Assessing the Costs for Hybrid versus Regular Transit Buses

Authors

Shauna L. Hallmark
Interim Director, Institute for Transportation;
Professor, Civil, Construction, and
Environmental Engineering
Iowa State University
515-294-5249, shallmar@iastate.edu

Bo Wang and Yu Qiu
Student Research Assistants
Iowa State University

Bob Sperry
Iowa Local Technical Assistance Program
Iowa State University

Sponsor

Iowa Energy Center

For More Information
www.intrans.iastate.edu/

Center for Transportation Research and Education
iowa energy center
Iowa State University
Institute for Transportation

INTRODUCTION

Fuel costs are a significant portion of transit agency budgets. Hybrid buses offer an attractive option and have the potential to reduce operating costs for agencies significantly.

Hybrid technology has been available in the transit market for some time. As of 2009, there are more than 1,200 hybrid buses in regular service in North America in more than 40 transit agencies (Transport Canada 2011). The majority of these buses are regular 40 ft buses, although some smaller (20 ft) shuttle buses and larger articulated (60 ft) buses are also in service.

The transit agency in New York, New York has approximately 1,000 hybrid vehicles as of 2009 (Maynard 2009) and Toronto, Canada has approximately 33 percent (Transport Canada 2011).

The main reasons agencies consider hybrid transit vehicles are fuel savings and reduced emissions. Hybrid electric buses offer an attractive option and have the potential to reduce operating costs for transit agencies significantly. Wayne et al. (2009) estimated that use of diesel-electric hybrid buses in 15 percent of the US transit fleet could reduce fuel consumption by 50.7 million gallons of diesel annually. However, purchase of hybrid transit buses requires a significant investment.

In addition, early estimates of cost savings may not have materialized to the extent transit agencies expected. Other costs, such as the cost of replacing batteries and reduced maintenance, are also issues that have not been substantiated with independent studies. To justify the expenditure, agencies require more quantitative information about the likely fuel economy, maintenance, and other costs for hybrid buses.

OBJECTIVES

This technical brief summarizes information about the costs and benefits that have been attributed to use of hybrid transit buses as found in the literature. Results from a demonstration project that compared fuel economy and emissions for 12 hybrid buses and 7 control buses for the transit agency for Ames, Iowa and Iowa State University, CyRide, were also included.

One of 12 hybrid CyRide buses

Costs and benefits include initial purchase cost differentials, savings in fuel, reduced emissions, potential reduced maintenance due to decreased engine and brake wear, and replacement costs for the hybrid battery pack. All costs are listed in US dollars (USD).

COSTS

The following sections discuss common costs that transit agencies consider in long-term cost analyses for hybrid buses. Information was summarized from a survey of existing literature, web resources, and the team's experience with evaluation of hybrid school buses and hybrid transit buses (Hallmark et al. 2010 and Hallmark et al. 2012). The term "cost" is used in the generic sense of being a positive cost or negative cost (benefit). As a result, costs may be actual costs or reductions in costs.

Purchase Cost

The difference in initial purchase price between a hybrid transit bus and regular transit bus can be substantial. Based on 2011 values in the US, the purchase cost of a regular 40 ft bus is $280,000 to $300,000 compared to a hybrid bus that is between $450,000 and $550,000. Because of the difference, agencies are anxious to recoup the cost differential through savings in fuel and maintenance.

In some cases in the US, the purchase price of hybrid transit buses has been offset by participation in programs such as the American Recovery and Reinvestment Act (ARRA) or Clean Fuels grant programs (EESI 2012). Funding packages to offset the purchase cost often make it much easier for transit agencies to invest in the technology that can reduce the lifecycle costs of hybrid buses. As an example, the CyRide agency in Ames purchased 12 hybrid buses through a Transportation Investments Generating Economic Recovery (TIGER) grant sponsored by the U.S. Department of Transportation (US DOT).

Fuel Economy

Actual savings depend on usage and fuel costs, but improved fuel economy is the main savings associated with use of hybrid transit buses. Early estimates of fuel savings for hybrid buses over conventional buses were based on laboratory studies that demonstrated significant fuel savings.

