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New York City Transit (NYCT) Hybrid (125 Order) and CNG Transit Buses

Final Evaluation Results

R. Barnitt
National Renewable Energy Laboratory

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Technical Report
NREL/TP-540-40125
November 2006

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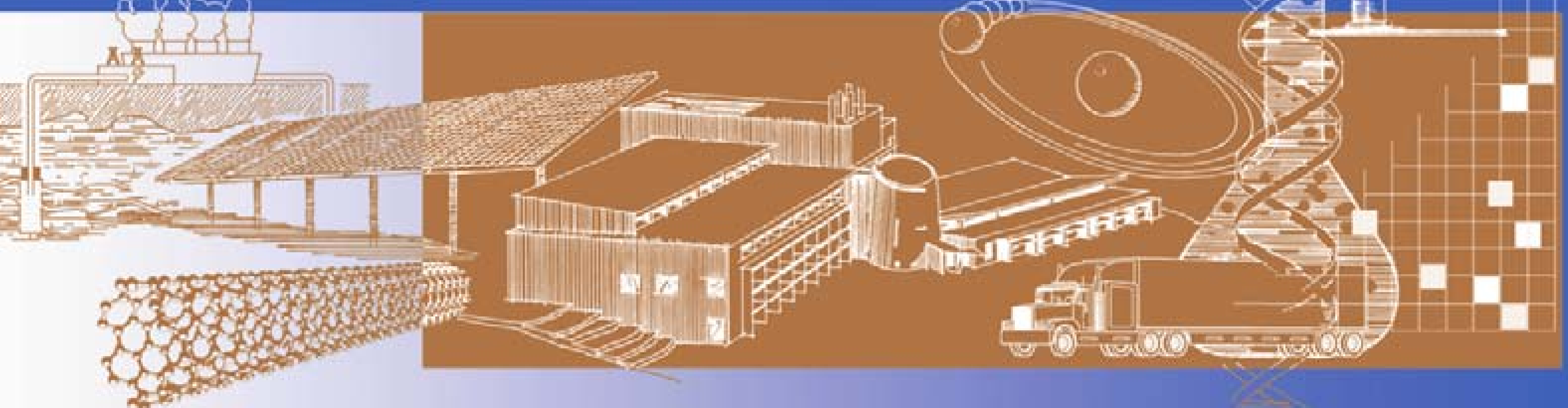

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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

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Table of Contents

Executive Summary

This report is part of a series of evaluations from the U.S. Department of Energy (DOE). DOE, through the National Renewable Energy Laboratory (NREL), has been tracking and evaluating new propulsion systems in transit buses and trucks for more than 10 years using an established and documented evaluation protocol. These DOE/NREL vehicle evaluations are a part of the Advanced Vehicle Testing Activity (AVTA), which supports DOE's FreedomCAR & Vehicle Technologies Program.

The role of AVTA is to bridge the gap between research and development and commercial availability of advanced vehicle technologies that reduce U.S. petroleum use while improving air quality. The main objective of AVTA projects is to provide comprehensive, unbiased evaluations of advanced vehicle technologies. Data are collected and analyzed for operation, maintenance, performance, 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 purchasing decisions.

DOE/NREL evaluated the original 10 prototype diesel-hybrid buses from Orion and BAE Systems (model Orion VI buses) operated at New York City Transit (NYCT). That evaluation was reported in July 2002 and provided results from the prototype buses from 1998 through 2001. This report focuses on 10 new compressed natural gas (CNG) and next generation diesel hybrid electric bus propulsion systems in NYCT's transit buses. Both of these propulsion systems are alternatives to standard diesel buses and allow for reductions in petroleum use and emissions (usually focused on reductions of particulate matter and oxides of nitrogen). CNG propulsion is an alternative to diesel fuel use, and diesel hybrid propulsion allows for increased fuel economy, which, in turn, reduces petroleum use.

Evaluation Design

This report describes the evaluation results for new Orion VII low floor buses at NYCT with CNG propulsion (equipped with Detroit Diesel Corporation Series 50G CNG) and new hybrid propulsion (equipped with BAE Systems' HybriDrive propulsion system). These final results represent a 12-month evaluation of these two groups of buses (October 2004 through September 2005).

The CNG buses evaluated were part of an order of 260 Orion VII CNG buses ($319,000 each) that started into service in September 2003 at Jackie Gleason Depot and later at West Farms Depot. NYCT expected the buses to seamlessly replace older diesel buses after CNG fueling infrastructure was added and training was completed at the newly opened West Farms Depot.

The hybrid buses we evaluated were part of an order of 125 Orion VII hybrid buses ($385,000 each) with the BAE Systems series hybrid propulsion system. The buses started service in March 2004 at Mother Clara Hale Depot in Manhattan and later were also introduced at Queens Village

Depot in Queens. This group of buses is the first large commercial hybrid bus delivery for Orion and BAE Systems.

The evaluation we present in this report examines 10 new CNG Orion VII buses (model year 2002) selected at random from the West Farms Depot, and 10 new hybrid Orion VII buses (model year 2002) chosen at random from the Mother Clara Hale Depot. This evaluation of the Orion VII CNG and hybrid buses compares buses that are the same age and the same bus platform. The CNG and hybrid buses have been operated on similar duty-cycles and the maintenance practices at the two depots appear to be similar. Older (non-exhaust gas recirculation [EGR] engine equipped) diesel buses at both West Farms (model year 1994) and Mother Clara Hale (model year 1999) depots were included in this evaluation for limited comparisons of mileage, fuel economy, and roadcalls for standard diesel technology. The evaluation team selected 10 vehicles from each study group for analysis; which was determined to be a sufficient number to provide some degree of statistical significance to the results obtained.

Implementation Experience

NYCT reported that the implementation experience of the CNG (260 buses) and hybrid (125 buses) fleets went well, and the buses were quickly put into full service. NYCT, Orion, and BAE Systems reported that the buses are performing as expected.

Facilities: A large CNG compression station was built at West Farms Depot that has the ability to compress 6,600 scfm of natural gas and fuel a bus in less than 5 minutes. Combustible gas detection was added for the maintenance area to accommodate the use of natural gas buses. The total cost of facility improvements at West Farms was $7.4 million including the station, facility improvements, and $2 million for blasting through solid rock to bury the high pressure gas lines. The hybrid buses required additional space at the Mother Clara Hale facility for two battery conditioning stations ($70,000 each); an overhead crane was also added to enable mechanics to service the battery tubs on top of the hybrid buses.

Operator comments: The bus operators reportedly like the new buses (both the hybrid and CNG buses)—especially the acceleration of the hybrid buses.

Mileage accumulation: Mileage accumulation for the entire order of 260 CNG buses through September 2005 was nearly 12 million miles with a general usage rate of 2,400 monthly miles per bus. The entire order of 125 hybrid buses accumulated nearly 4 million miles through September 2005 with a general usage rate of 2,400 monthly miles per bus for Mother Clara Hale Depot and around 2,900 monthly miles per bus for Queens Village Depot.

Reliability: Both the CNG and hybrid bus fleets experienced miles between roadcalls (MBRC) rates above NYCT's required 4,000 MBRC (nearly 6,000 MBRC for CNG, and about 5,000 MBRC for hybrid).

Evaluation Results

The following results and discussion focus only on the evaluated operating depots and study bus groups.

Duty Cycle
We have used average speed as an indicator of the general duty cycle for the evaluation locations. The average speed for the CNG buses at West Farms Depot was 6.5 mph for 2004 and 6.3 mph for 2005. The average speed or general duty cycle for the hybrid bus evaluation location, Mother Clara Hale Depot, was 6.5 mph and 6.1 mph for 2004 and 2005 respectively. The average speeds are comparable between the two evaluation locations. The buses at the two depots were randomly dispatched on all standard bus routes.

Bus Use
For the detailed study groups, the CNG buses had 3% lower bus use compared to the hybrid buses (2,295 monthly average mileage per bus for CNG buses and 2,370 monthly average mileage per bus for hybrid buses). This supports the premise that these two study groups are being used in a similar fashion. The diesel buses studied from Mother Clara Hale Depot had an average monthly mileage per bus of 2,385. Also, the monthly average mileages per bus for the CNG and hybrid study buses are similar to the overall fleet and appear to be representative of typical operation.

Fuel Economy

- CNG Buses—The CNG study group fuel economy was 1.70 miles per diesel energy equivalent gallon for the 12-month evaluation period. The CNG average fuel economy is 25% lower than the diesel study buses operating at West Farms Depot (2.28 mpg). Based on the duty cycle at West Farms (average speed between 6.3 mph and 6.5 mph), this lower fuel economy is within expectations based on previous CNG studies[1].

  Note: The NYCT bus duty cycle is a severe application for spark ignited (SI), natural gas engines because of the slow average speed (6.3 - 6.5 mph) and frequent stops, which indicates the engine is operating at a low speed and load for much of its operating time. SI engines typically have a lower thermal efficiency at low speed and load than compression ignition (CI) diesel engines. Consequently, lower natural gas fuel economy is expected in this type of operation.

  Both the DDC Series 50 diesel and DDC Series 50 CNG engines are no longer available for new transit buses. The DDC Series 50G natural gas engine, operated by NYCT is not the newest technology natural gas engine (fuel and electronic controls) currently available. Newer engines from other manufacturers may have shown better results.

[1] For example, DART's LNG Bus Fleet, Final Results, 2000, NREL, NREL/BR-540-28739 (www.nrel.gov/vehiclesandfuels/fleettest/pdfs/28739.pdf) and Alternative Fuel Transit Buses, Final Results, 1996, NREL, NREL/TP-425-20513 (www.eere.energy.gov/afdc/pdfs/transbus.pdf)

- Hybrid Buses—The hybrid study group 12-month average fuel economy was 3.19 mpg, which was 34% higher than the non-EGR diesel buses (average 2.38 mpg for a 12-month period) operating at Mother Clara Hale Depot and 40% higher than the non-EGR diesel buses (average 2.28 mpg for a 12-month period) operating at West Farms Depot.

  The hybrid bus average fuel economy for the 12-month evaluation period fluctuated between 60% and 120% higher than the CNG buses based on diesel gallon equivalent units. Figure ES-1 shows 12 months of average monthly fuel economy for the two diesel study groups, CNG, and hybrid buses. The two diesel study groups have similar average fuel economy results for the evaluation period shown. The hybrid bus fuel economy has fluctuated generally between 26% and 52% higher than for the diesel buses (in the same time frame) at Mother Clara Hale Depot; however, during the summer months (June 2005-September 2005), this positive difference dipped as low as only 12% (better compared to diesel average) for one month during the summer.

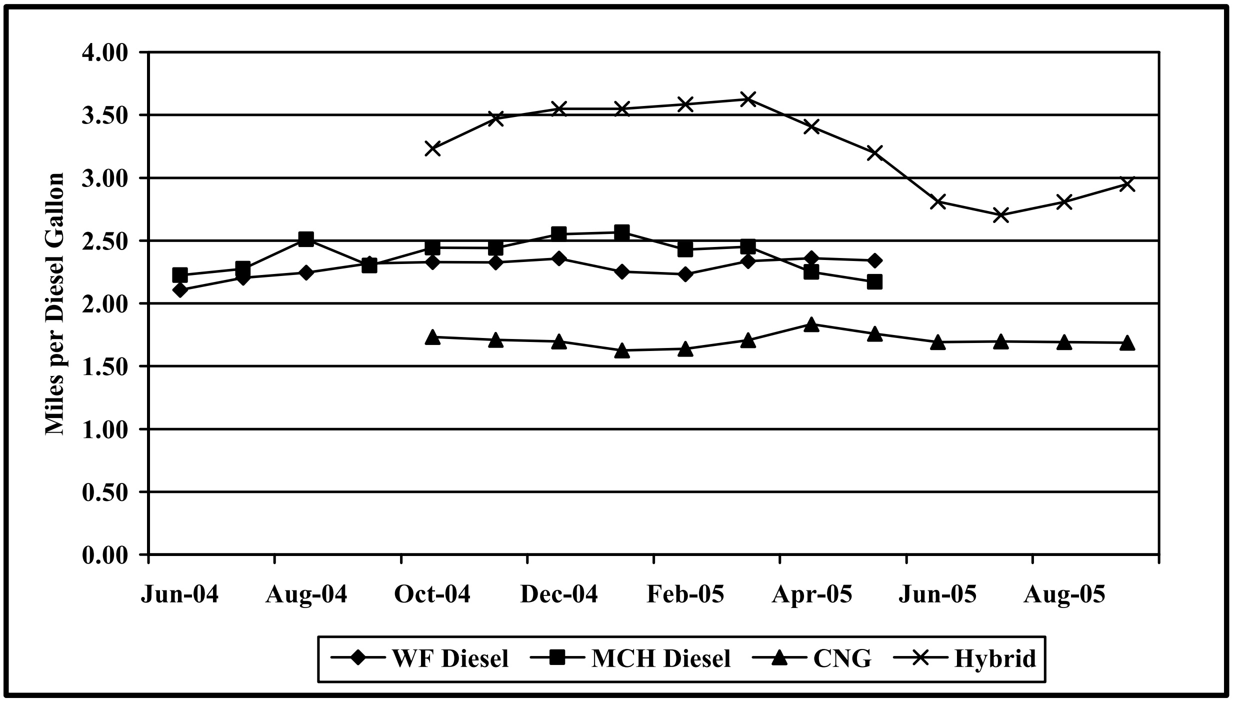


Figure ES-1. Average Fuel Economy (MPG)

The hybrid bus average fuel economy had a much larger decrease/fluctuation in fuel economy in the summer months (June through September) than any of the other three study bus groups shown. According to BAE Systems, much of this decrease is due to an increase in energy consumption for air conditioning. Although air conditioning load is similar for all four study bus groups, this is compared as a percentage to a much lower overall fuel consumption for the hybrid buses (see Figure ES-2). Additional factors such as different engine sizes, CNG engine thermal efficiency changes with loading, and others likely contribute to the magnitude of the summer versus winter fuel economy differences between the three different propulsion types. In other words, all four study bus groups have a significant increase of energy consumption for air conditioning in the summer months, but this increase represents a much larger percentage of overall fuel consumption for the hybrid buses, resulting in a larger penalty in fuel efficiency.

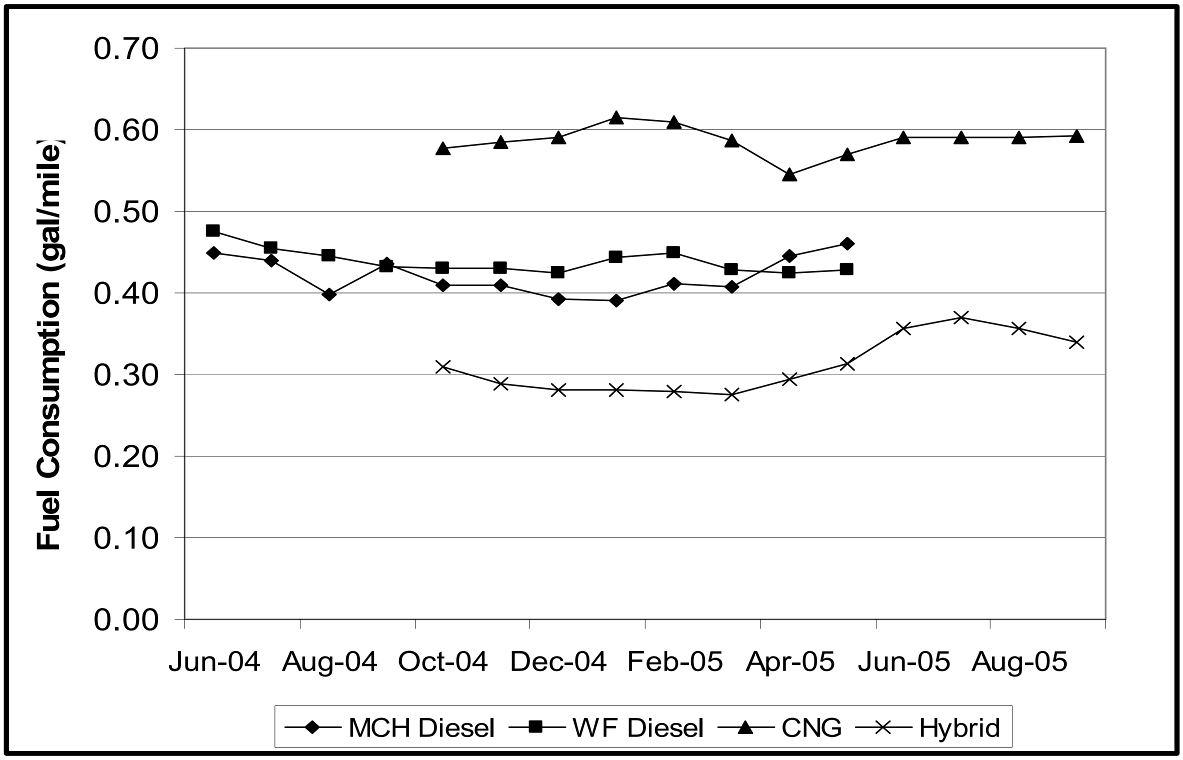


Figure ES-2: Average Fuel Consumption (Diesel Equivalent Gallons per Mile)

Fuel Cost

Fuel cost for the CNG buses is based on the commodity natural gas price paid by NYCT and an additional charge from Trillium USA to pay the operation and maintenance cost of the CNG fueling station. The average natural gas commodity price during the evaluation period was $1.00 per therm and the Trillium USA charge was $0.25 per therm for a total cost of $1.25 per therm or $1.74 per diesel energy equivalent gallon. The average diesel fuel cost—sulfur content less than 30 parts per million (ppm)—was $1.78 per gallon during the evaluation period. This translates into a CNG bus study group fuel cost per mile 45% higher than the hybrid buses and 31% higher than the diesel study group at West Farms Depot.

