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School Buses, Air Pollution & Children's Health:

Improving Children's Health & Local Air Quality by Reducing School Bus Emissions

November 2005

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Author & Project Manager:

Kim Perrotta, MHSc, Manager, OPHA Environmental Health Program (2002-05)

Project Advisory Committee:

This school bus project has benefited greatly by the expertise, policy direction and editorial advice offered throughout by:

- Louise Aubin, Research & Policy Analyst, Peel Health & OPHA Member
- Helen Doyle, Manager, York Region Health Services & OPHA Member
- Ronald Macfarlane, Supervisor, Environmental Protection Office (EPO), Toronto Public Health
- David Roewade, Public Health Planner, Environmental Health and Lifestyle Resource Division, Region of Waterloo Public Health
- Franca Ursitti, Research & Policy Analyst, Peel Health & OPHA Member (formerly Research Consultant, EPO, Toronto Public Health)

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- Ken Ogilvie, Executive Director, Pollution Probe
- Charles O'Hara, Researcher, Air Programme, Pollution Probe

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- Sandy Chan, Senior Policy Analyst, Student Transportation, Ministry of Education
- Patrick Cram, Senior Program Engineer, Transportation Systems Branch, Environment Canada
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Photos:

Kim Perrotta

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Executive Summary

This report examines emissions from school buses and recommends the establishment of a Healthy School Bus Program that is directed at improving children's health and local air quality.

We are concerned about emissions from school buses for several reasons. School buses are predominantly heavy-duty diesel vehicles that emit significant quantities of diesel-related air pollutants such as fine particulate matter, nitrogen oxides, and diesel particulate matter as they travel to and from our children's schools. They can also be self-polluting vehicles that expose children on-board to high levels of fine particulate matter and diesel particulate matter. These air pollutants have been clearly associated with a broad spectrum of acute and chronic impacts. They have been found to:

- Aggravate asthma, leading to more frequent and severe asthma attacks;
- Increase the number of respiratory infections;
- Reduce lung function;
- Aggravate and induce allergies;
- Increase school day and work day absences;
- Increase emergency room visits, hospital admissions and premature deaths; and
- Contribute to the development of chronic heart and lung diseases including lung cancer and possibly asthma.

While children may spend only a few hours per day on school buses, the high levels of exposure encountered on-board can add considerably to their daily and annual exposures to fine particulate matter and diesel particulate matter. With approximately 800,000 Ontario children being transported on school buses each year, these exposures can represent a significant public health concern. The respiratory systems of children are sensitive to air pollution, and children with pre-existing respiratory conditions such as asthma, are particularly vulnerable. With a 12% asthma rate among children in this country, there could be approximately 96,000 asthmatic children traveling in school buses in Ontario each year.

In addition to being the source of considerable pain, suffering, lost-time and anxiety, childhood respiratory diseases place a considerable strain upon our health care system. In 1999, they were responsible for over 8,000 hospital admissions and almost 20,000 hospital days among school-aged children in Ontario. In addition, asthma is reported to be responsible for over one-third of the Ontario Health Insurance Plan (OHIP) expenditures directed at children in this province.

Childhood exposures also can influence the health of exposed individuals in later life. For example, a small shift in the average lung function among a population of children can translate into a substantial increase in the number of adults who are more susceptible to respiratory diseases including lung cancer, and premature death, later in life.

Exposure studies directed at conventional diesel school buses found that emissions from tailpipes and engine compartments contribute significantly to concentrations of air pollutants on-board. They found that on-board concentrations were also influenced by local air quality in the communities studied, traffic density on the roads traveled, wind direction and the configuration of the windows (i.e. open or closed), and idling and queuing patterns.

The exposure studies also found that concentrations of air pollutants on-board school buses could be reduced almost to ambient air levels, even under idling conditions, by outfitting them with diesel particulate filters (on the exhaust system) and closed crankcase filtration devices (in engine compartments) and running them on ultra-low sulphur diesel fuel. These studies also suggest that on-board exposures can be reduced by keeping doors and windows closed when buses are idling, avoiding idling when buses are waiting in front of schools, and avoiding caravanning on roadways.

We have found that emissions from new diesel engines are much lower today than they were 10 years ago, and will decline significantly again between now and 2016 as new diesel engine emission standards are implemented. We have estimated that, in 2004, Ontario's 15,000 school buses collectively emitted approximately:

- 114 tonnes of particulate matter,
- 718 tonnes of hydrocarbons,
- 2,601 tonnes of nitrogen oxides, and
- 285 kilotonnes of carbon dioxide.

Given the introduction of low-emitting diesel school buses over the 2007-2010 period and the age of Ontario's school bus fleet, it appears that school buses that are already on the road, especially the 1994-2003 model year school buses, will be the dominant source of emissions from Ontario school buses for the next 10 years. Although pre-1994 school buses represent a quickly diminishing percentage of Ontario's fleet, they will continue to emit a disproportionate share of particulate matter for the next few years because of their higher emission rates. After examining the school bus exposure studies and the emission reduction options, it was concluded that:

Replacing Pre-1994 School Buses: The replacement of pre-1994 buses should be given high priority because of the high emissions associated with them. Given that the new buses purchased to replace them will be on the road for about 15 years, it is recommended that they be replaced with new buses that meet the 2007 emission standards. This scenario could cost about $17 million to implement because of the incremental costs (about $10,000 per bus) associated with the best available diesel technology relative to new buses that meet the 2004 emission standards. This scenario would also produce significant exposure benefits for the 90,000 children per year who may ride those 1,700 school buses over the next 15 years. While most of the buses in this cohort should be fully depreciated, additional incentives may be needed to ensure that all buses in this cohort are retired by 2007.

All School Buses: The closed crankcase filtration device has the potential to reduce concentrations of fine particulate matter on-board school buses to ambient air levels at a cost of about $400 to $600 per bus. The cost of installing these devices on all school buses in Ontario would be about $7.5 million.

Retrofitting 1994-2003 School Buses: Emissions from 1994-2003 model year school buses could be significantly reduced by retrofitting them with 2-stage diesel particulate filters and calibrating them for low NO_X emissions. If this scenario were applied to 9,000 1994-2003 model year school buses, emissions of particulate matter, hydrocarbons, and nitrogen oxides from Ontario's entire fleet of school buses could be reduced by 51%, 75%, and 15% respectively between 2006 to 2016 period at a cost of about $90 million. This scenario could also produce significant exposure benefits for the 477,000 children per year who may ride those school buses over the next 4 to 13 years.

Replacing 1994-2003 School Buses: Significant emission reductions could also be achieved if the 1994-2003 model year school buses were replaced with new buses that meet the 2007 emission standards. The emission profile of these new buses, which would cost about $10,000 more than a new bus built to 2004 emission standards, would be equivalent to retrofitting with a diesel particulate filter for particulate matter and hydrocarbons, but superior for nitrogen oxides. These new buses would also produce significant exposure benefits for the children transported on them. The decision about whether to retrofit or replace a 1994-2003 model year school bus would be influenced by the age of the existing bus and the financial situation of the school bus operator.

Maintenance and Driving Practices: Proper maintenance, idling, and vehicle operation practices should be employed to reduce emissions of air pollutants and greenhouse gases from all model year school buses. These practices cost little money to implement and can produce cost savings because of associated reductions in fuel consumption. They can also produce exposure benefits for the children and drivers transported on-board.

To fully implement all of the emission reduction options identified above in Ontario could cost up to $115 million or $23 million per year over 5 years. These costs must be considered in context. The Ontario school bus fleet has a replacement value of about $1.5 billion, annual capital investment in new buses is in the range of $100 million per year, and annual funding for student transportation hovers around $700 million. As a general rule, air pollutant emission reduction investments should be kept below one year's capital investment. In this context, the costs of the emission reduction options outlined above seem reasonable. However, given that funding for student transportation in Ontario has been extremely limited for several years, it is important that school bus upgrades and retrofits be funded out of a supplementary funding pool directed towards improving children's health and local air quality.

Several programs have been established in the United States to fund emission reductions from U.S. school buses. Since 2002, the U.S. Environmental Protection Agency (EPA) has run the Clean School Bus USA program that provides funds to schools and other organizations for retrofitting existing buses and replacing older buses. Since 2000, the California Air Resources Board (CARB) has run the Lower-Emissions School Bus Program which aims to reduce the exposure of school children to both toxic and smog-forming air pollutants by funding the replacement of old buses with new, low-emitting school buses and retrofitting in-use school buses with technologies that significantly reduce emissions of particulate matter.

A number of school boards across North America have developed formal anti-idling policies including the New Brunswick Board of Education. Among school boards in Ontario that responded to an informal survey, none had formal anti-idling policies in place, although several used contracts with school bus operators to encourage proper idling practices.

Recommendations

1. It is recommended that the Ontario Ministry of the Environment establish a multi-year Healthy School Bus Program, with $10-20 million per year, that has the dual goals of reducing childhood exposure to diesel-related air pollutants and improving local air quality by:

   a. Ensuring the retirement of all pre-1994 model year school buses by 2007;
   b. Encouraging the replacement or retrofitting of all 1994-2003 model year school buses by 2011;
      i. When retrofitting, encourage the use of diesel particulate filters wherever possible, and the next best available technology when conditions are not conducive to the effective use of diesel particulate filters;
   c. Ensuring that all new school buses purchased over the next year meet 2007 emission standards;
   d. Encouraging the installation of closed crankcase filtration devices in all school buses in Ontario;
   e. Supporting demonstration projects that promote the development of alternative technologies and fuels; and
   f. Developing, in collaboration with Natural Resources Canada, the Ontario School Bus Association, and Ontario school boards, a module on proper idling, fuel management, and low emission driving practices, to be included in the provincial curriculum for school bus operators.

The Healthy School Bus Program should be designed with recognition for both the financial pressures experienced by school boards and school bus operators and the varying realities of small and large school bus operators in the Province. The Program should facilitate bulk purchase arrangements that could significantly reduce the costs of retrofits and replacements.

Given both the potential contribution of school buses to air pollution in localized areas and the contribution of local air quality to pollutant concentrations on-board school buses, priority should be given to school boards operating in areas that experience poor regional air quality and to schools that experience poor local air quality. Priority should be given to school buses used for longer commutes, multiple-commutes, and greater numbers of passengers.

While improving the health of children in Ontario, this Program would also help the Province to achieve its 1996 commitment to reduce emissions of nitrogen oxides and volatile organic compounds in Ontario by 45% of 1990 levels by 2015. It would also help the Province to achieve its 2000 commitment to attain the Canada-Wide Standards for fine particulate matter of 30 µg/m3 (24-hour) and for ozone of 65 ppb (8-hour) by 2010.

2. It is recommended that the Federal Government establish a multi-year Healthy School Bus Fund, with $10 to 20 million per year, to support programs developed by provincial governments and other organizations, that are directed at the dual goals of reducing childhood exposure to diesel-related air pollutants and improving local air quality.

This Fund should give priority to school boards operating in communities that are currently out of attainment with the Canada-Wide Standards for fine particulate matter or ozone.

While improving the health of children across the country, in Ontario this Fund would also provide emission reductions that could be used to fulfill Canada's commitments to reduce emissions of nitrogen oxides and volatile organic compounds under the Ozone Annex of the Canada-U.S. Air Quality Agreement. It would also produce emission reductions that could be counted towards a Particulate Matter Annex under the Canada-U.S. Air Quality Agreement.

3. It is recommended that school boards in Ontario, in collaboration with the Ontario Ministry of the Environment and Natural Resources Canada, develop formal policies respecting idling in school buses particularly in the vicinity of school properties.

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Glossary of Terms & Acronyms

Air Pollutants & Emissions

Carbon black	Used as an indicator of diesel particulate matter (DPM)
CO_2	Carbon dioxide (a greenhouse gas)
CO	Carbon monoxide (common air pollutant)
DPM	Diesel Particulate Matter (particulate portion of diesel exhaust)
GHG	Greenhouse Gases
NO_2	Nitrogen Dioxide (common air pollutant)
NO_X	Nitrogen Oxides (including nitrogen dioxide)
PAHs	Polycyclic Aromatic Hydrocarbons (toxic contaminant)
PM	Particulate Matter (can mean PM_{10} and/or $PM_{2.5}$)
$PM_{2.5}$	Fine Particulate Matter – PM with less than 2.5 microns in diameter
PM_{10}	Coarse Particulate Matter – PM with less than 10 microns in diameter
$PM_{0.1}$ & $PM_{1.0}$	Ultra-fine particles – PM with less than 0.1 or 1.0 microns in size
SO_2	Sulphur Dioxide (common air pollutant)

Organizations, Programs & Databases

CARB	California Air Resources Board
CEPA	California Environmental Protection Agency
DSS	DSS Management Consultants Inc.
NB Lung	New Brunswick Lung Association
NPRI	National Pollutant Release Inventory
OMA	Ontario Medical Association
OPHA	Ontario Public Health Association
UCS	Union of Concerned Scientists
EHHI	Environment and Human Health Inc.
NRDC	Natural Resources Defense Council
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Technologies, Fuels & Units of Measurement

B20	80% petroleum-based diesel blended with 20% biodiesel
CNG	Compressed Natural Gas
DOC	Diesel Oxidation Catalyst
DPF	Catalyzed Diesel Particulate Filter
EGR	Engine Gas Recirculation
HEV	Diesel Electric Hybrid Vehicles
SCR	Selective Catalytic Reduction
ULSD	Ultra-Low Sulphur Diesel (diesel with 15 ppm sulphur or less)
ppb	parts per billion (concentration of gas in air)
g/VKT	grams per vehicle kilometre traveled (applied to tailpipe emissions)
bhp-hr	brake horsepower per hour (engine output)
$\mu g/m^3$	micrograms per cubic meter of air (concentration of particulate in air)

Introduction

The OPHA initiated this project in 2003 in response to two reports on school buses prepared by non-governmental organizations in the United States.

Emissions from School Buses

One report, produced by the Union of Concern Scientists (UCS), identified diesel-fuelled school buses as an important source of air pollutants that contribute to health impacts in the United States. The UCS estimated that the fleet of 454,000 school buses, used to transport about 25 million children in the United States, collectively release approximately 3,100 tons of particulate matter, 95,000 tons of nitrogen oxides, 213,000 tons of carbon monoxide, and 10.7 million tons of greenhouse gases annually (UCS, 2002).

The UCS also identified huge variations in emissions from school buses of different ages and run on different fuels. It found that buses built before 1990 and 1991 were emitting three times as much particulate matter and six times as much nitrogen oxides as current models (UCS, 2002). This report led the OPHA to consider the extent to which the 15,000 school buses in Ontario contribute to poor air quality and what steps could be taken to reduce their emissions.

Exposures On-board School Buses

The second report, produced by the Natural Resources Defense Council (NRDC) and the Coalition for Clean Air in collaboration with researchers from the University of California, Berkeley School of Public Health, brought attention to the exposure of children on-board school buses. The study team monitored black carbon (as an indicator for diesel particulate matter) and fine particulate matter in the cabins of four school buses for a total of 20 hours. They found a huge variability in pollutant concentrations inside buses of a similar age. They also found that concentrations of diesel particulate matter ranged from 8.5 to19 μg/m3. The study team concluded that these exposure levels presented cancer concerns for the children who ride on school buses.

This report led the OPHA to believe that the childhood exposures on-board school buses should be examined more closely. It also inspired us to think about how different technologies and fuels might be used to reduce on-board exposures for the 800,000 children in Ontario who are transported on school buses.

Report Structure & Goals

This report has been organized to address the following issues:

- **Chapter A** summarizes the health evidence available on the diesel-related air pollutants. It highlights some of the findings respecting air pollution's acute and chronic impacts on the health of adults and children. It also discusses some of the health outcomes that have been found among adults and children with traffic corridor studies.
- **Chapter B** summarizes the findings of exposure studies conducted on-board school buses.
- **Chapter C** describes the fleet of school buses currently in use in Ontario and estimates the air emissions associated with it now and in the foreseeable future.
- **Chapter D** assesses the technologies, fuels and practices that could be used to reduce emissions from Ontario's school buses for their effectiveness, cost, availability and reliability.
- **Chapter E** estimates of the emission reductions associated with various options when applied to different model year school buses on both on an annual per bus basis and on a cumulative fleet-wide basis.
- **Chapter F** discusses the school bus programs implemented in other jurisdictions, idling policies, policy considerations, and includes recommendations for Ontario.

A Air Pollution, Diesel Exhaust & Human Health

I Why Focus on School Buses?

There are three reasons to focus attention on emissions from Ontario's school buses:

1) School buses can be self-polluting, exposing children on-board to elevated levels of diesel-related air pollutants;
2) There are about 15,000 school buses in Ontario used to transport approximately 800,000 children to and from school each year; and
3) School buses are heavy-duty diesel vehicles that can emit substantial quantities of diesel-related air pollutants as they travel to and from our children's schools.

Composition of Diesel Exhaust

Diesel exhaust is the term used to describe the whole mix of air pollutants emitted from diesel-fueled vehicles. It is composed of hundreds of air pollutants including:

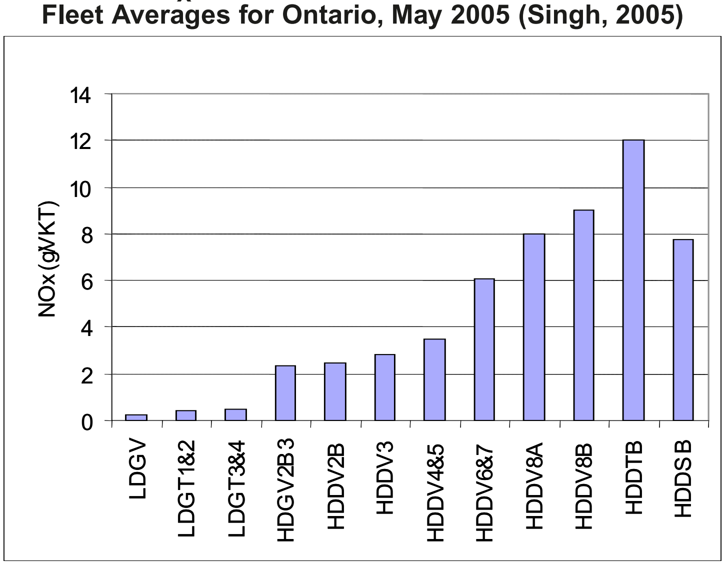
- The common air pollutants, nitrogen oxides (**NO_X**), carbon monoxide (**CO**), and sulphur dioxide (**SO_2**);
- The greenhouse gas, carbon dioxide (**CO_2**); and
- About 40 chemicals that have been classified as "toxic air contaminants" by agencies such as the California Air Resources Board (CARB) including benzene,1,3-butadiene, and polycyclic aromatic hydrocarbons (**PAHs**) (US EPA, 2002).

A significant portion of diesel exhaust is present as particulate matter (PM). PM is the term given to airborne pollutants that are present as solid particles or liquid droplets. PM can be emitted directly from sources or formed in the atmosphere from gaseous pollutants such as SO_2, NO_X and volatile organica compouns (VOCs).

The particulate portion of diesel exhaust, called **diesel particulate matter** (**DPM**), is composed largely of:

- $PM_{2.5}$ that are less than 2.5 microns in diameter (**$PM_{2.5}$**) (80 to 90%); and
- Ultra-fine particles that are less than 0.1 microns in diameter (1 to 20%)(**$PM_{0.1}$**).

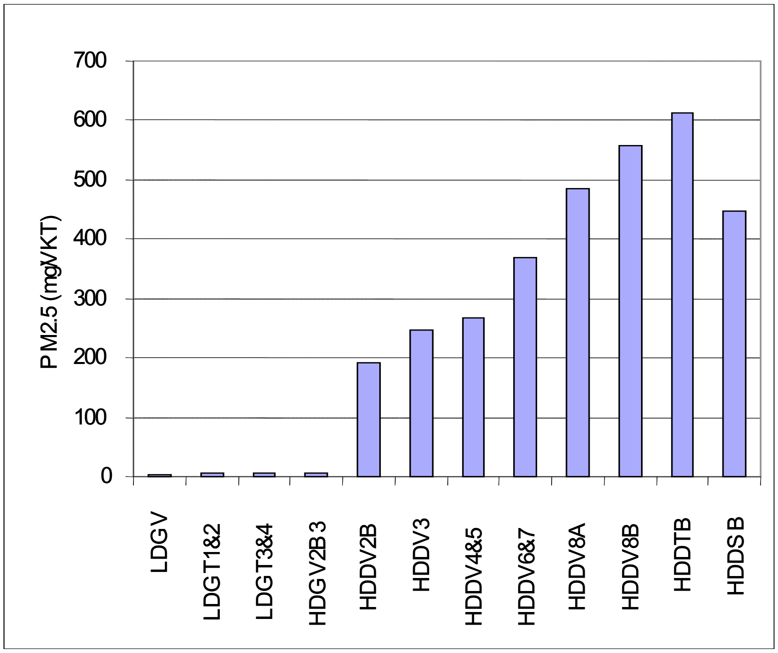
Figure 1: NO_X Emission Rates, Different Vehicle Types, Fleet Averages for Ontario, May 2005 (Singh, 2005)



These fine and ultra-fine particles are capable of penetrating deep into the lungs, entering the blood stream, and traveling to distant parts of the body. They have a large surface area which enables them to adsorb large quantities of inorganic and organic compounds, which they can then transport into the body (US EPA, 2002).

The US EPA has determined with modeling that DPM from on-road sources can be responsible for a significant percentage of the PM in ambient air and that the percentage can vary substantially from one community to another. For example, it estimated that DPM from on-road sources was responsible for 53% of the coarse particulate matter (**PM_{10}**) in the ambient air in Manhattan, New York, in 1993, and for 10 to 15% of the $PM_{2.5}$ in the ambient air in Phoenix and Denver, Colorado, in 1997 (US EPA, 2002).

