To: GVTA Board of Directors

From: Sheri Plewes, Vice President, Capital Management and Engineering

Date: December 5, 2006

Subject: Update on Bus Technology and Alternative Fuels Demonstration Project

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PURPOSE

To provide an update on the *Bus Technology and Alternative Fuels Demonstration* Project including the results of the Phase 1 test program and an overview of the Phase 2 test program. This project is part of TransLink's Urban Transportation Showcase.

BACKGROUND

On December 8, 2004, the Board received for information the report "Update on Bus Technology Demonstration Capital Project". The report outlined the revised project scope required to meet the Urban Transportation Showcase funding guidelines.

In May 2005, the Board received for information the report "Development of Fleet Emissions Policy". This report included an update on the Bus Technology and Alternative Fuels Demonstration Project.

In March 2006, the Board received for information the report "Bus Procurement Update". The report included the status of the initial Phase 1 Bus Technology and Alternative Fuels Demonstration Project results.

DISCUSSION

Test Program Objectives

The objective of Bus Demonstration and Alternative Fuel Demonstration Project is to provide test results and on-going performance data that will be used by TransLink to make well-informed business decisions relevant to the TransLink operating environment, to meet corporate financial and environmental objectives.

The information gathered through the testing programs and through on-going maintenance and fuel use records will assist in determining the most effective way of reducing our overall impact of emissions through new fleet purchases, retrofit programs and fuel choice. The emission data will also allow us to refine our fleet emissions inventory which is used to evaluate the effectiveness of emission reduction initiatives and to estimate the reduced emissions resulting from the implemented initiatives.

Vehicles of the Bus Technology Demonstration Project

As a component of the Showcase Program, the project scope includes:

- Retrofit two decommissioned buses (former Ballard Buses) with Allison Transmission diesel/electric hybrid drive technology (parallel hybrid technology);
- Assess and include (as feasible through purchased, lease, loan, re-power etc.) other vehicle technologies for comparison such as:
  - Diesel;
  - Compressed natural gas (CNG);
  - Hydrogen/compressed natural gas mixture (HCNG);
  - Diesel-electric hybrid – series technology; and
  - Electric trolley (new fleet);
- Design and implement a vehicle demonstration test program that will allow for a comprehensive comparative evaluation of technologies;
- Analyze and compare the results of the demonstration test program, and estimate total life cycle costs for each technology; and
- Design and implement a communications and public outreach program to promote awareness of the various bus technologies, and to obtain customer feedback.

The vehicle demonstration program was to be designed to evaluate and compare the operating and cost characteristics of the various vehicle technologies over a wide range of routes and conditions. The following areas were to be considered for evaluation:

- Noise/decibel levels;
- Operating costs;
- Fuel consumption/efficiency;
- Maintenance requirements;
- Safety;
- Infrastructure and equipment requirements;
- Training requirements;
- Public awareness and acceptance;
- Overall lifecycle costs; and
- Emissions.

After an assessment of the availability of the buses and alternative fuels to be tested, the project's test program was split into two phases. Although these two phases will complete the project scope, similar test programs will be undertaken by TransLink as new technologies and alternative fuels become available in the future.

Phase 1 Test Program Overview

M.J. Bradley & Associates developed a Work Plan and Test Program for Phase 1. The program was designed to be relevant to our service area and operating characteristics, comprehensive and repeatable. M.J. Bradley & Associates is a US-based consulting firm that has considerable experience in the testing of bus technologies for a number of large transit agencies in North America. The Emissions Research and Measurement Division of Environment Canada provided assistance to M.J. Bradley & Associates for the emissions testing. This division of Environment Canada has considerable experience in performing emissions tests on vehicles, including transit buses, on many projects throughout North America.

In order to obtain an independent assessment of the work performed on this project, the Centre for Alternative Fuels, Engines and Emissions of West Virginia University was retained to review the draft Final Report for Phase 1 based on the test results and analysis provided by M.J. Bradley & Associates. Generally, they found the program and report to be reasonable. Their comments have been incorporated into the Phase 1 report and the Phase 2 test program.

During Phase 1 a total of ten buses were evaluated. The tested technologies included combinations of alternative engine technologies, drivetrain configurations (standard vs hybrid), transmissions, exhaust after-treatment, and/or alternative fuels, as listed in Table 1.