Total Maintenance Costs

This evaluation focuses on bus operations spanning the first two years of the minimum 12-year life of a transit bus. This short evaluation period does not provide enough of the capital and operating costs to understand the full 12-year life cycle cost of the CNG, or hybrid buses. In order to gain a complete understanding of costs, one must examine the purchase cost of the buses, cost of facility modification or addition, warranty cost, operations cost (and savings), and longer term maintenance costs (such as engine rebuilds or replacements, traction battery replacements, brake repair savings, etc.). However, the intent of this evaluation is to provide accurate actual capital and known operations costs experienced for hybrid and CNG vehicles for the time period selected.

Total maintenance costs include mechanic labor at a standardized $50 per hour rate (this is not a NYCT mechanic labor rate) and parts, but do not include warranty costs.

The hybrid and CNG buses have had many repairs covered under warranty which are not included in this analysis. The cost of warranty repairs is accounted for in the bus purchase price set by the bus manufacturer. Not accounting for warranty repairs in the evaluation of total maintenance cost offers an incomplete picture of true maintenance cost. However, the maintenance cost reported with the absence of warranty costs does reflect the actual cost to the transit agency for the time period evaluated. Therefore, the maintenance cost analysis presented here does not include warranty repairs, but is limited to labor and parts costs associated with repair work performed by NYCT mechanics. This analysis is not predictive of maintenance costs which will be assumed by the transit agency beyond the warranty period. The general warranty on these particular hybrids is two years from date of purchase, with some drivetrain components warranted beyond two years. The exact components and warranty periods are negotiated by NYCT and Orion, and are contractual.

The CNG buses' average total maintenance cost was $1.29/mile which was 5% higher than the hybrid buses ($1.23/mile) during the evaluation period. Diesel baseline vehicle maintenance costs were not compared due to the older age of the diesels relative the CNG and hybrid vehicles.

Propulsion-Related Maintenance Costs
Propulsion-related maintenance costs include repairs for transmission, non-lighting electrical (charging, cranking, and ignition), air intake, cooling, exhaust, fuel, engine, electric propulsion, and hydraulics. The CNG buses' average propulsion-related maintenance costs per mile were 5% lower than the hybrid buses. A summary of propulsion-related maintenance costs is shown in Table ES-2.

Table ES-2. Summary of Propulsion-Related Maintenance Cost per Mile Comparisons*

System	CNG ($/mile)	Hybrid ($/mile)	Hybrid vs. CNG
Total Propulsion-Related	**0.349**	**0.367**	**5% (higher)**
Exhaust	0.020	0.024	22% (higher)
Fuel	0.058	0.015	-74% (lower)
Engine	0.064	0.061	-5% (lower)
Electric Propulsion/Transmission	0.036	0.181	403% (higher)
Non-Lighting Electrical	0.101	0.042	-58% (lower)
Air Intake	0.012	0.006	-53% (lower)
Cooling	0.053	0.031	-41% (lower)
Hydraulic	0.005	0.007	62% (higher)

* The cost comparisons are provided as hybrid compared to CNG as the baseline.
((Hybrid cost per mile/CNG cost per mile)—1) * 100% = Percent comparison

Other Important Maintenance Costs
In addition to the above measured maintenance costs, this report includes additional information on four maintenance cost topics because of their relevance to hybrid propulsion technology.

- **Engine**—NYCT plans to replace the smaller than standard transit bus diesel engine used in the hybrid buses at approximately year six out of the 12-year life. A standard diesel or CNG bus would typically have one engine overhaul during the 12-year life without any planned engine replacements.

- **Traction Batteries**—The traction batteries for the NYCT hybrid buses are sealed gel lead-acid batteries in two separate tubs of 23 batteries each or 46 battery modules total. These batteries (based on recommendations from the manufacturer), are expected to last at least three years, and then they will need to be replaced (or three sets of traction batteries during the 12-year life of the bus). A total of 22 traction batteries were replaced for the 10 study buses during the evaluation period. This translates into a 4.8% per year replacement rate. BAE Systems reports that analysis shows that none of those 22 traction batteries had failed, and they rolled out a software change in April 2006 (after this evaluation ended) to reduce the number of unnecessary traction battery replacements. While this software change could potentially improve battery life, it may also affect fuel economy; however, this software change occurred after the end of this evaluation period and the impact on fuel economy is unknown.
- **PMI**—this is preventive maintenance inspection labor time spent on the buses. Based upon the data collected during this evaluation, the hybrid buses had 50% more labor spent on scheduled maintenance time. However, due to the way in which the NYCT mechanics record their time, additional unscheduled activities are included in what is defined as PMI. No difference in PMI labor is expected between the CNG and hybrid buses. Recognizing this, but reporting the unmodified data collected on PMI costs, total PMI labor costs are: CNG—$0.12/mile vs. hybrid—$0.18/mile.
- **Brakes**—brake repairs and reline activities are a large expense for transit bus operations. The study's hybrid buses use regenerative braking, which converts energy back into the electric propulsion generator to slow down the vehicle instead of using only the mechanical brakes. This braking energy is then stored in the traction batteries for later use, and provides increased fuel efficiency for the hybrid buses. Hybrid buses are expected to have reduced brake reline and repair costs because they use regenerative braking. During this evaluation, the hybrid buses had brake repair costs that were 79% lower than for the CNG buses (CNG—$0.18/mile vs. Hybrid—$0.04/mile). CNG buses had nine four-wheel relines (planned at approximately 18,000 miles), and the hybrid buses had none as of the end of the evaluation.

Roadcalls

In this report, a roadcall (RC) is defined as an on-road failure of an in-service bus, which results in a bus being taken out of service or replaced on-route. RCs are a direct indicator of reliability for transit buses. Miles between RC (MBRC) is a typical industry measurement for RC performance for transit buses. NYCT expects transit buses to meet or exceed a rate of 4,000 MBRC for all RCs. The CNG buses had nearly 6,000 MBRC. The hybrid buses had around 5,000 MBRC.

For RCs related only to the propulsion system, the hybrid buses are around 8,000 MBRC, and the CNG buses are just above that at nearly 9,000 MBRC. For comparison, the older diesel buses at Mother Clara Hale Depot have the highest MBRC of the groups at just above 10,000.

What's Next?

DOE/NREL has started evaluating the EGR equipped hybrid buses from the order of 200 operating at Manhattanville Depot. This new evaluation provides an opportunity to look at newer MY2004 diesel engine technology to be utilized in the hybrid buses, improvements in the BAE electric propulsion system, and traction battery replacement experience. Results from this evaluation will be available in 2007.

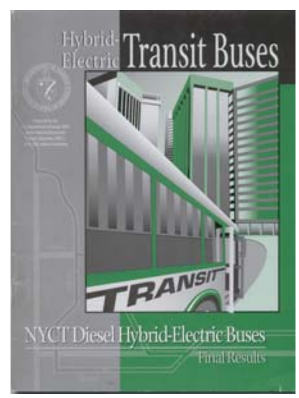
NYCT recently announced an additional order of 500 Orion/BAE Systems hybrid buses. The price for this additional hybrid bus purchase was reported to be a little less than $500,000 each, which is reportedly about $150,000 more than a similar, new standard diesel bus. The hybrid buses in this evaluation were reported to cost $385,000 or about 25%-30% higher than a similar new standard diesel bus.

Changes and Additions Since the Interim Report

This final evaluation report updates the *New York City Transit Hybrid and CNG Transit Buses: Interim Evaluation Results*, January 2006, NREL/TP-540-38843. The interim report covered the first eight months of a 12-month evaluation (October 2004 through September 2005) at New York City Transit of their Orion VII CNG and hybrid (from the order of 125) buses. This report completes the 12 months of data evaluation with the addition of the summer months (June 2005 through September 2005). This update also includes updates in average diesel fuel costs, which increased significantly by the end of the evaluation period. Additional maintenance information and analysis have been provided in this report including more attention to missing parts costs and work orders as well as describing the experience to date with traction battery failures.

Overview

This report includes results of an evaluation of the operation of new compressed natural gas (CNG) and diesel hybrid electric buses from Orion Bus Industries (model Orion VII buses) operating at New York City Transit (NYCT). This evaluation is completed by the U.S. Department of Energy (DOE). DOE, through the National Renewable Energy Laboratory (NREL), has been tracking and evaluating new propulsion systems in transit buses and trucks for more than 10 years with an established and documented evaluation protocol[2].



DOE/NREL previously evaluated the original 10 prototype diesel hybrid buses from Orion and BAE Systems operated at NYCT (model Orion VI buses). Results from that evaluation[3] were published in July 2002 and provided information on the prototype buses from 1998 through 2001.

NYCT's Clean Bus Program was created in 1992 to lower bus fleet emissions. In 2000, NYCT established a policy of only purchasing low emission buses for new bus orders. This policy, coupled with NYCT's desire to achieve the best fuel economy, has resulted in NYCT's purchase order for hybrid buses. The NYCT Clean Bus Program currently includes several activities:

- Use of CNG buses
- Replacement of the oldest diesel engines (two-stroke) with newer low emissions engines (Detroit Diesel Series 50 exhaust gas recirculation engines)
- Use of ultra low sulfur diesel fuel for all diesel equipment (starting in 1998 with less than 30 parts per million (ppm) sulfur, expected to be less than 15 ppm starting in 2006)
- Addition of diesel particulate filters (DPF) to the existing and new diesel engines
- Use of hybrid propulsion buses with engines equipped with DPFs.

[2] General Evaluation Plan, Fleet Test & Evaluation Projects, July 2002, NREL, NREL/BR-540-32392, www.nrel.gov/vehiclesandfuels/fleettest/pdfs/32392.pdf.
[3] NYCT Diesel Hybrid-Electric Buses, July 2002, NREL, NREL/BR-540-32427 www.eere.energy.gov/afdc/pdfs/nyct_diesel_hybrid_final.pdf.

Hybrid technology was tested at NYCT in an effort to explore options other than CNG technology. This is because not all of NYCT's operating depots are cost-effective candidates for CNG infrastructure due to space constraints inside buildings and the proximity of neighboring buildings. In early 2000, NYCT ordered 260 CNG buses in two orders from Orion Bus Industries (order one was 125 buses, order two was 135 buses). At the same time, NYCT made a commitment to purchase two orders of buses with the BAE Systems hybrid propulsion system from Orion Bus Industries. One order was for 125 buses, the other for 200 buses.

Once NYCT made this commitment to purchase new CNG and hybrid buses, DOE and NREL started planning the next phase of evaluation work, which is reported here. The current DOE/NREL evaluation work is a part of DOE's Advanced Vehicle Testing Activity (AVTA).

This evaluation report examines evaluation results from 10 buses from the order of 260 CNG Orion VII buses and 10 buses from the first hybrid order of 125 hybrid buses. The DOE/NREL evaluation of the hybrid and CNG buses is now complete through the standard 12-month evaluation. Evaluation of 10 buses from the order of 200 hybrid buses is also under way and will be reported in a future evaluation report.

NYCT and MTA Bus (both a part of Metropolitan Transportation Authority) recently made a joint order for an additional 500 Orion VII/BAE Systems diesel hybrid buses — 216 buses for NYCT and 284 buses for MTA Bus. This order of hybrid buses also allows for 389 additional hybrid buses in options. NYCT intends to add hybrid bus operations to the East New York and Casey Stengel depots as well as converting the entire Manhattanville Depot to only diesel hybrid bus operation.

DOE / NREL Advanced Vehicle Testing Activity

The role of AVTA is to help bridge the gap between research and development (R&D) and commercial availability for advanced vehicle technologies that reduce petroleum use while meeting air quality standards. AVTA supports DOE's FreedomCAR & Vehicle Technologies Program by examining market factors and customer requirements and evaluating performance and durability of alternative fuel and advanced technology vehicles in fleet applications.

The main objective of AVTA projects is to provide comprehensive, unbiased evaluations of advanced technology vehicles. Data collected and analyzed include the operation, maintenance, performance, cost, and emissions characteristics of advanced technology vehicles and comparable conventional technology in fleets operating at the same site. By comparing available advanced and conventional technology vehicles, AVTA evaluations help fleet owners and operators make informed purchasing decisions and also provide valuable data to DOE regarding the maturity of the technology being assessed.

In this evaluation at NYCT, the CNG bus study group was used as the baseline group. The CNG bus propulsion technology has been available since the early 1990s and has been used by many transit agencies. For the last six years, CNG bus purchases have accounted for up to 24% of all new transit bus purchases each year in the United States[4].

The AVTA team recently conducted or is in the process of conducting several evaluations of advanced propulsion heavy duty vehicles (Table 1). For information on these and other evaluations, visit www.nrel.gov/vehiclesandfuels/fleettest.

Table 1. AVTA Heavy Vehicle Evaluations

Fleet	Location	Vehicle	Technology	Evaluation Status
New York City Transit	Manhattan, Bronx, NY	Orion VII 40-ft transit bus	Series hybrid, BAE Systems HybriDrive propulsion system (diesel), Order of 125; DDC S50G CNG engines	Interim report for CNG and Hybrid (order of 125)
New York City Transit	Manhattan, NY	Orion VII 40-ft transit bus	Series hybrid, BAE Systems HybriDrive propulsion system (diesel), Order of 200 (next generation)	Just under way, Interim Report due by end of 2006
King County Metro	Seattle, WA	New Flyer 60-ft articulated transit bus	Parallel hybrid, GM-Allison E^P50 System (diesel)	Interim report completed in 2006; Final report planned for fall 2006
IndyGo	Indianapolis, IN	Ebus 22-ft bus	Series hybrid, Capstone MicroTurbine (diesel)	Completed in 2005
Knoxville Area Transit	Knoxville, TN	Ebus 22-ft bus	Series hybrid, Capstone MicroTurbine (propane)	Completed in 2005
Norcal	San Francisco, CA	Peterbilt/378, Class 8 truck	Cummins Westport ISXG high pressure direct injection LNG and diesel	Completed in 2004

Host Site Profile—NYCT

NYCT is a part of the Metropolitan Transportation Authority (MTA), which is a public-benefit corporation chartered by New York State in 1965 (www.nyct.org/index.html). In 2004, MTA had an annual operating budget of $8 billion and serviced 7.7 million passengers daily through seven major operating divisions:

- New York City Transit (NYCT)
- Long Island Rail Road (LIRR)
- Long Island Bus (LI Bus).
- Metro-North Railroad
- Bridges and Tunnels
- Capital Construction Company
- MTA Bus

This report focuses on the bus operations within the NYCT division, which operates 27 rail lines (660 track miles and 6,210 rail cars) and 244 bus routes (2,017 miles) with average weekday ridership of 7 million, or more than 2 billion passengers a year. The NYCT Department of Buses

[4] Based on data from the American Public Transportation Association (APTA) Fact Books for 2000 through 2005.

operates 4,483 buses from the following 18 operating depots in the five boroughs of New York City.

Bronx
- West Farms
- Gun Hill
- Kingsbridge

Manhattan
- 126th Street
- Mother Clara Hale
- 100th Street
- Manhattanville
- M.J. Quill

Staten Island
- Castleton
- Yukon

Brooklyn
- Jackie Gleason
- East New York
- Flatbush
- Fresh Pond
- Ulmer Park

Queens
- Jamaica
- Queens Village
- Casey Stengel

This evaluation focuses on the West Farms Depot in the Bronx Division and Mother Clara Hale Depot in the Manhattan Division. Other depots, including Jackie Gleason, Queens Village, Fresh Pond, and Manhattanville, were also involved in the activities described in this report.

Emissions Reductions Drive the Need for CNG and Hybrid Propulsion

The U.S. transit market, including NYCT, has been under public and EPA pressure to reduce emissions from large transit buses—especially those in urban areas (see Table 2).

Conventional diesel bus propulsion technology (non-hybrid) has also made emissions reduction improvements and is required to become much cleaner in the next few years. PM levels have been restricted to a low level of 0.05 g/bhp-hr since 1996 and are being regulated even lower starting in 2007. Future PM regulations are forcing the use of diesel particulate filters (DPFs) and will require ultra low sulfur diesel fuel (less than 15 ppm sulfur). This level of PM has been addressed by changes in control of engine combustion, and, in a few cases, a diesel oxidation catalyst (DOC) was added.

Table 2. EPA Emissions Requirements for Transit Buses

Model Years	Carbon Monoxide (CO)	Hydrocarbons (HC)	NOx	PM
	g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr
1990	15.5	1.3	6.0	0.60
1991-1992	15.5	1.3	5.0	0.25
1993	15.5	1.3	5.0	0.10
1994-1995	15.5	1.3	5.0	0.07
1996-1997	15.5	1.3	5.0	0.05
1998-2003	15.5	1.3	4.0	0.05
2004-2006*	15.5	2.4 combined or 2.5 with a limit of 0.5 for non-methane hydrocarbons		0.05
2007-2010	15.5	0.14**	0.2	0.01

* The 2004 standard was moved up to 2002 as part of an agreement between the U.S. Environmental Protection Agency (EPA) and engine manufacturers.
** Non-methane hydrocarbons (NMHC)

NOx levels were reduced from 4.0 g/bhp-hr in 1998 to 2.4 g/bhp-hr combined NOx and HC in 2004 (CNG levels are 2.5 g/bhp-hr NMHC + NOx with a limit of 0.5 g/bhp-hr NMHC). The 2004 level was actually moved up to 2002 based on an agreement between EPA and diesel engine manufacturers. The emissions reduction requirement of 2.4 g/bhp-hr HC + NOx caused several diesel engine manufacturers to use EGR to help reduce NOx levels. The use of EGR will have some effect on durability and fuel economy compared to non-EGR engines. The buses in this study did not utilize EGR equipped engines. The next order of 200 (which will be evaluated by NREL) will have EGR equipped Cummins engines.