Figure 2: $PM_{2.5}$ Emission Rates, Different Vehicle Types, Fleet Averages for Ontario, May 2005 (Singh, 2005)



Nitrogen oxides are a health concern for several reasons. There is evidence which suggests that they present a direct health risk when present in the atmosphere as nitrogen dioxide (NO2). They also contribute to ambient air levels of $PM_{2.5}$ when present in the atmosphere as nitrates, and they react with VOCs in the atmosphere to produce ground-level ozone. Ozone is the gaseous air pollutant that triggers most of the smog advisories experienced in the summer months in Ontario.

As illustrated in **Figures 1 and 2**, heavy-duty diesel trucks (HDDV), transit buses (HDDTB) and school buses (HDDSB) emit far greater quantities of NO_X and PM per kilometre traveled than gasoline-fuelled cars (LDGV) and trucks (LDGT).

II Common Air Pollutants – Health Impacts

The common air pollutants are those found in the air because of our use of fossil fuels such as oil, gasoline, diesel, natural gas and coal to heat our homes and businesses, run our cars and trucks, fuel our industries, and generate electricity. The Ontario Medical Association (OMA) has estimated that the six common air pollutants – particulate matter (PM_{10} and $PM_{2.5}$), ozone, NO_2, SO_2 and CO– will contribute to approximately:

- 5,829 premature deaths,
- 16,807 cardiovascular and respiratory hospital admissions,

- 59,696 emergency room visits, and
- 29 million minor illness days in Ontario in 2005 (OMA, 2005).

These estimates represent preventable health outcomes associated with that portion of air pollution that can be attributed to human activities alone. They do not include health outcomes associated with background air levels resulting from emissions from natural sources. The OMA has valued these health outcomes at about $7.8 billion in 2005: about $507 million for institutional care and medication; about $374 million in lost-time for patients and caregivers; $537 million for pain and suffering; and about $6.4 billion for loss of life. These costs do not include those associated with visits to doctors' offices, which are expected to be significant (DSS, 2005).

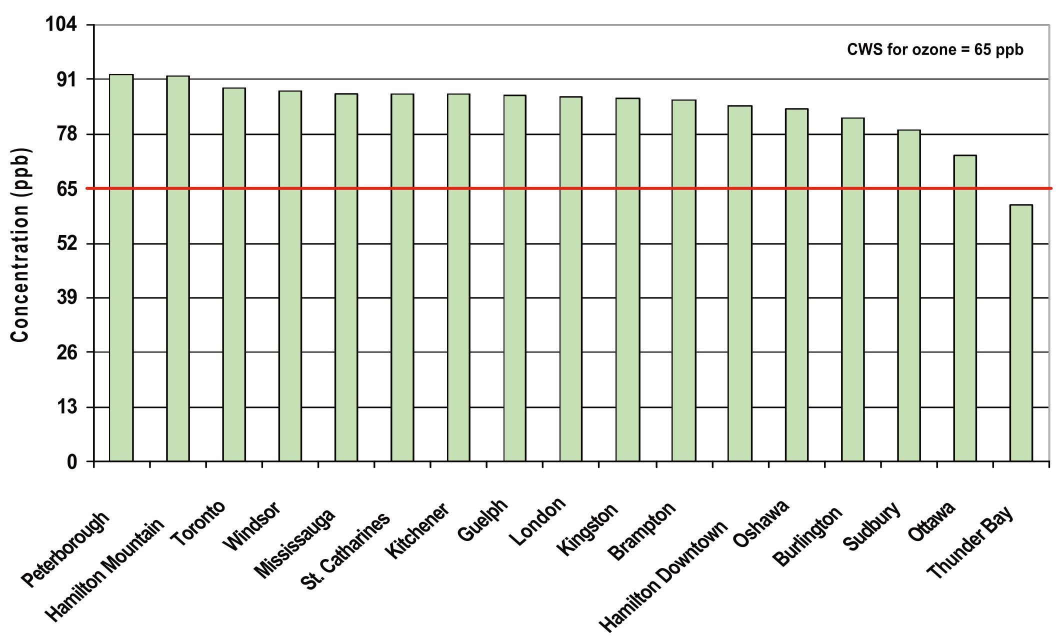
Health Impacts - Ozone

As noted above, diesel exhaust contains a high percentage of NOx, one of the precursors of ground-level ozone. Studies have demonstrated that short-term exposures to high levels of ozone are associated with increased hospital admissions, emergency room visits for respiratory problems and premature deaths (NAAQO, 1999a). Repeated exposures to lower levels of ozone have been associated with increases in respiratory infections and aggravation of pre-existing respiratory diseases such as asthma and bronchitis (US EPA, 2000). More recent studies of human populations have suggested that prolonged, repeated exposures to ozone can impair the lung's defense mechanisms, reduce lung function, and increase the incidence of chronic respiratory illnesses such as emphysema, bronchitis and asthma. Collectively, these studies have found that young children and people with pre-existing respiratory conditions such as asthma are most vulnerable to the adverse effects of ozone (US EPA, 2002).

In 1999, the Canadian Federal Provincial Working Group on Air Quality Objectives and Guidelines identified:

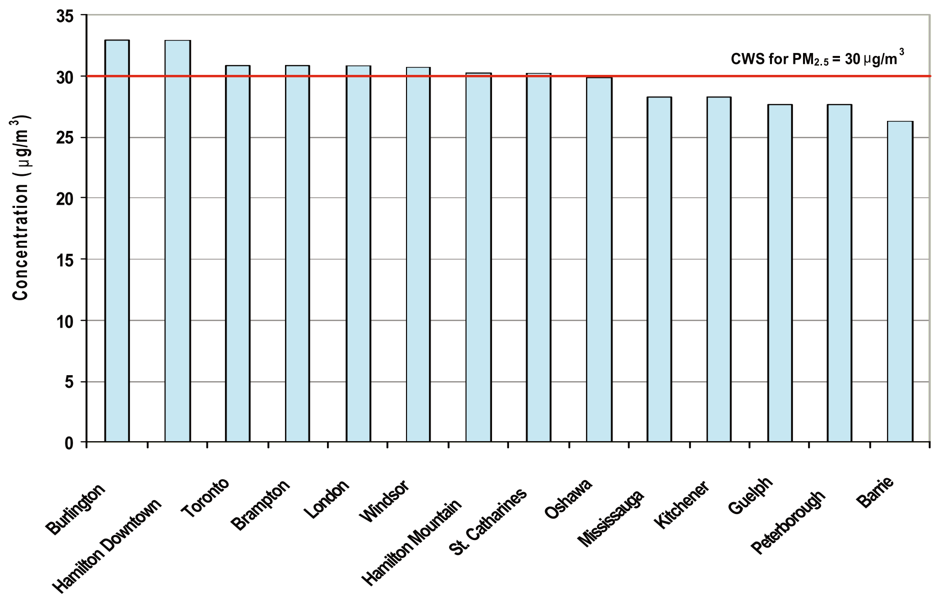
- 20 parts per billion (ppb) as the lowest air level of ozone (averaged over 1-hour) that was clearly and consistently associated with premature deaths; and
- 25 ppb as the lowest air level clearly and consistently associated with respiratory hospitalizations (NAAQO, 1999a).

Figure 3: Ozone Levels in Ontario Communities, 4th Highest Ozone 8-Hour Maximum, 2000-2003 (OMOE, 2005)



These reference levels were exceeded on a very frequent basis in most communities monitored in Ontario in 2003 (OMOE, 2004). Many communities in Ontario also exceed the Canada-Wide Standard for ozone of 60 ppb (8-hour) which comes into effect in 2010 (see Figure 3) (OMOE, 2005).

Figure 4: Fine Particulate Matter (PM2.5) Levels in Ontario Communities, 98th Percentile Daily Average, 2001-2003 (OMOE, 2005)



Health Impacts - Particulate Matter (PM)

Particulate matter (PM) has been clearly associated with a number of acute health effects in studies of human populations conducted in countries around the world. Short-term increases in PM have been associated with the following:

- Increases in premature deaths, hospital admissions and emergency room visits for respiratory and cardiovascular disease;
- Increases in respiratory symptoms, respiratory infections, school absences, work day absences and restricted activity days; and
- Reductions in lung function (US EPA, 2004).

A few long-term studies conducted on large populations have found that prolonged exposure to PM is statistically associated with an increased risk of cardiovascular and respiratory diseases including asthma and lung cancer, a reduced life expectancy, and reduced lung function (US EPA, 2004; Krewski, 2000).

For example, in one U.S. study which followed 1.2 million adults for 16 years, deaths from all causes, cardiopulmonary disease, and lung cancer increased by 4%, 6% and 8% respectively for every 10 $\mu g/m^3$ increase in air levels of $PM_{2.5}$. The researchers concluded that air pollution in some U.S. cities presents a health risk comparable to that presented by long-term exposure to second hand smoke (Pope et al., 2002).

Collectively, these health studies have found that children, the elderly, individuals with pre-existing respiratory or cardiovascular diseases, and individuals with infectious respiratory diseases are most sensitive to the harmful effects of PM (US EPA, 2000).

In 1999, the Canadian Federal Provincial Working Group on Air Quality Objectives and Guidelines identified:

- 25 μg/m^3 (24-hour) as the lowest air level of $PM_{2.5}$ that was clearly and consistently associated with premature deaths; and
- 15 μg/m^3 (24-hour) as the lowest air level clearly and consistently associated with hospital admissions (NAAQO, 1999b).

Air pollution in some U.S. cities presents a health risk comparable to that preseted by long-term exposure o second hand smoke (Pope, 2002).

The lower reference level was exceeded about 10% of the time in most communities in southern Ontario in 2003 (OMOE, 2004). Air levels in several Ontario communities also exceed the Canada-Wide Standard for $PM_{2.5}$ of 30 μg/m^3 (24-hour) which comes into effect in 2010 (see Figure 4) (OMOE, 2005).

III Diesel Exhaust – Health Impacts

Diesel exhaust varies in chemical composition and in particle size with changes in engine types, fuel formulations and engine operating conditions. It has also changed over time as engine technologies and fuel formulations have changed. These variations and changes have made it difficult for regulatory agencies to clearly define the health impacts associated with diesel exhaust. In addition, because it is difficult to separate the components of diesel exhaust from air pollutants emitted from other sources, it is difficult to identify the degree to which diesel exhaust contributes to the health impacts that have been attributed to the common air pollutants.

Diesel Exhaust - Acute & Chronic Health Impacts

Short-term exposures to diesel exhaust have been associated with a variety of inflammation-related symptoms such as headaches, eye irritation, asthma-like reactions, and increased sensitivity to allergens. In animal studies, short and medium-term exposures to DPM have been associated with inflammation of the airways, changes in lung function, and increased susceptibility to infections (CEPA/CARB, 1998; US EPA, 2002).

Diesel exhaust has also been associated with a number of long-term effects. Occupational studies have found a greater incidence of chronic bronchitis and reduced lung function among people exposed to diesel exhaust for prolonged periods, while animal studies have observed inflamed lung tissue among animals exposed in long-term studies. Studies conducted on humans and animals indicate that prolonged exposure to DPM can also induce allergic reactions, worsen allergic reactions to pollen, and increase respiratory resistance and airway constriction (CEPA/CARB, 1998; US EPA, 2002).

Diesel Exhaust - Cancer Concerns

Over 30 epidemiological studies have looked at the cancer-causing potential of diesel exhaust. These studies have found, on average, that long-term occupational exposure to diesel exhaust is associated with a 40% increase in the relative risk for lung cancer (CEPA/CARB, 1998; US EPA, 2002). Lung cancer has also been observed in experimental rat studies involving diesel exhaust. Many agencies including the International Agency for Research on Cancer (IARC) have designated diesel exhaust or DPM as a potential or probable human carcinogen (US EPA, 2002).

The US EPA has not developed a lifetime cancer risk factor for diesel exhaust because of the uncertainties associated with the existing exposure-response data. The US EPA has concluded however, that the lifetime cancer risk for diesel exhaust could be anywhere between 1 additional case per 100,000 people exposed and 1 additional case per 1,000 people exposed (US EPA, 2002).

The US EPA reports that ambient air levels of DPM ranged from an average of 1.2 to 4.5 $\mu g/m^3$ in suburban and urban areas in the United States in the 1990s with concentrations peaking to 13.2 to 46.7 $\mu g/m^3$ in micro-environments such as bus stops in Manhatten, New York (US EPA, 2002).

The US EPA has concluded that is important to reduce diesel particulate matter emissions because of the public health impacts that could be associated with air levels of diesel exhaust in the ambient air and in micro-enviroments.

When the US EPA compared environmental exposures to diesel exhaust to occupational exposures that were associated with an increased cancer risk (which ranged from 0.4 to 157 $\mu g/m^3$ when converted to an equivalent environmental lifetime estimate), it found that there was an overlap between environmental exposures and the low end of occupational exposures that were associated with cancer. This suggests that there is little or no margin of safety for some populations who are exposed environmentally. As a result of this analysis, the US EPA concluded that it is important to reduce emissions of DPM because of the public health impacts that could be associated with levels in ambient air and in micro-environments (US EPA 2002).

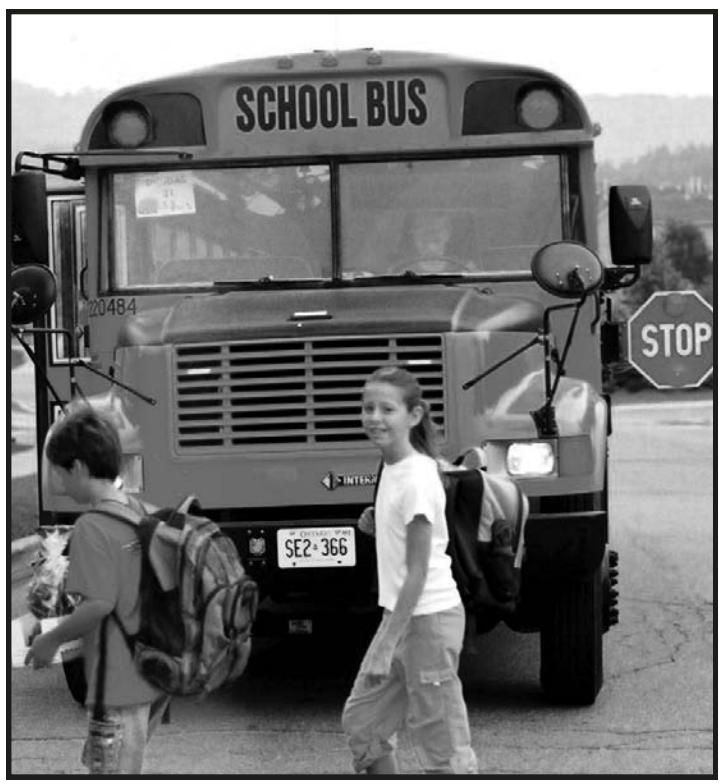
IV Traffic Corridor Studies – Health Impacts

Greater Impact from Traffic-Related Air Pollutants

In many epidemiological studies, it can be difficult to discern a clear health impact for specific air pollutants because estimates of exposure for large numbers of people are based on a small number of air monitors that are centrally located. To overcome this problem, a number of studies have been directed at traffic corridors using vehicle counts and proximity to roadways as an indicator of exposure to traffic-related air pollutants.

These traffic corridor studies suggest that people, and particularly children, who spend large amounts of time in close proximity to major roadways may be at greater risk for a broad range of adverse health impacts. They also suggest that traffic-related air pollutants may have a greater impact on human health than is suggested by studies that rely upon centrally located air monitors. For example:

- A study of 39,000 Italian children and adolescents found that residence on a street with frequent truck traffic was associated with a significant increase in the risk of adverse respiratory outcomes including infections, wheezing and bronchitis symptoms (Ciccone, 1998);
- A Dutch study found increased respiratory symptoms and increased sensitization to pollen among children who went to schools located near roadways with heavy truck traffic, but not among children who went to school near roadways with heavy car traffic. Symptoms were increased among children with asthma or allergies only, and were associated with increased concentrations of truck-related air pollutants (Janssen, 2003);
- A study conducted in the State of New York found that, after adjustments for age



and poverty, children hospitalized for asthma were more likely to live on, or within 200 meters of, a roadway with a heavy volume of traffic or trucks (Lin, 2002);

- A case-control study conducted in France found, after adjustments for second-hand smoke and allergies, increased rates of asthma among children who lived in close proximity to roadways with high density traffic before three years of age. The association did not apply to children who lived nearby high traffic roadways after the age of three (Zmirou, 2004);

- A case-control study conducted in Los Angeles found a 10 to 20% increase in the risk of pre-term births and low birth weight infants born to women who lived in close proximity to roadways with heavy traffic. These findings were not, however, corrected for confounding factors such as socioeconomic status (Willhelm and Ritz, 2003);
- A nation-wide case-control study conducted in Denmark found the risk of lung cancer among men who drive for a living, increased significantly with increasing duration of employment, with the highest risk among taxi drivers with 10 years of employment. The results, which were not explained by differences in smoking habits or socioeconomic status, suggest that exposure to vehicle exhaust plays an important part in the development of lung cancer among drivers (Hansen, 1998); and
- A case-control study conducted in northern Italy found a significant increase in the risk of childhood leukemia among children who were deemed to be heavily exposed to traffic emissions. Exposures were classified using estimates of benzene concentrations that were modeled using proximity to roads and density of traffic. The results, which were adjusted for socioeconomic status, suggest that motor traffic emissions may be involved in the development of childhood leukemia (Crosignani, 2004).

V Children are Sensitive to Air Pollution

Increased Vulnerability of Children

A considerable body of evidence suggests that children can be more vulnerable to chemical exposures because their bodies are still developing. The lungs, immune systems and detoxification systems, which are responsible for protecting the body from foreign substances, continue to develop and grow throughout childhood making them more sensitive to the adverse effects associated with toxic substances (Wigle, 2003).

A 20% increase in serious asthma attacks was observed among children with a 10 μg/m³ rise in $PM_{2.5}$.

Children and adolescents can also experience greater exposure to air pollutants than adults because of their behaviour, physiology and size. Children typically spend more time outdoors, can be more physically active while outdoors, and have higher respiratory rates than adults, so they can inhale greater quantities of air pollutants per body weight than the typical adult (Wigle, 2003).

Children also experience high rates of acute respiratory infections than adults, which can make them more vulnerable to harm from exposure to outdoor air pollutants (WHO, 2005). In addition, there is a large population of children who have underlying lung diseases such as asthma, which can make them more vulnerable to air pollution than children without those conditions (WHO, 2005).

With childhood exposures to air pollution, there is also a concern about the long-term implications of lung injury. Damage to the developing lung during childhood can enhance susceptibility during adult years to other factors such as smoking, occupational exposures and infections (WHO, 2005).

The child's respiratory system is a primary target for air pollutants. A wide range of acute and chronic effects can result from exposure to air pollutants acting alone, in combination with other agents, and/or the child's susceptibility. The developing lungs of the fetus and the infant are known to be more susceptible to injury by toxic substances including air pollutants at exposure levels that would not have an apparent effect on adults (WHO, 2005).

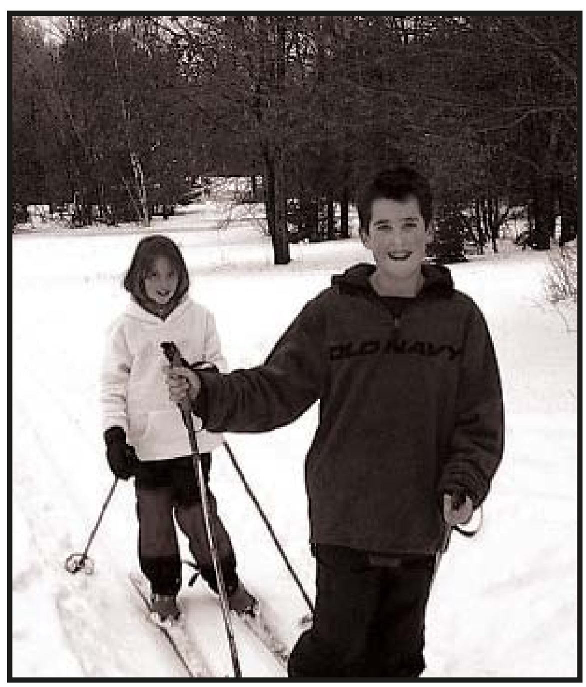
The human respiratory system begins developing about 24 days after fertilization. The branching of the airway system is complete at 17 weeks in utero, while the development of the alveoli, where gases are exchanged with the blood, begins at 28 weeks of gestation and continues until about 18 months of age. The lungs continue to grow until the late teens in girls (18-20 years) and early twenties in boys (22-25 years) (WHO, 2005).

Respiratory diseases are responsible for a significant burden of illness among children in Ontario and place a significant strain on the province's health care system. For example, respiratory diseases were responsible for over 8,000 hospital admissions and almost 20,000 days in the hospital among school-aged children in Ontario in 1999 (CICH, 2005). If each day in the hospital costs about $500, childhood respiratory diseases cost the health system about $10 million a year for hospital-related expenses alone.

Reduced Lung Function

Normal lung development and growth are necessary for optimal gas exchange (i.e. getting oxygen into the blood and removing carbon dioxide). Alterations in lung structure during development can adversely affect lung function and result in an increased risk of respiratory illness and premature death later in life. In a variety of studies, lung function at maturity has been shown to be a strong predictor of future lung function and premature mortality (WHO, 2005).

