BC TRANSIT FUEL CHOICE STUDY

Submitted To:

Crown Corporation Secretariat
Province of British Columbia

Submitted By:

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EXECUTIVE SUMMARY

Introduction

The purpose of this study was to provide the Province of British Columbia and BC Transit with sufficient information to make a decision for a fuel choice for BC Transit's 1997 bus purchase and to provide a framework for future transit fuel choices. The specific objectives for this study were:

- An assessment of currently available fuel technology options;
- A review of experiences of North American transit operations with alternative fuel buses;
- A review of BC Transit's Pilot CNG Bus Test.

Review of Transit Fuel Technologies

Manufacturers of heavy duty engines have greatly modified their products to meet new emissions regulations in North America. Low sulfur diesel fuel, as used by BC Transit, is required to meet current standards. The need for catalysts for treating exhaust emissions to meet 1996 - 1998 standards depends on the design strategy of the manufacturer. It is highly likely that diesel engines with further refinements and use of catalysts will be able to meet the proposed standards for 2004. Diesel fuel may have to be further reformulated. Therefore, it is anticipated that diesel engines will continue to compete effectively with alternative fuels from an emissions perspective.

The review of alternative fuel technologies shows that CNG is the only alternative fuel technology that is well developed and tested, available as a commercial product, uses a fuel which is readily available and may be cost competitive with diesel. Other fuel technologies such as LNG, propane, DME, alcohols, electric, hybrids, and biodiesel are either untested, not commercially available, too expensive or lack fuelling infrastructure.

There are also diesel technologies that can be applied to older buses that can reduce emissions. These technologies were not part of the scope of this study but should be evaluated as part of an overall strategy to reduce emissions for BC Transit.

Experience of Other Transit Fleets

Experience of North American transit operations indicates that CNG is the leading alternative fuel in public transportation applications. In 1995, CNG buses were operated by 40 transit properties in Canada and the United States, representing about 2% of the total North American transit fleet. In the first six months of 1996, about 20% of new bus orders in North America were for CNG powered vehicles, indicating a growing interest in the technology. A number of conclusions and lessons can be learned from the experience at other properties:

- Adoption of CNG has been a response to public and political concern about the environment.
- Successful alternative fuels programs have been actively supported by transit managers.
- Financial support from governments and utilities has made the implementation of CNG viable for the transit operator.
- Spares ratios have not been affected. Successful implementation of alternative fuels have not had a negative impact on levels of service provided to the public.
- Proper inspection, maintenance and training is required to ensure safe operation.
- Ancillary equipment failures such as electrical systems and methane detection have been a problem at some sites.
- CNG technology has improved over the last ten years and has become more reliable.

Pilot CNG Bus Test

In BC Transit's pilot test program, 10 of the 25 natural gas buses (conventional configuration) that were placed into service in Port Coquitlam starting in November 1995 were selected for performance monitoring. In addition, 10 similar vintage New Flyer low floor buses with DDC Series 50 diesel engines were selected as a control group at Burnaby. There are some differences between the two vehicle groups that limits the comparison of the results. The BC Transit pilot is an operational demonstration that was designed under constraints of the operating environment. The pilot is not an in-depth scientific study.

At the end of 1996, the Sypher recommended several steps that should be taken to improve the likelihood of obtaining useful and reliable data. These steps included:

- Expanding the pilot program to include small fleets of identical diesel control buses in Burnaby and Port Coquitlam.

- Implementing on-line data gathering at Burnaby as soon as possible.

- Use of data that can be downloaded from the on-board engine computer.

- Presenting data on the same scales (i.e., per kilometre).

- Segregating out fuel related data.

Since the initial design, BC Transit has made definite improvements in its data collection including: use of similar scales for comparing data, segregating out fuel and engine related information, implementing the Fuel Data Capture System at Burnaby, and establishing diesel control fleets.

In the March 6th draft report to its Board of Directors, BC Transit reported higher warranty claims and increased number of bad orders and road calls. At this time, the warranty claims are not true costs to BC Transit except for some additional labour time. The data does indicate that there are still reliability issues that could be of concern. However, the March 6th draft report does not outline which components were failing nor the frequency of failures. There were no indications in the report of progress that DDC or New Flyer were making in solving reliability problems. It is reasonable to expect that improvements will be made with efforts underway by DDC and New Flyer. However, there is some uncertainty in the timing and extent of these improvements, and whether warranty periods might be extended. This risk has been addressed in the financial analysis.

Financial Feasibility

Key variables that were assessed in the financial viability of CNG included: fuel consumption, maintenance, gas prices, bus prices, facility costs, engine rebuilds and staff. These variables were compared to diesel costs.

The financial viability of CNG for BC Transit is very dependent on tax considerations, the location of the buses, fuel consumption and maintenance. With the current tax structure, financial viability is marginal, as measured by NPV analysis. If BC Transit were to own and operate their own compressor stations and purchase gas "at the property line", the NPV is -$506,000 for CNG buses at the Port Coquitlam garage only, and $92,000 for CNG buses at the Port Coquitlam and Surrey garages. CNG is financially unattractive for natural gas purchased "at the filler nozzle" under current arrangements with BC Gas. BC Transit may be able to negotiate a better pricing structure with a larger number of buses being amortized over the compressor stations.

Buses operating out of the two garages considered have significantly lower fuel consumption than buses operating out of Burnaby since both of these garages are located in suburban areas where the operating environment is less severe. Since savings in fuel costs are required to offset the capital expenses associated with CNG buses, CNG buses should ideally be located in areas where fuel consumption will be greatest. The financial viability of CNG buses would have been very positive had the buses had the same fuel consumption rates as buses at Burnaby (NPVs over $0.8 million).

The financial viability is dependent on BC Transit negotiating a bulk purchase agreement with the gas supplier, reducing the fuel price from 16 cents per litre (diesel equivalent) to around 11 cents per litre. Under current BC regulations, this fuel price would be subject to approval of the BC Utilities Commission. If the present price of gas purchased from BC Gas is maintained for new CNG vehicles, the fuel is definitely not financially attractive for BC Transit.

If provincial and local taxes that are applied to diesel (but not to natural gas) are eliminated from the analysis, then the financial viability of CNG has a very negative NPV under both gas purchasing options - "at the property line" and "at the nozzle".

In addition to the financial viability being extremely sensitive to gas price, the sensitivity of the financial analysis was also tested for optimistic and pessimistic assumptions regarding major cost factors. Assuming the lower price of gas, only pessimistic assumptions about staffing (not reported at other properties), the diesel fuel consumption rate and maintenance costs reduced NPV significantly. Optimistic assumptions on the diesel fuel consumption rate and engine rebuild period led to positive NPVs for the scenarios where gas is purchased "at the property line", and current taxes are included.

Emissions

Emissions from CNG and diesel engines were reviewed. Based on the technology that will be available for BC Transit's upcoming purchase, the potential changes in emissions by using CNG compared with diesel were predicted:

- Particulates 25% reduction using CNG
- NOx 60% reduction
- CO 140% increase but within standards
- HC 700% increase for NMHC but within standards
- SO2 99% reduction
- CO2 equivalents 5% reduction.

It is not within the scope of this study to conduct an economic evaluation of the costs associated with these emissions (and thus the benefits of reducing them). Nevertheless, the relative significance of each in contributing to environmental health problems is well understood. Most transit buses operate in crowded and congested urban corridors where human exposure to emissions is relatively high. The particulate and NOx reductions are most important to air quality in the GVRD. NOx and particulates are associated with health concerns and heavy duty engines are major contributors to particulates and NOx. CO and HC produced by heavy duty vehicles, however, constitute only a small portion of the total CO and HC in the GVRD. CO2 has consequences for global, as opposed to local, environment as it is a greenhouse gas and primary cause of climate change.

It should be noted that the emissions levels for both diesel and CNG are very low compared with the standards of the early 1990s and that small absolute changes in emissions (e.g., grams/bhp-hr) can cause large percentage changes.

I. INTRODUCTION

A. BACKGROUND

The Province of British Columbia and the Greater Vancouver Regional District are the leaders in Canada in developing and implementing clean air policies. In 1995 the provincial cabinet approved a Clean Technology Vehicle Policy which requires that all vehicles purchased by provincial Ministries and Crown Corporations must be natural gas fueled in urban areas or meet specific air emission standards at least as good as provided by natural gas. Exceptions were allowed for applications where suitable vehicles are not available, or operational requirements precluded the use of clean fuel technologies.

BC Transit's fleet is the largest fleet affected by this policy, and they are presently assessing the operation of 25 OEM (CNG) buses placed into service in 1996. In the near term, BC Transit will be purchasing 100 new, standard 12 metre buses, and over the next decade will be faced with fleet additions and replacements likely totalling more than 500 buses (including replacement of the existing 244 unit trolley fleet).

The movement to alternative fuels for transit agencies all across North America has raised concerns that new engine technologies might have a serious impact on the transit agencies' ability to provide safe and reliable transportation. Given the increasingly important role assigned to transit within the Greater Vancouver Regional District, it is imperative that BC Transit be able to meet the expectations of the users and taxpayers with reliable service. Reductions in reliability, if serious, could lead to a shift to private automobiles, and a subsequent increase in emissions.

The potentially higher costs for OEM clean fuel vehicles may be offset by lower operating costs and environmental benefits. In addition as one of the most visible government fleets, BC Transit can play a major leadership role for the Province by demonstrating to other sectors of the economy that clean fuel technology is viable, and economically feasible.

B. OBJECTIVES

The purpose of this study was to provide the Province of British Columbia and BC Transit with sufficient information to:

- Make a fuel choice decision for BC Transit’s 1997 bus purchase which is consistent with the time and objectives of the Province’s Clean Technology Vehicle (CTV) policy and BC Transit’s service plans; and

- Provide the policy and technical framework to guide future transit fuel choices.

The specific objectives for this study were:

- An assessment of currently available fuel technology options;

- A review of experiences of North American transit operations with alternative fuel buses;

- A review of BC Transit’s Pilot CNG Bus Test.

C. METHODOLOGY

The study was conducted through site visits to a number of transit properties in North America; through interviews with engine suppliers, etc. BC Gas, and bus suppliers, etc., and through literature research.

Based on the information collected and reviewed, Sypher conducted a detailed life cycle cost analysis, as well as an analysis of potential emissions reductions though the use of compressed natural gas - the most likely alternative fuel in the near term.

II. OVERVIEW OF TRANSIT FUEL TECHNOLOGIES

Diesel fuel is the most popular fuel for transit buses. Current diesel engine technologies were reviewed and the feasibility of using alternative fuels in transit operations was examined. A number of the alternative fuels are still in the developmental stages and, for these fuels, the review focused on their properties and long term prospects. The alternative fuels considered were:

- compressed natural gas (CNG)
- liquefied natural gas (LNG)
- alcohol
- DME
- A-21
- electricity
- hybrid
- propane (LPG)
- biodiesel
- pine oil

A. DIESEL ENGINE TECHNOLOGY

In order to meet 1991 emissions standards, manufacturers of heavy duty engines made engine modifications such as turbocharging and aftercooling, air intake optimization, high pressure injection, and improved oil control. To meet 1996 - 1998 emission levels, manufacturers have made further engine modifications, and used electronic controls and low sulfur diesel. Oxidation catalysts have also been used, especially on engines for transit buses. For example, Detroit Diesel Corporation (DDC) is using a catalyst to meet emission standards for their series 50 diesel engine. (For their series 50 natural gas engine, a catalyst is not used.) Cummins Engine Company, on the other hand, is not using a catalyst on their L10 diesel (or natural gas engines).

To meet possible 2004 standards in the United States, diesel technology will require more R&D and some combination of advanced electronic controls, improved air handling such as exhaust gas recirculation, exhaust aftertreatment and possible fuel modification.[1] According to Cummins,

[1] Cummins Engine Company, Gary Farrel, February 1996.

natural gas engines available today, if equipped with a catalyst can meet proposed 2004 standards. Manufacturers such as Cummins expect to have certified heavy-duty diesel engines well into the 21st century. The cost of that technology relative to natural gas (or other technologies) is not known.

A number of enhancements to diesel technology for reducing emissions were considered and are summarized in Appendix A. The enhancements typically are applied during engine rebuilds.

B. ALTERNATIVE FUEL TECHNOLOGIES

1. Compressed Natural Gas

Compressed natural gas (CNG) is the most popular alternative fuel for transit bus operations. In addition to its “clean-burning” properties, it is less expensive than diesel on a unit energy basis. The low fuel price helps offset the higher capital cost of purchasing CNG buses and building a CNG fueling facility.

Production CNG engines for urban transit applications are now available from Detroit Diesel and Cummins. Detroit Diesel (DDC) is offering the Series 50G (275 bhp) and Series 40G (250 bhp) engine for full size, low floor buses. Cummins now offers the L10 (260 - 280 bhp) and a gas version of their 8.3 engine (275 bhp). The DDC Series 50 natural gas engine is a recent conversion of the Series 50 diesel engine, which itself was developed in the late 1980’s to replace the 2 stroke DDC engines commonly used in transit buses. The Cummins L10 engine was modified for natural gas use in the mid 1980’s and has gone through several generations of development before being offered as a production unit.

There are 3 major producers of urban transit buses in Canada: New Flyer, Orion, and Nova Bus. All three manufacturers are now offering full size (12 metre), low floor buses to Canadian transit properties and New Flyer and Orion offer CNG options. Until 1995 New Flyer was the only manufacturer that had successfully delivered low floor, CNG powered buses in Canada. New Flyer can deliver buses with either Cummins or DDC engines. Bus Industries of Ontario (Orion) are now producing low floor buses with Cummins L10 or DDC engines. Nova Bus is now offering their new low floor bus with either Cummins 8.3 or DDC Series 40 engines.

The transit bus manufacturing business has developed as a custom build industry. Each transit property generally develops its own unique specifications, and mixes and matches among major components suppliers for such elements as engines, axles, transmissions, seats, air conditioning systems, etc. which then must be integrated into the chassis by the bus manufacturer. As a result almost any combination of drive train and chassis are possible, albeit with higher price tag for more unusual, or low volume configurations.

Detailed discussion of the costs of using CNG in a transit fleet is given in Section III and the emissions reductions are discussed in Section V.

2. Liquefied Natural Gas (LNG)

Liquefied natural gas is stored on vehicles in heavily insulated tanks, at pressures around 0.4 MPa (60 psi), and a temperature of approximately -170ºC. LNG can be more practical as a fuel than CNG in some cases. The energy storage density of LNG is approximately twice that of CNG, and the complete fuel storage installation tends to be significantly lighter. LNG can therefore provide greater vehicle range from a given fuel storage space. It can also help to maintain bus axle weight loadings within permissible limits, so avoiding any reduction in the legal passenger capacity of a natural gas bus.

LNG buses were tested by two transit authorities in the NREL Alternative Fuel Transit Bus program[2]. The LNG buses in these trials were far less reliable than the diesel control buses, requiring twice as many road calls, and the maintenance cost were found to be 40% - 50% greater at both sites. The fuel efficiency of the LNG buses was 13% lower than the diesel control buses for the dual fuel buses at one site, and 40% lower for the dedicated LNG buses at the other site. The incremental capital cost of LNG buses in the trial was about $74,000[3] (10% more than CNG buses). The incremental capital costs for a completely new refuelling, maintenance and storage facility for a fleet of 160 LNG buses was estimated to be about $4.6 million (7% less than for CNG).

Based on the trials, LNG does not compare favourably with CNG as a fuel for transit buses. Initial capital costs are greater for LNG, the additional cost of the LNG buses outweighs the savings in the buildings and refuelling facilities. Further, the fuel economy, reliability, and maintenance costs were all found to be similar or worse for the LNG buses compared to CNG.

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2 “Alternate Fuel Transit Buses - Final Report”, prepared by NREL Vehicle Evaluation Program for U.S Dept. of Energy, October 1996.

3 All dollar amounts are in Canadian dollars unless otherwise specified.

3. Alcohol

The longest running alcohol fuels initiative has been the development of methanol-fueled transit buses. DDC built the first methanol transit bus in 1983, and field-tested the vehicle at Golden Gate Transit in San Francisco. Since then DDC has built well over 550 methanol engines, and DDC methanol transit buses have accumulated over 10 million miles in the field. DDC has also built ethanol engines, and 19 of these are currently in service[4]. DDC has achieved low emission levels with these alcohol engines. Fleet tests conducted under the NREL program have demonstrated alcohol fuels to have reduced particulate and NOx (nitrogen oxide) emissions, energy efficiencies similar to diesel and marginally greater maintenance expenses.

Interest in alcohol fueled buses has decreased due to high fuel costs which are over twice that of diesel on an energy equivalent basis. With the dwindling interest, Detroit Diesel discontinued production of methanol engines earlier this year. The methanol producers have also informed the Los Angeles RTA (the largest user of methanol powered buses) that they will no longer supply methanol fuel. Consequently the RTA is now examining options for repowering the 330 methanol fuelled coaches in their fleet. In 1996 about 75 methanol coaches were switched to ethanol.

4. DME

Dimethyl ether (DME)[5] is a synthetic fuel manufactured from natural gas suitable for use in diesel engines with only minor modifications. DME is a gas stored under moderate pressure, similar to propane. The volumetric energy content of DME is much less than diesel (54%) requiring 1.8 times the volume of diesel to travel the same distance for equal energy efficiency and weight. However, the engine energy efficiency can be up to 10% higher than with diesel, thus reducing the volume factor to 1.7.

DME is a colourless gas which is primarily used as an aerosol propellant. A production technique has been developed which will allow production levels of 5,000 to 10,000 tons a day at a cost 10% to 20% more than diesel fuel. The technique has been demonstrated in a much smaller 50 kg per day plant.

Tests on a 2.0 litre single cylinder engine using DME indicate that NOx and particulate emissions are dramatically reduced compared to diesel:

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4 "DDC Alternative Fuel Production Experience and Further Development". S.P. Miller. 1993 Windsor Workshop on Alternative Fuels.

5 T. Fleisch, 1996 World Conference on Refinery Processing and Reformulated Fuels, San Antonio, Texas, March 1996.

NOx by 50% and particulates by 80%. Emissions of CO and total HC are well below the 1998 CARB standard. Tests on a Navistar engine have achieved ultra-low emissions levels and demonstrated that the engine is totally smokeless.[6]

Currently engines and fuel systems are still being developed and tested. The Navistar DTA 530 heavy-duty truck and bus engine is the first application. The modifications to diesel engines required for DME fuel are: modification of the fuel injection system, rematching of the turbocharger with the addition of an EGR system, and a new fuel storage and supply system. A fleet demonstration project has been established in Denmark. Three dedicated DME fuelled buses manufactured by Volvo will be operated by three transit authorities beginning in 1997. A further three buses will be added to the program and over the test period 72 bus-months of data will be collected.

DME offers potential for reducing emissions in heavy duty applications. Preliminary studies indicate that DME could be cost competitive with diesel on an equal energy basis depending on fuel costs, taxation levels, energy efficiency and conversion costs. However, it will be several more years before the technology has been developed and tested in fleet applications. If these prove successful, fuel production facilities will need to be expanded greatly to accommodate potential demand which would further delay widespread use of the fuel.

5. A-21

A-21 is a fuel emulsion comprised of naptha (a petroleum based hydrocarbon fuel), water and an additive package. The additive package is a proprietary formulation that allows the oil and water to emulsify and protects against corrosion and freezing. Use of water injection can improve performance - the evaporation of water cools the intake charge, and the steam created during combustion adds gas volume during the expansion stroke of the engine. Depending on the engine, A-21 is a blend of naptha and between 30% and 55% water. The additive package makes up less than 1% of the fuel[7].

A-21 was marketed by Advanced Fuels (AF), a joint venture which included Caterpillar Inc. Caterpillar recently withdrew from the joint venture, but is continuing their evaluation of A-21 independently. Almost

[6] J.C. McCandless, "Design and Development of a Novel Fuel Injection System for Dimethyl Ether", 1996 Windor Workshop.

[7] "Water: Could it be the Next Alternative Fuel?", Clean Fuels Report June 1996, pp.21-22.

all testing on A-21 has been performed by AF and the reported results are attributable to them.

Fuel efficiency on an energy equivalent basis is expected to be similar to gasoline in cars and, nearly the same in diesel powered vehicles, without loss of power or torque. However, engines running on A-21 have experienced cold start problems when temperatures are less than 10° to 15° C. This is a serious obstacle to the widespread use of A-21 in Canada. In addition, the energy density of the fuel is 30% to 55% less than diesel. Buses will therefore require additional fuel tanks if driving range is to be maintained.

AF claims that engines running on A-21 exceed US federal pollution standards for the year 2004 and beyond without the pollution control devices required on current engines. In diesel engines, NOx and particulate emissions reductions of 50% - 80% are claimed depending on the water/naptha ratios[8]. Tests conducted for the Nevada State Department of Environmental Protection using a 1991 Ford Tauris backed up these claims.

A-21 fuel is expected to cost less than gasoline on an energy equivalent basis, as refined naptha costs approximately half that of gasoline or diesel. The fuel can be sold just like gasoline or diesel through the existing distribution infrastructure. Only minor engine modification will be necessary to run on A-21 which will cost about $1000 for diesel engines.

Many of the claims made by AF have yet to be verified by independent sources and much testing is required before they are substantiated. So far, only very limited testing has been carried out in diesel applications. These include a power plant application and a trial with a heavy duty truck. As shown with CNG, it takes a number of years to fully test new fuel types and overcome the many hurdles associated with new technology. Cold start problems are one such hurdle which must be overcome for the fuel to be of use in Canada. Currently naptha is available in only limited quantities and, if demand rises sharply, productions levels would need to be increased greatly. Shortages of naptha would likely lead to price increases making A-21 less attractive until production is increased.

