Report, NYCT Diesel Hybrid Electric Buses: Program Status Update, and Advanced Technology Vehicles in Service: Diesel Hybrid Electric Buses.*

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 3 summarizes improvements made from the Orion VI prototype to the most recent version of the bus.

Delivery of the 200-bus order began 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 3. Improvements in NYCT's Hybrid Electric Transit Buses, MY 1998–2004

	Orion VI (MY 1998)	Orion VII (MY 2002)	Orion VII (MY 2004)
Number of Buses	10	125	200
Engine	DDC S40	Cummins ISB	Cummins ISB with EGR
Emission Certification Level, g/bhp-hr	PM 0.05, NO_x 4.0	PM 0.05, NO_x 4.0	PM 0.05, NO_x 2.5
Emissions Control	Catalyzed DPF	Catalyzed DPF	Catalyzed DPF
DPF/HEV Control	Monitor only	Actively managed	Actively managed
Batteries	Lead acid	Lead acid	Lead acid (2 types)
Battery Control	Generation 1	Generation 2	Generation 3
Motor/Controller Cooling	Oil/WEG	Oil/WEG	Oil/Oil (integrated system)
Generator Mounting	Coupling	Coupling	Direct mount (no coupling)
Generator Control	Speed controlled	Electronically controlled	Electronically controlled

DPF—diesel particulate filter; EGR—exhaust gas recirculation; HEV—hybrid electric vehicle; WEG—water ethylene glycol.

EVALUATION PLANS

The AVTA 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. Comparison of both hybrid versions and conventional diesel buses will help show the evolution of the product toward commercialization. Detailed data will be collected from a total of 20 hybrid and 20 conventional diesel buses: 10 hybrid buses (125-bus order) and 10 conventional diesel buses at Mother Clara Hale Depot, and 10 hybrid buses (200-bus order) and 10 conventional diesel buses at Fresh Pond Depot.

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 integrate the hybrid buses fully 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.

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