Although lung function growth rate varies with a child's stage of growth, lung function in children follows a relatively consistent track over time. The same holds true for the decline in lung function that occurs in an aging population. A non-smoking adult loses about 1% of lung function per year while a smoking adult loses about 1.5% per year. The big differences in lung function among adults are due to maximal lung function attained at maturity. Consequently, factors that affect lung function growth in children are important in determining the level of lung function in adulthood (WHO, 2005).



After reviewing the high quality studies conducted on air pollution and lung function over the last 10 years, the World Health Organization (WHO) Europe Working Group concluded that:

- People who live in communities with high air pollution have lower lung function;
- Children who are chronically exposed to elevated levels of air pollution have lower rates of lung function growth;
- Improvements in air pollution can lead to improvements in lung function levels and/or lung function growth rates;
- Acute exposures to air pollution are associated with apparently reversible deficits in lung function;
- Children who spend a significant amount of time outdoors in polluted areas or those with poor nutrition may be more strongly affected by air pollution (WHO, 2005).

While it is clear that air pollution affects lung function, it is not as clear which pollutants, or combination of pollutants, are responsible for the effects observed. Studies have identified ozone, NO_2, acid aerosols, acid vapours, particulate matter (PM_{10} & $PM_{2.5}$), and SO_2 as candidates for these effects, but not consistently across all studies. Diesel exhaust, which contains high levels of NO_2, fine particles and organic compounds, have been implicated in both epidemiological and toxicological studies (WHO, 2005).

In a variety of studies, lung function at maturity has been shown to be a strong predictor of future lung function and premature mortality (WHO, 2005).

While air pollution appears to have a modest effect on lung function, accounting for only a small reduction in average lung function, studies suggest that the effect can be cumulative over a 20-year growing period, and it is not clear if the chronic effects are reversible. Also, it must be remembered that a small shift in average lung function in a population can reflect a substantial increase in the fraction of children with "abnormally" low lung function, which can in turn increase the number who are more susceptible to respiratory disease and premature death later in life (WHO, 2005).

Asthma and Allergies

Asthma is a chronic disease of the respiratory system that is characterized by inflammation of the airways and varying levels of airflow obstruction. According to the World Health Organization (WHO), asthma is a term used to describe several different disorders that produce similar symptoms and effects. The symptoms include wheezing, shortness of breath, cough and chest tightness. Usually lung function is reduced with asthma, and there is increased bronchial responsiveness in which the airways constrict in reaction to stimuli such as cold, pollen or air pollution. A substantial number of children with asthma also have allergies that produce runny noses or skin rashes (WHO, 2005).

Current estimates indicate that asthma affects about 12.2% of all Canadian Children.

Current estimates indicate that about 12.2% of all Canadian children have been diagnosed with asthma (Health Canada, 1999; TPH, 2005). It is the leading cause of absences from school for children and places a significant strain on the province's health care system. Children with asthma require approximately $100 per year more in health care than the general population and contribute to over one third of the total OHIP expenditures for children in Ontario (To et al., 2004).

When the WHO Europe Working Group reviewed all of the epidemiological studies conducted on air quality's impact on allergies and asthma, it found that:

- Long-term exposure to outdoor air pollutants, particularly PM, increases the prevalence and/or incidence of bronchitis and coughs in children, and that these effects are more pronounced in children with asthma;
- Only a few of the long-term community-wide studies suggest that air pollution increases the incidence and prevalence of asthma;
- The traffic corridor studies do suggest that living in close proximity to traffic is causally associated with an increase in the revalence/incidence of asthma symptoms and hay fever;
- Air pollution is associated with increases in hospital admissions and emergency room visits for asthma, and that these health outcomes are associated with traffic-related air pollutants including PM and NO_2; and
- Air pollution exacerbates respiratory symptoms (cough and wheezing) or increases medication use among children with asthma, and that these effects are associated with different pollutants including PM, NO_2 and ozone (WHO, 2005).

The WHO Europe Working Group concluded that the available data provide strong evidence that the respiratory health of children, particularly those with increased susceptibility such as children with asthma, will benefit substantially from reductions in air pollution, especially from motor vehicle exhausts (WHO, 2005).

Respiratory Infections

While many factors contribute to the risk of acute respiratory infections, indoor and outdoor air pollution is seen to be a growing contributor. When the WHO Europe Working Group examined the studies directed at air pollution and acute respiratory infections over the last ten years, it found that even at current day concentrations, exposure to outdoor air pollutants increase the risk of infections of the upper and lower respiratory system.

It found strong evidence that particulate matter ($PM_{2.5}$ and PM_{10}) produces a small, but significant, increase in the risk of respiratory infections (i.e. a small percentage change in the risk which translates into a significant number of infections because of the large number of people exposed). While the Working Group also found an association with NO_2, it could not determine if NO_2 is a "causal agent" or an indicator for traffic-related air pollution (WHO, 2005).

The WHO Europe Working Group concluded that there is strong evidence that: outdoor air pollutants increase the risk of respiratory infections in children; pose possible mechanisms of interaction between air pollution and infectious agents; and confirms that pollution reductions can improve the respiratory health of children (WHO, 2005).

VII Air Pollution – Other Health Impacts

Childhood Cancer

While childhood cancer is quite rare, it affects about 1,200 children each year in Canada. Leukemia is one of the most common forms of cancer among children, responsible for about 26% of new cases each year, followed by tumors of the central nervous system (TPH, 2005; WHO, 2005). Only a small percentage of childhood cancers can be explained by inherited traits or well-established risk factors such as exposure to ionizing radiation or Epstein-Barr virus. Air pollution from traffic is one of the risk factors suspected for childhood cancer because of its presence in many urban areas where populations are concentrated and its composition which includes many chemicals that are known or suspected carcinogens (WHO, 2005).

.....strong evidence that the respiratory health of children, particularly those with increased susceptibility, will benefit substantially from reductions in air pollution, especially from motor vehicle exhausts (WHO, 2005).

When the WHO Europe Working Group examined all of the health studies produced on the topic of air pollution and childhood cancer, it concluded that there is currently insufficient evidence to determine whether air pollution is or is not associated with childhood cancer.

The Working Group also noted that there is evidence that air pollution increases the risk of lung cancer in adults, and that while air pollution may not cause childhood cancer, childhood exposures may well contribute to the development of cancers later in life (WHO, 2005).

Birth Outcomes

Over the last decade, a number of studies have examined the impact of air pollution on birth outcomes and reproduction. Birth outcomes are important both as indicators of the health of newborns and infants, and as indicators of the individual's health in later life. Low birth weight, intra-uterine growth retardation, and impaired growth in the first years of life are associated with increased mortality and morbidity in childhood and an elevated risk of hypertension, coronary heart disease, and non-insulin-dependent diabetes in adulthood (Sram et al, 2005).

...childhood exposures may well contribute to the development of cancers later in life (WHO, 2005).

When a team of scientists conducted a review of the evidence related to air pollution and adverse birth outcomes, they concluded that:

- There is sufficient evidence of a causal relationship between airborne particulate matter and respiratory deaths among infants;
- The evidence suggests a causal relationship between air pollution and low birth weight;
- There is insufficient evidence to suggest causal relationship between air pollution and premature births, intra-uterine growth retardation, or birth defects, although the evidence is sufficient to warrant more research (Sram et al., 2005)

The reviewers reported that there are several studies which suggest that it is biologically plausible for air pollution to affect birth outcomes. For example, they point to toxicological studies which indicate that PAHs can increase rates of mutagenesis and may interfere with the endocrine system which directs placental growth and fetal development (Sram et al., 2005).

VIII Summary - Health Effects Associated with Diesel-Related Air Pollutants

Diesel exhaust is a complex mixture of pollutants that are present in both gaseous and particulate form. The gaseous emissions include NO_x, CO, SO_2, a number of hydrocarbons, and the greenhouse gas, CO_2. Many of the hydrocarbons in diesel exhaust are known to be toxic; some have been identified as potentially carcinogenic. The particulate component, called DPM, is composed largely of $PM_{2.5}$, ultra-fine particles, and hydrocarbons that are adsorbed to the surface of the particles. These particles are so small that they can travel deep into the lungs, enter the bloodstream, and travel to distant organs in the body.

Short-term exposures to diesel exhaust have been associated with a variety of inflammation-related symptoms such as headaches, eye irritation, asthma-like reactions, and increased sensitivity to allergens. Prolonged exposures to diesel exhaust have been associated with increases in lung cancer, chronic bronchitis, and respiratory responsiveness, reduced lung function, and inducement and aggravation of allergies. The U.S. Environmental Protection Agency (US EPA) has reported that DPM can be found in outdoor air at levels that are equivalent to those in occupational studies in which there were increased rates of lung cancer.

$PM_{2.5}$ in outdoor air has been clearly associated with a broad spectrum of acute health effects including:

- Increases in premature deaths, hospital admissions and emergency room visits for respiratory and cardiovascular disease;
- Increases in respiratory infections, respiratory symptoms, school day and work day absences, and restricted activity days; and
- Reductions in lung function.

In long-term studies of adults, prolonged exposures have been associated with:

- Increases in cardiovascular and respiratory diseases including lung cancer; and
- Reductions in life expectancy.

These acute and chronic health effects are known to occur at air levels of $PM_{2.5}$ that are common in Ontario.

Among children, short-term exposures to elevated levels of air pollution (particularly traffic-related air pollutants) have been associated with:

- Reductions in lung function;
- Increases in respiratory infections, school absences, and emergency room visits; and
- Increases in the number and severity of asthma symptoms.

Children with pre-existing health conditions such as asthma appear to be most sensitive to the acute effects of air pollution.

Long-term studies of children suggest that prolonged exposures to air pollution (particularly traffic-related air pollutants) can produce:

- Significant deficits in lung function among adolescents;
- Increased bronchitis symptoms among asthmatic children; and
- An increased incidence of asthma.

Several studies have also suggested that traffic-related air pollution may increase the risk of childhood cancer.

Respiratory diseases are responsible for a significant burden of illness among children in Ontario. In 1999, they were responsible for over 8,000 hospital admissions and almost 20,000 days in the hospital among school-aged children in Ontario. It has been reported that over one-third of the Ontario Health Insurance Plan (OHIP) expenditures for children in the province each year are directed at children with asthma.

Childhood exposures also can influence the health of exposed individuals in later life. For example, a small shift in the average lung function among a population of children can translate into a substantial increase in the number of adults who are more susceptible to respiratory disease and premature death later in life. Also, given that both $PM_{2.5}$ and diesel exhaust have been found to increase the risk of lung cancer among adults, it is likely that childhood exposures to these air pollutants can increase the risk of lung cancer in later life.

B Exposure Studies: Air Pollutant Concentrations On-Board School Buses

I Exposures on School Buses – Environment & Human Health Inc (EHHI)

In 2002, a U.S. non-profit organization, Environment & Human Health Inc. (EHHI), released a report prepared in collaboration with researchers from Yale University and the University of Connecticut that included exposure data for children riding school buses.

In this study, personal monitors were used to measure the exposure of 15 students to PM_{10} and $PM_{2.5}$ over a 7-hour period on a school day. The research team also monitored black carbon (an indicator for DPM) and $PM_{2.5}$ levels on-board buses as they idled and as they drove during 8 runs on 4 different days. They also collected samples on three different types of buses: a diesel bus with the engine in the front; a diesel bus with the engine in the back; and a bus run on compressed natural gas (CNG). Monitoring was conducted in environments with exceptionally low traffic and few other sources of air pollution.

EHHI Findings

The study team found that:

- While on-board school buses, children were exposed to average $PM_{2.5}$ levels that were 5 to 10 times higher than the air levels reported at ambient air monitors for their communities;
- There was huge variability in air levels in school buses affected by idling and queuing patterns, window configuration, road congestion, ambient air levels, and the fuel used in the buses;
- Average on-board air levels of $PM_{2.5}$ and black carbon were up to 10 to 15 times higher than ambient air levels when buses were idling; these increased levels could "linger" during bus trips depending upon factors such as window configuration and traffic congestion;
- On-board air levels of $PM_{2.5}$ and black carbon were higher when buses with open windows stopped and lower when buses with open windows were moving;
- On-board $PM_{2.5}$ levels in CNG buses were the same as ambient air levels;
- Overall, children's exposures to PM_{10} were increased around school bus rides; and
- Children were exposed to peaks of PM_{10} as high as 100 $\mu g/m^3$ inside their schools following the arrival or departure of school buses (Wargo, 2005).

EHHI Conclusions & Recommendations

The research team determined that, if school bus exposures to $PM_{2.5}$ were added to ambient exposures of $PM_{2.5}$ (which range from 10.8 to 17.9 $\mu g/m^3$), the national air standard for $PM_{2.5}$ of 15 $\mu g/m^3$ (24-hour mean averaged over 3 years) would be exceeded in some communities and greatly exceeded in others. When school bus exposures are not included in that calculation, the air standard is exceeded by only one of 13 communities in Connecticut (Wargo, 2002).

This study team recommended, among other things, that:

- Existing school buses should be retrofitted with diesel particulate filters (**DPFs**) or diesel oxidation catalysts (**DOCs**) to reduce emissions;
- Funding should be provided to encourage replacement of existing school buses with low emission or alternative fuel vehicles in areas of the country that are out of compliance with national air standards;
- Federal air standards in the United States should be adjusted to account for probable indoor and within-vehicle exposures to air pollution;
- Bus idling should be prohibited; and
- Routine maintenance should be required (Wargo, 2002).

Children on-board school buses were exposed to average $PM_{2.5}$ levels that are 5 to 10 times higher than the air levels reported at ambient air monitors in their communities (Wargo, 2002).

II Air Levels on Different Types of School Buses – California Air Resources Board (CARB)

The California Air Resources Board (CARB) released a report in 2003 that examined pollutant concentrations on-board school buses of various ages and types when driven on actual routes in Los Angeles. The context of this study was an earlier exposure assessment in which CARB found that while people spend only about 6% of their time in their vehicles, they experience one third of their exposure to DPM in cars, where air levels can be up to 5 times higher than ambient air levels (CARB, 2003b).

Monitoring was done for five diesel related air pollutants — black carbon, PAHs, NO2, ultra-fine particles ($PM_{0.1}$), and $PM_{2.5}$. It was done on seven different buses: 3 built before 1990; 2 built in the 1990s; a 1998 model year bus outfitted with a DPF; and a 2002 model year CNG school bus.

All diesel-fuelled buses used ULSD than contains 15 ppm of sulphur or less. Buses were driven multiple times on urban, rural and suburban routes with varying traffic density. A tracer gas was used in the fuel to help determine the extent to which on-board pollutants reflected the emissions of the bus being driven.

CARB Findings

When the researchers compared the pollutant concentrations on-board school buses, they found that:

- Concentrations of diesel-related air pollutants can be significantly higher on-board conventional diesel school buses than in other vehicles on the road due to "self pollution" (i.e. the bus's emissions are seeping into the cabin of the bus) (**Table 1**).
- Self-pollution was worse when windows were closed and worse for older buses;
- When windows were closed, concentrations of benzene, formaldehyde, NO_2, PAHs and DPM were up to 2.5 times higher on conventional diesel school buses than in light-duty vehicles such as cars (**Table 1**);
- Pollutant concentrations were 2 to 3 times higher when buses traveled on congested primary roadways than when they traveled on suburban and rural routes;
- Concentrations of diesel-related pollutants were much lower on-board both, the CNG school bus and the DPF-retrofitted diesel school bus;
- When windows were closed, concentrations of pollutants were 2 to 5 times higher on-board the diesel buses than on the CNG school bus or the DPF-retrofitted diesel school buses; and
- Concentrations related to natural gas such as formaldehyde were higher on the CNG bus than on the diesel school buses (CARB 2003; CARB 2003b).

CARB Conclusions & Recommendations

CARB estimated that children riding on conventional school buses can experience exposures to DPM that are 34% higher on a daily basis and 19% higher on an annual basis than that experienced by children riding in cars. CARB also estimated that, under a worst-case scenario, $PM_{2.5}$ exposures on school buses could increase daily exposures to $PM_{2.5}$ by 3.3 µg/m³ and annual exposures by 1.8 µg/m³ (above baseline levels of 23 µg/m³) (CARB, 2003b; CARB 2003).

Table 1: Concentrations, Diesel Particulate Matter (DPM) & Fine Particulate Matter ($PM_{2.5}$), On-Board School Buses, Inside Cars & Ambient Air, California (CARB, 2003)

	Concentrations On-Board School Buses	Concentrations in Cars	Daily Average Ambient Air Levels
DPM	9.2 µg/m3 (2 hours)	5.9 µg/m3 (1.5 hours)	1.1 µg/m3
$PM_{2.5}$	62 µg/m3 (2 hours)	N.R.	23 µg/m3

(N.R. – not reported)

CARB recommended reducing children's school bus exposures to diesel exhaust by:

- Accelerating the retirement of older, high-polluting buses;
- Accelerating the phasing-in of school buses run on CNG or retrofitting diesel school buses with DPFs;
- Discouraging bus caravanning by staggering departure times; and
- Minimizing bus idling (CARB, 2003).

III Exposure on School Buses & Walking to School – New Brunswick Lung Association (NB Lung)

In 2005, the New Brunswick Lung Association (NB Lung) completed a study, conducted in collaboration with Health Canada and Environment Canada, which compared exposure to diesel-related air pollutants between children who travel by school bus and children who walk to school.

Concentrations of diesel-related air pollutants can be significantly higher on diesel-fueled school buses than on other vehicles on the road due to "self pollution" (CARB, 2003).

Measurements, collected over 63 days in a 3-month period in 2003, were taken on 75 bus rides on 40 different buses and for 20 walking routes. The buses monitored were all full-size buses, most had a carrying capacity of 72 passengers, and they included buses manufactured between 1988 and 2002. Buses made in 1997 and before, with mechanically controlled fuel injection systems, were classified as older buses, while buses made in 1998 and after were classified as newer buses. All buses were fueled with diesel containing 436 ppm sulphur. Measurements were collected for five diesel related air pollutants: $PM_{2.5}$, ultra-fine particles ($PM_{1.0}$), black carbon, PAHs and VOCs (NB Lung, 2005).

NB Lung Findings

Idling of buses, noted as an important exposure factor by other studies, was not a common practice in this study. The research team found that:

- Average exposures to $PM_{2.5}$ on school buses were 5 to 6 times greater than ambient air levels of $PM_{2.5}$ (**Table 2**);
- Exposures to $PM_{2.5}$, PM1.0, black carbon, and volatile organic compounds were 2 to 4 times higher during the average bus ride than during the average walking commute (**Table 2**); and

- Exposures on buses can be a factor of 10 times higher than the average walking exposure for these compounds (NB Lung, 2005).

The research team found that concentrations measured on the buses were affected by: ambient air levels of $PM_{2.5}$; humidity and temperature; duration of the bus ride and the number of bus stops; the density of the traffic on the routes traveled; and the configuration of the windows. They found little difference in air levels between older buses (1988-1996 model year school buses) and newer buses (1997-2002 model year school buses) (NB Lung, 2005).

Table 2: Average Concentrations, Fine Particulate Matter ($PM_{2.5}$), Ultra-Fine Particles ($PM_{1.0}$), Black Carbon, Polycyclic Aromatic Hydrocarbons (PAHs), Walking Routes, School Bus Rides & Ambient Air, New Brunswick (NB Lung, 2005)

	$PM_{2.5}$ (µg/m^3)	$PM_{1.0}$ (particles/cc)	Black Carbon (µg/m^3)	PAHs (ng/m^3)
Walking	9.7	4,028	0.2	265.4
Bus Ride	32.1	10,786	0.7	775.3
Ambient	5.0	N.R.	N.R.	N.R.

N.R. – not reported

IV Intake of Diesel Particulate Matter on School Buses – University of California

Researchers from the University of California released a study in 2005 that was directed at both, calculating the extent to which "self-pollution" explains exposures on-board school buses, and estimating the fraction of the bus's emissions that is inhaled by individuals on the bus.

Exposure to diesel-related air pollutants on-board school buses can be 10 times higher than the exposures encountered by children who walk to school (NB Lung).

Tracer gas experiments were conducted on 6 buses while traveling along school bus routes in Los Angeles: 9 runs were done with windows open and 7 runs were done with windows closed. The experiments were done on 6 buses: two high emitting diesel buses (i.e.1975 and 1985 model years); two regular diesel buses (i.e.1993 and 1998 model years); one 1998 diesel bus equipped with a DPF; and one 2002 CNG school bus.

The researchers found that "self-pollution" values were:

- Higher on older buses (pre-1990 model years) than on newer buses (post-1990 model years);
  - Twice as high when windows were open;
  - Six times as high when windows were closed;
- Higher with windows closed than with windows open;
  - 20% higher with newer buses;
  - three times higher with older buses.

The researchers estimated that, on an annual basis, the average child's exposure to DPM could be reduced by:

- 40,000 µg if DPM emissions from the child's bus were reduced by 1 tonne if the bus is a newer one (1993 to 1998);
- 1,000,000-2,000,000 µg if DPM emissions from the child's bus were reduced by 1 tonne if the bus is an older one (1975 to 1985); and
- 3 µg if DPM emissions from any diesel-fueled vehicle in the community were reduced by 1 tonne (Marshall & Behrentz, 2005).

The researchers concluded that the most cost-effective way to reduce children's exposures to DPM is to reduce emissions from school buses (Marshall & Behrentz, 2005).

V Exposures with Different Fuels & Technologies – Clean Air Task Force (CATF)

The Clean Air Task Force (CATF) released a study that examined exposures on-board school buses using a variety of fuels and emission control technologies in 2005.

