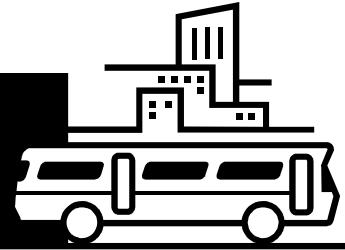




HYBRID BUSES COSTS AND BENEFITS



Key Facts

- In 2005, more than **60 percent** of the 9.7 billion transit passenger trips in the United States were **provided by buses**, approximately **84 percent of which are powered by diesel combustion engines**.¹
- Diesel exhaust contains ozone precursors, benzene, arsenic, dioxins, formaldehyde and other toxic substances and is a significant contributor to airborne concentrations of fine particulate matter (PM). Significant health impacts including lung damage and premature death are associated with exposure to fine particulate matter. It can also aggravate conditions such as asthma and bronchitis. Diesel exhaust has also been classified as a probable human carcinogen with no known safe level of exposure.²
- In response to air quality and health concerns as well as rising fuel costs, a growing number of transit agencies are turning to **hybrid-electric buses**, which consume less energy and produce significantly fewer emissions by combining an internal combustion engine with an electric motor.

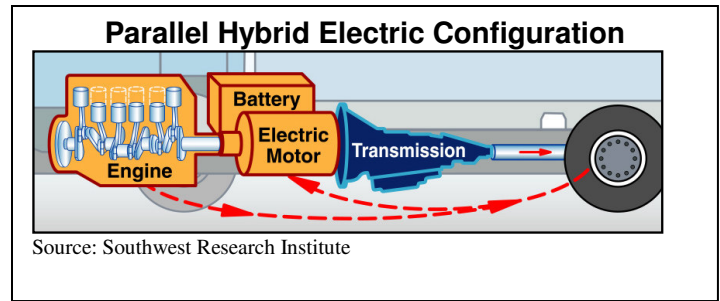
Technology Overview

- A hybrid-electric bus is powered by an electric motor, and a smaller than normal conventional internal combustion engine. To achieve heightened efficiency, the battery powered electric motor allows the combustion engine to operate at periods of maximum efficiency. The major components of a hybrid drive system include an internal combustion engine (ICE), a generator, a battery pack, and an electric motor. The most commonly used batteries in hybrid vehicles are lead-acid or nickel-metal hydride.
- Ultra low sulfur diesel is the most common fuel used to power the combustion engine in hybrids, although other fuels such as gasoline, compressed natural gas (CNG), liquid natural gas (LNG), biodiesel, and hydrogen have also been used.
- A majority of the hybrid buses in service are 40-foot buses. However, 22-foot shuttle buses and 60-foot articulated buses have also been deployed.
- The three major manufacturers of hybrid systems are GM-Allison Transmission, BAE Systems, and ISE Corporation. Ebus produces 22-foot shuttle buses.
- There are two different types of hybrid systems - parallel and series hybrids.

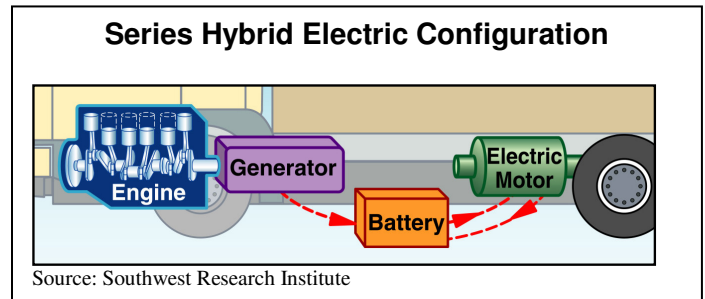
¹ American Public Transportation Association, Public Transportation Ridership Statistics, Fourth Quarter 2005
<http://www.apta.com/research/stats/ridership/riderep/documents/05q4cvr.pdf>

² US Environmental Protection Agency, "Diesel Exhaust and Your Health",
<http://www.epa.gov/cleanschoolbus/humanhealth.htm>

- In a *parallel hybrid bus*, the combustion engine and the electric motor are connected to the transmission independently. The electric motor is designed to provide power during stop-and-go traffic while at highway speeds the vehicle is powered solely by the internal combustion engine. During acceleration, both the electric motor and the combustion engine power the transmission. In addition, through a process called *regenerative braking*, energy lost due to braking is recovered and utilized to charge the battery.