Table 1 - Phase 1 Tested Technologies

Technology	Bus	Engine Systems			Drive Train	
		Engine Technology	Fuel	After-Treatment	Configuration	Transmission
BASELINE	NF D40LF	Diesel	Std Diesel	DOC	Standard	5-speed auto
CNG	NF C40LF	CNG	CNG	OC	Standard	3-speed auto
HYBRID	NF D40LF	EGR Diesel	ULSD	DPF	Hybrid	NA
BIODIESEL	NF D40LF	Diesel	B20 Biodiesel	DOC	Standard	5-speed auto
DIESEL+DPF	Nova LFS	Diesel	ULSD	DPF	Standard	6-speed auto

ULSD –Ultra Low Sulphur diesel with a sulphur content of less than 15 parts per million
DOC –Diesel Oxidation Catalyst muffler
OC –Oxidation Catalyst Muffler
DPF –Diesel Particulate Filter

The Baseline and Biodiesel buses in the test program were all older buses with between 295,000 and 325,000 kilometers accumulated on both the bus and the engine at the beginning of the test. The CNG and Hybrid buses were older buses that were re-powered with new engines/propulsion systems just prior to the beginning of the test, while the Diesel+DPF buses were brand new with very little accumulated mileage on either the buses or the engines.

The test program included a nine-month revenue service test as well as in-use emissions and performance testing of all ten test buses. All test buses were operated by Coast Mountain Bus Company from the Port Coquitlam Transit Centre. The buses operated in regular revenue service and rotated weekly between ten specific test routes. The performance tests were done at the Justice Institute's Boundary Bay Test Track.

The data collected during the revenue service testing included:

- Fuel economy;
- Maintenance; and
- Availability.

The data measured during the performance testing included:

- Exhaust emissions;
- Acceleration and braking; and
- Interior and exterior noise levels.

Phase 1 Results

The test program was designed to provide us with information to assist us in determining the most effective way of reducing our overall impact of emissions through new fleet purchases, retrofit programs and fuel choice. This information includes:

- Life cycle costs;
- Exhaust emissions; and
- Performance characteristics.

The primary factors affecting the results of the testing are the engine technology, fuel type, and fuel efficiency. Fuel efficiency depends on the engine, vehicle weight, transmission and gear ratio. Because of this, the results from the Phase 1 test program are specific to the buses and technologies tested and extrapolation of these results to other buses must be done with caution. However, some general conclusions can be made.

<u>In-service Fuel Use and Cost</u>

Hybrid buses are the most fuel efficient:

During the revenue service test the Hybrid buses had the lowest fuel use of the tested technologies, 20% less fuel than was used by the Baseline buses. The CNG buses used the most fuel, averaging 27% more than the baseline buses (based on diesel litre equivalents). The Biodiesel and Diesel+DPF buses used on average 2.3% and 1.5% more fuel per kilometer, respectively, than the Baseline buses.

Hybrid Diesel-Electric powered Bus

Hybrid buses have the lowest fuel cost:
The Hybrid buses have the lowest projected fuel cost at $0.38/km, followed by the CNG buses at $0.42/km. The projected fuel cost for Baseline, Biodiesel, and Diesel+DPF buses is $0.47/km. The CNG buses have a lower projected fuel cost than the Baseline, Biodiesel, and Diesel+DPF buses despite higher per-kilometer fuel use because natural gas costs less per diesel equivalent litre than diesel fuel.

The projected fuel costs are based on projected fuel prices that would be applicable for fuel quantities sufficient to fuel one hundred or more buses and include projected per-liter costs for operation and maintenance of the CNG and diesel fuel stations. The actual fuel prices paid during the Phase 1 test were higher for the CNG, Biodiesel, Hybrid, and Diesel+DPF buses because of the small purchase volumes required for only a few buses.