The fuel/technology combinations examined include:

- Conventional diesel buses (1998 to 2001 model year) using conventional diesel fuel;
- Diesel bus with ultra-low sulphur diesel (**ULSD**) fuel;
- Diesel bus with a DOC (an emission control device for the exhaust system) using conventional diesel fuel;
- Diesel bus with a closed crankcase filtration device (an emission control device for the engine compartment called a "Spiracle") using ULSD fuel;
- Diesel bus with a DPF (an emission control device for the exhaust system) using ULSD fuel;
- Diesel bus with a DPF, a closed crankcase filtration device, and ULSD fuel;
- Diesel bus with a DOC, a closed crankcase filtration device, and ULSD fuel;
- Diesel bus with a DPF, a filter designed to reduce oil spillage from the engine crankcase (product called "Enviroguard") and ULSD fuel; and
- CNG school bus.

In-cabin monitoring was conducted for five diesel-related air pollutants: $PM_{2.5}$, ultra-fine particles ($PM_{0.1}$), black carbon, and particle-bound polycyclic aromatic hydrocarbons (PPAHs). Monitoring was conducted under three scenarios: one bus idling in isolation; the middle bus of a 3-bus queue of conventional diesel buses; and a typical bus route of approximately 1-hour in duration. Monitoring was also done inside a car that drove directly in front of the school bus while traveling a typical bus route (CATF, 2005).

CATF Findings - Conventional Diesel Buses

The researchers found that ultra-fine particles, black carbon and PPAHs measured in the cabins of the buses could be traced directly to the tailpipes of the buses, while the $PM_{2.5}$ could be traced to emissions from the engine crankcase that is vented under the hood of the bus through a "road draft tube". Crankcase emissions are comprised of hydrocarbons, NOx and PM and can contain a significant fraction of organic particulate matter (CATF, 2005).

The monitoring conducted on-board conventional diesel buses (i.e. engine in front and no emissions control devices) demonstrated that:

- Air levels were highly variable and dependent upon wind direction relative to the two principal sources of emissions — the engine compartment and the tailpipe;
- Air levels inside the bus were consistently higher than in the lead car that drove in front of the bus, indicating that concentrations on-board school buses reflect a certain amount of "self-pollution";
- With windows closed, concentrations on-board school buses rose only at stops, while with windows opened, air levels would rapidly rise and fall as outside sources of air pollution (i.e. trucks and other buses) came and went;

- Spikes in ultra-fine particles were observed at each stop, while increases in PM2.5 were associated with engine operation and stops; and
- When buses were lined up end-to-end with the front doors open, air levels of $PM_{2.5}$ increased very quickly (CATF, 2005).

The research team found that that air levels of $PM_{2.5}$ built up over the course of the trip to levels that were several times greater than outdoor ambient conditions and above the daily U.S. national ambient air quality standard for $PM_{2.5}$ of 15 $\mu g/m^3$. For example, in the nine conventional diesel buses operated in three different cities (Ann Arbor, Chicago and Atlanta):

- The mean $PM_{2.5}$ concentrations ranged from 47 to 92 $\mu g/m^3$;
- The maximum $PM_{2.5}$ concentrations ranged from 90 to 336 $\mu g/m^3$; while
- The ambient $PM_{2.5}$ concentrations ranged from 12 to 65 $\mu g/m^3$ (CATF, 2005).

CATF Findings - Different Fuel/Technology Combinations

Figures 5, 6, 7, 8 and 9, drawn from the Clean Air Task Force report, illustrate the on-board concentrations of $PM_{2.5}$ and ultra-fine particles for five buses over time as they travel the same school bus route in Ann Arbor. In all five cases, the ambient air levels have been subtracted from the on-board concentrations to correct for background concentrations which varied from day to day. Black carbon and PPAH results, which are not shown on these figures, were closely tied to the concentrations of ultra-fine particles (CATF, 2005b).

Figure 5 depicts on-board concentrations for a conventional diesel bus and indicates significantly elevated levels of both $PM_{2.5}$ and ultra-fine particles.

Figure 5: On-Board Concentrations, Fine Particulate Matter ($PM_{2.5}$) & Ultra-Fine Particles ($PM_{0.1}$) Over Time, Conventional Diesel

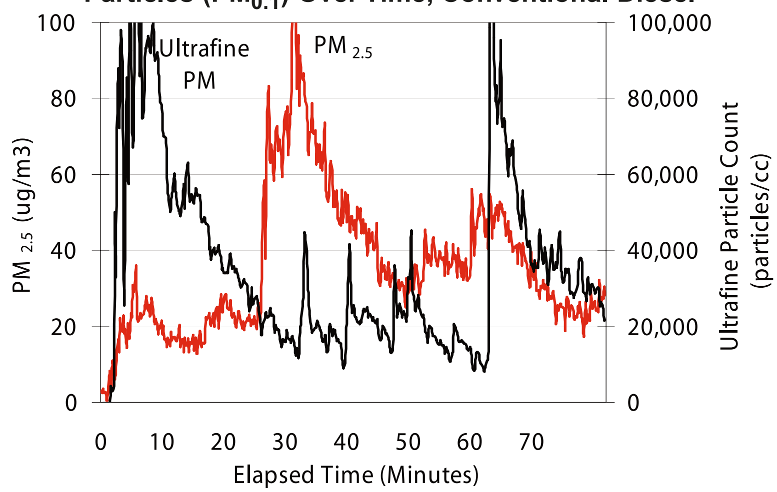


Figure 6 depicts on-board concentrations for a diesel bus retrofit with a DOC. Significant reductions in on-board concentrations of ultra-fine particles, black carbon, PAHs or $PM_{2.5}$ were not observed with this emission control device (CATF, 2005).

Figure 6: On-Board Concentrations, Fine Particulate Matter ($PM_{2.5}$) & Ultra-Fine Particles ($PM_{0.1}$) Over Time, Diesel with Diesel Oxidation Catalyst

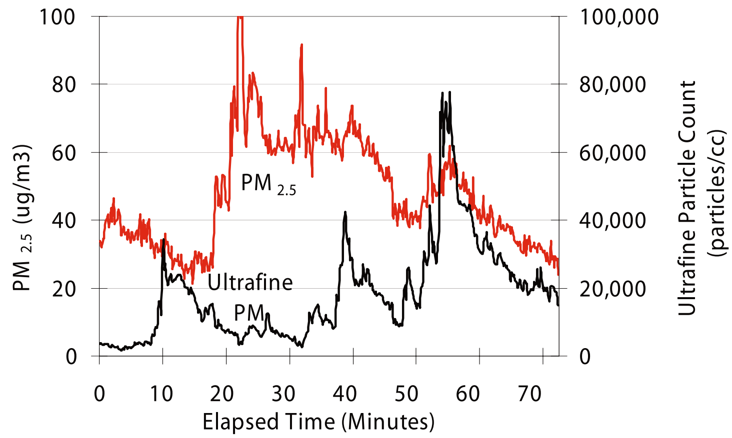


Figure 7 depicts on-board concentrations for a diesel bus retrofit with a DPF run on ULSD fuel. On-board concentrations of ultra-fine particles, black carbon and PPAHs were almost reduced to ambient air levels. However, this combination did not significantly reduce on-board concentrations of $PM_{2.5}$ (CATF, 2005b).

Figure 7: On-Board Concentrations, Fine Particulate Matter ($PM_{2.5}$) & Ultra-Fine Particles ($PM_{0.1}$) Over Time, Diesel with Diesel Particulate Filter & Ultra-Low Sulphur Diesel

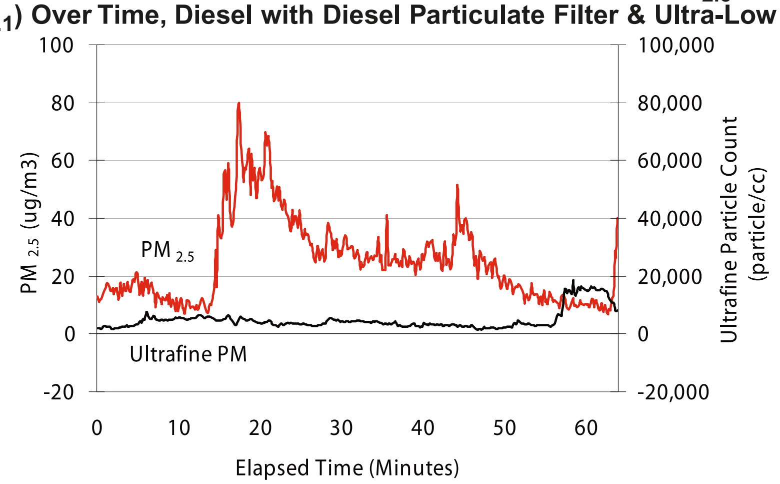


Figure 8 depicts on-board concentrations for a diesel bus run on ULSD fuel that has been retrofit with a closed crankcase filtration device. On-board concentrations of $PM_{2.5}$ were reduced almost to ambient air levels, while concentrations of other air pollutants remained relitivelyunaffected (CATF, 2005).

Figure 8: On-Board Concentrations, Fine Particulate Matter ($PM_{2.5}$) & Ultra-Fine Particles ($PM_{0.1}$) Over Time, Diesel with Closed Crankcase Filtration Device

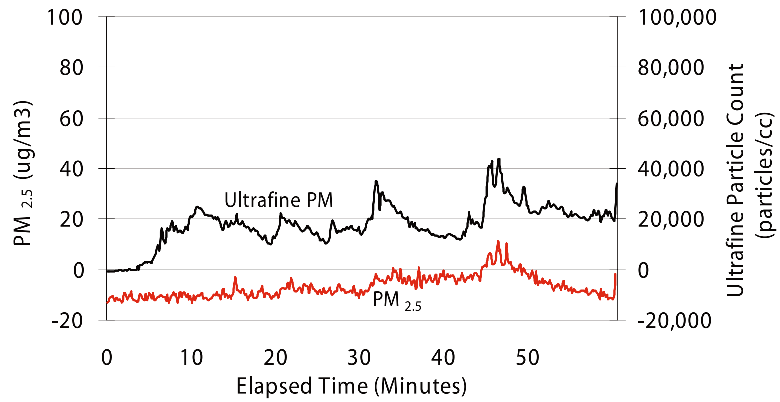
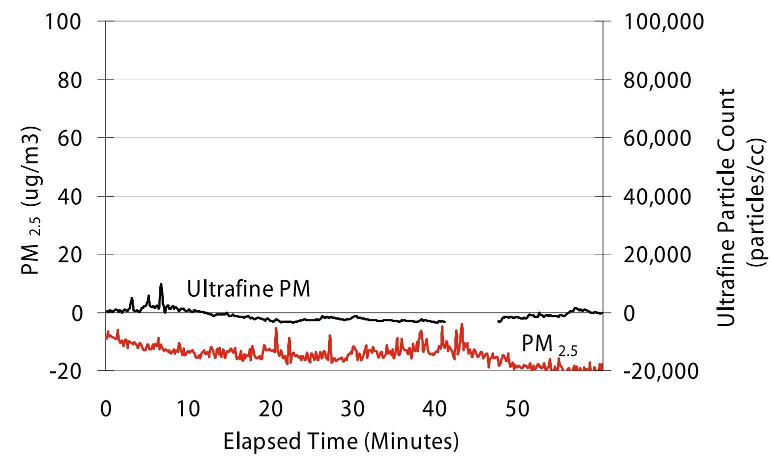


Figure 9 depicts on-board concentrations for a diesel bus retrofit with both a DPF and a closed crankcase filtration device and run on ULSD fuel. With this combination, on-board concentrations of all four diesel-related air pollutants were reduced almost to ambient air levels (CATF, 2005).

Figure 9: On-Board Concentrations, Fine Particulate Matter ($PM_{2.5}$) & Ultra-Fine Particles ($PM_{0.1}$) Over Time, Diesel with Diesel Particulate Filter, Closed Crankcase Filtration Device & Ultra-Low Sulphur Diesel



When monitoring was conducted on a compressed natural gas (CNG) school bus which had the engine in the back, on-board concentrations of $PM_{2.5}$ and ultra-fine particles remained near ambient air levels. However, the researchers found that on-board concentrations for all four air pollutants were lowest with the low-emitting diesel school bus (i.e. DPF, closed crankcase filtration device, and ULSD), with CNG school buses providing the second best exposure conditions (CATF, 2005).

CATF Findings re: Idling Patterns & Queuing

When the CATF research team examined the impacts of idling on cabin air quality, they found that little $PM_{2.5}$ entered the bus when doors and windows were closed tight. Once doors were opened however, pollutant levels rose rapidly and steadily on conventional diesel buses, and the magnitude of air levels was dependent upon wind direction.

When monitoring was done for idling buses retrofitted with a DPF using ULSD fuel, on-board concentrations of ultra-fine particles remained almost at ambient air levels while air levels of $PM_{2.5}$ rose substantially with open doors. When closed crankcase filtration devices were added to this combination, air levels of both ultra-fine particles and $PM_{2.5}$ remained almost at ambient air levels even under idling conditions with doors open (CATF, 2005).

When buses were idling in a 3-bus queue, air levels of all particulate matter remained low as long as doors and windows were closed. However, as soon as the doors were opened, air levels of all PM rose dramatically in the cabins of the buses. The researchers concluded that idling practices can be extremely important to exposures on-board conventional diesel school buses.

VI Summary re: Exposure Studies & Health Risks

Summary of Exposure Studies

Exposure studies conducted by several organizations in Canada and the United States have found that concentrations of diesel-related air pollutants can be significantly higher on-board school buses than concentrations in ambient air, on other vehicles, and along school walking routes. They found that air pollutant concentrations on-board school buses were highly variable. In one study of nine school buses tested in 3 different cities, on-board concentrations of $PM_{2.5}$ ranged from 12 to 336 $\mu g/m^3$.

The exposure studies found that conventional diesel school buses pollute themselves, with emissions from tailpipes and engine compartments contributing significantly to on-board concentrations of air pollutants. They found that on-board concentrations of air pollutants were also influenced by ambient air levels in the communities studied, traffic density on the roads traveled, wind direction and the configuration of the windows (i.e. open or closed), and idling and queuing patterns.

While children may spend only a few hours per day on school buses[1], the high levels of exposure encountered on-board school buses can add considerably to their daily and annual exposures to air pollutants such as DPM and $PM_{2.5}$.

The exposure studies also found that on-board concentrations of air pollutants could be reduced almost to ambient air levels, even under idling conditions, by outfitting school buses with DPFs and closed crankcase filtration devices and running them on ULSD fuel. They also suggest that exposures can be reduced by keeping doors and windows closed when buses are idling, avoiding idling when buses are waiting in front of schools, and avoiding caravanning on roadways.

Health Risks associated with School Buses

No attempt has been made to estimate the risks to Ontario children associated with riding on school buses because on-board exposures vary so greatly. However, given the acute health impacts associated with $PM_{2.5}$, diesel exhaust, and traffic-related air pollutants, it is fair to suggest that a significant number of acute health outcomes — such as respiratory infections, allergy symptoms, reductions in lung function, and increases in the number and severity of asthma symptoms — could be associated with the elevated concentrations of air pollutants that can be experienced on school buses.

[1] According to People for Public Education: 40% of children in elementary schools in Ontario are eligible for busing; 91% of elementary schools in Ontario report that some children are bused; the percentage of schools reporting that some students are bused ranges from 77% in the Greater Toronto Area to 99% for eastern Ontario; and the percentage of schools reporting that their longest one-way bus ride was 45 minutes or more ranged from 30% in the GTA to 57% in eastern Ontario (V. McDonald, 2005).

Acute health impacts are of particular concern for those children with pre-existing health conditions such as asthma. With approximately 800,000 children taking school buses and a 12% asthma rate among children in this country, it is possible that 96,000 asthmatic children are transported by school buses in Ontario.

It is more difficult to assess how relatively short, but frequent exposures, to elevated levels of air pollutants on-board school buses may affect the long-term health of the children exposed. However, if school bus exposures only increase the risk of chronic disease such as lung cancer, asthma and heart disease by a small percentage, because of the large number of people involved, that increase could translate into a significant number of chronic health outcomes.

C Emissions Associated with Ontario School Buses

The OPHA contracted the services of Torrie Smith Associates to: analyze the air emissions associated with Ontario's fleet of school buses; examine the technologies, practices and fuels that could be used to reduce emissions from this fleet; and estimate the emission reductions and costs that would be associated with the application of few preferred options to the entire fleet.

I Diesel Engine Emissions & Emission Standards

Emissions from heavy-duty vehicles are not directly regulated. Instead it is the new diesel engines that power these vehicles that are required to meet emissions standards for particulate matter (**PM**), hydrocarbons (**HC**), nitrogen oxides (**NO_X**), and carbon monoxide (**CO**). Of the four regulated air pollutants, it is the requirements for PM, HC and NO_X emissions that are currently setting the agenda for emission reduction technology. The emission limits for CO have not been adjusted since before 1990 and the actual emissions from diesel engines are well below the 15.5 grams per brake horsepower per hour (g/bhph). In addition, the initiatives being taken to reduce PM emissions are expected to reduce CO emissions even further. Consequently, CO emissions have not been included in the analysis that follows.

Sulphur oxide (**SO_X**) emissions are directly related to the sulphur content of diesel fuel. The maximum allowable level of sulphur in on-road diesel fuel will be reduced to "ultra low" levels starting in the fall of 2006 (i.e. from 500 ppm to 15 pm pursuant to the Canadian Sulphur in Diesel Fuel Regulations.) Accordingly, SO_X emissions from diesel truck and bus engines will be virtually eliminated as a concern (Torrie, 2005).

As the numbers in Table 3 illustrate, reductions in allowable emissions from new diesel engines have been frequent and significant since 1990. Compared to 1990, the new 2007 limits are 98% lower for PM, 89% lower for HC, and 97% lower for NO_X.

Table 3: Evolution of Emission Standards for New Heavy Duty Diesel Engines Used for Urban Buses[2]

	(g/bhph)			
Bus model year	**PM**	**CO**	**HC**	**NOX**
1989	0.60	15.5	1.3	6
1991	0.25	15.5	1.3	5
1994[3]	0.10	15.5	1.3	5
1998	0.10	15.5	1.3	4
2004[4]	0.10	15.5	2.4 NMHC + NO_X	
2007[5]	0.01	15.5	0.14	0.2

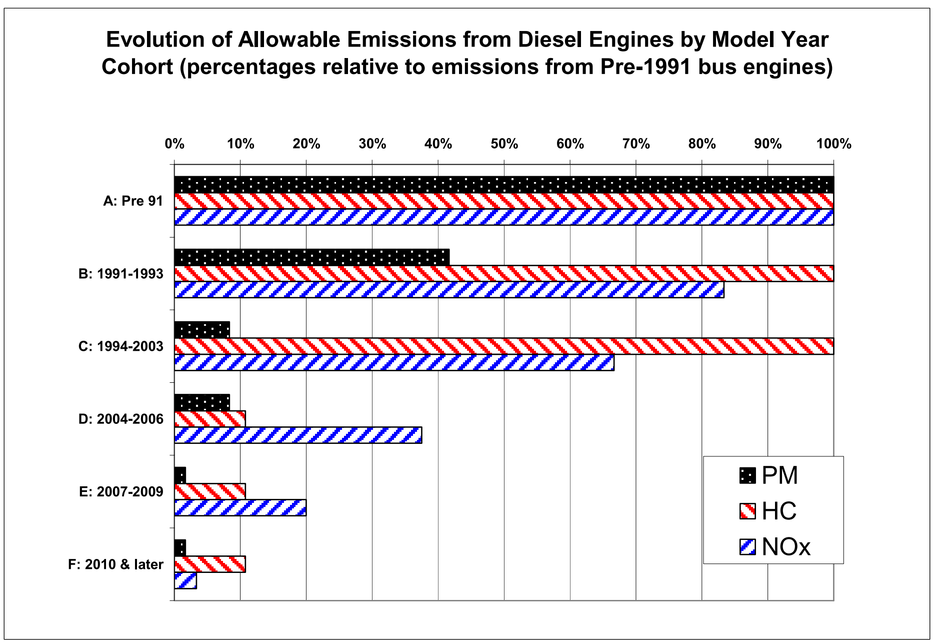
To facilitate analysis of emissions from Ontario school buses of different ages, buses have been grouped into "model year cohorts" with the cohorts defined by years in which significant changes were introduced to the allowable emissions of PM, HC or NO_X in new diesel engines. The cohorts, with the assumed emission levels, are defined in **Table 4**.

[2] The standards in the table are U.S. regulated limits. The 1991 and 1994 standards were complied with on a voluntary basis in Canada. Since then, the U.S. emission limits have been adopted by reference in Canadian regulations.

Table 4: Definition of Model Year Cohorts for School Bus Analysis				
Cohort	Model Years	Emissions (g/bhph)		
		PM	HC	NO_X
A	Pre 1991	0.60	1.3	6
B	1991-1993	0.25	1.3	5
C	1994-2003	0.10	1.3	4
D	2004-2006[6]	0.10	0.14	2.25
E	2007-2009	0.01	0.14	1.2
F	2010 and later	0.01	0.14	0.2

Figure 10 illustrates the relative drops in emissions of PM, HC and NO_X from new diesel engines assumed for each of the model year cohorts. Improvements to engine design and controls have reduced emissions of PM and HC below the current regulatory limits. The 2007 standard for HC and PM can and will be met with the application of emission control devices such as the catalyzed DPF, while the 0.2 g/bhph standard for NO_X that must be met by all new buses starting in 2010 will probably require the application of an emission control device designed to capture NO_X emissions (Torrie, 2005).

Figure 10



[3] Starting in 1993, a separate and lower standard was established for PM emissions from engines destined for "urban buses", and by 1998 the "urban bus" PM standard was lowered to 0.05 g/bhph, half that for other heavy duty vehicle engines. The "urban bus" category is inten ded to cover transit buses and does not include school buses, however. Starting in 2007, the PM standard for ALL heavy duty diesel engines will be set at 0.01 grams per brake horsepower-hour.

