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To: GVTA Board of Directors

From: Fred Cummings, Acting Vice President, Capital Management and Engineering

Date: November 28, 2007

Subject: Bus Technology and Alternative Fuels Demonstration Project – Phase 2 Results

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PURPOSE

To provide a summary of the results of Phase 2 of the *Bus Technology and Alternative Fuels Demonstration* Project and an overview of the planned Phase 3 test program.

BACKGROUND

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.

On December 5, 2006, the Board received for information the report "Update on Bus Technology and Alternative Fuels Demonstration Project". The report outlined the results of Phase 1 of the test program and provided an introduction to Phase 2 of the project that had begun in October of 2006.

DISCUSSION

Test Program Objectives

The objective of Bus Demonstration and Alternative Fuel Demonstration Project is to provide objective test results and performance data that will be used by TransLink to make well-informed business decisions related to the purchase and operation of transit vehicles, taking into account Greater Vancouver's operating environment, as well a corporate financial and environmental objectives. The information gathered through the testing programs and through ongoing maintenance and fuel use records will assist in determining the most effective way of reducing our overall impact of vehicle emissions through new fleet purchases, retrofit programs and alternative fuel choices.

The emission data will also allow us to refine our fleet emissions inventory used to estimate the effect of implemented strategies. To date, the project has included 21 test buses representing the following technologies and fuels:

Table 1 – Tested Technologies

		Engine Systems			Drive Train	
Technology	**Bus**	**Engine Technology**	**Fuel**	**After-Treatment**	**Configuration**	**Transmission**
BASELINE	2001 NF D40LF	Diesel	Std Diesel	DOC	Standard	5-speed auto
CNG	1998NF C40LF	CNG	CNG	OC	Standard	3-speed auto
	2006NF C40LF	CNG	CNG	OC	Standard	5-speed auto
HYBRID	NF D40LF	EGR Diesel	ULSD	DPF	Parallel Hybrid	NA
	Orion VII D40LF	EGR Diesel	ULSD	DPF	Series Hybrid	NA
BIODIESEL	NF D40LF	Diesel	B20 Biodiesel	DOC	Standard	5-speed auto
DIESEL+DPF	2005Nova LFS	Diesel	ULSD	DPF	Standard	6-speed auto
	2006 NF D40LF	Diesel	ULSD	DPF	Standard	6-speed auto
HCNG	1998 NF C40 LF	HCNG	HCNG	OC	Standard	3-speed auto
Trolley	2006 NF Kiepe ETB	NA	Electric	NA	NA	NA

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 vehicle demonstration program has been designed to evaluate and compare the operating costs and performance characteristics of the various vehicle technologies over a wide range of operating conditions - either on a test track or in regular revenue service. The following areas were identified for evaluation:

- Noise/decibel levels (test track);
- Acceleration capability (test track)
- Operating costs (revenue service);
- Fuel consumption/efficiency (revenue service);
- Maintenance requirements (revenue service);
- Safety (engineering evaluation);
- Infrastructure and equipment requirements (engineering evaluation);
- Training requirements (maintenance evaluation);
- Public awareness and acceptance (rider surveys);
- Overall lifecycle costs (calculated); and
- Emissions (test track).

To date, the Bus Technology and Alternative Fuels Demonstration program has included most of the fuels and propulsion system technologies currently available to transit system operators. The intent is to continue operating such a program to evaluate emerging technologies and to explore options for reducing the environmental footprint of the TransLink fleet. These reductions are intended to address local human health effects from air pollution as well as long-term effects related to global climate change.

Phase 2 Test Program Overview

M.J. Bradley & Associates developed the Work Plan and Test Program for both Phase 1 and Phase 2. 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 portions of the project, conducted at Boundary Bay in the fall of 2006. 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 suggestions have been incorporated into the Phase 2 test program.

During Phase 2, a total of eleven 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 below in Table 2.