The development of diesel hybrid bus propulsion systems is exciting for the transit industry because the systems offer potentially improved fuel economy during a time of fuel economy penalties for diesels engines with added emissions control systems. These systems may also offer an alternative to CNG which offer improved emissions over conventional diesels, but suffer from a fuel economy penalty.

AVTA Project Design and Data Collection

AVTA evaluation projects focus on using a standardized process for data collection and analysis, communicating results clearly, and providing an accurate and complete evaluation. The evaluation in this report is focused on hybrid buses from NYCT's first commercial purchase of 125 Orion VII hybrid buses and new CNG buses from an order of 260 Orion VII CNG buses as the baseline propulsion technology. These hybrid and CNG buses have been operated at two different depots at NYCT, which have similar average speeds as discussed later. In order to explore the standard baseline at each of these two depots, the operations of older diesel buses were included to compare to the hybrid and CNG buses at their respective depots. This extension of the evaluation looked at bus usage, fuel economy, and roadcall rate comparisons only.

The AVTA evaluations focus on data collection and analyzing advanced propulsion systems compared to baseline propulsion systems. The results from these evaluations are a snapshot of experience and actual capital and operating costs at a given location and for a given period of time. At this time, the AVTA evaluations do not include an attempt at life-cycle cost modeling.

AVTA evaluations also track multiple vehicles within a fleet in order to provide enough data samples to ensure some level of statistical significance. In this case, 10 vehicles of each technology were chosen for data analysis and the AVTA team felt that this number of vehicles should provide accurate and statistically valuable data.

All 40-foot buses at the two depots included in this evaluation (West Farms and Mother Clara Hale Depots) were dispatched randomly on all routes. There were no restrictions on the CNG or hybrid Orion VII buses at the two depots in this evaluation report. NYCT expects the new CNG buses to have diesel-like reliability and operating costs. The CNG buses do not have restrictions other than only operating from the two CNG depots. The hybrid buses were expected to be slightly less commercial than the CNG buses due to the lack of industry experience with hybrid propulsion technology. However, NYCT operated the hybrid buses with the intent that they be treated just like any other diesel bus for reliability and operations.

Data for this evaluation were taken from NYCT's data system, *MIDAS*. Data parameters included the following:

- Diesel fuel consumption by vehicle
- CNG fuel consumption by vehicle
- Mileage data from every vehicle
- Preventive maintenance action work orders, parts lists, labor records, and related documents
- Records of unscheduled maintenance, including roadcalls and warranty actions by vendors (when available in the data system).

Vehicle System Descriptions

Table 3 shows a summary of vehicle system descriptions for the CNG, hybrid, and two extended comparison diesel study groups of buses. The following discussion includes descriptions of each of the four study groups of buses and detailed differences between the CNG and hybrid buses versus their respective diesel baseline buses.

CNG Buses at West Farms Depot
Ten CNG buses operating at West Farms Depot were selected from the order of 260 Orion VII low floor, model year 2002 CNG buses. The CNG buses use the DDC Series 50G engine. NYCT did not purchase the optional catalyst for emissions aftertreatment for these buses.

Table 3. Vehicle System Descriptions

Vehicle System	West Farms		Mother Clara Hale	
	CNG Buses	Diesel Buses	Hybrid Buses	Diesel Buses
Number of Buses	10	9	10	9
Bus Manufacturer and Model	Orion VII, Low Floor	Orion V, High Floor	Orion VII, Low Floor	Orion V, High Floor
Model Year	2002	1994	2002	1999
Length/Width/Height	40 ft/102 in/135 in	40 ft/102 in/121 in	40 ft/102 in/132 in	40 ft/102 in/121 in
GVWR/Curb Weight	42,540/31,400 lbs	40,000/28,500 lb	42,540/31,840 lb	40,000/28,500 lb
Passenger Capacity	37 Seated, 36 Standing	39 Seated, 36 Standing	38 Seated, 32 Standing	39 Seated, 36 Standing
Engine Manufacturer and Model	DDC S50G	DDC S50	Cummins ISB (not EGR equipped)	DDC S50
Rated Horsepower	275 bhp @ 2,100 rpm	275 bhp @ 2,100 rpm	270 bhp @ 2,500 rpm	275 bhp @ 2,100 rpm
Rated Torque	900 lb-ft @ 1,200 rpm	890 lb-ft @ 1,200 rpm	660 lb-ft @ 1,600 rpm	890 lb-ft @ 1,200 rpm
Emissions Equipment	None	Retrofit DPF, Johnson Matthey	Engelhard DPX	Retrofit DPF, Johnson Matthey
Retarder/Regenerative Braking	Retarder	Retarder	Regenerative Braking	Retarder
Fuel Capacity	125 diesel equivalent gallons	125 gallons	100 gallons	125 gallons
Bus Purchase Cost*	$313,000	$290,000	$385,000	$290,000

* Costs listed in the table are actual costs at the time of purchase

Diesel Extended Comparison Buses at West Farms Depot

Although West Farms Depot is intended to be an all-CNG bus operating depot, some diesel buses have been operating there. The number of diesel buses operating at the depot decreased as the newer CNG buses were brought into service. The evaluation in this report used 10 Orion V high floor diesel buses for a limited comparison to the CNG bus evaluation of mileage usage, fuel economy, and roadcall rate results.

The diesel buses are model year 1994 and close to the end of their useful life. These diesel buses have DDC Series 50 diesel engines. One bus (number 416) had been repowered with a newer DDC Series 50 EGR engine as part of a test program. This bus was removed from the evaluation due to its significant difference in operation; however, some comments on this vehicle are provided in this evaluation.

Hybrid Buses at Mother Clara Hale

Ten hybrid buses from the order of 125 hybrid buses were selected from the Mother Clara Hale Depot. The hybrid buses are Orion VII low floor buses and use a smaller-than-standard diesel engine (5.9 liter versus an 8.3 or 8.9 liter engine) from Cummins, Inc. The hybrid buses are equipped with an Engelhard DPX for exhaust aftertreatment. This DPF is actively monitored and regenerated (as needed) as part of the BAE Systems HybriDrive hybrid propulsion system. Table 4 describes major components of the electric propulsion system.

Table 4. Hybrid Propulsion-Related Systems

Category	Hybrid Bus Description
Manufacturer/Integrator	BAE Systems (HybridDrive propulsion system)
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, Hawker XT, 2 enclosures, 23 modules each, roof mounted Voltage: 520-700 VDC

Diesel Extended Comparison Buses at Mother Clara Hale Depot

The diesel buses at Mother Clara Hale depot are model year 1999 Orion V high floor buses, but from a newer bus order than those at West Farms Depot. The diesel buses have DDC Series 50 diesel engines retrofitted with a DPF. These diesel buses are approaching their six to eight year rebuild and two of the ten diesel baseline buses have had the rebuild. One of those buses selected for this study (number 6014) was essentially out of service for four of the 12 month study period. This vehicle has been removed from the evaluation because of this lack of use.

DDC Series 50 Diesel and CNG Engine

Both the DDC Series 50 diesel and DDC Series 50 CNG engines are no longer available for new transit buses. In 2004, DDC discontinued the Series 50 diesel and CNG engine platform. For years, the diesel Series 50 engine has been the workhorse of the transit industry. DDC reported to customers that the Series 50 diesel engine platform could not meet the next round of emissions regulations and was being discontinued after limited refinements in the last few years. Thus, the DDC Series 50G natural gas engine, operated by NYCT is not the newest technology natural gas engine (with fuel and electronic controls) currently available. Newer engines from other manufacturers may have shown better results.

Hybrid and CNG Baseline Vehicle Differences

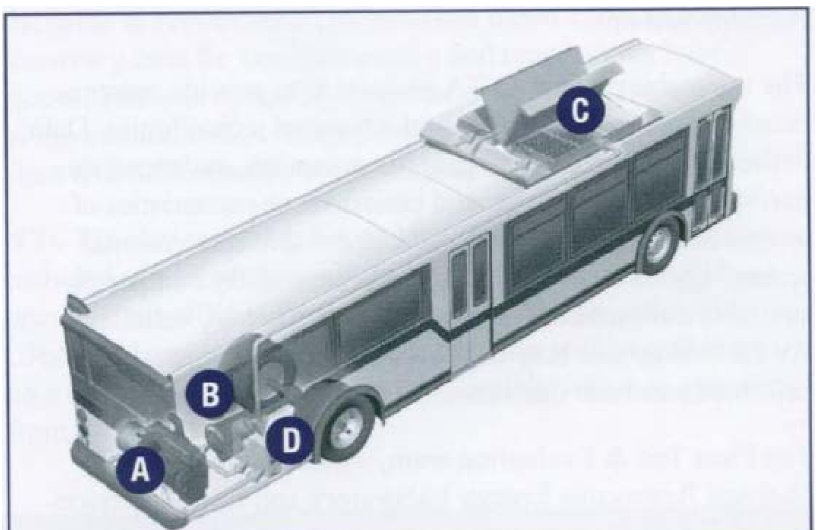
The hybrid and CNG baseline buses are the same model buses and essentially the same age (model year 2002). Both bus types met the NYCT performance requirements. Some of the differences between the two bus study groups follow.

- CNG buses are taller (3 inches)
- Hybrid buses are heavier (440 lbs)
- Hybrid buses have a smaller size engine (5.9 liter diesel versus a 8.5 liter natural gas)
- Hybrid buses have a DPF, the CNG buses did not have additional emissions control
- Hybrid buses have regenerative brakes and CNG buses have a retarder
- Hybrid buses have a smaller fuel capacity (100 gallons for hybrid and 125 gallons diesel equivalent for CNG)
- These hybrid buses (order of 125) were reported to be only $72,000 more per unit than a CNG bus; however, the recent purchase of 500 hybrid buses at NYCT show the incremental hybrid price will exceed $100,000 compared to CNG and $150,000 compared to new diesel buses.

BAE Systems HybriDrive Propulsion System

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

In this series hybrid electric system, a down-sized 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. Orion and BAE Systems currently (June 2006) have 325 Orion VII diesel hybrid buses in service at NYCT.



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.

Figure 1. BAE Systems HybriDrive Propulsion System

NYCT Facilities

NYCT has two CNG operating depots—Jackie Gleason Depot in Brooklyn and West Farms Depot in the Bronx. The newly built West Farms CNG depot, shown in Figure 2, opened on September 7, 2003. West Farms Depot has 157,000 square feet of office and maintenance space, outdoor parking for buses, and operates 256 buses including 163 CNG buses.

CNG fueling is provided under contract from Trillium USA and is integrated into the fueling island as shown in Figure 3. The CNG compressor station is outside the building (Figure 4) and includes three 800-horsepower compressors with a total output of 6,600 scfm. The capital cost for the facility was $7.4 million (it met all local New York building codes and requirements) including $2 million for construction costs to blast through solid rock to install the underground natural gas lines. The current cost for compression and upkeep for the CNG station is $0.25 per therm or $0.35 per diesel equivalent gallon (in addition to the base natural gas commodity price).

Figure 2. West Farms Depot

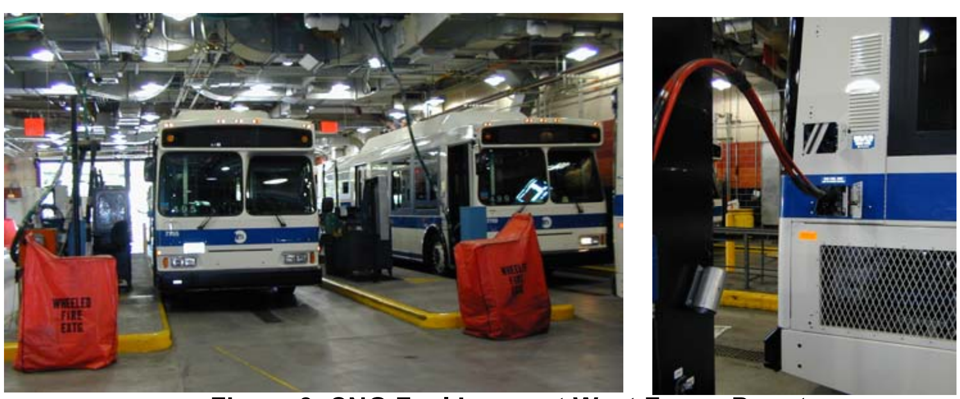


Figure 3. CNG Fuel Lanes at West Farms Depot

Figure 4. CNG Compression Station at West Farms Depot

The order of 125 hybrid buses was split between two operating depots—Mother Clara Hale Depot and Queens Village Depot. The Mother Clara Hale Depot, shown in Figure 5, has 125,690 square feet of office and maintenance space, indoor parking for buses, and operates 125 buses including 62 hybrids. Every six months, each hybrid bus requires a conditioning charge process for the traction batteries (which takes as much as 24 hours) as part of their scheduled maintenance routine; the charger is shown in Figure 6. The conditioning is done to help extend the battery pack life to at least three years. The battery conditioner performs a slow controlled charge of the batteries, while monitoring each battery for specific voltage changes that indicate the conditioning cycle is complete. Without this battery conditioning, the traction batteries will exhibit a hysteresis effect of lower and lower energy storage capacity over time. The depots with the Orion/BAE System hybrid propulsion system have received or will receive at least two of the conditioner units, which cost $70,000 each.

Figure 5. Mother Clara Hale Depot

Figure 6. Hybrid Traction Battery Conditioning Unit

Implementation Experience

The discussion in this section is based on overall fleet-level results (260 CNG buses and 125 hybrid buses) of mileage accumulation and roadcalls (RCs) for the CNG and hybrid bus fleets. NYCT has treated both of these fleets as standard buses for service. The depots have not been given special treatment for meeting pullout requirements for service.

For each study group (CNG and hybrid), several topics are covered in this section. They include:

- Background on NYCT expectations
- Bus delivery
- Total mileage accumulation from March 2003 through May 2005 for CNG and March 2004 through May 2005 for hybrid buses
- Average monthly mileage per bus
- Miles between roadcalls (MBRC) for all RCs and for propulsion-related RCs only
- Fleet issues and warranty maintenance campaigns.

NYCT has three standard expectations and measures for transit bus operations. They are availability, reliability, and recovery time.

- Availability—This measure, which should be 85% or above, allows for scheduled and some unscheduled maintenance for the bus. Buses that fall below the 85% availability can cause problems with having enough buses to make service.
- Reliability—The measure should be above 4,000 MBRC for all RCs.
- Recovery time—Buses should not be out of service for more than three days for any maintenance action (or anything else).

Of these three topics, reliability (MBRC) is the only one directly covered in this report. Availability and recovery time were not available for this study. Availability is collected in NYCT's system, but is not archived, so it was not available for this evaluation. Recovery time was not readily available from NYCT's system.

CNG Buses

NYCT currently has 481 CNG buses split between two depots—the West Farms and Jackie Gleason Depots.

NYCT was an early adopter of CNG transit buses. In 1995, it purchased 34 CNG buses; this number grew to 221 by 2001, all operating at Jackie Gleason Depot. As mentioned earlier, NYCT purchased 260 new CNG Orion VII buses.

The 260 CNG Orion VII buses were delivered and placed into service from March 2003 through approximately November 2004. West Farms Depot started its first new Orion VII CNG bus in service in September 2003. Figure 7 shows total mileage accumulation at the two CNG bus depots. At the end of September 2005, the total Orion VII CNG fleet had reached nearly 12 million miles of operation. Figure 8 shows average monthly mileage per CNG bus at the two CNG depots. This figure shows that the CNG buses were placed into service quickly and met an average usage per month of 2,300 to 2,500 miles per month.

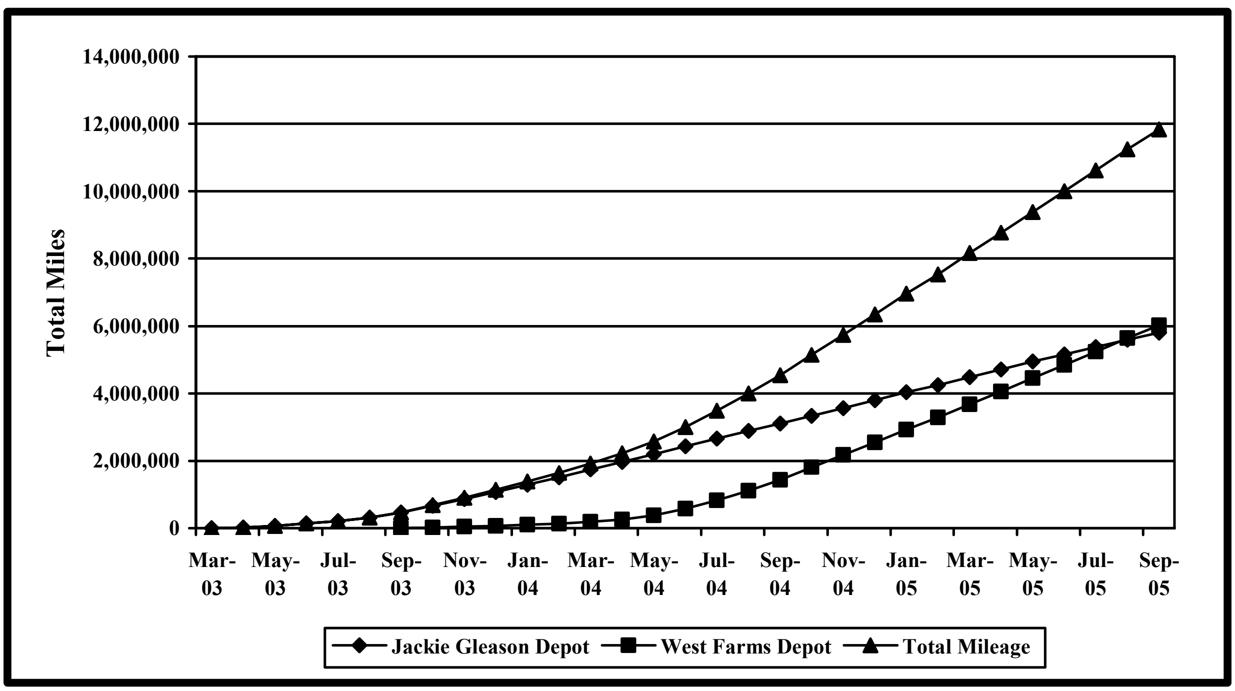


Figure 7. CNG Bus Fleet Cumulative Mileage (260 Buses)

Figure 8. CNG Bus Fleet Cumulative Average Monthly Mileage per Bus (260 Buses)

Figure 9 shows MBRC for CNG buses at both CNG bus depots. The figure shows that for all RCs, the Gleason Depot CNG buses were at or above 4,000 MBRC (as expected/required by NYCT) by April 2004; West Farms achieved this in December 2004. The propulsion-related MBRC for both depots was between 7,000 and 8,000 MBRC by the end of the data period. The most common RCs for the propulsion system were related to the engine, no start, electrical shutdown, or problem indicator lights.