Life Cycle Costs

The projected life cycle costs were calculated using a spreadsheet-based life cycle cost model developed specifically for TransLink as part of this project. The life cycle cost elements include:

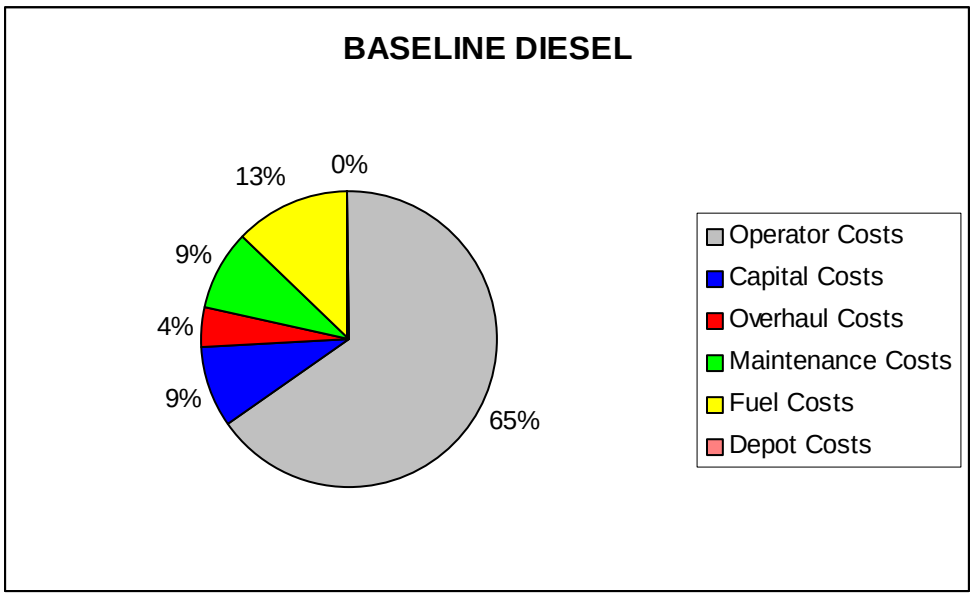
- Bus purchase;
- Purchase and installation of required fueling infrastructure;
- Purchase and installation of required depot modifications and special tools;
- Initial operator, mechanic and manager training;
- Operator labor costs;
- Annual bus maintenance and fuel costs;
- Annual maintenance and operating cost of required fueling infrastructure, depot modifications and special tools;
- Periodic bus overhaul costs; and
- Annual refresher training costs.

CNG and Hybrids have the highest life cycle costs:
The Phase 1 base case model run indicates that the Phase 1 Baseline diesel buses will cost on average $2.92/km to purchase, fuel, operate and maintain throughout their expected seventeen year useful life. The model indicates that the Phase 1 Biodiesel buses will cost on average $2.93/km over their life (<1% more than Baseline buses), the Phase 1 CNG buses will cost on average $3.03/km (4% more than Baseline buses), the Phase 1 Hybrid buses will cost on average $3.00/km (3% more than Baseline buses) and the Phase 1 Diesel+DPF buses will cost on average $2.88/km (1% less than Baseline buses). The higher capital costs (bus and infrastructure) and maintenance costs associated with Hybrid and CNG buses contribute to the higher LCC. However, lower overall fuel costs partially off-set these costs.

Compressed Natural Gas powered Bus

Figure 1 illustrates the proportion of costs for the Baseline buses which is fairly typical for all the diesel buses tested.

Figure 1 – Description of Total Lifecycle Costs



The Diesel+DPF buses experienced very few propulsion-related problems during the revenue service test, while the other test buses had a much higher number of road calls and bad orders for reasons such as “won’t start”, “low power/rough running”, or “check engine light”. The superior performance and lower cost for these buses may be due in part to the fact that both the buses and the engines were newer than the other test buses.