Table 2 – Phase 2 Tested Technologies

Technology	Bus	Engine Systems			Drive Train	
		Engine Technology	Fuel	After-Treatment	Configuration	Transmission
DIESEL+DPF	2006 NF D40LF	2006 Cummins ISL Diesel	ULSD B20 Biodiesel	DPF	Standard	6-speed auto
CNG	2006NF C40LF	C Gas Plus CNG	CNG	OC	Standard	5-speed auto
HYBRID	Orion VII D40LF	2005 Cummins ISB Diesel	ULSD	DPF	Series Hybrid	N/A
HCNG	1998 NF C40LF	C Gas Plus HCNG	HCNG	OC	Standard	3-speed auto
Trolley	2006 NF/Kiepe ETB	N/A	Electric	N/A	N/A	N/A

ULSD –Ultra Low Sulphur diesel with a sulphur content of less than 15 parts per million
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In addition to instrumented testing on a closed course at Boundary Bay Airport, all test buses, with the exception of biodiesel and trolleys, were operated in revenue service by Coast Mountain Bus Company from the Port Coquitlam Transit Centre for a period ranging from 5 to 36 weeks. The buses were operated in regular revenue service and rotated weekly between specific test routes.

The data collected during the revenue service testing included:

- Fuel economy;
- Maintenance; and
- Availability for service.

The data measured during instrumented testing at Boundary Bay included:

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

The test program was designed to provide TransLink with relevant information to be used in determining the most effective way of reducing the overall environmental impact of operations through new fleet purchases, retrofit programs and fuel choices. This information includes:

- Health-related and Greenhouse Gas Emissions;
- Customer and operator acceptability;
- Reliability and maintenance requirements; and
- Life cycle costs.

The primary factors affecting the results of the testing are the duty cycle (operating conditions), engine technology, type of exhaust after treatment, fuel type and fuel efficiency. Fuel efficiency depends on the vehicle weight, engine size/power, transmission type and final drive ratio. These results of this testing program are specific to TransLink's operating environment and the buses that were actually tested. Due to the varying duty cycles and wide range of choices available to bus purchasers in terms of chassis and powertrain configurations, care must be exercised if the results of TransLink's tests are to be used by other transit agencies.

Phase 2 Results

For Phase 2, the 2006 Diesel+DPF buses were considered to be the baseline for relative comparisons with other technologies. These buses reflect the highest level of technology available for a conventional diesel bus as of 2006 and are fairly representative of the engine and emission control that will be available between now and 2010.

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

The BAE Series Hybrid bus did not perform as well as the Allison Parallel Hybrid buses tested in Phase 1 (only about 3% more fuel efficient in revenue service than the Baseline buses and about 12% better than the Baseline buses on the test track). However, its performance was compromised by the fact that it only operated for 5 weeks (based on availability of the bus from Orion) on routes that did not fully take full advantage of the hybrid drive efficiencies. Retesting with a test methodology consistent with the other bus testing is required to achieve more conclusive results.

The 2006 CNG and the HCNG buses used the most fuel energy, averaging 20-35%% more than the Baseline buses in track testing. In revenue service, the typical difference was 15-20% higher fuel consumption than the Baseline buses (based on diesel litre equivalency). Higher energy consumption for the CNG buses was expected due to their higher curb weight and reduced engine thermal efficiency as a result of running on a spark-ignition cycle rather than a diesel cycle. Due to the lower cost of CNG relative to diesel fuel, the 2006 CNG buses had the lowest projected fuel cost at $0.44/km. The average fuel cost for the 2006 Diesel+DPF buses was $0.49/km. The projected fuel costs are based on projected fuel prices that would be applicable for fuel quantities sufficient to operate one hundred or more buses and include projected per-liter costs for operation and maintenance of the CNG and diesel fuel stations.

One of the Baseline buses was tested on the test track using a 20% blend of biodiesel and petroleum diesel. The results of this test confirmed expectations that the use of biodiesel at this concentration would have little impact on the performance of the bus. Differences between the baseline runs and the test on B20 were so small that they could be considered insignificant. Due to a lower energy content, the use of B20 biodiesel comes with a small increase in fuel consumption in the order of 1%.