Thus, it will likely be at least 5 years before sufficient testing has been done on A-21 in heavy duty transport and transit applications to confidently use the fuel. Fuel availability and its effect on fuel price could delay the attractiveness of the fuel for several more years. However, given the lack

[8] E. Schunter, “A-21 Fuel—Half Water, or Half Vapor?”, Products for a Better World, 1996.

of independently verifiable data, one cannot be confident that A-21 will ever provide the benefits that are claimed.

6. Electricity

Electric buses, powered via fixed catenary wire systems, have operated in high-traffic urban areas for over 100 years. However, fixed guideway system are capital-intensive, and are outside the terms of reference for this study.

Recently, battery-electric buses have been built and operated in transit applications. The Santa Barbara Transit District and Regional Transit in Sacramento each operate 6 battery-powered buses, built by Specialty Vehicle Manufacturing Corporation (SVMC), on the downtown/waterfront shuttle systems. SVMC shuttle buses are also operating in San Diego. Sacramento reports that the battery powered vehicles are the least reliable buses in their fleet, and as a consequence are very expensive to operate. Plans to build a new trolley system utilizing overhead catenary in Sacramento have also been shelved.

One of the most advanced electric buses, built by APS Systems, features an aerodynamic shape, light weight aluminium and composite materials, dual advanced drive motors and long life, high power nickel-cadmium batteries. The bus is 35 feet long, seats 35 passengers and has a range of 110 km.

Like all current efforts to build commercial electric vehicles, electric bus development is hampered by battery technology. Batteries today are heavy and expensive, and do not provide the range, top speed, or acceleration capabilities of liquid or gaseous fuels. As a result, hybrid buses, discussed below, are regarded as having greater potential than vehicles powered solely by electricity.

7. Hybrid

The engine in hybrid vehicles drives generators which provide power to electric motors to propel the vehicle. The engine is typically a small internal combustion engine which can use any one of a number of fuels including diesel, CNG, LPG, hydrogen, etc. to drive the generators. Current hybrids being tested have batteries linked to the generators for energy storage. The engine can then be optimized at a constant speed for efficiency and minimum emissions, and the batteries provide reserve power for accelerations. Flywheels could also be used as energy storage devices.

Fuel savings in the range 25% to 50% can be expected due to improved efficiency under acceleration and energy regeneration from the drive motors. The diesel hybrid buses can use the current diesel refuelling facilities while the CNG versions will require separate CNG refuelling station and building modifications similar to CNG buses. Emissions reductions for diesel hybrids will be similar to the fuel savings.

A number of demonstration projects of hybrid buses are underway.

- The Orion VI hybrid bus is being tested in New York City and the Advance Technology Bus (ATTB), powered by natural gas engines, is being tested by the Los Angeles County Metropolitan Transportation Authority. The bus seats 33 passengers and has a curb weight of 30,180 lbs.
- APS Systems Inc. have converted 3 buses to be powered by electric drive motors supplied by lead-acid batteries coupled to an auxiliary power unit (Cummins 4B 3.9-litre natural gas engines). The buses are operated at the Vandenberg Air Force Base.
- Another bus converted to a hybrid bus similar to the above bus will be used by the Golden Gate Transit District.
- APS Systems Inc. have developed a 12 metre hybrid transit bus with Saft nickel-cadmium batteries providing power to the drive train and a Cummins 4B 3.9 litre natural gas engine charging the batteries. The curb weight of the bus is only 9,300 kg, about 3,800 kg less than a standard bus. The bus will be used in transit service in the City of Lompoc.
- An experimental hydrogen fueled hybrid bus was demonstrated during the Olympic Games in Atlanta.
- Nova Bus has built a demonstration hybrid bus in the USA The drive train was installed in a RTS 06 coach with a final empty curb weight of 27,800 lbs. The vehicle generates electricity using 2 CNG fuelled rotary Wankel engines providing 160 bhp, and utilizes a 21.6 kWh battery storage system. The bus also utilizes regenerative braking to improve efficiency.

Hybrid buses are significantly more expensive than diesel buses and are usually heavier due to the additional drive motors and batteries. For example, the Orion VI hybrid bus has a curb weight 15% heavier than the diesel version. Hybrid buses are still in their developmental stages and cost are currently very high, around $600,000 compared to $313,000 for a similar diesel bus[9]. In addition, the batteries must be replaced every 3 - 4 years at a cost of around $80,000. The price increment and battery costs are expected to decrease as technology improves and development costs are covered.

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[9] P. Drozdz, “Hybrid Electric Bus Simulation”, 1996 Windor Workshop, Toronto, Canada.

8. Propane

Propane remains the most widely used alternative vehicle fuel in North America, but almost exclusively in light duty vehicles. The Chicago Transit Authority operated most of its buses on LPG in the late 1940's. More recently, the Orange County Transit Authority, OC Transpo in Ottawa, and Hamilton Street Railway have experimented with Cummins and IVECO LPG engines. Bluebird produces propane fueled school buses which are popular in many provinces, but the buses have engines which are essentially converted gasoline engines. Propane has not achieved the popularity of other fuels in the HD vehicle sector. Major North American manufacturers were slow to developed commercial heavy duty LPG engines, possibly because they saw more market opportunity with natural gas.

A number of manufacturers are now developing HD engines suitable for transit buses. Detroit Diesel has developed a Series 50P propane engine which is currently being tested by the Corpus Christi Regional Transit Authority and the Orange County Transit Authority in the US. Halifax Metro Transit will soon take delivery of two Series 50P propane powered coaches as part of the demonstration fleet. Cummins is developing a propane version of its C8.3 engine which meets the power and torque targets of equivalent diesel and natural gas engines. The engine is currently being tested in a delivery truck. DAF has developed an LPG bus engine[10] which has low emissions values (NOx less than 3.7g/bhp-hr and particulates 0.075 g/bhp-hr). The engine has been tested in two urban buses in The Netherlands and showed good results. In Finland, a mid-sized (20-30 seat) bus, known as the Ecobus, has a Valmet 634 GA LPG engine and meets the ultra-low European emissions standards.

Dual fuel diesel-LPG engines have also shown good performance in engine dynamometer trials. Power was increased by up to 23% and NOx emissions reduced by up to 50%. However, CO emissions increased significantly.[11]

LPG buses have been used in Vienna, Austria, for 30 years. From their experience fuel efficiency is lower than with diesel buses, and the initial purchase price is 10% - 15% higher for LPG buses. Maintenance costs are slightly higher and catalytic converters must be replaced every 2 years. Catalytic exhaust control is required on their LPG buses to achieve the regulated NOx levels and it also significantly reduces other emissions.

[10] "DAF Develops Heavy-duty LPG-fueled Horizontal Bus Engine", Clean Fuels Report, April 1996, pp. 121-122

[11] J. Barata, SAE Paper No. 952364, 1995.

Maintenance facilities must be modified to increase the ventilation. These additional costs are offset by much lower fuel prices and significant reductions in emissions.

Propane engine technology for transit buses in North America is currently about 5 years behind natural gas. Propane is a byproduct of natural gas production, and has pricing premium of 30%. However, compression costs for propane are significantly lower than for CNG. Both CNG and propane are exempt from Provincial road taxes in BC. A listing of all fuel taxes is shown in Appendix D. Onboard fuel storage will also be less expensive than CNG due to the lower storage pressure and higher energy density. Propane powered vehicles also requires different modifications to maintenance facilities to remove the danger of explosion or fire. Unlike natural gas which is lighter than air, propane is heavier than air and can collect in pits or under vehicles or cabinets. Safety does not appear, however, to be a major concern. Many fleets regularly service propane vehicles indoors.

In summary, depending on the capital and maintenance costs and the reliability of propane HD engines, propane has the potential to reduce both emissions and costs for transit operators in the medium to long term.

9. Biodiesel

Biodiesel refers to the compound methyl or ethyl ester which is produced from vegetable oils, animal fats or used cooking oils. Biodiesel can be used as a fuel in its pure form, but is usually combined with diesel at a blend 20% biodiesel, 80% diesel (BD20). When used in the blended form biodiesel can be used as if it were diesel. Thus, there are no additional fleet conversion costs, refuelling station costs, or range or payload penalties which are often associated with other alternative fuels.

Fuel economy and performance are expected to be the same as for diesel, however, there is insufficient operational data available to confirm this. Also, as stated in the NREL report, “problems with the engine and fuel system of vehicles operating on biodiesel blends attributed to the fuel are not currently covered by the engine manufacturer. Fuel system compatibility with a BD20 blend has not been proven, and none of the current heavy-duty engine manufacturers are currently offering BD20 specific engines.”

Biodiesel potentially offers significant advantages over diesel fuel[12,13]. In its blended form (BD20) these advantages include:

[12] “Canola Biodiesel - Turning Yellow to Green”, brochure produced by Canodev Research Inc., Saskatoon.

- reduced emissions - particulates[14] reduced by 10% to 30%,
  CO reduced by 3% to 20%,
  total HCs by 3% to 47%
  (the higher values were observed when a catalytic converter was used). NOx emissions remain similar to diesel;
- improved lubrication and reduced engine wear;
- carbon dioxide emitted from the biodiesel component equals that absorbed by oilseeds crops used in biodiesel production.

Biodiesel is currently produced and distributed in Europe where government subsidies encourage non-food use of crops. In the US biodiesel is produced by three companies and biodiesel is being tested for transit bus applications in St. Louis and in a garbage truck fleet in Chicago. There are no applications of soy or vegetable oil based biodiesel in Canada and the biodiesel industry is only just developing.

The major disadvantage of biodiesel is the cost of the fuel. Biodiesel currently costs more than twice the price of diesel. With this high fuel price differential, other alternative fuels offer more cost effective means for reducing urban bus emissions in the near future.

10. Pine Oil

Pine oil is actually a form of biodiesel which is being developed in Canada. Pine oil can be converted to a substance known as arbotane, which is blended with low sulphur diesel for use in diesel engines. Typically, the blend is 40% arbotane, 60% diesel. Blending is required because arbotane alone does not meet all the fuel specification requirements of diesel engines. As a blended fuel, no modifications are required for its use in diesel engines. Other biomass oils such as used cooking oils, animal fats and vegetable oils can be used instead of pine oil. Pine oil is extracted from the residues created at pulp and paper mills. The technology for extracting arbotane was developed by CANMET and the commercial rights have been acquired by the Vancouver company, Arbokem Inc.

The pine oil/diesel blend has a low sulphur content and high cetane value (about 60) which contribute to lower emissions. Tests were conducted on two transit bus engines (DD6V71 and DD6V92) on the Environment

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[13] J.A. Weber and S. Howell, "Biodiesel Marketing Opportunities and Future Research Needs", presented at the Windsor Workshop on Alternative Fuels, Toronto, Canada, 1994

[14] Tests by ORTECH indicate 20% reduction in emissions possible using B20, MTO NG Bus Working Committee Minutes, Feb. 1996

Canada chassis dynamometer using three bus duty cycles[15]. Results of the tests were mixed indicating that significant reductions in emissions with pine oil/diesel of up to 59% in THC, 26% in CO and 15% in NOx were possible, but results were not consistent. However, consistent reductions in particulates of almost 40% were found for the DDC 6V92 engine . Also, on a life cycle basis, pine oil/diesel reduces CO2 emissions by 26%.

Performance and emissions tests were also conducted on a Navistar DTA 360-185 engine with low sulphur diesel and 20% and 40% blends of pine oil/diesel using the engine dynamometer at BC Research Inc.[16] Power, torque and brake specific fuel consumption were very similar for the three fuels tested. Significant reductions in emissions were found for the 20% blend (HC 60%, NOx 17%, CO 21%), but unlike the DDC 6V92 engine particulates increased by 43% in the Navistar DTA engine. With the 40% blend, particulates were similar to the results in the Navistar diesel engine, but reductions in other emissions were minimal.

A consortium of groups[17] are evaluating the pine oil/diesel blend for use as a replacement to diesel. A field trail was recently conducted in Vancouver comparing the operation of three Canada Post vans fuelled with diesel with three vans fuelled with a 40% blend of pine oil/diesel (diesel in both cases is No.1 low sulphur). The vans were operated for 10 months and no problems were experienced associated with the use of the 40% blend of pine oil/diesel. Fuel savings were obtained for each of the three vans using the blend, the average saving being 5%. Emissions tests on the vans[18] using two drive cycles indicated that the 40% blend gives essentially the same emissions levels for all compounds except for CO which was reduced by 17%.

Pine oil/diesel is expected to have some price premium above diesel[19]. If pine oil receives the same tax advantages as natural gas (i.e., zero Federal excise and provincial road tax) the price increment could possibly be about 2 cents/L. It is estimated that five pulp mills in the Prince George area

15 "Pine Oil Diesel Fuel Evaluation Program", briefing notes prepared by Petro Canada, Sept., 1995.

16 BC Research Inc., NAVISTAR "Biodiesel" Engine Emission Test", BCRI report 1996.

17 Includes Arbokem, BC Chemicals, BC Transit, OC Transit, Environment Canada, NRCan, Petro Canada and Canada Post.

18 Environment Canada, 'Summary of "Bio-cetane enhancer" Biodiesel Testing', report by Mobile Sources Division, Environment Technology Centre, Environment Canada, May 1996.

19 M. Stumborg, A. Wong and E. Hogan, "Hydroprocessed Vegetable Oils for Diesel Fuel Improvement", Bioresource Technology 56 (1996) pp. 13-18.

produce enough feedstock to create 25 million litres of arbotane[20]. When blended, this is equivalent to 60 million litres of pine oil/diesel. The current BC Transit fleet of 750 buses uses about 30 million litres (diesel equivalent) of fuel each year, half the pine oil/diesel fuel created from the 5 pulp mills. Thus, although supplies are limited, there are sufficient supplies in BC for the transit portion of the diesel fuel market.

Pine oil is not an option for BC Transit in the short term. Further field tests with the fuel will be required, including trials with transit bus operations. There are currently no large scale production plants of arbotane.

C. SUMMARY

Exhibit II-1 summarizes the current state of alternative fuels for use in transit bus fleets in Canada. Currently, CNG is the only alternative fuel for which the technology for transit buses is well developed and tested, and which has the promise of long term economic viability in Canada.

[20] "PineDiesel - The new fuel made from the renewable forest resources of B.C.", brochure, Al Wong, Arbokem, Vancouver, BC.

Exhibit II-1. Current State of Alternative Fuel for Use in Transit Bus Fleets in Canada

Fuel	Engine and Vehicle Technology	Fuel Development & Availability	Current Financial Viability	Incremental Cost Per Bus	Typical Cost of $/Ldeq (Avg. diesel $0.4
CNG	Well developed and tested, OEM available	Available in major cities (except Maritimes)	May be competitive with diesel depending on fuel taxes	$70,000	$0.11 - $0.1
LNG	Well developed and tested, OEM available	Available in major cities (except Maritimes)	More expensive than CNG	$80,000	$0.11 - $0.1
Propane	Under development, transit fleet tests underway	Fully available	Will likely be competitive with diesel depending on results of fleet testing and fuel taxes	$55,000	$0.22 - $0.2
Alcohol	Well developed and tested, but no engines currently available	Fuel available but significantly more expensive than diesel	Significantly more expensive than diesel due to high fuel costs	$28,000 Production discontinued	Over twice the pric diesel
DME	Under development, transit fleet tests underway	Availability limited, no large scale production plants	Likely slight more expensive than diesel, not sufficiently well developed to confidently assess	Unknown (minor engine modifications)	10-20% more than (large scale produc
A-21	Under development, trucks currently being tested	Availability limited	Not sufficiently developed to assess	Unknown possible $1,000	Similar or slightly than diesel
Electricity	Continuing development and testing	Fuel available, but battery technology is a major drawback	Not cost competitive with diesel due to high battery and component costs	$100,000-$300,000 Est.	$0.04 - $0.06/kW-
Hybrid	Under development, fleet tests underway using buses	Fuel available, but battery technology is a major drawback	Not cost competitive with diesel due to high battery and component costs	$100,000-$300,000 Est.	Fuel savings of 25 50% expected
Biodiesel	Used in unmodified diesel engines	Limited availability	Not cost competitive with diesel due to higher fuel costs	$0	About twice price
Pine oil	Under development, testing has been carried out with vans	Availability limited, no large scale production plants	Not sufficiently developed to assess	$0	About $0.18/L mo diesel (including ta

III. EXPERIENCE OF NORTH AMERICAN TRANSIT OPERATIONS

A. OVERVIEW

Over the last 10 years North American transit system have tested, demonstrated and placed into service a variety of alternative fuelled vehicles. The reasons for pursuing alternative fuels vary but generally include:

- a desire to meet clean air requirements;
- concerns about energy security; or
- expectations of operating cost reductions.

The alternative fuels utilized in internal combustion bus engines have included compressed natural gas, liquid natural gas, propane, methanol, ethanol, hydrogen, and biodiesel. In addition, several alternative propulsion systems have also been developed and are in varying stages of refinement or acceptance. These technologies include dual propulsion (trolley & diesel), battery, hybrids (including various combinations of flywheels, batteries, natural gas and diesel energy sources powering electric traction motors) and fuel cell. One transit property is addressing the clean air issues by participating in a redesign of the coach itself to reduce the weight of the vehicle, and thereby reduce energy consumption and the resultant emissions.

Compressed Natural Gas (CNG) has emerged from this crowded field to become the leading alternative fuel for use in public transit applications. Exhibit III-1 shows that there are about 50,000 transit buses operated by members of the American Public Transit Association (APTA) in Canada and the USA. The majority of these vehicles are standard 12 metre urban transit buses, although the statistics also include some smaller shuttle buses, as well as 18 metre, 10 metre and 8 metre transit buses. In 1995 about 6.4% of the total fleet operated on some form of alternative fuel (i.e., a fuel source other than neat diesel).

Exhibit III-2 indicates the breadth of fuel choices adopted by North American transit systems. Exhibit III-2 shows that CNG is utilized by about 2% of the total transit fleet in 1995. This is more than double the next most popular fuel, methanol, which held about 0.8% of the market in 1995.

Exhibit III-1. Existing Fleet Makeup for APTA Members in Canada and USA

	Number of Transit Systems Reporting	Number of Vehicles Reported	Number in Active Service		Number Using Alternative Power Sources*	
	No.	Total No.	No.	% Fleet	No.	% of Fleet
Commuter Rail	14	4,687	4,547	97.0%	2,474	52.8%
Commuter Locomotive	12	532	509	95.7%	192	36.1%
Demand Response	188	6,950	6,613	95.2%	976	14.0%
Ferry Boat	6	50	49	98.0%	1	2.0%
Heavy Rail	14	10,433	10,236	98.1%	10,427	99.9%
Light Rail	19	1,275	1,091	85.6%	1,275	100.0%
Motor Bus	236	50,344	48,381	96.1%	3,247	6.4%
Other Rail	6	83	77	92.8%	31	37.3%
Trolley Bus	5	1,028	885	86.1%	1,028	100.0%
Vanpool	24	1,960	1,911	97.5%	0	0.0%

* Percentage of vehicles powered by anything except direct diesel drive however, percentage includes diesel engines with particulate traps.

Source: American Public Transit Association Statistics

Exhibit III-2. Motor Buses in Service by Fuel Type (1995)

Motor Bus	Number	% of Total
Compressed natural gas	938	1.9%
Compressed natural gas & diesel	79	0.2%
Compressed natural gas & gasoline	57	0.1%
Diesel & bio or soy fuel	25	0.0%
Diesel & ethanol	5	0.0%
Diesel fuel*	48,050	95.5%
Electric battery	39	0.1%
Electric battery & propane	2	0.0%
Ethanol	19	0.0%
Ethanol & diesel	58	0.1%
Gasoline	234	0.5%
Gasoline & propane	14	0.0%
Jet fuel	52	0.1%
Liquefied natural gas	64	0.1%
Liquefied natural gas & diesel	283	0.6%
Methanol	396	0.8%
Propane (liquefied petroleum gas)	29	0.1%
TOTAL	50,344	100.00%

Source: American Public Transit Association Statistics

* Includes engines with particulate traps.

Exhibit III-3 presents information regarding the market for new transit buses in Canada and the USA. The table provides the number of buses built in 1995, and the number of buses ordered during the first six months of 1996 by manufacturer, and by fuel type. The table also includes a forecast, by fuel type, of anticipated or planned orders for the remainder of 1996. This table shows interest in alternative fuels is strong, and CNG is the most popular choice. In 1995, 11.2% of all bus deliveries were powered by CNG. During the first six months of 1996, 19.2% of all bus orders were for natural gas buses. The projected market share for CNG for the remainder of 1996 and 1997 is projected to be only 9%, however, more than 20% of planned orders have not yet had a fuel choice confirmed. This exhibit shows there is also a continuing interest in liquefied natural gas. Other fuels are continuing to attract interest, however, they are capturing a very small part of the market. Future technologies such as propane, hybrids, and fuel cells have not yet begun to show up in measurable quantities on the order books of the manufacturers of full size transit buses. These propulsion options remain at the demonstration or prototype stage.

