The Benefits of Clean, Quiet, Emission-Free Transit Service:

Promoting the Trolleybus in Vancouver

Information and Materials Package

Written by Kevin Brown
The TBus Group

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http://vancouver.trolleybus.net

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Background

Vancouver has successfully operated revenue trolleybus service since August 16, 1948. The current fleet consists of 244 40-foot vehicles manufactured by Flyer Industries Limited of Winnipeg, Manitoba. Purchased new in 1982-83, these vehicles are equipped with Westinghouse Chopper Control systems for smooth performance and energy efficiency. Energy saving regenerative braking and battery auxiliary power for limited off-wire travel are two additional noteworthy features. The peak weekday trolley book-out is around 221 vehicles, with a number of diesel buses being dispatched for service on trolley routes because there are not enough trolleys to fill all runs.[57] The vehicles are employed on the busiest routes in Vancouver and have held up well considering the extreme conditions under which they must operate. However, after 18-19 years of service, they are approaching the end of their life cycle. The life expectancy of these vehicles is about 20 years, at least three years longer than a comparable diesel-powered bus.[57]

Size, Value and Condition of the System

The Vancouver system comprises about 309 one-way kilometres of overhead wire and twenty rectifier substations that convert AC current to the 600 Volt DC power required to operate the trolleys. A combination of aerial and underground feeder cable is used to power the overhead wire network. Sections of underground feeder cable connect some substations into the system. Underground feeder cable also powers a section west of Blanca Street leading to UBC and is also located along Kingsway east of Boundary to power the line to Metrotown Station in Burnaby. A conservative estimate of the cost to build such a system today would be in the range of $180 to 185 million dollars.[57] **(**A ballpark cost figure for the installation of trolley infrastructure is about $1 million per two-way kilometre. This can vary depending on the amount "special work" required—eg. switches and crossovers—and on the type of feeder system, size and type of substations used, etc. Straight overhead wire without significant "special work" costs in the range of $600,000 to 700,000 per kilometre.**)**[57]

The trolleybus infrastructure in Vancouver is very well maintained through an ongoing pro-active maintenance program under the direction of the Trolley Overhead Department at Coast Mountain Bus Company. Given expected patterns of use and the high quality of maintenance work, the life expectancy of the current infrastructure has been conservatively estimated at another 25-30 years.[57]

Fairly new additions to the system include a 3.0 km line to Metrotown Station opened in 1986. That same year extensions to Joyce Station (0.6) km, Nanaimo Station (0.3) km and 29th Avenue Station (0.3) km were also completed. In 1988, a 3.0 km section was completed to extend the Broadway, Fourth and Tenth Avenue services into the University of British Columbia. The replacement of older style mercury arc rectifier substations with new, state-of-the-art equipment was completed in 1993.[62] The Trolley Overhead

Department has replaced and upgraded older hardware and suspension fittings throughout the system, as well, in recent years.

Extent of Use of the Infrastructure

For the most part, the Vancouver network is well utilized. There are three significant sections of the overhead network along which scheduled trolley service has been discontinued, although they are still used by trolleys heading into and out of service. These are the Hastings express wire that stretches for 10.8 km along East Hastings Street, the overhead along 41st Avenue between Crown and Joyce Station, and a section running along West Pender and Georgia Streets to Chilco Loop at Stanley Park. All peak hour bus trips on Route 41, the 41st Avenue service, were recently extended to UBC, and without a westward extension of the overhead, trolley service on this route is not possible. Although trolley service to Stanley Park was suspended in 1992 due to traffic hazards associated with the left turn into Chilco Loop, a plan was approved in July 2000 to return trolley service to this area by Spring of 2002. The Vancouver system also contains numerous sections of wire--particularly in the Downtown area--that are not utilized for regular service, but which can be used for detours or to turn back trolleys in the course of managing on-road incidents. This enables maximal use of the trolley system in the event of disruptions. ***Because of its extent and condition, the Vancouver system is assured excellent utility value in the long term***.

Power Consumption and Energy Efficiency of Trolleybuses

A widely accepted average figure for trolleybus power consumption in North America is about 3.0 kWh per kilometre of travel, including line losses in power transmission.[61,44] The average consumption in Vancouver works out to about 2.7 kWh per km.[24] The Westinghouse Chopper Control systems on Vancouver's current vehicles are a power saving feature. In addition, regenerative braking allows trolleys to "feed" power back into the lines for use by other vehicles in the vicinity. These two features alone are estimated to reduce power consumption by up to 40% over vehicles not so equipped.[43]

The trolley's average power consumption translates into about 10 megajoules of energy per km. The energy consumption of a typical 40 foot diesel bus under similar load conditions is about 24 megajoules, meaning that ***the trolleybus is more than twice as energy efficient as the diesel***.[60] This is illustrated on **Chart 1**. Where energy savings are concerned, in particular energy derived from non-renewable resources, the trolleybus is a clear leader. The trolley not only uses power efficiently, but in Vancouver its power supply is chiefly hydroelectricity, which is a renewable resource.

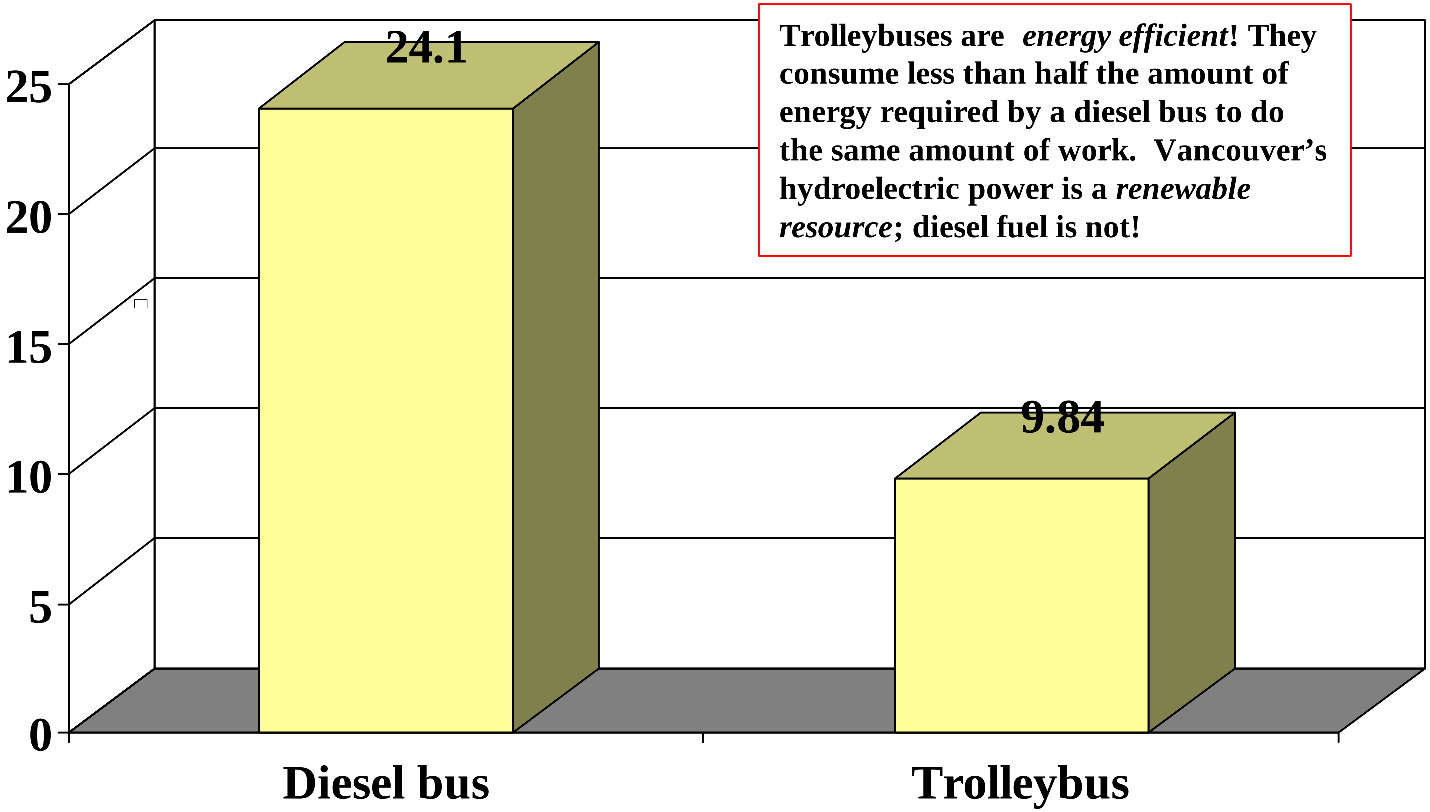
Environmental Factors

Air Pollution, Health and Mortality

The state of the environment is a matter of increasing concern globally. In particular, pollution in urban centres is reaching alarming levels. Motor vehicle exhaust from cars, trucks, buses and other mobile sources is to blame for a significant portion of that pollution--over 75% of all air contaminant emissions in the Vancouver area.[28] The Suzuki Foundation reports that, in Canada, at least 8% of all non-accidental deaths can be directly linked to air pollution.[10] This translates into 16,000 premature deaths each year.[10] The number of people suffering from respiratory ailments is rising significantly.

(Chart 1)

Comparative Energy Consumption
(in MJ per vehicle km)



Trolleybuses are *energy efficient*! They consume less than half the amount of energy required by a diesel bus to do the same amount of work. Vancouver's hydroelectric power is a *renewable resource*; diesel fuel is not!

Source: BC Transit (1994)

Hospitalization of young children in Canada for asthma increased by 28% among males and 18% among females between 1980 and 1990.[41] The City of Toronto Environmental Task Force estimates that health care costs resulting from vehicle emissions in the greater Toronto area total over $5 billion dollars annually, with about 1,800 premature deaths directly attributable to air pollution.[10] A comparison of the mortality figures from pollution with traffic fatality data indicates that air pollution is responsible for more annual deaths in the GVRD than traffic accidents. These statistics indicate that ***reducing the number of pollution-producing vehicles of all types on our roads is a task that must be pursued out of necessity today, for our own well-being as well as that of future generations***.

As the population in the Greater Vancouver Regional District (GVRD) continues to grow by some 40,000 people each year,[56] residents will find it difficult to escape the rising pollution from increasing travel demands and increasing numbers of vehicles on the roads. Indeed, good public transit will attract commuters away from Single Occupant Vehicles, but higher transit use will also mean more buses and more pollution from transit sources unless some of these vehicles are emission-free. Case in point: A recent move to expand the trolley system in Athens, Greece followed reports that estimated transit's share of the noxious pollutants to be between 20 and 40%.[64] In the United States, diesel-powered transport makes up just 6% of all the miles driven, yet it produces 40% of all the smog related chemicals and, in larger cities, up to half the airborne soot (particulate).[1] Clearly, adding more diesel-powered vehicles to the transit fleet is undesirable where other options exist.

In the GVRD and in particular in Vancouver, transportation planners have a clear choice in certain transit corridors of what kind of vehicle they choose to operate. Their decisions can set a precedent for making the GVRD a greener place and enhancing the quality of life in the entire region. The choice of operating a multi-modal transit system that includes trolleys also affects the image of the region in terms of environmental commitments and the perceived quality of its transit system. Trolleybuses have considerable environmental associations and are typically found in cities that offer a higher quality of transit service.[63]

Chart 2 describes the basic emissions that result from the combustion of various fossil fuels and contribute to poor air quality as well as the greenhouse effect (global warming). The first six of these are known as "*air contaminant emissions*" (ACE's) or "*common air contaminants*" (CAC's). They have toxic properties and contribute to health problems. Nitrogen oxides (NOx) alone and in reaction with hydrocarbons and CO constitute the greatest contributor to smog (ground level ozone). Diesel engines, in particular, produce high quantities of NOx. NOx and nitrogen dioxide (NO2) levels have risen in the GVRD over the past 10 years and are continuing to rise.[47]

The magnitude of the health affects caused by these emissions are largely determined by levels of exposure--exposure usually being the highest and risk being the greatest at locations nearest the source. In other words, the greatest health risk from vehicle emissions is in the streets where the emissions are released, but greater distance from the source by no means eliminates the risk. The quantity of fresh air required to dilute or remove these emissions completely is so great that they invariably have an impact on regional air quality. Calculations done in Edmonton, Alberta in 1984 showed that the amount of fresh air required to dilute the monthly NOx emissions from diesel transit

(Chart 2)

Description of Transportation Emissions

Hydrocarbons (HC): Essentially unburned fuel. Hydrocarbons are a significant contributor to poor air quality. They have toxic properties. In sunlight, they combine with NOx to form *ground level ozone* (smog). Ground level ozone is a major concern in Canadian cities, particularly during the summer months.

Carbon Monoxide (CO): A toxic gas that induces headaches, loss of visual acuity, drowsiness and decreased motor coordination. CO undermines the blood's ability to carry oxygen, and high levels may contribute to heart attacks. Contributes to smog as it combines in the atmosphere with NOx; also makes it more difficult for the atmosphere to cleanse itself of chlorofluorocarbons, which cause deterioration of the earth's protective ozone layer. Implicated in global warming (climate change) as a ***greenhouse gas*** and typically assigned a GWP* value of 1.6 or 3.0. Gasoline engines produce relatively large amounts of carbon monoxide.