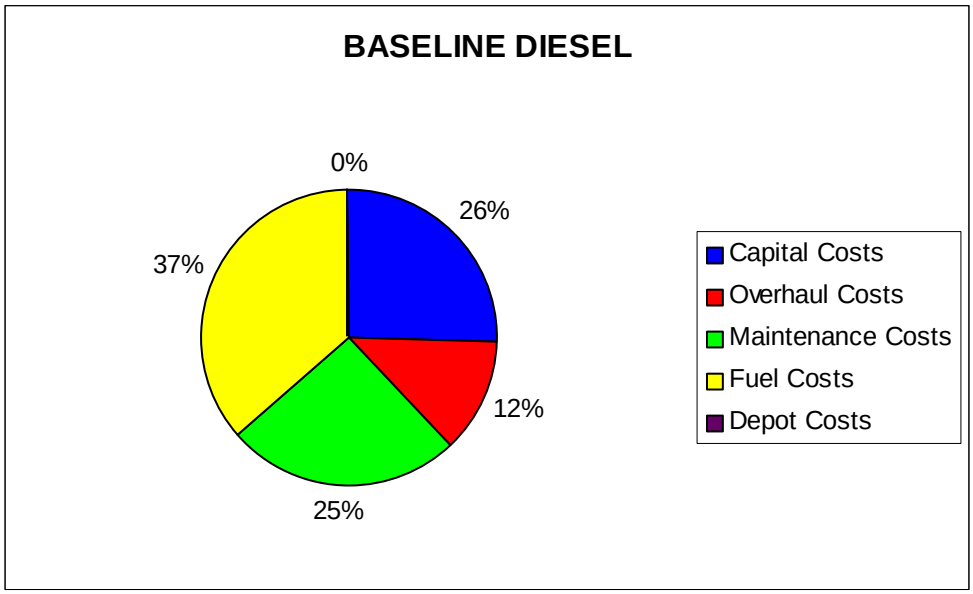
Diesel w/DPF powered Bus

The higher propulsion related maintenance cost for the CNG buses was primarily the result of a greater number of road calls and bad orders for engine problems. While the engines in these buses were new, they may have been negatively affected by the fact that the buses had been re-powered with new engines, which often involves some compromises in engineering the integration of the new engine into the existing bus chassis.

Baseline Diesel powered Bus

Operator wages constitute the largest percentage of life cycle costs at 65%. Without consideration of operator wages the average cost is $1.02/km for the Baseline buses. Figure 2 shows the proportion of costs for the Baseline buses without operator costs.

Figure 2 – Description of Total Lifecycle Costs without Operator Wages



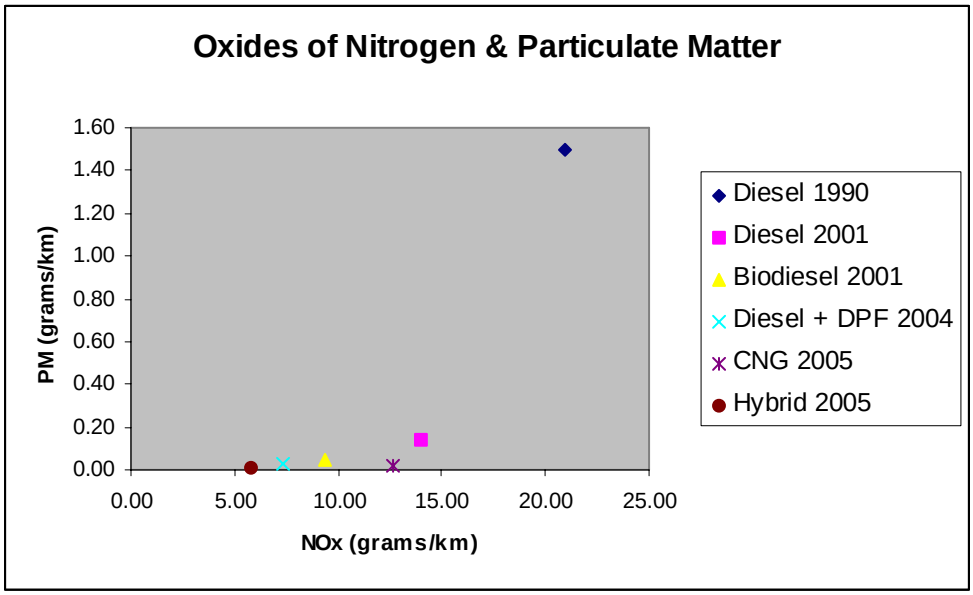
Exhaust Emissions

Hybrid buses have the lowest emissions:
Overall, the Hybrid buses had the lowest emissions of the tested propulsion technologies, for all pollutants of interest consistent with TransLink's Emissions Policy Report (June 2006), including particulate matter (PM), oxides of nitrogen (NOx), carbon dioxide (CO_2), total green house gases (GHG), carbon monoxide (CO), non-methane hydrocarbons (NMHC), and total hydrocarbons (THC). The reductions compared to the Baseline buses were due in part to the hybrid-electric drivetrain configuration, which reduced overall fuel usage, and low-NOx diesel engines equipped with diesel particulate filters (DPF). Figure 3 illustrates the particulate matter and oxides of nitrogen emissions for each of the tested propulsion technologies and fuel types.

