TO: Members of the Board of Estimates

FROM: Catherine Debo, Transit Manager

SUBJECT: Cost/Benefits of Hybrid-Electric Vehicles

At the September 12, 2005 meeting, the Board requested Metro to provide information on the cost and benefits of incorporating hybrid-electric vehicles into Metro's bus fleet. A recent report from the Northeast Advanced Consortium that was sponsored by the Federal Transit Administration[1] provides an overview of the current status of electric drive technologies for transit applications, including hybrid-electric. The benefits and costs associated with hybrid-buses identified below are largely taken from this report, unless noted otherwise.

Background

A hybrid bus uses a dual-energy system to operate. A combustion engine, usually powered with diesel, is coupled with an electric generator that receives its power from batteries. Currently, there are two major configurations for operating hybrid buses: series and parallel. In a series hybrid, all of the energy produced from the combustion engine is used to power the batteries, which in-turn provides power to the vehicle through the electric generator. In a parallel hybrid, both the combustion engine and the electric motor have independent connections to the transmission. Either power source – or both of them together – can be used to turn the vehicle's wheels. These vehicles are often designed so that the combustion engine provides power to battery during stops and low speeds with both power sources working together during accelerations.

Benefits of Hybrid Buses

The electric generator can improve drive system efficiency and reduce energy consumption through greater efficiency. Hybrid-electric buses also reduce emissions. . This efficiency improvement is achieved by two primary means: the ability to operate the engine in a "steady state" mode and the recovery of regenerative braking energy. It is believed that regenerative braking may also save wear-and-tear on the brakes.

Emissions

A report published by the Connecticut Academy of Science and Engineering in 2001, contains a comparison of the level of emissions from hybrid buses and conventional buses.[2] This comparison is provided in table 1 below.

[1] Callaghan, Lisa and Sheila Lynch, *Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric, and Fuel Cells*, Northeast Advanced Vehicle Consortium and the Federal Transit Administration, August 2005.

[2] The Connecticut Academy of Science and Engineering, *A Study of Bus Propulsion Technologies Applicable in Connecticut*, Connecticut Department of Transportation, February 23, 2001, p. 24.

Table 1. Estimated Reduction in Emissions by Gram Per Mile*			
Emission Type	**Diesel**	**Hybrid Bus**	**Est. Reduction**
PM	0.24	0.12	0.12
NO_x	30.1	19.2	10.9
Volatile Organic Compound (VOC)	0.14	.08	0.1
CO	3.0	0.1	2.9
CO_2	2,779.0	2,262.0	517.0

* Emissions for diesel are based on #1 diesel fuel. Metro currently uses ultra-low sulfur diesel fuel, a cleaner burning fuel.

The emission reductions described above assume the usage of #1 diesel fuel. However, Ultra Low Sulfur Diesel (ULSD) fuel will soon (June, 2007) be required for use in all buses. ULSD contains 95 percent less sulfur than conventional diesel and requires no major changes to transit operations or infrastructure. The sulfur content in ULSD is reduced from 500 to 15 parts per million.

Fuel Economy

Projecting hybrid bus fuel economy is difficult since there is limited data from such buses in service. Current estimates have shown fuel economy improvements of 28 to 48 percent over comparable diesel buses. The level of fuel savings depends on a number of factors such as the hybrid system configuration, average vehicle speed, and other bus accessories (e.g., air conditioning). Nevertheless, table 2 below provides an estimate of the annual fuel savings per vehicle. The estimate assumes a 35 percent increase in fuel economy with a hybrid bus.

Table 2. Comparison of Estimated Annual Fuel Costs by Vehicle Type		
	Conventional Diesel	**Hybrid Bus**
Fuel Cost * (per gal.)	$2.41	$2.41
Fuel Usage **	4.6 mpg	6.3 mpg
Est Cost Per Mile	$0.52	$0.39
Avg Annual Vehicle Miles ***	39,231	39,231
Estimated Annual Fuel Cost	$20,589	$15,120

* Rate of ultra-low sulfur diesel on June 23, 2005
** Diesel bus based on miles per gallon for New Flyer vehicle. Hybrid bus assumes 35% increase in fuel efficiency.
*** Based on average annual vehicle miles for each New Flyer bus.

Based on the assumptions mentioned above, it is estimated that Metro could realize an annual fuel savings of $5,469 per hybrid vehicle. Metro has a fleet of 220 buses. If the whole fleet were converted (over a period of time), an entire fleet of hybrid diesel-electric buses would save about $1.2 million in diesel fuel purchases at the rate per gallon shown.

Capital, Maintenance, and Operating Costs

Currently, hybrid buses carry a significant purchase price premium over conventional diesel buses. There is 80% federal funding of capital items, and the hybrids would be eligible for federal participation at that level. The City of Madison will not, however, receive additional capital dollars if we choose to purchase hybrid buses. As part of its 2006 purchase agreement, Metro will be purchasing 15 forty-foot diesel buses at a cost of around $272,000 per vehicle on a contract bid made three years ago. Currently bids for new diesel buses are around $290,000/vehicle (local share $58,000). An estimate for similarly equipped hybrid bus is $465,000 per vehicle (local share $93,000).

Our capital bus dollars could be used to purchase:

- 15 conventional diesel buses,

- 5 hybrids and 7 conventional diesels, or
- 3 hybrids and 10 conventional diesels.

As emission standards for diesel bus engines continue to be tightened, engine manufacturers and bus companies will have to employ more advanced technologies, which will likely increase the price of conventional diesel buses. One thing to keep in mind; there may be outside organizations in Madison that would be interested in funding the increased local share.

The other major cost associated with hybrid buses is battery replacement, as batteries in current vehicles are not expected to last the 12-year life of a transit bus. The expected battery life (depending on type of battery and technology utilized) varies from three to six years with replacement cost ranging from around $15,000 to $45,000 per vehicle.

Since hybrid buses are a relatively new technology, they currently do not have the same reliability as conventional diesel buses, which are a very mature technology. Therefore, maintenance costs associated with hybrid vehicles could be higher. Reports from transit systems utilizing hybrid buses indicate that while the reliability of hybrid-buses is increasing, it is too early to estimate the difference between diesel and hybrid in maintenance costs over the life of the bus.

Table 3 below, provides a comparison of some annualized capital and operating costs. The costs assume a 12-year life cycle for each vehicle type. Information is not available concerning differences in operating and maintenance costs over the lifetime of the bus because hybrid buses are a relatively new technology.

Table 3. Comparison of Annualized* Capital & Operating Costs

	Conventional Diesel	**Hybrid Bus**
Acquisition	$4,830**	$7,750**
Battery Replacement	N/A	$3,750***
Fuel Cost	$20,589	$15,120
Total	$25,419	$26,620

* Capital cost per year for a 12-year life cycle

** Based on 20% Local Share over 12-year life cycle

***Assumes one battery replacement of $45,000 during life of coach

Summary

As described above, the main benefits of hybrid buses are the lower emission levels and lower fuel costs. The level of these benefits depends on several conditions such as operating environment (average vehicle speed, use of air conditioning, etc.) and the specific configuration (series/parallel) of vehicle technology being used. Currently, hybrid vehicles carry a significant price premium in purchase price over conventional diesel buses. In addition, transit agencies that purchase hybrid buses must also budget for battery replacement. However, the price differential could change as technological improvements are made and emission standards for diesel bus engines are tightened. A more thorough analysis on the cost and benefits of hybrid buses is not possible until more information on the lifetime operating and maintenance costs of these vehicles becomes available.