[4] The interim standard introduced with the 2004 bus model year required that the sum of non-methane hydrocarbon (NMHC) emissions plus NOx emissions should be no more than 2.4 grams per brake horsepower-hour. An optional standard allows a limit for the sum of non-methane hydrocarbon (NMHC) emissions plus NOx emissions to be 2.5 g/bhph, provided the NMHC emission level does not exceed 0.5 g/bhph.

[5] With regard to the new emissions limits that come into effect in 2007, the PM standard must be fully implemented in all new vehicles starting with the 2007 model year but the NOx and NMHC limits will be phased in. For the 2007-2009 model years, manufacturers are required to produce a sales weighted fleet average that is equivalent to a fleet in which 50% of the vehicles have engines that meet the new standard. It is now expected that most if not all manufacturers will comply by producing a vehicle fleet in which 100% of the vehicles achieve 50% of the required emission reduction., as compared with the 2004 limit.

II Ontario's Changing Fleet of School Buses

Information on the age, number and operation of school buses in Ontario was obtained from the Ontario School Bus Association (OSBA), Statistics Canada, the Ontario Drive Clean database, the Office of Energy Efficiency of Natural Resources Canada and, through Polk Consulting, from the Ontario Ministry of Transportation vehicle registration database (Torrie, 2005).

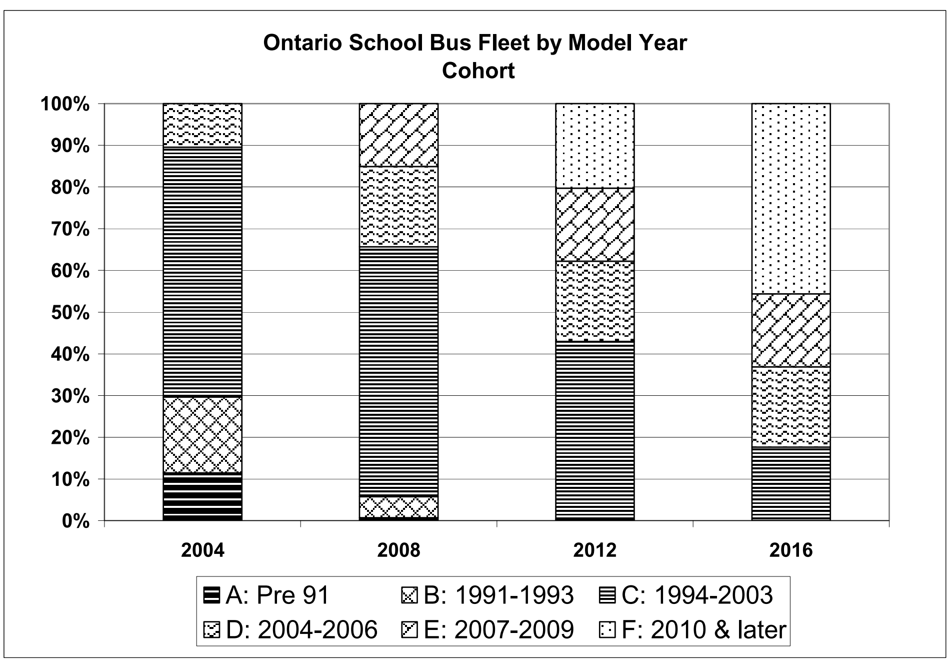
The engine technology in Ontario school buses is predominantly diesel with over 93% of the buses being fueled by diesel (5% on gasoline and 2% on propane). International Diesel makes over two thirds of the diesel engines being used in Ontario school buses, and the other engines are made by four firms – Cummins, GMC, Ford and Caterpillar (Torrie, 2005).

School bus ownership is also concentrated. There are about 200 school bus operators in the OSBA, but the three largest fleets (Laidlaw, Stock and Northstar) account for 53% of the school buses in Ontario. Operators with fewer than 30 buses account for 75% of the OSBA membership but only 10% of the buses (Torrie, 2005).

When developing projections of the school bus fleet, the total number of buses has been held steady at 15,000 for lack of a better assumption. With regard to bus turnover, it has been assumed that buses are retired at the rate of 50% per year once they reach the age of 15, an approximation of current industry practice. **Figure 11** illustrates how the age of Ontario's fleet of school buses is expected to change over time under a "business as usual" scenario (See Torrie 2005 report for more detail).

There are three different sizes of school buses; those that transport 72, 48 and 19 passengers. A detailed breakdown of school buses by size was not available although it is known that the overwhelming majority seat 72 passengers. For the purposes of this analysis, it was assumed that all school buses in Ontario seat 72 passengers[7].

Figure 11



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[6] The emission limits for NO_X and non-methane hydrocarbons (NMHC) are not specified separately in the 2004 standard; the 0.14 and 2.25 g/bhph values used here for NMHC and NO_X, respectively, are based on the pre-2004 limit for NMCH and our interpolation/estimate for the NO_X value (Torrie, 2005).

[7] Emissions of air pollutants and greenhouse gases would likely be less for smaller school buses than larger buses. Costs associated with retrofits would likely be the same regardless of the size of the bus, while costs for fuel and replacement would likely be less for the smaller buses.

III Estimating Emissions from Ontario School Buses

The emission rates expressed in grams per brake horse power hour (g/bhph) are emissions per unit of energy delivered to the engine shaft during a specified test cycle that is carried out on a laboratory bench with the engine removed from any vehicle. The actual tailpipe emissions, expressed in grams per vehicle-kilometre traveled (g/VKT) depend not only on the emissions per engine output, but also on the efficiency with which the engine output is converted to motion over a range of loads, terrains, driving conditions and maintenance, and are affected by the driving cycle (urban vs. highway), driver behaviour, and vehicle maintenance (Torrie, 2005).

Table 5: School Bus Emission Factors Derived from Regulatory Engine Emission Limits and MOBILE Conversion Factors

Cohort	Model Years	Emissions (grams per vehicle-km)		
		PM	HC	NOX
A	Pre 1991	1.12	2.42	11.18
B	1991-1993	0.47	2.42	9.32
C	1994-2003	0.19	2.42	7.46
D	2004-2006[6]	0.19	0.26	4.19
E	2007-2009	0.02	0.26	2.24
F	2010 and later	0.02	0.26	0.37

To convert emission rates for engine output (in g/bhph) to tailpipe emission rates (in g/VKT), conversion factors for school buses have been used from the MOBILE6 model developed by the US EPA. The resulting emission rates for the three air pollutants are provided in **Table 5**. These emission rates were compared to the results of three studies in which tailpipe emissions from school buses were measured under laboratory or on-road conditions and found to be valid estimates of actual tailpipe emissions from school buses (see Torrie 2005 report for more detail).

To estimate the air emissions associated with school buses under a “business as usual” scenario, it was assumed that the school buses travel on average 22,000 kilometres (km) per year, based on estimates provided by Statistics Canada and the OSBA. For purposes of projecting future emissions, it was assumed that: school buses of all ages continue to be operated for the average 22,000 km per year; the total number of school buses remains constant at 15,000; and buses are retired at the rate of 50% per year once they reach the age of 15 years. With respect to greenhouse gas emissions, it has been assumed that diesel school buses have a fuel economy of 32.5 Litres/100 km and that this remains unchanged over time (Torrie, 2005).

IV Emission Results & Observations

Air emissions from new diesel engines are much lower today than they were 10 to years ago, and will decline significantly again between now and 2016 as new diesel engine emission standards are implemented. Diesel vehicles are being made “cleaner” with improvements in the design and operation of conventional diesel engines, the use of ULSD fuel, and the application of emissions control devices such as DPFs and NO_X adsorbers. While these technology changes are being made to meet engine emission standards for PM, HC and NO_X, they will also significantly reduce emissions of toxic air contaminants such as PAHs. Unfortunately, they will not reduce greenhouse gas emissions.

The air pollutant and greenhouse gas emissions expected from Ontario’s diesel school bus fleet over the next decade under a "business as usual" scenario are summarized in **Tables 6 & 7**. **Table 6**, which summarizes the annual emissions expected for the overall fleet and for each model year cohort for 2004, 2008, 2012 and 2016, indicates that in 2004, Ontario's 15,000 school buses emitted approximately:

- 114 tonnes of PM;
- 718 tonnes of HC;
- 2,601 tonnes of NO_X; and
- 285 kilotonnes of CO_2.

Table 7 summarizes the cumulative emissions released from the fleet between 2006 and 2016 under a "business as usual" scenario. It indicates that, over that 11 year period, Ontario's 15,000 school buses are expected to emit approximately:

- 529 tonnes of PM;
- 4,736 tonnes of HC;
- 17,790 tonnes of NOx; and
- 3,105 kilotonnes of CO_2.

1994-2003 Model Year School Buses: Buses in Cohort C, the 1994-2003 model year cohort, dominate annual emissions from Ontario's school buses for most years between 2004 and 2016. In 2016, when buses in Cohort C represent less than 20% of the bus population, they will still be the source of 41% of PM emissions, 66% of HC emissions and 49% of NOX emissions from Ontario's fleet of school buses (**Table 6**).

On a cumulative basis, this cohort is expected to be responsible for 57% of all PM emissions, 83% of all HC emissions, and 68% of all NOX emissions from Ontario's school buses between 2006 and 2016 (**Table 7**). These numbers suggest that the most effective way to reduce emissions from Ontario's school buses in the short and medium term is to retrofit or replace the buses in Cohort C.

Pre-1994 Model Year School Buses: The buses in Cohorts A and B, the pre-1994 model year cohorts, will be responsible for a disproportionate share of annual PM emissions until about 2008 when they are expected to be almost eliminated from the fleet. However, because the PM emission rates for these model years are so much higher, they will continue to have a substantial impact on PM emissions from the fleet for several years. In 2008, when it is expected that they will make up only 6% of the buses in Ontario's fleet, they are still expected to emit about 17% of the annual PM emissions from the fleet. These numbers suggest that early retirement Cohorts A and B could be an important component of an overall strategy to reduce emissions from Ontario's school buses.

All Model Year School Buses: Finally, it is expected that greenhouse gas emissions (essentially CO2 emissions) will continue mostly unabated under the status quo projection, reflecting the relatively constant fuel efficiency and continued dependence on conventional diesel that is expected under this scenario.

Table 6: Status Quo Projection of VKT and Emissions from Model Year Cohorts							
	A Pre 91	B 1991-1993	C 1994-2003	D 2004-2006	E 2007-2009	F Post 2009	Total
2004							
VKT (thousands)	37,840	59,931	197,809	34,419	-	-	330,000
PM (kg)	42,323	27,930	36,874	6,416	-	-	113,543
HC (kg)	91,700	137,973	479,360	8,983	-	-	718,015
NO_X (kg)	423,231	558,594	1,474,954	144,364	-	-	2,601,143
CO_2 (tonnes)	35,148	55,667	165,361	28,773	-	-	284,950
2008							
VKT (thousands)	2,336	16,560	197,809	63,387	49,908	-	330,000
PM (kg)	2,613	7,717	36,874	11,816	930	-	59,950
HC (kg)	5,661	38,124	479,360	16,542	13,025	-	552,712
NO_X (kg)	26,126	154,348	1,474,954	265,861	111,642	-	2,032,930
CO_2 (tonnes)	2,170	15,382	165,361	52,989	41,722	-	277,624
2012							
VKT (thousands)	121	1,035	140,771	63,387	57,785	66,901	330,000
PM (kg)	136	482	26,241	11,816	1,077	1,247	4,100
HC (kg)	294	2,383	341,137	16,542	15,080	17,460	392,896
NO_X (kg)	1,356	9,647	1,049,652	265,861	129,261	24,942	1,480,718
CO_2 (tonnes)	113	961	117,680	52,989	48,306	62,141	282,190
2016							
VKT (thousands)	-	54	58,132	63,387	57,785	150,642	330,000
PM (kg)	-	25	10,837	11,816	1,077	2,808	26,563
HC (kg)	-	125	140,875	16,542	15,080	39,314	211,937
NO_X (kg)	-	506	433,462	265,861	129,261	56,163	885,253
CO_2 (tonnes)	-	50	48,597	52,989	48,306	139,923	89,866
Percentage by Model Year Cohort	-	45	43,197	47,102	42,939	111,939	245,221
Percentage by Model year Cohort							
2004							
VKT (thousands)	11%	18%	60%	10%	0%	0%	100%
PM (kg)	37%	25%	32%	6%	0%	0%	100%
HC (kg)	13%	19%	67%	1%	0%	0%	100%
NO_X (kg)	16%	21%	57%	6%	0%	0%	100%
CO_2 (tonnes)	12%	20%	58%	10%	0%	0%	100%
2008							
VKT (thousands)	**1%**	**5%**	60%	19%	15%	0%	100%
PM (kg)	**4%**	**13%**	62%	20%	2%	0%	100%
HC (kg)	1%	7%	87%	3%	2%	0%	100%
NO_X (kg)	1%	8%	73%	13%	5%	0%	100%
CO_2 (tonnes)	1%	6%	60%	19%	15%	0%	100%
2012							
VKT (thousands)	0%	0%	43%	19%	18%	20%	100%
PM (kg)	0%	1%	64%	29%	3%	3%	100%
HC (kg)	0%	1%	87%	4%	4%	44%	100%
NO_X (kg)	0%	1%	71%	18%	18%	2%	100%
CO_2 (tonnes)	0%	0%	42%	19%	19%	22%	100%
2016							
VKT (thousands)	0%	0%	**18%**	19%	18%	46%	100%
PM (kg)	0%	0%	**41%**	44%	4%	11%	100%
HC (kg)	0%	0%	**66%**	8%	7%	19%	100%
NO_X (kg)	0%	0%	**49%**	30%	15%	6%	100%
CO_2 (tonnes)	0%	0%	**17%**	18%	17%	48%	100%

Table 7: Status Quo Projection of VKT & Emissions, 2006-2016 Cumulative Totals							
	A Pre 91	B 1991-1993	C 1994-2003	D 2004-2006	E 2007-2009	F Post 2009	Total
VKT (thousands)	18,664	115,500	1,624,254	697,256	553,217	621,141	3,630,033
PM (kg)	20,875	53,827	302,779	129,976	10,313	11,579	529,349
HC (kg)	45,229	265,903	3,936,133	181,967	144,376	162,103	4,735,712
NO_X (kg)	208,750	1,076,530	12,111,179	2,924,469	1,237,512	231,576	17,790,016
CO_2 (tonnes)	17,336	107,283	1,357,820	582,881	462,470	576,947	3,104,737
Percentage by Model Year Cohort							
VKT	1%	**3%**	**45%**	19%	15%	17%	100%
PM	4%	**10%**	**57%**	25%	2%	2%	100%
HC	1%	6%	**83%**	4%	3%	3%	100%
NO_X	1%	6%	**68%**	16%	7%	1%	100%
CO_2	1%	3%	**44%**	19%	15%	19%	100%

D Emission Reduction Options

I Introduction

Reducing emissions from the existing fleet of Ontario school buses can be achieved by:

- Implementing maintenance and operation practices that reduce emissions and/or fuel consumption;
- Retrofitting existing buses with emission control devices;
- Fuel Switching; and/or
- Replacing existing buses with buses built to lower emission standards or with alternative technologies.

Ultra-Low Sulphur Diesel (ULSD)

Starting in the fall of 2006, the maximum allowable sulphur content in on-road diesel fuel in Canada will be reduced from its current limit of 500 ppm to 15 ppm. This is necessary to both reduce sulphur oxide (SO_X) emissions from diesel vehicles and to enable the use of the DPFs that will become standard equipment starting with the 2007 model year diesel engines. As noted above, the move to ULSD fuel essentially eliminates concern about SO_X pollution from school buses and other diesel vehicles. In so far as sulphates make up some portion of the PM in diesel exhaust, ULSD will also reduce PM being emitted.

The primary advantage of ULSD is that it enables the application of catalyst-based technologies for reducing PM, HC and NO_X. DOCs will work with conventional diesel fuel but they are more effective with ULSD. For catalyzed DPFs, ULSD is required to prevent clogging or "poisoning" of the catalytic filter . In fact, the major reason for making ULSD fuel mandatory before the 2007 model year diesel engines are introduced is because DPFs will be standard equipment on those new engines.

Some of the NO_X emission control devices under development, such as NO_X adsorbers, are particularly prone to sulphur "poisoning" and will eventually become "clogged" with sulphur even with concentrations as low as 15 ppm. Solutions to this problem are currently the focus of an intensive research and development effort, but it is possible that sulphur concentrations in diesel will have to be lowered even further in order for engine manufacturers to meet the 2010 emission standards (Torrie, 2005).

II Operating and Maintenance Practices

Proper Maintenance

Emissions of air pollutants and greenhouse gases will be lower in buses that are properly maintained and serviced for clean and efficient operation. Prompt attention to leaky gaskets and seals will reduce evaporative emissions and regular maintenance of the engine and auxiliary systems will reduce tailpipe emissions associated with incomplete combustion or sub-optimal combustion conditions (Torrie, 2005).

Idling Practices & Proper Vehicle Operation

The manner in which the bus is operated will affect both the fuel consumption and the emissions of greenhouse gases and air pollutants. Engine idling and rapid acceleration increases air emissions as well as vehicle maintenance costs. Future diesel engine and vehicle designs may reduce the extent to which emissions and fuel consumption "spike" during periods of rapid acceleration, but for existing buses the bus driver is the key player in reducing fuel consumption and emissions from unnecessary rapid acceleration (Torrie, 2005).

Emissions from bus idling will not generally represent a large percentage of bus emissions. On average, Ontario school buses consume about 40 litres of fuel per day of operation, and bus idling consumes fuel at a rate of about 2 litres per hour. Emissions that occur during idling are nevertheless of particular concern because the emissions often occur in situations where there is direct exposure to passengers, drivers and other members of the school community.

The bus operators interviewed for this report all had anti-idling policies, but consideration should be given to including an environmental/public health component to the school bus driver training curriculum so that drivers are educated on the effects of their driving techniques on tailpipe emissions and on-board exposures (Torrie, 2005).

The US EPA web site (http://www.epa.gov/otaq/schoolbus/antiidling.htm) contains examples of anti-idling policies developed by school boards in Canada and the USA, as well as other useful information, model practices and links. There is also information on the use of driver training to reduce emissions on NRCan's Fleet Smart web site.[8]

There are also technological options that can facilitate the reduction of idling time in school buses. The operation of lights and safety equipment and the need to heat the bus are the most common reasons for bus idling. With regard to the operation of the safety lights and equipment, they should be wired so that they will operate even with the ignition off and the door open. This wiring configuration should be specified in all new school buses, and existing buses can be rewired if necessary to allow the safety equipment to operate when the ignition is off. Experience in New Brunswick has confirmed that safety lights can be operated this way without draining the battery (http://www.nb.lung.ca/schools/3000e/ehi_sbi_e.htm) (Torrie, 2005).

Simple plug-in engine block heaters are a cost effective way to reduce bus "warm up" time, and cost about $100. Diesel powered engine block heaters are also available, but are more expensive (in the range of $2,000 per bus); these heaters use only a fraction of the diesel fuel required to idle the engine (Torrie, 2005).

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[8] http://oee.nrcan.gc.ca/transportation/fleetsmart.cfm?text=N&printview=N.

Finally, at a cost in the range of $3,000-$3,500 per bus (installed), there are auxiliary heaters that use diesel fuel to heat both the engine block and the passenger compartment; they use only 10-15% of the fuel required to keep the engine idling and provide both maintenance and safety advantages over the practice of engine idling. However, while installing such a device yields financial and economic benefits beyond the fuel savings, the fuel savings themselves would not justify its installation, even on a bus that is being idled excessively (more than an hour a day)(Torrie, 2005).

Even when bus idling is being minimized, fuel consumption and emissions will be higher for some buses than for others depending on the nature of the route, driving practices, and bus maintenance. Fuel consumption and emissions can be higher by 25% or more for driving cycles that include frequent accelerations, hilly terrain, or severe traffic congestion (Brown 1997). Fleet operators would be well advised to track the fuel consumption and odometer readings of their buses and investigate situations where a particular bus, route or driver is exhibiting above average consumption compared to their fleet or to the provincial average, which is about 32.5 L/100 km (Torrie, 2005).

For the purposes of this report, it has been estimated that proper maintenance, idling and driving practices can reduce emissions of air pollutants and greenhouse gases from all model year school buses by about 10% (Torrie, 2005).

III Retrofitting with Emission Control Devices

Engine Crankcase Filter

The diesel engine crankcase is the second source of emissions from a school bus; the first being tailpipe emissions. According to one manufacturer, engine crankcase emissions can represent as much as 25% of total emissions from a bus. Engine crankcase emissions, composed mainly of oil droplets, carbon and traces of engine wear include particles that range from 0.03 to 6 microns in size ($PM_{0.03}$ to PM_6). According to the manufacturer, a closed crankcase filtration system eliminates 100% of engine crankcase emissions by capturing 90% of all sizes of PM in a filter before recycling the gases back into the engine intake. This device has been field tested for over two years and "verified" as an emission control device to be used in series with the DOC by both the US EPA and the CARB. It produces no discernible fuel penalty. The manufacturer recommends that the filter cartridge be replaced every 25,000 miles or every 500 hours (Donaldson, 2005).

Several thousand units have been sold including 1,100 that were recently sold for use by the New York City School Board. The manufacturer reports that interior air pollution in school buses can be cut by 54% or more with the addition of a crankcase filtration system and a DOC (Donaldson, 2005). The Clean Air Task Force, a non-profit organization in the United States, found that concentrations of $PM_{2.5}$ on-board school buses were reduced almost to ambient air levels when a closed crankcase filtration system was installed (CATF, 2005).