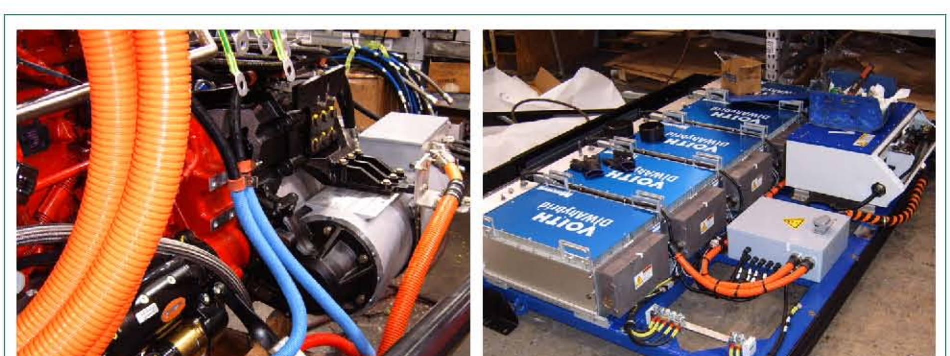
Chassis dynamometer tests were conducted for 10 low-floor hybrid buses and 14 conventional high-floor diesel transit buses run by New York City Transit (NYCT) (Chandler and Walkowicz 2006). Buses were evaluated over three driving cycles including the Central Business District (CBD), the New York (NY) bus cycle, and the Manhattan cycle. The operating costs, efficiency, emissions, and overall performance were also compared while both types of buses were operating on similar routes. The researchers found that fuel economy was 48 percent higher for the hybrid buses.

A study by Battelle (2002) tested emissions using a dynamometer for one diesel hybrid-electric bus and two regular diesel buses (with and without catalyzed diesel particulate filters/ DPFs). The researchers reported that fuel economy for the hybrid bus was 54 percent higher than the two regular diesel buses.

In another study, two buses were tested using a dynamometer at the National Renewable Energy Laboratory (NREL) ReFUEL facility in Golden, Colorado (Chandler and Walkowicz 2006). One bus was a conventional diesel and the other was a hybrid bus and both were tested over several drive cycles including Manhattan, Orange County Transit A (OCTA), CBD, and King County Metro (KCM) Transit in Seattle, Washington. Results indicate 30.3 percent lower fuel use for the KCM cycle, 48.3 percent lower for the CBD cycle, 50.6 percent for the OCTA cycle, and 74.6 percent for the Manhattan cycle. Fuel economy was reported as miles per gallon.

In another study, Clark et al. (1987) evaluated six transit buses with traditional diesel engines, two powered by spark-ignited compressed natural gas (CNG), and one hybrid transit bus in Mexico City using a mobile heavy-duty emissions testing lab. Buses were tested over a driving cycle representative of Mexico City transit bus operation, which was developed using global positioning system (GPS) data from in-use transit buses. Depending on how fuel economy was evaluated, the hybrid bus ranked fourth and first in fuel economy.

Transport Canada (2011) evaluated hybrid transit buses for several transit agencies in Canada. In one laboratory study using the Manhattan Test Cycle, the authors found a reduction in fuel consumption of 36 percent. In a test track study, the authors found a 28 percent fuel reduction for hybrid transit buses compared to regular buses when the buses were operated at an average speed of 10 km/h with 10 stops per



CyRide engine and electric motor setup (left) and battery pack configuration (right) kilometer. As average speed increased, the differences in fuel consumption were smaller.

In a later test track study, the authors found average fuel use reduction to be 28 percent. The researchers also reported that the Toronto Transit Corporation, which has about 500 hybrid buses, was only achieving a reduction of 10 percent for in-use fuel consumption.

A study was conducted by the Center for Transportation Research and Education (CTRE) at Iowa State University (ISU) to study the fuel economy of 12 hybrid transit buses. Seven control buses with similar characteristics were also evaluated.

Average fuel economy for hybrid buses was 11.8 percent higher than for control buses (Hallmark et al. 2012). The study also showed that fuel economy was correlated to number of passengers per route, average running speed, average acceleration, average deceleration, percent of time spent in acceleration, and season.

Fuel economy estimates from various studies are summarized in Table 1. To make the table consistent, differences in fuel economy were normalized to show decrease in fuel consumption (rather than improvement in fuel economy) given this information was presented both ways in the various studies.

As noted, fuel economy savings range from 10 to 74.6 percent. However, most of the studies showing significant fuel economy were laboratory tests that do not always replicate actual on-road conditions.