Nitrogen Oxides (NOx): A mixture of oxides of nitrogen, including nitric oxide (NO), nitrous oxide (N2O) and nitrogen dioxide (NO2). Results in the brown composition of smog and is a very significant contributor to poor air quality. Most often the primary target of emissions reduction programs in urban areas, NOx has been shown to affect health, contributing to asthma and other respiratory problems. It suppresses growth of vegetation and corrodes metals. The NO component of NOx is slowly oxidized to NO2, which is a poisonous gas. In combination with the moisture in the lungs, NO forms nitric acid. NOx also combines with atmospheric water to produce nitric acid, a component of acid rain. NOx is considered a ***greenhouse gas*** and is typically assigned a GWP* value of 7. Diesels produce NOx in greater quantities than other engine types.

Sulphur Oxides (SOx): Substances formed by the combustion of sulphur in fuel, including sulphur dioxide (SO2). Sulphur oxides react with atmospheric water, contributing to acid rain. They are also considered a lung irritant. In terms of global warming, they have been shown to exert a *global cooling effect* (opposite of the greenhouse effect). Diesel engines and coal-fired power plants are significant contributors of atmospheric SOx.

Particulate Matter (PM): Inhaleable particles such as small bits of oil, fuel, carbon and soot. They vary in size, some are visible as black smoke, others are microscopic and cannot be seen with the naked eye. Scientists now agree that the microscopic, invisible variety are the most harmful. These particles contain toxic and carcinogenic substances. They affect the respiratory system, causing asthma and other chronic respiratory ailments. (Respiratory ailments are the fourth leading cause of death in the industrialized world and a growing health concern; asthma alone costs some $11 billion in health dollars annually in the U.S. and is a continuing health concern in the GVRD and other urban centres.) They also cause various types of cancer and have been linked to heart disease. Diesel engines are responsible for a large percentage of inhaled particulate matter from transportation sources, and it is generally agreed that diesel particulate is the most toxic.

Volatile Organic Compounds (VOC): A variety of organic compounds that form toxic aerosols. Inhalation of these substances can lead to lung problems, asthma and other ailments. Some, such as benzene, toluene and formaldehyde, are strong carcinogens and are responsible for much of the cancer-causing potential of transportation emissions.

Carbon Dioxide (CO2): A by-product of the combustion of carbon containing fuels. CO2 is a ***greenhouse gas*** and is considered the primary contributor to global warming. Assigned a GWP* value of 1.

*GWP = Global Warming Potential, the potential of a substance to cause global warming relative to carbon dioxide.

(Sources: Environment Canada, US Environmental Protection Association, American Lung Association, NAAVC, TransLink, ETS, Diesel Fuel News) buses to a level where they no longer posed a risk was enough to cover the entire city 9 km deep![12] Although today's vehicles have slightly different emissions profiles, more than twice the number of diesel buses currently operate in the GVRD than did in Edmonton at the time this calculation was done.

Comparison of Air Contaminant Emissions for Diesels and Trolleys

Chart 3 compares the levels of *air contaminant emissions* produced by different technologies and different power sources. The chart illustrates a typical emissions profile for conventional diesel buses, 'clean' diesel buses, trolleybuses powered by a coal-fired power plant, trolleybuses powered by a gas-fired plant and trolleybuses powered by hydroelectricity. Notice the level of emissions for the combination of trolleybus technology and hydroelectric power is ZERO. ***In Vancouver, practically all power fed into the trolley system is hydroelectrically generated, making the trolleybus essentially a ZERO EMISSION VEHICLE.***[26,40] Note additionally that hydrocarbon emissions, CO and NOx are lowest for trolleybuses *regardless* of the electricity source, so even the introduction of power from fossil fuelled plants into the system does not change the cleaner status of the trolleybus in relation to its diesel counterpart.

The combined total amount of air contaminant emissions per million km of service for trolleybuses in Vancouver is essentially ZERO. **Chart 4** compares this to the combined total amount of air contaminants for a million km of new technology 'clean' diesel service. Each year, trolleybuses provide over 12 million km of service and around 60 million total trips in the GVRD, all without contributing any significant contaminants to the regional air**.**[62] ***The replacement of trolleybuses in Vancouver with any internal combustion technology would effect a marked increase in pollution from transit sources and increase the average emissions per passenger on the transit fleet***.

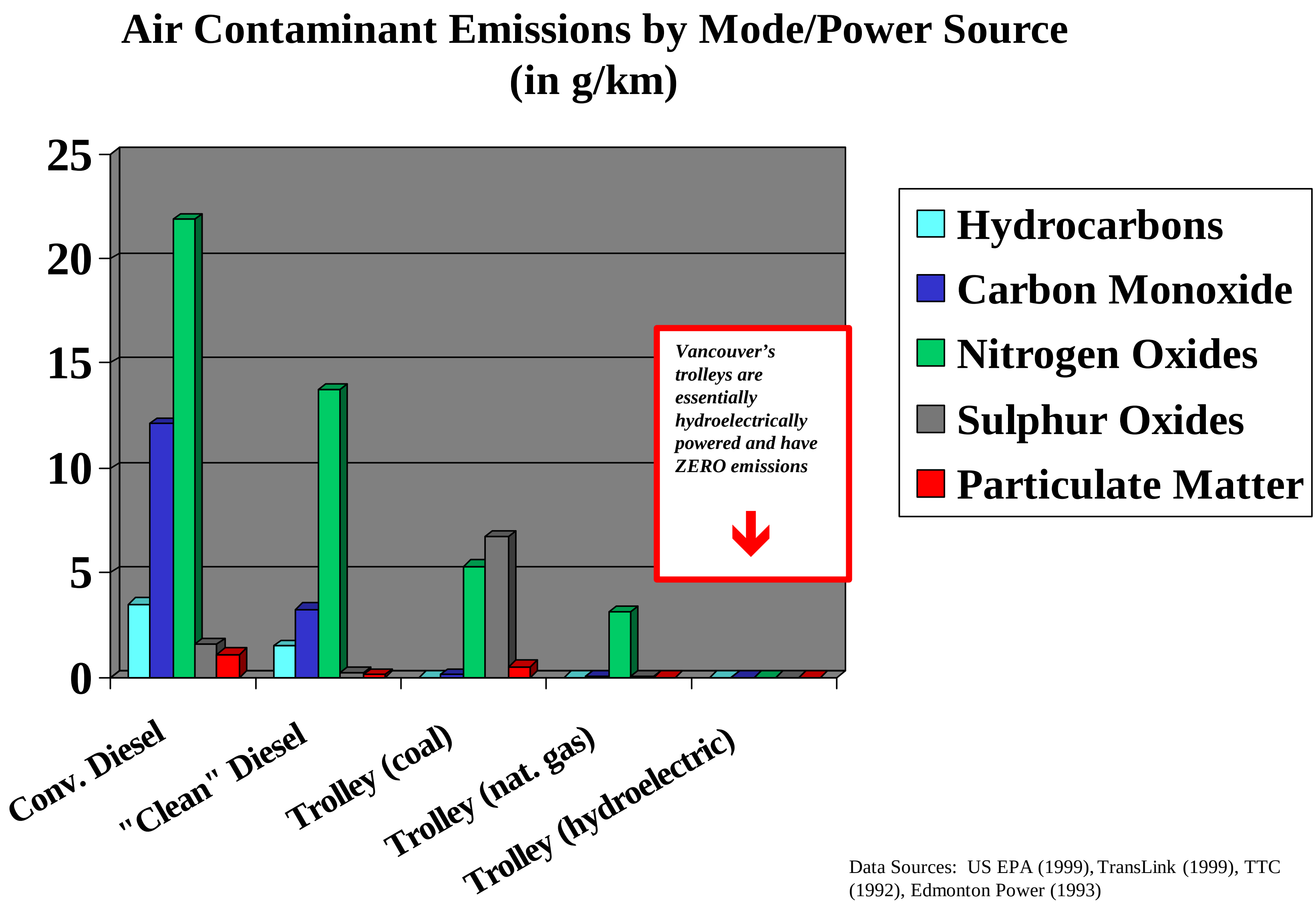
Toxins in Diesel Exhaust

The California Air Resources Board (CARB) recently made very strict rulings that will force the acquisition of zero emission vehicles among larger transit operating companies in that state.[8] They have also examined the effects of diesel exhaust on air quality as well as its health hazards extensively. In addition to the major emissions of HC, CO, NOx, SOx and particulate matter, a 1998 report by the Natural Resources Defense Council (NRDC) provides a list of other toxins found in diesel exhaust. There are over 40 different toxins, listed in **Chart 5,** including such commonly known poisons as arsenic, benzene, cyanide, formaldehyde, lead, mercury, phosphorus and toluene.[25] The diesel bus spews these poisons into the streets, in the midst of pedestrians and transit users and very often directly into human airways. Particulate is especially toxic. This and other harmful substances emitted by the diesel engine are known to remain suspended in the ambient air for more than 15 minutes after the passing of a diesel bus.[25] British studies involving residents living adjacent to transportation corridors found diesel particulate lodged deep in the lung tissues of infants and young children; a direct link was established between exposure to diesel exhaust and inflammation of the respiratory tract.[32] The diesel's contribution to rising asthma and respiratory disease rates is proven.

'Clean' Diesel

With the advent of cleaner combustion technologies and exhaust treatments, the per-km contaminant emissions from diesel engines are declining. Over half the diesel bus fleet operated by Coast Mountain Bus Company in the GVRD currently consists of so-called 'clean' diesel buses.[13] The continued replacement of older diesel buses with newer ones of the 'clean' diesel variety will continue to help reduce specific emissions from transit sources. But it must be emphasized that even the 'cleanest' diesel buses do not compete

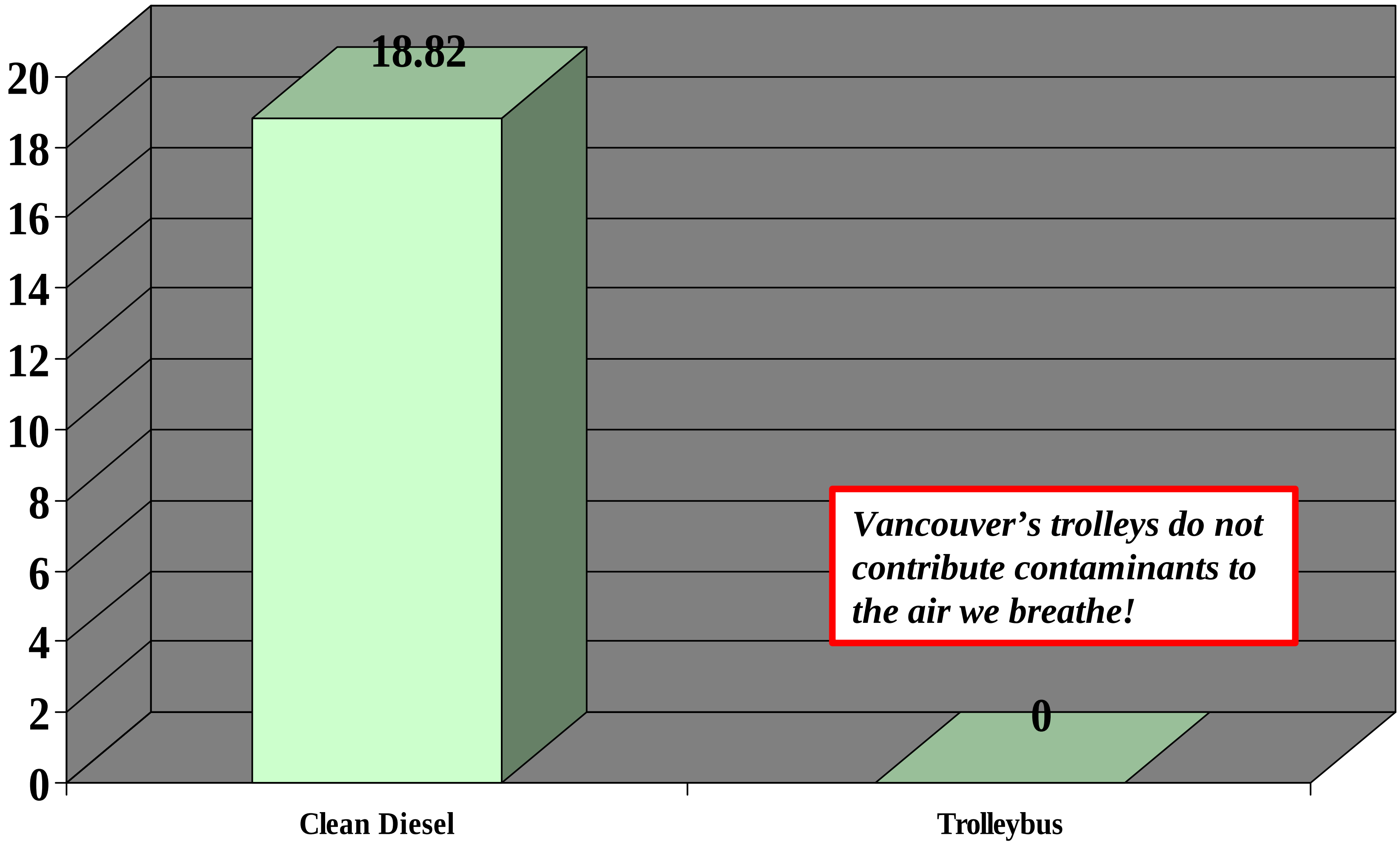
(Chart 3)



Data Sources: US EPA (1999), TransLink (1999), TTC (1992), Edmonton Power (1993)

(Chart 4)

Total Air Contaminant Emissions per Million Kilometres (in tonnes)



Air Contaminant Emissions **include Hydrocarbons, Carbon Monoxide, Nitrogen Oxides, Sulphur Oxides, Particulate Matter.**

Data Sources: US EPA, OTT, TransLink (1999)

(Chart 5)

Toxins identified in Diesel Exhaust by the EPA

Acetaldehyde	Inorganic lead
Acrolein	Manganese compounds
Aniline	Mercury compounds
Antimony compounds	Methanol
Arsenic	Methyl ethyl ketone
Benzene	Naphthalene
Beryllium compounds	Nickel
Biphenyl	4-Nitrobiphenyl
Bis(2-ethylhexyl)phthalate	Phenol
1,3-Butadiene	Phosphorus
Cadmium	Polycyclic organic matter including polycyclic aromatic hydrocarbons and their derivatives
Chlorine	Propionaldehyde
Chlorobenzene	Selenium compounds
Chromium compounds	Styrene
Cobalt compounds	Toluene
Creosol isomers	Xylene isomers and mixtures
Cyanide compounds	o-xylenes
Dibutylphthalate	m-xylenes
Dioxins and dibenzofurans	p-xylenes
Ethyl benzene	
Formalehyde	

In-street diesel emissions have been linked to cancer, asthma, pneumonia, chronic respiratory ailments and heart disease!