The Diesel+DPF buses had the second lowest emissions of the tested propulsion technologies. In comparison to the Hybrid buses they had approximately 25% higher CO_2 and GHG emissions, 30% higher NOx emissions, marginally higher PM emissions, and similarly low CO, THC, and NMHC. The low PM, CO, THC, and NMHC emissions resulted from the use of a DPF. The relatively low NOx emissions from these buses, in comparison to the Baseline diesels, resulted from the use of low-NOx diesel engines.

The Biodiesel buses had lower PM and NOx emissions, on average, than the Baseline buses. Testing the same bus with both biodiesel and standard diesel fuel would determine whether the lower NOx was engine related or fuel related. Emissions of all other measured exhaust components from the Biodiesel buses, including CO_2, CO, GHG, THC, and NMHC were similar to emissions levels from the Baseline diesel buses.

Figure 3 -NOx & PM Emissions Results

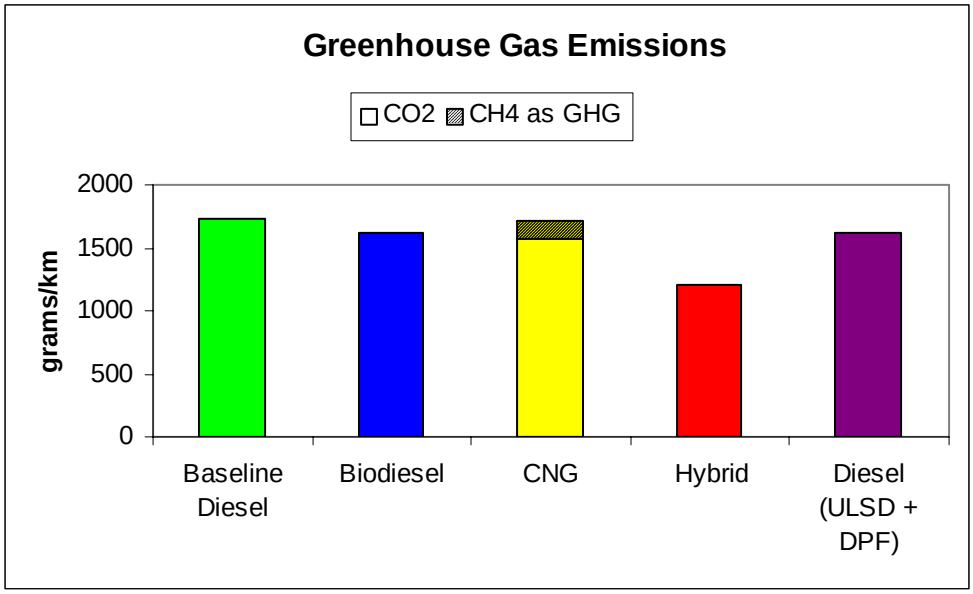


Diesel 1990 emission results based on EPA 1990 certification numbers

The CNG buses produced very low levels of CO and PM, equivalent to the levels produced by the Hybrid and Diesel+DPF buses. They had marginally lower CO_2 emissions, but marginally higher GHG emissions than the Baseline diesel buses, due to relatively high methane (CH_4) emissions. They also had higher NMHC emissions than the Baseline buses, and much higher NMHC emissions than the Hybrid and Diesel+DPF buses. NOx emissions from the CNG buses were nearly equivalent to those from the Baseline buses. NOx emissions from these buses appear to be more sensitive to duty cycle and operator behavior than NOx emissions from diesel buses. The slow speed stop-and-go transit duty cycle and consistently quick accelerations used for this test program may be less conducive to optimal NOx performance compared to higher speed cycles with fewer stops per kilometer and slower rates of acceleration. A higher speed suburban duty-cycle is more consistent with the simulated duty-cycle used for engine certification testing. Figure 4 illustrates the carbon dioxide and methane emissions for each of the tested propulsion technologies and fuel types.