For Phase 2, two of the new trolley buses were tested for 4 weeks, alternating between two typical urban routes. Energy consumption data was collected and analyzed on a weekly basis. The net energy consumption for the two buses averaged 2.14 kW-hr per kilometer driven during the test period. Based on the price paid by CMBC for electricity, the trolley “fuel” cost was calculated to be $0.14/km. The superiority of trolley buses to internal combustion engine-powered buses is undeniable and maximum use of trolley buses will yield substantial reductions in energy use and cost.

Maintenance Cost

During revenue service testing, the CNG buses experienced more maintenance cost than the other test buses. Maintenance was sub-divided into propulsion-related and non-propulsion related. Propulsion-related maintenance issues are of greater importance in this study because they are closely related to the type of technology used. In Phase 2, the propulsion-related maintenance costs for the diesel buses was $0.05/km while the average propulsion-related maintenance cost for the CNG buses was $0.21. Maintenance costs for the hybrid bus were negligible but the short duration of our test makes any conclusions regarding its long-term maintenance costs impossible.

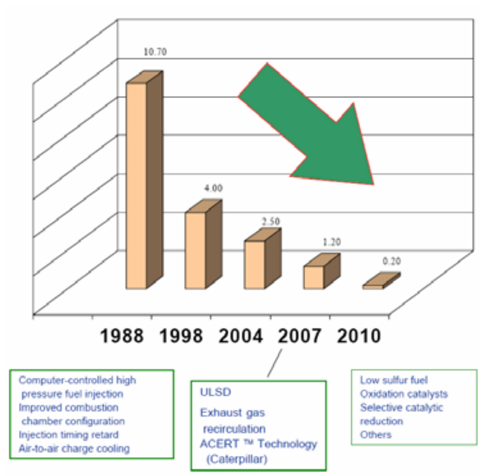
Exhaust Emissions

TransLink’s Emissions Policy Report (June 2006) identified particulate matter (PM), oxides of nitrogen (NOx), carbon dioxide (CO_2), total greenhouse gases (GHG), carbon monoxide (CO), non-methane hydrocarbons (NMHC), and total hydrocarbons (THC) as pollutants to be reduced wherever possible. With the exception of greenhouse gases (carbon dioxide, methane and nitrous oxide), the remaining pollutants are subject to regulation by the federal government by virtue of their effect on human health and environmental quality. The federal limits apply to manufacturers of new heavy-duty engines and compliance with these standards tends to drive the development of engine and exhaust emission control technology. Diesel engines have inherently low emissions of CO and THC, leaving NOx and PM as the pollutants of chief concern and the main challenges for reduction measures.

NOx, along with NMHC, participates in the formation of photochemical smog - the brown haze seen hanging over the city on hot, sunny days. The ozone produced by this interaction is a respiratory irritant and can trigger health effects such as asthma attacks in sensitive individuals. Ozone also causes crop damage in agricultural areas. PM is a significant health risk and has been directly linked to human mortality. Metro Vancouver has identified PM emissions as the number one air quality concern in the region.

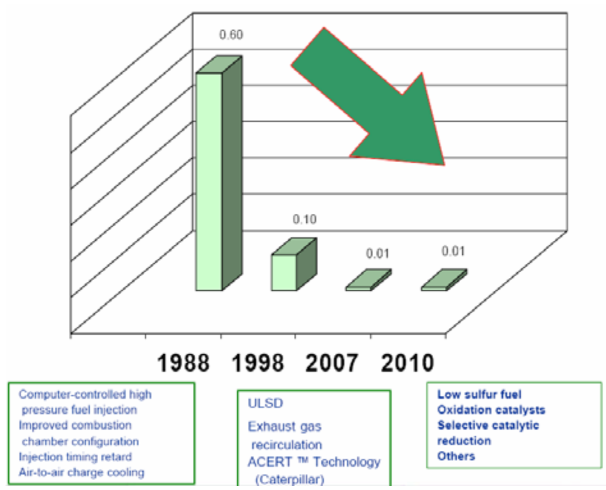
Since the early 1990's, heavy-duty engine manufacturers have been under considerable pressure to reduce emissions of both NOx and PM in on-road applications. Significant milestones occurred in 2003 and 2007 when more stringent NOx and PM standards, respectively, came into effect. The 2003 limits saw widespread introduction of exhaust gas recirculation (EGR) to cool the peak combustion temperature and reduce NOx formation. The 2007 PM standards effectively forced the use of diesel particulate filters on all engines and, prior to this, created the need for widespread availability of ultra low sulphur diesel fuel (<15 ppm). Figures 1 and 2 illustrate the regulated improvements in NOx and PM emissions requirements for engines since 1988 along with the technological developments that were (and will be) needed to comply with those standards.