Fuel economy varies and is correlated to a number of factors including number of stops per unit distance, road grade, surrounding traffic volume and conditions, environmental conditions, driving style, type of hybrid technology (parallel versus series) (Liang et al. 2009), roadway type, and passenger load (Frey et al. 2007). Given driving style can have a significant impact on the fuel economy of hybrid buses, many transit agencies provide training for their drivers.

Short-Term Maintenance and Operating Costs

Short-term maintenance costs have not been well quantified. Some agencies have experienced up-front maintenance issues with hybrid buses. NYCT reported initial issues with batteries and need for software modifications (Chandler and Walkowicz 2006). The Ames transit system, which purchased 12 hybrid transit buses in 2010, has reported the need for various software adjustments to achieve better fuel economy, given initial fuel economy was much lower than expected. In addition, adjustments to the brake pedal had to be made (Hallmark et al. 2012).

Transport Canada (2011) also reported issues early on but indicated later that mean distance between failures was similar to that of regular transit buses. Transport Canada found that after eight months of hybrid transit bus operation in Montreal, no significant additional maintenance issues occurred with hybrid buses.

Although early maintenance problems have been present, most of the initial maintenance is covered by manufacturer warranties and is not likely to have additional costs to the transit companies.

One study was available that summarized operating costs other than fuel economy. KCM evaluated operating costs using a cost of $1.98 per gallon for diesel for 60 ft buses. For regular transit buses, they found that fuel costs were 79 cents per mile and maintenance costs were 46 cents per mile, for a total operating cost of $1.25 per mile. In comparison, diesel-electric hybrid buses had fuel costs of 62 cents per mile with maintenance costs of 44 cents per mile for a total cost of $1.06 per mile (Chandler and Walkowicz 2006). Hence, the savings were 19 cents per mile.

Long-Term Maintenance Costs

Several long-term costs/benefits contribute to the lifecycle equation for a hybrid bus versus a conventional bus. However, hybrid buses have not been on the market long enough for these costs/benefits to be substantiated by transportation agencies. Potential long-term costs/benefits include those associated with reduced engine wear, replacing the battery pack, and increased bus weight.

Initial feasibility studies and marketing of hybrid school buses indicated that the hybrid technology would result in less engine wear and regenerative braking was estimated to result in less brake wear (IC Bus 2011, Thomas Built 2011, and Pritchard et al. 2011).

Transport Canada (2011) reported a 50 to 100 percent improvement in brake life for hybrid transit buses.

However, replacement battery costs are expected to add to the lifecycle cost of hybrid buses. IC Bus (2011) indicates that lithium-ion batteries have a life of five to seven years, but the replacement

Table 1. Summary of fuel economy performance of hybrid versus conventional transit buses

Agency	Sample Size	Reduction in Fuel Consumption for Hybrid versus Regular Buses (%)	Study Type
New York City Transit (Chandler et al. 2002)	10 hybrid and 14 conventional diesel transit buses	32	Laboratory
Battelle (2002)	1 hybrid and 1 regular	35	Laboratory
NREL (Chandler and Walkowicz 2006)	1 hybrid and 1 regular over several drive cycles	30 to 75	Laboratory
Transport Canada (2011)	8 hybrid and 6 regular buses	36	Laboratory
		28	Test track
	500	10	In-use
CyRide (Hallmark et al. 2012)	27	12	In-use

costs are still somewhat unknown. Battery technology/economics are evolving rapidly, so costs will depend on this when it's time to replace the battery pack.

Finally, Iowa school districts that piloted hybrid electric school buses were concerned that the weight of the battery pack may increase wear on some parts, such as shock absorbers and tires (Hallmark 2010), given the battery pack for hybrid school buses added approximately 2,000 lbs to each bus. Data on this concern are not available at this time.

Reduced Emissions

Reduced emissions are one of the main benefits attributed to hybrid buses. A number of studies have indicated a substantial reduction in pollutants for hybrid buses over regular transit buses. Wayne et al. (2009) conducted an evaluation scenario comparing use of hybrid transit buses to regular transit buses. The authors estimated that use of diesel-electric hybrid buses in just 15 percent of the US transit fleet could reduce annual emissions by 1,800 tons of carbon monoxide (CO), 400 tons of hydrocarbons (HC), 4,400 tons of nitrogen oxides (NO_x), 200 tons of particulate matter (PM), and 491,400 tons of carbon dioxide (CO_2).