General problems at start-up or within the first year or so of operation were mostly related to the Orion VII bus, rather than the propulsion system, such as axle bolts coming loose and cooling pump failures. A few items specific to the CNG bus fleet included:

- CNG engines were burning excessive amounts of oil—determined to be an engineering and design issue; cylinder kits and sleeves are in the process of being changed out.
- Spark plugs were initially a reliability issue (5,000 miles between changes)—NYCT changed to a different spark plug and is now getting the required 24,000 miles between changes.
- Fuel door switches were changed out.
- Hydraulic cooling fan motor; changing configuration and motors
- Regulator problems; now resolved.

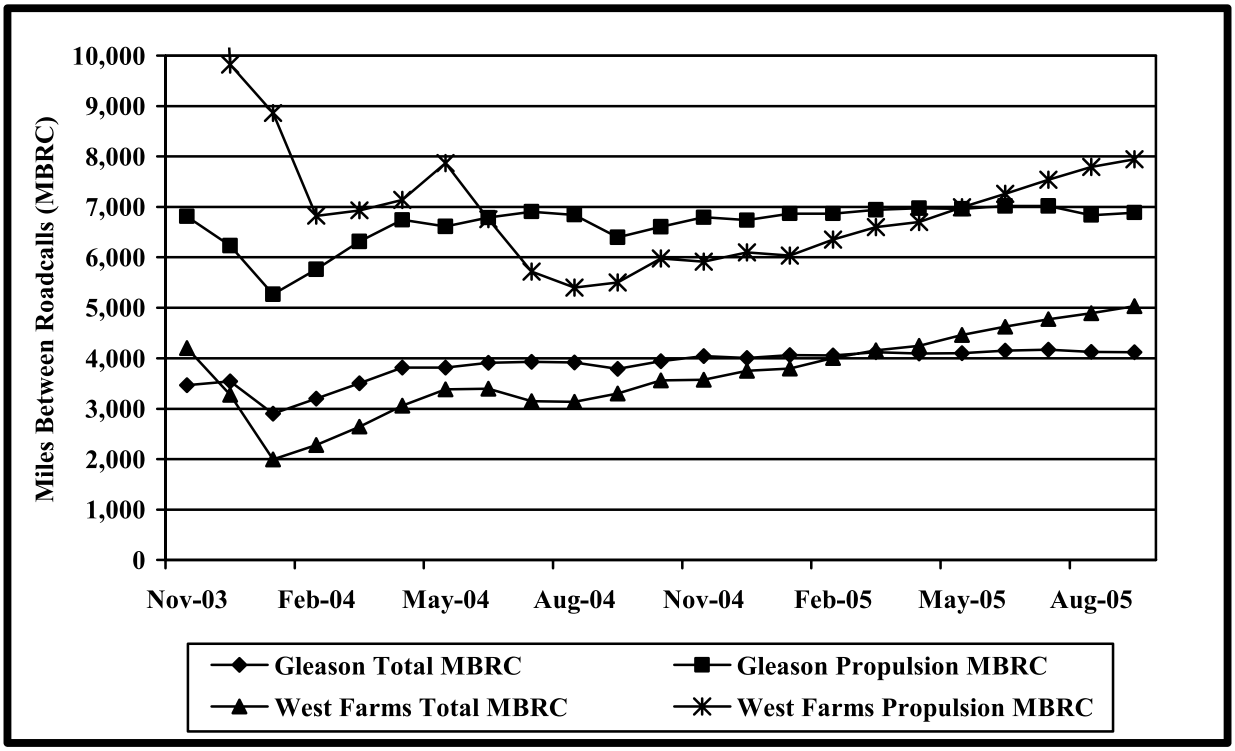


Figure 9. CNG Bus Fleet Cumulative Average MBRC (260 Buses)

Hybrid Buses

NYCT started operating prototype diesel hybrid buses from Orion and BAE Systems in 1998 with the first of 10 prototype buses. This prototype operation led to a large purchase of hybrid buses to solidify commitment from NYCT and the manufacturers (Orion and BAE Systems). The new orders of 125 hybrid buses and 200 hybrid buses have now been delivered to NYCT. The order of 125 hybrid buses was split between Mother Clara Hale and Queens Village Depots. The order of 200 hybrid buses was split between the Fresh Pond and Manhattanville Depots (Manhattanville was the operating location for the original 10 prototype hybrid buses).

The first new hybrid bus was placed into service at Mother Clara Hale Depot in March 2004 and the first new hybrid bus was placed into service at Queens Village Depot in November 2004.

Figure 10 shows total mileage accumulation at these two hybrid bus depots and a total. At the end of September 2005, the hybrid fleet had reached nearly 4 million miles of operation. Figure 11 shows average monthly mileage per hybrid bus at the two hybrid depots. This figure shows that the hybrid buses were placed into service quickly and came up to the average usage of 2,400 miles per month for Mother Clara Hale and approximately 3,000 miles per month for Queens Village.

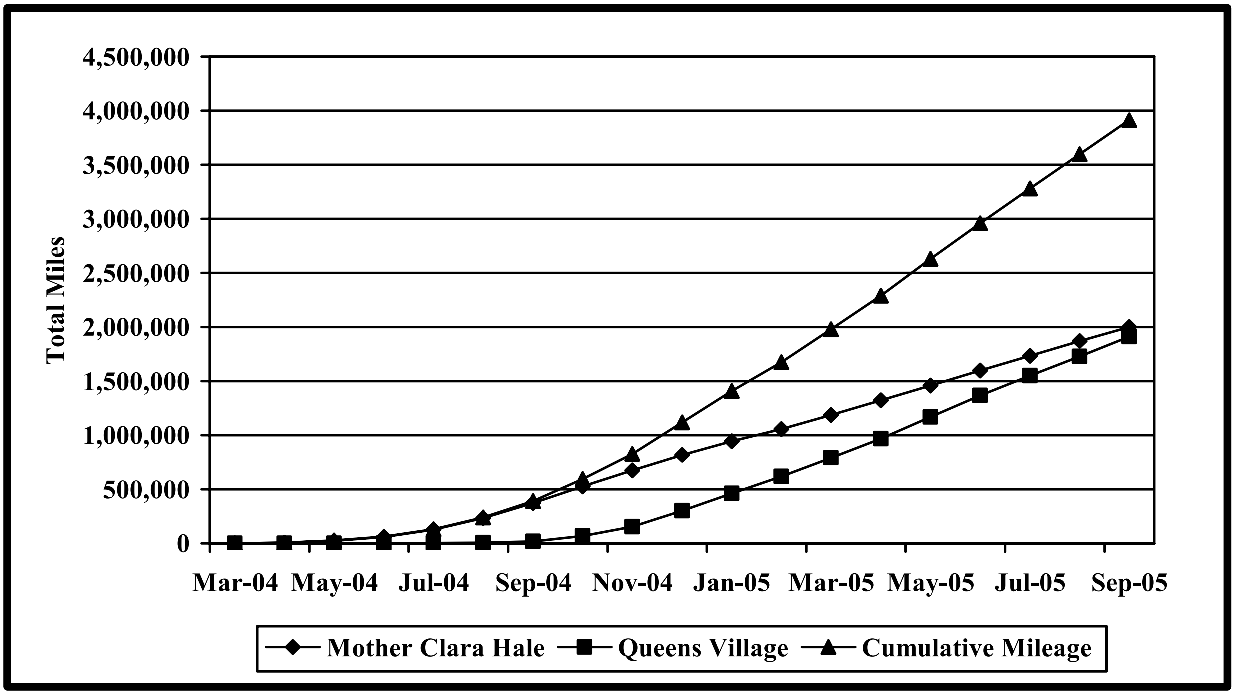


Figure 10. Hybrid Fleet Cumulative Mileage (125 Buses)

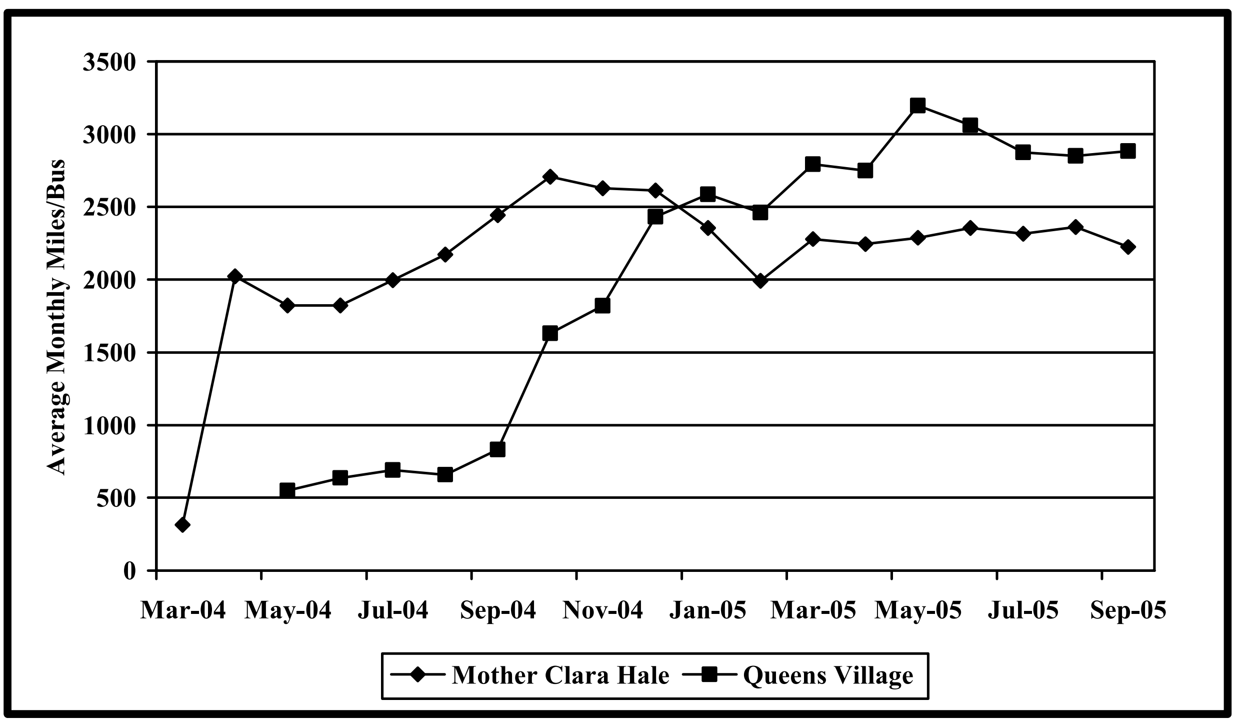


Figure 11. Hybrid Fleet Cumulative Average Monthly Mileage per Bus (125 Buses)

Figure 12 shows MBRC for hybrid buses at the two hybrid bus depots. The figure shows that for all RCs, the Mother Clara Hale Depot hybrid buses were at or above 4,000 MBRC (as expected/required by NYCT) by October 2004; the buses at Queens Village Depot achieved this in December 2004. The propulsion-related MBRC for Mother Clara Hale Depot is above 6,000 and Queens Village Depot is approaching an MBRC of 10,000. The propulsion-related MBRC for both depots jumped in December 2004. The most common RCs for the propulsion system were related to the engine and the hybrid control system shutdown or problem indicator lights. Many of the shutdown indicators for the hybrid propulsion system did not necessarily mean there was a repair required for the propulsion system. Problems in other bus systems can also be indicated by the propulsion control system.

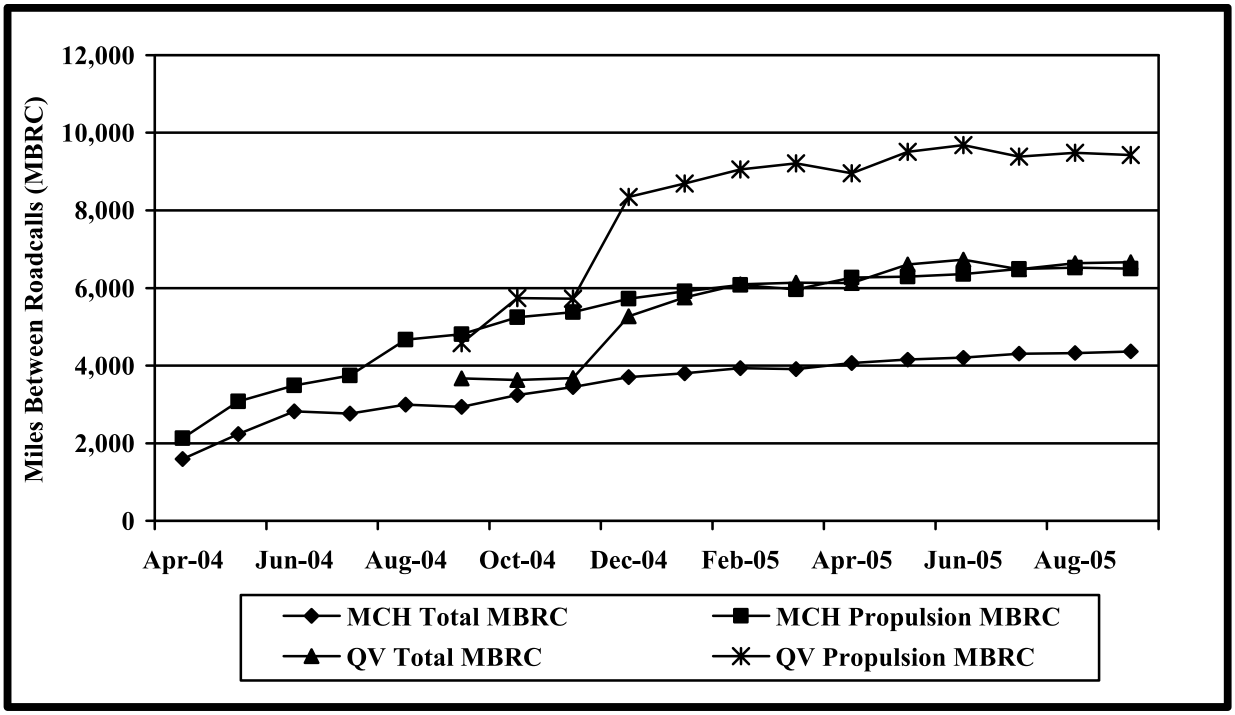


Figure 12. Hybrid Fleet Cumulative Average MBRC (125 Buses)

A few items specific for the hybrid buses have been:

- Radiator baffle—surge tank overflowing
- Water in wiring/connectors
- Engine grid heater relay
- Water in engine from air intake
- Issues with the triple pump (the triple pump has been eliminated from subsequent orders)
- Power control system (PCS) internal coolant leaks; some modification to the cooling system was done.
- Software upgrades; moved some of the propulsion fault codes from the dash display to be on the engine compartment display; changed signal processing to be more tolerant of wiring intermittent signals.

The entire Orion VII fleet (CNG and hybrid) underwent a warranty maintenance campaign to address the items listed above for both groups and several other items. This is a significant fleet campaign that was completed at the end of 2005.

Evaluation Results

In any evaluation, a starting point must be chosen. In the DOE/NREL evaluations, this starting point is typically called a “clean point.” The clean point is chosen to avoid some of the early and expected operations problems with a new vehicle going into service, such as early warranty maintenance campaigns. In some cases, the clean point may require three to six months of operation before the evaluation can start.

October 1, 2004 has been used as the start date for the evaluation at West Farms and Mother Clara Hale depots; however, this is not a clean point. As mentioned earlier, Orion (and their suppliers) agreed to a significant campaign of the entire Orion VII fleet at NYCT (hybrid and CNG) completed at the end of 2005. The entire evaluation of the hybrid order of 125 and the CNG buses was completed before that major campaign finished. We intend to capture the results and impact of this campaign (for the hybrid buses) during the evaluation of the order of 200 hybrid buses.

The evaluation results shown in this section of the report are focused on a 12-month evaluation period for the selected ten CNG and ten hybrid buses (October 2004 through September 2005). The evaluation start date was chosen to remove a fueling data collection problem at the fueling stations at both depots during the summer of 2004. The two study groups of older diesel buses (nine diesel buses in each group) were evaluated during a 12-month period of June 1, 2004 to May 31, 2005. The diesel buses were being transferred out of the two study depots due to the addition of the new CNG and hybrid buses, so the evaluation period of the diesel baselines was started a little earlier than the two study bus groups (CNG and hybrid) to ensure that the study buses would not be transferred during this study.