Exhibit III-3. New Bus Market by Power Source 1995 -- 1997 APTA Members Canada and USA

Power Source	Built in 1995		On Order Jan-Jun 1996		Planned Orders Jul-Dec 96 & 1997[2]	
	No.	%	No.	%	No.	%
Compressed natural gas	354	11.2%	1,162	19.2%	424	9.0%
Diesel (inc particulate trap)	2,756	87.0%	4,749	78.5%	2,749	58.4%
Electric catenary	3	0.1%	60	1.0%	250	5.3%
Gasoline	47	1.5%	31	0.5%	0	0.0%
Liquefied natural gas	3	0.1%	31	0.5%	267	5.7%
All others	5	0.2%	14	0.2%	56	1.2%
Undecided	NA	NA	NA	NA	962	20.4%
Total	3,168	100.0%	6,047	100.0%	4,708	100.0%

1 Data from APTA survey including about 75% of bus transit vehicles. Includes motor bus and trolley bus

2 Data for 1996 and 1997 plus a few orders extending into future years. Data are tentative.

Source: American Public Transit Association Statistics

Methanol is being discontinued as a motive fuel for heavy duty applications. For example, the major user, the Los Angeles County Mass Transit Authority, is now seeking replacement fuels or engines for its 330 bus methanol fleet. Liquefied natural gas has been limited to fleets located in close proximity to LNG plants. Ethanol, biodiesel and soy diesel have so far attracted interest only in regions where there is an abundant local supply of the fuel stock. Battery propulsion is generally limited to small buses.

The review of North American transit experience with alternative fuels therefore concentrates on compressed natural gas since it is the most widely available OEM product on the market today.

B. COMPRESSED NATURAL GAS

1. Pierce County (Tacoma)

Pierce Transit, in Pierce County adjacent to Seattle, is one of the largest and earliest proponents of CNG in the USA. Today the transit system operates 58 standard CNG buses, out of a total fleet of 193 standard buses. Fifteen additional CNG Orion buses are on order. Pierce Transit has had CNG coaches in their fleet since the first experimental models were tested in 1986. They received their initial order of OEM, CNG coaches in 1991. Pierce Transit operates in a similar climatic zone to Vancouver, and serves a population of 600,00 residents in a service area of 450 square miles. The Puget Sound region in which it operates faces air quality issues similar to Greater Vancouver.

All of the CNG vehicles at Pierce Transit are powered by Cummins L-10 gas engines. The earliest models were rated at 240 bhp, the later units were rated at 260 bhp and the next order will be equipped with 280HP units. The Pierce Transit CNG vehicles are among the highest mileage alternative fuel vehicles operating in the United States. The agency anticipates being a 100% CNG fleet by 2003 based on the current vehicle replacement schedule.

The performance of the fleet was tracked as part of a national study of alternative fuels for transit by the National Renewable Energy Laboratory (NREL). The Pierce Transit fleet operated both natural gas and diesel versions of the L10 engine. The long term study found that the CNG buses had the same rate of road calls as the Cummins diesel engines in the Pierce fleet (0.21 calls per 1,000 miles). Total maintenance costs were found to be almost identical, at $161 per 1,000 miles for the CNG buses and $159 per 1,000 miles for the diesel buses.

The CNG engines were found to be about 20% less fuel efficient than the diesel engines (4.5 miles per gallon for CNG compared to 5.8 mpg for diesel). The NREL study found the fuel cost of the CNG to be about $116 per 1,000 miles, compared to $112 per 1,000 miles for diesel. At the time fuel was being purchased from the local, regulated utility. Today Pierce is purchasing gas directly from wholesalers or the spot market. This has reduced the price of the fuel by up to 30%.

Engine overhauls on the CNG L10 are forecast to be necessary at 400,000 miles. The highest mile vehicles presently have only 200,000. Pierce Transit typically overhauls diesel engines at approximately 200,000 miles.

The additional cost of the CNG buses is mitigated by a federal grant ($5,200) and today's lower fuel costs. The State of Washington does not offer any incentives for alternative fuel vehicles. CNG vehicles in Washington are exempt from emissions controls inspections, and pay an annual fee, based on gross vehicle weight instead of motor fuel excise taxes. Pierce Transit presently maintains approximately 20% spares. This ratio has improved slightly as new CNG buses have been added to fleet. According to the Federal Transit Administration the spares ratio at Pierce Transit in 1994, prior to large scale purchases of CNG buses, was 22.4%.

2. Sacramento

Sacramento Regional Transit operates a fleet of 200 standard transit buses. There are presently 95 CNG buses in the fleet, and 40 additional units are on order, 30 as replacements and 10 for fleet expansion. The original 95 buses are equipped with Cummins L10 240G engines, however the new units will be equipped with L10-280G power plants. They will be replacing buses equipped with DDC 6V92 engines. Sacramento does not operate any Cummins diesel engines. All of the CNG buses are Orions.

The oldest CNG engines in the fleet are approaching 200,000 miles, and rebuilds are anticipated at 250,000 to 350,000 miles. The DDC 6V92 engines are generally rebuilt at approximately 200,000 miles. The actual timing of a rebuild is based on an ongoing oil sampling and analysis system.

The installation of the compressor station and modifications to the maintenance garage cost $3.2 million (US) in 1993. The refuelling facility can refuel a bus in 3 minutes, is equipped with an off-load facility and can accommodate 3 buses at a time. Funding for the modifications and the additional initial cost of the buses came from Pacific Gas and Electric (PG&E), the Federal Department of Transportation and a local sales tax. The transit authority is now purchasing their gas on the spot market, and PG&E only provide the transmission service. The compressor station is owned and operated by Regional Transit. In lieu of a fuel tax on CNG, the State of California charges a flat alternative fuel tax of $170 per CNG bus. In September 1996 the diesel fleet averaged 7,456 miles between road calls for all causes, not just fuel related, while the new CNG fleet averaged 6,564 miles. During this month the system was experiencing problems with the CNG fuelling stations. This resulted in the buses receiving only about 80% of a complete fill. This resulted in a large number of instances of roads calls for buses that ran out of fuel.

The diesel fleet at Sacramento in September 1996 had an average fuel consumption rate of 3.31 miles per gallon, and oil consumption of 207 miles per quart of oil. The CNG buses averaged 2.31 miles per gallon, and 602 miles per quart of oil.

From July 1, 1996, to September 30, the average operating cost per mile for the diesel buses was $0.51 ($0.22 for fuel and $0.29 for maintenance). The operating cost per mile for the same period for the CNG buses was $0.335 ($0.108 per mile for fuel, $0.031 per mile for compression of the CNG and $0.196 for maintenance). It should be noted that maintenance costs are not directly comparable. The diesel buses are much older than the CNG buses and would be expected to have higher maintenance costs. Older buses generally run fewer miles per year and show higher maintenance costs per mile (or kilometre). These maintenance costs are usually overstated since the lower number of miles must absorb many fixed maintenance costs such as cleaning and overhaul. Therefore, little weight should be placed on comparisons unless the CNG and diesel engines are approximately the same age.

Sacramento presently operates with 19% spares. In 1994, prior to delivery of the CNG buses, the FTA reported a spares ratio of 20.9% for the RTA.

3. Monterey Salinas Transit

Monterey Salinas Transit (MST) serves a sprawling, low density urban agglomeration along the central coast in California. The system operates a fleet of 77 buses including 69 diesel buses powered by DDC 6V92 engines, and eight DDC Series 50 G buses introduced in 1995. All of the buses were built by Flxible. They also have on order 18 new buses equipped with Cummins L10 gas engines.

The property has not been entirely satisfied with the performance of the Series 50G engine. Some of the specific complaints include:

- Excessive noise and vibration, resulting in homeowner complaints;
- Requirement for special low ash oil;
- Short spark plug life of 10,000 to 12,000 miles;
- Computrol valve failures (now being replaced with a DDC unit); and
- Need for reprogramming of DDEC unit, engines quickly go out of tune.

The CNG coaches have also had problems with the 12 volt electrical system and the methane detection and fire suppression systems. On site they have a slow fill system, however, it is poorly located and designed, and requires the buses to backup into position. Consequently they usually fuel the buses at an adjacent municipal works yard where the fast fill system can refill a bus in 17-22 minutes.

During the summer of 1996 the average fuel cost per mile for the diesel coaches was about $0.1609 per mile. The fuel cost per mile for the CNG coaches is about $0.1996 per mile for the same period. The average distance between road calls was 8,311 miles for the diesel fleet, and 4,734 miles for the CNG vehicles. Maintenance data were not available. MST operates with approximately 20% spare vehicles.

4. South Coast Area Transit (Oxnard/Ventura County)

South Coast Area Transit (SCAT) operates 29 CNG buses and 9 diesel coaches in Ventura County California, between Santa Barbara and Los Angeles. The decision to switch the entire fleet (9 additional CNG buses are on order) was made to reduce nitrogen oxide emissions and reactive hydrocarbons. The 29 CNG coaches were supplied by Flxible and are powered by DDC Series 50G engines.

The compressor station is owned and operated by SCAT, and is powered by two Caterpillar 4608 natural gas engines. An off-load facility was not incorporated into the design of the fuelling station. The use of natural gas for compression is believed to be saving about 0.3 cents/Ldeq over the use of electricity.

The Series 50G engines have had some problems with fan belts, short spark plug life (12,000 miles + 3,000 miles after cleaning), the ignition system, the compuvalve and coalescing air filters and fuel filters. The compudyne fuel tanks are inspected every 6,000 miles and recalibrated once per year.

The CNG buses are obtaining about 2.3 to 2.5 miles per gallon diesel equivalent compared to 3.5 - 4 miles per gallon of diesel fuel.

Maintenance costs and road call experience were not available. Reported problems include electrical system (12 volt) and the Amerex detection and fire suppression system.
SCAT presently operates with a spares ratio of about 17%. Prior to delivery of the CNG buses the system operated with a spares ratio of up to 27%.

5. Los Angeles MTA

Los Angeles County Mass Transit Authority (MTA) operates a total of 2,374 buses, including 464 alternative fuelled transit buses. The agency plans to have a 100% alternative fuel fleet by 2005. The agency is supporting the development of an advanced design transit bus that will reduce the curb weight by 9,000 lbs. The MTA is also planning to purchase 5 hybrid-electric buses for testing. The fleet includes 150 CNG buses at the present time, and 200 additional units are on order. The current fleet is composed of Neoplan coaches equipped with Cummins L10 engines. Two operating divisions are presently capable of handling CNG buses and a third is coming online. The fleet presently operates with a spares ratio of about 18%.

The MTA has reported that operating costs of their CNG fleet are equivalent to the operating costs for clean diesel coaches, however the capital costs have been up to $60,000 (US) greater. The installation of retarders has significantly improved brake life. Prior to installation of the retarders the CNG buses required brake relines at between 9,000 and 12,000 miles. The interval between relines has now been extended to 16,000 to 20,000 miles with the installation of retarders compared to 40,000 miles for diesel. Direct comparisons of maintenance costs of similar diesel and CNG buses were not available.

Division 15, in Sun Valley, in the San Fernando Valley was the scene of a CNG tank rupture in August 1996. The tank ruptured while the bus was being refueled. There was no fire, and no one was injured, however, the bus sustained major damage. The MTA believes the cylinder that ruptured was stressed and weaken as a result of damage caused by being dropped prior to installation, or as a result of a major impact during bus operations (the tanks are located under the bus). As a result of the incident, a metal protective shield is being installed, and an extensive inspection of all CNG tanks has been undertaken. The fleet is being operated at reduced pressures (2,400 lbs) until a definitive cause is identified. With the new shields, visual inspections of the tanks will be done with brake inspections every 1,000 miles. Every 6,000 miles the shields will be removed and a more complete inspection completed to ensure that no bolts are rubbing the tanks or that securement straps have not shifted.

The compressor station at Division 15 was originally designed to deliver 600 cubic feet per minute, and was recently upgraded to deliver 1,200 cubic feet per minute. This decreased the fuelling time from 14 minutes to 10 minutes.

6. San Diego

San Diego Transit Corporation operates 50 CNG buses, and has 50 vehicles on order. In addition 50 CNG buses are operated and maintained under contract on behalf of the Corporation. The 50 vehicles being operated by the Corporation are Neoplan coaches equipped with DDC Series 50G engines. The property does not operate any Series 50 diesel engines.

The compressor station was built and is operated by San Diego Gas and Electric. They charge a premium of 5% on the price of the gas to cover the cost of compression. The fuelling station can refuel one bus at a time in 8 minutes. No additional staff were required to compensate for the slower refuelling process.

The first 4 CNG coaches placed in service have now travelled 50,000 miles. There has been one turbo charger failure, and spark plugs are lasting about 18,000 miles. The fuel consumption of the Series 50G engines has been about 2.7 miles per diesel gallon equivalent. The 6V92 diesel engines operated by San Diego Transit average about 3.2 miles per gallon.

San Diego Transit is anticipating that overhauls will be necessary at approximately 240,000 miles. The DDC 6V92s are overhauled approximately every 100,000 miles. There have been some complaints raised about the low rumble emitted by the engine.

The Series 50G engines have not produced an excessive number of road calls. Brake life is about 18,000 miles rather than the 40,000 miles experienced on the diesel coaches. No other concerns regarding maintenance were reported.

7. Toronto Transit

Description

The Toronto Transit Commissions (TTC) has 25 standard, 40 foot, Orion Vs in operation equipped with Cummins L10 -240 natural gas engines. Out door fast fuelling is available at one garage. The buses started operation in 1989 and have accumulated an average of 330,000 km per bus. The highest mileage for a bus is 357,000 km. It should be noted that TTC was one of the first properties, along with Hamilton and Mississauga, to use the early production models of the Cummins natural gas engine. Engines technology has been refined since the first generation of Cummins engines.

TTC decided to implement natural gas buses in response to local and provincial concerns about the environment that were forcing adoption of either new trolleys or CNG buses. Management supported the CNG initiative because of attractive financial projections with all infrastructure paid for by the province and a 75% subsidy on bus purchases.

In addition to the original order of 25 natural gas buses, 50 new Orion high floor buses with Cummins L10 natural gas engines have gone into service in the last several months. Fifty (50) low floor Orions equipped with L10 natural gas engines are on order, with delivery expected in mid 1997. No additional natural gas buses are anticipated after all 125 buses are in service.

TTC spares ratio for their entire bus fleet is about 15% and has not been adjusted for natural gas buses.

Operations and Maintenance

The operating range of the original Orion Vs is 585 km but due to less than complete fills and sticking cylinder solenoid valves, this range had not always been achieved and resulted in about 360 maintenance incidents over two years (1992 - 1993) according to a report published by the Ministry of Transport of Ontario (MTO).[21] The problem with the fuelling station continues and as a result, buses have been placed on shorter runs pending refinement of fuelling station controls. The average trip length is 239 km.[22]

MTO also reported that the ignition system, particularly spark plugs and spark plug wires required significant maintenance efforts, as well a catalyst repairs. MTO went on to report that the overall maintenance record of the fuel system and engines had improved and were comparable to diesel buses. No comparative cost data was available. Availability of CNG buses was reported as being comparable with diesel.[21]

MTO reports that the maintenance of the ignition system will introduce some extra costs but cost data related to maintenance and repairs is not collected.[22,23] In an interview with TTC, they expected maintenance cost

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21 "Ontario's Experience with Natural Gas Powered Buses", Ministry of Transportation of Ontario, October 1994.

22 Status Report to the NG Bus Working Committee", Ministry of Transportation of Ontario, June 1996.

23 Telephone Conversation with MTO, October 1996.

would be the same for diesel and natural gas engines with the latest technology.

With respect to engine life, MTO did not believe that there was enough data and experience with the L10 engine to conclude that engine life would differ from a comparable diesel engine.[23] In discussions with TTC, they concurred that no conclusions could yet be made regarding engine life, although oil analysis had found much cleaner oil than for diesel buses.

TTC experience with fuel consumption is described in the chapter on Life Cycle Cost Analysis.

Fuel Costs

TTC reported fuel cost as follows (similar costs apply to other Ontario properties):

- Diesel — 48 cents/L
- Average cost of gas — 15 cents/Ldeq
- Electricity cost — 5 - 6 cents/Ldeq (expected to drop to 2 cents/Ldeq with additional 100 buses)

8. Hamilton Ontario

Hamilton Street Railway (HSR) plans to replace its entire 200 bus fleet with natural gas buses in response to environment pressures of the late 1980s and early 1990s. The province's 75% subsidy of capital and 10% sales tax rebate on alternative fuel buses was also instrumental in HSR's decision. HSR's spares ratio is 15% and has not been adjusted to account for natural gas buses.

Hamilton Street Railway (HSR) originally converted eight GMCs using IVECO engines in the late 1980s. Two of these 1977 vintage buses have been retired. In 1991 and 1992, HSR introduced 30 OEM Orion series V transit buses with Cummins L10 gas engines. The 1991 Orions have accumulated an average of 316,000 km per bus; the 1992 series buses have accumulated an average of 258,000 km per bus.

In September 1996, 25 Flyer low floor buses with DDC series 50 G engines went into service. These new buses have apparently operated very well so far, with one solenoid valve problem. Average mileage is about 6,400 km per month. An additional order of 25 Orions with Cummins gas engines is expected in 1998.

As detailed in the life cycle cost analysis, HSR has reported no increase in routine maintenance but has experienced engine and radiator problems that were covered through warranties for the original 30 Orion buses. Testing has indicated that oil has been retaining its properties longer than diesel but no conclusions have been made with respect to engine life.

9. Mississauga

Mississauga Transit purchased 11 CNG Orion CNG transit buses in 1993. A slow fill outdoor fueling facility was installed at one garage. The average mileage per bus to the end of May 1996 was 226,000 km compared with 340,000 km for comparable diesel buses. Fuel consumption has averaged 67 Ldeq/100 km. (No data is available for comparable diesel buses.)

Since the introduction of the CNG buses, Mississauga reports that it has closely monitored operating costs. In 1995, the costs for repair (maintenance and labour) averaged about $19,135 compared with $13,776 for diesel buses. On average, the operating cost of a CNG bus was $5,360 more than a diesel bus. Three engines had to be rebuilt with less than 200,000 km on them. [24,25]

Given higher operating costs, new diesel engines that meet emissions standards, and the extra $64,000 premium for a natural gas bus, Mississauga has decided not to purchase any more CNG buses. Furthermore, because Mississauga had budgetary approval to purchase another 77 buses, the capital cost savings would mean that an additional nine diesel buses can be purchased to replace older stock.

C. OTHER FUELS

1. St. Louis -- Biodiesel

The Bi-State Transit Authority in St. Louis operates five 6V92 engines on a blend of 80% diesel and 20% soybean derived oil as part of the NREL evaluation of alternative fuels. The five biodiesel buses were matched with a control fleet of five buses with 6V92 engines running on diesel. The test ran into significant problems related to fuel contamination and the blending of the constituent fuels. The problems reduced the reliability of some of the data collection and test results. The NREL did determine that the fuel costs were significantly higher for biodiesel ($329 per 1,000 miles, for

[24] Mississauga Transit Report, March 1996.
[25] Telephone Conversation, Mississauga Transit, October 1996.

biodiesel, compared to $142 per 1,000 miles for diesel). Biodiesel blends have also been tested in Cincinnati (Soybeans) and Boston (methyl ester).

Biodiesel produced from soybean is presently selling in US markets for about $0.79 per litre. NREL has estimated that this price can be reduced to $0.38 per litre for biodiesel utilizing recycled fats and oils. NREL is also sponsoring research to convert coal power plant flue gas into biodiesel using microalgae for a projected price of $0.31 per litre (by 2015).

2. Halifax, Corpus Christi and Denver -- Propane

In 1996 NREL in cooperation with Detroit Diesel began a development program for the use of propane as a fuel for standard urban transit buses. The development program supported development of pre-production engines and placement of prototype DDC Series 50 LPG equipped buses in revenue service in Halifax, Corpus Christi and Denver. The buses will be operated for up to one year in order to evaluate fuel consumption, maintenance costs and reliability. The demonstration of revenue service should begin in late 1996.

3. Portland -- LNG

TriMet in Portland, Oregon operates a fleet of Cummins L10 240G engines fuelled by liquefied natural gas (LNG). During the NREL test, the performance of 8 LNG engines was compared to 5 Cummins L10 diesel equipped buses. The LNG buses had 50% more road calls for engine and fuel related systems than the control diesel fleet. The leading cause of the road calls (16 of 172 calls) however was fuel leak detection alarms. False warnings were found in 75% of the alarms, and replacement of the sensors has reduced the problem. The LNG buses were about 30% less efficient than diesel buses and the NREL found them to be less fuel efficient than the CNG buses. NREL attributed the difference to the greater idle time recorded by the LNG buses. TriMet staff believed that additional idle time was required to control pressure buildup and venting of the tanks. The maintenance costs for the LNG engines were found to be slightly higher than the Cummins L10 CNG engines operating at other properties. The cryogenic pumps included on the L10 LNG engines were a maintenance problem that has now been resolved with a newer engine design that eliminates the fuel pump.
Overall LNG buses were more expensive than CNG buses (and diesels) due to the lower fuel efficiency and the higher maintenance costs. The capital cost for refuelling and maintenance facilities for CNG and LNG were also found to be very similar.

The Oregon Department of Energy offers a small scale loan program for conservation and renewable resource related projects that may be used for Alternative Fuel projects. State regulations require that mass transit vehicles purchased after July 1, 1993, be capable of operating on alternative fuels to the maximum extent economically possible. State regulations also allow investor owned utilities to offer money to customers to help purchase vehicles and infrastructure for CNG.

4. Miami & New York -- Methanol

Miami and New York were among 10 U.S. and Canadian transit properties that operated methanol powered transit buses. The largest fleet, 330 buses, was operated by the Los Angeles MTA. Methanol engines are no longer being produced, fuel prices have increased and the remaining fleets are phasing out their methanol buses. Five buses in the Miami and New York fleets were selected for the NREL alternative fuel evaluation project. The evaluation found that methanol buses were very expensive to operate. Both New York and Miami found that the neat methanol 6V92 buses were twice as expensive to operate as 6V92 diesel equipped coaches.

