alchemy

LEVELTON
Engineering Solutions

BC Clean Transportation Analysis Project
Final Report

Prepared for
Clean Transportation Analysis Project Steering Committee

Prepared by
Alchemy Consulting Inc.
and
Levelton Engineering Ltd.

in association with
Constable Associates Consulting Inc.
and
Prof. Sara C. Pryor, Indiana University

January 2000

Contents

Disclaimer

This report has been reviewed by representatives of the Sponsors, but the interpretation of the results of this study, as expressed in the report, is entirely the responsibility of the consultants and does not imply endorsement of specific points of view by any or all of the Sponsors. The expressed conclusions based on the findings are consensus conclusions supported by all of the Sponsors.

Study Sponsors

- BC Ministry of Environment, Lands & Parks
- Greater Vancouver Regional District
- Environment Canada (Pacific & Yukon Region)
- Canadian Petroleum Products Institute (CPPI)
- Canadian Vehicle Manufacturers' Association (CVMA)
- Association of International Automobile Manufacturers of Canada (AIAMC)
- TransLink (Greater Vancouver Transportation Authority)
- Fraser Valley Regional District

The Canadian Petroleum Products Institute (CPPI), one of the Sponsors, supports the study's intent to provide rational analysis of the relative benefits of the various alternative regulatory scenarios that were assessed; however, CPPI does not endorse the analytical methodology used to estimate the potential health effects of air quality improvements and their deemed economic value. CPPI participated fully in the study Steering Committee and its project direction and review activities, but its financial contribution to the project was not used to fund the tasks that estimated the health impacts and valuation of air quality improvement. Appendix G of this report contains a brief statement of CPPI's reasons for not endorsing the portions of the study that addressed estimation of effects and their economic values.

Summary

Background

The Province of British Columbia is assessing the impact of implementing more stringent motor vehicle emission regulations for light-duty passenger cars and trucks (up to 8,500 lbs gross vehicle weight or 3,865 kg GVW) to complement the existing BC Motor Vehicle Emission Reduction Regulation (1995, amended 1999). One of the possibilities is to implement low emission vehicle (LEV) requirements equivalent to those currently being scheduled by California for vehicle model years (MY) 2004 and later (referred to as the "LEV II" standards). The US Federal Government has also promulgated stringent low emission vehicle emission standards for the whole US to take effect in MY 2004 and later (referred to as the "Tier 2" standards). Both California and the US Federal Government have implemented low emission vehicle programs that bridge the transition from current standards to Tier 2 or LEV II (referred to as "LEV" and "NLEV," respectively).[1] Any regulatory action by BC would take place in the context of the influence that these US programs will have on the future availability of new, low emission vehicles for purchase in BC.

A group of interested parties funded the current project, whose purpose is to evaluate the above programs as possible options for BC. The sponsors' representatives constitute the project steering committee—

- BC Ministry of Environment, Lands & Parks
- Greater Vancouver Regional District
- Environment Canada
- Canadian Petroleum Products Institute (CPPI)
- Canadian Vehicle Manufacturers' Association (CVMA)
- Association of International Automobile Manufacturers of Canada (AIAMC)
- TransLink (Greater Vancouver Transportation Authority)
- Fraser Valley Regional District

The Clean Transportation Analysis Project is being conducted to assess the relative benefits of a number of transportation-related initiatives in the Lower Fraser Valley. The core objective is to support the analysis of the impact of various vehicle emission standards for the period 2004-2020. The analysis includes—

1. estimating emission reductions from implementation of the US EPA and California emission standards and programs for the period 2001-2020
2. estimating related ambient air quality improvements in the Lower Fraser Valley
3. estimating economic costs of achieving the air quality improvements and, hence, estimating cost-effectiveness of the programs, and

---

[1] The BC Motor Vehicle Emission Reduction Regulation requires that NLEV-equivalent vehicles be available in BC beginning in 2001. New York State recently announced that it will implement the California LEV II standards.

4. estimating health and other benefits associated with the air quality improvements.[2]

Additional transportation initiatives in the Lower Fraser Valley that are not related to possible changes in light- and medium-duty motor vehicle emission regulations were also evaluated. These were evaluated for comparative cost-effectiveness with the light-duty vehicle regulations and include—

- purchase of alternate-fuelled transit buses (compressed natural gas, Ballard fuel cell-powered and diesel hybrid, all relative to future diesel bus emissions)
- AirCare On-Road Program (ACORP) inspection and maintenance program for heavy-duty vehicles
- BC Scrap-It older vehicle early retirement program.

Synopsis of Methodology

The process that was followed during this study comprises the following steps—

1. Estimate the emission baseline against which the changes resulting from the emission reduction measures are evaluated.
2. Estimate changes in emissions of specific pollutants resulting from two standards implementation scenarios.
3. Estimate changes in ambient concentrations of pollutants (air quality) corresponding to the emission changes.
4. Estimate the changes in health (and other) effects associated with the estimated changes in air quality.
5. Estimate the economic impact of the two scenarios, including, estimating direct costs of implementing the emission reduction and estimating the cost-effectiveness by comparing costs against the emission reductions.
6. Estimate the hypothetical economic value of the effects that would be avoided by reducing the emissions.

Baseline and Emission Reduction Scenarios

The new emission standards were evaluated for light-duty, on-road, gasoline-fuelled vehicles only (i.e., excluding the relatively small number of light-duty diesel-fuelled vehicles in the existing fleet—which affects only the baseline in an insignificant way—and all heavy-duty vehicle classes). Committed and pending changes in standards for heavy-duty, diesel-fuelled vehicles were not analyzed, but they will further reduce emissions from this portion of the overall fleet over the study period. Heavy-duty vehicles were omitted from the Terms of Reference primarily because the BC Government is not considering additional regulations for this sector at present. The new Canadian requirements for low-sulphur gasoline were incorporated in the Study Baseline (reference emission levels).

---

[2] This latter activity is funded by the sponsor group excluding CPPI. See Disclaimer and Appendix G for a summary of CPPI's position.

Emission reductions in the Lower Fraser Valley were estimated for NOx, VOC and CO for two regulatory scenarios: NLEV + Tier 2 and NLEV + LEV II. NLEV with either Tier 2 or LEV II was treated as a component of a continuous transition from the earlier standards to the new standards. NLEV was not evaluated separately. Thus, some of the emission reductions and benefits estimated for the transition years (2004-2009) are attributable to NLEV, but not separately accounted for. Avoided health effects were estimated for reduced emissions of NOx and VOC as precursors of ozone and secondary PM_{10}. Direct effects of CO, NO_2 and VOC were not evaluated, because they were judged to be small relative to those that were evaluated, based on results of previous studies.

The estimates accounted for expected population growth and increase in the number of vehicles and distance travelled per vehicle over the period 2001-2020. Certain initiatives that will further influence emissions from the LDGV fleet were not addressed by the study, for example—

- greenhouse gas emission reduction measures or programs
- Cleaner Technology Vehicle (CTV) consortium activities
- changes in fuels and vehicle technology beyond the 2004 Tier 2 and LEV II requirements
- AirCare II.

Key Findings

The following are the principal findings of the study.

1. The emission model developed for this study has allowed a significant update to estimates of emissions from the Lower Fraser Valley vehicle fleet—leading to a more accurate database. The new results indicate a significant reduction in the estimated emissions of CO, NOx and VOC (NMOG) of the current fleet compared with earlier estimates throughout the study period (1995-2020).[3] The principal source of the downward revisions is significantly improved vehicle performance deterioration factors. The following table shows the adjustments to the original light-duty gasoline-fuelled vehicle fleet[4] inventory for NOx and VOC that were determined in this study for 1995 and 2020:

---

[3] CO results are included in the body of the report for completeness. The CO reductions, although considerable, were not evaluated further for potential impacts because of the apparent weak association with health effects. CO itself is not a priority regional air quality issue, and it does not contribute appreciably to formation of particulate matter or ozone. Vehicle CO emissions are also being reduced by other measures than the ones evaluated here. The CO data are omitted from the Summary.

[4] Vehicles with gross vehicle weight, GVW, less than 8,500 lbs. Excluding the small number of light-duty diesel-fuelled vehicles in the existing fleet.

Revisions to Original LDGV Inventory to Produce New Study Baseline

Pollutant	Year	Original Inventory (tonnes/year)	Study Baseline (tonnes/year)	Percent Reduction (%)
NOx	1995	19,151	15,345	20
	2020	14,830	9,537	36
VOC (NMOG)	1995	21,025	16,971	19
	2020	18,428	6,536	65

2. The following table summarizes the scenario results for 2020 for the light-duty, gasoline-fuelled vehicles in the on-road fleet.[5]

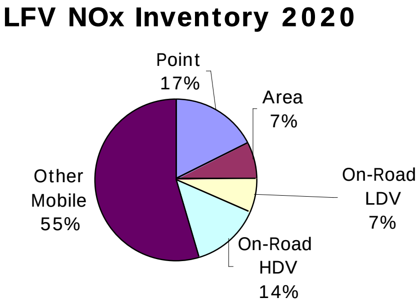
LDGV Emission Baseline and Scenario Reductions in 2020

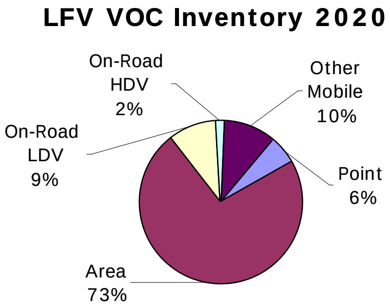
	LDGV	**LDGV NLEV/Tier 2**			**LDGV NLEV/LEV II**			
	Study Baseline (t/y)	Emission (t/y)	Reduction (t/y)	% Red. (%)	Emission (t/y)	Cumulative Reduction (t/y)	Incremental Reduction (t/y)	Incr. % Red. (Δ%)
NOx	9,537	2,363	7,174	75%	2,181	7,356	182	2%
VOC	6,536	4,762	1,774	27%	4,462	2,074	300	5%

3. The incremental reductions in emissions of NOx and VOC for the LEV II implementation scenario are small in comparison with the Tier 2 reductions—a few percent of the Tier 2 reductions (as shown in the last column of the summary table).
4. By 2020, emissions of NOx and VOC from the on-road light-duty vehicle fleet would comprise about 7% and 9%, respectively, of the total regional emission inventory of these pollutants, compared with 31% and 26%, respectively, in 1995. The following graphics illustrate the relative contribution of the LDGV fleet to the overall regional inventory by 2020 that would result from the implementation of the NLEV/Tier 2 scenario.