Route Descriptions

West Farms Depot operates 40-foot buses on 11 to 13 Bronx routes. Buses at West Farms Depot are randomly dispatched on all routes, and there are no route assignment restrictions for the CNG buses. As shown in Table 5, bus operations from West Farms Depot for 40-foot standard buses had an overall average speed of 6.47 mph in 2004 and 6.33 mph in 2005.

Table 5. Average Speed for All Standard Buses (40-foot) at West Farms

Year	Day of Week	Miles/Day	Hours	Avg. Speed
2004	Weekday	18,825.29	2,939.1	6.41
	Saturday	15,416.50	2,359.2	6.53
	Sunday	12,947.86	1,869.3	6.93
	Total	**122,490.81**	**18,923.7**	**6.47**
2005	Weekday	18,522.74	2,962.4	6.25
	Saturday	14,902.57	2,319.1	6.43
	Sunday	12,499.17	1,832.2	6.82
	Total	**120,015.44**	**18,963.3**	**6.33**

Mother Clara Hale Depot operates 40-foot buses on two Bronx routes and five Manhattan Routes. Buses at the depot are randomly dispatched on all routes, and there are no route assignment restrictions for the hybrid buses. As shown in Table 6, bus operations from Mother Clara Hale Depot for 40-foot standard buses had an overall average speed of 6.52 mph in 2004 and 6.13 mph in 2005 (this reduction in average speed was the result of a high-speed route being moved to another depot).

Both depots showed a general downward trend in average speed from 2004 to 2005. Average speeds for the West Farms and Mother Clara Hale depots appear to be similar and comparable. Total mileage differences are caused by the number of buses assigned to the depots (approximately 250 buses at West Farms and 125 buses at Mother Clara Hale).

Table 6. Average Speed for All Standard Buses (40-foot) at Mother Clara Hale

Year	Day of Week	Miles/Day	Hours	Avg. Speed
2004	Weekday	9,722.27	1,542.4	6.30
	Saturday	8,329.96	1,180.1	7.06
	Sunday	7,201.13	951.8	7.57
	Total	**64,142.44**	**9,843.9**	**6.52**
2005	Weekday	8,472.37	1,418.1	5.97
	Saturday	6,760.61	1,031.0	6.56
	Sunday	5,501.83	790.2	6.96
	Total	**54,624.29**	**8,911.7**	**6.13**

Bus Use

Table 7 shows average monthly mileage per bus for the evaluation period for the CNG and hybrid buses. The overall 12-month average monthly miles per bus are essentially the same for the CNG and hybrid buses, with the hybrid buses having a 3% higher average. This supports the premise that these two study groups are being used in a similar fashion. One other aspect of the table is the end hubodometer reading for these two study groups. The average end hubodometer for the CNG study group (average of 44,103 miles) is an average of 3,000 miles higher than the hybrid study group (average 40,978 miles). This would be a mileage difference of about one preventive maintenance work order cycle. This also supports the premise that these two study groups should be similar for maintenance cost per mile comparisons.

Figure 13 shows cumulative average monthly miles per bus for the CNG and hybrid buses. The average monthly mileage for the hybrid buses went down over time as the number of hybrid buses at the depot increased, and therefore the need for higher usage went down. The CNG bus average usage did not change much during the evaluation period, and the two study fleets essentially had the same average usage by the end of the evaluation period.

Table 7. CNG and Hybrid Monthly Mileage per Bus

Bus	Starting Hubodometer	Ending Hubodometer	Total Mileage	Months	Monthly Average
7657	26,249	53,732	27,483	12	2,290
7662	20,490	51,042	30,552	12	2,546
7666	23,754	44,607	20,853	12	1,738
7670	25,240	52,118	26,878	12	2,240
7677	16,597	45,229	28,632	12	2,386
7688	13,231	41,131	27,900	12	2,325
7708	9,772	39,947	30,175	12	2,515
7715	11,386	39,684	28,298	12	2,358
7719	10,412	37,793	27,381	12	2,282
7721	8,454	35,746	27,292	12	2,274
CNG			**275,444**	**120**	**2,295**
6367	15,224	41,607	26,383	12	2,199
6368	15,391	43,378	27,987	12	2,332
6369	14,081	40,244	26,163	12	2,180
6375	12,063	41,799	29,736	12	2,478
6378	11,328	42,212	30,884	12	2,574
6379	8,874	37,684	28,810	12	2,401
6380	13,320	40,480	27,160	12	2,263
6381	10,904	39,269	28,365	12	2,364
6382	12,889	42,003	29,114	12	2,426
6387	11,260	41,101	29,841	12	2,487
Hybrid			**284,443**	**120**	**2,370**

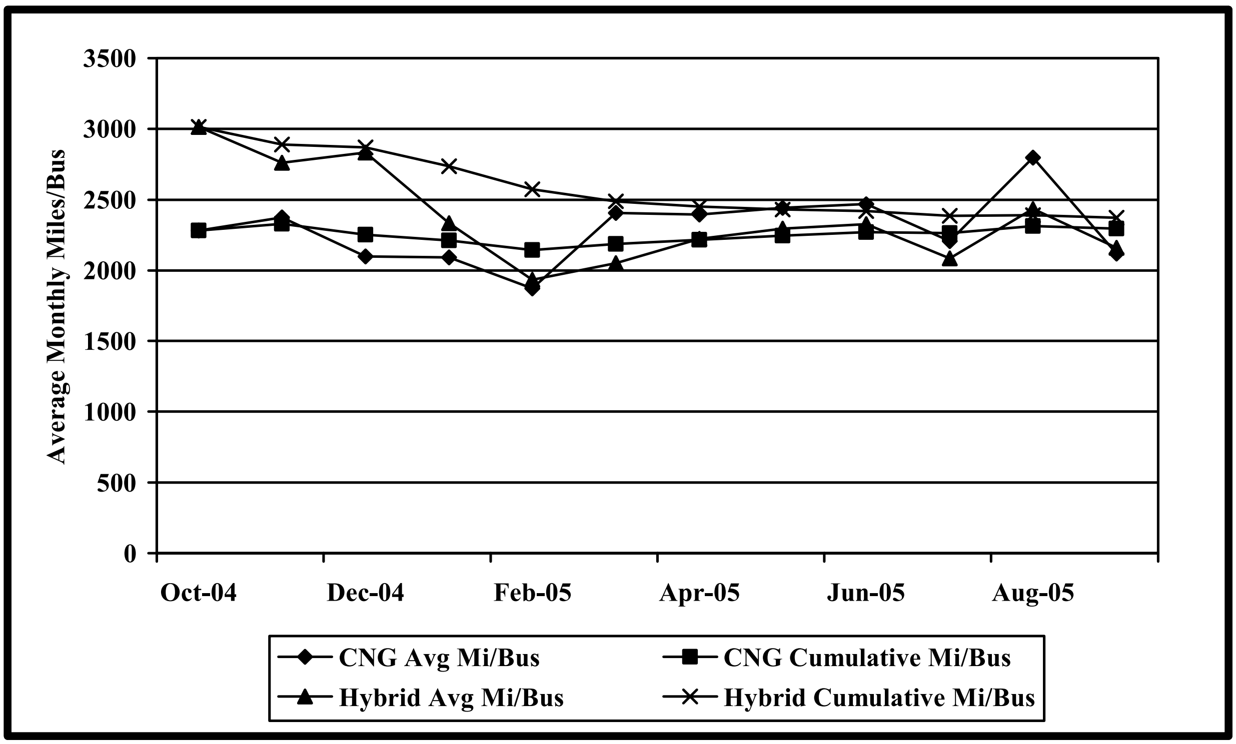


Figure 13. CNG and Hybrid Monthly Mileage per Bus

Table 8 summarizes the two diesel study bus groups' monthly mileage per bus. The diesel bus study group at West Farms Depot had an overall average mileage per bus of 1,952 and the diesel buses at Mother Clara Hale Depot had 2,385 miles per bus average (both for a 12-month period between June 2004 to May 2005). The diesel buses at West Farms Depot have a much lower average mileage per bus, and this has most likely occurred because of the age of the buses. The older buses are typically used less than newer buses (especially compared to buses under warranty). Comparing the diesel buses from Mother Clara Hale Depot with the CNG and hybrid buses, the CNG buses had an average monthly mileage per bus 4% lower and the hybrid buses were 1% lower (or essentially the same).

Table 8. Diesel Study Bus Monthly Mileage per Bus

Bus	Starting Hubodometer	Ending Hubodometer	Total Mileage	Months	Monthly Average
403	228,750	247,081	18,331	10	1,833
407	227,496	248,486	20,990	11	1,908
408	211,730	233,021	21,291	11	1,936
412	228,689	247,729	19,040	10	1,904
413	223,767	242,570	18,803	10	1,880
428	204,180	226,368	22,188	11	2,017
438	218,618	240,833	22,215	11	2,020
448	222,992	247,696	24,704	12	2,059
450	227,366	251,068	23,702	12	1,975
West Farms Diesel			**191,264**	**98**	**1,952**
6002	143,605	172,184	28,579	12	2,382
6004	156,587	185,787	29,200	12	2,433
6005	163,153	193,499	30,346	12	2,529
6006	160,513	189,600	29,087	12	2,424
6008	163,845	193,285	29,440	12	2,453
6011	156,097	183,498	27,401	12	2,283
6015	159,521	186,976	27,455	12	2,288
6018	162,137	191,639	29,502	12	2,459
6020	161,862	188,476	26,614	12	2,218
Mother Clara Hale Diesel			**257,624**	**108**	**2,385**

Fuel Economy and Cost

NYCT buses use ultra low sulfur No. 1 diesel fuel at less than 30 ppm sulfur content. This sulfur level is required to be less than 15 ppm by the end of 2006.

CNG fuel is provided at West Farms Depot by a compression station operated and serviced by Trillium USA. The CNG study group fuel consumption and economy is shown in Table 9 and Figure 14. The fuel economy for the CNG buses is shown in diesel gallon equivalent units based on an energy conversion of CNG to diesel equivalent at the dispenser. With a fuel economy of 1.70 miles per diesel equivalent gallon, the CNG study group has a 25% lower fuel economy than the diesel buses operating at West Farms. Based on the duty cycle at West Farms Depot (average speed between 6.3 mph and 6.5 mph), this lower fuel economy is within typical expectations based on previous studies.[5] A more recent study from DOE/NREL showed that newer technology CNG engines might show only a 16%-18% penalty compared to diesel.[6] The low average speed of the NYCT operation is the key to this significantly lower fuel economy. Compared to the diesel buses operating in a similar duty cycle at Mother Clara Hale Depot, the CNG buses had a 28% lower fuel economy.

The NYCT bus duty cycle is a severe application for spark ignited (SI) natural gas engines because of the slow average speed (about 6 mph) and frequent stops, which indicates the engine is operating at a low speed and load for much of its operating time. SI engines typically have a lower thermal efficiency at low speed and load than compression ignition (CI) diesel engines. Consequently, lower natural gas fuel economy is expected in this type of operation.

The hybrid study fleet fuel consumption and economy is also shown in Table 9 and Figure 14. The 12-month average fuel economy for the hybrid buses (average of 3.19 mpg) is 34% higher than the diesel buses (average 2.38 mpg for a 12-month period, June 2004 to May 2005) operating at Mother Clara Hale Depot and 40% higher than the diesel buses (average 2.28 mpg for a 12-month period, June 2004 to May 2005) operating at West Farms Depot. Compared to the average diesel fuel economy between both depots, the hybrid study fleet achieved 37% higher fuel economy. The hybrid bus study fleet also exhibited 88% higher fuel economy than the CNG study fleet.

Figure 14 shows 12 months of average monthly fuel economy for the two diesel study groups, CNG, and hybrid buses. The two diesel study groups have data shifted four months prior to the start of data for the CNG and hybrid study groups. The two diesel study groups have similar average fuel economy results for the evaluation period shown. The hybrid bus fuel economy has fluctuated generally between 26% and 52% higher than for the diesel buses in the same time frame at Mother Clara Hale Depot; however, during the summer months this positive difference dipped as low as only 12% for one month during the summer.

[5] For example, DART's LNG Bus Fleet, Final Results, 2000, NREL, NREL/BR-540-28739 (www.nrel.gov/vehiclesandfuels/fleettest/pdfs/28739.pdf) and Alternative Fuel Transit Buses, Final Results, 1996, NREL, NREL/TP-425-20513 (www.eere.energy.gov/afdc/pdfs/transbus.pdf)

[6] Washington Metropolitan Area Transit Authority: Compressed Natural Gas Transit Bus Evaluation, 2006, NREL, NREL/TP-540-37626 (http://www.nrel.gov/vehiclesandfuels/ngvtf/pdfs/37626.pdf).

Table 9. CNG and Hybrid Bus Fuel Use and Economy

Bus	Mileage (Fuel Base)	Gallons Consumed	MPG
7657	25,236	14,737.1	1.71
7662	28,795	15,384.0	1.87
7666	20,086	12,213.5	1.64
7670	24,581	14,667.8	1.68
7677	26,370	15,240.0	1.73
7688	26,067	15,686.0	1.66
7708	28,860	17,508.8	1.65
7715	27,187	15,509.1	1.75
7719	26,368	16,619.8	1.59
7721	25,533	14,449.9	1.77
CNG	**259,083**	**152,016.0**	**1.70**
6367	25,278	8,035.0	3.15
6368	24,989	8,025.5	3.11
6369	24,229	7,416.5	3.27
6375	22,541	6,951.5	3.24
6378	28,161	8,535.5	3.30
6379	26,744	8,497.5	3.15
6380	23,979	8,042.0	2.98
6381	26,738	8,196.9	3.26
6382	27,171	8,239.5	3.30
6387	28,090	8,844.5	3.18
Hybrid	**257,920**	**80,784.4**	**3.19**

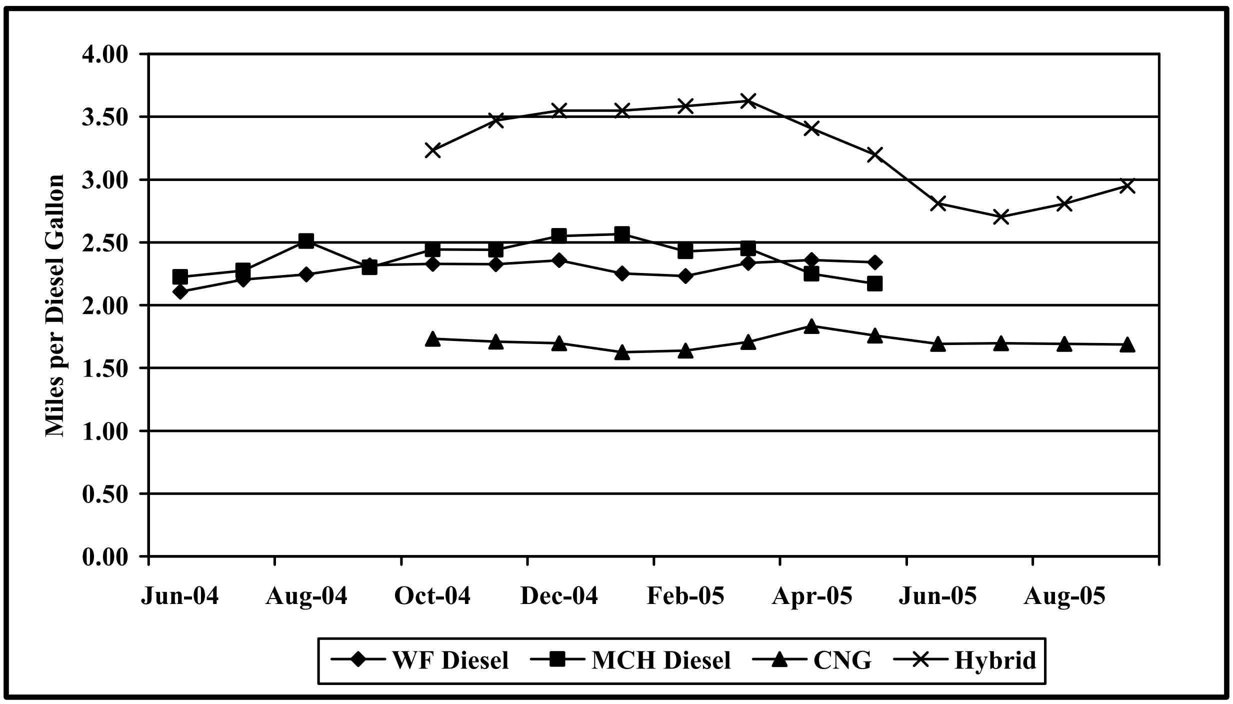


Figure 14. Average Fuel Economy (MPG)

The hybrid bus average fuel economy had a much larger decrease/fluctuation in fuel economy in the summer months (June through September) than any of the other three study bus groups shown. According to BAE Systems, much of this decrease is due to an increase in energy consumption for air conditioning. Although air conditioning load is similar for all four study bus groups, this is compared as a percentage to a much lower overall fuel consumption for the hybrid buses (see Figure 15). Additional factors such as different engine sizes, CNG engine thermal efficiency changes with loading, and others likely contribute to the magnitude of the summer versus winter fuel economy differences between the three different propulsion types. In other words, all four study bus groups have a significant increase of energy consumption for air conditioning in the summer months, but this increase represents a much larger percentage of overall fuel consumption for the hybrid buses, resulting in a larger penalty in fuel efficiency.