This device was not included in our emission reduction analysis because it addresses engine compartment emissions (rather than tailpipe emissions) which have not historically been measured and regulated. It is added here because of its impact on concentrations of diesel-related air pollutants on-board school buses.

Diesel Oxidation Catalyst (DOCs)

The diesel oxidation catalyst (DOC) is perhaps the simplest emission control device consisting of a catalyst-coated honeycomb through which the exhaust gas passes. The DOC can be installed upstream of the muffler or can be integrated with the vehicle muffler. DOCs can be installed on school buses of any age and can be operated with conventional diesel fuel although they are more effective when used in conjunction with ULSD fuel.

DOCs are very effective at removing HC from the exhaust stream. As these HC are often adsorbed on to PM in the exhaust stream, DOCs also reduce the mass of PM emissions in the exhaust stream. For example:

- When two 1992 model year school buses were tested in a laboratory using conventional diesel fuel (with 500+ ppm sulphur), the DOC reduced tailpipe emissions of PM, HC and CO by 30%, 88% and 93% respectively (Brown & Rideout, 1997); and
- When a 2000 model year school bus was tested on the road with ULSD fuel, the DOC reduced PM, HC and CO by 13-14%, 95%, and 80-90% respectively (Rideout, 2002).

For the purposes of modeling the effect of DOCs on Ontario school bus emissions, it has been assumed that DOCs would reduce PM and HC emissions by 25% and 85% respectively for all buses in model years up to 2004 (Torrie, 2005).

The DOC is a proven, mass-produced technology that has been installed on tens of thousands of urban transit buses in Europe, Asia and North America. DOCs are essentially a passive, maintenance-free technology, and the large body of experience with their operation provides a high degree of confidence in their reliability and performance. They can be retrofit on heavy-duty diesel vehicles of any vintage. As a stand alone device, installed upstream of the vehicle muffler, costs are consistently reported in the range of $1,000-3,000 USD per vehicle for single installations and $1,000-2,000 USD when purchased in quantity. The cost of an integrated muffler/DOC will be up to twice as much as a stand alone DOC (Torrie, 2005).

Exposure testing conducted by the Clean Air Task Force, found that the DOC did not significantly reduce on-board concentrations of $PM_{2.5}$ or DPM (CATF, 2005).

Catalyzed Diesel Particulate Filter (DPF)

The catalyzed DPF is a 2-stage device that achieves deep reductions in total HC, CO and PM. The DPF requires ULSD fuel to be effective. The catalyzed DPF represents a significant breakthrough in emission control technologies for PM because it can be operated in a passive mode with low and infrequent maintenance requirements (Torrie, 2005).

DPFs can be stand-alone devices or they can be integrated into the vehicle muffler. The DPF is most effective when mounted close to the engine where the temperature of the exhaust is high. The DPF also works best when installed on buses with electronic engine control modules (ECM) that can be adjusted to achieve emission level targets for PM, HC and NO_X. The DPF is well suited to retrofit applications, but is not recommended for buses that predate the 1994 model year or for those buses that do not have the electronically controlled fuel injection systems that were introduced in the mid-1990's (Torrie, 2005).

While the DPF does not have a direct effect on NO_X emissions, it can be used to reduce NO_X emissions. When a vehicle is calibrated for low NO_X emissions, PM emissions tend to increase. However, because the DPF is so effective at removing PM emissions, a DPF-equipped vehicle can be tuned for low NO_X emissions, and the vehicle will still maintain PM emissions well below the regulated maximums. The use of a DPF is therefore integral to the strategy being employed by engine-manufacturers to meet the interim 2007 standards for NO_X, as well as for meeting the 2007 standards for PM and HC (Torrie, 2005).

Laboratory and on-road testing of school buses outfitted with DPFs confirm that this technology is highly effective at removing PM, ultra-fine particles, HC, unregulated air toxics, as well as facilitating a reduction in NO_X emissions. For example:

- When laboratory testing was conducted on a 2001 model year school bus retrofit with a catalyzed DPF that was tuned for low NO_X emissions: emissions of HC and CO were reduced to extremely low levels; total PM was reduced by 95%; and NOx emissions were reduced by 29%. The DPF also reduced tailpipe emissions of aldehydes, ketones, PAHs and other hydrocarbons to trace levels. On the down side, fuel economy was reduced by 5% as a result of the low NO_X setting (Ullman, 2003); and
- When on-road tailpipe testing was conducted on a late model year school bus retrofit with a catalyzed DPF, emissions of PM, total HC, and CO were reduced by 83%, 78% and 97% respectively. While there is no indication that this bus was tuned for low NOx emissions, NOx emissions were reduced by 9% and there was no apparent change in fuel economy (Rideout, 2004).

These research results are consistent with industry claims and with research that has been conducted by the New York City Transit Authority on ULSD and DPF technology on transit buses.

For purposes of modeling the impact of DPF technology on Ontario school buses, it has been assumed that DPF can reduce emissions of PM and HC by 90% from 1994-2003 model year school buses. If installed with a low NO_X engine control calibration, it has been assumed that NO_X emissions from Cohort C can be reduced by 25%, but with a 5% increase in CO_2 emissions resulting from the associated fuel economy penalty (Torrie, 2005).

For the 2004-2006 model year school buses, it has been assumed that DPF retrofits could reduce PM emissions by 90% relative to our baseline. No reduction in total HC or NO_X has been assumed for this cohort as total HC and NO_X emissions from these buses are already significantly lower than those for the 1994-2003 model year school buses (Torrie 2005).

Reports indicate that it costs about $3,000-4,000 USD for an in-line DPF and $3,750-5,000 USD for a muffler replacement equipped with a DPF, with the lower costs reflecting bulk purchase rates. When the low NO_X engine control configuration is included, the retrofit cost climbs to $7,500 USD. These prices are in line with industry claims and other reported DPF prices. For policy planning purposes, we recommend a figure of $10,000 CDN per retrofit be assumed for installing a catalyzed DPF on school buses in Cohorts C or D (1994-2003 and 2004-2005 model years) with a low NO_X engine calibration (Torrie 2005).

While improvements are ongoing, the DPF is a mature technology; there are several competitive products on the market, and on a worldwide basis there are now over 50,000 vehicles retrofit with DPF technology, some with over 500,000 vehicle-kilometres.

No significant maintenance or infrastructure issues have been reported for the application of this technology to transit buses in 1994 model year or later. New York City Transit removes and cleans the filters on an annual basis (2-4 hours per bus) but this level of maintenance would not be necessary for the much lighter duty associated with Ontario school buses (Torrie, 2005).

In the United States, about 10,000 school buses have been retrofit with DPFs. While technical problems have been reported with some DPFs because of the low temperatures of exhaust systems given the driving cycles of school buses, experience has been very good with the 2-stage DPFs (Balon, 2005).

The Clean Air Task Force found that, when a school bus was retrofit with a DPF and run on ULSD fuel, on-board concentrations of ultra-fine particles, black carbon and PAHs were reduced almost to ambient air levels (CATF, 2005).

Other Technologies

Several other technologies were examined by Torrie Smith Associates for their suitability to Ontario's existing fleet of school buses including exhaust gas recirculation (EGR), selective catalytic reduction (SCR), lean nitrogen catalysts, and NO_X reduction adsorbers. However, these options were eliminated from further consideration as retrofit technologies at this time because of issues related to costs or market readiness (see Torrie 2005 report for more detail).

IV Fuel Switching

Biodiesel Fuel

Biodiesel is a fuel that is very similar in its combustion profile to petroleum-based diesel but it is derived from vegetable oils or tallow (animal fats from rendering plants). It can be blended with petroleum diesel fuel (for example B20, refers to diesel fuel that is 20% biodiesel and 80% petroleum diesel) or it can be burned neat as 100% biodiesel (B100).

There are unresolved issues related to the viscosity of B100 in cold temperatures, and the effect it has as a solvent on engine components especially in pre-1994 model year buses. Even B20 is not yet widely accepted as a reliable substitute for regular diesel in cold weather conditions, and some engine manufacturers will not warranty their engines' performance if B20 is used. Reliable performance is of paramount importance to school bus operators and their clients, especially on cold winter days, so uptake of biodiesel in concentrations above 10% will require demonstrated resolution of cold weather issues (Torrie, 2005).

Biodiesel is a relatively clean-burning fuel. B100 emits about 50% less PM than conventional diesel, and at least 50% less CO and HC. Emissions of toxic air contaminants such as formaldehyde and ketones are 60-90% less with biodiesel than with petroleum-based diesel fuel. On the down side, biodiesel can increase NO_X emissions by up to 10%; more so for plant-derived biodiesel than for tallow-derived biodiesel (Torrie, 2005). The impact of biodiesel on concentrations of diesel-related air pollutants on-board school buses is currently unknown.

Because the tailpipe emissions of CO_2 from biodiesel combustion are biogenic and offset by the atmospheric carbon that was fixed in the growing of the plant or animal from which the fuel is derived, tailpipe CO_2 emissions from biodiesel are not included in quantification of greenhouse gases from human activities. There is a modest fuel economy penalty associated with biodiesel use, but this is not a significant concern from a greenhouse gas perspective given the biogenic nature of the tailpipe emissions (Torrie, 2005).

The market for biodiesel is still new in Ontario, and price fluctuations can be expected until a fully developed and competitive market is developed. The City of Brampton, for example, paid a $0.04 per litre (7%) premium for B20 in 2002 and expected the premium in 2003 to be $0.12 per litre (20%) (Torrie, 2005).

Biodiesel is not yet widely available at retail pumps and this represents a serious obstacle to most school bus operators. Finally, there is the question of the compatibility of biodiesel with the ultra low-sulphur petroleum-based diesel that will become the standard for diesel fuel in Canada in mid-2006. While no serious new issues are expected, operators can be expected to take a "wait and see" attitude before committing to biodiesel blends in the post 2006 diesel engine environment (Torrie, 2005).

V Replacing Buses with New Technologies

There can be significant benefits associated with the replacement of older school buses with new buses. Existing buses could be replaced with:

- New diesel buses that meet the 2004 emission standards;
- New diesel buses the meet the 2007 emission standards;
- A compressed natural gas (CNG) school bus; or
- A diesel-electric hybrid vehicle (HEV) school bus.

Replacing with New Diesel

There are significant air quality and modest greenhouse gas benefits associated with the replacement of pre-1994 model year school buses with school buses the meet 2004 or 2007 emission standards. For example, relative to a 1991-1993 school bus, the 2004-2006 school bus emits 60% less PM, 90% fewer HC, 55% fewer NO_X, and 10% less CO_2. However, for a cost premium of about $10,000 per bus, a pre-1994 diesel bus could be replaced with a new diesel bus that meets the 2007 emission standards. This new bus, which would be outfitted with a DPF, would emit 90% fewer PM emissions and 46% fewer NO_X emissions than the bus built to 2004 emission standards. It would also produce exposure benefits equal to or greater than that associated with a DPF-retrofitted school bus.

Substantial air quality benefits would also be associated with the replacement of a 1994-2003 model year school bus with a new bus built to 2007 emission standards. The 2007 school bus would emit 90% less PM emissions, 88% fewer HC, and 70% fewer NO_X than a 1994-2003 school bus. This replacement, which would cost about $10,000 more than a new diesel bus built to 2004 emission standards, would produce exposure benefits equal to or greater than those associated with a DPF-retrofit school bus.

Compressed Natural Gas (CNG)

Natural gas is comprised mainly of methane (CH_4) and requires a vehicle that is designed or modified to burn natural gas. While historically, CNG technologies have had lower emission rates for PM than conventional diesel technologies, that relationship is changing as diesel-based technologies improve. When tailpipe emissions tests were conducted on a conventional diesel school bus, a low emitting diesel school bus (i.e. ULSD, low NO_X calibration, electronic engine control, and DPF) and a CNG school bus, the low emitting diesel school bus outperformed the CNG school bus on every emission parameter except CO_2 (**Table 8**) (Ullman, 2003; Torrie, 2005).

There is a cost premium associated with CNG when applied to heavy-duty vehicles. By way of illustration, the New York City Transit Authority which has extensive, practical experience with both DPF-equipped diesel buses and CNG-powered buses, reports that it cost six times as much to run a 200-bus depot for CNG buses than a 200-bus depot for diesel buses outfitted with DPFs and run on ULSD fuel (Lowel 2003). It is estimated that a CNG school bus could cost $50,000 more to purchase plus $5,000 per year more for maintenance costs (Torrie, 2005).

Fuel costs may be somewhat lower for CNG buses, but this may not hold over the fifteen year life of a bus. Like biodiesel, CNG does deliver a greenhouse gas benefit that the low emitting diesel technologies do not. However, even here, the cost premium is high compared to other ways to achieve greenhouse gas emission reductions in general (Torrie, 2005).

Table 8: Comparison of Conventional Diesel, Low Emitting Diesel & CNG School Buses (grams/mile)			
	Diesel	**Low Emitting**	**CNG**[9]
NO_X	14.13	**10.08**	16.19
PM	0.18	**0.01**	0.05
THC	0.39	**Trace**	9.34
NMHC	0.39	**Trace**	0.65
Methane	Trace	**Trace**	8.69
CO	1.76	**Trace**	4.78
CO_2	1526	1623	**1200**
Fuel (miles per US gallon) diesel or equivalent	6.6	**6.3**	4.3
Polycyclic organic matter (includes PAHs) (mg/mi)	2.8	**0.076**	0.16
Formaldehyde, (mg/mi)	27	**5.2**	500
Acetaldehyde (mg/mi)	9.5	**2.7**	24
Benzene (mg/mi)	4.7	**not detected**	4.3

Diesel-Electric Hybrid Vehicles (HEV)

Diesel-electric hybrid vehicles (HEV) have a diesel combustion engine and one or more electric motors. The diesel and electric motors can be designed as "in-series configurations" or "in-parallel configurations". With the in-series configurations, the electric motors provide the traction and the diesel engine is used to provide the power to the electric motors, while with in-parallel configurations, the diesel engine powers the drive train directly while also providing the electricity generation for the electric motors (Torrie, 2005).

HEVs usually incorporate some on-board battery storage and regenerative braking. The advantages of the HEV system include the efficiency with which it can deliver high torque and the overall improvement in fuel efficiency. The parallel hybrid concept allows the combustion engine to be off in low power output conditions (such as those characteristic of the stop and go pattern of urban driving), thus reducing emissions in congested urban cores. The series hybrid configuration allows the diesel motor to be downsized and to be run at a more constant power output which lowers emissions (Torrie, 2005).

New York City Transit Authority, which has over 150 hybrid electric buses, has found the infrastructure and facility preparations required for the hybrid buses were minor, especially compared to the infrastructure modifications required to fuel and maintain CNG buses. Emissions are lower than for CNG and low emission diesel buses, and the buses have faster acceleration, better traction, and smoother braking than conventional diesel technology (Torrie, 2005).

There may be a role for HEV technology for new school buses, but it seems more likely that this technology will first be deployed on public transit buses where the incremental capital cost is a smaller percentage of the bus cost and where the high vehicle utilization leads to a stronger justification for the initial capital investment (Torrie, 2005).

[9] This CNG school bus was not outfitted with an oxidation catalyst, which would be expected to improve the emissions profile of the CNG school bus.

E Emissions Reductions for Ontario School Buses

I Emission Reductions associated with Various Options

The annual emission reductions associated with each emission reduction option were estimated for individual buses for each model year cohort. In this analysis, it was assumed that school buses travel 22,000 km per year. The results of this analysis are summarized below, recorded in **Table 9** and illustrated in **Figures 12, 13, 14, and 15**.

Maintenance and Driving Practices: Proper maintenance, idling and vehicle operation practices can be used to reduce emissions of air pollutants and greenhouse gases from all model year school buses by about 10% (**Table 9**). These practices cost little money to implement and can produce cost savings because of increases in fuel efficiency.

Closed Crankcase Filtration Device: The closed crankcase filtration device has not been included in the emission analysis because it does not directly affect tailpipe emissions. It is included here because of its potential to reduce concentrations of $PM_{2.5}$ on-board school buses almost to ambient air levels at an approximate cost of $400 to $600[10].

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[10] Assuming a U.S – Canadian exchange rate of 1.3

Diesel Oxidation Catalyst (DOC): At a cost of about $2,500[11] per bus, DOCs can be a cost effective means of reducing emissions (PM by 25% and HC by 85%) from 1994-2003 model year school buses (**Table 9**). While this retrofit would substantially reduce emissions along traffic corridors and in school yards, testing conducted to date, suggests that it does not significantly reduce concentrations of diesel-related air pollutants on-board school buses.

Diesel Particulate Filters (DPF): By retrofitting a diesel school bus with a DPF and calibrating it for low NOx emissions, emissions from 1994-2003 model year school buses could be significantly reduced (PM, HC and air toxics by 90 to 95% and NO_X by 25%) for about $10,000 per bus (**Table 9**). This retrofit has the potential to reduce concentrations of DPM on-board school buses almost to ambient air levels.

Biodiesel: A 20% biodiesel fuel (B20) can produce modest reductions in air pollutants (PM and HC by 10% and air toxics by 12 to 18%) and substantial reductions in greenhouse gases (CO_2 by about 20%) (**Table 9**). However, costs for B20, which are still quite volatile, can present a cost premium as high as 20% for fuel (about $1,000 per year). It is not known at present how this option would impact on concentrations of air pollutants on-board school buses.

Replacement with New Diesel: Significant emission reductions could be achieved by replacing pre-1994 school buses with new diesel school buses that meet 2007 emission standards (PM by 97%, HC by 90% and NOx by 78%) (**Table 9**). These new buses would cost about $10,000 more than new buses that meet the 2004 emission standards. These new buses would be expected to significantly reduce concentrations of DPM on-board school buses.

Significant emission reductions could also be achieved if 1994-2003 school buses (Cohort C) were replaced with new diesel buses that meet the 2007 emission standards. The emission profile of the 2007 buses is equivalent to that of a DPF-retrofit school bus for PM and HC, but superior for NO_X emissions (**Table 9**). The 2007 school bus would also provide significant exposure benefits for children on-board.

The decision about whether to retrofit or replace a Cohort C bus would likely depend upon the age of the existing bus and the financial situation of the school bus operator. (This option is not included in the replacement option illustrated in Figures 13, 14, 15 and 16.)

Replacement with Compressed Natural Gas (CNG): While PM and NO_X emissions from a pre-1994 bus could be significantly reduced by replacing it with a CNG school bus, this replacement would increase HC emissions by 50% (**Table 9**). This option produces fewer air pollution benefits than the best diesel technology while costing considerably more. For these reasons, it is not recommended as a replacement option for school buses in Ontario at this time.

Replacement with Diesel-Electric Hybrid Vehicle (HEV): A diesel-electric hybrid (HEV) school bus was not included in the emission analysis even though it could outperform both CNG and low-emitting diesel school buses on emissions of air pollutants and greenhouse gases, because it is expected that this technology will be developed for the public transit sector before it becomes cost-effective for the school sector.

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[11] ibid.