5. Minneapolis & Peoria -- Ethanol

Minneapolis and Peoria operate 6V92 engines powered by a blend of either 93% or 95% ethanol, and diesel. The ethanol buses cost up to four times as much to operate and maintain as those with 6V92 diesel engines. Fuel quality problems accounted for a large number of road calls. In Peoria the ethanol powered coaches had a road call rate (fuel and engine related) about 40% greater than that of 6V92 diesel buses. At Minneapolis the ethanol buses actually had a slightly lower rate of road calls than the diesel control fleet. DDC recently received emission certification for its 6V92 ethanol engine. This engine is being used by Los Angeles MTA to replace some of the methanol engines now in operation.

6. Honolulu & New York -- Hybrid

TheBus in Honolulu is conducting a revenue service demonstration of two hybrid-electric buses. The first was built by Kaman Electromatics and is a standard NovaBus RTS 06 model, 12 metre transit bus. The bus uses a propane rotary engine to power a 70 kW generator set to create electricity for a single electric traction motor. The second bus is a 30 foot mini-bus built by El-Dorado National. The NovaBus utilizes large banks of nickel cadmium batteries that are also charged by a regenerative braking system. Although the vehicle is not expected to be able to withstand the rigors of daily transit service, a series of upgrades are planned to improve the prototype components. The technology is being viewed by TheBus as an alternative until fuel cell powered buses are viable.

New York purchased 5 hybrid-electric buses from Bus Industries of New York (Orion). The buses are powered by a Cummins natural gas engine which drive electric traction motors. Results from the demonstration fleet are not yet available.

D. LESSONS LEARNED

Compressed natural gas is the most mature alternative fuel choice available to transit systems. CNG is in use at about 40 transit properties in Canada and the USA. The most successful CNG programs have been in transit systems where strong support for the fuel is apparent at all levels of the organization. Most transit systems which have switched to CNG have done so in order to support or meet clean air objectives or regulations. Properties generally do not face significant financial roadblocks to shifting to CNG. The additional financial support available to transit properties from sources such as increased federal funding, dedicated sales taxes, car excise taxes, air pollution funds, and from the sale of pollution credits can actually make the acquisition CNG buses less expensive than clean diesel buses. In some US jurisdictions natural gas fuel costs are presently equivalent or even more expensive than diesel fuel.

There are several other fuels in use, including, hybrids, ethanol, LNG, biodiesel, propane. However, many are in test or demonstration projects, and none of these other fuels has proven as economical, or reliable as CNG. The technology itself for CNG has been evolving over the last ten years, and has become noticeably more reliable. Cummins engines are probably the most highly evolved gas engines, although they are still faced with relatively short spark plug life. The DDC series 50G has not been in service long enough to form any long term reliability or maintenance impacts. Emissions results are continuing to improve for CNG engines, particularly as electronic and tamperproof controls are developed.

Some of the specific lessons of the US experience include:

a) Keys to Success

- Adoption of CNG has been in response to public and political concern about the environment;
- Successful alternative fuel programs have not had any negative impact on the amount, and level of service being offered to passengers;
- A strong commitment to alternative fuels at all levels of the organization are required for a successful program;
- Successful programs have also included a strong training component to ensure that drivers, fuelers and maintenance personnel are comfortable with the vehicles;
- The most successful operations had fleets that met a critical mass of at least 50 coaches at a operating base (garage).
- CNG is the most viable alternative fuel available today based on availability of fuel and engines, and maturity of the technology.

b) Risks and Concerns

- Ancillary onboard components such as 12 volt electrical systems, and methane detection and fire suppression systems have been problematic in some sites;
- No major US properties have implemented an alternative fuel while introducing a change in level service such as introduction of low floor buses/accessible service.
- Although CNG buses are operating in about 40 North American transit properties, there is limited standardization for fuelling station design, and building modifications;
- Successful implementation also requires strong backup and support from the natural gas utility and key suppliers including the engine, chassis and fuel system manufacturers.
- Incidents in Los Angeles (fuel tank rupture) and Thousand Palms (garage fire/explosion) are strong reminders that the fuel system must be respected, inspected, maintained and proper safety equipment installed.
- Some properties have been able to successfully integrate engines and vehicles from different suppliers.

IV. BC TRANSIT PILOT CNG BUS TESTS

A. DESCRIPTION

BC Transit purchased 25 CNG buses in 1994. The 25 vehicles were delivered and placed into service beginning in November 1995. The buses are 12 metre suburban transit coaches built by New Flyer, and are equipped with DDC series 50G engines, and include underfloor CNG tanks.

BC Transit purchased the vehicles as a pilot fleet to identify the impacts of regular revenue service with state of the art vehicles. BC Transit has been testing and demonstrating various CNG technologies since 1985. However, the New Flyer/DDC pilot program represents the first large scale adoption of CNG for urban transit use in Western Canada. The BC Transit pilot is an operational demonstration that was designed under the constraints of the operating environment. The pilot is not an in-depth scientific study.

In the pilot program, 10 of the 25 natural gas buses were selected at random for performance monitoring. In addition, 10 similar vintage New Flyer low floor diesel buses with DDC Series 50 were selected as a control group. There are some differences between the two vehicle groups that limit a scientific comparison of the results. The CNG buses operate from the Port Coquitlam Transit Centre and serve suburban routes, many of which include express service via the Barnet Corridor to downtown Vancouver. The diesel buses are based at the Burnaby Transit Centre, and serve urban routes in Burnaby and Vancouver. BC Transit was not able to base the buses in the same operating centre because of the different configurations (urban versus suburban) of the vehicles and current fleet and traffic requirements. BC Transit found that it was not possible to find routes based at each garage that shared the same operating characteristics or duty cycle. Similarly they found that it was not possible to quantify the differences between the routes due to ever changing traffic, and passenger load patterns. It is notable that BC Transit appears to be the only transit fleet in North America presently operating both CNG and diesel versions DDC Series 50 engines.

The specific differences between the CNG and diesel buses in the test that limit the comparability of the data are:

- The duty cycles, including passenger loads, idle time, stops per day, average cruising speed, and grades, for the two groups of vehicles may not be similar;
- The weight of the New Flyer high floor chassis is 1050 kg heavier than the chassis of the low floor bus, not including any weight difference due to fuel type (e.g., CNG cylinders);
- The buses are being operated and maintained from two different divisions, which potentially have different morale, attitude or manpower issues that could impact on bus performance;
- The same drivers do not operate the two groups of buses; and
- Although the two groups of buses have the same transmissions they do not have the same axles, wheels, brakes or suspensions, all of which could be impacted by the additional weight of the CNG components.

BC Transit began collecting data for the two bus fleets on May 1, 1996. In October 1996 BC Transit presented a report to their Board of Directors on the results to date. The data in the report included:

- Bad Orders;
- Road Calls;
- Warranty and Deficiencies;
- Fuel and Oil consumption;
- Maintenance and Operating Costs;
- Kilometres Operated.

Some of the concerns regarding the initial design of the pilot project included:

- Until December 1996, the fuel and oil information collected at Burnaby was manually recorded, while the Port Coquitlam information was recorded automatically.
- Until December 1996, the distance travelled (in km) data for Burnaby was estimated from the booking sheets and is subject to significant errors, while the distance travelled (metreage) by the Port Coquitlam buses was recorded automatically.
- Labour and cost data has not been available for specific components that could be impacted by the fuel choice.
- Road call and bad orders do not specifically list types of issues of interest to the study such as ancillary equipment (i.e. Amerex methane detection and fire suppression system) and running out of fuel, or failure to be able to fuel (signifying reliability problems with compressor station).

B. IMPROVEMENTS RECOMMENDED

The initial design of the pilot project raised a number of issues that cast some doubts on the validity of the comparisons being undertaken. Sypher recommended several steps that should be taken to improve the likelihood of obtaining useful and reliable data. These steps included:

1. a) Operating the Series 50 diesels from Port Coquitlam, or as an alternative;
   b) Expanding the pilot program to include small fleets of identical diesel control buses in Burnaby and Port Coquitlam. These identical buses could be drawn from the 4200 group of MCI Classic buses which are operated from both Burnaby and Port Coquitlam. The inclusion of these buses in the trial would provide a direct comparison between operating conditions at the two garages, and would assist in interpreting the results from the comparison of the DDC Series 50 fleets in the program.

2. Bringing the Burnaby operating centre online for automated fuel , oil and mileage data collection as early as possible (online since December 1996).

3. Downloading the engine performance and operating data from DDEC electronic engine control systems on the CNG and diesel Series 50 engines. Each DDEC unit can store up to 30 days of engine information including engine speed, idle time, etc., that could be useful in analyzing the performance of the pilot vehicles.

4. Ensuring that all data presented on the performance of the vehicles in the pilot project is presented on similar scales (i.e. per kilometre).

5. Ensuring that maintenance data segregates costs associated with the fuel choice, including ancillary impacts such as the impact of the additional weight, or related systems such as the Amerex methane detection and fire suppression system.

IMPROVEMENTS MADE

Since the initial design, BC Transit has made definite improvements in its data collection including: use of similar scales for comparing data, segregating out fuel and engine related information, implementing the Fuel Data Capture System at Burnaby, and establishing diesel control fleets.

In the March 6th draft report to its Board of Directors, BC Transit reported higher warranty claims and increased number of bad orders and road calls. At this time, the warranty claims are not true costs to BC Transit except for additional labour time. The data does indicate that there are still reliability issues that could be of concern. However, the March 6th draft report does not outline which components were failing nor the frequency of failures. There were no indications in the report of progress that DDC or New Flyer were making in solving reliability problems. In conversations with DDC, they indicated that they were planning to introduce a new fuelling system by January 1998 to replace the GFI Compuvalve. With respect to exhaust valve damage, DDC reported similar problems in other fleets but that the reasons for the failures were not completely understood as of March 1997. DDC does plan to upgrade its engines when a solution is found. DDC also reported that problems with the gas detection system were not wide spread. Other problems such as the regulator and tank solenoid valve were apparently being dealt with by New Flyer. It is reasonable to expect that improvements will be made but there is some uncertainty in the timing and extent of these improvements. Subsequent estimates of maintenance costs have taken these risks into account.

V. LIFE CYCLE COST ANALYSIS

A. DESCRIPTION OF ANALYSIS

Life cycle cost analyses were used to evaluate the financial implication of switching from diesel to an alternative fuel. As discussed in the previous section, CNG is the only alternative fuel for which the technology and infrastructure is sufficiently well developed and cost effective to be considered for the BC Transit fleet. A full life cycle cost analysis was conducted for two CNG bus purchase scenarios in combination with two fuel supply scenarios.

The life cycle cost analysis considers the incremental capital and operating costs of using CNG in comparison to diesel fuel over the expected life of the buses. Annual cash flows, the net present value (NPV) for the switch to CNG fuel are calculated. A discount rate of 8% is used in calculating the NPV. The costs considered in the analysis include:

- fuel costs;
- capital cost of buses, refuelling plant and building modifications;
- additional vehicle maintenance and operating costs;
- engine rebuilds; and
- additional staff, training and updating of procedures.

The analysis assumes that staff salaries, insurance, vehicle cleaning, administration and other overheads will be unaffected by a change from diesel to CNG fuel.

Use of natural gas fuel is expected to lead to a reduction in harmful exhaust emissions. However, the economic evaluation of the costs associated with these emissions is not within the scope of this study and any economic benefit due to the reductions in emissions were excluded from the analysis. Possible reductions in emissions due to the use of CNG are discussed in Section V.

B. CNG - DIESEL INPUT DATA

Data used in CNG-diesel life cycle cost analyses are described below. Where values are drawn from other studies, the factors influencing the values and the results of the studies are discussed.

1. Fuel Prices

The current prices of fuels for BC Transit are [26]:

- Diesel - $0.443 per litre (under new contract, previously $0.467/L)
- natural gas property line: $0.16 per litre diesel equivalent (Ldeq) or $0.154 per cubic metre [27]
- CNG - at filler nozzle: $0.26 per Ldeq excluding electricity cost
$0.275 per Ldeq ($0.264/m^3) including electricity cost

The diesel price includes the Federal excise tax of 4 cents/L, the local diesel urban transit tax of 4 cents/L, the provincial road tax on diesel (11 cents/L) and the effective GST. The "property line" price is for natural gas delivered by pipeline to the user before compression to 3000 psi. The "at filler nozzle" price refers to gas that has been compressed and is supplied to the vehicle. However, this cost excludes the costs of electricity which is charged directly on BC Transit's meter. The effective GST of 3% is charged on the total cost of the natural gas. There is currently no Federal excise tax on CNG.

BC Gas contributed $50,000 towards each of the 25 CNG buses purchased in 1996. To make this contribution it had to receive approval from the BC Utilities Commission which regulates the price charged for gas. BC Gas got approval from the Commission to not receive its usual margin for the gas supplied to these buses and to charge for the gas at BC Gas' cost plus a margin to cover the $50,000 they contributed towards the buses. This price is the $0.16/Ldeq charged at the "property line". The $0.10/Ldeq difference between the "property line" and "at filler nozzle" prices covers their costs for the refuelling plant.

If BC Transit purchases gas for any additional buses from BC Gas, the price charged for this gas should not be equal to the current price as this price includes a margin for recovering their contribution to the cost of the

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26 "Natural Gas Bus Cost Tracking and Maintenance Monitoring Pro gram", BC Transit report, September 1996.

27 Based on low heating value energy contents of 35.09 MJ/m3 for CNG, and 36.51 MJ/L for diesel. Source: BC Gas (CNG high heating value 38.6 MJ/m3 reduced by factor of 1.1 to convert to low heating value)

current buses. The price charged by BC Gas to commercial and industrial users is in the range 13-17 cents/m^3 depending on the level of usage and can be less for high volume users. The B.C. Utilities Commission has previously approved the sale of NG in excess of 80,000 Ldeq at a discount price of $0.11/Ldeq to a high volume user (see Appendix E). It is anticipated a similar discount would be approved for gas sold to BC Transit for the new buses[28]. Thus, in the analysis, the base case price of gas for any additional CNG buses is assumed to be:

- natural gas property line: $0.11 per litre diesel equivalent (Ldeq) or $0.106 per cubic metre
- CNG - at filler nozzle: $0.21 per Ldeq excluding electricity cost
  $0.225 per Ldeq ($0.216/m^3) including electricity cost

The price charged by gas utilities is, however, dependent on the wholesale price of natural gas. The wholesale price is forecast to increase at approximately 0.46% per year between 1995 and 2020 [29]. Since the wholesale price of natural gas accounts for about 70% of the "at property line" price and about 30% of the "at filler nozzle" price, the forecast wholesale price increase corresponds to an annual increase of about 0.33% in the "property line" price and 0.14% in the "at filler nozzle" price.

A draft of the 1996 Energy Outlook [30] forecasts of crude oil prices (WTI at Cushing) developed by NRCan gave the following predicted changes in crude oil prices:

- 1995 $US 17.5 /bbl
- 2000 $US 17.0 /bbl (1996 - 2000 annual decrease of 0.49%)
- 2005 $US 19.5 /bbl (2001 - 2005 annual increase of 2.03%)
- 2010 $US 22.0 /bbl (2006 - 2010 annual increase of 2.4%)
- 2020 $US 22.0 /bbl (2011 - 2020 zero annual increase)

These forecast percentage price changes were used, although short term, spot market prices can vary significantly from the forecast price. The component of the diesel fuel price attributable to the crude oil cost was obtained from the Transportation Energy Handbook (NRCan 1991). The crude oil component accounts for about 14.5 cents/L of the final cost. The change in the diesel price due to the change in crude oil price was found by increasing only the crude oil cost component (14.5 cents/L) by the annual

[28] Telephone conversation with Al Basham, Marketing Department, BC Gas on January 10th 1997.

[29] "Energy Outlook", Natural Resources Canada, 1996.

[30] 1996 Energy Outlook had not been finalized, values from a draft provided by NRCan.

percentage increases given above. Other cost components were assumed to remain constant. On average over the 25 years, the diesel fuel price paid by BC Transit is forecast to increase by 0.32% per year.

In the analysis, small increases of 0.33% per year in the natural gas "property line" price (0.14% in the "at filler nozzle" price) and 0.32% in the diesel price were included. In addition, the analysis was conducted for optimistic and pessimistic fuel prices. The pessimistic case assumes that a discounted price cannot be obtained and that BC Transit must pay the current 1997 "property line" cost. The optimistic case assumes the price is discounted by slightly more than the base case. In each case, diesel fuel prices increased by 0.32% per year. The natural gas "property line" prices were:

- optimistic case - $0.10/L deq and stable
- base case - $0.11/Ldeq, increasing by 0.33% per year ("at filler nozzle" price increasing by 0.14% per year)
- pessimistic case - $0.16/Ldeq, increasing by 1.0% per year ("at filler nozzle" price increasing by 0.43% per year)

2. Taxes

All purchases of fuel, parts and capital equipment are subject to the GST. For BC Transit, the effective GST is 3%. Applicable Federal excise must be paid on all transport fuels purchased. Currently, natural gas is exempt from excise tax, but the excise on diesel is 4 cents/L. The GST is levied on the total cost of fuel including all other local, provincial and Federal taxes.

The Provincial road tax on fuels must be paid by BC Transit This tax is 11.5 cents/L on diesel fuel and zero for CNG. However, BC Transit must pay the Provincial Sales Tax (PST) on all parts and equipment purchased and this tax is included in the life cycle cost analysis.

3. Fuel Consumption Rates

Fuel consumption rates are very dependent on the type and age of bus and the driving cycle under which the bus is driven. New buses, with the latest technology engines, are more fuel efficient than older buses. Buses driven in congested conditions with frequent stops and long idle times are less fuel efficient. In very congested conditions with average speeds of only 10 km/h, fuel economy is estimated to be 60% worse than in uncongested conditions with average speeds of 30 km/h[31]. Chassis dynamometer tests of

[31] Fuel consumption rates of 678 ml/km and 419 ml/km for average speeds of 10 and 30 km/h estimated using vehicle fuel consumption program, ARFCOM (Biggs,

Cummins L10 buses by the Ontario Ministry of Transport (MTO)[32] found the fuel efficiency to be 33% lower using the Central Business District (CBD) drive cycle (average speed 20 km/h) than when following the EPA heavy duty cycle (average speed 30 km/h). Thus, similar driving cycles are critical when comparing the energy efficiency of different fuel types. Results of comparisons of the fuel economy of different fuel types can be misleading if the study is not well designed.

Effect of Additional Weight

Currently, CNG buses weigh approximately 1,770 kg (14%) more than similar diesel buses due largely to the weight of the CNG storage cylinders[1]. These buses would be therefore be expected to have a lower energy efficiency than similar diesel buses. The effect of this additional weight was estimated using the vehicle fuel consumption estimation program ARFCOM[33]. Using several different driving cycles representative of transit buses (with frequent stops and long idle times), the additional weight reduced fuel efficiency by 7% to 8%. For cycles with higher average speeds (40 km/h) and fewer stops, the additional weight had less effect, reducing efficiency by 6%. Currently, natural gas engines are not more fuel efficient than similar diesel engine. Thus, the 7% lower fuel efficiency of CNG buses due to the additional weight represents an upper bound on the comparative fuel efficiency of CNG buses relative to diesel buses.

Newer design all-composite tanks can reduce this weight penalty significantly but at a cost.

BC Transit

In the current BC Transit project involving CNG and diesel buses with Detroit Diesel Series 50 engines and Allison transmissions, the fuel efficiencies (based on a seven month period) of the buses with the two fuel types, and the garage they are located, are as follows:

- diesel low floor buses 52 L/100km Burnaby garage
- CNG high floor buses 54 Ldeq/100km Port Coquitlam garage

The fuel efficiency of CNG buses in the BC Transit project was 4% lower than the diesel buses. However, the diesel buses in the project were operated out of a different garage than the CNG buses in the study and

D.C. (1988), ARFCOM User Guide, Australian Road Research Board, ATM 28), for typical 1995 bus.

32 T. Topaloglu and J.E. Turner, "Ontario's Experience with Natural Gas Powered Buses", Conference proceedings, pp. 173.

33 Biggs, D.C. (1988), ARFCOM User Guide, Australian Road Research Board, ATM 28.

much of their use was on routes with more stops and lower average speeds. As noted above, this can significantly affect fuel efficiency and the fuel consumption rate of the new Series 50 diesel buses at Port Coquitlam is likely to be lower than 52 L/100km observed for the Burnaby garage.

Data on a “control set” of buses operating out of each garage were provided by BC Transit to determine the possible effects of the different driving environments. The control buses were early 1990 model high floor buses with DDC 2 stroke engines. The fuel consumption rates of these older buses would be expected to be higher than buses with the new Series 50 engine due to the fuel efficiency improvements with the 4 stroke engine and the lower weight of the low floor buses. The average fuel consumption rates for the control buses were:

- Burnaby: 57.1 L/100km
- Port Coquitlam: 43.7 L/100km

The fuel efficiency of the diesel control buses at Burnaby is 9% lower than the new Series 50 diesel buses operating at that garage. Assuming the same efficiency improvement for the Series 50 diesel buses at Port Coquitlam, the fuel consumption rate for these buses would be 40 L/100km. Fuel consumption rates of this magnitude are low compared to rates reported by other transit properties (see discussion to follow), although the higher rates could in part be due to air conditioning at other sites. However, as indicated earlier, driving environment can effect consumption rates by at least 30%. The rates for the Series 50 buses are based on data for when the bus is less than a year old. The average rate over the 20 year life of the bus is expected to be a little higher. Due to the uncertainty in the fuel consumption rates of the new low floor buses with DDC Series 50 diesel engines operating out of Port Coquitlam, three average rates were used in the analysis:

- optimistic case - 50 L/100km
- base case - 45 L/100km
- pessimistic case - 40 L/100km

With the base case for diesel fuel consumption, the reported fuel consumption rate for CNG buses is 20% higher than for similar diesel buses. Under the pessimistic case, the fuel consumption rate is 35% higher for CNG buses, while in the optimistic case, the rate is 8% higher.