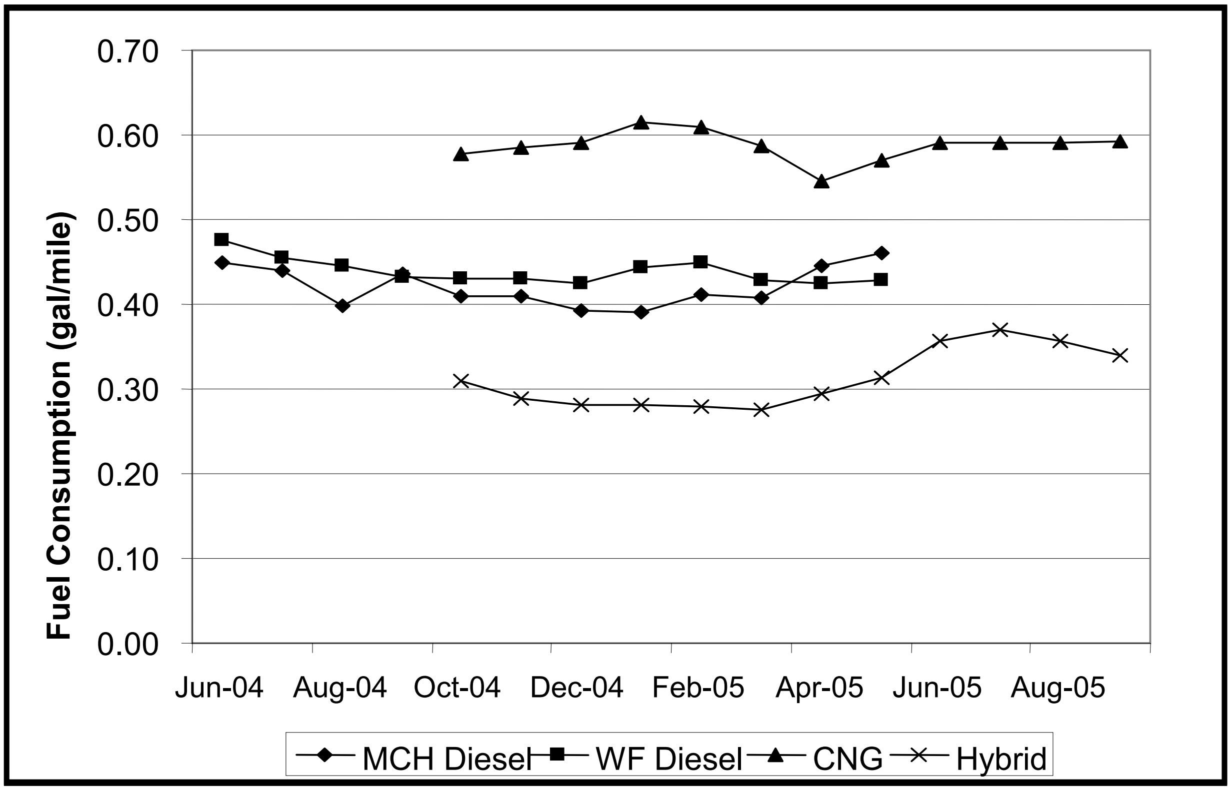


Figure 15. Average Fuel Consumption (Diesel Equivalent Gallons per Mile)

Table 10 shows fuel consumption and economy results for the two diesel study groups of buses. There is one diesel bus from West Farms Depot listed (and shaded) that is not included in the total because this bus had a new DDC Series 50 EGR engine installed in place of the original DDC Series 50 engine. This bus showed a fuel economy (2.04 mpg) that was consistently 10% lower than the rest of the diesel study group from West Farms Depot (2.28 mpg). This would indicate that for this repower, the fuel economy effect of having the newer, lower emissions engine was a 10% loss of fuel economy.

Table 10. Diesel Bus Fuel Use and Economy

Bus	Mileage (Fuel Base)	Gallons Consumed	MPG
403	17,762	7,916.7	2.24
407	20,542	8,862.5	2.32
408	21,064	9,195.2	2.29
412	18,475	8,200.4	2.25
413	18,473	8,106.6	2.28
416*	20,488	10,053.7	2.04
428	21,774	9,744.9	2.23
438	21,310	9,124.7	2.34
448	24,269	10,647.1	2.28
450	23,013	10,221.3	2.25
West Farms Diesel	**186,682**	**82,019.4**	**2.28**
6002	27,467	11,805.5	2.33
6004	28,859	11,936.0	2.42
6005	28,742	11,704.5	2.46
6006	27,978	12,021.5	2.33
6008	28,754	11,929.0	2.41
6011	26,614	11,401.0	2.33
6015	27,078	11,614.0	2.33
6018	29,048	11,909.5	2.44
6020	25,450	10,816.5	2.35
Mother Clara Hale Diesel	**249,990**	**105,137.5**	**2.38**

* Results for bus 416 are not included in the total.

The hybrid bus average fuel economy for the 12-month evaluation period fluctuated between 60% and 120% higher fuel economy than the CNG buses based on diesel equivalent units.

During the evaluation period, diesel fuel at NYCT cost an average of $1.78 per gallon for ultra low sulfur diesel fuel with sulfur less than 30 ppm. The diesel fuel cost went up significantly by the end of the evaluation period for this report ($2.26 per gallon in September 2005).

NYCT's CNG cost is based on two components—the commodity price of the natural gas from the pipeline and the Trillium add-on to pay for the station operation. Over the evaluation period, this has been an average of $1.00 per therm for the natural gas and $0.25 per therm for Trillium, which results in a total cost of $1.25 per therm or $1.74 per diesel equivalent gallon.

When compared to the diesel baseline study group, the fuel cost per mile for the CNG buses was $1.02 per mile for CNG ($0.78 per mile for diesel)—31% higher for CNG at West Farms Depot. The fuel costs for hybrid buses were 25% lower than their diesel baseline study group at $0.75 per mile for diesel and $0.56 per mile for hybrid buses at Mother Clara Hale Depot. Across both depots, the CNG buses have a fuel cost per mile 45% higher than the hybrid buses.

Maintenance Analysis

This evaluation focuses on bus operations spanning the first two years of the minimum 12-year life of a transit bus. This short evaluation period does not provide enough of the capital and operating costs to understand the full 12-year life cycle cost of the CNG, or hybrid buses. In order to gain a complete understanding of costs, one must examine the purchase cost of the buses, cost of facility modification or addition, warranty cost, operations cost (and savings), and longer term maintenance costs (such as engine rebuilds or replacements, traction battery replacements, brake repair savings, etc.). However, the intent of this evaluation is to provide accurate actual capital and known operations costs experienced for hybrid and CNG vehicles for the time period selected. This analysis is not predictive of maintenance costs assumed by the transit agency beyond the warranty period. The general warranty on these particular hybrids is two years from date of purchase, with some drivetrain components warranted beyond two years. The exact components and warranty periods are negotiated by NYCT and Orion, and are contractual.

The maintenance analysis in this section provides a comparison of hybrid buses to CNG buses. The diesel buses at the two depots are older, and are therefore an inappropriate comparison due to their higher maintenance costs. The CNG and hybrid buses are new enough that much of the maintenance is done under warranty by the manufacturers and their distributor mechanics. When possible, this warranty maintenance cost is captured and provided separately in the report, but is not included in the maintenance cost analysis. Not accounting for warranty repairs in the evaluation of total maintenance cost offers an incomplete picture of true maintenance cost. However, this analysis, with the absence of warranty costs, does reflect the actual cost to the transit agency during the time period selected.

Both the CNG and hybrid buses are similar in age and the maintenance costs have been collected in a similar way for each study group. The duty cycle and maintenance practices at West Farms and Mother Clara Hale depots are similar and do allow a comparison between the CNG and hybrid buses. These buses are the same model (Orion VII) and have been in service about the same amount of time (as discussed above in Bus Usage).

For the CNG and hybrid buses, maintenance data were collected from the start of operations through the end of the evaluation period (September 2005). All work orders and parts information available were collected for the study buses. The maintenance analysis discussions include only maintenance data from the evaluation period of October 2004 through September 2005.

Total Maintenance Costs

Total maintenance costs include the costs of parts and hourly labor costs of $50 per hour, and do <u>not</u> include warranty costs. Cost per mile is calculated as follows:

Cost per mile = ((labor hours * 50) + parts cost)/mileage

The labor rate has been artificially set at a constant rate of $50 per hour so that other analysts can change this rate to one more similar to their own. Also, this rate does not directly reflect NYCT's current hourly mechanic rate.

Table 11 shows total maintenance costs for the CNG buses at West Farms Depot and Hybrid buses at Mother Clara Hale Depot. One of the CNG buses had higher total maintenance costs than the other CNG buses. These higher costs were caused mostly by brake reline activities. There was also one hybrid bus (bus 6379) that had total maintenance costs higher than the rest. These higher total maintenance costs were caused by significant repairs troubleshooting the hybrid propulsion system, hydraulic pump, PCS cooling system, doors, and air conditioning. There was one significant accident in June 2005 for this bus as well. Several of these significant repairs are a part of the aforementioned campaigns for the hybrid buses.

The total maintenance cost per mile for the CNG buses was 5% higher than the hybrid buses, parts costs on average were 40% higher for the CNG buses, and labor hours were 13% higher for the hybrid buses. These differences will be explored further in the next discussion about maintenance cost breakdown by vehicle systems.

Table 11. CNG and Hybrid Bus Total Maintenance Costs (October 2004—September 2005)

Bus	Mileage	Parts ($)	Labor Hours	Cost per Mile ($)
7657	27,483	9,524.10	609.5	1.46
7662	30,552	9,245.59	504.1	1.13
7666	20,853	12,510.57	619.7	2.09
7670	26,878	10,097.71	482.5	1.27
7677	28,632	13,169.32	582.0	1.48
7688	27,900	12,678.36	581.9	1.50
7708	30,175	9,562.91	454.6	1.07
7715	28,298	6,155.98	422.1	0.96
7719	27,381	9,638.15	433.7	1.14
7721	27,292	7,397.03	442.8	1.08
Total CNG	**275,444**	**99,979.72**	**5,132.8**	**1.29**
Avg. per Bus	**27,544**	**9,997.97**	**513.3**	**--**
6367	26,383	8,172.50	591.4	1.43
6368	27,987	4,856.74	479.9	1.03
6369	26,163	6,109.25	604.5	1.39
6375	29,736	6,009.55	649.1	1.29
6378	30,884	4,901.92	556.2	1.06
6379	28,810	9,240.45	761.1	1.64
6380	27,160	5,070.21	419.3	0.96
6381	28,365	5,092.11	556.2	1.16
6382	29,114	5,591.24	572.0	1.17
6387	29,841	5,433.59	602.8	1.19
Total Hybrid	**284,443**	**60,477.56**	**5,792.5**	**1.23**
Avg. per Bus	**28,444**	**6,047.76**	**579.3**	**--**

Maintenance Cost Broken Down by System

Table 12 shows maintenance costs by vehicle system and bus study group. The vehicle systems shown in the tables include the following:

- Preventive maintenance inspections (PMI)—Labor only for inspections during preventive maintenance
- Tires—This only includes tire repairs; costs for the replacement of the tires themselves are not collected or presented in the maintenance analysis

- Propulsion-related systems—Repairs for exhaust, fuel, engine, electric motors, traction batteries, and propulsion control, non-lighting electrical, air intake, cooling, transmission, and hydraulics
- Cab, body, and accessories—Includes body repairs following accidents, glass, and paint; cab and sheet metal repairs on seats and doors; and accessory repairs such as hubodometers and radios
- Frame, steering, and suspension
- Brakes—Excludes regenerative braking for the hybrids, which is included in propulsion-related systems
- Heating, ventilation, and air conditioning (HVAC)
- Axles, wheels, and drive shaft
- Lighting
- Air System, general.

Table 12. Breakdown of Vehicle System Maintenance Cost per Mile (October 2004—September 2005)

Vehicle System	CNG West Farms		Hybrid Mother Clara Hale	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Cab, Body, and Accessories	0.33	26	0.39	32
Propulsion-related	0.35	27	0.37	30
PMI	0.12	9	0.17	14
Brakes	0.18	14	0.04	3
Frame, Steering, and Suspension	0.06	5	0.07	6
HVAC	0.07	5	0.08	6
Lighting	0.05	4	0.05	4
Air, General	0.05	4	0.03	2
Axles, Wheels, and Drive Shaft	0.04	3	0.02	2
Tires	0.04	3	0.01	1
Total	**1.29**	**100**	**1.23**	**100**

Table 13 summarizes the top five maintenance cost categories from the total maintenance breakdown for each study group. Each of the study groups has propulsion-related, cab, body, and accessories, and HVAC costs in the top five. The other two categories that show up in the top five are brakes or frame, steering, and suspension. These categories are discussed in more detail in the following sections.

Table 13. Top 5 Maintenance Cost Categories

Rank	CNG West Farms	Hybrid Mother Clara Hale
1	Propulsion-related	Cab, Body, and Accessories
2	Cab, Body, and Accessories	Propulsion-related
3	Brakes	PMI
4	PMI	HVAC
5	HVAC	Frame, Steering, and Suspension

Propulsion-Related Maintenance Costs

The propulsion-related vehicle systems include the exhaust, fuel, engine, electric propulsion, air intake, cooling, non-lighting electrical, transmission, and hydraulic systems. Table 14 shows the total propulsion-related maintenance costs and lists the costs for the two study groups. Table 15 summarizes the cost comparisons between the study groups. All comparison calculations are hybrid compared to CNG as the baseline.

Total propulsion-related systems maintenance costs per mile for the CNG buses were 5% lower than the hybrid buses.

A breakdown of the propulsion-related maintenance costs included:

- **Exhaust system maintenance**—The hybrid and CNG buses had essentially the same maintenance costs for this system. The hybrid bus group had troubleshooting issues involving the DPF backpressure sensor and a few exhaust backpressure sensors were replaced. The rest of the maintenance costs for this system were related to inspections of the exhaust piping and clamps. All 10 hybrid buses appeared to have undergone the yearly cleaning for the DPF. The CNG buses have had a problem with the thermal blanket on the exhaust wearing out from vibration. The thermal blanket insulation was replaced 19 times during the evaluation period. This issue has not yet been permanently resolved.
- **Fuel system maintenance**—The CNG buses had fuel system maintenance costs 74% higher than the hybrid buses. This difference was mostly due to the extra fuel filter costs for the CNG buses and a few problems with the CNG fuel leak sensors.
- **Engine system maintenance costs**—The CNG buses had engine system maintenance costs 5% higher than the hybrid buses. The CNG buses were reported to have high engine oil consumption. This extra cost was not captured here. The CNG engines are also in the process of being rebuilt as part of a campaign with new cylinder kits along with new spark plugs, which is not reported here as a cost as it is covered under warranty. The hybrid bus diesel engine is smaller than the CNG engine and parts costs for standard preventive maintenance are lower for the hybrid buses.
- **Electric propulsion systems maintenance costs**—These costs pertain only to the hybrid buses evaluated at Mother Clara Hale Depot. Most of the maintenance issues for the hybrid buses had to do with troubleshooting the hybrid control system and learning to diagnose electric propulsion system failures. Some of the problems reported in the

maintenance system included the PCS cooling system, triple pump, filters, traction battery, and traction motor. Troubleshooting work orders in this category included "won't start" and "check" or "stop" hybrid electric vehicle lights.

Table 14. Propulsion-Related Maintenance Cost by System (October 2004—September 2005)

Vehicle System	CNG West Farms	Hybrid Mother Clara Hale
Mileage	275,444	284,443
Total Propulsion-related Systems (Roll-Up)		
Parts Cost ($)	37,080.52	10,880.98
Labor Hours	1181.5	1870.1
Total Cost ($) per Mile	**0.349**	**0.367**
Exhaust System Repairs		
Parts Cost ($)	3,058.60	879.07
Labor Hours	48.0	120.2
Total Cost ($) per Mile	**0.020**	**0.024**
Fuel System Repairs		
Parts Cost ($)	8,226.37	1,845.80
Labor Hours	154.2	48.8
Total Cost ($) per Mile	**0.058**	**0.015**
Engine System Repairs		
Parts Cost ($)	3,320.92	2,477.86
Labor Hours	288.2	295.8
Total Cost ($) per Mile	**0.064**	**0.061**
Electric Motor, Generator, and Battery Repairs		
Parts Cost ($)		2,922.96
Labor Hours		972.9
Total Cost ($) per Mile		**0.181**
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)		
Parts Cost ($)	10,890.80	849.89
Labor Hours	340.6	220.7
Total Cost ($) per Mile	**0.101**	**0.042**
Air Intake System Repairs		
Parts Cost ($)	2,342.26	922.20
Labor Hours	20.5	13.8
Total Cost ($) per Mile	**0.012**	**0.006**
Cooling System Repairs		
Parts Cost ($)	2,920.49	361.91
Labor Hours	232.6	169.0
Total Cost ($) per Mile	**0.053**	**0.031**
Transmission Repairs		
Parts Cost ($)	6,213.90	
Labor Hours	75.0	
Total Cost ($) per Mile	**0.036**	
Hydraulic Repairs		
Parts Cost ($)	107.18	621.29
Labor Hours	22.5	29.0
Total Cost ($) per Mile	**0.005**	**0.007**

Table 15. Summary of Propulsion-Related Maintenance Cost Comparisons*

Vehicle System	CNG ($/mile)	Hybrid ($/mile)	Hybrid vs. CNG
Total Propulsion-Related	**0.349**	**0.367**	**5% (higher)**
Exhaust	0.020	0.024	22% (higher)
Fuel	0.058	0.015	-74% (lower)
Engine	0.064	0.061	-5% (lower)
Electric Propulsion/Transmission	0.036	0.181	403% (higher)
Non-Lighting Electrical	0.101	0.042	-58% (lower)
Air Intake	0.012	0.006	-53% (lower)
Cooling	0.053	0.031	-41% (lower)
Hydraulic	0.005	0.007	62% (higher)

* The cost comparisons are provided as hybrid compared to CNG as the baseline.
((Hybrid cost per mile/CNG cost per mile)—1) * 100% = Percent comparison
For example, the total propulsion related entry is 5% higher; this is hybrid costs being 5% higher than CNG for this category.