Figure 12: Ontario's School Buses
Annual PM Emissions per Bus, Cohort C
(Grams/Year)

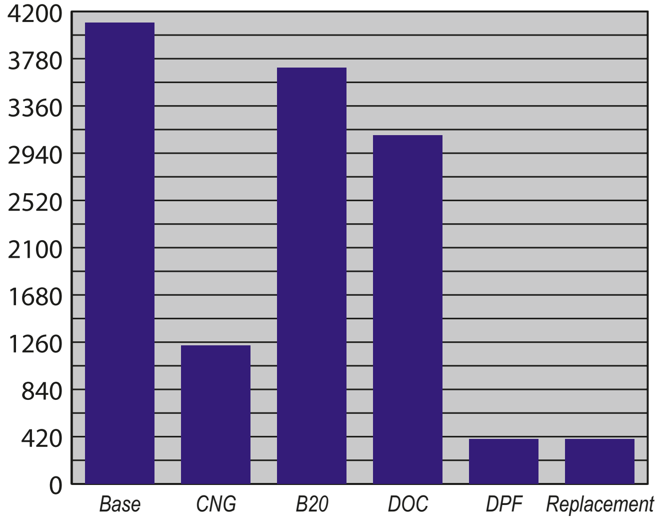


Figure 13: Ontario's School Buses
Annual HC Emissions per Bus, Cohort C
(Grams/Year)

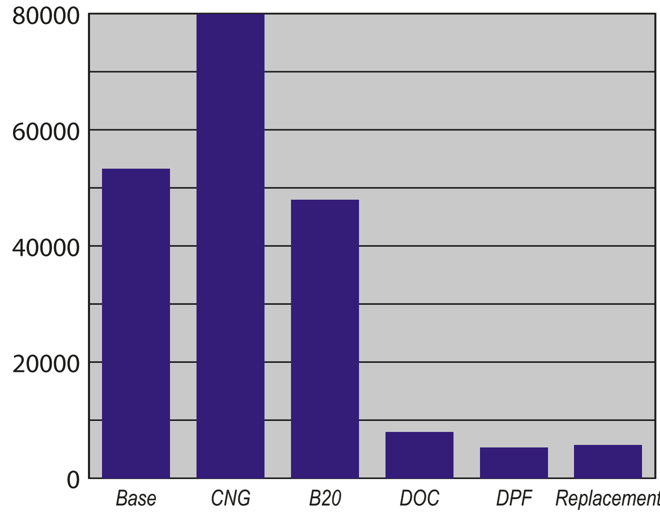


Figure 14: Ontario's School Buses
Annual NO_X Emissions per Bus, Cohort C
(Grams/Year)

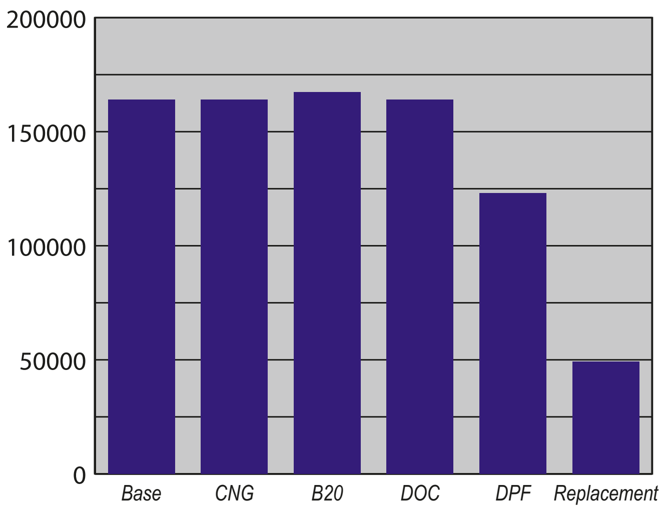


Figure 15: Ontario's School Buses
Annual GHC Emissions per Bus, Cohort C
(Kilograms/Year)

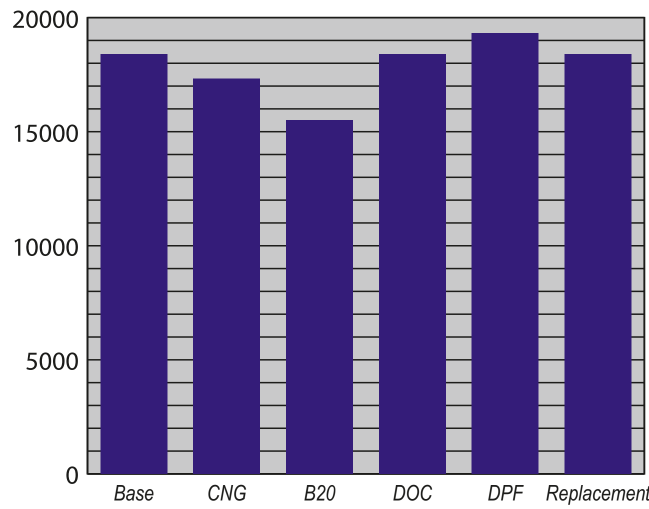


Table 9: School Bus Emission Reduction Options – Annual Reductions Per Bus Per Model Year					
	PM	HC	NO_X	eCO_2	Estimated Implementation Cost
	grams per year			kg per year	
Cohort A – Pre 1991					
Baseline Emissions per Bus	***24,600***	***53,300***	***246,100***	***20,400***	
Per Bus Emission Reductions per Year					
Maintenance and Driver Behaviour	2,500	5,300	24,600	2,000	Low cost
Replace with New (Cohort D) Bus	20,500	47,600	153,800	2,000	Buses this old would be fully depreciated. Best technology would cost estimated $10,000 more than conventional new bus. CNG would cost $50,000 more per bus, plus $5,000 per year.
Replace with Best Technology (Cohort E)	**24,200**	**47,600**	**196,900**	**2,000**	
Replace with a CNG Bus[12]	23,370	(26,650)	82,100	1,484	
Diesel Oxidation Catalyst (DOC)	6,200	45,300	-	-	$1300-4000 ($2500)*
Run on B20	2,500	5,300	(4,900)	3,300	Fuel cost premium of 20%, around $1,000 per year
Cohort B – 1991-1993					
Baseline Emissions per Bus	***10,300***	***50,600***	***205,100***	***20,400***	
Per Bus Emission Reductions per Year					
Maintenance and Driver Behaviour	1,000	5,100	20,500	2,000	Low cost
Replace with New (Cohort D) Bus	6,200	44,900	112,800	2,000	Buses fully depreciated. Best technology would cost $10,000 more than a conventional new bus. CNG would cost $50,000 plus $5,000/yr more.
Replace with Best Technology (Cohort E)	**9,900**	**44,900**	**155,900**	**2,000**	
Replace with a CNG Bus[13]	9,070	(29,350)	41,100	1,484	
Diesel Oxidation Catalyst	2,600	43,000	-	-	$1300-4000 ($2500)*
Run on B20	1,000	5,100	(4,100)	3,300	Fuel cost premium of 20%, around $1,000 per year
Cohort C – 1994-2003					
Baseline Emissions per Bus	***4,100***	***53,300***	***164,000***	***18,400***	
Per Bus Emission Reductions per Year					
Maintenance and Driver Behaviour	400	5,300	16,400	1,800	Low cost
Replace with New (Cohort D) Bus	-	47,600	71,700	-	Dependent on the undepreciated value of the bus being replaced.
Replace with Best Technology (Cohort E)	**3,700**	**47,600**	**114,800**	**-**	
Replace with CNG Bus[13]	2,870	(26,650)	-	1,064	
Diesel Oxidation Catalyst	1,000	45,300	-	-	$1300-4000 ($2500)*
Diesel Particulate Filter (Catalyzed)	3,690	47,970	-	-	$6500-10,000*
Diesel Particulate Filter (Catalyzed), Low NO_X configuration	**3,690**	**47,970**	**41,000**	(920)	$7800-12,000 ($10,000)*
Run on B20	400	5,300	(3,300)	2,900	Fuel cost premium of 20%, around $1,000 per year
Cohort D – 2004-2006					
Baseline Emissions per Bus	***4,100***	***5,700***	***92,300***	***18,400***	
Per Bus Emission Reductions per Year					
Maintenance and Driver Behaviour	400	600	9,200	1,800	Low cost
Replace with Best Technology (Cohort E)	3,700	-	43,100	-	$3250*.
Run on B20	400	600	(1,800)	2,900	Fuel cost premium of 20%, around $1,000 per year

*Assuming a USD/CDN exchange rate of 1.3; using average cost.

[12] CNG buses emit less CO_2 per kilometre traveled, but this is partly offset by their higher emissions of methane (CH4). The value shown in the eCO2 column represents the net emission reduction of equivalent CO2 (eCO2), after allowing for the methane offset.

[13] Ibid.

II Emission Reduction Scenarios - Entire Fleet & Over Time

Introduction

The analysis above provides an indication of the emission reductions that can be achieved when particular emission reduction options are applied to individual buses in different model year cohorts. To fully assess the emission reduction benefits of any particular option however, it is also necessary to consider the impacts over time, given the changing demographics of the bus fleet.

With a computer model, the emission reductions associated with the application of several alternative scenarios have been estimated on a cumulative basis between 2006 and 2016 for each model year cohort in Ontario's fleet of school buses. All of the alternative scenarios are based on the same assumptions that were applied to the "business as usual" scenario: the total number of buses is held constant at 15,000; every bus travels 22,000 km per year regardless of age; and all buses of any particular model year remain in-service for 15 years, after which they are retired at the rate of 50% per year. The use of ULSD, which will become widely available beginning in the fall of 2006, is included in all scenarios so there are no incremental costs or emission reductions built into any of the alternatives for this fuel (Torrie, 2005).

While there are many alternative scenarios that could be identified and analyzed, for practical purposes, options have been limited to:

- Replacement of all pre-1994 model year buses with best diesel technology currently available (i.e. meet 2007 emissions standards);
- Fuelling the entire fleet with biodiesel (B20) beginning in 2006; (The results and the costs of this scenario can be linearly scaled down for lower percent blends.)
- Retrofitting all 1994-2003 model year school buses with DOCs by the end of 2006; and
- Retrofitting all 1994-2003 model year school buses with DPFs by the end of 2006.

Emission Reduction Analysis – Results and Conclusions

The cumulative emission reductions over the 2006-2016 period are shown in **Table 10** and illustrated in **Figures 16, 17, 18 and 19**.

Replacement of Pre-1994 Buses: Cumulative emissions of PM, HC, and NO_X could be reduced from the "business as usual" scenario by about 14%, 6%, and 6% respectively by retiring 1,700 pre-1994 school buses by 2007 and replacing them with buses that meet the 2007 emissions standards (**Table 10**).

This scenario could cost about $17 million to implement because of the incremental costs (about $10,000 per bus) associated with the best technology relative to new buses that meet the 2004 emission standards.

This option could produce significant exposure benefits for the 90,000 children per year[14] who could ride the 1,700 new school buses over the next 15 years.

Biodiesel (B20): While a B20 biodiesel blend could reduce cumulative greenhouse gas emissions from the fleet by about 13%, its impact on air pollutants is mixed. It could decrease cumulative PM and HC emissions by about 8 and 10% respectively and increase NOx emissions by about 2% (**Table 10**).

Assuming a 20% premium for B20, this option could cost about $16 million per year or about $115 million over the 2006-2016 period.

[14] With about 800,000 children taking 15,000 school buses, there is an average of 53 riding each school bus. 53 times 1700 school buses equals 90,100 per year.

Given the modest air quality impacts associated with this option (relative to the other options), the high costs, and uncertainties respecting on-board exposures, this option is not recommended for Ontario school buses at this time. However, when costs for this fuel come down and stabilize, it may be a viable means of reducing greenhouse gas emissions from school buses.

Diesel Oxidation Catalysts (DOCs): To retrofit 9,000 1994-2003 model year school buses with DOCs would cost about $22.5 million. This retrofit could reduce cumulative emissions of PM and HC from Ontario's fleet by 14% and 71% respectively (**Table 10**).

While this option does not appear to reduce on-board exposures, it is a cost-effective way to reduce emissions from older school buses that cannot be retrofit with DPFs.

Diesel Particulate Filters (DPFs): To retrofit 9,000 1994-2003 model year school buses with DPFs and calibrate them for low NO_X emissions would cost about $90 million. This retrofit scenario could reduce cumulative emissions of PM, HC and NO_X from Ontario's fleet of school buses by 51%, 75%, and 15% respectively between 2006 and 2016 (**Table 10**). It could also produce significant exposure benefits for the 477,000 children per year[15] who could ride the 9,000 buses retrofitted over the next 4 to 13 years.

Figure 16: Ontario's School Buses, Cumulative PM Emissions for 15,000 Buses, Various Scenarios, 2006-2016

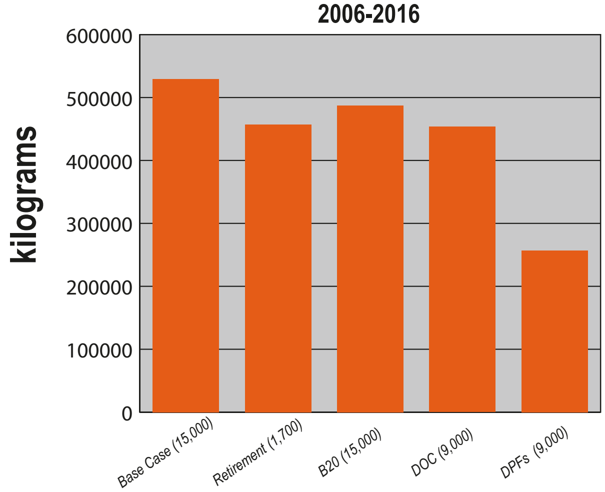


Figure 17: Ontario's School Buses, Cumulative HC Emissions for 15,000 Buses, Various Scenarios, 2006-2016

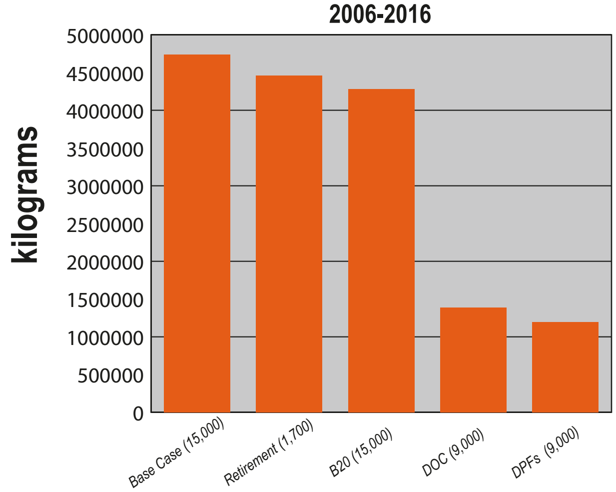


Figure 18: Ontario's School Buses, Cumulative NO_X Emissions for 15,000 Buses, Various Scenarios, 2006-2016

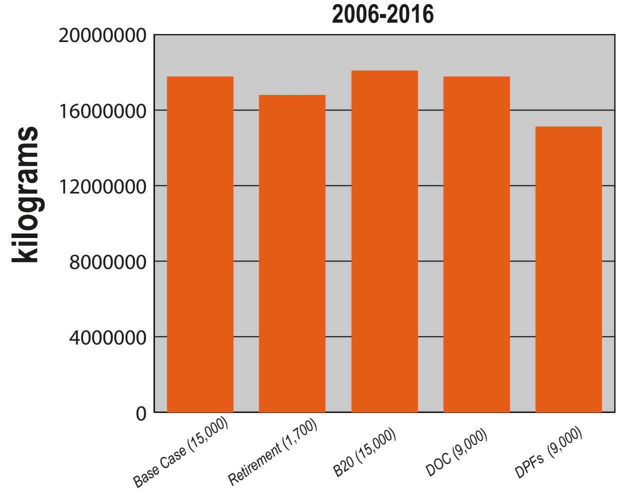
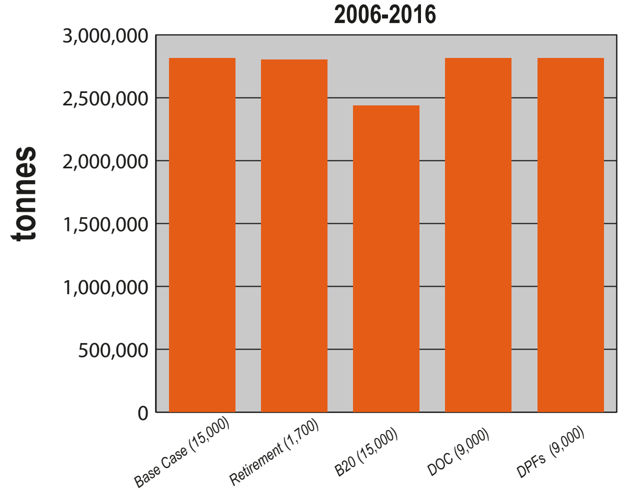


Figure 19: Ontario's School Buses, Cumulative GHG Emissions for 15,000 Buses, Various Scenarios, 2006-2016



[15] With approximately 800,000 per year riding on approximately 15,000 school buses, it is assumed that on average, 53 children are transported on each bus in the province each year. 53 children times 9000 buses equals 477,000 each year.

Table 10: Cumulative Emission Reductions from Ontario School Bus Fleet, 2006-2016						
		PM	HC	NO_X	GHG	
		Kg	Kg	Kg	Tonnes	
Baseline Emissions 2006-2016		**529,349**	**4,735,712**	**17,790,016**	**2,814,872**	
Emission Reduction Scenarios:	**No. of buses affected**	**Cumulative Emission Reductions 2006-2016**				**Notes on Cost**
Early Retirement of Old Buses	1,700	72,200	276,118	985,163	12,457	The old buses in question are fully depreciated. **About $17 million** to cover cost of best technology.
B20 Starting in 2006	15,000	41,990	458,250	(306,552)	378,992	Approx. **$115 million**. Assuming a 20% premium for B20, the premium would be about $16 million per year.
DOCs on 1994-2003 MY Buses	9,000	75,695	3,345,713	N.A.	N.A.	**$22.5 million** to fit 9,000 buses with DOCs at $2,500 per bus.
DPFs on 1994-2003 MY Buses	9,000	272,502	3,542,520	2,653,334	N.A.	**$90 million** to fit 9,000 buses with DPFs at $10,000 per bus.

III Conclusions – Emission Reduction Options for Ontario

There are two reasons to implement emission reduction options on Ontario school buses:

1) To reduce children's exposures to diesel-related air pollutants; and
2) To reduce emissions that contribute to poor local air quality.

Given the introduction of low-emitting diesel school buses over the 2007-2010 period and the age of Ontario's school bus fleet, it appears that school buses that are already on the road, especially the 1994-2003 model year school buses, will be the dominant source of emissions from Ontario's school buses for the next 11 years. Although pre-1994 school buses represent a quickly diminishing percentage of Ontario's fleet, they will continue to emit a disproportionate share of particulate matter (PM) emissions for the next few years because of their higher emission rates.

After examining the school bus exposure studies and the emission reduction options, it was concluded that:

Replacing Pre-1994 School Buses: The replacement of pre-1994 buses should be given high priority because of the very high emissions associated with them. Given that the new buses purchased to replace them will be on the road for about 15 years, it is recommended that they be replaced with new buses that meet the 2007 emission standards.

This scenario could cost about $17 million to implement because of the incremental costs (about $10,000 per bus) associated with the best technology relative to new buses that meet the 2004 emission standards. This scenario would also produce significant exposure benefits for the 90,000 children per year who may ride those 1,700 school buses over the next 15 years. While most of the buses in this cohort should be fully depreciated, additional incentives may be needed to ensure that all buses in this cohort are retired by 2007.

All School Buses: The closed crankcase filtration device has the potential to virtually reduce concentrations of $PM_{2.5}$ on-board school buses to ambient air levels at a cost of about $400 to $600 per bus. Cost of installing these devices on all school buses in Ontario would be about $7.5 million.

Retrofitting 1994-2003 School Buses: Emissions from 1994-2003 model year school buses could be significantly reduced by retrofitting them with DPFs and calibrating them for low NO_X emissions. If this scenario were applied to 9,000 1994-2003 model year school buses, emissions of PM, HC and NO_X from Ontario's entire fleet of school buses could be reduced by 51%, 75%, and 15% respectively between 2006 and 2016, for a cost of $90 million.

This scenario could also produce significant exposure benefits for the 477,000 children per year who may ride those 9,000 school buses over the next 4 to 13 years. With a per bus cost of $10,000, and 4 to 13 years of service life remaining in these buses, these emission and exposure benefits would cost about $750-2500 per bus per year or $14-47 per child per year depending upon the model year of the bus.

Replacing 1994-2003 School Buses: Significant emission reductions could also be achieved if 1994-2003 school buses were replaced with new buses that meet the 2007 emission standards. The emission profile of these new buses, which would cost about $10,000 more than a new bus built to 2004 emission standards, would be equivalent to retrofitting with a DPF for PM and HC, but superior for NO_X emissions. These new buses would also produce significant exposure benefits for the children transported on them.

The decision about whether to retrofit or replace a 1994-2003 model year school bus will depend upon the age of the existing bus and the financial situation of the school bus contractor.

Maintenance and Driving Practices: Proper maintenance, idling practices and vehicle operation should be employed to reduce emissions of air pollutants and greenhouse gases from all model year school buses. These practices cost little money to implement and can produce cost savings because of increases in fuel efficiency.

F Programs & Policies

I Emission Reduction Programs

In the United States, several programs have been established to reduce emissions from, and exposures on-board, school buses. These programs have been developed by the federal government in the United States, the California State government, and by a utility company in New York City.

US EPA Clean School Bus Program

The Clean School Bus USA program is a multi-year initiative that began in 2003. The U.S. Congress allocated $5 million US for a cost-shared program designed to assist schools, school districts, school transportation associations or non-profit organizations to upgrade their fleets and reduce pollution through the use of U.S. Environmental Protection Agency (US EPA) verified technology[16]. All applicants must contribute a minimum of 5 percent of the total project cost with either cash or an in-kind contribution (US EPA, 2005).

- The Clean School Bus initiative has three primary goals:
- To reduce school bus idling;
- To retrofit existing buses with devices that reduce pollution; and
- To replace the oldest buses with new, cleaner buses including CNG school buses.

[16] EPA's verification process evaluates retrofit technologies under a range of conditions and quantifies the percent reduction in emissions that the technology achieves. The verification process also identifies engine operating criteria and conditions that must exist for these technologies to achieve the certified reductions. A list of verified or certified technologies is availiable at www.epa.gov/otaq/retrofit/retroverifiedlist.htm.

In 2003, the US EPA received over 120 applications requesting nearly $60 million in funds. Seventeen projects were selected for funding involving 4,000 school buses. These projects demonstrated a variety of approaches to reducing school bus-related pollution. In 2004, Congress allocated another $5 million USD to the program which funded 20 new demonstration projects across the U.S. These projects were drawn from the 2003 pool of applicants. The projects funded in 2003 and 2004 include:

- Replacing pre-1987 school buses with compressed natural gas (CNG) school buses;
- Retrofitting school buses with DPFs;
- Retrofitting existing buses with DOC;
- Using biodiesel (B20) or ULSD to fuel school buses;
- Installing closed crankcase filtration systems; and
- Installing radio transmitters to monitor the idling time of school buses (US EPA, 2005).

A detailed list of the demonstration projects funded in 2003 and 2004 by the Clean School Bus USA Program is provided in **Appendix A**.

When approving grants for this program, the US EPA considers whether the applicant is located in an area of poor air quality (i.e. areas considered to be in non-attainment or maintenance for a criteria air pollutant or have localized air pollution problems).

In 2005, Congress allocated an additional $7.5 million for the 2005 Clean School Bus Program and the US EPA expects to announce a solicitation for applications shortly (US EPA, 2005).

California Lower-Emissions School Bus Program

In 2000, the California Air Resources Board (CARB) in conjunction with the California Energy Commission (CEC) established a Lower-Emissions School Bus Program that aims to reduce the exposure of school children to both toxic and smog-forming air pollutants by:

- Supporting the replacement of the oldest, highest-polluting buses with new, lower-emitting buses that meet the latest emissions standards; and
- Supporting the retrofitting of in-use school buses with technologies that significantly reduce PM emissions.