<u>Ontario</u>
The Ontario Ministry of Transport (MOT) initiated natural gas bus programs in Toronto, Mississauga and Hamilton. These programs started in 1989 and have accumulated over 6 years of experience. However, much

of this experience is with the first generation natural gas engines and buses which may not be representative of current model buses. The fuel economy of CNG and diesel buses, both using Cummins L10 engines, was tested on the Environment Canada chassis dynamometer using three different driving cycles at the same inertia weight setting for both buses. The CNG buses consumed between 16% and 19% more energy than the diesel bus. However, CNG buses weigh more than diesel, and the use of equal inertia weight setting will under-represent the inertia component of fuel consumption. Since the inertia component is roughly half the total component of fuel consumption related to weight (depending on drive cycle, the other half being rolling resistance), the energy efficiency would be 19% to 23% lower for the CNG bus.

In service fuel economies for the CNG buses in the MTO programs are, on average:

- Toronto CNG buses : 71 Ldeq/100km
- Hamilton: 77 Ldeq/100km
- Mississauga: 65 Ldeq/100km

Comparative diesel fuel consumption rates were not reported.

NREL Study

Under a study conducted by NREL[34], alternative fuel and diesel buses were monitored under similar conditions to determine their comparative fuel economy, reliability, operating costs and emissions. Transit operators in Miami and Tacoma compared diesel and CNG buses both powered by Cummins L10 engines. The energy efficiency of the CNG buses was found to be, on average, 3% worse than diesel in the Miami program and 23% worse at Tacoma. However, in Miami, the diesel buses were operated on more “severe service” than the CNG buses and, as discussed above, this can significantly affect fuel consumption invalidating the comparison. The CNG buses in Tacoma were operated on similar routes as the diesel control buses and accumulated 4 times greater mileage than the Miami buses. The Cummins L10 engines used in these studies are older model engines and, according to Cummins, the efficiency of the new natural gas L10 engine has been improved.

Other Studies

The Central New York Regional Transit Authority introduced 8 CNG buses in 1993 and conducted a three year field test with the buses [35]. Comparisons were made with a control group of 8 diesel buses used in

34 “Alternate Fuel Transit Buses - Final Report”, prepared by NREL Vehicle Evaluation Program for U.S Dept. of Energy, October 1996.

35 “The Cleaner Less Costly Choice”, Natural Gas Fuels Oct. 1996, pp.16-19.

transit service over the same routes. Both groups used the Cummins L-10 four-cycle engine. The observed fuel efficiencies were much lower than the BC Transit buses, likely due to the route characteristics. The values were:

- CNG 80.8 Ldeq/100km
- Diesel 60.5 L/100km

Thus, the CNG buses used 33% more fuel to cover the same distance. The Authority attributes this increase to differences in weight, engine design and drivetrain rear end ratios.

A comparative study of CNG and diesel buses conducted in West Sacramento, California[36], over an 18 month period found the fuel efficiency of the CNG buses to be 58.2 Ldeq/100km compared to 57.2 L/100km for the diesel buses. However, the CNG buses were much newer (8 years) and operated primarily on inter-city routes while the diesel buses were run on a variety of routes. Also, the CNG buses had a four-stroke Cummins L10 engine while the diesel buses had a DDCV-92TA two stroke engine. The rate of 58 Ldeq/100km is similar to rates for CNG buses in the BC Transit pilot study, while the diesel rate is close to typical rates for older diesel buses. Little can be learnt about the relative energy of the two fuel types from this study.

Monterey-Salinas Transit operate 8 DDC Series 50 CNG buses, similar to the natural gas engines in buses operated by BC Transit. The fuel consumption rates average 2.55 miles per US gallon (92 Ldeq/100km). This is 11% higher than the diesel buses which are equipped with two stroke DDC 6V92 engines. Many of the diesel buses are much older than the new CNG buses and have higher fuel consumption rates than new diesel buses.

Idaho's city owned Urban Stages transit fleet operates CNG powered El Dorado National buses. They report fuel economies of 52 L/100km for their diesel buses and 58 Ldeq/100 km for the CNG buses[37]. This represents a 13% increase over diesel.

Other heavy duty applications of CNG have reported higher fuel consumption using CNG compared to diesel. For example, the New York City Department of Sanitation operates CNG garbage trucks and report 5 to 20% lower fuel efficiency than diesel trucks[38].

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[36] SAE Paper No. 960769.
[37] "Transit Agencies Tell All", Natural Gas Fuels, October 1996, pp 21-25.
[38] Clean Fuels Report, Sept. 1996, pp. 94.

Cummins, from their experience with natural gas engines, states that: "in general, if you have a natural gas engine in the same vehicle with the same duty cycle, the diesel fuel consumption will be approximately 20% better than the natural gas.[39]

Factors Used in Analysis

Based on the review of the previous studies and analyses, the fuel efficiency of the CNG buses range from 8% to 35% lower than that of similar diesel buses. In the life cycle cost analyses, the following fuel efficiency reductions for CNG were assumed:

- optimistic case - 10% reduction
- base case - 20% reduction
- pessimistic case - 35% reduction

4. Distance Travelled

The annual distance travelled by the buses in the BC Transit fleet varies by division, and age of the bus. At Port Coquitlam the average annual mileage is about 67,000 km while at Surrey the average annual distance travelled is 78,000 km. The annual distance travelled decreases over the life of the bus, which is expected to be 20 years for future bus purchases at BC Transit. Based on distance travelled data provided by BC Transit for a study on optimal replacement of buses[40]and discussions with BC Transit, the following values of annual distance travelled by age of bus were used in the life cycle cost analysis:

- Years 1 - 6: 90,000 km
- Years 7 - 20: 60,000 km

It is assumed that the CNG buses will be used in the same way diesel buses are used, and accumulate similar mileage each year. Costs could be reduced to some extent by making greater use of the CNG buses, but this was not evaluated in the life cycle cost analysis. BC Transit does not expect the lower range of CNG buses to lead to additional trips back to the garage to refuel.

5. Capital Costs of Buses

The following costs for New Flyer low floor buses with DDC Series 50 engines, which were recently tendered by BC Transit, were used:

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39 Personal communication, e-mail from PowerMaster, Cummins Engine Company Inc., Customer Assistance Center, Dec. 1996

40 Soren Lemche, Real Asset Management Program.

- diesel version: $313,000
- CNG version: $383,000

These costs are for a diesel engine with a catalyst and for a CNG engine without a catalyst. As discussed in Section V, DDC has not developed a catalyst for the 1997 model year natural gas engine. The cost of such an engine, particularly for a small order for BC Transit and given the cost of certification, are not known at this time.

The incremental cost for these CNG buses is $70,000 (excluding taxes). This is similar to the incremental cost of $50,000 US, equivalent to $66,700 Canadian, given in the NREL study.

BC Transit specifies DDC engines for all transit bus purchases. Introducing a competitive engine specification to the tender process may reduce capital costs. At the present time, BC Transit operates only DDC engines. The introduction of engines from other manufacturers such as Cummins would mean that additional operating costs would be incurred for training, tooling and storage, and spares for a new engine type.

The cost of buses in future years may vary depending on factors such as competition between manufacturers, total demand for CNG buses and government incentives. Until recently, New Flyer was the only company in Canada manufacturing low floor CNG buses, but Orion is now manufacturing low floor CNG buses. The increased competition could possibly lead to lower prices. Similarly, the increasing demand for CNG buses (discussed in Section III), could lead to price reductions as manufacturers recoup their development costs. However, this optimism must be tempered by the fact that the price increment for CNG buses has not decreased over the last 5 years.

In the life cycle cost analysis, the CNG bus price increments used were:

- optimistic case - $70,000 in 1997 and $60,000 in subsequent years
- base case - $70,000
- pessimistic case - $70,000 in 1997 and $80,000 in subsequent years

6. Spares Ratios

Transit operating and maintenance practices differ between Canada and the United States. One of the key differences is the higher spares ratio maintained by U.S. transit properties. According to 1994 Federal Transit

Administration figures[41] the average spares ratio for all U.S. transit properties operating large transit buses is 18.5%. Among U.S. transit properties with 500 or more large diesel buses the average spares ratio is 20.3%.

In order to compare the impact of CNG buses on the spares ratio, a survey was conducted of 6 transit properties operating significant numbers of CNG buses. As shown in Exhibit V-1, the survey revealed that the spares ratio for the fleets with a large number of CNG vehicles were between 17% and 22%, a rate consistent with the national average. None of the fleets reported any changes to the spares ratio specifically as a result of adding CNG buses.

Exhibit V-1. Spares Ratio Comparison

Transit Authority	Total Fleet	CNG	Spares*
Pierce Transit	193	30%	20%
Sacramento RTA	200	48%	19%
Monterey Salinas Transit	77	10%	20%
Sunline Transit	40	100%	18%
Tucson Sun Tran	193	21%	22%
South Coast Area Transit	29	78%	17%
San Diego	339	15%	20%
Total/Average of survey	1071	30%	20.0%
US Average Fleets Over 500 buses			20.3%
US Average Fleets 100 - 500 buses			18.5%

*Based on maintenance requirements
Source: US FTA, and telephone survey of properties

Canadian transit properties with approximately 500 or more buses have an overall spares ratio of 15.5% [42]. If Canadian transit systems with old fleets (i.e., Edmonton, Winnipeg) are excluded from the calculation the average spares ratio for large Canadian properties is reduced to about 14%. The spares ratio for both Toronto and Hamilton is about 15% and has not been changed due to natural gas buses. The apparent difference in spare ratios between Canada and the USA may be attributed in part to the differences in transit funding practices between the two countries. Most U.S. properties are eligible for capital grants from the FTA. These grants fund 80% or more of the purchase price of new buses. The funding formula also

41 Federal Transit Administration, DOT, 1994 National Transit Database, Table 21, Transit Operating Statistics Service Supplied and Consumed: Details by Transit Agency

42 1995 CUTA Fact Book

allows for replacement buses to be purchased after 12 years. Consequently transit properties may find that purchasing additional new buses (for $0.20 on the dollar) for spares may be a more efficient use of local funds than expending money on maintenance facilities and practices designed to support a low spares ratio.

Year to year changes in the spares ratio at specific transit agencies may also be caused by many factors other than maintenance requirements. Some of the typical factors that may cause spares ratios to fluctuate include:

- arrival of new buses before new services are added;
- cut backs in service hours as a result of budget constraints;
- delayed retirements in order to meet a future special event; and
- seasonal fluctuations in peak demand.

Based on the above findings, the spares ratios were assumed to be unaffected by the conversion to CNG buses in the life cycle cost analysis.

7. Maintenance Costs of Buses

Natural gas has several advantages over diesel affecting maintenance costs:

- no routine fuel filter changes; and
- no cylinder wall washing due to unburned fuel.

However, these are offset by the following disadvantages:

- The fuel system is considerably more complicated. A diesel system has none of the various valves and regulators present in an CNG system, or the high pressure lines and joints.

- Periodic fuel cylinder checks will be required and currently cylinders must be recertified after 15 years. BC Transit has applied for an extension as the 15 year period is based on 750 refills per year, but BC Transit only refills their buses about 450 times per year. Over 25 years, a BC Transit bus would have the same number of refills as one with 750 refills per year over 15 years. BC Transit does not expect any extra costs due to inspection at this time.

- The best developed and most readily available technology for natural gas bus engines at present is spark ignition. All ignition components, including coils, spark plugs, ignition wires and the associated power and control circuits, are incremental to diesel practice.

- The additional weight of a natural gas bus is likely to increase the wear rate of brakes, tires and suspension. The additional weight may also increase wear of the road system, however this cost is external to BC Transit.

- Introduction of any new technology tends to be accompanied by increased maintenance costs until operating and service staff become thoroughly familiar with it and deficiencies with the systems have been identified and resolved.

BC Transit

The current BC Transit CNG monitoring project is tracking the number of bad orders and road calls, the cost of work conducted under warranty, and the cost of regular maintenance. The study commenced less than a year ago and results are preliminary, based on only 7 months experience. The findings are summarized below with costs translated, where possible, to a per kilometer scale to allow comparisons and a summation of the effects.

- Both the CNG and diesel buses had more bad orders than the fleet average. Extrapolating 7 months data, the CNG buses had on average 32 more engine related bad orders per year per bus than the diesel buses[43]. If it is assumed a bad order costs $50 to rectify (parts and labour) and the buses travel 90,000 km/year, the additional bad orders cost about 1.8 cents/km.

- Again both sets of buses had significantly more road calls than the fleet average. The CNG buses had 0.5 more engine related road calls per month than the diesel buses[44]. If it is assumed a road call costs on average $200 (down time, parts, labour, etc.) and the buses travel 90,000 km/year, the additional bad orders cost about 1.2 cents/km.

- Warranty and deficiency costs for the diesel buses were $0.04 per km compared to $0.15 per km for CNG buses. "Although this money is recovered [from the manufacturer], a mechanic is still tied up while troubleshooting and repairing these coaches". If the value of the mechanic's time was equivalent to 10% of these warranty costs, this would add another 1.1 cent/km (10% of difference of $0.15-$0.04) to the incremental costs for CNG buses.

- The cost of parts and labour were similar for the diesel and CNG buses (excluding warranty claims). With the limited data available to date, the

43 Statistically significant at the 1% level assuming bad orders follow a Poisson distribution.

44 Statistically significant at the 1% level assuming bad orders follow a Poisson distribution

variation is too great to be able to draw any conclusions regarding the comparative costs of parts and labour.

Early indications from the study are that maintenance costs will be higher for CNG buses, possibly by up to 4 cents/km. The higher costs observed so far could, however, be due to start up problems with the new equipment and may settle down to similar levels as for diesel buses. Since many of the start-up problems will be rectified with the existing 25 CNG buses, the maintenance increment would be expected to be lower for a new order. Maintenance costs could, however, increase after the expiry of the two year warranty period, depending on the extent to which the problems with the new technology have been resolved, and the continued support of DDC.

Ontario

The MTO CNG bus program has accumulated considerable experience with CNG buses and their maintenance requirements. However, many of the problems they encountered could be attributed to the testing of new technology. From the analysis of maintenance records from Toronto Transit[24], it was concluded that "the overall maintenance record of the engine and fuel system have gradually improved and is now comparable to that of the diesel". The reliability of CNG buses, as measured by their utilization rates, was found to be similar to that of diesel buses, varying between 70% to 85%.

The 11 CNG buses in Mississauga have accumulated 2.4 million km of service. These buses were powered by an earlier generation of natural gas engines. These buses have had a utilization rate of 68%. A number of problems have been experienced with the CNG buses, the latest being melted pistons in one engine. Rough estimates put the additional maintenance costs at $6,000 per year. On a per kilometer basis, this is equivalent to about 6 cents/km.

Hamilton has a total of 38 CNG buses in service with total accumulated mileage of 9.8 million km. They have reported no increase in routine maintenance costs. However, they have experienced considerable problems with failures of cylinder heads (overspeed), oxidizers and turbos. Twelve of their fifteen Cummins 9100 series and five of their fifteen 9200 series CNG buses have had their engines completely overhauled. Much of the cost of this work was covered under warranty. They also experience overheating problems in many of their CNG buses and replaced all radiators with new ones with 33% more cooling capacity.

Most of the additional maintenance costs experienced at the three MTO sites are due to design problems and are covered under warranty, or would not be expected to continue for the life of the bus.

NREL Study

Maintenance costs and reliability were tracked in the NREL study and are summarized below. These costs do not include warranty work, most of which was covered by the manufacturer.

- At Tacoma, the average maintenance costs for CNG and diesel control buses at 10.6 cents/km[45] were almost identical. Costs in the engine/fuel system also very close, CNG buses being 0.8 cents/km higher. Similarly, the CNG and diesel buses travelled the same distance between road calls.

- In Miami, maintenance costs for the CNG buses were 2.8 cents/km higher than for the diesel control buses, 20.3 cents/km compared to 17.5 cents/km. Most of this difference was due to higher engine/fuel system costs for the CNG buses. Unlike in Tacoma, the CNG buses had 4 times as many road calls per kilometer as the diesel control buses. It should be noted that the distance travelled by the CNG buses was a quarter that travelled in Tacomo, and that the driving cycle differed between the CNG and diesel buses in Miami.

New York

The Central New York Regional Transit Authority (CENTRO) field test comparisons showed that after the first year of the trial, maintenance costs were nearly equal for the CNG and diesel buses. However, during the first year a number of maintenance problems occurred specific to the CNG buses, some of which took several years to resolve. The cost to resolve these problems were covered by manufacturers warranty, but required the valuable time of CENTRO staff. Despite the reported additional weight of the CNG buses of 1745 kg, expenditure on the brakes and suspension were actually slightly less for the CNG buses.

Experience with CNG garbage trucks in the City of New York indicates that maintenance costs are slightly higher for CNG than diesel due to the need to replace spark plugs in the natural gas engines. The additional cost is small, only about 0.2 cents/km. As with CENTRO, maintenance costs were initially higher, but through working with the engine manufacturer, the problems were resolved or costs reduced.

Other Studies

45 Converted to Canadian dollars using an exchange rate of $1 Can. = $0.75 US.

In the CNG bus trial at West Sacramento, California, parts and labour costs were estimated to be $0.149 per km for CNG buses and $0.169 per km for diesel buses. It should be noted, however, that the diesel buses were 8 years older than the CNG buses and had accumulated over 300,000 more kilometers.

Sacramento Regional Transit operates 95 CNG buses and 105 diesel buses. They report 12% higher road calls for CNG buses, the increase being due to under-filling caused by computer system problems. The volume of engine oil consumed per kilometer by their CNG buses was one third that consumed by their diesel buses. Similarly, an eighth the volume of transmission fuel per kilometer was used by the CNG buses. However, their CNG buses are much newer than the diesel buses.

Monterey-Salinas Transit report maintenance costs for their CNG buses which are significantly less than those for their diesel buses, 21.2 compared to 28.9 cents/km, during the 4 months July to September 1996. However, the CNG buses are all new, being purchased in March 1996, while the diesel buses range in age from 1 to 20 years. The miles travelled between mechanical failures were also much better (40%) for the CNG buses, but the bus age could again be a factor. Oil consumption per kilometer was marginally better (3%) for the CNG buses.

Cummins[46], based on their analysis of trial results using Cummins natural gas engines, reports that during the period November 1994 to June 1995, the distance travelled between road calls for 1994 natural gas engines was approximately 2.5 times greater than for 1993 natural gas engines. This indicates that the reliability is improving for more recent engines.

[46] D.R. Welliver, "Cummins Heavy Duty Natural Gas Engine Products", 1996 Windsor Workshop, pp. 295.

Costs Used in Analysis

Based on the findings of these studies, the maintenance costs of the CNG buses are typically greater than diesel buses during the first few years due to a learning curve with new technology. The incremental maintenance costs during this period range from about zero to 6 cents/km. After the “teething” problems with the new fuel type have been resolved, maintenance cost are similar to, or only slightly greater than, those for diesel. Since some of the start-up problems have already been resolved with the current 25 buses, an incremental cost of 3 cents/L during the first two years was assumed for the base case. Some of the current problems may not be resolved during the warranty period of the new buses, and higher costs might prevail for several more years. These costs should be much less than the 15 cents/km experienced during the first 7 months of the current 25 buses. In the base case the incremental maintenance costs during years 1 to 4 are assumed to be 3 cents/km and to drop off to 0.5 cents/km from year 5 onwards. The pessimistic case assumes a continuation of the current unresolved problems with resolution taking place over four years and little cooperation from DDC after the warranty period expires.

The optimistic, base and pessimistic incremental maintenance costs used in the life cycle cost analyses were as follows:

- optimistic case - years 1 to 4: 2.0 cents/km, after that 0.0 cents/km
- base case - years 1 to 4: 3.0 cents/km, after that 0.5 cents/km
- pessimistic case - years 1 to 4: 6.0 cents/km, after that 1.0 cents/km

8. Cost and Frequency of Engine Rebuilds

BC Transit rebuilds the engines of their diesel buses after about 450,000 kms, or on average about every 6 years. BC Transit experience with CNG buses is too short to provide any indication of whether the distance travelled between rebuilds for natural gas engines is any different from diesel engines.

Natural gas tends to produce fewer harmful combustion products which lead to oil deterioration and accelerated engine wear. Natural gas engines are expected to have a longer engine life than diesel. However, due to the limited service history of CNG buses, there is little evidence to specifically determine what this life might be.

Engine wear was evaluated in the Central New York Regional Transit Authority (CENTRO) field tests by comparing the total wear metals that accumulate in the drain oil. Over the 18 month period that these were tested, the total wear metals in the drain oil of CNG buses was four times lower than those in the drain oil of diesel buses. From this they conclude that over the 12 year life of an urban bus, the maintenance costs may be less for CNG buses than diesel buses.

Natural gas engines have been operating in other transportation applications which provide some indication of engine life. The two Albion ferries operated by the BC Ministry of Transportation and Highways across the Fraser river are powered by natural gas/diesel dual fuel engines. Both engines are four stroke, turbo charged Cat 3406B engines rated at 312 bhp at 1800 rpm. The engines use 80% to 90% natural gas when running under loaded conditions. The life of diesel versions of this engine before a rebuild is required is typically 30,000 hours. The natural gas dual fuel engines remained in service for 8 years accumulating 60,000 hours operating time before being rebuilt, twice that of a diesel engine. At that time the operator commented “both engines were in very good condition”. The 60,000 hours was compared to running a highway truck for 2.4 million kilometers between major overhauls. Although the engine types and operating environments differ from natural gas bus engines, this experience indicates that CNG bus engines will likely be able to remain in service for significantly longer periods between rebuilds.