Sources: Natural Resources Defense Council (1998), U.S. Environmental Protection Association, American Lung Association (2000).

Diesel Exhaust is a complex mixture of hazardous particles and vapors, some of which are known carcinogens and other probable carcinogens.

The US Environmental Protection Association (California) has identified at least 41 substances in diesel exhaust listed by the State of California as" toxic air contaminants".

A "toxic air contaminant"is defined as an "air pollutant which may cause or contribute to an increase in mortality or in serious illness, or which may pose a present or potential hazard to human health".

In addition to, or as part of the commonly cited contaminants CO, NOx, SOx and particulate matter, the highly toxic substances listed at the left have also been identified in diesel exhaust.

The immediate health threat posed by the use of diesel engines in transit buses arises from the fact that the emissions are released **directly into the streets where they easily enter** the airways of pedestrians and transit patrons waiting at bus stops. Ventilation systems mix them into the air in adjacent buildings.

Studies of emissions from co-called 'clean' diesel engines reveal that, while NOx and CO levels may be lower, the levels of many toxins such as dioxins, benzene, toluene, 1,3-butadiene and PAH's are essentially unchanged. While the weight of the particulate matter is reduced substantially, the total number of particles emitted by 'clean' diesel engines may be 15 to 35 times greater than by conventional diesels. The particles are simply finer, not fewer. Finer particles are more likely to penetrate deeper into the lungs, where they would be trapped and retained. They easily enter the bloodstream.

with ZERO emission trolleys. The National Resources Defense Council and other environmental agencies have also questioned some of the assumed benefits of 'clean' diesel technology.[16,25,2] While the amount of harmful particulate matter released by such engines is smaller in size and lower in weight, the number of particles is greater.[16,25] The finer, invisible particles have been shown to penetrate the mucous membranes of the lungs more easily. NRDC expresses concern that fewer of the fine particles may actually have greater damage potential that a greater number of the large, visible particles associated with the smoke from conventional diesel buses.[16,25] It has been posited that fine particulate capable of entering the bloodstream may be a contributing factor in heart disease.[30,32] NRDC states that it does not consider 'clean' diesel buses to be a viable solution to pollution in congested cities because one of these vehicles still emits more pollution than over 100 automobiles in its lifetime.[16]

Diesel Cancer Risk

The 1998 NRDC report makes reference to an assessment of cancer risks associated with diesel exhaust by Dr. Dale Hattis from Clark University. Dr. Hattis found that exposure to diesel exhaust at levels as low as 1 microgram per cubic metre was sufficient to result in an estimated 230 to 350 lifetime additional cancer cases per million population.[25] In fact, Dr. Hattis discovered that levels much higher than this existed ***inside*** some dwellings in the Los Angeles area.[25] Higher levels are certain to be found in pedestrian areas and even in buildings along transit corridors frequented by diesel buses in any city, including the GVRD. In fact, a study of cancer risks resulting from the particulate component in diesel emissions estimated that levels in the GVRD would indeed be similar to those in large U.S. cities.[19]

There are a number of other studies that have drawn similar conclusions. A recent Swedish study found that exposure to diesel fumes on the job increased the likelihood of developing lung cancer by 63%.[18] Reports from some U.S. cities warn of possible class action lawsuits resulting from on-the-job exposure to diesel fumes.[22] The South Coast Air Quality Management District concluded that 70% of the total cancer risks in the Los Angeles region are due to diesel emissions.[34,48,53] Another U.S. study linked diesel exhaust to over 125,000 new cancer cases ***each year*** across the United States.[53] Estimates show the emissions from one diesel-powered vehicle to have the carcinogenic potential of 24 vehicles powered by gasoline.[29,30] If this is correct, and one bus in the GVRD is assumed to take the place of 21 cars,[56] operating diesel transit vehicles instead of cars does not produce a reduction in cancer-causing pollutants!

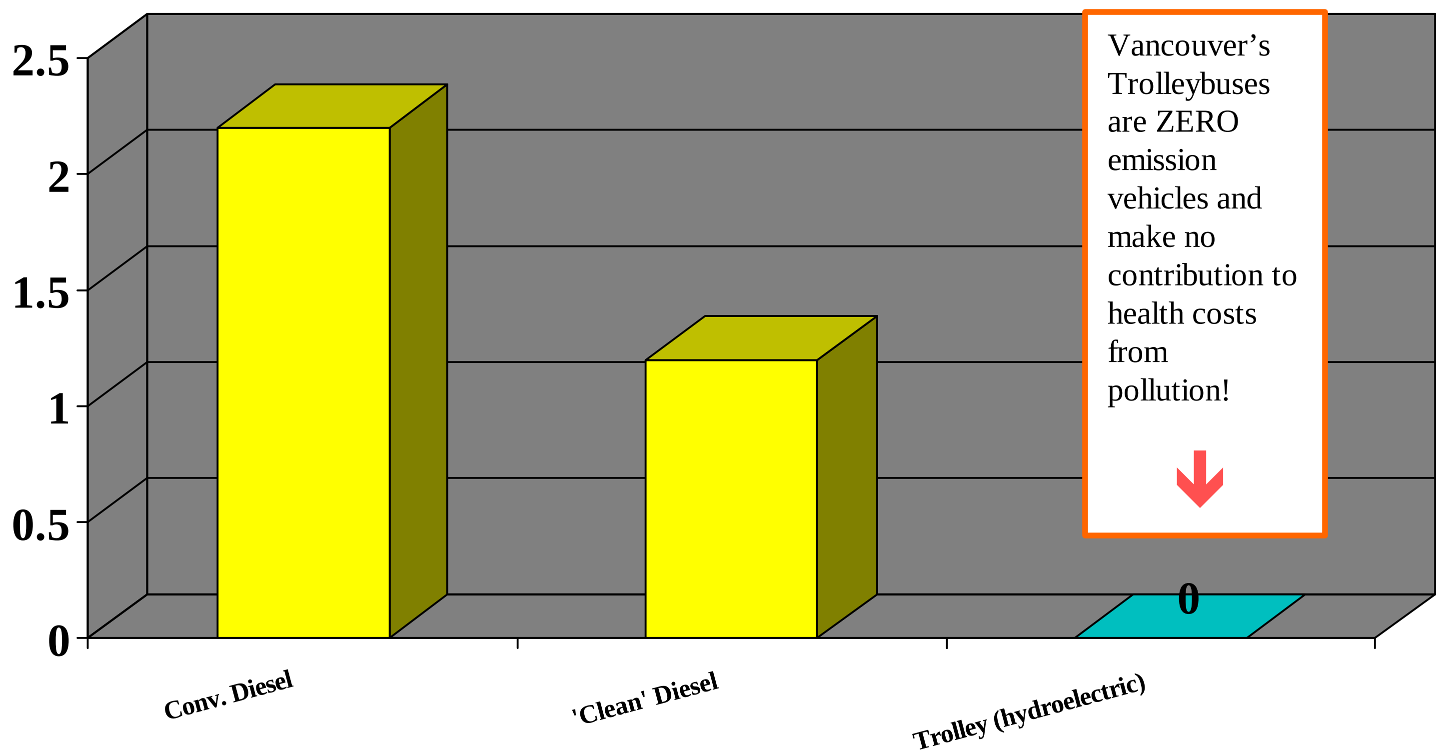
Diesel exhaust therefore, even in its 'cleanest' form, makes a contribution to human mortality that cannot be ignored.

Costs of Pollution In Health Dollars

The exact costs of the health impacts of different transportation modes are difficult to quantify. California studies cite a health value of $75,000 for every tonne of the air contaminants HC, NOx, PM and VOC (volatile organic compounds). (Carbon monoxide would have a value about 1/10th of this because its toxicity is not as great.) A recent TransLink study states the value of $75,000 per tonne of these contaminants is generally accepted as a proxy.[40] If we apply this value to the total contaminant emissions per km produced at source for diesel buses, as shown in yellow on **Chart 6**, we find that that diesel buses ring up a considerable health bill. By contrast, trolleys powered by hydroelectricity make essentially no contribution to health costs whatsoever! In other

(Chart 6)

Air Contaminant Emissions in Health Dollars in Millions of Dollars per Million Kilometres (calculated @ $75,000 per tonne)*



* Includes dollar value for Carbon Monoxide @ 1/10th the value of the other more toxic emissions; does not include dollar value for Volatile Organic Compounds. Conventional diesel calculations based on data for mid-1980's model buses, 'clean' diesel data based on current (1998-99) emission test results.

The health impacts in dollars of vehicular emissions are difficult to quantify. Many dollar estimates exist. The above value of $75,000 per tonne originates from a California study and was quoted in a recent TransLink report as being a widely accepted proxy. Here the figure has been applied to the contaminant emissions HC, CO,NOx, SO and Particulate Matter in the quantities emitted directly from the tailpipe or power plant. While newer 'clean' diesel engines have reduced health impacts, the health costs associated with diesel operation are still immense compared with the zero-emission trolleybus. In addition to asthma and other respiratory conditions, diesel emissions have been linked to cancer and heart disease.

words, ***an investment in trolleybuses appears to effect a savings in health costs***, not to mention a reduction in health problems and mortality.

Greenhouse Gas Emissions

Another significant emissions issue associated with the question of whether to retain or increase trolley usage is that of *"greenhouse gas emissions"* (GHG's). Greenhouse gases, generated through the burning of fossil fuels, contribute to climate change or global warming. About 40% of the world's GHG's are produced by transportation sources, i.e. largely internal combustion vehicles using gasoline, diesel fuel or natural gas.[27] According to the terms of the *Kyoto Accord*, to which Canada has agreed, greenhouse emissions must be reduced by 6% over 1990 levels between 2008 and 2012. Since these emissions have actually increased since 1990, this will require a reduction of some 29% from current levels. The primary target of GHG reduction programs is carbon dioxide (CO2), but other greenhouse gases include CO, NOx, N20 and methane. Sulphur oxides, released from both diesel engines and coal-fired power plants, are actually believed to have a global cooling effect—the opposite to the greenhouse effect—and are therefore not GHG's.[27] (This is not meant to imply in any broad terms that the release of SOx is 'good' for the environment.)

In older, conventional diesel engines, the technology employed to achieve combustion resulted in higher amounts of hydrocarbons (unburned fuel) and CO, lower power output at low rpms and a certain amount of CO2 per km. Newer diesel technology enables a more complete burn, reducing the quantities of hydrocarbons and CO, but at the same time increasing the CO2. This, combined with the increased power output of the newer engines, means that newer diesel engines really make no contribution toward the reduction of greenhouse gases. In fact, GHG production, as measured in tests conducted for the Office of Transportation Technologies at the University of West Virginia, tend to indicate that levels are higher with the more powerful, newer diesels.[45] In addition, today's urban traffic conditions mean that diesel buses spend more time idling in traffic, increasing their CO2 output.