---

[5] NLEV standards were not evaluated separately—only in combination with Tier 2 or LEV II. Each scenario was treated as a continuous transition from current standards to Tier 2 or LEV II. NLEV vehicles contribute to emission reductions between 2001 until Tier 2 or LEV II is phased in fully. Some of the emission reductions during the transition years are attributable to NLEV vehicles, but by 2020, the fleet is essentially all Tier 2 vehicles or all LEV II vehicles.





5. The effects on air quality of implementing NLEV and Tier 2 would be—
    - lower regional PM_{10} levels in 2020 by about 0.2 µg/m^3 on annual average (relative to a forecast 14 µg/m^3)
    - lower average peak ozone levels in the eastern part of the Lower Fraser Valley in 2020 by about 4 ppb (relative to a forecast peak of about 60 ppb)
    - no measurable effect on ozone levels in the urban (western) part of the region—possibly a slightly detrimental effect.
6. Corresponding reductions in health effects outcomes for reaching the Tier 2 emission levels occur for both PM_{10} and ozone—including on average about 1 premature death per year over the period 2004-2020. Most of the avoided health effects are attributable to lower PM_{10} ambient concentrations.
7. The central estimate of the monetized benefit of hypothetical avoided health effects of implementing NLEV and Tier 2 averages $11 million per year over the period 2004-2020, 93% of which is due to lowered PM_{10}. The annual benefit reaches $19 million in 2020.
8. The hypothetical health effects benefit of the additional emission reduction that would be achieved by implementing NLEV and LEV II would be about $0.4 million per year on average over the period. This is about 4% of the NLEV and Tier 2 benefit.
9. The incremental direct consumer costs of the two programs are estimated to be[6]—
    - $120 per new passenger car purchased for Tier 2 (relative to NLEV/Tier 1) and
    - $270 per new passenger car purchased for LEV II (relative to NLEV/Tier 1).

---

[6] Illustrative cost estimate for passenger cars only. Other classes of vehicles, such as SUVs and light and medium-duty trucks, are included in the programs, but available cost estimates are very approximate. The final Tier 2 rule cost-effectiveness analysis by EPA suggests incremental costs for the heavier classes of vehicles of less than about twice the passenger car cost for light trucks and less than 3.5 times the passenger car cost for medium-duty passenger vehicles. For our purposes, we can assume that the new vehicle purchases consist of about 50% passenger cars, 25% light-duty trucks and 25% medium-duty passenger vehicles (heavy SUVs, etc.).

10. The corresponding incremental cost-effectiveness values for passenger cars are (very approximately)—

    - $1,700/tonne of (NOx +VOC) for Tier 2 relative to NLEV/Tier 1 and
    - $33,000/tonne of (NOx + VOC) for LEV II relative to Tier 2.

    The Tier 2 value compares favourably with the cost-effectiveness of other measures in the GVRD and FVRD Air Quality Management Plans, including other transportation-related measures. The LEV II value would place it in a category generally considered to be not cost-effective.

11. A rough estimate of the annual consumer cost of implementing Tier 2 is about $34 million per year, given the new vehicle purchase premiums cited above (9) and approximately 150,000 new light- and medium-duty passenger vehicles purchased each year in the LFV region. This is a partial and approximate statement of annual consumer costs, but the central estimates of estimated purchase costs and average benefits are approximately in balance within the significant uncertainties in both quantities. Taking the relative LEV II costs for passenger cars as applying to the new purchase fleet, the estimated incremental consumer cost of LEV II (compared with NLEV/Tier 1, as above) would be about $75 million per year.

12. There are major uncertainties in the values of all of the parameters that make up the bottom lines of this analysis. It is believed that the relative numbers—differences between various baseline and scenario estimates—are reasonably sound. In particular, the relative difference between vehicle emissions in the Tier 2 and LEV II implementation scenarios is believed to be acceptably accurate, since consistent, up-to-date emission modelling was used for both. Statistical uncertainty analysis indicates that the range of the monetized health benefit, for example, could be a factor of 2 or more larger to a factor of 3 or more smaller than the central value cited above (7). The Tier 2 and LEV II cost estimates in (11) are probably accurate to within a factor of 2.

13. For the additional measures analyzed, the cost-effectiveness of emission reductions varies significantly—

    - Transit buses: The available data do not permit a definitive statement about the cost-effectiveness of the alternatives to diesel transit buses. All of the alternatives to conventional diesel transit buses are currently less cost-effective than NLEV/Tier 2 and other measures considered, but may be more cost-effective than NLEV/LEV II. The estimates are based on partial analysis that considers only capital costs and ignores operating, maintenance and fuel costs. A more complete analysis is required.
    - ACORP. Cost-effectiveness for this program is good, considering that it targets PM and HC reductions only.
    - Scrap-It Program. Cost-effectiveness is good (comparable with NLEV/Tier 2) based on the costs of the full package of incentives.

Conclusions

1. The principal conclusion to be drawn from this study is that future vehicles conforming to the Tier 2 standard will eventually lower emissions from the BC motor vehicle fleet considerably (particularly SUVs and light- and medium-duty trucks). Implementing the California LEV II standards would produce relatively small incremental emission reduction benefits at a cost per tonne of pollutants in a range that is generally considered not cost effective.
2. With the revisions to the light-duty fleet emission inventory reported here and the implementation of the NLEV/Tier 2 scenario, the LDGV portion of the mobile source sector will become a relatively minor contributor to the total regional emission inventories of NOx and VOC (NMOG) by 2020.
3. Of the additional measures analysed, only the Scrap-It program is comparable with NLEV/Tier 2 in cost-effectiveness. Alternatives to diesel buses appear to be less cost-effective than Tier 2, but based on preliminary analysis, may be potentially more cost-effective than LEV II on a cost/tonne of pollutants basis.

Data Gaps and Future Work

The next steps to substantiate the findings of this study or fill data gaps, for subsequent action by the sponsors or others are as follows—

1. It is strongly advised that the vehicle emission estimates be redone when the US EPA's MOBILE 6 model becomes available. The preliminary estimates based on the adapted MOBILE 5b model (which incorporates many of the inputs that will go into MOBILE 6) should not be relied on as definitive. EPA indicates currently that a preliminary version of the model should be released by fall 2000. The new model will have, among other enhancements, capability to better model any fuel quality-related factors that have not been addressed here.
2. Better, Canadian-specific consumer cost and program implementation data for future low emission vehicles in BC are required to determine the accurate cost-effectiveness of the programs. This is also true for alternative heavy-duty vehicles.
3. The implications of the revised emission inventory for the current ongoing development of the UAM-V modelling system need to be assessed, including the impacts of the estimated emission reductions on both ozone and fine particle concentrations. Estimates from this study based on earlier UAM-V results may be significantly in error.
4. The potential implementation of stringent low emission vehicle requirements in the eastern US states (possibly equivalent to LEV II) should be tracked through continued contact with NESCAUM, since opening such a large market to low emission vehicles would undoubtedly influence the cost-effectiveness of bringing them into Canada.

1.0 Background

The Province of British Columbia is assessing the impact of implementing more stringent motor vehicle emission regulations to complement the existing BC Motor Vehicle Emission Reduction Regulation (1995, amended 1999). One of the possibilities is to implement low emission vehicle (LEV) requirements equivalent to those currently being scheduled by California for vehicle model years (MY) 2004 and later (referred to as the "LEV II" standards). The US Federal Government has also promulgated stringent low emission vehicle emission standards for the whole US to take effect in MY 2004 and later (referred to as the "Tier 2" standards). Both California and the US Federal Government have implemented low emission vehicle programs that bridge the transition from current standards to Tier 2 or LEV II (referred to as "LEV" and "NLEV," respectively).[7] Any regulatory action by BC would take place in the context of the influence that these US programs will have on the future availability of new, low emission vehicles for purchase in BC.

A group of interested parties funded the current project, whose purpose is to evaluate the above programs as possible options for BC. The group of sponsors constitutes the project steering committee and comprises—

- BC Ministry of Environment, Lands & Parks
- Greater Vancouver Regional District (GVRD)
- Environment Canada
- Canadian Petroleum Products Institute (CPPI)
- Canadian Vehicle Manufacturers' Association (CVMA)
- Association of International Automobile Manufacturers of Canada (AIAMC)
- TransLink (Greater Vancouver Transportation Authority, GVTA)
- Fraser Valley Regional District (FVRD)

The Clean Transportation Analysis Project is being conducted to assess the relative benefits of a number of transportation-related initiatives in the Lower Fraser Valley. The core objective is to support the analysis of the impact of various vehicle emission standards for the period 2004-2020. The project Terms of Reference address standards for the light-duty gasoline vehicle portion of the fleet, since BC is not contemplating additional requirements for light-duty diesel vehicles or the heavy-duty portion of the fleet at present. The analysis includes—

1. estimating emission reductions from implementation of the US EPA and California emission standards and programs for the period 2001-2020
2. estimating related ambient air quality improvements in the Lower Fraser Valley
3. estimating economic costs of achieving the air quality improvements and, hence, estimating cost-effectiveness of the programs, and

---

[7] The BC Motor Vehicle Emission Reduction Regulation requires that NLEV-equivalent vehicles be available in BC beginning in 2001. New York State recently announced that it will implement the California LEV II standards, and the NESCAUM consortium of US northeastern states is considering doing the same.