The Sacramento Regional Transit Authority operates 95 CNG buses with Cummins L10 engines. They typically rebuild diesel engines after 200,000 miles, but, based on the cleanness of the natural gas engines, hope to extend this to 250,000 - 350,000 miles for their CNG buses. As yet, none of their buses have accumulated this mileage. Pierce Transit have CNG buses that have accumulated 200,000 miles and predict engine rebuilds will not be necessary until 400,000 miles, twice that of their diesel buses. The New York Regional Transit Authority expects the natural gas engines to extend the time between rebuilds, with a possibly that rebuilds will not be required until the 10th year. Based on their experience in Hamilton and Toronto, transit operators could not be conclusive on engine life or rebuild time for CNG engines.

A number of transit authorities have reported engine or engine component failures. These failures are, for the most part, covered under the manufacturers warranty, although the transit authority experiences some cost. These are included under the maintenance costs discussed above.

In the life cycle cost analyses rebuilds of diesel engines are assumed to be done during years 6 and 13 of the bus’s life. Based on the above discussion, the time period between rebuilds of natural gas engines is expected to be longer, possibly by more than 50%. In the analyses, the following rebuild frequencies for natural gas engines were used:

- optimistic case - 50% increase, rebuild in year 8

- base case - 15% increase, rebuild in years 7 and 16
- pessimistic case - 0% increase, rebuild in years 6 and 13

Engine rebuilds for buses at BC Transit cost approximately $30,000 [47]. Costs are expected to be the same for both CNG and diesel buses.

9. Refueling Plant Capital and Maintenance Cost

Two natural gas fuel supply cases were considered:

- where BC Transit purchases natural gas “at the filler nozzle” from BC Gas; and
- where BC Transit owns and operates the refuelling facility and purchases gas “at the property line”

When BC Transit purchases natural gas “at the filler nozzle”, BC Gas provides the compressor and storage facilities. Costs for these facilities, including maintenance, will be included in the price paid by BC Transit for the gas. BC Transit will, however, pay directly for the electricity used by the refueling plant, primarily for compression of the gas. This cost has been included with the price of the gas in the life cycle cost analysis (see Section IV-B.1).

In the case where BC Transit owns and operates the refuelling facility, they must pay for the initial installation cost and the ongoing maintenance and operating costs. These costs depend on the size of the facility, which in turn will depend on the number of CNG buses using the facility. When natural gas is purchased “at the property line”, the gas can be purchased directly from BC Gas, or from a consolidator at possibly a slightly lower price.

Based on estimates provided by BC Gas, the following assumptions for the initial capital cost of the compressor station to provide quick-fill refuelling were used:

- 25 - 35 buses $1 million
- 75 buses $1.7 million
- 130 buses $2 million

Annual maintenance costs for a facilities capable of refuelling 25 - 30 buses is typically about $15,000. Maintenance costs increase as the size of the station increase. It was assumed that costs increase at a rate of $10,000 for every 50 buses. The cost of gas compression was accounted for by adding

47 Estimate provided by Chris Lythgo, VP Technical Services, BC Transit, Dec. 1996.

4% to the total cost of the gas consumed by the bus fleet [48]. The additional 4% equates to about an extra 1 cents/Ldeq.

10. Building Modification Costs

California transit properties have spent up to $1,000,000 each on garage modifications. NREL gave the following estimates of the incremental costs to convert a 170 bus facility (excluding refuelling plant) to CNG:

- Maintenance $1.1 million(1994 US $)
- Storage $1.2 million(1994 US $)

The total cost of modifications to the Port Coquitlam transit centre to accommodate the current 25 CNG powered buses was approximately $200,000. Similar costs are anticipated for the Surrey facility, however a detailed engineering assessment has not been done[49].

Increasing the number of CNG buses at Port Coquitlam from 25 to 100 would require further building upgrades costing approximately $250,000.

Modifications will also have to be done at the Burnaby overhaul and heavy maintenance site. It is assumed that these upgrades will be done the year prior to the first natural gas engine rebuilds. BC Transit has estimated the cost for the changes to be $850,000.

The primary safety concern for natural gas buses is the possibility of leaks from the high pressure gas storage system on a bus in the refuelling, parking and maintenance areas. However, natural gas buses are designed to reduce this possibility to extremely low levels, assuming proper maintenance of the systems.[50] BC Gas' design of the fuelling station and modifications of the maintenance garages are additional precautions in the event of a leak.

Conversion of a large proportion of the fleet to CNG may reduce the cost of replacing underground diesel storage tanks. However, the tanks at Port Coquitlam and Surrey garages are only one to two years old and will last most of the analysis period. Thus, any cost savings will be minimal.

11. Depreciation Life

48 Sypher:Mueller, "Evaluation of Clean Fuel Options: BC Transit Victoria", April 1994.

49 BC Transit "Compressed Natural Gas for Buses" Strategy", report prepared by BC Transit, March 1996.

50 Feasibility of Natural Gas Bus Operations in Alberta, Sypher:Mueller International Inc., March 1994.

In the life cycle cost analysis, the residual value of assets was calculated using straight line depreciation. The residual values were summed, converted to Net Present Value, and incorporated into the total NPV result. The depreciation life was taken as 20 years for buses assuming engine rebuilds are carried out when needed. A depreciation life of 20 years was used for refuelling equipment, based on information received from Centra Gas; and 30 years was used for buildings. The duration of the analysis was 25 years, which covers the life of all buses purchased under the scenarios examined.

12. Other Costs

Depending upon their function, personnel will require training in natural gas safety, use of refuelling equipment, maintenance of buses and equipment, and operation of the buses. Other topics may have to be covered; for example, record keeping from automated fuel dispensers if used. The training required will range from fairly simple short internal courses; for example, a safety overview, to intensive courses on the maintenance of the pressurized gas system in response to required statutory qualifications. The cost estimate covered material preparation and delivery only. It did not account for staff "lost time" while receiving training.

BC Transit has indicated [51] that the use of CNG fuelled buses will not affect their refuelling and maintenance procedures. The analysis therefore assumes that no additional staff will be required (beyond that which is already accounted for by the maintenance cost increment). However, an earlier report indicated that additional service person and/or mechanic may be required at some garages, depending on the number of CNG buses added. The cost of these additional staff, including all overheads, at BC Transit would be approximately $100,000 per year per person. Two cases of additional staff requirements were analyzed:

- base case - no additional staff requirements
- pessimistic case - 2 additional staff required at Port Coquitlam and 2 at Surrey

[51] Personal communication with Dan Levy, December 1996.

C. SCENARIOS EXAMINED

Two CNG bus purchase and placement scenarios were examined:

1. CNG buses at Port Coquitlam only; and
2. CNG buses at Port Coquitlam and Surrey

The number of CNG buses delivered each year over the period July 1997 to June 2002 and the placements of the CNG buses is shown in Exhibit V-2. The building modification and refuelling station costs (for cases where natural gas is purchased "at the property line") are also given.

Exhibit V-2. CNG Buses Under Scenarios 1 and 2

Garage	Capital Item	1997/98	1998-99	1999/00	2000/01	2001/02
Scenario 1						
Port Coquitlam	No. of CNG buses	61*	101	101	101	101
	Building mod.	$250,000	$0	$0	$0	$0
	Refuelling plant ✧	$1,750,000 #	$0	$0	$0	$0
Surrey	No. of CNG buses	0	0	0	0	0
	Building mod.	0	0	0	0	0
	Refuelling plant ✧	0	$0	$0	$0	$0
Total CNG Bus Deliveries		36	40	0	0	0
Scenario 2						
Port Coquitlam	No. of CNG buses	61*	101	101	101	101
	Building mod.	$250,000	$0	$0	$0	$0
	Refuelling plant ✧	$1,750,000 #	$0	$0	$0	$0
Surrey	No. of CNG buses	0	39	39	75	135
	Building mod.	0	$200,000	0	0	0
	Refuelling plant ✧	0	$1,200,000	$0	$800,000	$0
Total CNG Bus Deliveries		36	79	0	36	60

* Including 25 CNG buses presently at Port Coquitlam
✧ Refuelling plant capital cost only incurred in Scenarios 1B and 2B
\# Cost includes the purchase of the existing CNG refuelling plant from BC Gas

For each bus purchase scenario considered, two fuel supply scenarios were examined:

A. natural gas purchased "at the filler nozzle"
B. natural gas purchased "at the property line"

The refuelling plant at Port Coquitlam is currently owned by BC Gas and cost approximately $100,000 to install. Under Scenarios 1B and 2B whereby BC Transit buys natural gas "at the property line" and owns and operates the refuelling plant, it is assumed that BC Transit purchases the plant from BG Gas. The 25 CNG buses currently owned by BC Transit would still use the refuelling plant at Port Coquitlam, but would pay only the "property line" price for the gas, not the higher "at filler nozzle" price [52]. Thus, fuel savings would be realized for these buses which would offset the cost of the existing station paid to BC Gas. In the life cycle cost analysis, the fuel consumption of the existing 25 CNG buses was estimated for the years 1997 to 2015. The fuel savings were then calculated and added to the fuel savings for the buses purchased under Scenarios 1B and 2B.

The NPV and internal rates of return were calculated both with and without Provincial and local taxes applying:

(i) Current taxes apply
(ii) Provincial road tax, local urban diesel transit tax and PST are excluded

Thus a total of eight scenarios were examined: 1A(i), 1A(ii), 1B(i), 1B(ii), 2A(i), 2A(ii), 2B(i), and 2B(ii). Fuel prices, the compression allowance and taxes for these scenarios are given in Exhibit V-3.

Exhibit V-3. Fuel Prices, Compression Allowance and Taxes

A. At Filler Nozzle	CNG price $/Ldeq	$0.225
	Compression Allowance	0.0%
B. At Property Line	Natural gas price $/Ldeq	$0.11
	Compression Allowance	4.0%
(i) Current Taxes	PST	7%
	Diesel urban transit tax	$0.040
	Diesel road tax	$0.115
(ii) Zero Provincial/Local Taxes	PST	0%
	Diesel urban transit tax	$0.000
	Diesel road tax	$0.000

Each of the scenarios were analysed using the base case values given in Section VI-B. In addition, sensitivity tests based on the optimistic and pessimistic cases given in Section VI-B were carried out using Scenario 1B(i) - Port Coquitlam only, "at property line" and current taxes. The

[52] Note that the "property line" price for gas used by the original 25 buses will be higher than that paid by the additional buses because the capital cost of the original 25 buses must be recovered by BC Gas (see Section IV-B). The gas price for these buses will be $0.16/Ldeq (equal to the current price $0.26/Ldeq less the compression cost of $0.10/Ldeq) for the period of the existing contract (9 more years) over which the refueling station costs are recovered. After that the property line cost with a compression allowance and increment to cover maintenance would apply. The pricing structure could be set up so that the price below a threshold will be the higher price, where the threshold corresponds to the fuel used by the original 25 buses.

variables examined in the sensitivity tests and the optimistic, base and pessimistic values are given in Exhibit V-4.

Exhibit V-4. Values of Variables Tested in the Sensitivity Analysis

Variable	Optimistic	Base	Pessimistic
Ratio of CNG to diesel fuel consump. rate	1.1	1.2	1.35
Diesel fuel consumption rate (L/100km)	50	45	40
Incremental maintenance cost ($/km) - years 1 to 4	$0.02	$0.03	$0.06
- years 5 onwards	$0.00	$0.005	$0.01
Natural gas property line - 1997 price $/Ldeq	$0.10	$0.11	$0.16
- % change per year	0.0%	0.3%	1.0%
CNG bus prices increments after 1997	$60,000	$70,000	$80,000
CNG engine rebuild period	8	7, 16	6, 13
Additional staff at each garage		0	2

D. RESULTS OF ANALYSIS

The estimated NPV for investments under each of the bus purchase and fuel supply scenarios, with and without Provincial/Local taxes, are given in Exhibit V-5. NPVs for the base case use base case values of parameters, while the worst and best cases correspond to minimum and maximum NPVs calculated over possible ranges of these parameters (examined in the sensitivity analysis which follows).

Exhibit V-5. NPV for Each Scenario With and Without Provincial/Local Taxes and Sensitivity Range

Provincial/Local Taxes	**Scenario**	**NPV**		
		Base Case	**Worst Case**	**Best Case**
Current Taxes	**1. Port Coquitlam Only**			
	A. At filler nozzle	-$2,728,000	-$4,933,000	-$1,934,000
	B. At property line	-$506,000	-$2,811,000	$458,000
	2. Port Coquitlam & Surrey			
	A. At filler nozzle	-$5,113,000	-$9,654,000	-$3,139,000
	B. At property line	$92,000	-$4,949,000	$2,358,000
Excluding Taxes	**1. Port Coquitlam Only**			
	A. At filler nozzle	-$6,316,000	-$8,522,000	-$5,523,000
	B. At property line	-$3,971,000	-$6,277,000	-$3,178,000
	2. Port Coquitlam & Surrey			
	A. At filler nozzle	-$14,120,000	-$18,660,000	-$12,145,000
	B. At property line	-$8,670,000	-$13,711,000	-$6,696,000

With current Provincial and local taxes included, only the Port Coquitlam and Surrey scenario where gas is purchased “at the property line” is financially viable. The worst case NPVs indicate that there are significant financial risks associated with conversion to CNG. The best case NPVs with Provincial and local taxes included are around the breakeven point for the Port Coquitlam only scenario and are positive for the Port Coquitlam and Surrey scenario.

Much lower financial returns will be obtained if they purchase gas “at the nozzle”. The savings to BC Transit due to owning and operating the refuelling station are due to the reduction in compression costs per vehicle for larger fleets. With the price increment of $0.10/Ldeq for compression currently charged by BC Gas, the $1,000,000 capital costs for the refuelling station would be covered in 10 years by the 25 CNG buses assuming an interest rate of 10%. However, with 100 CNG buses, the $1,750,000 capital cost of the refuelling station would be covered by only a $0.05/Ldeq levy on the fuel price over the same period and interest rate. Thus, BC Transit would be saving about $0.05/Ldeq by owing and operating the refuelling station.

If Provincial and local taxes are excluded, all scenarios become uneconomic.

The sensitivity of a number of key parameters for which there is some uncertainty was determined using the pessimistic and optimistic cases given in the previous section. The NPV for these cases were determined for scenario 1B(i): CNG Buses at Port Coquitlam garage with fuel purchased “at the property line” and including taxes. The results are given in Exhibit V-6 and shown graphically in Exhibit V-7.

Exhibit V-6. Sensitivity of NPV to Key Variables for Case 1B(i)

Variable	NPV over 25 years at 8% rate		
	Pessimistic	Base Case	Optimistic
Ratio of CNG to diesel fuel rate	-$869,000	-$506,000	-$264,000
Diesel fuel consumption rate	-$1,469,000	-$506,000	$458,000
Incremental maintenance cost	-$1,314,000	-$506,000	-$114,000
Natural gas “property line” cost	-$2,478,000	-$506,000	-$97,000
CNG Bus price*	-$913,000	-$506,000	-$98,000
CNG Engine Rebuild Period	-$795,000	-$506,000	$287,000
Additional Staff	-$2,811,000	-$506,000	

As shown in Exhibit V-7, the NPVs for converting to CNG are very dependent on the price of natural gas and whether additional staff will be required at each garage. Additional staff and natural gas price each reduced the NPV by at least $2.0 million resulting in NPVs well below zero for Scenario 1B(i). Pessimistic values of the diesel fuel consumption rate and maintenance costs also have a significant effect reducing NPVs by $0.8 - 1.0 million. Pessimistic values of the other key variables have a much smaller effect on the NPV, reducing values by $0.28 to $0.41 million each. For the optimistic cases, the diesel fuel consumption rate and the engine rebuild period have the greatest effect on the NPV and both lead to positive NPVs for scenario 1B(i). The optimistic cases increase NPVs by between $0.24 and $0.96 million.

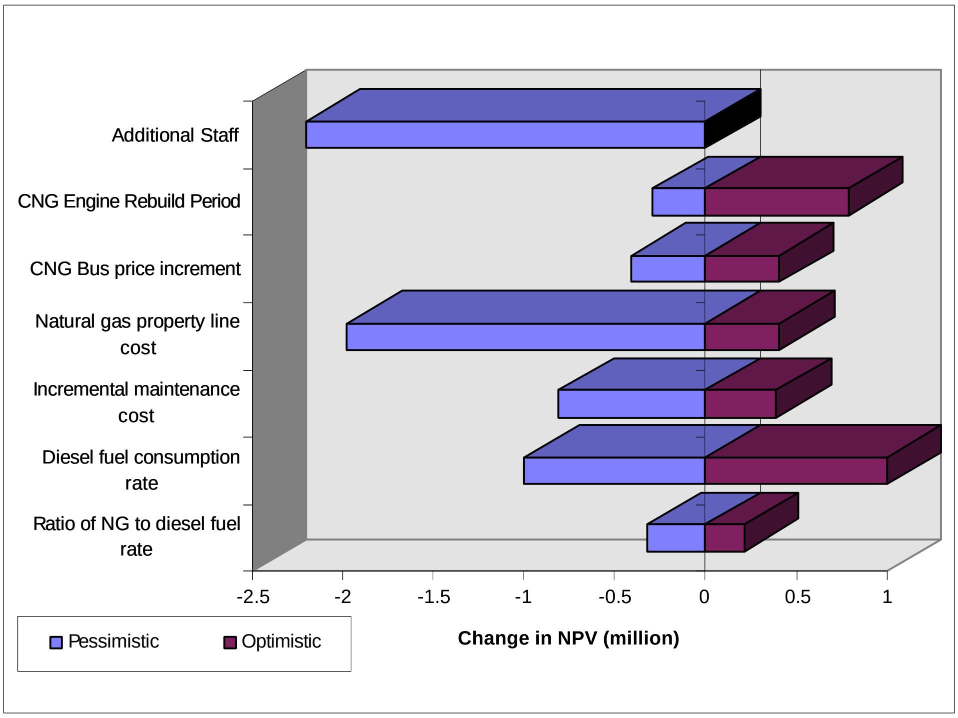

Exhibit V-7. Changes in NPV for Key Variables

The NPV is very sensitive to the price of natural gas and, as discussed in Section V-B.1, this price is not fixed. The maximum prices at which each scenario with taxes included become economic (NPV is positive) were determined and are given in Exhibit V-8. Base case values of other parameters were used.

Exhibit V-8. Maximum Price of Natural Gas at which NPV is Positive for Each Scenario With Provincial and Local Taxes

Scenario	At Filler Nozzle		At Property Line
	Including Compression	Excluding Compression	
1. Port Coquitlam Only	$0.140	$0.025	$0.095
2. Port Coquitlam & Surrey	$0.161	$0.046	$0.111

VI. EMISSIONS

A. EMISSION STANDARDS

The current Canadian emissions standard for urban buses, and the current and future emission standards set by the U.S. EPA and the California Air Resources Board (CARB) are shown in Exhibit VI-1. The emissions standards applicable to transit buses in BC are loose. Crown Corporations must buy CNG vehicles, or vehicles that meet emission standards as clean as CNG. An exception to the policy may be made where suitable vehicles are not commercially available, or where operational requirements preclude their use.

Exhibit VI-1. Canadian, U.S. EPA and CARB Urban Bus Emission Standards

Model	Emissions (g/bhp-hr)			
Year	HC	NOx	CO	PM
Canada Current	1.3	5.0	15.5	0.07
	HC[1]	NOx	CO	PM
US EPA 1998	1.3	4.0	15.5	0.05
2004	2.4 [3]		15.5	0.05
	HC[2]	NOx	CO	PM
CARB 1996	1.3	4.0	15.5	0.05
2004	2.4 [4]		15.5	0.05

1 Total hydrocarbons (THC) for all fuels but methanol. Methanol standard is 1.3 g/bhp-hr organic material hydrocarbon equivalent (OMHCE).

2 Total hydrocarbons for all fuels but methanol. Methanol standard is 1.3 g/bhp-hr OMHCE. Diesel, CNG, and LPG engines have the option to certify to a 1.2 g/bhp-hr Non-methane hydrocarbon (NMHC) standard.

3 Total: NOx + NMHC. EPA offers a second option where NOx + NMHC = 2.5 and NMHC is 0.5 g/bhp-hr or less.

4 Total: NOx + NMHC.

NOx and particulate matter standards have the most critical effects on heavy duty engine design. All current engines surpass the carbon monoxide (CO) standards by a considerable margin, and the hydrocarbon (HC) emissions are to some extent controlled by the same measures used to reduce particulates. However, the advent of alternative fuels has led to some re-assessment of the definition of hydrocarbon emissions, in order to account for exhaust products such as unburned methane and aldehydes. These are either not present, or present in negligible proportions, in diesel exhaust.

For heavy duty engines, hydrocarbon emissions certification output is basically measured by a flame ionization detector (FID), and includes methane and ethane. The EPA refers to these emissions as total hydrocarbon emissions (THC). It should be noted that THC does not account for formaldehyde or about half of the acetaldehyde present. In practise, methane and ethane are not present in diesel exhaust and the aldehyde level is negligible.