- A *series hybrid bus* is exclusively propelled by the electric motor. In a *series hybrid bus*, the internal combustion engine (ICE) is connected to an electric generator which converts the energy produced by the ICE into electric power. This electricity powers a motor which turns the wheels of the vehicle. The generator also recharges a battery pack which provides supplemental power to the motor. Since the ICE is not connected to the wheels, it can operate at an optimum rate and can even be switched off for short periods of time for a temporary all-electric operation of the bus.



- Parallel hybrids have greater fuel efficiency than series hybrids at constant high speeds (highway driving) while the series hybrids fare better in stop-and-go urban driving.

Benefits of Hybrid Buses

Hybrid buses offer a wide range of benefits including significantly lower emissions, increased efficiency, and decreased maintenance costs.

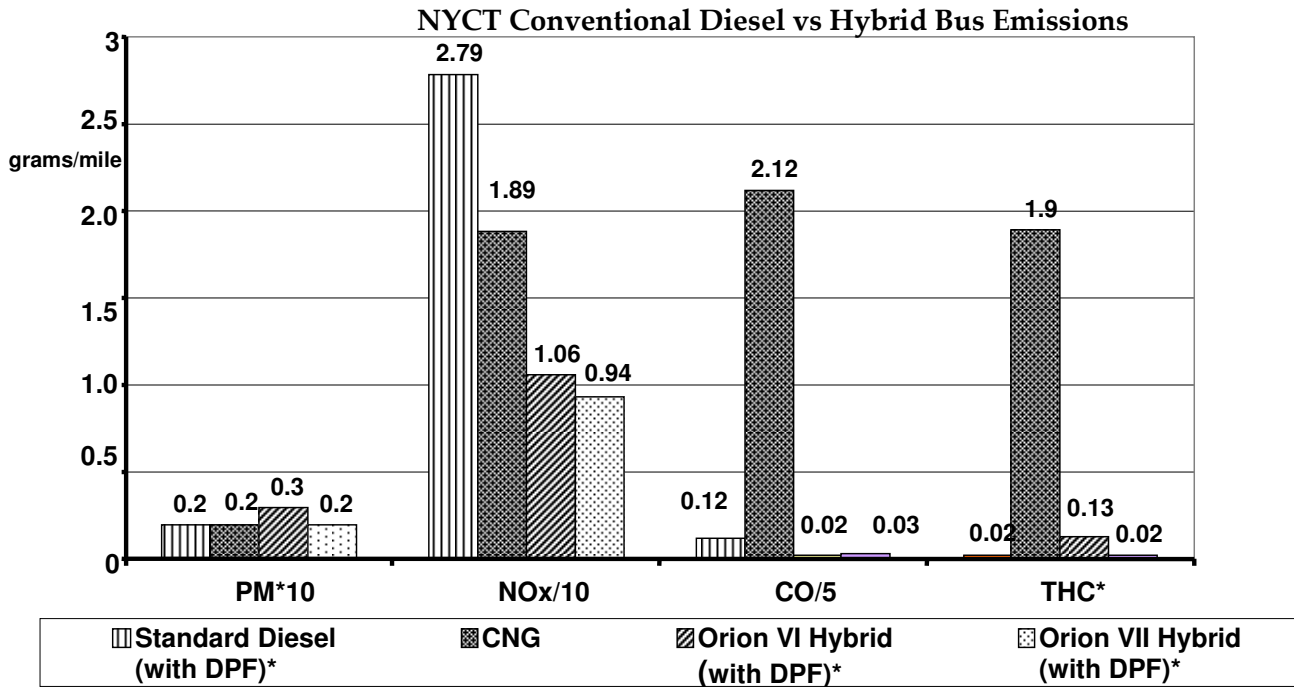
Reduced Emissions

Hybrid buses are estimated to cut emissions by as much as 75 percent when compared to conventional diesel buses. The emissions reductions are a function of the electric drive, ultra low-sulfur diesel (ULSD) fuel use in conjunction with particulate trap technology and improved fuel economy from the hybrid system.