During the evaluation period (October 2004 through September 2005), the hybrid study bus group had 11 incidents involving seven of the 10 buses that required at least one traction battery to be replaced; a total of 22 traction batteries. This translates into a 4.8% per year failure rate taking into account that each of the 10 hybrid buses has 46 traction batteries and the evaluation period is one year long. Two of these incidents caused a roadcall as well. On average, each of these incidents required 13 hours of mechanic time to troubleshoot, remove, and replace the affected traction batteries.

NYCT reported some concern about the amount of labor required and the number of these incidents. BAE Systems has been investigating the situation including having the traction battery manufacturer (Hawker/EnerSys) inspect and report on the removed traction batteries. The results from this investigation showed that none of the traction batteries failed, a few had manufacturing defects, and a few had mechanical damage (maybe from installation). Hawker/EnerSys reported changes in procedure to improve the manufacturing process. BAE Systems released a software change in April 2006 for the hybrid propulsion system to make identifying faulty batteries a little less aggressive and reduce the overall number of traction batteries removed with no true failure. This may have a small effect on fuel economy; however, BAE Systems did not expect any measurable difference in fuel economy.

These batteries are approaching their three-year life expectancy in another year. The competing traction battery technology (nickel metal hydride—NiMH) for this application is currently reported to be three to four times more expensive than the lead-acid technology in use now with only a two times life expectancy increase. NYCT and BAE Systems are planning the first traction battery changeouts for the order of 125 hybrid buses.

During the evaluation, all 10 hybrid buses had the traction batteries conditioned with the on-site chargers at Mother Clara Hale Depot. The conditioning charge is needed to help extend the life of the traction batteries and was completed twice (every six months) during the evaluation period (first around 10-11/2004 and second around 6-7/2005). Although there was a work order created for this traction battery conditioning, there was essentially no mechanic time charged to this activity. NYCT spent time making sure that the traction battery conditioning is scheduled as part the preventive maintenance.

- **Non-lighting electrical systems maintenance costs**—These costs include general electrical maintenance other than lighting including charging, cranking, and ignition systems. The CNG buses had maintenance costs 58% higher than the hybrid buses.

  The CNG buses had issues with the starter, the main power control, and communications systems. The spark plugs on the CNG buses have been an issue with failures as early as 4,000 miles. The CNG engines now use four iridium spark plugs costing $261 for the set. DDC paid for the first set of these iridium spark plugs as part of the CNG engine campaign and now NYCT will be paying for the subsequent changes on a 24,000 mile interval or approximately once per year. Four of the 10 CNG buses received these new spark plugs during the evaluation period. NYCT reports that the new spark plugs are working much better so far. Issues for the hybrid buses in this category included the voltage regulator, alternator, and wiring.

- **Air intake system maintenance costs**—The CNG buses had maintenance costs 53% higher than the hybrid buses. There were no major problems or issues for either fleet in this category. The hybrid bus diesel engine is smaller than the CNG engine and parts costs for standard preventive maintenance are lower for the hybrid buses.

- **Cooling system maintenance costs**—The CNG buses had maintenance costs 41% higher than the hybrid buses. The hybrid bus diesel engine is smaller than the CNG engine and parts costs for standard preventive maintenance are lower for the hybrid buses.

- **Transmission system maintenance costs**—The hybrid buses do not have a transmission. The CNG buses had six oil coolers replaced at approximately $900 each plus labor.

Figure 17 shows the monthly average propulsion-related maintenance cost per mile for the CNG and hybrid buses. The hybrid propulsion maintenance cost starts out low and comes up above $0.40 in February 2005 and then climbs slowly up to $0.48 per mile by the end of the evaluation period. This is most likely due to the added maintenance costs of the NYCT mechanics taking over some of the unscheduled warranty-related troubleshooting and maintenance of the hybrid buses from the BAE Systems technicians.

The CNG propulsion maintenance cost starts high in the first month (four transmission oil coolers and three natural gas regulators), peaks in April 2005 (electrical, exhaust blanket insulation, and transmission), drops significantly below the hybrid line, and then comes back up to the level of the hybrid costs at the end of the evaluation period (electrical, exhaust blanket insulation, and fuel system).

The CNG propulsion maintenance costs for parts are more than three times those reported for the hybrid group, which most likely had many of the more expensive parts covered under warranty; warranty costs are not included here. The comparison of labor hours shows the opposite—the hybrid propulsion maintenance has 57% more labor hours than for the CNG propulsion maintenance. This is most likely due to NYCT learning how to troubleshoot the more complex hybrid electric propulsion system.

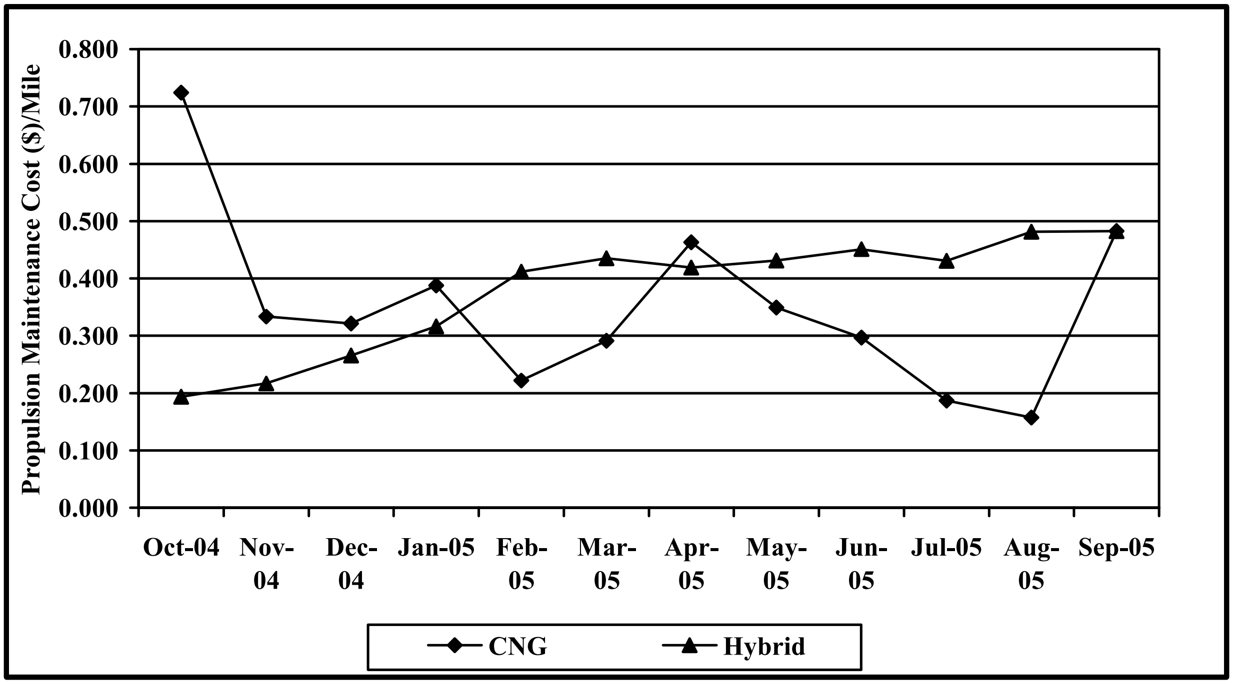


Figure 16. Propulsion-Related Maintenance Cost per Mile for CNG and Hybrid Buses

Cab, Body, and Accessories Systems

The vehicle systems included in this grouping are shown in Table 16. The maintenance costs associated with these systems are shown by bus study group and are generally independent of the advanced technology being evaluated in this study. It is included to give some perspective to the various bus maintenance costs.

Table 16. Breakdown of Cab, Body, and Accessory Maintenance Cost per Mile (October 2004—September 2005)

Vehicle Subsystem	CNG West Farms		Hybrid Mother Clara Hale	
	Cost per Mile ($)	Percent (%)	Cost per Mile ($)	Percent (%)
Doors and Interlock	0.05	15	0.10	25
Wheelchair Lift / Ramp	0.04	12	0.05	13
Body—Exterior	0.11	34	0.12	31
Cleaning	0.04	12	0.04	10
Mirrors	0.02	6	0.02	5
General Interior and Seats	0.03	9	0.03	7
Windshield Wipers	0.02	6	0.01	3
Supplies and expendable items	0.01	3	0.00	0
Horn	0.01	3	0.01	3
Fire Extinguisher	0.00	0	0.01	3
Total	**0.33**	**100**	**0.39**	**100**

HVAC

This category includes all maintenance actions for heating and ventilation and the air conditioning system. The majority of the costs in this category are related to the air conditioning. Both study groups of buses utilized the same HVAC system. The maintenance costs for the two study groups are shown in Table 17. The maintenance cost per mile for the CNG buses was 11% lower than for the hybrid buses.

Table 17. HVAC System Maintenance Costs (October 2004—September 2005)

Fleet	Mileage	Parts Cost ($)	Labor Hours	Cost per Mile ($)
West Farms CNG	275,444	7,097.42	241.2	0.070
Mother Clara Hale Hybrid	284,443	4,202.86	361.4	0.078

Brakes

The brake system maintenance costs are expected to be dramatically lower for hybrid propulsion systems with regenerative braking. The regenerative braking allows the electric drive motors to be used to slow down a bus, similar to a transmission retarder. The energy from braking is taken into the electric motor and then fed back to the traction batteries. Non-hybrid buses are expected to have a four-wheel reline of the brakes every 18,000 miles on average at NYCT.

Table 18 shows the maintenance costs for the brake system repairs for the two study bus groups. During the evaluation period, the CNG buses had 79% higher brake maintenance cost per mile compared to the hybrid buses. The six oldest CNG buses in the study group had at least one four-wheel reline of the brakes during the evaluation period. Three of those six CNG buses had the four-wheel reline twice during the evaluation period. There were also some repairs for issues with the antilock brake system for the CNG and hybrid buses. Brake maintenance costs for CNG buses were consistently around 80% higher for CNG for the entire 12-month evaluation period.

Table 18. Brake System Maintenance Costs (October 2004—September 2005)

Fleet	Mileage	Parts Cost ($)	Labor Hours	Cost per Mile ($)
West Farms CNG	275,444	12,517.92	725.1	0.177
Mother Clara Hale Hybrid	284,443	1,797.66	171.9	0.037

PMI

This is preventive maintenance inspection labor time spent on the buses. Based upon the data collected during this evaluation, the hybrid buses had 50% more labor spent on scheduled maintenance time. However, due to the way in which the NYCT mechanics record their time, additional unscheduled activities are included in what is defined as PMI. No difference in PMI labor is expected between the CNG and hybrid buses. This reporting discrepancy must be recognized when considering the apparent difference in PMI labor for CNG and hybrid buses. However, in keeping with our intent of reporting unbiased data, but applying the appropriate caveats, PMI costs are presented in Table 19, below.

Table 19. Preventive Maintenance Inspection Maintenance Costs (October 2004—September 2005)

Fleet	Mileage	Parts Cost ($)	Labor Hours	Cost per Mile ($)
West Farms CNG	275,444	0.00	646.8	0.117
Mother Clara Hale Hybrid	284,443	0.00	996.2	0.175

Frame, Steering, and Suspension

This category includes repairs for the frame, steering, and suspension systems of the buses. As shown in Table 20, the CNG buses had maintenance cost per mile 19% lower than the hybrid buses.

Table 20. Frame, Steering, and Suspension Maintenance Costs (October 2004—September 2005)

Fleet	Mileage	Parts Cost ($)	Labor Hours	Cost per Mile ($)
West Farms CNG	275,444	5,324.46	244.9	0.064
Mother Clara Hale Hybrid	284,443	8,175.53	267.7	0.076

Warranty Costs

Maintenance costs that were covered under warranty were generally removed. NYCT requested that suppliers working on the CNG and hybrid buses enter mechanic time into the maintenance system. During the evaluation period, the CNG buses had 19.5 labor hours and $5,575.09 in parts costs removed from the analysis in this report. The hybrid buses had 13 labor hours and $13,651.82 in parts costs removed from the evaluation period analysis in this report. The reported labor hours were from Atlantic Detroit Diesel Allison (local dealer), Cummins, Vapor Corporation, and Orion. These figures do not include all warranty costs experienced at NYCT and are not included in the previous maintenance cost sections. Many repair actions were performed for both study fleets by the manufacturer service representatives on site at NYCT and not captured in the maintenance tracking system or this evaluation.

Roadcall Analysis

Figure 18 shows the cumulative average MBRC for all RCs for the CNG, hybrid, and two diesel baseline fleets. With an average of 2,000 MBRC, the diesel buses at West Farms Depot are well below NYCT's expectation that all buses should meet or exceed 4,000 MBRC. Both the diesel buses at Mother Clara Hale Depot and the CNG buses are above the goal at around 5,000 MBRC for the MCH diesel buses and just under 6,000 MBRC for the CNG buses. The MBRC of the hybrid buses has started to settle below 6,000 MBRC for the evaluation period.

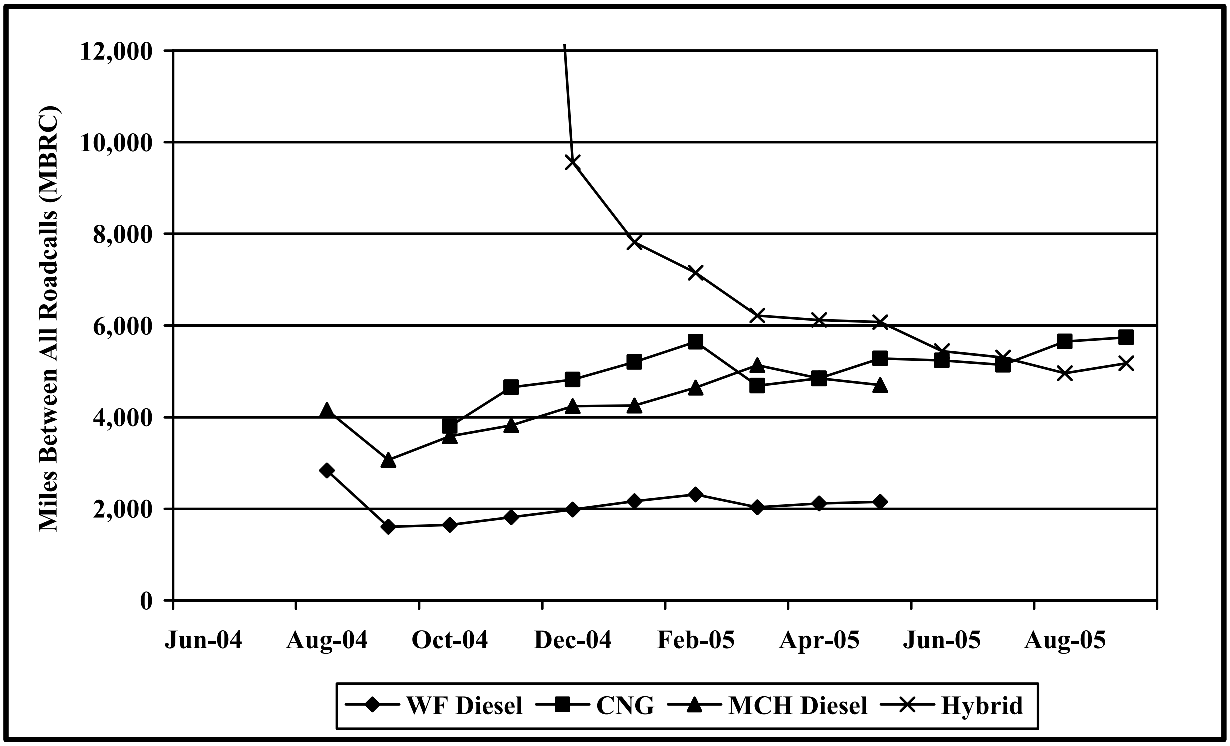


Figure 17. Cumulative Average MBRC

Figure 19 shows cumulative average MBRC over the evaluation periods for RCs that involved the propulsion-related systems in all four of the study groups. Propulsion-related systems include the transmission, non-lighting electrical (general electrical, charging, cranking, and ignition), air intake, cooling, exhaust, fuel, engine, and electrical propulsion. RCs for June 2004 and July 2004 were not available for the diesel buses and are not included in the figure.

The diesel buses at West Farms Depot had the lowest propulsion-related MBRC at around 5,000. The CNG buses had a propulsion-related MBRC that steadily rose over the evaluation period to around 8,800. The diesel buses at Mother Clara Hale had the highest propulsion-related MBRC at the end of the evaluation period at just over 10,000. The hybrid buses started the evaluation at a high propulsion-related MBRC that has leveled out a little lower than the CNG buses (8,100).