Figure 1 – Canadian Federal NOx Standards for Heavy-Duty Diesel Engines



Source: Caterpillar Inc.

Figure 2 – Canadian Federal PM Emission Standards for Heavy-Duty Diesel Engines



Source: Caterpillar Inc.

As engine manufacturers have developed technologies to meet tighter emission standards, engine emission performance has improved accordingly. During the 1990's, CNG engines held a decided advantage over diesel engines when it came to PM emissions. However, since the advent of commercially-viable diesel particulate filters, this advantage has almost been eliminated. All of the buses tested in Phase 2 had PM emissions below the stated detection limit of the test apparatus. Relative differences between CNG and diesel engines are therefore not significant and it should be considered that the performance of all the tested buses with respect to PM emissions was the same.

Lean-burn CNG engines have similar NOx emissions to diesel vehicles, meaning that the emissions performance of a lean-burn CNG bus and a diesel bus with a DPF is effectively equal.

Although not yet regulated by the federal government for engines, greenhouse gas emission reductions are a priority for both TransLink and the Provincial Government. Greenhouse Gases such as carbon dioxide, nitrous oxide and methane accumulate in the atmosphere and enhance the absorption of solar radiation, thereby increasing average ambient temperatures. Although often described as "pollution", GHG's are not toxic and their effects are global as opposed to local. The concentration of carbon dioxide in the earth's atmosphere has increased significantly since the industrial revolution and increased burning of fossil fuels and will continue to increase with every tonne of carbon that is burned. Aggressive GHG reduction targets recently announced by the Province strengthen the need for more fuel-efficient buses as the cleanest, most fuel-efficient technology will always have the best emissions performance.

The CNG buses tested so far have produced very low levels of CO and PM, effectively equivalent to the levels produced by the Hybrid and Diesel+DPF buses. They had marginally lower CO_2 emissions, but comparable GHG emissions to the diesel-powered buses due to relatively high methane (CH_4) emissions. (Because methane is 23 times as potent as CO_2 in its effect on global warming, the amount of CH_4 is multiplied by 23 when determining total GHG 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 equivalent-to-slightly-higher-than those from diesel buses.

The HCNG buses have not been evaluated yet in revenue service, but two examples were tested at Boundary Bay for emissions and performance. Modifications to the C Gas Plus engine have been made to take full advantage of the hydrogen in the HCNG. Basically, the engine runs even more to the lean side of combustion than the already-lean-burn CNG engine with the theoretical advantage of greater fuel efficiency and lower NOx emissions. The hydrogen serves as a combustion enhancer that allows CNG to burn at fuel-air ratios that would not be possible with CNG alone. The emission testing at Boundary Bay has confirmed the expected results with lower NOx emissions than the corresponding CNG buses tested in 2005 using the same chassis and engines. Another advantage of HCNG is that 20% by volume of the CNG is displaced by a non-carbon fuel. This results in lower CO_2 emissions, since the combustion of hydrogen yields only water vapour as a product.

The trolley buses have zero direct exhaust emissions, but it is necessary to take into account how the electricity was generated when making a calculation of the emissions associated with trolley bus operation. Since 94% of the electricity in British Columbia is generated from hydro sources, there are no pollutants attributable to this type of energy. The remaining 6% was considered to be supplied by gas-or coal-fired thermal electric generating stations resulting in small amounts of both smog-forming and Greenhouse Gas emissions being attributed to the trolley buses. However, these levels were almost zero for smog forming emissions and only about 5% of the GHG emissions associated with a diesel bus.