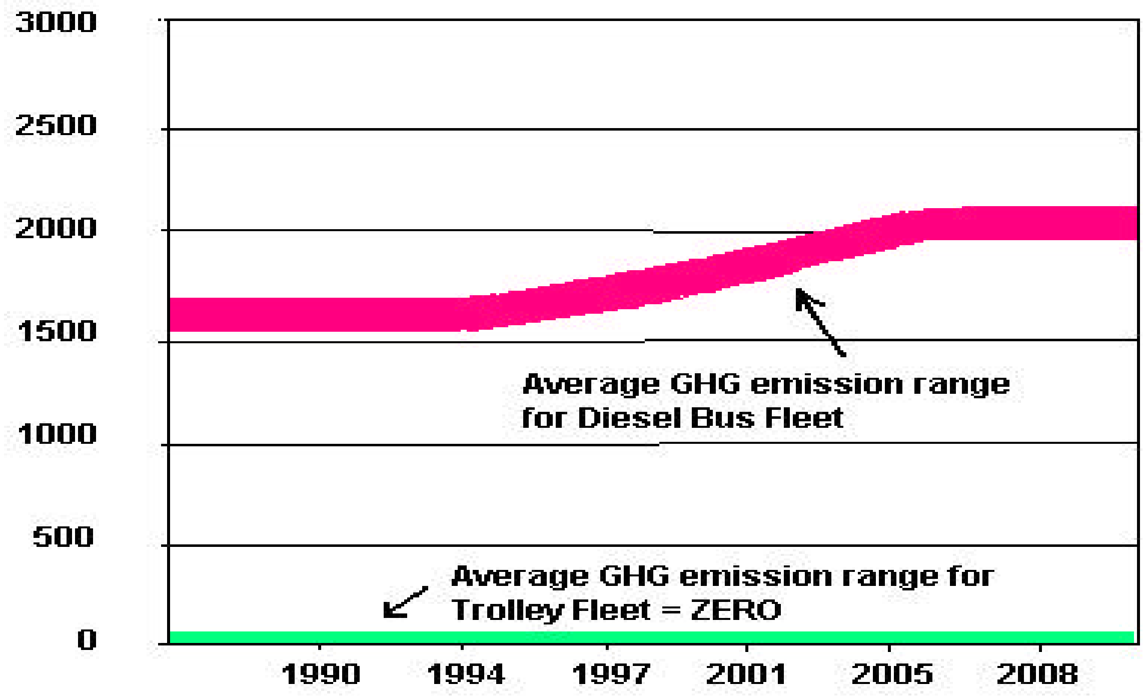
One way to reduce GHG's, as well as other emissions, is by finding ways of making a technology more *energy efficient*. Diesel engine technology, however, has practically reached its developmental limit efficiency-wise, and the amount of GHG's diesels produce is not likely to change much in the foreseeable future. Assuming higher CO2 emissions from newer diesels, **Chart 7** posits an approximate greenhouse gas emissions trend for diesel buses in the GVRD alongside the levels projected for power generation to operate trolleybuses. The trolley's GHG emissions remain at zero, while the diesel's greenhouse gases rise slightly throughout the 1990's--as older diesels are replaced with newer models—and then level off at a higher level than previously. Approximate GHG emissions for trolleys and diesels per km of travel in the year 2006 are depicted on **Chart 8**; the diesel column essentially reflects a fleet of 'clean' diesel buses. ***Trolleybuses are unquestionably advantageous in controlling greenhouse gas production.***

Carbon Credits

In order to provide incentives for meeting the aims of the Kyoto Accord, the World Bank established a '*Carbon Fund*' in January 2000, encouraging companies to invest in the reduction of greenhouse gases.[57] This essentially gives greenhouse emissions a value on the commodities exchange. GHG reductions earn 'carbon credits'. A company that can reduce its GHG production can offset the costs of this reduction by trading its carbon credits, which may be desirable for a company that is less able to reduce its greenhouse

Transit Vehicle Greenhouse Gas Emission Trends by Vehicle Type based on approximated fleet average ranges (in g/km of CO2e*)

(Chart 7)



Larger, more powerful diesel engines on newer transit vehicles have meant a slight increase in the CO2 emission levels from transit sources. On the other hand a trolleybus, powered by hydroelectric power, does not contribute any greenhouse emissions to the environment. Carbon credits can be earned for the GVRD through the reductions in greenhouse gases that are possible with Vancouver's electric trolleybuses.

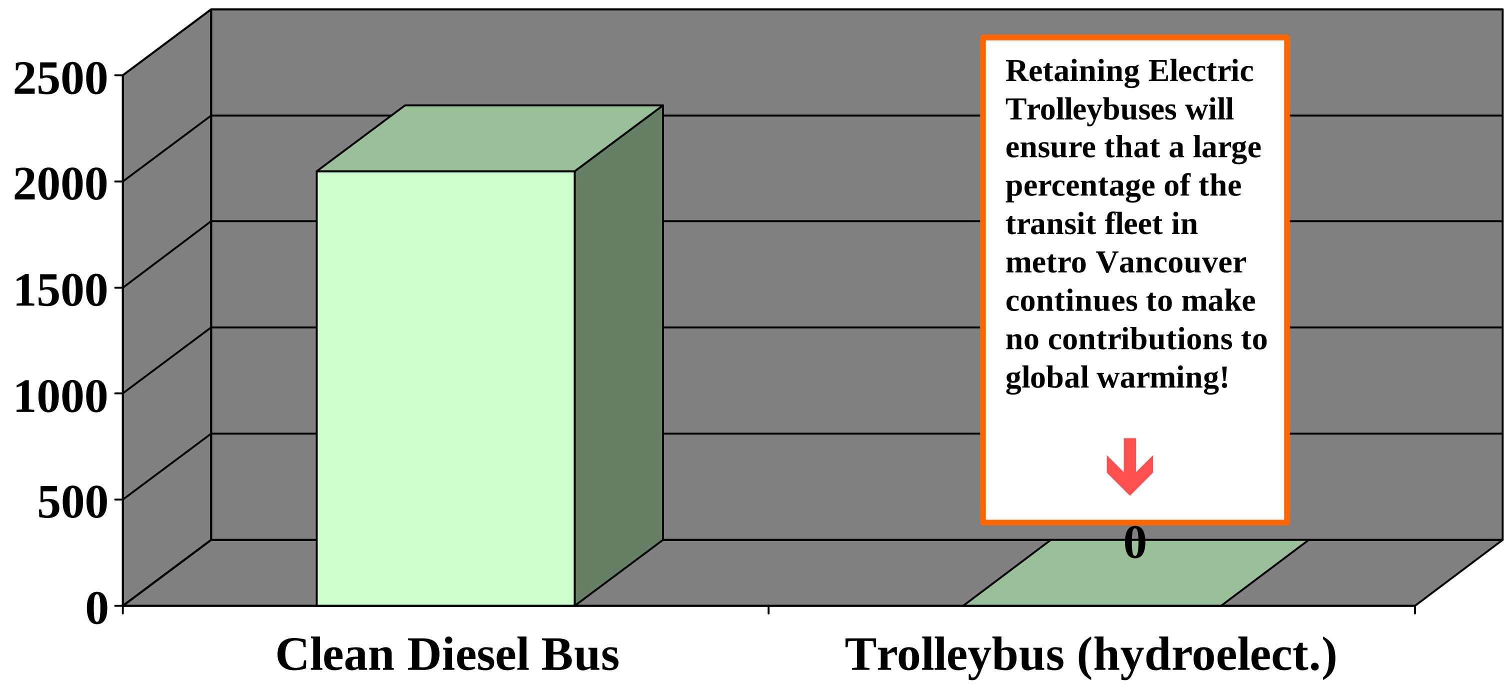
***CO2 Equivalent – includes greenhouse gas values for emissions of CO, NOx, N2O, CH4.**

Data Sources: TransLink (1999), TTC (1992), ETS (1993), NAAVC/OTT (1998-99)

(Chart 8)

Estimated Greenhouse Gas Emissions per Kilometre in 2006 by Mode

(in grams/km of CO2e)



Source: Estimates based on TransLink (1999) data.

emissions. By acquiring the credits, the emissions producer essentially buys 'insurance' against incurring any possible emissions penalties that may be established through the Kyoto Accord.[57] While the concept of earning and trading of carbon credits is still in its early development, the fact that trolleybuses in Vancouver are ZERO emission vehicles and have carbon credit earning potential weighs heavily in the trolley's favor. On the other hand, increasing the use of diesel buses could place transit authorities at a disadvantage with respect to GHG reduction programs.

Noise Emission Levels

Noise *is* a pollutant and it *can* be measured. Its negative effects on the quality of life are very real. Noise has the ability to cause serious disturbances by creating the kind of atmosphere that people will actively seek to avoid. It can effectively drive people indoors and deter the kind of social interaction that forms the basis for sound communities. It also creates a poor climate for business. In addition, daily exposure to noise in excess of 90 decibels is known to cause hearing loss.

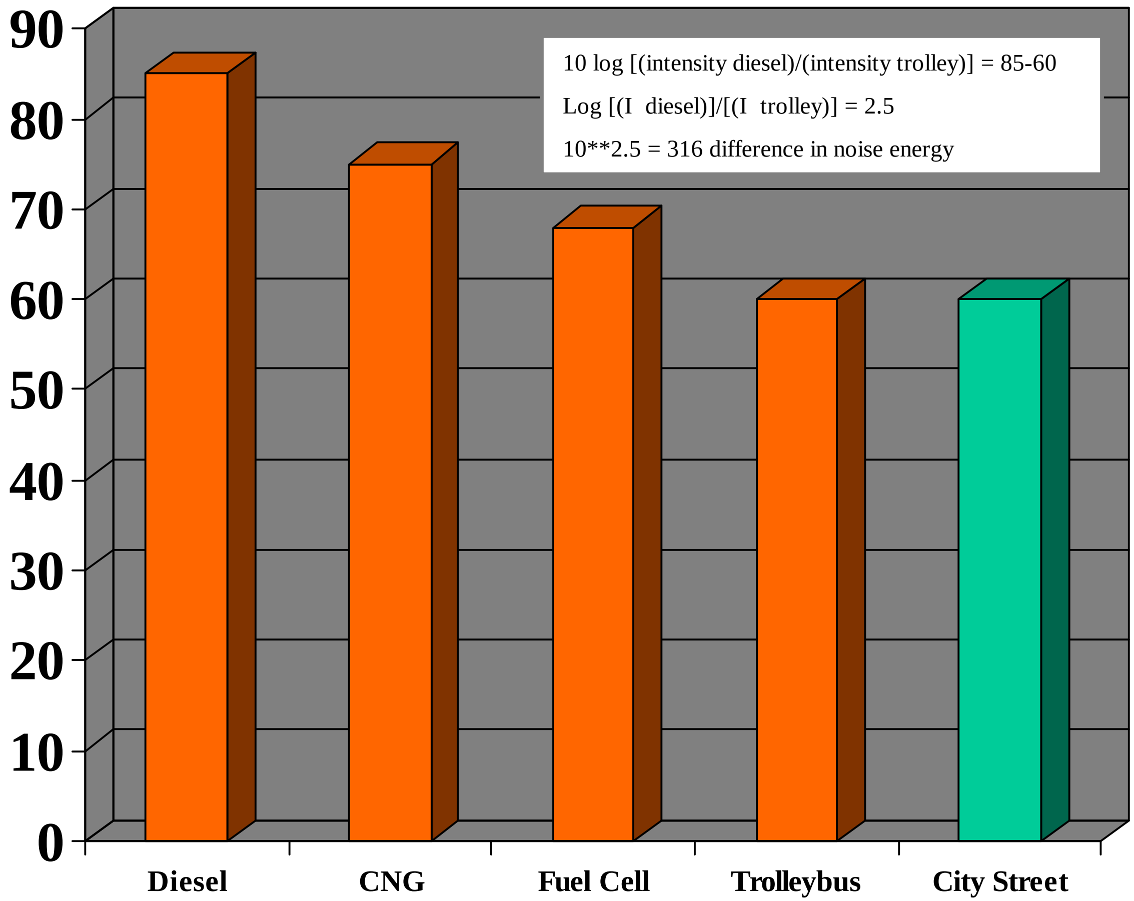
The noise level on an average city street measures about 60 decibels. Studies done in Philadelphia demonstrated that the passing of a trolleybus was barely discernible above the ambient street noise.[24] However, the diesel bus has a very significant impact on its surroundings in terms of noise. At 22-25 decibels louder than the trolley, an accelerating diesel bus is associated with sound energy levels some *175-300 times greater* than ambient street noise and *175-300 times greater* than a passing trolleybus.[40,57] The noise produced by various bus modes are compared on **Chart 9**. ***The trolleybus is inarguably the quietest and least disruptive of all bus modes.***

Potential for Increasing Transit Ridership

Aside from the environmental benefits, the higher infrastructure investment needed to operate trolleys and the visibility of a transit presence created by overhead infrastructure make trolleys a higher quality transit service. The post-WWII history of transportation in most of North America into the late 1970's has been characterized by massive investments in roadways and de-investment in public transit, resulting in the displacement of higher quality transit services like electric rail transit and trolleybuses by less attractive and cheaper diesel buses.[63] A 1974 report to the United States Senate blames the conversion of electric bus and streetcar lines to diesel operation for the rapid deterioration of public transit and a subsequent increase in private automobile use.[51] If one compares North American developments to those in European cities, one finds that where substantial investments in high quality electric transit continued, public transit has maintained its popularity relative to the private automobile.[63] **Chart 10** compares typical North American developments with respect to automobile use and transit patronage with those in Germany over the same time period. It is noteworthy that Germany invested consistently in high quality electric transit throughout this period and that trends there do not show the same huge losses of public transit patronage to the private auto that are characteristic of North America. In other words, the failure to place financial emphasis on developing and operating effective, high quality multi-modal systems exerts a negative effect on transit's ability to compete with the private automobile. A similar effect is possible in Vancouver if electric trolleys were replaced with internal combustion vehicles. With some 23,000 additional cars per year being added to roadways now,[56] the GVRD cannot afford this.