- In-use testing and industry reports indicate that particulate matter (PM) emissions from hybrid buses equipped with particulate matter filters are **almost 90 percent lower** than a conventional diesel bus without a particulate filter.
- According to a study conducted by the Northeast Advanced Vehicle Coalition (NAVC) to demonstrate energy efficiency and emissions performance of diesel-electric hybrid buses, nitrogen oxides (NOx) emissions for diesel hybrids were **30 to 40 percent lower** than conventional diesel vehicles.

- Diesel hybrid buses exhibited the lowest carbon monoxide (CO) emissions of any of the buses tested including CNG and conventional diesel.
- Hybrids demonstrated lower greenhouse gas emissions than those of a conventional diesel bus or CNG powered bus as a result of improved fuel economy.³

A separate evaluation by New York City Transit (NYCT) reports significant emissions reductions for the Orion VII buses equipped with BAE Systems' series hybrid drive. In the chart below, emissions from the hybrid bus are compared with the emissions from a conventional diesel bus equipped with a diesel particulate filter and a comparable CNG bus.⁴



*ULSD Fuel was used in all diesel and hybrids

Performance

- Hybrid buses typically exhibit performance levels comparable to their non-hybrid counterparts. Transit agencies report that acceleration in hybrid-electric buses is smoother and faster due to the increased low-end torque characteristics of electric motors.⁵
- **Quieter Operation:** Although there has been little systematic testing of hybrid buses for noise emissions, anecdotal evidence from bus drivers and passengers suggests that hybrid buses offer a quieter ride when compared to conventional diesel buses.

³ The Transit Cooperative Research Program "Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project Final Emissions Report", Report Number 59, 2000

⁴ New York City Transit Presentation, Society of Automotive Engineers (SAE), October 2004.

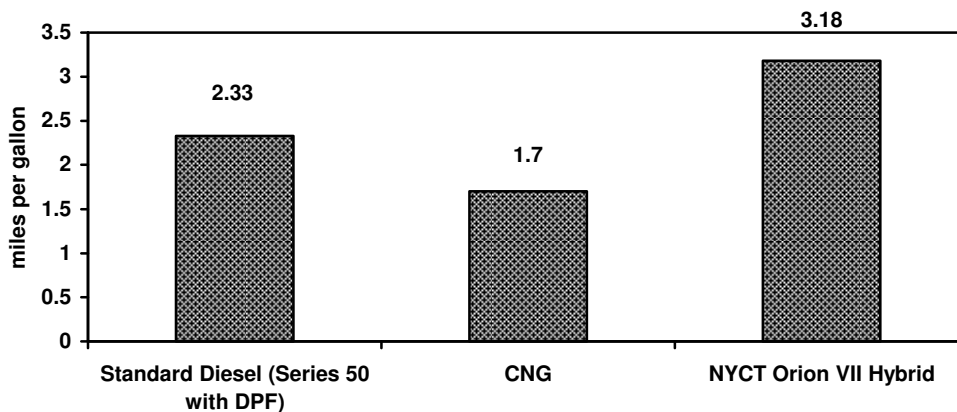
⁵ Federal Transit Administration, "Analysis of Electric Drive Technologies For Transit Applications: Battery Hybrid-Electric, and Fuel Cells Final Report" August 2005 http://www.fta.dot.gov/documents/Electric_Drive_Bus_Analysis.pdf