Chandler et al. (2002) conducted chassis dynamometer tests for 10 low-floor hybrid buses and 14 conventional high-floor diesel transit buses run by NYCT. The buses were tested over three driving cycles: the CBD, NY, and Manhattan. The operating costs, efficiency, emissions, and overall performance were also compared while both types of buses were operating on similar routes. Data were collected from 1999 through 2001.

Results indicated that, for the CBD cycle, emissions for the hybrid transit buses were 97 percent lower for CO, 36 percent lower for NO_x, 43 percent lower for HC, 50 percent lower for PM, and 19 percent lower for CO_2.

Results from the NY bus cycle showed a decrease of 56 percent for CO, 44 percent for NO_x, 77 percent for PM, and 40 percent for CO_2. HC emissions, however, increased by 88 percent for the hybrid buses.

With the Manhattan cycle, the researchers found a decrease for the hybrid buses of 98 percent for CO, 44 percent for NO_x, 28 percent for HC, 99 percent for PM, and 33 percent for CO_2.

In another study, emission tests for one diesel hybrid-electric bus and two diesel buses (the Orion V with and without catalyzed DPFs) were evaluated using a dynamometer in Ottawa, Canada (Battelle 2002). The buses were tested on the CBD cycle using ultra-low sulfur diesel (ULSD) #1 fuel.

The researchers indicated that the hybrid bus had 94 percent lower emissions for CO, 49 percent lower for NO_x, 120 percent higher or HC, 93 percent lower for PM, and 37 percent lower for CO_2 than the diesel bus without a catalyzed DPF.

Emissions for the hybrid bus compared to the diesel bus with the catalyzed DPF installed were 38 percent lower for CO, 49 percent lower for NO_x, 450 percent higher for HC, 60 percent lower for PM, and 38 percent lower for CO_2. These tests were conducted in February 2000.

In another study, two buses—one from a conventional diesel fleet and another from a hybrid fleet—were tested using a dynamometer at the NREL ReFUEL facility in Golden, Colorado (Chandler and Walkowicz 2006). The buses were tested over several drive cycles including Manhattan, OCTA, CBD, and KCM. These tests were conducted in May and June 2005 and results are shown in Table 2 for each drive cycle.

Table 2 shows the percentage difference in emissions among the buses. Emissions were reported in grams per mile. As indicated, emissions were lower in all cases for the hybrid bus, except for the CO_2 emissions on the CBD and the cases where the differences were not statistically significant (indicated as NS in the table).

Clark et al. (2006) evaluated six transit buses with traditional diesel engines including two powered by spark-ignited compressed natural gas (CNG) and one hybrid transit bus. This evaluation was conducted in Mexico City using a transportable, heavy-duty emissions testing lab and buses were tested over a driving cycle representative of Mexico City transit bus operation, which was developed using GPS data from transit buses in use.

Depending on how emissions were compared, the hybrid bus and one of the CNG buses had the lowest NO_x emissions of the nine buses tested. Particulate emissions from the hybrid bus were less than 10 percent of the average PM emissions for the diesel-powered buses. The hybrid bus and one of the CNG buses had the lowest CO emissions, and the hybrid bus and buses equipped with a continuously regenerating trap (CRT) exhaust after-treatment had hydrocarbon emissions that were below the detectable limit of the instrument used.

Shorter et al. (2005) used a chase-vehicle sampling strategy to measure NO_x from 170 in-use New York City transit buses. The authors sampled emissions from conventional diesel buses, diesel buses with continuously regenerating technology, diesel hybrid-electric buses, and CNG buses. The authors found that NO_x emissions from CNG buses and hybrid buses were comparable. NO_x emissions for the hybrid buses were approximately half of those for conventional transit buses.

Table 2. Summary of NREL percentage decreases for hybrid versus regular buses

Cycle	CO	NO_x	HC	PM	CO_2
Manhattan	NS	-38.7	NS	-92.6	-43.8
OCTA	-32.0	-28.6	NS	-50.8	-34.5
CBD	-48.0	-26.6	-75.2	-97.1	34.8
KCM	-59.5	-17.8	-56.3	NS	-24.1

NS = Not statistically significant (Chandler and Walkowicz 2006)

Close up of CyRide engine (left) and engine compartment (right)

In contrast, Jackson and Holmen (2009) collected second-by-second particle number (PN) emissions from four conventional and one hybrid transit bus in Connecticut over six pre-defined test routes that had multiple road types and ranges of driving conditions. For most of the routes, the authors noted few differences between the conventional and hybrid transit buses. However, the hybrid had higher emission rates on two routes with steep uphill grades and PN emissions were 51 percent higher on one route and 24 percent higher on the other.