For natural gas engines, the inclusion of unburned methane in the hydrocarbon emissions assessment gives levels higher than the permitted standards. Since methane is not regarded as harmful, a non-methane hydrocarbon emissions standard was approved by EPA and CARB. This allows the methane fraction to be deducted from the hydrocarbon emissions when certifying natural gas engines. The non-methane typically accounts for only between 1% and 15% of the total hydrocarbon emissions from natural gas engines, depending on the engine, driving cycle and whether a catalyst is used. Use of a catalytic converter tends to lower the non-methane emissions. Tests on an Orion 5 CNG bus by Environment Canada found the following breakdowns of methane and non-methane HC emissions.

Exhibit VI-2. Methane/Non-Methane Content (g/mile) of Hydrocarbon Emissions from a CNG Bus

	Drive-cycle	Methane	Non-methane	% Methane
With Catalyst	HD composite	3.14	0.06	98%
	CBD	4.43	0.46	91%
	New York bus	16.85	0	100%
	NY composite	5.83	0.03	99%
Without Catalyst	HD composite	10.38	0.72	94%
	CBD	13.78	1.48	90%
	New York bus	40	4.11	91%
	NY composite	17.44	2.29	88%

NREL states that “HC emissions from CNG vehicles are typically 95% methane”.

B. COMPARISON OF DIESEL AND NATURAL GAS FUELLED BUSES

For regulatory purposes heavy duty engine emissions are measured with an engine dynamometer, rather than with a vehicle on a chassis dynamometer, and emissions are reported in units of grams per brake horsepower-hour. However, emissions achieved by buses in service may be significantly different from those indicated by the engine dynamometer measurements. To provide a better measure of typical emissions of buses while they are in service, emissions must be measured while the bus is driven on a chassis dynamometer following a preset driving cycle. Several driving cycles have been developed for representing typical speed profiles of transit buses in inner city and other urban areas.

Certification emissions values, based on *engine* dynamometer tests (given in g/bhp-h), include a deterioration factor to account for normal wear on the engine over its life. *Chassis* dynamometer results (given in g/mile) are actual measured values for buses while in service and include any deterioration in emissions up to that time. Adjustments for average deterioration over the life of the bus are not included.

The results of emissions tests have been collected from a number of different sources. Comparisons of CNG and diesel buses are presented below and comparisons for other promising alternative fuel types discussed in Section III are given in Appendix B. Emission values are very dependent on the type of engine, the year the engine was developed and whether is has a catalytic converter.

Exhibit VI-3 summarizes the comparative emissions results for natural gas and diesel engines from the various sources. Emissions values are given in units of g/bhp-hr for engine dynamometer measurements and g/mile for chassis dynamometer measurements (note that the results from several sources were transformed to these units). HC emissions are often not directly comparable as non-methane emissions for CNG are often not measured (as in the NREL study).

Chassis dynamometer test results are available for both the latest Cummins L10-260G natural gas engine and its predecessor, the L10-240G. Results were only available for the newly developed DDC S-50 natural gas engine on an engine dynamometer as part of certification testing. The tests show:

Exhibit VI-3. Comparison of Natural Gas and Diesel Emissions Values from Various Sources

Fuel	Engine Make/Model #	Engine Year	Emissions (g/bhp-hr or g/mile) Unit	PM	NOx	CO	THC	Year of Test	Notes
Cummins Engines									
CNG	L10-240G	1992/91	g/mile	0.01	30.1	20.6	9.26	1995	1,2
	L10-260G	1994	g/mile	0.02	11.2	0.74	15.5		1,3
Diesel	L10		g/mile	1.74	24.6	11.2	2.37		1
CNG	L10-240G	1991/90	g/mile	0.01	29	15.8	20.6		4,2
	L10-260G	1994	g/mile	0.03	12	1.56	16.1		4,3
Diesel	L10		g/mile	1.77	23.9	21.9	1.8		4
	Avg. L10-240G	% change		-99%	22%	10%			
	Avg. L10-260G	% change		-99%	-52%	-93%			
CNG	L10	1993	g/mile	0.11	29.47	0.43		1996	5
Diesel	L10		g/mile	2.33	47.4	31.99			5
	% change	% change		-95%	-38%	-99%			
CNG	L10		g/mile		7 - 50	.01 - 68	0.02-105	1996	6(a)
			g/mile		25.3	1.4			6(b)
Diesel	L10		g/mile		18 - 50	.01 - 40	0.01 - 5		6(c)
CNG	L10-260G	1993	g/mile	0.03	12	1.6	16.1		8
CNG	L10-280G (cat.)	1996	g/bhp-h	0.03	2.4	5.3	0.5*	1996	9
Diesel	M11-280D (cat.)	1996	g/bhp-h	0.04	4.0	0.5	0.2		9, EPA
Diesel	M11-280D (cat.)	1996	g/bhp-h	0.04	4.8	0.6	0.2		9,CARB
	% change			-25%	-45%	860%			
CNG	C8.3G	1996	g/bhp-h	0.01	2.6	1.1	0.1*		9
Diesel	C8.3 (cat.)	1996	g/bhp-h	0.08	4.7	0.7	0.2		9
	% change	% change		-88%	-45%	57%			
Detroit Diesel Engine									
CNG	S-50 (without cat.)	1996/7	g/bhp-h	0.03	1.9	2.6	0.8*	1996	7
Diesel	S-50 (cat.)		g/bhp-h	0.04	4.7	1.1	0.1		7
	% change	% change		-25%	-60%	136%			
CNG	S-50 (without cat.)	1994/5	bhp-h	0.05	2.7	2.7	0.07*	1995	10
Diesel	S-50 (cat.)	1995	g/mile	0.09	31.09	3.19	0.11	1996	11
	S-50 (without cat.)	1995	g/mile	0.11	36.08	3.93	0.11		

Notes	Comments/Sources
#	"cat." is indicated if engine is known to have a catalyst
*	Non-methane component of hydrocarbons
1	SAE 961082 - Alternative Fuel Transit Bus Evaluation Program Results, NREL Project, Tacoma
2	L10-240G non-certified demonstration engine
3	L10-260G CARB-certified version
4	SAE 961082 - Alternative Fuel Transit Bus Evaluation Program Results, NREL Project, Miami

… Notes continued on next page.

5 Central NY Reg. Transit Authority, Onondaga County, NY, 3 year test, Natural Gas Fuels, Oct. 1996, pp.16 (both CNG & diesels were 4 cycle engines)
6(a) Range over buses tested, 1996 Windsor Workshop
6(b) Bus with high NOx & CO emissions after maintenance
6(c) Range in emissions for similar diesel buses
7 John Fisher, Manager of Certification, DDC, January 1997.
8 New York, SAE 961082 - Alternative Fuel Transit Bus Evaluation Program Results, NREL Project
9 Cummins Engine Company, EPA and CARB Certification Data
10 Dave Rowland of DDC: CARB Emissions Certification Data
11 Environment Canada tests, Ottawa, chassis dynamometer tests - urban cycle, new engine

- Particulate emissions of all natural gas engines are extremely low and are less than 5% of particulate emissions of the earlier model diesel engines. With the more stringent standards, particulate emissions of the latest diesel engines (such as the DDC Series 50) have improved and reductions range from 0% to 70% for natural gas engines (without a catalyst).
- NOx emissions for the early natural gas engines are higher than similar diesel engines, but more recent natural gas engines cut NOx emissions by 40% to 60% compared to similar diesel.
- CO emissions vary greatly from engine to engine for natural gas. The Cummins engines were higher than diesel for the early natural gas engines, but for their later engines, CO emissions are reduced by 83% - 99%. However, CO emissions are again high with their latest 280G engine. The DDC Series 50 engines have relatively high CO emissions, over double that of similar diesel engines.
- Total hydrocarbon emissions are much greater for natural gas engines compared to diesel. Excluding the non-toxic methane component, non-methane HC emissions are similar to those of diesel for Cummins engines, but still much higher than diesel for DDC engines. However, HC emissions are still within the 1998 standards for all these engines.

Deterioration rates in emissions depend greatly on the type of application and how well the engines are maintained. No data has been published on the deterioration of emission rates of natural gas engines over time in comparison to diesel engines. In any case, deterioration rates based on the early natural gas engines would likely not be relevant to the latest engines as many improvements have been made. It is therefore not possible to include deterioration rates directly in the life cycle comparisons of emissions.

A full or complete air quality comparison would also include consideration of secondary PM-10 produced from pre-cursors SOx, NOx and VOC, in addition to the comparison of direct PM-10 emissions from the exhaust that is presented. This can significantly affect the benefit calculations, ultimately favouring the engine/system with the lowest NOx, SOx, VOC and PM-10. Unfortunately, only regulatory emissions data is currently available on the DDC diesel and natural gas engines under consideration and this data does not include SOx and VOC emissions.

However, direct SOx emissions can be approximated based on the sulphur content of the fuels calculated as SO2. This method does not include the secondary formation of PM-10. The sulphur content and approximate SO2 emitted per litre of fuel consumed for diesel and natural gas [53] are:

- Diesel: 0.05% (w/w) sulphur content (BC Regulation)
  846 gram/litre (based on 36.5 MJ/L low heat value (LHV) energy content)
  23.2 g SO2/GJ (approximate value, LHV)
- Natural gas 20 mg/m^3 (15 ppm) sulphur @ 15 °C, 101.325 kPa, dry
  Assuming energy content: 35.09 MJ/L LHV
  1.1 mg SO2/GJ (approximate value, LHV)

SO2 emissions from natural gas are therefore much lower than from diesel, even allowing for the lower energy efficiency of CNG buses.

Investigation of high emissions from in-service alternative fueled buses indicate that careful maintenance is required to sustain the low emissions levels of CNG buses[54].

C. PREDICTION OF CHANGES IN EMISSIONS UNDER CNG BUS PURCHASE SCENARIOS

Buses powered by the DDC Series 50 natural gas engine, which are the preferred engine of BC Transit, have not been tested on a chassis dynamometer. Thus, in service emissions rates must be estimated from engine dynamometer results. The EPA have developed factors for

[53] CNG SO2 content: Natural Gas Characteristics and Combustion, BC Gas Inc. Diesel SO2 content: Maximum allowable under the BC Diesel Fuel Regulation and the Automotive Low Sulphur Diesel Fuel CAN/CGSB-3.517-93 standard.

[54] N.N. Clark, W. Wang, D.W. Lyons, M. Gautam and R.M. Bata, “Troubleshooting High Emissions from In-service Alternative Fueled Heavy Duty Vehicles and Buses”, presented at the 1996 Windsor Workshop, Toronto, Canada.

converting emissions in g/bhp-hr to g/mile for transit buses[55]. The factors are given in Exhibit VI-4.

Exhibit VI-4. EPA Factors for Converting Emissions in g/bhp-hr to g/mile for Transit Buses

Drive Cycle	PM	NOx	CO	HC
Urban bus cycle	7.9	4.3	10.6	2.3
Heavy urban bus cycle	18.1	7.0	25.6	5.4

As is evident from these factors, the estimated emissions are very dependent on the drive cycle (driving environment and use of the bus). The conversion factors are based on a number of engines and buses, and only give very approximate results for any particular engine, bus and type of use. For example, shown in Exhibit V-5 are the engine dynamometer emissions rates of the 1996/7 diesel DDC Series 50 engine given in Exhibit VI-3, the estimated grams per mile based on the urban bus cycle factors, and measured grams per mile for a bus with a new DDC S50 diesel engine.

The conversion factors do not provide good estimates of the in service emissions for the DDC Series 50 transit bus tested by Environment Canada.

Exhibit VI-5. Estimated and Measured In Service Emissions for Transit bus with Diesel DDC Series 50 Engine

	PM	NOx	CO	HC
Certification Emissions (g/bhp-h)	0.04	4.7	1.1	0.1
Urban cycle factor	7.9	4.3	10.6	2.3
Est. in service emissions (g/mile)	0.32	20.2	11.7	0.23
Measured in service emissions (g/mile)	0.09	31.1	3.2	0.11

Given the possible inaccuracies using the conversion factors and the availability of a set of chassis dynamometer results for a diesel DDC Series 50 bus, the in-service emissions were not estimated using the EPA factors. Instead, the in-service emissions were estimated based on the chassis

55 EPA, "Development of Conversion Factors for Heavy Duty Engines", EPA-AA-EVRB-92-01, 1992. Note, these conversion factors are dated and will be updated in the future.

dynamometer results for the diesel bus and the percentage differences in emissions from engine dynamometer (certification) results.

Values for a natural gas engine without a catalyst and a diesel engine with a catalyst were used as these are the choices available to BC Transit. By considering a diesel engine with a catalyst and a natural gas engine without one, emissions reductions due to the choice of CNG buses are significantly reduced. DDC has been able to meet the 1998 certification for Series 50 natural gas engines without the use of a catalyst. Previously, a 1994 model year of their Series 50 engine was tested with a catalyst. The tests found that the catalyst reduced all emissions values. However, the 1997 model year Series 50 engine without a catalyst is cleaner than the 1994 model engine and has a lower level of NOx than achieved with the 1994 engine with a catalyst. A Series 50 natural gas engine with a catalyst would be required to meet the same standards as an engine without a catalyst. However, such an engine would require separate certification if it was provided by an engine or bus manufacturer. In order for Detroit Diesel to bring a Series 50G "Cat" engine to market they would have to develop a catalyst optimized for the natural gas engine, perhaps retuning the DDEC electronic engine controls, and recertifying the engine with the regulatory authorities. The costs for such an engine, (and the emissions benefits) particularly for a small order for BC Transit, are not known at this time.

The estimated particulate, NOx and CO emissions per bus and for each scenario are given in Exhibit VI-6. Estimated HC emissions values, broken down into the methane and non-methane components, are given in Exhibit VI-7. These estimates are very approximate as they are based on limited data and make no allowance for possible differences in deterioration rates between diesel and natural gas. High, likely and low values are given due to the uncertainty in the emissions levels of these new engines, the variation in available data and the lack of chassis dynamometer test data. [56] The likely values are the estimates for buses with the 1996/7 DDC S50G engine. The high and low values were based on the both the engine and chassis dynamometer results for the DDC series 50 engines and Cummins L10 engines. The likely values are much closer to the low values for particulates because the emissions levels of the new DDC Series 50 diesel engines with catalysts are comparatively low.

It should be noted that NOx and particulate emissions are associated with health concerns and reductions in these emissions are important for the air quality in the Greater Vancouver Regional District (GVRD). Heavy duty

[56] The changes in emissions rates from chassis dynamometer test are based on the average of 5 to 10 in-service buses tested at each site and reduced rates could be achieved through engine diagnosis, repair and adjustment.

vehicles, including transit buses, contribute relatively more NOx and particulates than CO and VOCs to the total emissions in the GVRD. [57]

Exhibit VI-6. Predicted Changes in Total Particulate, NOx and CO Emissions Due to Converting from Diesel to CNG Buses.

Fuel		Particulates			NOx			CO		
		Low	Likely	High	Low	Likely	High	Low	Likely	High
Per Bus over 20 years										
Diesel	Rate (g/mile)	1.70	0.09	0.09	36	31	24	32.0	3.2	3.2
	Est. (tonnes)	1.46	0.08	0.08	31	27	21	27.4	2.7	2.7
CNG	% change	-99%	-25%	0%	-60%	-60%	-38%	-99%	136%	127%
	Rate (g/mile)	0.02	0.068	0.09	14.4	12.4	14.9	0.3	7.6	7.3
	Est. (tonnes)	0.01	0.06	0.08	12.4	10.6	12.8	0.27	6.48	6.23
	Change (tonnes)	-1.44	-0.02	0.00	-18.5	-16.0	-7.8	-27.2	3.7	3.5
Scenario 1.										
Diesel	Est. (tonnes)	110.8	5.9	5.9	2,347	2,021	1,564	2,086	209	209
CNG	Est. (tonnes)	1.1	4.4	5.9	939	808	970	21	492	473
	Change (tonnes)	-109.7	-1.5	0.0	-1,408	-1,212	-594	-2,065	284	265
Scenario 2.										
Diesel	Est. (tonnes)	307.6	16.3	16.3	6,515	5,610	4,343	5,791	579	579
CNG	Est. (tonnes)	3.1	12.2	16.3	2,606	2,244	2,693	58	1,367	1,315
	Change (tonnes)	-304.6	-4.1	0.0	-3,909	-3,366	-1,650	-5,733	788	735
Notes:	7	1	2	3	5	2	4	6	2	2

Notes: 1 Based on Cummins L10 Diesel chassis dynamometer data from NREL, and % reduction for L10-260G buses at those sites
2 Based on DDC S50 diesel with cat. chassis dynamometer data, and % change for 1996/7 DDC S50 certification data (NG without cat., diesel with cat.)
3 Based on DDC S50 diesel with cat. chassis dynamometer data, and % change for 1994/5 DDC S50 from CARB certification data for NG (without catalyst), diesel with catalyst.
4 Based on Cummins L10 Diesel chassis dynamometer data from NREL, and % reduction for L10-260G buses at Miami transit site
5 Based on DDC S50 diesel without cat. chassis dynamometer data, and % change for 1996/7 DDC S50 certification data
6 Based on Cummins L10 Diesel chassis dynamometer data and % reduction for L10-260G buses from New York transit site
7 Based on distances travelled (million km): 1.38 per bus, 104.9 under Scenario 1, and 291.2 under Scenario 2. Scenario 1: 76 new CNG buses at Port Coquitlam, Scenario 2: 76 new CNG buses at Port Coquitlam & 135 at Surrey. Emissions under Scenarios 1 and 2 are over the life of the buses purchased under those scenarios

Approximate estimates of the reduction in SOx emissions, based on the sulphur content of the fuels calculated as SO2 (as discussed earlier), are as follows:

- Scenario 1: SO2 reduction of 40 tonnes
- Scenario 2: SO2 reduction of 110 tonnes

[57] GVRD Air Quality Management Plan, Dec. 1994, Table 4-1 - Summary of 1990 GVRD Emissions Inventory.

Exhibit VI-7. Predicted Changes in HC Emissions Due to Converting from Diesel to CNG Buses.

Fuel		Non-methane HC			Methane HC			Total HC		
		Low	Likely	High	Low	Likely	High	Low	Likely	High
Per Bus over 20 years										
Diesel	Rate (g/mile)*	2.4	0.1	0.1	0.1	0.1	0.1	2.4	0.1	0.1
	Est. (tonnes)	2.1	0.1	0.1	0.09	0.09	0.09	2.14	0.17	0.17
CNG	% change	-25%	700%	700%						
	Est. (tonnes)	1.5	0.7	0.7	12.9	7.6	11.4	14.4	8.3	12.1
	Change (tonnes)	-0.5	0.6	0.6	12.8	7.5	11.3	12.3	8.1	12.0
Scenario 1.										
Diesel	Est. (tonnes)	156	7	7	7	7	7	163	13	13
CNG	Est. (tonnes)	117	52	52	978	579	869	1,095	632	921
	Change (tonnes)	-39	46	46	971	573	863	932	619	908
Scenario 2.										
Diesel	Est. (tonnes)	434	18	18	18	18	18	452	36	36
CNG	Est. (tonnes)	326	145	145	2,715	1,609	2,413	3,040	1,753	2,558
	Change (tonnes)	-109	127	127	2,696	1,591	2,395	2,588	1,717	2,521
Notes:	7	1	2	2	3	4	5	6	6	6

Notes: 1 Based on Cummins L10 Diesel chassis dynamometer data from NREL, and % reduction for L10-260G buses at those sites assuming 90% non-methane

2 Based on DDC S50 diesel with catalyst chassis dynamometer data, and % change for 1996/7 DDC S50 certification data (NG without catalyst, diesel with catalyst)

3 Based on non-methane values and assuming 88% of HC emissions are methane

4 Based on non-methane values and assuming 91% of HC emissions are methane

5 Based on non-methane values and assuming 94% of HC emissions are methane

6 Sum of methane and non-methane values in each (low, medium and high) case

7 Based on distances travelled (million km): 1.38 per bus, 104.9 under Scenario 1, and 291.2 under Scenario 2. Scenario 1: 76 new CNG buses at Port Coquitlam, Scenario 2: 76 new CNG buses at Port Coquitlam & 135 at Surrey. Emissions under Scenarios 1 and 2 are over the life of the buses purchased under those scenarios

* Methane component for diesel based on value of 0.16 g/L given in Environment Canada greenhouse gas emissions, 1995 draft.

Carbon dioxide (CO2) emissions are directly related to the fuel consumed and varies by fuel type. CO2 emissions were estimated based on the fuel consumption rates of the DDC series 50 buses used in the life cycle cost analysis and the following published emissions factors[58]:

- CO2 per litre of diesel: 2730 g
- CO2 per cubic meter of natural gas: 1880 g (equivalent to 1956 g/Ldeq)

[58] "Canada's Greenhouse Gas Emissions: Estimates for 1990", Environment Canada, Environmental Protection Series, Report EPS 5/AP/4, December 1992 (natural gas at standard temperature).

Estimated CO2 emissions per bus per year and for each scenario are given in Exhibit VI-8. The low, likely and high values given correspond to the optimistic, base and pessimistic cases for the reduction in fuel efficiency with CNG compared to diesel buses. Conversion from diesel to CNG is estimated to reduce CO2 emissions by between 7% and 21%, with a most likely value of 14%. This compares with a 12% reduction found by Environment Canada in chassis dynamometer tests on bus with a Cummins L10 engine.

In addition to CO_2, methane and N_2O also contribute to greenhouse gas emissions. Estimates of methane emissions under each scenario are given in Exhibit VI-7. Methane has a relative global warming potential (GWP) of 21. Data on N_2O emissions from CNG buses could not be found and the N_2O contribution to greenhouse gases could not be estimated. The greenhouse gas equivalents of CO2 and methane were estimated (based on the "likely" case) and are given on the right side of Exhibit VI-8. Conversion from diesel to CNG is estimated to reduce CO2 equivalents by about 5%.