- **Reduced Costs:** The hybrid buses are expected to have lower maintenance costs due to reduced stress and maintenance on mechanical components such as brake linings, which may extend brake life by 50 – 100 percent. In addition, the electric drive has fewer parts, therefore requiring less maintenance than a traditional transmission.
- **Increased fuel efficiency:** Results from the National Renewable Energy Laboratory’s (NREL) evaluations show significant increases in fuel economy compared to conventional diesel buses. NREL evaluated 10 CNG 40-foot Orion VII buses (Model Year 2002) equipped with Detroit Diesel Corporation’s Series 50G CNG engine and 10 hybrid 40-foot Orion VII buses (Model Year 2002) fitted with BAE Systems series HybriDrive propulsion system. These buses were compared with nine standard diesel Orion V buses (Model Years 1994 and 1999) for bus usage, fuel economy and miles between maintenance calls. The evaluated buses were part of a 260 CNG bus order (\$319,000 each) and a 125 diesel-electric hybrid bus order (\$385,000 each) in 2003 and 2004.

Results from the evaluation indicate that the hybrid buses offered on average, a **37 percent improvement in fuel economy** over standard diesel buses. It is important to note that the comparison to the standard diesel bus is limited because the engine fitted in these older buses (DDC Series 50) is no longer available for transit application. Further, neither the baseline standard diesel buses nor the hybrids were fitted with exhaust gas recirculation (EGR) for emission control. EGR systems tend to lower fuel efficiency. The fuel economy improvements for hybrids fluctuated between 26 – 52 percent higher (compared to diesel buses). Typically fuel economy is expected to decrease when the hybrid bus is operated in the summer months due to increased energy demand by vehicle accessories such as air conditioning.

In comparison to the CNG buses, the **hybrids improved fuel efficiency on average by 88 percent**. The DDC Series 50 CNG engines used in the evaluation are no longer available for transit use. In comparison to diesel buses, CNG buses demonstrated 25 percent lower fuel economy.

Average Fuel Economy Comparisons



In conclusion, in-use testing of hybrid buses (both parallel and series, 40-foot and 60-foot configurations) reveals that they are more fuel efficient than conventional diesel buses, with fuel economy gains ranging from 28-48 percent depending on the type of hybrid and

operating conditions.^{6, 7}

Fuel is a huge expense for transit fleets, representing nearly \$700 million annually, or nearly three percent of operating costs. With rising diesel costs, increased fuel efficiency offered by the hybrids will result in substantial cost savings.

Hybrid Bus Cost Barriers

Currently hybrid buses carry a large price premium over conventional diesel buses. The average price of a 40-foot hybrid bus typically ranges from \$450,000 - \$550,000 when compared to \$280,000 - \$300,000 for a conventional diesel bus. The price variation in hybrids is due to the order volumes and individual specifications of transit agencies.

However the price differential for hybrids can be offset by various federal incentives and grant programs. Assuming that a standard diesel bus costs \$300,000 and a hybrid bus costs \$500,000, the incremental cost of purchasing a hybrid is \$200,000. The federal **Clean Fuels Grant Program** covers **90 percent of the incremental cost of alternative fuel buses**, including hybrids. In addition, the Federal Transit Administration (FTA) covers up to 80 percent of the purchase price of a standard diesel bus.

Therefore a transit agency's share of matching funds for a hybrid is \$80,000 when compared to \$60,000 for a conventional diesel. This translates to **an incremental cost of only \$20,000 to purchase a hybrid over a conventional diesel bus.** As the technology matures and the market develops, the cost differential for hybrids is likely to decrease.