(Chart 9)

Comparative Noise Levels by Mode
(in decibels)



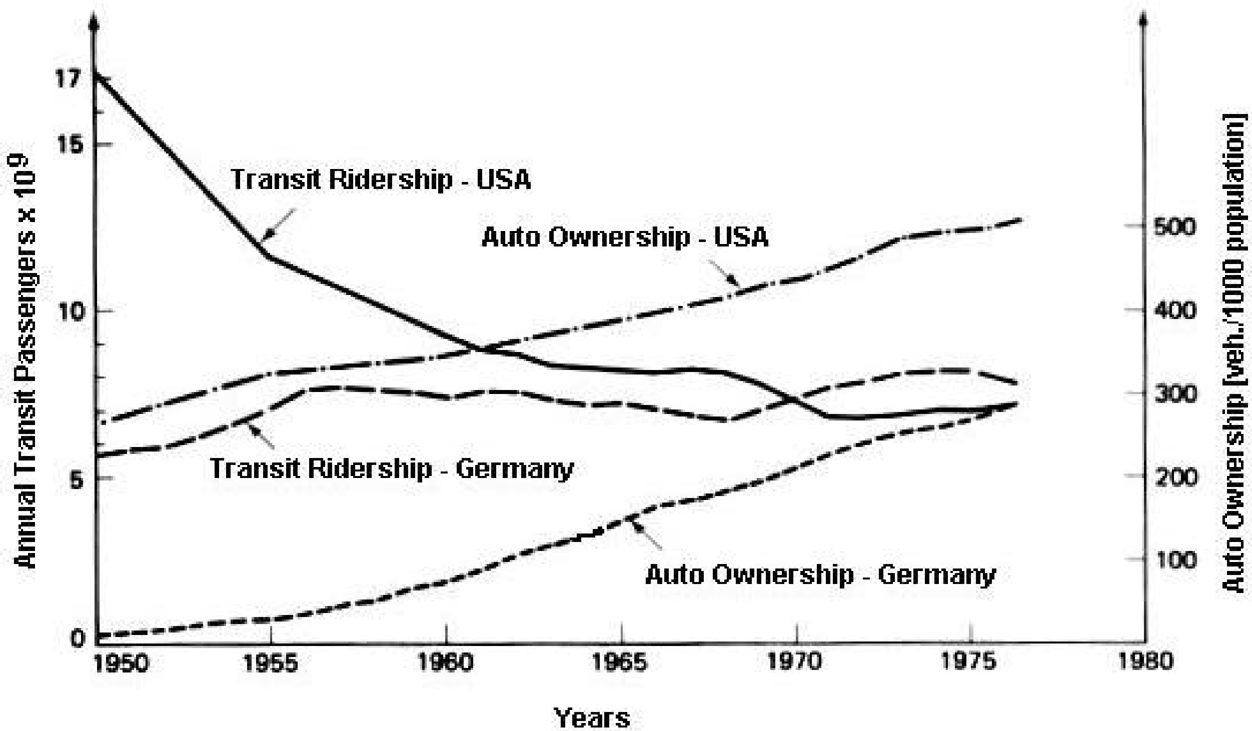
- **Hearing loss occurs at levels of 90 db or higher; diesel buses approach such levels**
- **Tests show the noise energy produced by a diesel bus is 175-300 times greater than that from a passing trolley**
- **A Philadelphia study showed that the passing of a trolleybus could not be heard above the ambient street noise**

Adapted from Coast Mountain Bus Company (Vancouver); KC Metro (Seattle).

Effects of Investment in Higher Quality Transit Modes on Transit Ridership and Automobile Use

A Comparison between the United States and West Germany, 1950-77

(Chart 10)



Consistent investment in high quality, electric public transit options like trolleybuses and LRT in many European countries has enabled these countries to attract and retain higher levels of transit patronage. The de-investment in public transit in North America and abandonment of higher quality modes in favor of cheap diesel buses has effectively promoted the automobile and led to the deterioration of public transit.

Source: Vukan Vuchic, *Urban Public Transportation*, p. 109

The trolley's 'quality' translates into an ability to attract ridership. In other North American cities that operate trolleybuses as part of their transit service, ***the conversion of diesel bus lines to electric operation has resulted in gains in patronage*** of up to 18% (San Francisco).[24] **Chart 11** gives some patronage gain and loss data for North American cities where such information is available. Vancouverites have long shown a preference for electric service, as demonstrated by the public uproar over BC Transit's attempt to substitute diesel coaches on Routes 5/6 during weekends several years ago.[26] Vancouver City Council has consistently echoed the public support for trolleys in Vancouver. Almost 2/3 of Vancouverites surveyed by BC Transit in 1990 agreed with the statement: "Trolleybuses are better than diesel buses."[26] A vehicle preferences survey conducted in Edmonton, Alberta in 1993 not only revealed that the public prefers to see investments in electric transportation over other modes, but 2/3 of the respondents indicated that they would stick with their choice even if the costs associated with that choice turned out to be higher.[23] In other words, respondents did not feel that the higher investments required to operate trolleybuses should be seen as a deterrent. Obviously, if the public is so supportive of electric transit, it is logical that they would use electrified services more often than if diesel buses replaced electric vehicles on these lines.

Operational Costs

North American transit agencies generally agree that trolleybuses require higher investments than internal combustion vehicles because of the requirement for fixed infrastructure, but comparing operating costs between the two modes is a matter that is fraught with complications. By itself, cost per km, a unit commonly used to express operating expenses, does not provide a reliable basis for comparisons because it is based on distance traveled and does not reflect the amount of work performed.[3,12,26] In the Vancouver area, any cost comparison will be skewed by the fact that there are some very fundamental differences between the trolley and diesel systems. The trolley system essentially serves the most heavily travelled routes on the system: Passenger loads are heavy, stops are more frequent, traffic congestion is great and average speeds are therefore slower.[57] For the most part, the diesel system serves areas of lower density, and thus routes tend to have lighter loads, less frequent stops, less traffic congestion and higher average speeds. As might be expected, any vehicle operating under the conditions that characterize the trolley system will incur greater operating costs because it is working harder.

As mentioned above, the Vancouver trolley fleet consists of 244 vehicles. The internal combustion fleet operated by Coast Mountain Bus Company comprises over 860 diesel and 50 natural gas vehicles.[13,57] In 1999, the trolley fleet provided 58,891,900 trips to commuters; the internal combustion fleet provided 117,826,300 trips.[5] In other words, trolleybuses make up just over 20% of the total fleet, but they provide 33% of all trips taken by bus. Diesel and natural gas buses make up close to 80% of the fleet, but only provide about 67% of all bus trips. Spread over the year, this means that each trolleybus carries an average of 661 passengers per day compared to only 354 on each internal combustion powered vehicle. (TransLink reports *weekday* boardings on trolleys average just over 1,000 compared to about 500 on diesel buses.)[57] ***Trolleybuses average about twice the number of passengers as diesel buses on the system.*** The reported cost differential between trolleys and diesels on the entire system indicates that trolleybuses have about 28% higher operating costs per km of travel than diesel buses, but since they

(Chart 11)

Trolley Coaches attract Riders

OTHER CITIES OPERATING TROLLEY COACHES REPORT RIDERSHIP INCREASES IN THE 10% TO 15% RANGE WHEN TROLLEYS REPLACE DIESELS !

➔ SF MUNI

- **Conversion of No. 1 line to trolley completed in 1981: 18% increase in ridership between 1979 and 1982.**
- **No. 3, 4 and 55 lines also converted to trolley in 1982 with increases in patronage of approximately 10% to 15%.**
- **California and Jackson lines temporarily converted from <u>trolley to diesel</u> in 1970's with a 10% to 15% <u>decrease</u> in ridership.**

➔ SEATTLE METRO

- **Approximate 10% increase in ridership when a line is converted from diesel to trolley coach operation.**

➔ *Estimates for Proposed Systems in CLEVELAND and LOS ANGELES*

- ***A proposal to install a trolley bus line along Euclid Avenue in Cleveland predicted a 10% increase in ridership. A similar ridership increase was expected when trolley buses were proposed for Los Angeles in the early 1990's.***

Sources: Booz, Allen & Hamilton, Trolley Bus Study for the RTD and LACTC (1991); San Francisco MUNI, Seattle METRO and Greater Cleveland Regional Transit Authority.

are doing twice the work this is not surprising.[57] In fact, heavily travelled mainline routes may be deemed relatively efficient in their operation if they are carrying twice the passenger volume at only 28% higher cost. This is borne out by the fact that during the past twelve years of operation, the hourly operating costs for trolleys have been up to 14% *lower* than for diesel buses.[37] Trolley routes also earn higher revenues due to their passenger volume and therefore have a greater ability to cover associated costs. In addition, the trolley vehicles last at least 3 years longer than diesel despite heavier use.

Chart 12 summarizes a number of key points from the above discussion relating to trolley coach economics in the Vancouver-area.

Independence from Petroleum-based Fuels

Public transportation experts generally agree the greatest opportunity to create efficient, effective and attractive transit exists in cities with *multi-modal systems*.[63] In particular, there is an advantage to a system that is not completely dependent on one energy source. On one hand, it may be the case that electricity costs are currently on the rise due to high demands placed on current supplies. On the other hand, ***dramatic increases in oil prices (diesel fuel, gasoline) are absolutely assured in the long term***.[20] According to projections, illustrated on **Chart 13**, world petroleum production will reach its peak by about 2012 at the latest, after which production will steadily decline and prices will begin to skyrocket.[20] Even in the short term, oil prices are by no means stable. For instance, in December 2000, Libyan leader Moammar Gadhafi sought the support of Venezuelan President Hugo Chavez to persuade oil-producing nations to stop pumping for one to two years to prevent any attempts to lower oil prices.[39] Such political actions have the potential to plunge oil-dependent nations like the United States and Canada into another energy crisis of similar magnitude to that experienced in the 1970's. Allowing electrically operated street transit to decline in favor of petroleum-dependent modes such as diesel buses is clearly short-sighted and unwise. In particular, the GVRD is fortunate to have a local supply of renewable hydroelectric power; it does not suffer from energy dependency on other regions to operate a large portion of the Vancouver transit system.

Trolleybus Usage Worldwide

As was previously mentioned in connection with Chart 10, many North American trolleybus systems were abandoned in the 1950's and 60's as part of a general trend toward de-investment in public transit.[63] This also occurred in other parts of the world as a result of budgetary changes or reductions in transit funding that made cheaper diesel buses more attractive economically. Most of these abandonments occurred at a time or under conditions when the environmental impacts of operating internal combustion engines were not given much consideration. Nor was the fact that potential riders tend to favor higher quality services like trolleybuses of great importance in a climate where public transit was not highly valued nor highly supported financially. The trend toward abandoning trolleybus systems was reversed by the late 1970's for the most part in light of the energy crisis, environmental concerns and a gradual reinvestment in transit.[63] The abandonment of an existing trolleybus system today would be out-of-step with the general industry trend.

(Chart 12)

Trolley Coach Economics In the GVRD

Vehicle operating costs are usually measured in terms of *cost per km* or *cost per hour*. In comparing the costs of different modes, such as diesels and trolleys, neither measure can be taken alone to provide an accurate comparison. Comparisons in cost per km can be particularly misleading unless the differences between the trolley and diesel systems are properly considered.

Over the past twelve years, trolleys have cost about 28% more than diesels in terms of cost per km, but they have cost up to 14% less than diesel buses in terms of cost per hour.

In Vancouver, trolleys serve the busiest mainline routes. They operate in heavy traffic conditions with frequent stops and heavy loads. On average, each trolleybus carries TWICE as many passengers as each diesel bus. In other words, trolleybuses are doing TWICE THE WORK of diesel buses. It is therefore not surprising that the cost per km is higher for trolleys. The 100% greater productivity of trolleys for only a 28% higher cost per km represents good value!

C*ost per hour* comparisons may have shown trolleys to be slightly cheaper. However, the type of vehicle employed is actually of minor significance in any cost per hour calculation. The largest portion of hourly costs are those associated with the operator.

Put into perspective, *any extra operational expenses or savings associated with trolleybuses vs. diesels would be fairly nominal in the overall cost of operating a transit system*. Transit's largest operating costs are associated with staffing, administration and facilities, not the operation of specific vehicle types.

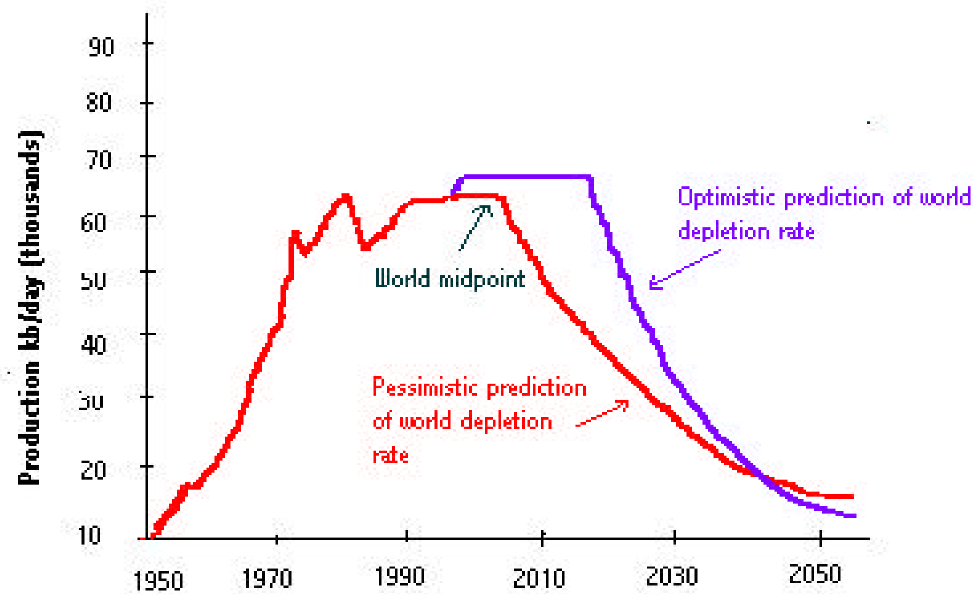
It is generally agreed that the operation of trolleys requires a higher investment than other modes. This is mainly due to the need to build and maintain fixed infrastructure, although the puchase price of trolley vehicles is also higher than for diesels in North America. However, diesel and other internal combustion powered buses most definitely increase environmental burdens as well as risks to health and mortality. It is arguable whether any potential savings gained in buying diesel buses could be so great as to be worth the added risk to the health and lives of transit workers, citizens and the many visitors to the GVRD.