The test cycle used for the emissions testing during Phase 1 was designed to be representative of low-speed urban TransLink service. In-use data collection subsequent to the emissions testing has shown that while the Phase 1 emissions test cycle is representative of a sub-set of TransLink routes, many routes in fact have fewer stops per kilometer and slower acceleration rates, both of which can affect gram per kilometer emission rates. The emissions results from Phase 1 are therefore more representative of "worst case" expected emissions levels when operated in TransLink service. For Phase 2 in this test program, a new test cycle has been developed which is more representative of the average TransLink bus duty cycle.

Figure 4 -GHG Emission Results



Performance Characteristics

Acceleration, deceleration, interior and exterior noise for all the buses tested met the minimum standards set by the American Public Transit Agency. These performance characteristics were primarily a function of the bus design rather than the technology or fuel utilized.

In-Service Availability & Reliability

During the time period of the Phase 1 test program, it was not possible to draw any conclusions regarding technology and bus availability and reliability.

Phase 2 Overview

In Phase 2 of the Bus Technology and Alternative Fuels Demonstration Project, the experience and knowledge acquired during Phase 1 was incorporated into the test program to provide a more relevant and robust testing program. As done in the earlier phase, suppliers and industry experts, such as Westport Innovations and Cummins, provided input to help refine the overall testing program.

M.J. Bradley & Associates has been retained as the Test Program Consultant for Phase 2. As in Phase 1, the Emissions Research and Measurement Division of Environment Canada will assist in the emissions testing component of the test program.

During Phase 2 of this project the following buses/technologies will be evaluated:

- **HCNG:** four existing TransLink buses re-powered with new natural gas engines and oxidation catalyst mufflers and operated on a mixture of hydrogen and compressed natural gas fuel.
- **Series Hybrid:** one new bus equipped with a diesel-electric series hybrid propulsion system, a low NOx diesel engine and a diesel particulate filter.
- **CNG:** two new buses with 2006 natural gas engines, oxidation catalyst mufflers, and compressed natural gas fuel systems and operated on natural gas.
- **Diesel:** two new buses with 2006 low NOx diesel engines and diesel particulate filters
- **Trolley:** two new electric trolley buses.

All diesel buses will be operated using ultra-low sulfur diesel fuel with less than 15 parts per million (ppm) sulfur. In addition, emissions testing will be performed on one of the diesel buses using biodiesel so that the results can be directly compared with ultra-low sulfur diesel.

As in Phase 1, the test program will be comprised of two major components:

- Controlled tests of specific performance parameters, including emissions, noise, and acceleration; and
- Revenue service tests where test buses will be operated in regular revenue service for a minimum of thirty weeks to determine differential reliability, maintenance and operating costs.

Since some of the Phase 2 test buses and fueling infrastructure are not yet ready for testing purposes, commencement of revenue service testing will be staggered. Revenue service tests for some of the test buses commenced in early November 2006 and it is anticipated that the remaining tests buses will commence revenue service testing before the end of the year. With the exception of the trolley buses, each of the test buses will experience a minimum of thirty weeks of revenue service testing. The formal in-service testing of the Trolley buses will be more abbreviated, lasting for four weeks, and will focus on in-service energy use only. This revenue service testing will be supplemented by controlled tests of specific performance parameters, including emissions, noise, and acceleration.

It is anticipated that the Final Report for Phase 2 will be issued in the fall of 2007.

CONCLUSION

The Phase 1 Bus Technology and Alternative Fuel Demonstration Project, although specific to the buses tested, was useful in providing information to assist us in determining the general direction for most effectively managing our fleet (new fleet purchases, retrofit programs and fuel choice) with respect to meeting Emission Policy objectives and business considerations. The Phase 1 test program also confirmed the cost, emissions and performance assumptions used for evaluating recent bus purchases.

The Phase 1 program results showed where improvements to the test program can be made to develop a more representative duty cycle and robust test program. These improvements have been incorporated into the Phase 2 program.

Maintaining an on-going testing program is important with the rapidly changing technology and fuel options available. These test programs will provide current information to assist us in making well-informed business decisions relevant to the TransLink operating conditions, to meet corporate financial and environmental objectives. It is also important to maintain the flexibility within our existing infrastructure to accommodate various bus technologies and fuel types. (TransLink currently can operate and maintain diesel, electric, hybrid and CNG buses.) This will allow future procurements and emission reduction retrofit initiatives to occur relatively quickly and cost effectively.