In addition, a year-long evaluation from NREL indicates that operational costs for hybrids are 15 percent lower than conventional diesel buses. According to their evaluation, King County Transit's 60-foot articulated New Flyer buses equipped with GM-Allison's parallel hybrid drive cost less to operate and maintain when compared to regular diesel buses. These cost savings, based on a diesel fuel price of \$1.98, are likely to increase even further as diesel fuel prices continue to sky rocket.⁸

King County Transit Parallel Hybrid Bus Operating Costs Comparison		
	Diesel (60-foot)	Diesel-electric Hybrid (60-foot)
Fuel (\$1.98 per gallon)	\$0.79/mi 2.50 mpg	\$ 0.62/mi 3.17 mpg
Maintenance	\$0.46/mi	\$ 0.44/mi
Total	\$1.25/mi	\$1.06/mi

⁶ Department of Energy, "Early Results from National Renewable Energy Laboratory Transit Bus Evaluations," Presentation at the APTA Bus and Paratransit Conference May 2005
<http://www.nrel.gov/vehiclesandfuels/fleettest/pdfs/38158.pdf>

⁷ Department of Energy, "New York City Transit Hybrid and CNG Transit Buses: Final Evaluation Results," National Renewable Energy Laboratory November 2006
<http://www.nrel.gov/vehiclesandfuels/fleettest/pdfs/40125.pdf>

⁸ Department of Energy, "King County Metro Transit Hybrid Articulated Buses: Final Evaluation Results," National Renewable Energy Laboratory December 2006
<http://www.nrel.gov/vehiclesandfuels/fleettest/pdfs/40585.pdf>

Current Applications

Hybrid bus deployment has grown tremendously in recent years. In 2006, there were more than 900 hybrid buses in regular service in more than 40 transit agencies in North America with several hundred on order.^{9, 10}



Some of the largest hybrid fleets in the United States include New York City's fleet of 325 buses with an additional 500 vehicles on order, King County in Seattle which operates 214 parallel hybrid buses, and Washington DC which has placed an order for 100 diesel-electric hybrid buses. In addition, more than 15 states such as California, Connecticut, Indiana, Kentucky, Mississippi, New Mexico, Pennsylvania, Tennessee, and Texas to name a few, have deployed hybrid buses in their transit fleets with the several more looking to add hybrid buses to their fleets.

Additional Reading

Connecticut Academy of Science and Engineering, "A Study of Bus Propulsion Technologies Applicable in Connecticut" dated February 2001, and "Study Update" dated March 2003.

<http://www.easternct.edu/depts/sustainenergy/publication/reports/BUS%20FINAL%20REPORT.pdf>

Connecticut Transit Quarterly Reports on Hybrid Bus Test Program, July 2003 through December 2004.

<http://rip.trb.org/browse/dproject.asp?n=7973>

Federal Transit Administration, "Design Guidelines for Bus Transit Systems Using Electric and Hybrid Electric Propulsion as an Alternative Fuel," March 2003. <http://transit-safety.volpe.dot.gov/Publications/cleanair/DesignGuidelines/HTML/DesignGuidelines.htm>

National Renewable Energy Laboratory and Battelle, "Challenges and Experiences with Electric Propulsion Transit Buses," November 2003. <http://www.nrel.gov/docs/fy04osti/34323.pdf>

National Renewable Energy Laboratory and Battelle, "Early Results from DOE/NREL Transit Bus Evaluations," presentation at the American Public Transportation Association Conference, May 2005. <http://www.nrel.gov/docs/fy05osti/38158.pdf>

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New York City Transit, "NYCT Operating Experience with Hybrid Transit Buses," presentation at the SAE World Congress dated October 2004.

Northeast Advanced Vehicle Consortium, "Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project," February 2000. <http://www.navc.org/Navc9837.pdf>

Transportation Research Board, "Hybrid-Electric Transit Buses: Status, Issues, and Benefits," July 2000. http://gulliver.trb.org/publications/tcrp/tcrp_rpt_59.pdf

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⁹ Federal Transit Administration, "Analysis of Electric Drive Technologies For Transit Applications: Battery Hybrid-Electric, and Fuel Cells Final Report" August 2005 http://www.fta.dot.gov/documents/Electric_Drive_Bus_Analysis.pdf

¹⁰ Department of Energy, Heavy-Duty Hybrid Vehicle Projects, National Renewable Energy Laboratory, July 2006 <http://www1.eere.energy.gov/vehiclesandfuels/avta/overview.html>