In an age of environmental awareness, it would be foolish to consider any notion to abandon or downsize an effective ZERO EMISSION transportation system with a capital replacement value of over $180 million on its fixed infrastructure alone under the belief that public funds were being wisely spent for the good of the GVRD.

(Chart 13)

Projected Worldwide Oil Production

1950 - 2050



Early in this century, half the world's known oil supply will have been used, and oil production will slide into permanent decline. This will result in price increases far above current levels. Having a trolley system may help mitigate the effects of rising petroleum prices and dwindling oil reserves on transit and on the public purse.

Source: ***Discover***, October 2000

Outside Canada And the U.S.

There are currently around 350 trolleybus systems operating worldwide. 37 new systems opened in the last decade, a total of ***101 new trolleybus systems have been placed in service since 1980***.[58] A review of systems outside Canada and the U.S. reveals that many have reaffirmed their commitment to the trolleybus with either route extensions or the renewal of infrastructure and the purchase of new vehicles. The city of Arnhem in the Netherlands launched its "Trolley 2000" program last year to place increased emphasis on its commitment to clean and quiet transit vehicles.[11] All vehicles carry the slogan "Arnhem – Trolley Stad" (Arnhem – Trolley City). Some noteworthy renewal programs have also been carried out in Athens, Greece; Linz, Austria; Nancy, France; Quito, Ecuador; Lausanne, Switzerland; as well as in the Chinese cities of Beijing, Guangzhou and Shanghai, just to name a few.[58] The trolleybus has been gaining increased attention globally in light of growing environmental concerns, and several cities are now seriously considering or even testing trolleybuses. These include Hong Kong, London, Havana and Rome; some examples of new systems currently under construction include Merida, Venezuela and Paris.[58] Sao Paulo, Brazil, which already has a fairly extensive trolleybus system, recently opened an ultra high capacity line that runs on a right-of-way similar to LRT. Some highlights from the trolleybus scene around the world are recorded on **Chart 14**.

In Canada And the U.S.

In Canada and the U.S., other cities operating trolleybuses have taken steps toward the continuation and renewal of their systems. Dayton, Ohio just completed major extensions to its overhead system in 2000 and has a brand new fleet purchased in 1998. San Francisco is in the process of buying a new trolleybus fleet and is currently evaluating prototypes. Seattle is extending its wires and will upgrade the propulsion systems from its existing vehicles and install them in new bus bodies. Boston has new low floor trolleybuses on order; government officials there have also ruled against the purchase of new diesel-powered vehicles because of environmental concerns.[21] Philadelphia has included $44 million in its budget for the years 2004-2011 to purchase new trolleybuses.[7] In California, AC Transit states it is currently looking at cleaner options for public transit in the Berkeley-Oakland-San Leandro corridor and is considering trolleybuses as one of its options.[9] Recently, Cleveland did consider trolleybuses as a means to improve ridership and reduce environmental impacts in its busy Euclid corridor, but the financial focus of the project gradually shifted away from public transit and toward streetscape improvements.[50] The developments in Canadian and U.S. cities are summarized on **Chart 15**.

Alternative and New Technologies

In the foregoing, the modal comparisons made compared the trolley against the diesel bus because the diesel appears to constitute the primary alternative to trolleybuses in Vancouver at this time. However, there are other technologies available which also merit discussion here. Refer to **Chart 16** for air contaminant emissions comparisons of the *Compressed Natural Gas* and *Hybrid Diesel-Electric* vehicles discussed below.

Compressed Natural Gas

For some years now, buses operated on *Compressed Natural Gas* (CNG) have made headlines in various cities in Canada and the United States. They have been touted as an environmentally friendly vehicle essentially on the grounds that their emissions profile is leaner on *air contaminants* than the diesel's.[25,2] Emissions tests have shown that CNG buses produce less NOx, less carbon monoxide and markedly less particulate matter than

Recent Developments on the Trolleybus Scene I

(Chart 14)

- There are approximately 350 electric trolleybus systems worldwide
- 37 new trolleybus systems were opened in the last decade

Some Highlights from around the World

Linz, Austria – New Volvo low floor articulated trolleys arriving; system expansion.
Sao Paulo, Brazil – Eleven route extensions under consideration; work progressing on Fura Fila articulated guided trolleybus line.
Beijing, China – New route recently opened, another existing line recently extended.
Guangzhou, China – $70 million trolley system expansion planned to include 49 km of new overhead. Fleet will be expanded to 350 trolleybuses to operate on 11 routes.
Hong Kong, China – **NEW TROLLEY SYSTEM?** Proposing to introduce trolleybuses to replace diesel buses to reduce pollution. Demonstration line.
Shanghai, China – New air conditioned low floor trolleybuses entering service.
Brno, Czechoslovakia – New route opened in September 2000; new Škoda trolleys arriving.
Quito, Ecuador – 59 new trolleybuses in service. Extensions to Quito's large, ultra-modern trolleybus line that uses articulated vehicles, platform loading and operates on a right-of-way.
London, England – **NEW TROLLEY SYSTEM?** London Transport is considering implementing trolleybuses on four routes for environmental reasons and to boost patronage.
Nancy, France – New trolleys bearing the mark of the designer 'Pinifarina' appeared in Fall 2000.
Paris, France – **NEW TROLLEY SYSTEM!** A 6.5 km route is to be constructed for guided trolleybuses.
Athens, Greece – Took delivery of 200 brand new low floor trolleybuses in preparation for the Olympic Games.
Arnhem, Holland – Launched "Trolley 2000" in 1999, a public transportation plan that will place renewed emphasis on the city's trolleybus system in the 21st century as a practical and environmentally-friendly way of travel. Trolleybuses carry signs: "Arnhem – Trolley Stad" ("Arnhem – Trolley City").
Naples, Italy – New fleet of low floor trolleybuses began arriving in February 2000.
Mexico City, Mexico – New Mitsubishi trolleybuses recently added to fleet.
Moscow, Russia – 271 new trolleybuses were purchased in 1999, adding to a trolley fleet of over 1,600 vehicles.
Bern, Switzerland – New batch of low floor Swisstrolleys now in operation.
Lausanne, Switzerland – Extensions in progress; Neoplan to test a 25 m, three-section mega-trolleybus in Lausanne in the near future.
Merida, Venezuela – **NEW TROLLEY SYSTEM!** Construction of a new 18 km segregated, high platform trolleybus route.

(Dec. 2000)
Data Sources: International Trolleybus News List, Trolleybus Magazine

(Chart 15)

Recent Developments on the Trolleybus Scene II

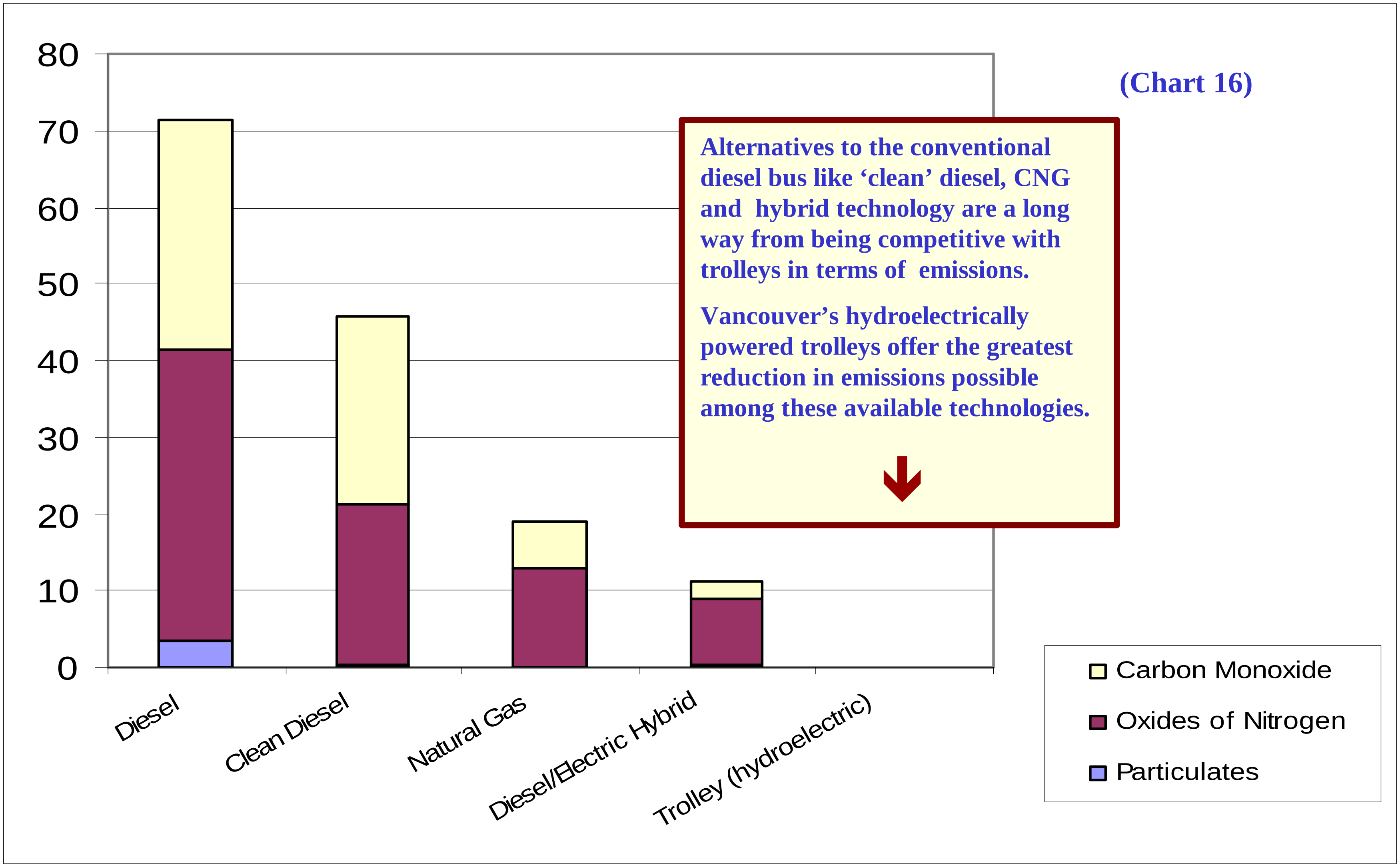
Some Highlights from Canadian and U.S. Cities

City	Approx. Active Fleet	Recent Developments
Boston	40 Flyer (1976)	Current fleet to be replaced w. **new trolleys**; **new route** planned east of Downtown Boston to use Neoplan articulated low floor trolleys.
Dayton	57 ETI/Skoda (1998-99)	Fleet renewed in 1998-99; last of four new **extensions** opened August 20, 2000.
Edmonton	59 BBC/GMC	Recent overhead upgrades; new trolley power substation opened in Sept. 2000.
Philadelphia	66 AM General (1979)	$44 M in budget for **new trolleys**, 2004-2011. Frankford Depot to be rewired.
San Francisco	276 Flyer (1976-77) 60 Flyer artic (1993)	Fleet currently undergoing renewal with **new 40 and 60 foot trolleys** from ETI/Skoda.
Seattle	102 AM General (1979) 46 MAN artic (1986) 236 Breda artic dual mode (1990)	AM General **fleet being 'rebodied'** using 100 40 ft. Gillig bodies on order and updated/refurbished electrics and controls; construction on an **extension** to Rte. 36 to be completed in June 2001.
Vancouver	**244 Flyer (1982-83)**	**Vancouverites promised new low floor trolleys within next five years; new 0.8 km extension into Stanley Park to be completed by Spring 2002.**

(May 2001)

Data sources: International Trolleybus News List, Trolleybus Magazine

Comparative Maximum Levels of Air Contaminant Emissions by Mode of Propulsion (in g/km)



Sources: NAAVC/OTT (1999), TransLink (1999)
NAAVC/OTT figures based on tests using CBD cycle

diesels. But significant contaminant emissions are still produced. In addition, like any other internal combustion vehicle, the CNG bus' emissions are released into the streets and are breathed in by pedestrians and transit users. In spite of the reduction in contaminant emissions over diesel levels, there have been studies in both the UK and the United States linking emissions from compressed natural gas buses to cancer.[2,4,14] A recent Swedish study claimed the cancer risk was higher with CNG than with 'clean' diesel buses equipped with particulate traps.[4] The risks stem from ultra-fine particulate and the formaldehyde component in the CNG exhaust.[2] A recent item in the journal *Professional Engineering* raised the point that all the health risks posed by the ultra-fine particles released in CNG emissions need to be thoroughly evaluated before a massive switch to CNG is deemed beneficial.[46]

While CNG buses may produce less air contaminant emissions, they are worse offenders than diesel buses in terms of greenhouse gases.[2,40] CNG buses release methane as a result of incomplete combustion. Methane has a value as a greenhouse gas (Global Warming Potential) *21 times higher than that of CO2*. Typical CNG noise emissions are only slightly lower than those of a diesel bus; in some instances they are actually greater.