4. estimating health and other benefits associated with the air quality improvements.[8]

Additional transportation initiatives in the Lower Fraser Valley that are not related to possible changes in light- and medium-duty motor vehicle emission regulations are also being evaluated. These were evaluated for comparative cost-effectiveness with the light-duty vehicle regulations and include—

- purchase of alternate-fuelled transit buses (compressed natural gas, Ballard fuel cell-powered, diesel hybrid relative to future diesel bus emissions)
- AirCare On-Road Program (ACORP) inspection and maintenance program for heavy-duty vehicles
- BC Scrap-It older vehicle early retirement program.

---

[8] This latter activity is funded by the sponsor group excluding CPPI. See Disclaimer and Appendix G for a summary of CPPI’s position.

2.0 Methodology

2.1 General model

The process that was followed during this study to produce the required data comprises the following steps:

1. Estimate the emission baseline against which the changes resulting from the emission reduction measures are evaluated.
2. Estimate changes in emissions of specific pollutants resulting from two standards implementation scenarios.
3. Estimate changes in ambient concentrations of pollutants (air quality) corresponding to the emission changes.
4. Estimate the changes in health (and other) effects associated with the estimated changes in air quality.
5. Estimate the economic impact of the two scenarios, including, estimating direct costs of implementing the emission reduction and estimating the cost-effectiveness by comparing costs against the emission reductions.
6. Estimate the hypothetical economic value of the effects that would be avoided by reducing the emissions.

The methods for each of these steps are described in this section. The results obtained are summarized in the Section 3.

2.2 Study Baseline Emissions

The pollutants that would be reduced by implementation of either US Tier 2 or California LEV II standards for new vehicles are CO, NO_x and VOC. The regulated reduction of sulphur in gasoline already committed to in Canada will reduce emissions of SO_2 and particulate matter. Road dust, another source of particulate emissions, would not be affected by changes in vehicle emission standards, nor would brake and tire wear emissions. The study baseline developed for this study includes revised estimates of emissions from light duty gasoline vehicles for CO, NO_x, VOC, SO_x, total particulate, PM_{10}, $PM_{2.5}$, and a previous estimate of emissions of road dust.

The study baseline is identical for all sources except light duty gasoline vehicles to that referred to as Scenario B[9] in the *Forecast and Backcast of the 1995 LFV Emission Inventory* prepared for the GVRD (Levelton, 1998). Emissions from the fleet of light duty gasoline vehicles (EPA categories: LDGV, LDGT and MC) in the LFV have been re-estimated in this study using the latest available emission model assuming:

- Continuation of US EPA Tier 1 vehicle emission standards first introduced in Canada in 1994;

---

[9] Emission forecast which accounts for the emission reductions from controls identified in the GVRD Air Quality Management Plan introduced/committed/legislated as of the end of 1997.

- Reformulated gasoline meeting the requirements of US RFG (see Appendix B);
- Emission reductions from AirCare® remain as estimated in the earlier forecast/backcast study and do not reflect any of the planned refinements of the AirCare® program (AirCare II); and
- Emissions of SO_2 and particulate matter from light duty gasoline vehicles decrease in proportion to the reduction in the sulphur content of gasoline in accordance with the Canadian Federal Sulphur in Gasoline Regulations.

The new estimates of emissions from the light duty gasoline motor vehicle fleet were recombined with the earlier estimates of emissions from all other sources in the region to produce the emission baseline used in this study. The study presents the emission results for the 1995-2020 period of interest for light duty gasoline vehicles alone, all light and heavy duty vehicles together and all point, area and mobile sources. Details of the emission estimation methodology and the emission model and input data used for the analysis are provided in Appendix B. Highlights of the methodology is provided in Section 2.4.

The estimates accounted for expected population growth and increase in the number of vehicles and distance travelled per vehicle over the period 2001-2020. Certain initiatives that will further influence emissions from the LDGV fleet were not addressed by the study, for example—

- greenhouse gas emission reduction measures or programs
- Cleaner Technology Vehicle (CTV) consortium activities
- changes in fuels and vehicle technology beyond the 2004 Tier 2 and LEV II requirements
- AirCare II.

2.3 Emissions with Tier 2 or LEV II Standards for Light Duty Gasoline Vehicles

This study estimates the emission reductions that could be achieved relative to the study baseline by implementing either US EPA Tier 2 or California LEV II emission and evaporative standards beginning in 2004. In both cases, it has been assumed that US NLEV emission standards will be implemented prior to Tier 2 or LEV II, starting with 100% of the new car fleet in 2001. Hence, emission reductions estimated for 2005 and later years show the combined effects of implementing either NLEV and Tier 2 standards, or NLEV and LEV II standards.

The US EPA has promulgated a program[10] to implement the mandatory Tier 2 national low emission vehicle program to follow on from the voluntarily regulated NLEV program (MY 2001-2003). For the analysis of emissions with implementation of Tier 2 standards in BC, it has been assumed the Tier 2 standards and the associated phase-in

---

[10] This analysis used the Tier 2 requirements as defined in the May 1999 proposed rule as documented in US *Federal Register*/Volume 64, No. 92/Thursday, May 13, 1999/Proposed Rules, pp. 26004 ff. The final rule was promulgated on December 21, 1999 in a *Notice of Final Rule*. Any differences between the proposed and final versions of the Tier 2 standards are not believed to affect this analysis materially.

schedules for the different classes of light duty vehicle apply. Vehicles produced under these requirements would become available in BC, and the rest of Canada, because of Canada-US vehicle emission standards harmonization which is captured in regulations under the Canada Motor Vehicle Safety Act.

Furthermore, it has been assumed that the EPA's NLEV program would be implemented for 100% of the new car fleet in BC beginning in 2001 and continue until being phased-out as vehicles meeting either Tier 2 or LEV II standards are introduced into the fleet beginning in 2004. NLEV vehicles are assumed to meet an average NLEV tailpipe emission standard. Although compliance with an NLEV program in Canada is presently voluntary, it has been assumed for this analysis that all automobile manufacturers will comply with the NLEV fleet average standards beginning in 2001.

The California Air Resources Board (CARB) in August 1999 adopted a set of emission standards for 2001 and later year passenger cars, light duty trucks and medium duty vehicles[11]. These incorporate plans to phase-in LEV II exhaust emission standards which are more stringent than LEV I standards. The analysis in this study models the effect of implementing the LEV II emission standards as described in the August, 1999 notice of the adopted standards (CARB, 1999). An important feature of the LEV II analysis is that implementing such standards for BC, in the absence of their being required elsewhere in Canada, would require a unique vehicle to be manufactured for BC. This is because of current differences between Transport Canada and US DOT vehicle safety equipment requirements.[12]

Details of the Tier 2, LEV II and existing exhaust emission standards are summarized in Appendix B. A simplified comparison of the Tier 2 and LEV II standards is provided in Table 2.1 to illustrate the most significant changes. Both Tier 2 and LEV II offer large decreases in emission standards for NMOG and NO_x from current Tier 1 standards that have been in effect since 1994. The fleet average NMOG standard specified under the LEV II program is lower than the Tier 2 NMOG standard. The mix of vehicle technologies that satisfy the LEV II fleet NMOG average (many technology combinations are possible) will also yield fleet CO exhaust emission standards that are significantly lower, and fleet NO_x standards that are slightly lower than the Tier 2 standards.

An important feature of both the Tier 2 and LEV II exhaust emission standards is that, when fully implemented, the same exhaust emission standards apply to all light duty vehicles having a gross vehicle weight up to 8,500 lbs. The LEV II program also applies new exhaust emission standards to heavier vehicles, including vehicles with gross vehicle weights of 8,500 to 14,000 lbs, although these are outside the scope of this study and were not included in the emission analysis. Existing exhaust emission standards generally allow higher emission standards with increasing vehicle weight.

---

[11] CARB, 1999, *California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles*, Adopted by the Air Resources Board of the California Environmental Protection Agency, 8/5/99.

[12] Such differences include, for example, full-time daytime running lights and stronger bumpers on vehicles sold in Canada.

Table 2.1. Current and Past Full Life (120,000 mi) Exhaust Emission Standards for Light Duty Gasoline Vehicles (g/mi)

Vehicle	NOx	NMOG	CO	Particulate
LDGV				
Tier 0	1.2	0.80	10	-
Tier 1	0.6	0.31	4.2	-
NLEV	0.3	0.09	4.2	-
Tier 2	0.07	0.09	4.2	0.01
LEV II				
LEV	0.07	0.09	4.2	0.01
ULEV	0.07	0.055	2.1	0.01
SULEV	0.02	0.01	1.0	0.01
2004 Fleet avg	-	0.053	-	-
2010 Fleet avg.	-	0.035	-	-
LDGT1 (0-3750 lbs)				
Tier 0	1.7	0.80	10	-
Tier 1	0.98	0.40	5.5	-
NLEV	0.5	0.13	5.5	-
Tier 2	Same as for LDGV			
LEV II	Same as for LDGV			
LDGT2 (3750-8500 lbs)				
Tier 0	1.7	0.80	10	
Tier 1	1.153	0.56	7.3	
Tier 2	Same as for LDGV			
LEV II	Same as for LDGV except for fleet NMOG avg.			
2004 Fleet avg		0.085		
2010 Fleet avg.		0.043		

It should be pointed out that although the NMOG exhaust standards shown in Table 2.1 differ appreciably in some instances, the standards for evaporative emissions of NMOG are essentially the same. As the exhaust emission levels of NMOG decrease, the total vehicle emissions of NMOGs become dominated by the evaporative emissions and the overall differences between the two standards for this pollutant are reduced.