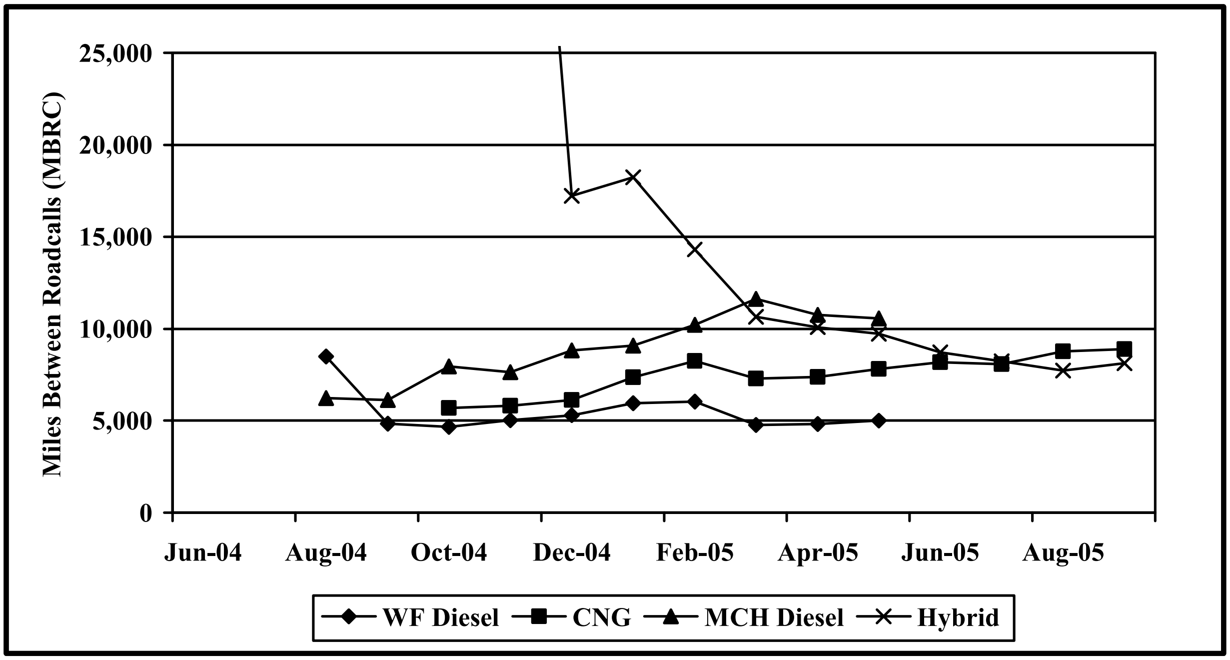


Figure 18. Cumulative Average MBRC, Propulsion-Related Only

Table 21 provides a summary of the RCs for each study group of buses for the evaluation period. The diesel buses at West Farms Depot had the most RCs for doors and interlock, cooling (hydraulic fan), and engine. The CNG buses had the most RCs for non-lighting electrical (mostly for problems starting), doors and interlock, and engine. The diesel buses at Mother Clara Hale Depot had the most RCs for doors and interlock, non-lighting electrical, and wheelchair lift/ramp. The hybrid buses had the most RCs for the electric propulsion system and air system. The electric propulsion system RCs were mostly caused by “check” or “stop” HEV lights.

Table 21. Roadcalls for Each Fleet by System (October 2004—September 2005)

System	Diesel West Farms		CNG West Farms		Diesel Mother Clara Hale		Hybrid Mother Clara Hale	
	RCs	Percent (%)	RCs	Percent (%)	RCs	Percent (%)	RCs	Percent (%)
HVAC	3	4	1	2	1	2	5	9
Door and Interlock	16	22	9	19	10	22	5	9
Mirrors and Sun Visor	1	1	0	0	0	0	0	0
Air-General	1	1	0	0	1	2	4	7
Brakes	2	3	0	0	0	0	1	2
Steering	3	4	1	2	1	2	1	2
Suspension	2	3	3	6	2	5	2	4
Transmission*	3	4	2	4	1	2	0	0
Non-Lighting Electrical*	5	7	13	27	6	13	4	7
Lighting	0	0	1	2	2	5	0	0
Cooling*	16	22	1	2	5	11	5	9
Exhaust*	2	3	0	0	2	5	0	0
Fuel*	2	3	6	13	4	9	2	4
Engine*	10	14	9	19	4	9	2	4
Electric Propulsion*	0	0	0	0	0	0	22	39
Wheelchair Lift/Ramp	6	9	2	4	6	13	2	4
Total	**72**	**100**	**48**	**100**	**45**	**100**	**55**	**100**

* These systems represent the propulsion-related vehicle systems.

Summary of Costs

Table 22 summarizes fuel and maintenance cost per mile for the CNG and hybrid study groups. The hybrid buses have a cost per mile 23% lower than the CNG buses. This lower cost is due almost entirely to the difference in the fuel economies of the hybrid and CNG buses.

Table 22. Summary of Cost per Mile for CNG and Hybrid Buses (October 2004—September 2005)

Bus	Fuel Cost / Mile ($)	Maintenance Cost / Mile ($)	Total Cost / Mile ($)
7657	1.02	1.46	2.48
7662	0.93	1.13	2.06
7666	1.06	2.09	3.15
7670	1.04	1.27	2.31
7677	1.01	1.48	2.49
7688	1.05	1.50	2.55
7708	1.05	1.07	2.12
7715	0.99	0.96	1.95
7719	1.09	1.14	2.23
7721	0.98	1.08	2.06
CNG avg.	**1.02**	**1.29**	**2.31**
6367	0.57	1.43	2.00
6368	0.57	1.03	1.58
6369	0.54	1.39	1.93
6375	0.55	1.29	1.84
6378	0.54	1.06	1.60
6379	0.57	1.64	2.21
6380	0.60	0.96	1.56
6381	0.55	1.16	1.71
6382	0.54	1.17	1.71
6387	0.56	1.19	1.75
Hybrid avg.	**0.56**	**1.23**	**1.79**

What's Next?

This is the final report for the 12-month evaluation of NYCT's hybrid buses from the order of 125 and the CNG Orion VII buses. NYCT has also taken delivery of all of an order of 200 more hybrid buses from Orion and BAE Systems. The order of 200 new hybrid buses are model year 2004 buses and include a Cummins ISB engine with EGR and some of the electric propulsion equipment and controls have been refined. The 200 new hybrid buses are being split between Fresh Pond Depot in Brooklyn (138) and Manhattanville Depot in Manhattan (62).A selection of 10 of these new hybrid buses from the Manhattanville depot will be evaluated. The evaluation of the order of 200 hybrid buses is intended to document improvements and experience at NYCT.

NYCT recently placed another large order for diesel hybrid buses from Orion and BAE Systems including 500 hybrid buses with the option to purchase up to a total of 889 buses. NYCT is expecting to take delivery of 216 of these hybrid buses and 284 hybrid buses are for their sister agency, MTA Buses. NYCT intends to add hybrid bus operations to the East New York and Casey Stengel depots as well as converting the entire Manhattanville Depot to only diesel hybrid bus operation.

The purchase price of these hybrid buses was a little less than $500,000 each, which is reportedly about $150,000 more than a new standard clean diesel bus. Currently, NYCT has no plans to purchase more CNG buses; however, NYCT still considers CNG buses a potential option for future purchases.

Contacts

U.S. Department of Energy
Lee Slezak
Manager, Advanced Vehicle Testing Activity
Phone: 202-586-2335
E-mail: lee.slezak@ee.doe.gov

National Renewable Energy Laboratory
Robb Barnitt
Project Engineer
Phone: 303-275-4489
E-mail: robb_barnitt@nrel.gov

Battelle
Kevin Chandler
Principal Research Scientist
Phone: 614-424-5127
E-mail: chandlek@battelle.org

New York City Transit
Gary LaBouff
Director, Research and Development
Department of Buses
Phone: 718-566-3535
E-mail: galabou@nyct.com

Orion Bus Industries
Mark Brager
Vice President, Sales
Phone: 905-403-7806
E-mail: mbrager@orionbus.com

BAE Systems
Tom Webb
Business Development, Transit
Phone: 413-253-2564
E-mail: thomas.webb@baesystems.com

Trillium USA
Jennifer de Tapia
Director of Market Services
Phone: 800-920-1166
E-mail: jdetapia@trilliumusa.com

Acronyms and Abbreviations

AVTA—Advanced Vehicle Testing Activity
bhp—brake horsepower
CNG—compressed natural gas
CO—carbon monoxide
DDC—Detroit Diesel Corporation
DOC—diesel oxidation catalyst
DOE—U.S. Department of Energy
DPF—diesel particulate filter
EPA—U.S. Environmental Protection Agency
EGR—exhaust gas recirculation
g/bhp-hr—grams per brake horsepower hour
HC—hydrocarbons
HEV—hybrid electric vehicle
HVAC—heating, ventilation, and air conditioning
LIRR—Long Island Railroad
LI Bus—Long Island Bus
MBRC—miles between roadcalls
MCH—Mother Clara Hale Depot
MTA—Metropolitan Transportation Authority
NREL—National Renewable Energy Laboratory
NYCT—New York City Transit
NMHC—non-methane hydrocarbons
NOx—oxides of nitrogen
PCS—power control system
PM—particulate matter
ppm—parts per million
PMI—preventive maintenance inspection
RC—roadcall
R&D—research and development
rpm—revolutions per minute
scfm—standard cubic feet per minute
SCR—selective catalytic reduction
ULSD—ultra low sulfur diesel

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Appendix: Fleet Summary Statistics

CNG (Orion VII) at West Farms Depot and Hybrid (Orion VII) at Mother Clara Hale Depot Evaluation Period

Fleet Operations and Economics

	CNG	**Hybrid**
Number of Vehicles	10	10
Period Used for Fuel and Oil Op Analysis Total Number of Months in Period Fuel and Oil Analysis Base Fleet Mileage	10/04-9/05 12 259,083	10/04-9/05 12 257,920
Period Used for Maintenance Op Analysis Total Number of Months in Period Maintenance Analysis Base Fleet Mileage	10/04-9/05 12 275,444	10/04-9/05 12 284,443
Average Monthly Mileage per Vehicle Fleet Diesel Usage in Gal.	2,295 152,016	2,370 80,784
Representative Fleet MPG (energy equiv)	1.70	3.19
Diesel Cost per gallon	1.74	1.78
Fuel Cost per Mile	**1.021**	**0.558**
Total Scheduled Repair Cost per Mile Total Unscheduled Repair cost per Mile Total Maintenance Cost per Mile	0.287 1.008 **1.295**	0.279 0.952 **1.231**
Total Operating Cost per Mile	**2.316**	**1.788**

Maintenance Costs

	CNG	**Hybrid**
Fleet Mileage	275,444	284,443
Total Parts Cost Total Labor Hours Average Labor Cost (@ $50.00 per hour)	99,979.72 5132.8 256,642.00	60,477.56 5792.5 289,625.00
Total Maintenance Cost Total Maintenance Cost per Bus	356,621.72 35,662.17	350,102.56 35,010.26
Total Maintenance Cost per Mile	**1.295**	**1.231**

Breakdown of Maintenance Costs by Vehicle System

	CNG	Hybrid
Fleet Mileage	275,444	284,443
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)		
Parts Cost	37,080.52	10,880.98
Labor Hours	1181.5	1870.1
Average Labor Cost	59,073.50	93,507.00
Total Cost (for system)	96,154.02	104,387.98
Total Cost (for system) per Bus	9,615.40	10,438.80
Total Cost (for system) per Mile	**0.349**	**0.367**
Exhaust System Repairs (ATA VMRS 43)		
Parts Cost	3,058.60	879.07
Labor Hours	48.0	120.2
Average Labor Cost	2,400.00	6,010.00
Total Cost (for system)	5,458.60	6,889.07
Total Cost (for system) per Bus	545.86	688.91
Total Cost (for system) per Mile	**0.020**	**0.024**
Fuel System Repairs (ATA VMRS 44)		
Parts Cost	8,226.37	1,845.80
Labor Hours	154.2	48.8
Average Labor Cost	7,707.50	2,437.50
Total Cost (for system)	15,933.87	4,283.30
Total Cost (for system) per Bus	1,593.39	428.33
Total Cost (for system) per Mile	**0.058**	**0.015**
Power Plant (Engine) Repairs (ATA VMRS 45)		
Parts Cost	3,320.92	2,477.86
Labor Hours	288.2	295.8
Average Labor Cost	14,407.50	14,792.00
Total Cost (for system)	17,728.42	17,269.86
Total Cost (for system) per Bus	1,772.84	1,726.99
Total Cost (for system) per Mile	**0.064**	**0.061**
Electric Propulsion Repairs (ATA VMRS 46)		
Parts Cost		2,922.96
Labor Hours		972.9
Average Labor Cost		48,645.00
Total Cost (for system)		51,567.96
Total Cost (for system) per Bus		5,156.80
Total Cost (for system) per Mile		**0.181**
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)		
Parts Cost	10,890.80	849.89
Labor Hours	340.6	220.7
Average Labor Cost	17,030.00	11,033.50
Total Cost (for system)	27,920.80	11,883.39
Total Cost (for system) per Bus	2,792.08	1,188.34
Total Cost (for system) per Mile	**0.101**	**0.042**

Breakdown of Maintenance Costs by Vehicle System (continued)

	CNG	Hybrid
Air Intake System Repairs (ATA VMRS 41)		
Parts Cost	2,342.26	922.20
Labor Hours	20.5	13.8
Average Labor Cost	1,025.00	687.50
Total Cost (for system)	3,367.26	1,609.70
Total Cost (for system) per Bus	336.73	160.97
Total Cost (for system) per Mile	**0.012**	**0.006**
Cooling System Repairs (ATA VMRS 42)		
Parts Cost	2,920.49	361.91
Labor Hours	232.6	169.0
Average Labor Cost	11,631.00	8,450.00
Total Cost (for system)	14,551.49	8,811.91
Total Cost (for system) per Bus	1,455.15	881.19
Total Cost (for system) per Mile	**0.053**	**0.031**
Hydraulic System Repairs (ATA VMRS 65)		
Parts Cost	107.18	621.29
Labor Hours	22.5	29.0
Average Labor Cost	1,125.00	1,450.00
Total Cost (for system)	1,232.18	2,071.29
Total Cost (for system) per Bus	123.22	207.13
Total Cost (for system) per Mile	**0.005**	**0.007**
Transmission Repairs (ATA VMRS 27)		
Parts Cost	6,213.90	
Labor Hours	75.0	
Average Labor Cost	3,747.50	
Total Cost (for system)	9,961.40	
Total Cost (for system) per Bus	996.14	
Total Cost (for system) per Mile	**0.036**	
General Air System Repairs (ATA VMRS 10)		
Parts Cost	10,150.20	3,429.39
Labor Hours	111.5	116.9
Average Labor Cost	5,572.50	5,846.00
Total Cost (for system)	15,722.70	9,275.39
Total Cost (for system) per Bus	1,572.27	927.54
Total Cost (for system) per Mile	**0.057**	**0.033**
Brake System Repairs (ATA VMRS 13)		
Parts Cost	12,517.92	1,797.66
Labor Hours	725.1	171.9
Average Labor Cost	36,254.00	8,592.50
Total Cost (for system)	48,771.92	10,390.16
Total Cost (for system) per Bus	4,877.19	1,039.02
Total Cost (for system) per Mile	**0.177**	**0.037**

Breakdown of Maintenance Costs by Vehicle System (continued)

	CNG	Hybrid
Inspections Only - no parts replacements (101)		
Parts Cost	0.00	0.00
Labor Hours	646.8	996.2
Average Labor Cost	32,341.50	49,811.50
Total Cost (for system)	32,341.50	49,811.50
Total Cost (for system) per Bus	3,234.15	4,981.15
Total Cost (for system) per Mile	**0.117**	**0.175**
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)		
Parts Cost	24,184.50	28,491.44
Labor Hours	1315.8	1647.0
Average Labor Cost	65,789.50	82,350.50
Total Cost (for system)	89,974.00	110,841.94
Total Cost (for system) per Bus	8,997.40	11,084.19
Total Cost (for system) per Mile	**0.327**	**0.390**
HVAC System Repairs (ATA VMRS 01)		
Parts Cost	7,097.42	4,202.86
Labor Hours	241.2	361.4
Average Labor Cost	12,059.00	18,071.00
Total Cost (for system)	19,156.42	22,273.86
Total Cost (for system) per Bus	1,915.64	2,227.39
Total Cost (for system) per Mile	**0.070**	**0.078**
Lighting System Repairs (ATA VMRS 34)		
Parts Cost	3,092.94	2,634.10
Labor Hours	197.8	233.9
Average Labor Cost	9,891.00	11,695.00
Total Cost (for system)	12,983.94	14,329.10
Total Cost (for system) per Bus	1,298.39	1,432.91
Total Cost (for system) per Mile	**0.047**	**0.050**
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)		
Parts Cost	5,324.46	8,175.53
Labor Hours	244.9	267.7
Average Labor Cost	12,245.00	13,384.50
Total Cost (for system)	17,569.46	21,560.03
Total Cost (for system) per Bus	1,756.95	2,156.00
Total Cost (for system) per Mile	**0.064**	**0.076**
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)		
Parts Cost	531.76	865.60
Labor Hours	227.2	69.6
Average Labor Cost	11,362.00	3,481.50
Total Cost (for system)	11,893.76	4,347.10
Total Cost (for system) per Bus	1,189.38	434.71
Total Cost (for system) per Mile	**0.043**	**0.015**

Breakdown of Maintenance Costs by Vehicle System (continued)

	CNG	Hybrid
Tire Repairs (ATA VMRS 17)		
Parts Cost	0.00	0.00
Labor Hours	241.1	57.7
Average Labor Cost	12,054.00	2,885.50
Total Cost (for system)	12,054.00	2,885.50
Total Cost (for system) per Bus	1,205.40	288.55
Total Cost (for system) per Mile	**0.044**	**0.010**

Notes

1. The engine/fuel-related systems were chosen to include only those systems of the vehicles that could be directly impacted by the selection of a fuel.
2. ATA VMRS coding is based on parts that were replaced. If there was no part replaced in a given repair, the code was chosen by the system being worked on.
3. In general, inspections (with no part replacements) were only included in the overall totals (not by system). 101 was created to track labor costs for PM inspections.
4. ATA VMRS 02-cab and sheet metal represents seats, doors, etc. ATA VMRS 50-accessories represent things like fire extinguishers, test kits, etc. ATA VMRS 71-body represents mostly windows and windshields.
5. Average labor cost is assumed to be $50 per hour.
6. Warranty costs are not included.

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This report describes the evaluation results for new Orion VII buses at NYCT with CNG propulsion and new hybrid propulsion.

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