Figure 3 shows the amount of NOx and PM measured for each of the Phase 2 buses and fuels tested.

Figure 3 -NOx & PM Emissions Results

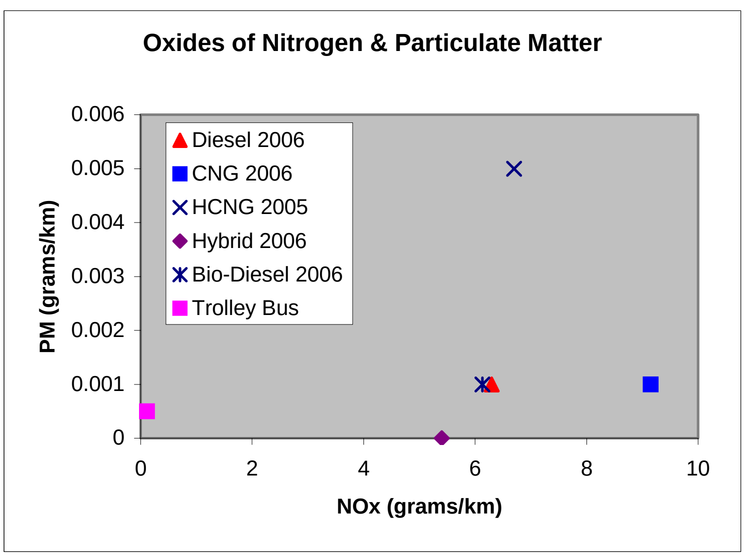
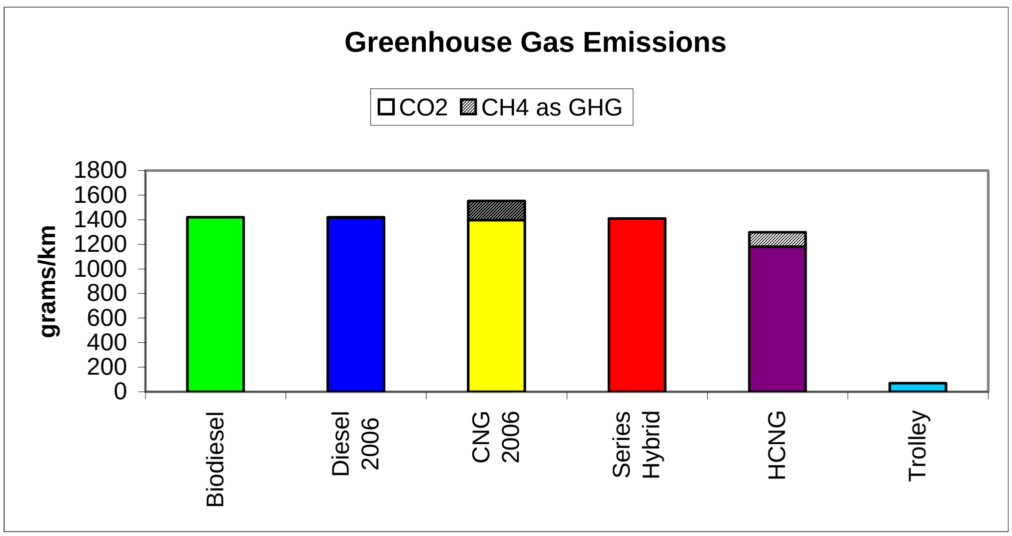


Figure 4 shows the relative GHG tailpipe characteristics of the technologies evaluated to date. For CNG, the effect of the tailpipe methane emissions is shown. As a rule of thumb, GHG production is a direct function of the amount of fossil fuels consumed. Therefore, low GHG emissions are associated with high energy-efficiency.

As this figure shows tailpipe emissions only, the life cycle CO2 emissions for biodiesel and trolley buses has not been included. Since biofuels are derived from sources that consume CO2 during growth, the CO2 emissions produced when they are burned are effectively re-absorbed during the regeneration of the plants or animals used to make them. The effect is not 100%, however, as there is energy consumed and emissions generated in the growing, harvesting and processing of the material used and this must be factored into the calculation as well. Since biofuels typically come from an agricultural source, there are also broader social, environmental and economic factors to bear in mind.