The pollutants that are addressed in this report are CO, NO_x, VOC, particulate matter (specifically, PM_{10}[13]) and ozone. These pollutants are currently the subjects of Canada-Wide Standards (CWS) development processes and have been shown to dominate other assessments of air quality impacts of emission reduction programs in Canada and the US.

2.4 Emission estimates

The principal emphasis of the project is estimating the emission reduction benefits of the light-duty gasoline vehicle fleet under the various regulatory scenarios as described in Chapter 1. The additional transportation measures mentioned in Chapter 1 were addressed in less detail to provide preliminary estimates of emission reductions that might be achieved by means other than LDGV tailpipe emission requirements, for comparison with the results of the LDGV analysis. This section describes the approaches taken to each group of measures.

2.4.1 Light-duty gasoline vehicles (LDGV)

LDGV vehicle emissions are estimated using the following equation:

> Emission (g/year) = vehicle kilometres travelled (VkmT/year) x emission factor (g/VkmT)

Base Quantity Data

For the 1995 LFV inventory forecast, the vehicle kilometres travelled (VkmT) for each class of vehicle defined for modelling purposes by the US EPA were estimated by GVRD using the EMME2 transportation model, while emission factors for CO, NOx and VOC were generated using the MOBILE5C model. These VkmT data have been used again for the present study. However, the emission factors have been re-estimated to address the improved data on emissions from motor vehicles, the effects of gasoline sulphur content on the performance on pollution controls and the effects of vehicles meeting more stringent US Federal Tier 2 and California LEV II standards.

The VkmT values developed previously by the GVRD reflect the mix of vehicles on the road in the early 90's. There has been an increasing shift in new cars sales to larger vehicles such as vans and sport utility vehicles. With time this is changing the on-road fleet significantly from what was determined for the 1995 LFV emission inventory. The significance of the shift in VkmT distribution was investigated using data provided by Natural Resources Canada for BC on the on-road vehicle stock, distances travelled and survival fractions by age of vehicle. This data was used to estimate the distribution of

---

[13] Particles having effective diameters less than or equal to 10 micrometers, 10 millionths of a meter. A smaller size fraction of PM_{10}, namely $PM_{2.5}$, is currently of greater concern respecting health effects and is being addressed in the CWS process. Currently, inadequate monitoring data and concentration-response factors are available to enable reliable analysis of the effects of this size fraction of ambient particles. Even smaller particle size fractions are now implicated in respiratory health effects, as well as visibility degradation. PM_{10} encompasses all of the smaller size fractions within it. Essentially all of the particle emissions and ambient concentrations addressed in this study are in the $PM_{2.5}$ (and smaller) size fraction. Generally speaking, the effect of evaluating these emissions as PM_{10} is to underestimate the impact on health, for example, but not by a large factor, it is believed.

distance travelled by on-road gasoline passenger cars and light duty trucks gasoline vehicles. These results are shown below and compared to the VkmT used in the 1995-2020 LFV emission forecast and re-used in this study (note that the distribution is assumed constant in the emission forecast):

Comparison of latest VkmT data and LFV Emission Forecast

Vehicle Category	**Latest NRCan Data for BC 1997 Fleet ****		**Used for the 1995-2020 LFV Emission Forecast****
	VkmT	%	%
Cars	1.70E+10	64.9	71.9
Light duty trucks*	9.18E+09	35.1	28.1
Total for these categories only**	2.61E+10	100.0	100

* Sum of EPA LDT1 and LDT2. **The VkmT distribution shown in this comparison applies only to the listed categories and not to the full vehicle fleet.

The NRCan data for BC show passenger car VkmT are decreasing and light duty truck VkmT are increasing. The significance of this shift in VkmT to the emissions estimated in this study using the previously used VkmT distribution for the LFV is discussed in the results section of this report.

Almost all base quantity information needed to model emissions from motor vehicles were assumed to be the same as used previously for the 1995-2020 LFV emission forecast. This includes meteorological inputs, gasoline RVP, vehicle speeds and vehicle fleet characteristics. Using the modelling options available in the MOBILE model (see below) light duty vehicles were assumed to use US conventional gasoline in 1995 and 2000 and US reformulated gasoline in 2005 and later years. Gasoline sulphur content was assumed to decrease as follows: 1995-1999, 330 ppm sulphur; 2000-2004, 150 ppm and 2005 -2020, 30 ppm. Actual gasoline sulphur levels in the region were somewhat lower than 330 ppm for the initial period (175 - 250 ppm), but this discrepancy does not introduce a significant error in the current estimates, especially for the latter period, which is of most interest. These assumptions are not quite synchronized with the new Canadian requirements (150 ppm in 2002 and 30 ppm in 2005), but again, this has no material effect on the estimates.

Emission Modelling

MOBILE 5C is a Canadianized mobile source emission model based on the US EPA's MOBILE 5a model. This model was used to develop the 1995 emission inventory. However, its default basic emission rates (BERs) do not model either the Tier 2 or LEV II exhaust or evaporative emission standards. The number of BERs that can be read by the model in an input file is not sufficient to model Tier 2 or LEV II phase-in requirements, and the model does not correctly treat the effects of gasoline sulphur content on emissions. Consequently, MOBILE 5C was concluded to be unsuitable for the present study.

The US EPA is developing a vastly improved MOBILE 6 emission model for motor vehicles, however, a preliminary version of it will not be available until fall of 2000 at the earliest. The best model presently available, and the one used in this study, is the MOBILE 5b-Tier 2evap model (more specifically, Modified MOBILE5b Version 2 released June 1999), which was created by the US EPA for their own analysis of the proposed Tier 2 standards. This model addresses the problems indicated above regarding the MOBILE 5C model and incorporates an option that enables prediction of emissions assuming Tier 2 evaporative standards have been implemented.

The vehicles in Canada and the US had different emission standards and control technologies between MY 1980 and 1987. The BERs used in the present study were obtained from MOBILE 5C documentation for the 1980-1987 model years. BERs for all later model years were obtained from EPA analysis prepared in support of the development of MOBILE 6.

In developing BERs for the present study, fuel sulphur effects were isolated to allow the calculation of the changes in emissions due to a change in the sulphur content of gasoline. The factors used to calculate the effect of sulphur content on emissions were obtained from a US EPA report supporting the notice of proposed rule making for Tier 2 (EPA, 1999). The effects of all other fuel characteristics were accounted for using non-sulphur fuel factors developed for conventional gasoline and RFG in the same reference. For pre-Tier 1 vehicles, non-sulphur fuel effects were derived by the EPA from the MOBILE 5b fuel corrections, using the US Complex Model.[14] For Tier 1 and later vehicles, these factors were generated based on results reported for Tier 0 vehicles with port fuel injection and three-way catalyst technology.

The US EPA Supplemental Federal Test Procedure (SFTP) standards require manufacturers to control emissions from vehicles under aggressive driving conditions, specifically, when operated at high speed/acceleration (US06 test cycle), at high ambient temperature and with air conditioning loads (SC03 test cycle). SFTP requirements will be phased-in over three years starting with the 2000 model year for passenger cars and light duty trucks. The phase in for heavy light duty vehicles starts with the 2002 model year. Modelling of the effect of SFTP on vehicle emissions would involve considerably more complexity and difficulty because of the additional phase in requirements, the need to develop algorithms to relate test results to on-road emissions, and the additional level of standards.

Conceptually, the SFTP attempts to offset the effects of air conditioner use and aggressive driving behaviour, which lead to higher emission rates than that predicted using correlations developed by the EPA for “normal” emitter vehicles. From review of the emission factors reported by Koupal (EPA, 1999), the SFTP will result in almost total reduction in the emissions from aggressive driving and air conditioner use, and this simplifying assumption has been used in the present study. The modeling results reported in this study are based on emission correlations developed by the EPA for the

---

[14] Concerns have been expressed about the reliability of the Complex model for estimating fuel sulphur-emissions interactions, since it is based on older, possibly outdated data. It is the best estimation tool available at present.

normal emitter vehicles and assumes these fairly represent emissions from the total vehicle fleet. The emission estimates developed with this approach are anticipated to be somewhat lower than actual.

The effect of the AirCare® program on emissions from light duty vehicles was applied externally from the MOBILE model using the same emission reduction factors for CO, NO_x and VOC as applied in the forecast/backcast of 1995 LFV emission inventory (Levelton, 1998). The potential effects of AirCare II on the future vehicle emissions were not able to be evaluated. The emission reductions achieved by AirCare® relative to the estimates modelled assuming no inspection and maintenance program were assumed to be constant for the 1995-2020 period at the following rates:

CO	26.5%
VOC	19.1 %
NOx	2.3 %

Emission factor deterioration rates used in MOBILE 5C have been shown to substantially over-estimate emissions from on-road vehicles based on testing programs which have been analyzed in support of MOBILE 6 model development efforts. Consequently, the existing LFV on-road vehicle emission baseline was revised to reflect these changes. The new data indicate significantly better long-term emission reductions from the existing fleet than previously thought. The result is a large reduction in estimated emissions of CO, NOx and VOC from the existing fleet compared to the emission estimates prepared for the previous 1995-2020 LFV emission forecast.