CNG buses require expensive refueling infrastructure to permit their operation and specially equipped maintenance shops to repair them because of the volatility of the fuel. They are also much more maintenance intensive than either diesel or trolleybuses, not only because the engine and fuel system require more maintenance, but the higher vehicle weight also takes its toll on the braking system.[42] Data from TransLink indicates that CNG buses consume about 20% more fuel than diesel buses and are therefore much less energy efficient than either the diesel or the trolley.[42] Their reliability is poorer than trolleys or diesels. Because of the weight of the CNG fuel tanks, the ability of the CNG vehicle to handle heavy passenger loads is reduced compared to diesel or trolley vehicles of equivalent size.[42] In essence, one pays higher costs to operate CNG buses for a loss in energy efficiency and reliability--and in many respects for questionable and certainly limited environmental gain over new technology diesels. Some transit systems have cited the operational costs of CNG buses as being higher than for diesels or trolleys.[6]

Coast Mountain Bus Company operates 50 CNG buses out of its Port Coquitlam garage. They do not plan to purchase more CNG buses because of the very limited advantages they provide. The Toronto Transit Commission operates 125 CNG buses and has ten years of CNG experience. The TTC found that the supposedly 'clean' emissions profile of the CNG bus rapidly deteriorated after about two years of service, reducing its claimed advantage over diesel.[4] They have also found the operating and maintenance expense of CNG vehicles, together with rising natural gas prices, quite daunting. TTC Chairman Howard Moscoe issued a statement in August 2000 that the transit authority regretted the abandonment of its clean electric trolleybus system some years ago under the assumption that CNG would provide a relatively clean and viable alternative.[4]

The MBTA in Boston is currently acquiring CNG vehicles, as are several other transit operators in the United States and especially in California as an alternative to diesel-powered buses. However, these cities lack Vancouver's extensive investment in trolleybus infrastructure.

Diesel-Electric Hybrid

The *Hybrid Diesel-Electric* bus represents a new technology in the industry, although this concept has been used to power railroad locomotives for several decades. There are some differences among the various hybrid drive trains, but essentially this technology employs a diesel engine (of smaller displacement than for a regular diesel bus) operating at a relatively constant speed. The engine keeps a battery pack charged which supplies power to an electric traction motor(s). At cruising speeds, the diesel engine generates enough electricity to move the bus, while additional power is drawn from the batteries for acceleration.[17] New York City Transit, among others, has been testing such vehicles and intends to begin replacing its diesel fleet with them. The MBTA in Boston also intends to place hybrids into service as a diesel substitute.[21] (Boston will *not* use hybrids to replace electric trolleys.)[21] Experience with the hybrid in a wide range of service conditions is not extensive at this time, so it is really not yet a proven technology in the same sense as diesel propulsion, trolleybus or even CNG. Some problems have been cited under heavy load conditions as well as when ascending steep grades. The long-term maintenance cost profile for these vehicles is still unknown, but one must consider that there are essentially two separate propulsion systems to maintain.

So far, New York City has given the hybrid a fairly favorable rating. Fuel consumption compared to standard diesel buses is reduced by at least 30%;[49] noise is also reduced compared to standard diesel because of the fact that the engine is not placed under additional load during acceleration. Performance has been rated favorably on flat surfaces and in stop-and-go traffic. CO and NOx emissions are reduced below the levels of both conventional diesels, 'clean' diesels and even CNG buses,[49] but the hybrid still fares poorly against the cleanliness of trolleybuses with respect to these pollutants. The hybrid still releases particulate emissions into the streets, although in lesser amounts than vehicles powered solely by diesel. Because of its reduced emissions, it may have a lesser health impact than the use of diesel buses, but its health impact is certainly many times greater than the trolley's. CO2 is also reduced over diesel bus levels.

In short, the hybrid diesel-electric appears hold much promise as an alternative to diesel buses on routes with low ridership, where erecting overhead wires is not feasible. It is conceivable that with sufficient development, these vehicles could one day displace diesel buses. ***The hybrid, however, makes a poor substitute for Vancouver's trolleybuses which have essentially no negative environmental impacts.***

Fuel Cell Bus

An emerging new technology is seen in the much talked about *Hydrogen Fuel Cell* bus, engineered by such well-known companies as Ballard Power Systems. The fuel cell bus uses a set of hydrogen "fuel cells" to produce electricity. The electricity is stored in battery packs, from which it is fed to an electric traction motor(s). The most recent engineering efforts have sought ways to eliminate the battery pack as it has been labeled a source of problems.[7] Similar to CNG buses, hydrogen fuel cell vehicles must be equipped with leak detectors because hydrogen is extremely volatile.[40]

It must be emphasized that the fuel cell bus is truly experimental at the present time. While fuel cells may hold promise in some applications for the future, technologies with a proven track record will always be the most desirable choice for any transit authority seeking to acquire vehicles simply for reasons of reliability and the relative predictability of costs.

Hydrogen fuel cell buses face a number of tough obstacles that must be overcome to make them viable transit vehicles. First of all, the fuel cells and storage tanks are extremely heavy. Without even a single passenger on board, 40-foot fuel cell buses on test had about the weight of an equivalent diesel bus *with a fully seated load*. Because of vehicle weight limitations, a current fuel cell vehicle could not currently handle the passenger volumes found on typical mainline bus routes. Acceleration was cited as a problem on early fuel cell test buses in the GVRD and in Chicago. In one incident in Vancouver, a fuel cell bus was unable to ascend a hill. Subsequent adjustments and modifications to the vehicle managed to overcome this, but somewhat to the detriment of fuel consumption. In Vancouver tests, the range and reliability of these vehicles was such that they were only permitted to remain in service for a maximum 4.5 hours at a time.[7]

Similar to CNG buses, fuel cell vehicles require expensive infrastructure.[26] This may include equipment to produce and store hydrogen as well as special refueling stations. The fuel costs alone for the operation of fuel cell test buses in Vancouver were found to be at least three times those of a diesel or trolleybus.[7] The investment of large sums of money in this infrastructure represents a questionable venture for most transit systems at this time, particularly when one considers that a similar investment in trolleybus infrastructure would at least result in adopting a proven technology. The British Columbia provincial government once proposed offering an annual subsidy of $40 million to TransLink for the operation of fuel cell buses. Given the reliability and cost issues, the transit authority considered such funds might be better spent on adding 40 km of overhead to its trolleybus system each year.[7]

Fuel cell vehicles are practically a non-starter in terms of energy efficiency. The fuel cell bus requires uses at least 9 kWh of electricity to produce 1 kWh of tractive output at the wheels of the bus. A trolleybus without regenerative braking needs only 1.56 kWh of electricity to produce 1 kWh of tractive output; regenerative braking can reduce the energy requirement down to 1.1 kWh for each kWh of output.[54] This makes the trolley at least six times more energy efficient than a fuel cell bus.[54] Factoring in the reduced passenger capacity of a fuel cell bus, the trolley becomes about 12 times more efficient.[54] Even in the most optimistic scenario of fuel cell development, the trolleybus is still likely to remain 5 times more energy efficient. **Chart 17** compares the energy efficiency of the fuel cell bus to a trolleybus and a battery bus in terms of number of vehicles that can be driven by one unit of power. Chartered Mechanical Engineer Irvine Bell estimates the total energy efficiency of a fuel cell bus at around 11%. This compares with a diesel bus at 25-40% and a trolleybus driven by electricity generated by the latest high technology gas-powered turbines at upwards of 60%. Hydroelectric power is a renewable resource.

The operation of large numbers of fuel cell vehicles requires a large and steady supply of hydrogen. Currently, the most readily available and most economical sources of hydrogen are fossil fuels. The hydrogen molecules are removed by a process called "stripping".[31] ***The making of hydrogen in this fashion creates considerable quantities of carbon dioxide and thus contributes to the greenhouse effect***. Although the amount of CO2 produced is slightly less than that for internal combustion vehicles operating on standard diesel fuel or gasoline, there are some indications that changes to the fuel can actually reduce CO2 emissions on internal combustion engines below the amounts that would be generated in hydrogen production.[31] Using data gathered by Daimler-Benz,

(Chart 17)

Energy Efficiency of Fuel Cell Vehicles

Ten units of power produced at a power plant will power:

- **ten** direct electric vehicles (e.g. trolleybuses)

- **five** lead-acid battery vehicles

- **one** fuel cell vehicle

Fuel Cell bus developers have promised a lot. Aside from the fact that their vehicles are yet unproven in the rigors of heavy transit service, they are also very poor in terms of energy efficiency.

Source: Eur Ing Irvine Bell BSc CEng MIMechE CDipAF PGCE

Chart 18 shows that hydrogen production for the operation of a subcompact car would yield 77% of the CO_2 emissions that would be generated by the same car with a diesel engine.[26] Thus, the ability to effect substantial reductions in greenhouse gases through the use of fuel cell buses in, say, the next fifty years is highly questionable even if the technology can be made reliable and affordable. The prospect of reducing GHG emissions with trolleybuses appears far greater (and more economical!) than would be the case with the most feasible methods of hydrogen extraction.

Summary

The Washington Society of Professional Engineers made several key findings when they undertook to assess the continued economic viability of the Seattle trolleybus system some years ago,[3] and their conclusions have much in common with many of the points raised above with respect to promoting the trolleybus in Vancouver. Some of the statements made by the Washington engineers that are applicable to *any* trolleybus operation are included on **Chart 19**.

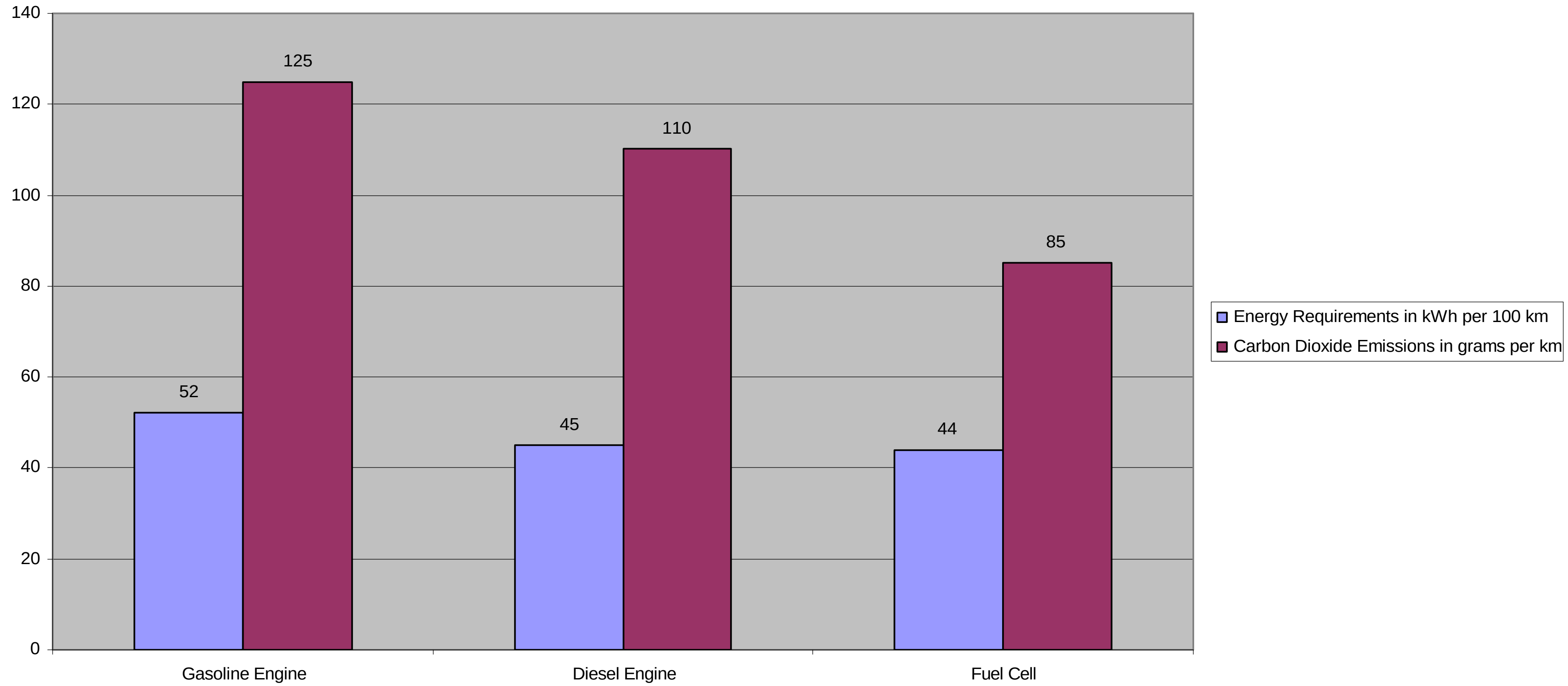
As has become evident in the foregoing, there are very solid reasons to support the retention of the trolleybus system in Vancouver and to encourage increased use of trolleys in the future. Concisely stated, a basis for support can be built on the following key points (**Chart 20**):

• Vancouver has extensive trolleybus infrastructure with excellent utility value
• The infrastructure is in excellent condition
• Trolleybuses are twice as energy efficient as diesel buses
• Trolleybuses in Vancouver have ZERO EMISSIONS and are environmentally advantageous
• Diesel bus emissions have been linked to cancer, asthma and chronic respiratory diseases; trolleys have no such associations with mortality and disease
• Trolleys have no health costs associated with their operation; diesel emissions are associated with considerable health costs
• Trolleybuses do not emit greenhouse gases and could therefore earn carbon credits
• In the urban setting, trolleybuses make no significant contributions to noise pollution
• Trolleybuses are favored by citizens and have a greater potential to increase transit ridership than diesel or other internal combustion powered buses
• Electrically powered street transit helps provide security against future cost increases associated with declining oil reserves
• The popularity of the trolleybus around the world has been growing over the past 20 years
• Other trolley systems in Canada and the U.S. have moved in the direction of renewing their trolleybus fleets with new trolleybuses
• None of the existing and new alternative technologies (CNG, hybrid) can really compete with the trolleybus in terms of emissions, health effects, load capacity, noise or reliability. Fuel cell buses are currently unproven, but are an absolute non-starter in terms of energy efficiency. Fuel cell buses also contribute greenhouse gases during the production of the hydrogen required to power them.