Hallmark et al. (2012) evaluated three hybrid and two control transit buses for the City of Ames CyRide transit system. Emissions were tested using a portable emissions monitoring system (PEMS). Speed, acceleration, and passenger load were also collected and emissions were correlated to vehicle-specific power (VSP), which has been used as a proxy variable for power demand or engine load.

The researchers noted only minor differences between buses for any pollutant in the lower VSP ranges. In the middle VSP bin ranges, emissions were higher for control buses, with differences between 0.3 and 0.4 g/s (9.4 to 27.3 percent higher). In the highest VSP ranges, emissions were significantly higher for control buses than for hybrid buses with differences between 0.7 and 2.7 g/s higher (15.0 to 97.0 percent).

Average carbon monoxide emissions were higher for control buses than hybrid buses. In the medium- and higher-VSP bins, control buses had CO emissions that were higher than hybrid buses by 1.0 to 3.1 mg/s (1.35 to 3.07 times higher).

Control buses had HC emissions that were 1.2 to 1.8 mg/s higher in the mid-VSP ranges (68.5 to 131.0 percent higher). In the higher VSP ranges, emissions were much higher for control buses than hybrid buses by 2.3 to 3.0 mg/s (94.2 to 182.8 percent).

Average nitrogen oxide emissions were higher for the hybrid than the control buses in the mid to higher VSP bin ranges. Differences ranged from 0.8 to 3.5 mg/s (18.4 to 40.1 percent) higher.

Although significant reductions in emissions have been reported, it is difficult to allocate costs to pollutant reduction. Factors in the selection of hybrid technology include political, social, and environmental pressures to reduce emissions, improve health, and conserve energy. However, social costs associated with reduction in emissions and improved health are difficult to quantify, making it difficult to include emission reduction in long-term cost analyses.

Agencies in non-attainment areas for criteria pollutants have some methods to quantify costs. (The Clean Air Act and Amendments of 1990 define a nonattainment area as a locality where air pollution levels persistently exceed National Ambient Air Quality Standards or that contributes to ambient air quality in a nearby area that fails to meet standards.) A report by the Transit Cooperative Research Program (TCRP 2000), for example, estimated a value of $1,000 per ton of NO_x reduced and $3,000 per ton for volatile organic compounds (VOCs).

Obviously, one additional problem for use of cost-reduction benefits involving pollutants is that cost savings are not usually accrued to the transit agency, making it more difficult to assess long-term agency costs.

Other Benefits and Costs

Although also difficult to quantify, another benefit of hybrid buses is reduced noise due to either a smaller internal combustion engine or lower revolutions per minute (RPM) (Transport Canada 2011). Use of hybrid transit buses may also be a good marketing and public relations strategy, given the buses promote environmental sustainability.

SUMMARY

Although hybrid transit buses offer significant fuel savings and other benefits, there is still some concern that it is difficult to recuperate initial capital costs (Transport Canada 2011). Hybrid buses have not yet been in service through the 15 to 20 year service life that is used by transit agencies.

This technical brief summarized costs for hybrid transit buses compared to conventional transit buses based on a summary of the literature, web resources, and team experience. Costs include those related to initial purchase cost differentials, savings in fuel use, reduced emissions, potential reduced maintenance due to decreased engine and brake wear, and replacement of the hybrid battery pack. To quantify lifecycle costs fully, agencies will need additional information about actual costs as well as methods to calculate savings from non-tangibles such as reduction in emissions.

REFERENCES

Battelle (August 2002). *Technical Assessment of Advanced Transit Bus Propulsion Systems.* For the Dallas Area Rapid Transit. Dallas, Texas.

Chandler, K., K. Walkowicz, and L. Eudy (July 2002). *New York City Transit Diesel Hybrid-Electric Buses: Final Results. DOE/NREL Transit Bus Evaluation Project.*

Chandler, K., and K. Walkowicz (December 2006). *King County Metro Transit Hybrid Articulated Buses: Final Evaluation Report.* National Renewable Energy Laboratory. NREL/TP-540-40585.