In the present study, Tier 2 Bin 5 standards are applied as the Tier 2 average, while distributions across LEV2, ULEV2 and SULEV2 are considered as LEV II average standards. The phase-in program is dictated by NOx emission reduction for Tier 2, but by NMOG emission reduction for LEV II. A complex phase-in of LEV II was estimated based on the proposed California vehicle exhaust emission standards.[15] More details of the emission modelling approach are presented in Appendix B.

2.4.2 Additional measures

As noted in Chapter 1, three additional measures were evaluated:

- alternatives for transit bus engines and fuels
- the AirCare On-Road Program (ACORP) inspection and maintenance program for heavy-duty diesel trucks and buses
- the Scrap-It program for early retirement of older passengers cars and light-duty trucks.

The methods used to estimate emission reductions for each are described in the following sections.

---

[15] California Air Resources Board, 1999, *Proposed California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles*.

Transit buses

The emissions issue for transit buses is whether the purchase of low emission engines and engine technologies is a cost-effective emissions reduction strategy. In this analysis, we calculate the emissions benefit on a per vehicle basis, since detailed operating scenarios and future fleet makeup have not been considered. It should be emphasized that the analysis is based on existing studies and a re-working of this information. Additional, more detailed work will be required to support TransLink's future plans. This analysis does not evaluate diesel buses *per se*, since we compare the alternatives with diesel, not diesel with the displaced passenger cars. The latter analysis has been done many times previously.

It must be emphasized that this analysis is preliminary, since many factors that affect emissions and costs were not able to be incorporated because of lack of data and inconsistencies—including contradictions—among the available data.

Emissions

Four engine technologies for standard 40-foot transit buses are considered in this analysis: current diesels, natural gas, diesel-electric hybrid, and Ballard fuel cells. The comparison is for buses ordered today with delivery in 2000 or 2001. Diesel-electric hybrids and Ballard fuel cell buses are clearly still at the demonstration stage; consequently delivery and cost assumptions have been treated appropriately for these two technologies.

Diesel engine emission standards have been tightened in the 1990s and will be further tightened as the US EPA 2004 standards become effective.[16] The following table summarizes these standards. The 2004 standards were not used in this analysis of current purchases.

USEPA Heavy-Duty Vehicle Emission Standards (g/bhp.h)

Year	**NOx**	**PM**		**HC**	**CO**
		Trucks	Buses	1.3	15.5
1989	6.0	0.6	0.6	1.3	15.5
1991	5.0	0.25	0.1	1.3	15.5
1996	5.0	0.1	0.07	1.3	15.5
1998	4.0	0.1	0.05**	1.3	15.5
2004	2.4/2.5*	0.1	0.05**	See NOx	15.5

*Combined NOx plus NMHC, **0.07 in-use

Natural gas fuelled (NGV) transit buses have gained a 10 to 25% market share of new bus purchases in North America in the last five years based on the expectation of better emission performance than diesels, as well as purchase incentives. About 93% of the US transit fleet is diesel buses and 3% NGV buses (as at December 1997). The experience

---

[16] Diesel engine manufacturers have agreed to meet the 2004 standards by October 1, 2002 as part of the 'Diesel Engine Settlement' between the manufacturers and the US Federal Government.

with natural gas has been mixed. NGV buses have delivered emission improvements (especially for PM), but vehicle costs, fuelling station costs, maintenance and operations have been problem areas. Opinions are polarized on NGV buses: a number of transit operators are pleased with their NGV buses, but a significantly greater number are not.[17] NGV transit buses are available from suppliers such as New Flyer and Orion.

A diesel-electric hybrid bus has a smaller than normal diesel engine (horsepower about 50-60 percent of a standard diesel bus) and a battery/electric motor arrangement in various series or parallel configurations to optimize power delivery for acceleration and to take the benefit of regenerative braking. The smaller diesel engine operates at a consistent load point with improved emissions performance. Overall, fuel efficiency improves 70 to 100% and emissions are reduced accordingly. Orion Bus Industries has five hybrid buses on trial with the New York City Transit with five more planned for delivery in 2000. [18] Environment Canada has tested the Orion hybrid bus on the Central Business District (CBD) test cycle, the most commonly used test cycle for these vehicles.

The fuel cell bus is, effectively, a zero emission vehicle although there are emissions associated with the hydrogen fuel supply (dependent also on whether hydrogen is used directly or is derived from on-board reformed methanol, for example). For purposes of this calculation the Ballard buses are considered to be zero emission vehicles.[19]

AirCare On-Road Program (ACORP)

AirCare On-Road (ACORP) is an on-road inspection program for heavy-duty vehicles. The program is currently provided by and funded through ICBC. It is jointly administered by the AirCare® Program Administration office, which provides functional direction, administrative support and program oversight. The program consists of two vans each with a complement of two people: a peace officer (with authority to stop vehicles and issue safety infraction tickets) and an emission test technician.

The two-man teams observe heavy-duty diesel vehicles (HDDV) on public roadways and stop smoking vehicles that they believe may fail the opacity test (SAE J1667). The vehicle operator is instructed to provide a snap acceleration demonstration, and depending on the result the driver is either free to go or the SAE J1667 smoke opacity test is administered. The test consists of three snap accelerations to clear any smoke (particulate) build-up in the exhaust system followed by three snap accelerations that are tested. A probe placed in the exhaust conducts samples to the test equipment in the van that measures the opacity of the exhaust (percentage of light absorbed).

---

[17] US General Accounting Office (1999), *Mass Transit: Use of Alternative Fuels in Transit Buses*, GAO/R CEP-00-18, December 1999.

[18] On December 20, 1999, Orion announced that New York City Transit (MTA) has ordered 125 hybrid-electric diesel buses and 125 low-floor CNG buses.

[19] If fuels produced from fossil sources are used for on-board reforming, small amounts of CO and significant amounts of CO_2 are emitted. CO_2 emissions are relatively smaller than from internal combustion engines because of the higher energy conversion efficiency of the fuel cell. See Levelton (1999).

ACORP targets particulate emissions (smoke) from HDDV. Since excessive particulate emissions are associated with over-fuelling of the engine, vehicles that fail the smoke test and are repaired subsequently achieve reduced particulate (PM) and hydrocarbon (HC) emissions. The emission reduction estimates used in this analysis are those provided by Sierra Research in the Phase II Feasibility Report[20]. No more recent information correlating the SAE J1667 snap-acceleration opacity test with on-road emission performance was uncovered [21]. The Sierra report attributes PM and HC emission reductions to ACORP, but no reductions in NOx or CO.

For 1990 and older vehicles a failure is an opacity reading of 55 percent or greater. For 1991 and newer vehicles a failure is a reading of 40 percent or greater. Vehicles that fail the test receive an 'Emissions Notice and Order' and may be issued a violation ticket with 30 days in which to repair and have the vehicle re-tested. If, after 30 days, no repair and retest has been performed, a 'Refuse to Issue' is registered against the vehicle and ICBC will refuse to license the vehicle at its next renewal date. A vehicle owner can repair and retest at anytime and clear the 'Refuse to Issue' order allowing the owner to license the vehicle.

Emission Estimates

The Sierra report considered six different configurations for the ACORP. The excess emissions factors in the Sierra report corresponding to the current ACORP ('On-Road Inspection by Trained Smoke Observers in Patrol Vehicles – Focussed Variant') are used to estimate the emission reductions for the Lower Fraser Valley.[22] Note that the 'Study Baseline' emissions of the HDDV fleet are the starting point.

The Sierra report indicated ten test vans and 10,400 tests would be needed to achieve full coverage for the Lower Fraser Valley. The experience, after six months of operation of the program, is that two vans and 1,400 tests per year will provide full coverage of the Lower Fraser Valley.

The operating numbers are that each van, in a normal working day, observes 60 trucks, stops six trucks for a snap-acceleration pre-screen, tests three trucks using the J1667 test, and two trucks fail and receive repair and retest Notices and Orders:

---

[20] Sierra Research Inc. (1994) *Phase II Feasibility Study: Heavy-Duty Vehicle Emissions Inspection Program in the Lower Fraser Valley*, September 1994.

[21] Nigel N. Clark et al (1999) *"Field Measurement of Particulate Matter Emissions, Carbon Monoxide, and Exhaust Opacity from Heavy-Duty Diesel Vehicles*, Journal of Air and Waste Management, Volume 49: September 1999. This paper concludes "that opacity measurements may not prove to be a precise tool for identifying high PM emitters."

[22] The Sierra report estimates 'excess' emissions for HDDV resulting from tampering or engine maladjustment. It is these excess emissions that are the target of ACORP.

ACORP Statistics (actual performance, 1999)[23]

	Trucks per Van per Day	Percent	Trucks per Year*
Observed	60	100	28,000
Stopped/Pre-screened	6	10	2,800
Tested	3	5	1,400
Failed	2	3.3	933

* with two vans

About 22,000 HDDV are registered with ICBC in the Lower Fraser Valley, and possibly as many again are registered elsewhere and visit the LFV on occasion (see Footnote 23). Twenty-eight thousand HDDV vehicle observations per year provide essentially complete coverage of the LFV fleet. The anecdotal evidence to support completeness of the ACORP coverage is that, during the first six months of operation, 40 percent of vehicles reported to the Smoke Hotline (to which private individuals can phone in to identify and report a smoking truck) had already been stopped and issued Emission Notices and Orders.

Scrap-It Program

Scrap-It is an air-emission reduction program designed to take older, high-polluting vehicles off the road. In British Columbia a pilot program commenced in early 1996 [24]. By the end of 1997, the Scrap-It Pilot Program had removed about 1,000 older vehicles from the Lower Fraser Valley and Victoria. An evaluation of the Pilot Program was conducted to determine whether the program met its emission reduction objectives and whether the program was a cost-effective means of emission reduction[25].