Under this program, $49.5 million was allocated to the purchase of "safe, lower-emitting new school buses" and $16.5 million was allocated to the purchase and installation of emission control devices on in-use diesel school buses during the 2000/2001 and 2001/2002 fiscal years. By 2003, 336 new school buses had been purchased, 1,500 buses had been retrofitted with catalyzed DPFs, and 1,500 buses had been retrofitted with DOCs (CARB, 2003).

In the spring of 2002, California passed Bill 425 which directed an additional $10 million USD to be directed towards the purchase of additional "clean, safe, school buses" for use in California's public schools over a 2-year period (CARB, 2003).

Funds for the Lower-Emissions School Bus Program have been allocated on the basis of population so that the greatest number of low-emitting buses was directed at the most densely populated urban areas where they would reduce exposure to DPM for the greatest number of people (CARB, 2003).

The "environmental justice" provisions in Proposition 40 that was the basis for Bill 425 in 2002, stipulates that air districts in California with populations greater than 1 million must ensure that half of the money is allocated in such a way that it directly benefits low-income communities and communities of colour that are disproportionately impacted by air pollution (CARB, 2003).

With the Lower-Emission School Bus program, the State paid 85% of the total cost of a new school bus that replaced an in-use pre-1977 school bus and 75% of the total cost of a new school bus that replaced an in-use 1977-1986 school bus. Until October 2002, in order to qualify as a lower-emission school bus eligible for funding with this Program, a new school buses had to emit less PM and NOx than was allowed by California's emission standards. After October 2002, the eligibility criteria were changed slightly to reflect the introduction of tighter emissions standards. After October 2002, to quality as lower-emission school buses, diesel-fuelled buses have to be equipped with catalyzed DPF and CNG buses had to be equipped with DOCs (CARB, 2003).

New York Power Authority Clean School Bus Program

The New York Power Authority (NYPA) has announced its intention to reduce emissions of particulate matter (PM) from school buses in New York City by retrofitting between 1,500 and 2,000 school buses with DOCs and/or DPFs and fuelling them with ULSD. This Clean School Bus Program, which will cost in excess of $6 million, is expected to reduce emissions of particulate matter (PM) from school buses by 12.5 tons annually (ENS, 2005).

The Clean School Bus Program is part of a voluntary $23 million plan developed by the NYPA that aims to off-set emissions from its new power plants that are being located at six sites in New York City (ENS, March 7, 2005). The NYPA decided to retrofit school buses because they are emission sources that have a direct impact on the population living in New York City (NYPA, 2005).

II Idling Policies

Introduction

Idling control by-laws, policies and programs have been developed by municipalities, corporations and senior levels of governments to meet a number of policy objectives:

- To reduce emissions of greenhouse gas emissions;
- To improve fuel efficiency and reduce fuel costs;
- To address localized air quality concerns that can be associated with frequent idling;
- To provide citizens with a tool with which to address chronic idling that can present a nuisance and/or health concerns; and
- To increase awareness about the contribution of vehicles to poor air quality and climate change.

With school buses, idling practices take on greater significance because:

- Concentrations of diesel exhaust can increase rapidly inside school buses that idle with doors or windows open;
- Diesel exhaust contains a potent mixture of ultra-fine particles and toxic contaminants that can penetrate deep into the lungs; and
- Children are particularly susceptible to toxic air pollutants.

School Bus Idling Programs: United States

In the United States, the US EPA Clean School Bus USA program includes an anti-idling program that is implemented at the State level. The EPA provides resources to local counties and school departments to develop and implement anti-idling campaigns and policies. At a minimum, the EPA suggests that an anti-idling policy should require the following:

- As a general rule, buses should be moving whenever the engine is on. The engine should be turned off as soon as possible after arriving at loading or unloading areas. The school bus should not be restarted until it is ready to depart; and
- Limit idling time during early morning warm-up to the time recommended by the manufacturer (generally no more than five minutes).

Anti-idling policies usually include language to address extreme weather temperatures to ensure that children are protected from the stress of weather extremes and to accommodate the warm-up period required by engines in extreme weather conditions (usually 5 minutes or less at start-up).

School Board Policies: Canada & the United States

A number of school boards across North American have developed anti-idling policies including New Brunswick, Houston, Portland, Minnesota, California, and Maine. According to the US EPA, many other local governments and school districts are working with State agencies and/or other organizations to implement programs to reduce children's exposures to diesel emissions. For example, a school board in Portland, Oregon, implemented a strict no-idling policy for its whole fleet of buses. However, in a manner similar to State and municipal policies, idling is permitted where temperatures drop below 20 degrees F and where frost or cooler temperatures in buses are observed.

School Board Policies: Ontario

Staff in 36 school boards in Ontario were contacted by phone or e-mail and asked about their idling control policies. Among the 40% who replied, none had formal anti-idling policies in place. Boards which make some attempt to control idling on school grounds place time limits on idling and allow exemptions for extreme weather conditions. In those situations where time limits are placed on idling, the time limits are frequently 3-5 minute intervals because this is the time period that is required to raise cabin temperatures to acceptable levels.

Some school boards in Ontario control idling practices with language in their contracts with school bus operators. For example, the public and separate school boards in the City of Toronto and Halton Region have clauses in their contracts with school bus operators that prohibit idling over 5 minutes (Lacroix, 2005). Other school boards inform bus drivers directly that idling periods are limited on school property except during extreme weather conditions. For example, in the Region of York, drivers are notified that they should not idle for more than 5 minutes unless temperatures drop below, or exceed, designated temperatures (Nell, 2005).

III Policy Considerations

Costs in Context

To implement all of the emission reduction options identified in Section E could cost up to $115 million or $23 million per year over 5 years. While these costs may seem overwhelming, they must be considered in context. The Ontario school bus fleet has a replacement value of about $1.5 billion, annual capital investment in new buses is in the range of $100 million per year, and annual funding for student transportation hovers around $700 million. As a rule of thumb, an air pollutant emission reduction investment should be kept below one year's capital investment. In this context, the costs of emission reduction retrofits outlined above seem reasonable. However, given that funding for student transportation in Ontario has been extremely tight for several years, it is important that school bus upgrades and retrofits be funded out of a supplementary funding pool that aims to improve children's health and local air quality.

Funding Emissions Reductions

It is important to consider the structure of the Ontario school bus industry when shaping policy recommendations for accelerating the rate of emission reduction in the Ontario school bus fleet. School bus budgets have been cut deeply and frequently by Boards throughout the province. The school bus fleet is now largely consolidated in a small number of companies that are operating very large fleets of school buses across Canada and North America.

Most school bus operators however, are small or medium sized firms, often locally based, that run relatively small fleets (less than 30 buses). The same policies and approaches that will be most effective with the large firms are not likely to be effective with these small and medium sized firms. The smaller companies are generally under capitalized and often contract out for everything from maintenance to drivers, and are struggling to cover their operating costs. Assistance to cover the capital cost of the recommended technologies will likely be necessary to deploy the retrofit options in large or small firms (Torrie, 2005).

Bulk Purchasing & Program Support

Bulk purchase arrangements could significantly reduce the costs of the technologies identified in the scenarios presented here, and government may wish to consider playing a leadership or coordinating role in negotiating preferred prices with suppliers.

Consideration should be given to a program focusing on the top five or ten operators that would develop a joint government/industry schedule for emission reductions by those firms. This would kick-start the transition, cover over half the bus fleet in the province, and would also have the effect of deploying the technologies and the retrofits on a sufficient scale that the smaller and medium sized companies would then benefit from the expertise and parts and service infrastructure that would grow up around the new technologies (Torrie, 2005).

Retirement Assumptions & Incentives

While we have assumed that the Ontario school bus fleet will maintain its current age profile (with 90% of the fleet renewed after fifteen years and 99% after 20 years), it is possible that financial pressures and uncertainty over the future societal commitment to school busing will cause school bus operators to hold off on investments in new vehicles and run the older buses longer than they have in the past. Incentives to retire pre-1994 model year school buses could make a difference in such a scenario (Torrie, 2005).

It is also possible that there will be a real and permanent increase in the cost of new school buses (in the order of $5-10,000) in 2007 when the new low emission technology becomes standard equipment. Operators seeking to avoid this increase might accelerate their replacement investment between now and then, suggesting a possible role for policies that promote or incent the accelerated adoption of the 2007 standard in new bus purchases (Torrie, 2005).

There is some statistical evidence that the older school buses are more likely to belong to the smaller school bus operators than the large firms. This would be consistent with the tendency for the smaller firms to be under capitalized relative to the larger transnational conglomerates that operate fleets that number in the thousands of buses. As with the previous point, this suggests that assistance or incentives to invest in new vehicles could be effective at getting the oldest and dirtiest school buses off the road. (Torrie, 2005).

When considering policies for the accelerated retirement of school buses from the Ontario fleet, the final destination of the buses should be considered. We could find only anecdotal evidence on this point, but it is clear that at least some of Ontario's retired school buses remain in-service, either in Ontario or elsewhere, for example in public and private transit fleets in developing countries. Emission reduction technologies that are retrofit to Ontario school buses, even old Ontario school buses, will continue delivering environmental benefits even after the bus has been retired from the Ontario school bus fleet, and this is worth consideration in the context of the Ontario's commitment to sustainable development. A deliberate strategy to encourage the retirement of older, higher-emitting buses from the active Ontario school bus fleet may be transferring the emissions source to another location and another operator, perhaps one less able than Ontario to invest in emission reduction technology (Torrie, 2005).

Proper Maintenance, Idling and Vehicle Operation Practices

Consideration should be given to including in the provincial curriculum for school bus operator training a module on fuel management and low emission driving techniques. While the school bus operators interviewed have anti-idling policies, there does not appear to be any uniform training on this or the more general topic of lowering bus emissions through driving technique.

IV Recommendations

1. **It is recommended that the Ontario Ministry of the Environment establish a multi-year Healthy School Bus Program, with $10-20 million per year, that has the dual goals of reducing childhood exposure to diesel-related air pollutants and improving local air quality by:**

- **Ensuring the retirement of all pre-1994 model year school buses by 2007;**
- **Encouraging the replacement or retrofitting of all 1994-2003 model year school buses by 2011;**
  - ◇ **When retrofitting, encourage the use of diesel particulate filters (DPFs) wherever possible, and the next best technology when conditions are not conducive to the effective use of diesel particulate filters;**
- **Ensuring that all new school buses purchased over the next year meet 2007 emission standards;**
- **Encouraging the installation of closed crankcase filtration devices in all school buses in Ontario;**
- **Supporting demonstration projects that encourage the development of alternative technologies and fuels; and**
- **Developing, in collaboration with Natural Resources Canada, the Ontario School Bus Association, and Ontario school boards, a module on proper idling, fuel management, and low emission driving practices, to be included in the provincial curriculum for school bus operators.**

The Healthy School Bus Program should be designed with recognition for both, the financial pressures experienced by school boards and school bus operators, and the varying realities of small and large school bus operators in the Province. The Program should facilitate bulk purchase arrangements that could significantly reduce the costs of retrofits and replacements.

Given both, the potential contribution of school buses to air pollution in localized areas, and the contribution of ambient air pollution to pollutant concentrations on-board school buses, priority should be given to school boards operating in areas that experience poor regional air quality and to schools that experience poor local air quality. Priority should be given to school buses used for longer commutes, multiple-commutes, and greater numbers of passengers.

While improving the health of children in Ontario, this Program would also help the Province to achieve its 1996 commitment to reduce emissions of NO_X and VOCs in Ontario by 45% of 1990 levels by 2015. It would also help the Province to achieve its 2000 commitment to attain the Canada-Wide Standards for $PM_{2.5}$ of 30 $\mu g/m^3$ (24-hour) and for ozone of 65 ppb (8-hour) by 2010.

2. **It is recommended that the Federal Government establish a multi-year Healthy School Bus Fund with $10 to 20 million per year to support programs developed by provincial governments and other organizations, that are directed at the dual goals of reducing childhood exposure to diesel- related air pollutants and improving local air quality.**

This Fund should give priority to school boards operating in communities that are currently out of attainment with the Canada-Wide Standards for $PM_{2.5}$ or ozone. While improving the health of children across the country, in Ontario this Fund would also provide emission reductions that could be used to fulfill Canada's commitments to reduce emissions of NO_X and VOCs under the Ozone Annex of the Canada-U.S. Air Quality Agreement. It would also produce emission reductions that could be counted towards a PM Annex under the Canada-U.S. Air Quality Agreement.

3. **It is recommended that school boards in Ontario, in collaboration with the Ontario Ministry of the Environment and Natural Resources Canada, develop formal policies respecting idling in school buses particularly around school properties.**

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Appendix A:

Projects Funded in 2003/2004 by the US EPA School Bus Program

Arizona

Paradise Valley Unified School District #69 – Phoenix, AZ

The Paradise Valley Unified School District will demonstrate how a large, suburban school district near Phoenix, Arizona will retrofit 20 buses with DPF, fuel 114 with ULSD, and introduce this fuel into an area of the country where it is not currently available.

California

San Diego Air Pollution Control District

San Diego Air Pollution Control District will establish a sub-grant program for school districts throughout San Diego County to retrofit diesel school buses with DPF. The county includes many areas where environmental justice is a concern. Federal grant: $355,000.

South Coast Air Quality Management District

The South Coast Air Quality Management District will replace seven pre-1987 diesel school buses with new CNG buses. The grant will also install up to 100 DOC on 1990 to 1993 model year diesel school buses in primarily environmental justice areas. Federal grant: $495,000.

Clovis Unified School District – Clovis, CA

The Clovis Unified School District will demonstrate how a large, suburban school district near Fresno, California will retrofit 53 buses with DOC and evaluate their performance running on emulsified diesel fuel; plus retrofit 9 buses with DPF and fuel them with ULSD fuel.

Colorado

Littleton Public Schools

Littleton Public Schools will use B20 biodiesel in its fleet of 67 diesel buses. Federal grant: $21,406.

Regional Air Quality Council – Denver, CO

The Regional Air Quality Council will establish a subgrant program that allows urban and rural school districts in 10 counties to install DOC in 160 buses and evaluate their performance running on biodiesel fuel.

Florida

Hillsborough County Environmental Protection Commission

The Hillsborough County Environmental Protection Commission will install approximately 170 DOC on diesel school buses in the Tampa, Florida area. Federal grant: $200,000.

Georgia

Georgia Adopt-A-School Bus Program

Georgia's Department of Natural Resources will develop a statewide Adopt-A-School Bus program. Initially, the program will provide four participating school districts with funding and technical support to retrofit school buses and use ULSD fuel. The program will also develop extensive outreach materials. Federal grant: $490,000.

Illinois

City of Chicago

In partnership with the Chicago Public School System, the American Lung Association, and the Illinois Environmental Protection Agency, the City of Chicago will equip about 80 buses with DOC and 20 buses with DPF in combination with ULSD diesel fuel. Federal grant: $315,000.

Illinois Environmental Protection Agency

The Illinois Environmental Protection Agency will assist a small, urban school district in Chicago, Illinois in retrofitting 14 buses with DOC and in doing so, launch a Chicago area clean school bus initiative.

Indiana

Indiana Department of Environmental Management

Indiana Department of Environmental Management will retrofit about 227 school buses in Evansville and near Indianapolis (Marion County Township Schools) with DOC. Federal grant: $250,000.

Iowa

Iowa Foundation for Education Administration

The Bus Emission Education Program (BEEP) will partner with school districts throughout the state of Iowa to replace three older school bus engines and install DOC on 126 school buses, which will be fueled with various blends of biodiesel. Federal grant: $250,000.

Maine

Maine Department of Environmental Protection

The Maine Department of Environmental Protection will establish a sub-grant program to assist 21 primarily rural school districts across the state in establishing bulk purchasing to acquire DOC and in retrofitting 266 buses with these catalysts. The state will also purchase 180 new buses as part of its match.

Massachusetts

City of Medford – Medford, MA

The city of Medford will demonstrate how a small, urban Boston-area school district with a contract school bus fleet will retrofit 54 buses with DPF and fuel the fleet of 65 buses with ULSD fuel.

Michigan

Ann Arbor and Manchester Public Schools

The Ann Arbor Public Schools will equip 110 buses with DOC. The Manchester Public Schools, a nearby small school district, will operate its fleet of 18 buses on biodiesel (B20). As a pilot for the area, Ann Arbor will also install crankcase filtration systems in three buses. Federal grant: $95,357.

Okemos Public Schools

In the greater Lansing, Michigan area, the Okemos Public Schools will equip 40 to 50 buses from up to seven different area school districts with DOC and crankcase filtration systems. Federal grant: $70,000.

Mississippi

Moss Point Public School District

The Moss Point Public Schools will equip its entire fleet of 31 buses with DOC and implement anti-idling policies. Federal grant: $50,000.

Columbus Municipal School District – Columbus, MS

The Columbus Municipal School District will demonstrate how a small, rural school district in northeastern Mississippi will retrofit 47 of its fleet of 59 buses with diesel oxidation catalysts.

Montana

Missoula Area Clean School Bus Program

The Missoula City-County Health Department will purchase biodiesel (B20) for eight school buses in two Missoula-area school districts. Federal grant: $4,500.

Nebraska

Lincoln Public Schools

Lincoln Public Schools will equip 118 diesel school buses with DOC. Federal grant: $150,000.

New Hampshire

New Hampshire Department of Environmental Services

Working with public and private transportation providers, the New Hampshire Department of Environmental Services will install at least 30 closed crankcase systems in combination with DOC on buses in the Manchester School District and will install at least 15 closed crankcase systems in combination with DOC on buses in Nashua School District. Federal grant: $100,000.

New Jersey

Vineland Board of Education

The Vineland Board of Education will install radio transmitter devices on 20 of its diesel buses in order to monitor the idling times of its fleet. In addition, all 94 diesel buses will be fitted with DOC. Federal grant: $180,000.

New Mexico

New Mexico Energy, Minerals and Natural Resources Department and State Department of Education

Working in partnership with the State Department of Education, the New Mexico Energy, Minerals and Natural Resources Department will replace three older diesel school buses with new CNG buses. Federal grant: $105,000.

New York

New York State Energy Research and Development Authority

The New York State Energy Research and Development Authority, in partnership with the NY Association of Pupil Transportation, will assist 11 geographically diverse school districts to retrofit approximately 334 buses with DOC or DPF. Federal grant: $504,037.

Corning-Painted Post Area School District – Painted Post, NY

The Corning Painted Post Area School District will demonstrate how a small, rural school district in upstate New York will retrofit 17 buses with DPF and acquire ULSD fuel for its fleet of 19 buses.

North Carolina

Western North Carolina Regional Air Quality Agency – Asheville, NC

The Western North Carolina Regional Air Quality Agency will establish a sub-grant program to expand a pilot retrofit project and help four primarily rural counties buy DOC for 321 buses.

Ohio

Cleveland Municipal School District – Cleveland, OH

The Cleveland Municipal School District will demonstrate how a large, urban school district will expand its new clean school bus initiative and sustain the availability of ULSD fuel in the Cleveland area by retrofitting 36 buses with DPF and fueling these buses with ULSD fuel.

Regional Air Pollution Control Agency – Dayton, OH

The Regional Air Pollution Control Agency will assist a small, urban school district that provides bus service to special needs children in retrofitting 33 buses with DOC.

Oregon

Oregon Clean School Bus Program (Lane Regional Air Pollution Authority)

The Lane Regional Air Pollution Authority will make ULSD available to 15 fleets across Oregon (approximately 4 million gallons per year) and retrofit 42 school buses with DPF. Federal grant: $500,000.

Pennsylvania

Upper Darby School District

The Upper Darby School District near Philadelphia will retrofit 58 buses with DPF and operate its entire fleet on ULSD fuel. Federal grant: $485,000.

General McLane School District – Edinboro, PA

The General McLane School District will demonstrate how a small, rural school district near Erie, PA will retrofit its fleet of 40 buses with DOC.

North Allegheny School District – Pittsburgh, PA

The North Allegheny School District will demonstrate how a large, suburban Pittsburgh-area school district will retrofit its fleet of 84 buses with DOC and work to bring ULSD fuel into an area where it is not currently available.

Rhode Island

Warwick Public School Department

The Warwick Public School Department will equip 20 buses with DPF and 20 buses with DOC. Ultra Low B20 fuel (ultra low sulfur diesel blended with 20 percent biodiesel) will be provided to the entire fleet of 72 buses. Federal grant: $350,000.

Tennessee

Chattanooga-Hamilton County

Through a public/private partnership between the Chattanooga-Hamilton County Air Pollution Control Bureau and First Student, Inc., a local private school bus contractor, this project will equip 83 buses with DOC. Federal grant: $100,000.

Texas

Texas State Energy Conservation Office

The Texas State Energy Conservation Office will assist 3 large school districts (Dallas/Fort Worth, Austin, and Houston) in retrofitting about 73 buses with DPF, purchasing new diesel buses, and fueling the entire fleet with ULSD.

Utah

Salt Lake Clean Cities Coalition – Salt Lake City, UT

The Salt Lake Clean Cities Coalition will assist a large, urban school district that is already using some CNG buses in acquiring 10 new buses that run on CNG to replace the district's oldest diesel-fueled buses.

Washington

Puget Sound Clean Air Agency – Seattle, WA

The Puget Sound Clean Air Agency will work with four other clean air agencies to assist four rural school districts in the Western part of Washington state in retrofitting 139 buses with DOC and 21 with DPF and ULSD fuel.

Ontario Public Health Association
Lawrence Square
700 Lawrence Ave. West, Suite 310
Toronto, Ontario M6A 3B4
(416) 367-3313
www.opha.on.ca/resources/schoolbus.pdf