Figure 4 -GHG Emission Results (Tailpipe)



Performance Characteristics

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

As expected, the trolley buses made the least noise during acceleration. Interior noise was comparable to the other bus technologies tested but was highly dependent on whether accessory devices such as the air compressor, heater fans etc., were operating. When these devices were off and the trolley was at rest, the interior was silent. Due to the fact that noise measurements for the trolleys were taken in a different location than the other buses, it is difficult to compare numerical measurements but a subjective evaluation confirms the superiority of trolleys in terms of quiet operation.

<u>In-Service Availability & Reliability</u>

Many factors affect reliability. For the purpose of the technology evaluation, it has been necessary to employ judgment to determine if any recorded breakdown or component failure of a test bus was technology-specific. Only propulsion-related maintenance is considered in the study.

To date, CNG buses have generally higher maintenance costs and have more breakdowns than other types of buses. Conversely, the hybrid buses have been shown to be extremely reliable.

OVERALL TEST RESULTS

Phase 2 of the test program has reinforced the lessons learned in Phase 1. The newer technology engines and drivetrains tested in Phase 2 delivered better emissions performance as expected. The trolley buses have no direct exhaust emissions and the favourable mix of hydro and other sources of electricity in British Columbia means that the use of trolley buses is a very effective means of reducing Greenhouse Gas emissions from the transit fleet.

Biodiesel had little effect on tailpipe emissions. The principal benefit of biodiesel is that it replaces a fossil fuel with a renewable fuel. Greenhouse gas benefits derive entirely from the life cycle of the fuel, including the cultivation and processing of the fuel feedstocks. Although numbers vary, a reasonable assumption is that B20 results in 15% less GHG emissions than burning straight petroleum diesel.

As in Phase 1, the hybrid bus had the lowest fuel consumption. Buses are well suited to benefit from hybrid drivetrain technology because the stop-start nature of bus service means that a lot of energy can be recovered during braking. Benefits are highly dependant on the duty cycle. The lower the average speed and the more stops per kilometer, the greater the potential benefit

PHASE 3

The intent of the Bus Technology and Alternative Fuel Test Program is to continue to evaluate emerging technologies and to explore options for reducing the environmental footprint of the TransLink fleet. Consistent with this intent, Phase 3 of the program has been initiated with the following buses and fuels:

1) Two 2007 NovaBus diesel buses equipped with Cummins ISL diesel engines with active DPFs
2) Two 2007 New Flyer articulated buses with Cummins ISM diesel engines and active DPF’s
3) Two 1998/99 New Flyer 40’ buses powered by Detroit Diesel Series 50 – upgrade retrofit from Diesel Oxidation Catalysts (DOC’s) to DPFs
4) Two 2006 New Flyer 40’ buses running on 50% Biodiesel and 50% Petroleum Diesel

5) Two 2008 40’ buses with Cummins ISG Stoichiometric CNG engines

These buses represent a significant technology or fuel change compared to buses in the current fleet and the acquisition of data for these buses will assist us in upcoming procurement and retrofit/repower decisions.

Revenue service testing has started on some of the Phase 3 test buses in mid-November, 2007. Emission and performance testing at Boundary Bay will be performed in April or May of 2008 when the likelihood of rain is reduced and all test vehicles are available. A draft report is expected in the third quarter of 2008.

CONCLUSION

To achieve TransLink’s objectives of reduced emissions, cost effectiveness, performance (safety) and reliability (customer service), trolley and hybrid technology are the best choices among the technologies evaluated to date.

Based on track testing, the test program has shown that advances in engine technology are reflected in lower emissions. Any type of newer technology bus is greatly superior to any bus older than 2001 engine technology. As trolley buses are electric, they have no tailpipe emissions and provide the most environmental benefits.

The intent of the Bus Technology and Alternative Fuel Test Program is to continue to evaluate emerging technologies and to explore options for reducing the environmental footprint of the TransLink fleet. Consistent with this intent, Phase 3 of the program has been initiated and will progress throughout the first half of 2008.