Choi, H., and H. C. Frey (2010). "Method for In-Use Measurement and Evaluation of the Activity, Fuel Use, Electricity Use, and Emissions of a Plug-In Hybrid Diesel-Electric School Bus." *Environmental Science and Technology.* Vol. 44, No. 9. pp. 3601-3607.

Clark, N., N. Borrell, R. Enrique, D. L. McKain, V. Paramo, W. Hugo, W. Vergara, R. A. Barnett, M. Gautam, G. Thompson, D. W. Lyons, and L. Schipper (2006). "Evaluation of Emissions from New and In-Use Transit Buses in Mexico City, Mexico. *Journal of the Transportation Research Record.* Vol. 1987. pp. 42-53.

EESI. *Hybrids Buses Costs and Benefits.* http://www.eesi.org/files/eesi_ hybrid_bus_ 032007.pdf. Environmental and Energy Study Institute. Accessed Jan. 2012.

Frey, H. C., N. M. Rouphail, H. Zhai, T. L. Farias, C. A. Goncalves (2007). "Comparing Real-World Fuel Consumption for Diesel and Hydrogen-Fueled Transit Buses and Implications for Emissions." *Transportation Research Part D.* Vol. 12. pp. 281-291.

Hallmark, S., R. Sperry, and A. Mudgal (July 2010). *In-Use Fuel Economy and Emission Benefits of Hybrid-Electric School Buses in Iowa.* Center for Transportation Research and Education at Iowa State University. http://www.intrans.iastate.edu/research/detail.cfm?projectID=-1735833459

Hallmark, S., S. Kong, A. Mudgal, M. Orellana, and D. Kroeger (August 2008). *Evaluation of On-Road and Laboratory Engine Dynamometer Emission Tests to Compare the Emission Reduction Potential of Different Biodiesel Blends.*

Hallmark, S., B. Wang, and R. Sperry (October 2012). *Evaluation of In-Use Fuel Economy and On-Board Emissions for Hybrid and Regular CyRide Transit Buses.* Center for Transportation Research and Education at Iowa State University, Ames, Iowa.

Hybrid Center (2010). http://www.hybridcenter.org/hybrid-transit-buses.html

IC Bus (2011). *Hybrid Technology.* www.icbus.com/Static%20Files/ICCorp/PageContent/ Community/Hybrid%20 Power/Hybrid%20FAQs.pdf. Accessed Dec. 2011.

Jackson, E. D., and B. A. Holmen (2009). "Modal Analysis of Vehicle Operation and Particulate Emissions from Connecticut Transit Buses." *Journal of the Transportation Research Record* No. 2123. pp. 76-87.

Liang, X., C. Wang, C. Chapelsky, D. Koval, and A. M. Knight (2009). "Analysis of Series and Parallel Hybrid Bus Fuel Consumption of Different Edmonton Transit System Routes." *5th IEEE Vehicle Power and Propulsion Conference, VPPC '09*, pp. 1470-1475.

Maynard, M. (2009). "As Hybrid Buses Get Cheaper, Cities Fill Their Fleets." *The New York Times.* October 20, 2009.

Pritchard, E., G. David, and R. R. Johnson (September 2002). *The Hybrid Electric School Bus Technical Feasibility Study.* Advanced Energy. http://www.advancedenergy.org. Accessed Dec 2011.

Shorter, J. H., S. Herndon, M. S. Zahniser, D. D. Nelson, J. Wormhoudt, K. L. Demerjian, and C. E. Kolb (2005). "Real-time Measurements of Nitrogen Oxide Emissions from In-Use New York City Transit Buses Using a Chase Vehicle." *Environmental Science and Technology.* Vol. 39. pp. 7991-8000.

TCRP (2000). TCRP Report 59: *Hybrid-Electric Transit Buses: Status, Issues, and Benefits.* Transit Cooperative Research Program. Transportation Research Board.

Thomas Built. *Hybrid Bus Benefits.* Accessed Dec. 2011. http://www.thomasbus.com/earth-friendly/ hybrid/benefits.asp

Transport Canada. *Hybrid Buses.* http://www.tc.gc.ca/eng/programs/environment-utsp-casestudy-cs71e-hybridbuses-272.htm. Accessed Dec. 2011.

Wayne, W. S., J. A. Sandoval, and N. N. Clark. "Emission Benefits from Alternative Fuels and Advanced Technology in the US Transit Bus Fleet." *Energy and Environment.* Vol. 20, No. 4. 2009. pp. 497-515.

About the Center for Transportation Research and Education

The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.