Continuation and expansion of trolleybus service will ensure a commitment toward better public transit, a better quality of life and a better environment for all residents of the GVRD.

(Chart 18)

Energy Requirements and Carbon Dioxide Emissions for a Subcompact Car



With currently available methods of hydrogen production, fuel cells do not contribute significantly to greenhouse gas reduction.

Fuel cell emissions based on hydrogen generated from natural gas or methanol. Note that fuel cell technology still results in 77% of the CO2 emissions produced by a diesel engine.

Sources: Daimler-Benz (1994); Ian Fisher, Electric Trolleybuses in Vancouver, 1997

Statements of the Washington Society of Professional Engineers with regard to trolleybus operations and the replacement of trolleybuses by diesel-powered vehicles

(Chart 19)

- The . . . general belief that the diesel engine is the most efficient and adaptable of all motive units for urban transit vehicles is a modern-day phenomenon that finds a parallel only in such well-known misconceptions of the past as the world is flat!

- [A] major function of an urban transit system is to transport patrons to and from the central business district--without strangling it! This cannot be done with the motorbus, particularly the diesel because of the offensive odor and high toxicity of its exhaust.

- Subsidizing an all-diesel system is tantamount to subsidizing the motor coach industry and air pollution.

- No urban community can afford to use the diesel bus for transit purposes . . . from the standpoint of . . . air pollution and public health.

- The ultimate in poor transit management is the practice of scheduling motorbuses under the wires, when trolleys are left standing idle in the barn.

- Those who contend that the cost per mile is meaningful as a method of evaluating equipment either do not have adequate knowledge to express an opinion on the matter, or their motives must be suspect.

- Cost of power and maintenance of trolley overhead track and feeder are negligible in the overall costs of operating. The three largest costs, by far, are platform hours, equipment maintenance and garaging and administrative and general expense. Whatever management's reason for conversion [to diesel], economy of operation and service to the patron have nothing whatsoever to do with it!

- Any proposal contemplating the retirement of an efficient trolley coach operation of assured longevity and utility value and the abandonment of its newly constructed substation system not only indicates a lack of moral responsibility to the public and a sister city utility, but also a complete disregard for the realities of economics. (S. M. Shockey)

Source: WSPE and Seattle Civic Affairs Committee

Reasons to Support Trolleybus Usage in Vancouver

(Chart 20)

- **Vancouver has extensive trolleybus infrastructure with excellent utility value**
- **The infrastructure is in excellent condition**
- **Trolleybuses are twice as energy efficient as diesel buses**
- **Trolleybuses in Vancouver have ZERO EMISSIONS and are environmentally advantageous**
- **Diesel bus emissions have been linked to cancer as well as asthma and other chronic respiratory diseases; trolleys have no such associations with mortality and disease**
- **Trolleys have no health costs associated with their operation; diesel emissions are associated with considerable health costs**
- **As ZERO EMISSION VEHICLES, trolleys do not produce greenhouse gases and could earn carbon credits**
- **In the urban setting, trolleybuses make no significant contributions to noise pollution**
- **Trolleys are favored by citizens and have a greater potential to increase transit ridership than diesel or other internal combustion powered buses**
- **Electrically powered street transit helps provide security against future cost increases associated with declining oil reserves**
- **The popularity of the trolleybus around the world has been growing over the past 20 years**
- **Other trolley systems in Canada and the U.S. have moved in the direction of renewing their trolleybus fleets with new trolleybuses**
- **None of the existing and new alternative technologies (CNG, Hybrid) can really compete with the trolleybus in terms of emissions, health effects, load capacity, noise or reliability. Fuel cell buses are currently unproven, but are an absolute non-starter in terms of energy efficiency. Fuel cell buses also contribute greenhouse gases during the production of the hydrogen required to power them.**

Continuation and expansion of trolleybus service will ensure a commitment toward better public transit, a better quality of life and a better environment for present and future generations in the GVRD.

Key Sources

(Note: Superscripted numbers in text refer to source numbers below.)

[1]"A Cleanup for the Big Rigs", *The New York Times*, December 26, 2000.

[2]*Analysis of Alternative Fuel Technologies for New York City Transit Buses.* NYC Transit Riders Council, February 2000.

[3]*An Analysis of Simpson and Curtin's Report to the Mayor's Transit Study Committee of Seattle called "Financial Requirements of Seattle Transit System"*, Seattle Civic Affairs Committee of the Washington Society of Professional Engineers (E. E. Van Ness, et. al.), February 1966.

[4]"Another Major City Sours on CNG; Advocate Report attacks Clean Diesel", *Diesel Fuel News*, August 14, 2000.

[5]*American Public Transportation Association* (APTA) website: "Statistics" (http://www.apta.com)

[6]APTA Electric Bus Subcommittee Meeting, February 14-16, 1999. Notes.

[7]APTA Electric Bus Subcommittee Meeting, November 8, 1999. Notes.

[8]"ARB cuts Emissions from Transit Buses", News Release of the California Environmental Protection Agency—Air Resources Board, February 24, 2000.

[9]"Berkeley-Oakland-San Leandro Major Investment Study", *Community Connections* (published by AC Transit, http://www.actransit.org/mistudy.html), Spring 2000.

[10]*Better Public Transit: An Essential Economic Strategy for Canada*. Canadian Urban Transit Association, 2000.

[11]Burmeister, Jürgen. "KAN Masterplan und Trolley 2000: Nahverkehr in der Region Arnhem-Nijmegen", *Stadtverkehr International*, June 1998.

[12]Clark, Robert. *Guidelines for the Planning and Operation of Trolley Bus Service in Edmonton.* 1984.

[13]*Coast Mountain Bus Company* website (http://www.coastmountainbus.com)

[14]"Debate heightens over Compressed Gas", *The Earth Times* (http://www.earthtimes.org/aug/environmentdebateheightensaug3_00.htm), August 3, 2000.

[15]"Diesel Cited as Health Hazard", *The Georgia* Straight, December 7-14, 2000, p. 11.

[16]*Diesel-Electric Hybrid Buses: Addressing the Technical and Public Health Issues*. Clean Air and Energy, Transportation Policy Papers of the Natural Resources Defense Council, April 1999.

[17]*Diesel Electric Hybrid 40' Low Floor Coach DE40LF* (Information pamphlet produced by New Flyer Industries, Winnipeg, Manitoba, 1999.

[18]"Diesel Exhaust Contributes to Lung Cancer", *Mediconsult/Reuter's Health Information* (http://www.mediconsult.com/mc/mcsite.nsf/condition/general~reuters+news~mstg-4mdv4n), July 19, 2000.

[19]*Diesel Particulate Matter and Associated Environmental Concerns: Health Risks and Tradeoffs.* Vancouver: The Onroad Diesel Emissions Evaluation Task Force, March 3, 2000.

[20]*Discover*, October 2000, p. 85.

[21]Duffy, Jim. "Silver Lining in Boston", *Mass Transit*, November/December 2000, p. 10-26.

[22]"Early Warning: Class Actions possible from Diesel Fumes", *Transport Topics* (http://www.ttnews.com/members/printEdition/0003047.html), November 10, 1999.

[23]*Edmonton Transit Vehicles Survey - Public Opinions.* Edmonton Transit Marketing and Planning, Customer Services, April 1992.

[24]*Electric Trolley Bus Study for RTD and the LACTC, Final Report, Part A.* Booz, Allen and Hamilton, June 1991.

[25]*Exhausted by Diesel: How America's Dependence on Diesel Engines Threatens our Health.* Natural Resources Defense Council and the Coalition for Clean Air, April 1998.

[26]Fisher, Ian. *Electric Trolleybuses in Vancouver: Past, present and future alternatives.* (1997) Transport 2000 BC Website at: http://vcn.bc.ca/t2000bc/learning/_trolleybus/trolleybus_essay.html, 1997.

[27]"Global Warming", *Environmental Protection Association* website (http://www.epa.gov/globalwarming/glossary.html#S)

[28]*Greater Vancouver Regional District 1999 Emission Inventory Update for the Lower Fraser Valley Airshed*, August 2000. (www.gvrd.bc.ca)

[29]"How Carcinogenic is your Car?", Centre for Science and the Environment News Releases at: http://www.oneworld.org/cse/html/au/au4_20000504.htm.

[30]"How good is your Diesel Engine?" *Deccan Herald*, December 5, 2000. (http://www.deccanherald.com/deccanherald/dec05/st1.htm)

[31]"How Green is your Hydrogen?", *The Economist*, April 2000, p. 74.

[32]"How Road Pollution pumps Asthma into Childrens' Lungs", *Daily Mail*, December 27, 2000.

[33]Hybrid *Electric Drive Heavy-Duty Vehicle Testing Project—Final Emissions Report*. Northeast Advanced Vehicle Consortium, West Virginia University, February 15, 2000.

[34]"L.A. Study links Cancer and Diesel Particulates", *Transport Topics* (http://www.ttnews.com/members/printEdition/0003075.html), November 17, 1999.

[35]Lawrence, Llew. "Why have Trolley Buses?" *Transit News*, November/December 1982.

[36]"Legislation to Prevent NYC Transit Diesel Bus Purchases", *Mobilizing the Region* (http://www.tstc.org/bulletin/19950421/mtr03107.htm), April 21, 1995.

[37]Leicester, Glen. *Trolleybuses in Vancouver – Overview.* BC Transit, August 15, 1988.

[38]Leicester, Glen. *BC Transit (Vancouver) Electric Bus Status Report to the APTA Electric Bus Sub-Committee Meeting in Vancouver, BC – February 14-16, 1999.* BC Transit, February 1999.

[39]"Libya urges cutting off oil supply", *The Oregonian*, December 26, 2000.

[40]Lythgo, Chris. *Bus Technology Review.* TransLink, September 1, 1999.

[41]*Making the Case for Senior Government Support for Public Transit* (Speakers' Package), Large Urban Communities Forum, UBCM Convention. October 24, 2000.

[42]"Natural Gas vs. Electric Power for Buses". Extract from correspondence from Glen Leicester, Manager, Implementation Planning, TransLink, located on the Electric Trolleybus Website at: http://members.home.net/dearmond/Natural_Gas.htm.

[43]Natvig, Carl. "Economic Feasibility of Electrifying Selected Motor Coach Lines." San Francisco Municipal Railway Planning Division, 1982. (portion of a larger document)

[44]Natvig, Carl. *Five Year Plan 1977-82, Issue Paper No. 3: The Environmental and Economic Feasibility of Trolley Coach Expansion.* San Francisco Municipal Railway Planning Division, July 1978.

[45]Office of Transportation Technologies Heavy Vehicle Emissions Testing – Bus Emissions Database (http://www.ctts.nrel.gov/heavy_vehicle/emissions.html).

[46]Porteous, A. "Of Particulate Concerns", *Professional Engineering*, January 31, 2001, p. 22.

[47]"Region's Air Cleaner—but More Polluted", *Times Colonist*, October 17, 2000, p. D9.

[48]*Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fuelled Engines and Vehicles.* California Environmental Protection Association – Air Resources Board, October 2000.

[49]Siuru, W. D. "Study Shows Advantages of Hybrid-Electric Buses", *Mass Transit*, May 2000, p. 76-81.

[50]Slack, Chris. "The Euclid Corridor Improvement Project: Greater Cleveland Transit Authority Undertakes $292 Million Euclid Renovation", *Busline*, January/February 2000.

[51]Snell, Bradford C. *American Ground Transport: A Proposal for Restructuring the Automobile, Truck, Bus and Rail Industries.* Presented to the Subcommittee on Antitrust and Monopoly of the Committee on the Judiciary, United States Senate. Washington: U.S. Committee on the Judiciary, February 1974.

[52]"South Bay won't get Natural Gas Buses", *San Francisco Chronicle*, December 15, 2000.

[53]"Study: Diesel Exhausts cause Cancer", *Health – The Station of the People* (http://www.channel2000.com/sh/health/cancercenter/health-cancercenter-20000315-170549.html), March 15, 2000.

[54]"The Fuel Cell, Trolley and the Hybrid Bus – Where Should We Invest?", *Transport Canada 2000 Western Newsletter*, November 2000.

[55]*Toxics Link* website*:* "Automobile Fuels*"* at: http://www.toxicslink.org/facts_autos.htm.

[56]*TransLink* website (http://www.translink.bc.ca)

[57]*TransLink Capital Plan: Trolley Bus Service Replacement--Fleet Assessment Report*, TransLink, June 2000.

[58]*Trolleybus Magazine (Journal of the National Trolleybus Association)*, various issues.

[59]*Trolleybus System in Jeopardy? Trolleybus Fact and Fiction.* Transport 2000 BC Website (http://vcn.bc.ca/t2000bc/learning/_trolleybus/trolley_alert.html)

[60]*Trolley Expansion Program – SEPA Final Supplemental Environmental Impact Statement/NEPA Environmental Assessment.* Municipality of Metropolitan Seattle, June 1993.

[61]*Trolley Operation Review.* Edmonton Transit, Marketing and Planning, February 1993 and earlier draft versions.

[62]*Vancouver's Trolley Buses 1948-1998: Celebrating a Half-Century of Service*. BC Transit, 1998.

[63]Vuchic, Vukan. *Urban Public Transportation—Systems and Technology* (Prentice-Hall, 1981)

[64]*World Wide Trolley Bus Technology Development: A Preliminary Report to the Hong Kong Environmental Protection Department*, Ecotraffic Research and Development, March 1999.