The Scrap-It Pilot Program was a strictly voluntary program that offered incentives for owners of 1983 model year and older vehicles, who met the qualifying criteria, to scrap their vehicle. The success of the Scrap-It Pilot Program lead to an expanded Scrap-It Program commencing in November 1998.

Since the primary objective of Scrap-It is to reduce tail pipe emissions, the qualifying criteria for participating in the program are designed to ensure that vehicles accepted are high polluting vehicles in regular use. To participate in the program, a vehicle owner must meet the following criteria:

---

[23] Neil Brown, ACORP, personal communication, December 1999.

[24] British Columbia Lung Association (1995) Feasibility Study. Voluntary Scrappage Program for Older High Polluting Vehicles for the British Columbia Lower Fraser Valley Area. Prepared for the British Columbia Lung Association by BOVAR-Concord Environmental and Constable Associates Consulting Inc. May. This multi-stakeholder feasibility study lead to the Scrap-It pilot program.

[25] Scrap-It Program, 1997. *Evaluation of the Scrap-It Pilot Program*, Scrap-It Program Steering Committee. August.

- Must own and currently operate a 1987 model year or older car or light-duty truck
- Must have insured the vehicle for the last year in the Lower Mainland AirCare® test area
- The vehicle must have failed an AirCare® at some point in its history
- If the insurance is for ‘pleasure use only’, must have travelled at least 5,000 kilometers in the last year.

The vehicle owners are free to choose among the following incentives:

- $1,000 toward a new natural gas vehicle
- $750 toward the purchase of a vehicle
- $500 toward a 1988 or newer used vehicle
- 8 months of a 3-zone transit pass ($824 value)
- 10 months of a 2-zone transit pass ($780 value)
- 14 months of a 1-zone transit pass ($756 value)
- $900 toward a bicycle (bicycle retailer provided $150 and the program $750; since reduced to $500 total)
- $750 toward van pooling.

The expanded Scrap-It program has been operating for about one year and has approved 556 vehicles for scrapping (number limited by availability of funding for various incentives).

2.5 Air quality changes

The estimates of changes in emissions for the LDGV scenarios described in the previous section were translated into changes in air quality as follows. Only changes in emissions of pollutants that significantly affect changes in PM_{10} and ozone ambient concentrations were analyzed. Both primary (direct from emission sources) and secondary (indirect, through conversion in the atmosphere) contributions to PM_{10} concentrations were included. Air quality changes related to the additional measures were not estimated.

PM_{10} model

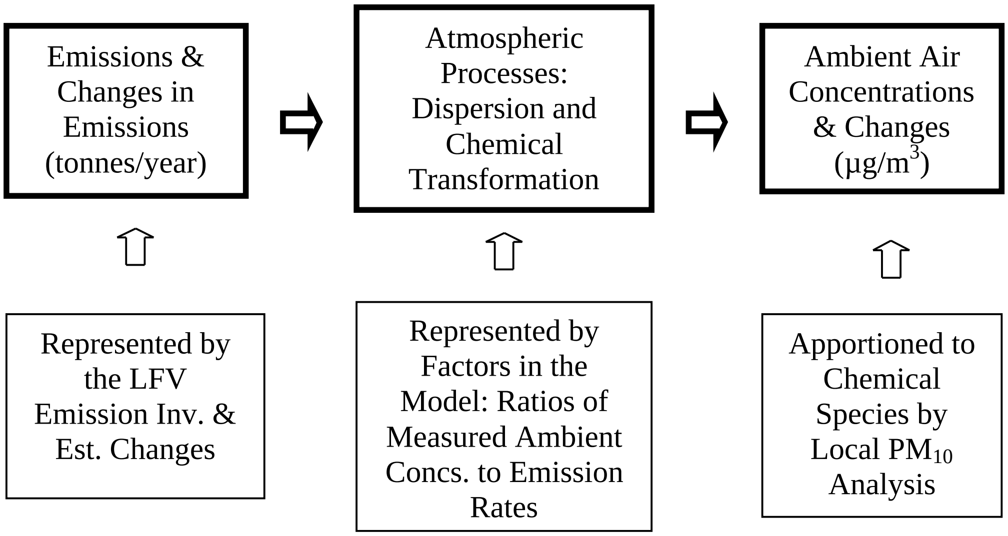
A simple spreadsheet model was developed based on algebraic relationships between measured concentrations and chemical composition of ambient particles in the Lower Fraser Valley and emission quantities of contributing pollutants. This model is similar in structure to one that has been applied to economic analysis of air quality improvements in the region for the past several years.[26] The fundamental premise of the model is that changes in ambient concentrations of particles are related to appropriately weighted changes in the amounts of emitted pollutants that end up constituting the particles at the

---

[26] See *Clean Air Benefits and Costs in the GVRD*, The ARA Consulting Group Inc. and BOVAR-Concord Environmental, May 1994 (draft), issued unchanged as final in November 1995 and *Economic Analysis of Air Quality Improvement in the Lower Fraser Valley*, BOVAR-Concord Environmental, November 1995. Both reports issued by GVRD, Air Quality Department.

locations at which they are monitored. The following graphic illustrates the elements of the model.

Schematic of the PM_{10} Air Quality Model



The model uses empirical factors that combine dispersion and chemical conversion processes to relate changes in emissions to changes in ambient air concentrations. Thus, the “Atmospheric Processes …” box above is treated as a ‘black box’ by this model. These factors are the ratios of measured ambient concentrations of pollutants or their secondary products to the emission rates of their related primary pollutants. For example, the factor for the sulphate component of PM_{10} is the ratio of the measured average ambient concentration of sulphate in the region to the total amount of SO_2 emitted annually. Thus, the factor integrates the dispersion of emitted SO_2 between sources and monitors and the conversion of SO_2 to SO_4 in travelling from sources to monitors. The estimated change in the sulphate component of PM_{10}, then, is the product of this factor and the estimated change in SO_2 emission due to reduced vehicle emissions. This is a form of linear roll-back model, which is often used in such applications. It accounts for both primary and secondary components of PM_{10}. The other constituents of PM_{10}[27] are treated similarly and the effects summed up to produce an estimate of change in the overall PM_{10} concentration. This approach is an expedient pending the availability of better physical and chemical process modelling.

---

[27] Our model comprises six components: direct non-vehicle emissions, direct vehicle emissions, soil from road dust and agriculture, sulphates (from SO_2), nitrates (from NOx) and secondary organic aerosol (from VOCs). The factors are based on the local emission inventory and local ambient air measurements, taking account of background levels.

Recent information about PM_{10} concentrations in the region,[28] as well as details provided by special studies of the chemical composition and behaviour of fine particles ($PM_{2.5}$) in the eastern part of the Lower Fraser Valley,[29] have allowed significant improvement of the earlier spreadsheet model.

The model is not a sophisticated simulation model, but it captures the essential features of relationships between emissions and ambient concentrations for the purpose of forecasting. It has the advantage of simplicity for applications such as the current estimates. Its purpose is to provide a reasonable forecast of future scenarios based on current conditions, not to provide a rigorous method for simulating these conditions in an absolute sense. The model does not explain the significant drop in regional PM_{10} levels between 1985 and 1994, but as will be seen, it now tracks PM_{10} air quality changes since 1994 reasonably well (since the introduction of the GVRD Air Quality Management Plan).

The formation of secondary (photochemically-produced) constituents of PM_{10} from gaseous precursors is a difficult process to simulate. The empirical approach of the PM_{10} model described here was extended to take into account the results of some additional advanced simulation modelling that was carried out for this study by Prof. Sara Pryor of Indiana University.

More details about the algebra of the PM_{10} model are provided in Appendix C.

The detailed steps in estimating the values that are required for the effects analysis are as follows:

1. Using the model described above, estimate the change in annual mean PM_{10} concentrations for the western and eastern portions of the LFV (divided along the line demarcating the more urban and more rural portions, roughly east and west of the Surrey-Langley boundary) for each year of the study period (1995-2020). All of the available PM_{10} data from the LFV monitoring network for the 4-year period 1995-1998 were analyzed for this study.
2. From the detailed monitoring data from the LFV network, determine the number of days on which the 24-hour average concentration exceeds a possible effects threshold (taken as 0, 10, 15, 20 or 25 µg/m^3, with 15 as the default). See below for rationale. The model accommodates specifying any threshold value or a statistical distribution. The days so selected are referred to as ‘effective days’ subsequently.
3. Combine the mean annual concentration change with the number of effective days[30] by assuming that the mean annual change occurs on each of the effective days, if that

---

[28] GVRD and FVRD currently operate 13 PM_{10} monitors in the LFV network, and detailed chemical analysis is carried out on samples from two additional monitors in the GVRD that have been operated by GVRD for Environment Canada since 1984.

[29] Such studies include the Pacific ’93 intensive field study carried out by a large team of academic and government researchers, and the REVEAL and REVEAL II studies of visibility impairment in the eastern Valley sponsored by the Province and the FVRD from 1993-95.

[30] The reason for selecting the effective days according to these criteria is that the health effects concentration-response factors are, for the most part, expressed as risk factors for a change of 1 µg/m^3 in daily mean concentration for those days on which any threshold of a given health outcome is exceeded. For

is appropriate to the health outcome being evaluated. Otherwise, the change in mean annual concentration is taken to occur on each day of the year for estimating effects responses.