Exhibit VI-8. Predicted Changes in CO2 Emissions and CO2 and Methane Greenhouse Gas Equivalents Due to Converting from Diesel to CNG Buses#

Fuel		**CO2**			Greenhouse Gas
		Low	Likely	High	Equivalents*
Per Bus over 20 Years					
Diesel	Fuel (L/100km)	45.00	45.00	45.00	
	CO2 rate (g/km)	1,229	1,229	1,229	
	Est. (tonnes)	1,695	1,695	1,695	1,697
CNG	Fuel (L/100km)	49.50	54.00	60.75	
	CO2 rate (g/km)	968	1,056	1,188	
	Est. (tonnes)	1,336	1,458	1,640	1,618
	Change (tonnes)	-359	-238	-56	-79
Scenario 1.					
Diesel	Est. (tonnes)	128,845	128,845	128,845	128,982
CNG	Est. (tonnes)	101,547	110,778	124,626	122,946
	Change (tonnes)	-27,298	-18,067	-4,219	-6,036
Scenario 2.					
Diesel	Est. (tonnes)	357,715	357,715	357,715	358,095
CNG	Est. (tonnes)	281,926	307,556	346,000	341,337
	Change (tonnes)	-75,788	-50,159	-11,714	-16,758

* Average fuel consumption rate of DDC Series 50 diesel buses in BC Transit fleet.

** Based on reduction in fuel efficiency in optimistic, base and pessimistic cases in life cycle cost analysis.

\# Based on distances travelled (million km): 1.38 per bus, 104.9 under Scenario 1, and 291.2 under Scenario 2. Scenario 1: 76 new CNG buses at Port Coquitlam, Scenario 2: 76 new CNG buses at Port Coquitlam & 135 at Surrey. Emissions under Scenarios 1 and 2 are over the life of the buses purchased under those scenarios

VII. SUMMARY AND CONCLUSIONS

Review of Transit Fuel Technologies

Manufacturers of heavy duty engines have greatly modified their products to meet new emissions regulations in North America. Low sulfur diesel fuel, as used by BC Transit, is required to meet current standards. The need for catalysts for treating exhaust emissions to meet 1996 - 1998 standards depends on the design strategy of the manufacturer. It is highly likely that diesel engines with further refinements and use of catalysts will be able to meet the proposed standards for 2004. Diesel fuel may have to be further reformulated. Therefore, it is anticipated that diesel engines will continue to compete effectively with alternative fuels from an emissions perspective.

The review of alternative fuel technologies shows that CNG is the only alternative fuel technology that is well developed and tested, available as a commercial product, uses a fuel which is readily available and may be cost competitive with diesel. Other fuel technologies such as LNG, propane, DME, alcohols, electric, hybrids, and biodiesel are either untested, not commercially available, too expensive or lack fuelling infrastructure.

There are also diesel technologies that can be applied to older buses that can reduce emissions. These technologies were not part of the scope of this study but should be evaluated as part of an overall strategy to reduce emissions for BC Transit.

Experience of Other Transit Fleets

Experience of North American transit operations indicates that CNG is the leading alternative fuel in public transportation applications. In 1995, CNG buses were operated by 40 transit properties in Canada and the United States, representing about 2% of the total North American transit fleet. In the first six months of 1996, about 20% of new bus orders in North America were for CNG powered vehicles, indicating a growing interest in the technology. A number of conclusions and lessons can be learned from the experience at other properties:

- Adoption of CNG has been a response to public and political concern about the environment.

- Successful alternative fuels programs have been actively supported by transit managers.

- Financial support from governments and utilities has made the implementation of CNG viable for the transit operator.

- Spares ratios have not been affected. Successful implementation of alternative fuels have not had a negative impact on levels of service provided to the public.

- Proper inspection, maintenance and training is required to ensure safe operation.

- Ancillary equipment failures such as electrical systems and methane detection have been a problem at some sites.

- CNG technology has improved over the last ten years and has become more reliable.

Pilot CNG Bus Test

In BC Transit's pilot test program, 10 of the 25 natural gas buses (conventional configuration) that were placed into service in Port Coquitlam starting in November 1995 were selected for performance monitoring. In addition, 10 similar vintage New Flyer low floor buses with DDC Series 50 diesel engines were selected as a control group at Burnaby. There are some differences between the two vehicle groups that limits the comparison of the results. The BC Transit pilot is an operational demonstration that was designed under constraints of the operating environment. The pilot is not an in-depth scientific study.

At the end of 1996, the Sypher recommended several steps that should be taken to improve the likelihood of obtaining useful and reliable data. These steps included:

- Expanding the pilot program to include small fleets of identical diesel control buses in Burnaby and Port Coquitlam.

- Implementing on-line data gathering at Burnaby as soon as possible.

- Use of data that can be downloaded from the on-board engine computer.

- Presenting data on the same scales (i.e., per kilometre).

- Segregating out fuel related data.

Since the initial design, BC Transit has made definite improvements in its data collection including: use of similar scales for comparing data, segregating out fuel and engine related information, implementing the Fuel Data Capture System at Burnaby, and establishing diesel control fleets.

In the March 6th draft report to its Board of Directors, BC Transit reported higher warranty claims and increased number of bad orders and road calls. At this time, the warranty claims are not true costs to BC Transit except for some additional labour time. The data does indicate that there are still reliability issues that could be of concern. However, the March 6th draft report does not outline which components were failing nor the frequency of failures. There were no indications in the report of progress that DDC or New Flyer were making in solving reliability problems. It is reasonable to expect that improvements will be made with efforts underway by DDC and New Flyer. However, there is some uncertainty in the timing and extent of these improvements, and whether warranty periods might be extended. This risk has been addressed in the financial analysis.

Financial Feasibility

Key variables that were assessed in the financial viability of CNG included: fuel consumption, maintenance, gas prices, bus prices, facility costs, engine rebuilds and staff. These variables were compared to diesel costs.

The financial viability of CNG for BC Transit is very dependent on tax considerations, the location of the buses, fuel consumption and maintenance. With the current tax structure, financial viability is marginal, as measured by NPV analysis. If BC Transit were to own and operate their own compressor stations and purchase gas “at the property line”, the NPV is -$506,000 for CNG buses at the Port Coquitlam garage only, and $92,000 for CNG buses at the Port Coquitlam and Surrey garages. CNG is financially unattractive for natural gas purchased “at the filler nozzle” under current arrangements with BC Gas. BC Transit may be able to negotiate a better pricing structure with a larger number of buses being amortized over the compressor stations.

Buses operating out of the two garages considered have significantly lower fuel consumption than buses operating out of Burnaby since both of these garages are located in suburban areas where the operating environment is less severe. Since savings in fuel costs are required to offset the capital expenses associated with CNG buses, CNG buses should ideally be located in areas where fuel consumption will be greatest. The financial viability of

CNG buses would have been very positive had the buses had the same fuel consumption rates as buses at Burnaby (NPVs over $0.8 million).

The financial viability is dependent on BC Transit negotiating a bulk purchase agreement with the gas supplier, reducing the fuel price from 16 cents per litre (diesel equivalent) to around 11 cents per litre. Under current BC regulations, this fuel price would be subject to approval of the BC Utilities Commission. If the present price of gas purchased from BC Gas is maintained for new CNG vehicles, the fuel is definitely not financially attractive for BC Transit.

If provincial and local taxes that are applied to diesel (but not to natural gas) are eliminated from the analysis, then the financial viability of CNG has a very negative NPV under both gas purchasing options - “at the property line” and “at the nozzle”.

In addition to the financial viability being extremely sensitive to gas price, the sensitivity of the financial analysis was also tested for optimistic and pessimistic assumptions regarding major cost factors. Assuming the lower price of gas, only pessimistic assumptions about staffing (not reported at other properties), the diesel fuel consumption rate and maintenance costs reduced NPV significantly. Optimistic assumptions on the diesel fuel consumption rate and engine rebuild period led to positive NPVs for the scenarios where gas is purchased “at the property line”, and current taxes are included.

Emissions

Emissions from CNG and diesel engines were reviewed. Based on the technology that will be available for BC Transit’s upcoming purchase, the potential changes in emissions by using CNG compared with diesel were predicted:

- Particulates 25% reduction using CNG
- NOx 60% reduction
- CO 140% increase but within standards
- HC 700% increase for NMHC but within standards
- SO2 99% reduction
- CO2 equivalents 5% reduction.

It is not within the scope of this study to conduct an economic evaluation of the costs associated with these emissions (and thus the benefits of reducing them). Nevertheless, the relative significance of each in contributing to environmental health problems is well understood. Most transit buses operate in crowded and congested urban corridors where human exposure to emissions is relatively high. The particulate and NOx reductions are most important to air quality in the GVRD. NOx and particulates are associated with health concerns and heavy duty engines are major contributors to particulates and NOx. CO and HC produced by heavy duty vehicles, however, constitute only a small portion of the total CO and HC in the GVRD. CO2 has consequences for global, as opposed to local, environment as it is a greenhouse gas and primary cause of climate change.

It should be noted that the emissions levels for both diesel and CNG are very low compared with the standards of the early 1990s and that small absolute changes in emissions (e.g., grams/bhp-hr) can cause large percentage changes.

APPENDIX A

DIESEL ENGINE ENHANCEMENTS

DIESEL ENGINE ENHANCEMENTS

A number of enhancements to diesel engines have been developed for reducing emissions. These enhancements could have the potential for emissions reductions to similar levels as alternative fuels, but at less cost and/or financial risk, and with little or no change in current operations. Most of these enhancements are usually applied during engine rebuilds. Several promising enhancements are discussed below.

1. CMX Catalytic Converter

Engelhard has developed a catalytic converter muffler for retrofitting to diesel buses. The CMX converter muffler is approved by the EPA under its urban bus-emissions regulation (phase I) for engine retrofit/rebuilds. Approximately 5,500 buses have been fitted with the CMX converter muffler in the US.

The CMX converter muffler is EPA certified to reduce HC by 50%, CO by 40% and total particulate emissions by a minimum of 25%. The units have no associated fuel penalties nor maintenance requirements.

2. ETX-2002 Engine Upgrade System

Engelhard has also more recently developed the ETX-2002 engine upgrade system to meet the EPA's phase II emissions requirements for urban bus retrofit/rebuild program. The system exceeds the standard engine rebuild kits (CMX converter muffler described above) by 65% for particulates, 66% for HC 75% for CO and 3% for NOx. The ETX-2002 system is pending EPA certification.

3. GPX Coating

The GPX combustion management coating developed by Engelhard are applied during engine rebuilds. The coatings reduce emissions by reflecting heat back into the combustion process, which allows a more efficient and cleaner burn of the fuel. When applied in conjunction with an exhaust catalytic converter, comprehensive control of emissions is achieved.

A trial has been completed using the coatings on buses operated by the Greater London Bus company (UK). Results indicate that there is a significant reduction in smoke. In addition, fuel consumption on the test fleet was reduced by an average of 8% and drivers reported an increase in power and improved derivability.

4. CRT Filter

The engineering specialists, Johnson Matthey (JM), have combined a filter with a catalytic converter to make a system known as the continuously regenerating particulate trip (CRT)[59]. The by-products of the catalytic conversion destroy both the soot and harmful nitrogen oxides. The soot-laden exhaust fumes pass from the engine into the CTR where they flow through a platinum-coated ceramic honeycomb. The metal catalyses the conversion of the hydrocarbons in the exhaust to CO2 and water, CO to CO2 and NO to NO2. The gases and soot then flow into a ceramic filter and, instead of clogging the filter, the soot burns in the NO2 stream to produce CO2 and nitrogen gas.

Tests using the CTR on buses in London (UK), Cambridge (UK) and Gothenburg show that the CTR removes 92% of particulates, 96% of hydrocarbons and 98% of CO from the exhaust of diesel engines without catalytic converters.

The CRT costs about $7,000 and JM states that it requires very little maintenance and can be fitted to most existing diesel engines. However, engine fuel efficiency is reduced by about 2% and low-sulphur diesel fuel must be used.

5. PFC Plus Catalyst

Clean Diesel Technologies Inc. have developed a diesel fuel catalyst known as Platinum Plus (PFC). PFC is used in diesel engines with an oxidation catalyst or particulate filter. It is a stable fuel additive that continuously adds minute amounts of platinum to the engine. The platinum improves engine combustion and constantly refreshes the catalytic activity of the diesel oxidation catalyst or particulate filter.

Tests on a four-cycle bus engine indicate that particulate emissions are reduced by: 26% when PFC is used with the diesel oxidizer, compared to 18% with the oxidizer alone. However, the company states that greater reductions, as much a 95% reduction, are possible. The tests also showed the PFC and oxidation catalyst reduced HC emissions by 90%, CO by 62%, NOx marginally (4%). The PFC was also found to improve engine power and fuel economy. Similar results were found with light-duty engines.

Fleet tests and further engine tests are currently being conducted.

6. Micro-Pulse Controls Low-NOx Engine-control System

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59 "Sweeping the Soot from Dirty Diesel", Chemistry and Industry Magazine, February 1996.

A California company has announced that it has developed a new technology to meet proposed EPA diesel emission standards. Micro-Pulse Controls, a developer of advanced diesel engine technology, announced a new low-NOx engine-control system. It has the potential to meet the most stringent emission regulations under consideration by the U.S. Environmental Protection Agency (EPA) and the Los Angeles-area's South Coast Air Quality Management District (SCAQMD). Unlike other low NOx technologies that increase production of particulates, the new Limited-Temperature Cycle combines a fast-burn technique with a reduced flame temperature to avoid formation of particulates from retarded injection timing. NOx reduction and particulate control are key components of the proposed EPA rule. The new Limited-Temperature Cycle engine-control operating system achieves NOx compliance below 1.0 g/bhp-hr, a level over three times cleaner than can be met by current diesel technology, in combination with particulate control below 0.1 g/bhp-hr. Micro-Pulse Controls expects to demonstrate the clean diesel technology in early 1997.

7. Detroit Diesel Oxidation Converter Muffler

Detroit diesel has released an oxidation converter muffler (OCM) designed for use on DDC two-cycle engines originally installed on urban buses from model year 1979 to 1993 (excluding those with particulate traps or using alcoholic fuels). The chassis dynamometer and engine tests indicate that installation of the OCM reduces particulate emissions by at least 25%. The muffler can be installed at the time of engine retrofit/rebuild.

APPENDIX B

EMISSIONS FOR OTHER ALTERNATIVE FUELS

APPENDIX C

LIFE CYCLE COST ANALYSIS MODEL

EMISSIONS FOR OTHER ALTERNATIVE FUELS

In most cases emissions are measured on a similar diesel vehicle for comparative purposes and in some cases, only the percentage change in emissions are given. Comparative emissions values are given in Exhibit 1.

Biodiesel

Comparative emissions tests with biodiesel and diesel can be conducted using exactly the same engine, thus improving the comparability of results. Engine dynamometer results indicate that for 20% and 35% biodiesel blends:

- particulates can be reduced by about 20% (typical range 0% - 30%);
- NOx emissions are similar to diesel;
- CO emissions can be reduced by about 10% (range 0% - 20%); and
- Total HC emissions can be reduced by about 15% (range 0% - 50%).

Chassis dynamometer tests were conducted on transit buses using biodiesel, but the variation between buses was greater than the differences between diesel and biodiesel, so no conclusions could be reached.

A-21 Fuel

Little detailed data has been published on the emissions of A-21 fuel in heavy duty engines. Based on tests on a Caterpillar 3176 engine and reports from other sources on unspecified engines, A-21 fuel is claimed to:

- reduce particulate emissions by 30% to 70%;
- reduce NOx emissions by 50% - 80%; and
- reduce both CO and HC emissions.

In addition, CO2 emissions are reduced by 50%. The exhaust stream is reported to consists of 70% water vapour and contains no harmful products. No independents verifiable tests have been conducted with A-21 in heavy duty engines, and in practice, the emissions reductions could be much less than those claimed.

Dimethyl Ether (DME)

DME is a very new fuel and reported emissions values are based on engine dynamometer results. Tests indicate that the ULEV emissions levels can be met with DME without the use of exhaust treatment or catalytic converters. The findings from three tests are summarized below:

- Particulate emissions are in the range 0.02 to 0.04 g/bhp-hr, half the current transit bus standard, and 75% less than typical diesel engines without catalysts.

- NOx emissions are in the range 2.0 to 2.9 g/bhp-hr, 30% less than the current transit bus standard, and 50% less than diesel engines without catalysts.
- CO emissions of about 1.6 g/bhp-hr, one tenth the current standard.
- Total HC emissions of about 0.15 g/bhp-hr, one tenth the current standard.

Exhibit 1. Comparison of Biodiesel, A-21, DME and Pine Oil Emissions with

Fuel	Engine	Emissions (g/bhp-hr or g/mile or % change)						Year	Comments/Sources
		PM	NOx	CO	THC	CO2	Other		
Biodiesel									
BD-20		-20%						1996	20% blend, ORTECH work, M
BD-20		-31%		-21%	-47%	-60%		Unkn	20% blend, THC, Canola Biod
BD-20	DDC S-60	-12%	1%	-3%	-3%			1995	20% blend, THC, 1995 Windso
BD-35		-27%	1%	-19%	-15%				35% blend, Total hydrocarbon
BD-20	DDC 6V92	0.89	54.50	9.6	2.20			1995	Units: g/mile, 20% blend, chas
Diesel	DDC 6V92	0.85	52.40	9.6	2.60				NREL Program, St. Louis trial
	% change	5%	4%	0%	-15%				A lot of variation between tests
BD-35	DDC Series 60	-22%	1%	-26%	-15%			1996	3 trucks, Clark & Lyons, 1996
	Cummins 855	-23%	4%	-5%	-15%				3 trucks, 1989 & 1992 model y
	Mack E-6	9%	7%	-7%	4%				2 trucks, 1989 model year
Est. % change for DDC S-50		-20%	0%	-10%	-15%				Values Used in Emissions Red
A-21									
A-21	Cat. 3176	-30%	-60%					1996	CFR, June 1996, pp21
A-21		up to	-	------ all reduced	----------	-50%			E.Schunter, Products for a Bet
DME									
DME		0.018	1.9				Smoke-	1996	CFR, June 1996, pp23, estima
Diesel	bus engine	0.073	4.5						units: g/bhp-hr
	% change	-75%	-58%						
DME	Navistar T 444E	0.037	2.87	1.62	0.15	-9%		1995	units: g/bhp-hr, Total HC, CFR
DME	AVL 2L 1 cyl.	0.030	1.50		< 0.1			1996	1996 Windsor Workshop, pp.
DME		0.020	1.00		< 0.1				units: g/bhp-hr, Turbo/intercoo
DME		0.02	2.10					1995	units: g/bhp-hr, CFR, April 19
Diesel		0.15	4.5						typical diesel (stated in report)
	% change	-87%	-53%						
Est. % change for DDC S-50		-40%	-50%	40%	0%				Values Used in Emissions Red
Pine Oil									
Pine Oil	DDC 6V92	-39%	-15%	-26%	-59%	-26%			Upper end of range of emission

APPENDIX D

TRANSPORTATION FUEL TAXES ON CANADA

TRANSPORTATION FUEL TAXES IN CANADA

APPENDIX E

NATURAL GAS PRICE FOR VEHICLES APPROVED BY BC UTILITIES COMMISSION

NATURAL GAS PRICE FOR VEHICLES APPROVED BY BC UTILITIES COMMISSION

Tariff Rate #6, Natural Gas Vehicles, as approved by BC Utilities Commission on January 1, 1994 provides for:

Basic monthly charge $42.00 per site plus
Delivery charge of $2.318 per gigajoule plus
Gas Cost Recovery charge of $1.345 per gigajoule

and

"BC Gas may in its sole discretion reduce the delivery charge per gigajoule to any customer where such reduction is necessary to encourage expansion of the NGV market. Any reduction in the delivery charge will be specified in the Service Agreement"

Natural Gas Vehicle Service Agreement, between Beach Place Ventures and BC Gas was approved by BC Utilities Commission on Dec 16, 1994.

This agreement states that:

> For gas delivered up to and including 2,750 gigajoules per month the delivery charge will be as specified (above). For gas delivered in excess of 2,750 gigajoules per month the delivery charge will be 25% of the delivery charge from Dec 16, 1994 to Dec 15, 1995, and then 50% of the delivery charge until Dec 16, 1999.

These discounts to natural gas delivery costs were applied to the natural gas that would be purchased by BC Transit if they were to refuel 101 buses with CNG. The average price per litre diesel equivalent for the two discount rates are given in Exhibit E-1. With these discounts and this level of demand, the average price of natural gas would be of the order of 10 to 12 cents per litre diesel equivalent.

Exhibit E-1. Estimated Natural Gas Fuel Price Under the Natural Gas Services Agreement* for a fleet of 101 CNG Buses#

Fixed Charge				
Basic charge	$42.00			
Variable Price		Delivery discount over 80,000 Ldeq		
		Initial price	50% discount	25% discount
	$/GJ	$/Ldeq	$/Ldeq	$/Ldeq
Gas cost	$1.345	$0.0491	$0.0491	$0.0491
Delivery	$2.318	$0.0846	$0.0423	$0.0635
Total cost				
Gas cost		$19,034	$19,034	$19,034
Delivery	under 80,000	$6,770	$6,770	$6,770
	over 80,000	$26,033	$13,017	$19,525
Basic Charge		$42	$42	$42
Total cost		$51,879	$38,863	$45,371
Equivalent Cost	**per Ldeq**	$0.134	$0.100	$0.117

* Agreement between Beach Place Ventures and BC Gas, approved by BCUC Dec. 16, 1994.

\# Based on yearly fuel per bus = 4,600 Ldeq.