The ozone model

Ozone is not emitted directly in any significant amount from emission sources in the region. It is formed in the atmosphere by chemical reactions among directly emitted precursor pollutants. These chemical reactions take place primarily under the influence of sunny days and warm temperatures (25C and greater) with calm winds. Several models have been developed to relate emissions of ozone precursors to production of peak ozone concentrations in the region during high ozone formation episode days or periods. A long-term program to implement and apply an advanced model of photochemical formation of ozone in the Lower Fraser Valley is in progress.[31] This modelling system is currently based on the UAM-V model developed in the US, with the addition of customized local emission inventories, and meteorological and wind field modules. Other advanced photochemical simulation models have also been applied in the region (see Footnote 31). Their results to-date have been confined to estimating peaks in ozone concentrations that are produced during a few short episodes. Their repertoire is expanding, and they have led to a significantly improved understanding of how changes in precursor emissions are related to changes in ozone concentrations and their geographic patterns. The results of the regional ozone modelling to-date have been adapted to aid in this study.

The principal ozone precursors are NOx and VOCs (NMOGs). Changes in their emissions have been estimated as described above. The results of the regional ozone formation modelling cited in the previous paragraph were provided by Environment Canada in a format that permits application to the requirements of this study. The UAM-V results for simulation of a 1993 mild ozone episode are the principal basis for estimating changes in peak ozone concentrations as a function of changes in NOx and VOC emissions.

Changes in peak ozone concentrations estimated to result from NOx and VOC reductions were used to scale the mean peak-hour ozone concentrations as monitored at selected LFV monitoring stations. Determination of changes in peak hour ozone was done only for those days on which the mean daily concentration significantly exceeded a typical background concentration.[32] This screening is to select those days on which changes in

---

most health responses to PM_{10}, no threshold has been identified—premature death being the only possible exception. The effects model used here differs from AQVM in this respect. See the section below on health effects for more information. The US EPA has used a threshold PM_{10} mortality response threshold of 15 $\mu g/m^3$ in its cost-benefit analysis of the Tier 2 standards.

[31] The program is coordinated by Environment Canada, and several academic, government research and consulting organizations are involved. The program is currently being expanded to include capability to model particle dispersion and formation. The National Research Council of Canada (NRC) has also developed an LFV modelling system based on the CALGRID model.

[32] This value was taken as 25 (default) or 35 ppb (sensitivity), which is about twice the annual average level and characteristic of regional background on days on which elevated ozone levels occur. This screening level selects the days similar to those that have been modelled in episode analyses. Alternatively, the CWS

anthropogenic emissions would significantly influence changes in peak concentrations (referred to hereafter as the number of ‘effective days’) and to be consistent with the episode focus of the modelling work. Ozone monitoring data for the entire LFV network for the four-year period 1995-1998 were analyzed.

The detailed steps in determining the change in ozone concentration associated with changes in emissions were as follows:

1. Estimate the change (decrease or increase) in peak ozone for each of four sub-regions of the LFV for the estimated emission reductions at 5-year intervals through the study period (2000-2020).[33]
2. Scale the mean peak hour ozone concentrations for the recent 4-year monitoring period (current conditions) at related monitoring sites by the estimated relative changes determined in (1).
3. Estimate the year-to-year changes in mean peak hour ozone concentrations for the various sub-regions of the LFV by interpolating between the five-year interval values determined in (2).
4. Determine the number of days per year for which the change in ozone concentration is to be counted (by having a mean daily 24-hour concentration greater than a background value of either 25 or 35 ppb). This defines the number of ‘effective days.’

It must be emphasized that this procedure for estimating ozone concentration changes is fraught with uncertainty. The regional photochemical model results, for example, are for a small number of selected episodes. The meteorology associated with these episodes may not represent the conditions even of similar episodes over the long study period. The results and conclusions respecting ozone, then, must be used with caution. In addition, as we will see, the emission inventory on which the modelling has been based may have overestimated actual emissions appreciably.

2.6 Cost-effectiveness estimates

Calculating the cost effectiveness is a means of comparing program costs with the estimated physical reduction in emissions. Specifically, what are the direct consumer costs per tonne of pollutant reduction? The costs are the incremental retail prices for a vehicle that meets the new emission standards, i.e., Tier 2 standards or LEV II standards. The pollutant reductions evaluated here are NOx and VOC primarily, although CO is shown for completeness.

Reference Levels for ozone could be used to select the effective days. The uncertainty that such a choice of screening tool creates has been addressed in the statistical analysis described in Chapter 4.

[33] Environment Canada data (based on UAM-V modelling for a 1993 episode) relating changes in ozone concentration with changes in NOx and VOC emissions are available for the following locations: Kitsilano, Pitt Meadows, Surrey East and Abbotsford.

The US Environmental Protection Agency (EPA) has analyzed the costs associated with the introduction of Tier 2 (compared to NLEV) and estimated the near term costs at US$ 80 for a light-duty vehicle (passenger car), with higher costs for most of the light-duty truck categories (See Appendix E).[34]

The California Air Resources Board (CARB) has analyzed the costs associated with LEV II and estimated the incremental retail price of a ULEV II passenger car (PC) at US$ 71 (See Appendix E). Again the estimated costs for the light-duty truck categories and SULEV vehicles are higher. The CARB estimate is believed to be a surrogate for the cost differential between a LEV II vehicle and a Tier 2 vehicle.

The Canadian Vehicle Manufacturers' Association (CVMA) and the Association of International Automobile Manufacturers of Canada (AIAMC) are in the process of developing estimates of the incremental retail price differentials for Tier 2 and LEV II vehicles for the British Columbia market. The LEV II value will include the added costs of Canadianizing (i.e., meeting Transport Canada's safety standards) since these vehicles for BC would be unique, if only BC requires LEV II performance. At the time of writing, the CVMA/AIAMC data were not available.

For the purposes of this discussion the following incremental retail price increases per light-duty passenger vehicle (typical passenger car) have been assumed:

Estimated incremental consumer costs

Program	**US $**	**Cdn $**
Tier 2 (relative to NLEV)	80	120
LEV II (relative to Tier 2)	100	150
LEV II (relative to NLEV)	180	270

The LEV II cost estimate has been increased from US$ 71 to US$ 100 to reflect the Canadianization costs. Both the Tier 2 and LEV II costs are likely to be higher once the CVMA/AIAMC data are incorporated in the analysis, since there are other issues such as dual certification, service training costs and parts inventories that are not addressed by the above estimates. Dual certification costs might be incurred (and passed through to buyers) by having to operate two different emission certification testing procedures for conventional and LEV II Canadian vehicles. It is not clear whether this requirement would create extra costs.

If we assume that the BC new purchase fleet of about 150,000 vehicles per year consists of 50% passenger cars, 25% light trucks and 25% medium-duty passenger vehicles, these data suggest that the annual consumer cost of implementing Tier 2 will be about $34 million/year. If the relative LEV II incremental cost for passenger cars applies to the whole new purchase fleet, the incremental consumer cost for LEV II would be $77

---

[34] In its Final Tier 2 Rule cost-effectiveness analysis, the US EPA estimates that the incremental purchase cost of light trucks meeting Tier 2 will be less than about 2 times that of passenger cars and for medium-duty passenger vehicles (SUVs, etc.), less than about 3.5 times that of passenger cars.

million/year on the same basis as the Tier 2 value. These cost estimates are probably not accurate to better than a factor of 2 (erring on the high side). To place these numbers in context, these increments amount to 1 to 2% of the total vehicle cost.

2.7 Health and other effects[35]

The emissions and air quality model is used to estimate effects resulting from changes in air quality by linking concentration changes to response factors for various health and other outcomes in exposed populations (people or non-human receptors). For this report, only human health response outcomes were evaluated in detail. The concentration-response factors that were used for this study are an updated extension of the set used for the earlier economic analysis studies in the region. The response factors are essentially those found in the current version of the Air Quality Valuation Model (AQVM) developed by Health Canada and Environment Canada to carry out analysis of national air quality improvement benefits.[36] These factors are the subject of ongoing and extensive research. The US EPA has earmarked significant research funds over the next 5 years to better understand PM_{10} and its health effects, in part, in response to recommendations by the US National Academy of Sciences/National Research Council.[37]

The approach to estimating effects of air quality changes and their valuation that is used here has become common practice in North American regulatory impact analysis. Current practice is summarized in a recent GVRD report[38]. Some of that material is presented here and in Section 2.8 below for completeness. The model for estimating effects that was used in this study, like AQVM and numerous similar studies in Canada and the US, is based on the following sequence of steps, as outlined in the Introduction. These pre-suppose the estimated changes in air quality that have been determined as described in the previous sections.

---

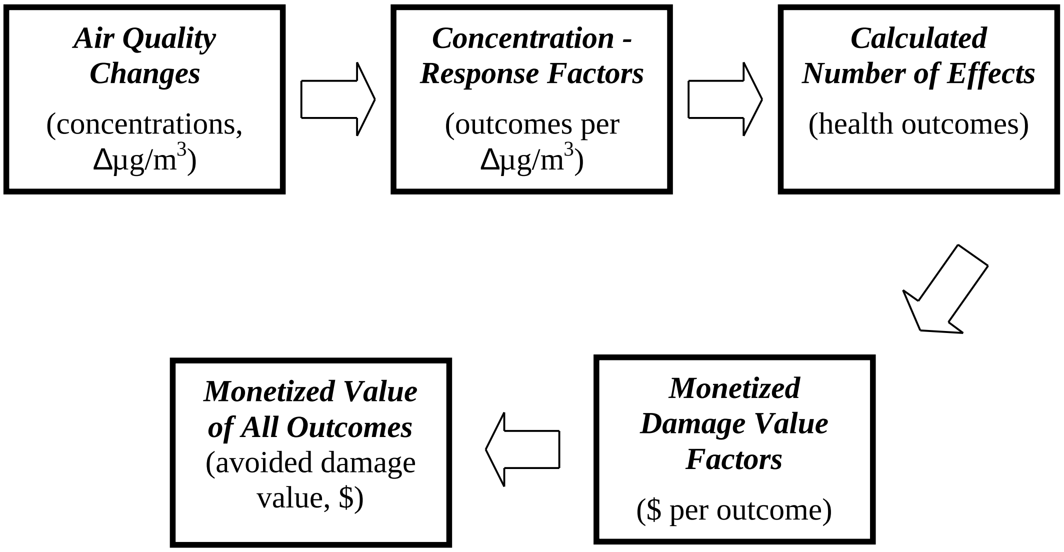
[35] See Disclaimer and Appendix G for a summary of CPPI’s position.

[36] See *Air Quality Valuation Model (AQVM), Report 2: Methodology*. Draft Final Report, Prepared for Environment Canada & Health Canada by Hagler Bailly Consulting, Inc., June 17, 1996.

[37] National Academy of Sciences/National Research Council, 1998, *Research Priorities for Airborne Particulate Matter I: Immediate Priorities and a Long-Range Research Portfolio,* National Academy Press, Washington, DC.

[38] *Greater Vancouver and Fraser Valley Air Quality Management Plan Discussion Paper: Issues, Policies and Approaches,* Alchemy Consulting Inc. and Levelton Engineering Ltd. for GVRD Air Quality Department, May 1999. Pages 24-37 of this report address the issues of air quality valuation in some detail.

Schematic of the Air Quality Effects and Valuation Model



As shown in the schematic, there are several databases that contribute to the end result—the total estimated avoided damage value. Each of these is subject to selection of the most appropriate values from the literature with associated uncertainty. The monetization aspects of the model are discussed in the Section 2.8. The specific methodology for the effects estimates follows.

<u>PM_{10} and ozone health effects</u>

A number of health responses to PM_{10} and ozone exposure were evaluated, as presented in the AQVM documentation. These responses or outcomes range from respiratory symptoms through severely debilitating respiratory and cardiac symptoms and hospital admissions (various degrees of morbidity) to premature death (mortality).

The risk factors for each potential outcome of exposure to ambient pollutants (likelihood of an outcome per unit change in ambient concentration of PM_{10} or ozone) is expressed in terms of daily or annual outcomes per 1 $\mu g/m^3$ change in PM_{10} concentration (24-hour average) or 1 ppb change in daily peak hour ozone concentration.[39]

The number of health outcomes that would be avoided by a given reduction in concentration is calculated by multiplying the following factors together:

$$\text{No. of outcomes/year} = \Delta\left[PM_{10} \text{ or } O_3\right] \quad RF \quad POP \quad \text{Effective Days/year}$$

where,

Δ symbolizes the change in ambient concentration $[\ ]$

---

[39] These concentration averages were chosen to coincide with the metrics for the concentration-response factors in AQVM.

"RF" is the specific concentration-response factor (outcomes per exposed person per µg/m^3 or ppb change in ambient concentration)

"POP" is the exposed population or sub-population, such as children or asthmatics, and

"Effective Days/year" is the estimated number of days on which the concentration reductions are deemed to apply (separate definitions for PM_{10} and ozone, see above).

2.8 Monetized benefits[35]

The project valuation model, like AQVM and the previous economic evaluations of air quality changes in the region, provides monetized avoided damage values for each of the outcomes evaluated for this project.[40] The deemed monetized value of the hypothetical health outcomes enumerated as described in the previous section and shown in the schematic diagram is the product of the value per outcome multiplied by the number of outcomes. This approach is used routinely in regulatory impact analysis to express the diverse outcomes (health or other effects) in a common unit, namely, dollars. Some of the model dollars are hard expense currency (for example, avoided health care costs) and some are deemed social costs (for example, value of a shortened life). Economists consider both types of costs to be valid elements of benefit models. A good recent summary of the status of effects estimation and valuation in cost-benefit analysis may be found in a 1997 primer by Resources for the Future.[41]

Each of the health outcomes was valued in this way. The total deemed economic value of avoiding these health outcomes by reducing emissions is the sum over pollutants (i.e., PM_{10} and ozone) and outcomes for each year. The total value for the study period is the sum over the years when the emission reduction measures would be in effect, i.e., 2001-2020 for the NLEV & Tier 2 or NLEV & LEV II combinations.

It is controversial whether these benefits over the extended period of time should be discounted to determine present value, and if discounted, by what percent. For this study, we have not proposed discounted values and express the results in nominal current Canadian dollars.

---

[40] In current practice in North America, cost-benefit analysis in more or less the form used here is routinely applied to evaluating impact of regulatory initiatives. The US Office of Management and Budget (OMB), for example, specifies that monetized benefits are to be estimated according to a "best practices" directive under Executive Order 12866, January 1996. Draft recommended practice in Canada is similar—see *Framework for the Application of Socio-Economic Analyses in Setting Environmental Standards*, Economic Integration Task Group, Canadian Council of Ministers of the Environment, July 1998.

[41] *Cost-Benefit Analysis and Regulatory Reform: An Assessment of the Science and the Art*, R.J. Kopp, A.J. Krupnick and M. Toman, Resources for the Future Discussion Paper #97-19, January 1997. See also *Greater Vancouver and Fraser Valley Air Quality Management Plan Discussion Paper: Issues, Policies and Approaches*, Alchemy Consulting Inc. and Levelton Engineering Ltd., for GVRD, May 1999.

2.9 Uncertainty

It is clear just from the number of factors that enter into all of the above estimates that there will be significant uncertainty in the final benefit estimates. For the purposes of this report, we have reported our "central" estimates as the best representation of the results. Uncertainty analysis based on ranges of values or statistical distributions for the following factors has been carried out to illustrate the effect of uncertainty in these parameters on the range of possible overall estimates:

- PM_{10} concentration change (as surrogate for overall uncertainty in emission estimates and extension to ambient concentration)
- ozone concentration change uncertainty (as for PM_{10})
- PM_{10} mortality outcome threshold (controls number of effective days)
- ozone number of effective days (surrogate for reference level or threshold)
- PM_{10} concentration-response factors (all)
- ozone concentration-response factors (all)
- outcome monetized values (all).

Other factors in uncertainty that have not been addressed quantitatively include, for example:

- potential effect on emissions of greenhouse gas reduction measures
- formal cost uncertainty (does not affect benefit estimates)
- increasing uncertainty in emission estimates as time progresses (creating larger relative uncertainty in concentration changes further into the future)
- fundamental emission model uncertainties
- fundamental concentration-response model uncertainties
- impact of potential changes in other mobile source sectors (i.e., off-road heavy-duty, rail, marine, air)
- uncertainty in the non-vehicle portion of the regional emission inventory (affects the relative contribution of vehicle emission reductions)
- timing and form of new vehicle emission requirements, including classes of vehicles covered
- impact of advanced on-board diagnostics technology (OBD II, etc.) and other technologies not yet tested
- impact of promulgated and potential new standards for heavy-duty vehicles
- impact of fuel quality parameters not addressed, such as MMT or oxygenate content and ultra-low sulphur.

The uncertainty estimates were integrated by means of a probabilistic simulation using a Monte Carlo random sampling program.[42] This method selects values randomly from the

---

[42] This technique was applied in the 1995 economic analysis cited above, and more details may be found in the report, *Economic Analysis of Air Quality Improvement in the Lower Fraser Valley*, BOVAR-Concord

uncertainty distributions assigned to the various parameters and carries the calculations through to the final result (either the number of health or other outcomes or the monetized value of those outcomes). The process is iterated as many times as necessary (in our case, 5,000) to build up an adequate picture of the statistical distribution of possible final results. Statistically-defined assumptions specifying the uncertainty distributions for thirty-one parameters were used in the analysis.

The analysis method includes sensitivity analysis for each parameter to which an uncertainty distribution assumption is assigned.

Details of the uncertainty analysis are given in Appendix F.

Environmental, November 1995. It was also used in the 1997 work of the Atmospheric Science Expert Panel in the Joint Industry/Government Study of Sulphur in Gasoline and Diesel Fuels.

3.0 Results

3.1 Emission estimates

The emission estimates for the principal measures analyzed here—the LDGV tailpipe emission regulation scenarios—are presented in detail. The results of the analysis of the additional measures described in Section 2.4.2 follow the presentation of the LDGV results.

3.1.1 Light-duty gasoline vehicles

The MOBILE 5b/T2/v.2 emission model was used to calculate motor vehicle fleet emissions for the study period, including a backcast to 1995 for comparison with the current GVRD and FVRD inventory numbers. The new model estimates considerably lower emissions for the existing fleet (i.e., Tier 0 and Tier 1 vehicles in the light-duty gasoline vehicle class – passenger cars) than the current model used for the regional mobile source emission inventory. This revision was taken into account by adjusting the original inventory. The NLEV/Tier 2 and NLEV/LEV II scenarios were then referenced to the revised baseline for the existing fleet—referred to as the “study baseline” throughout this report.

The following graphs show the estimated emissions for the NLEV/Tier 2 and NLEV/LEV II scenarios for the conditions described in detail in Section 2.3 and 2.4 and Appendix B. The data include all on-road light-duty gasoline-fuelled vehicles (LDGV). The original baseline before adjustments applied in this study is shown, as well as the revised study baseline for the existing fleet. NOx, VOC (NMOG) and CO data are shown here, but only changes in NOx and VOC emissions affect the subsequent impact evaluation of Tier 2 or LEV II. SO_2 emission changes due to implementation of low-sulphur gasoline requirements are incorporated into the baseline, and neither Tier 2 nor LEV II causes a change in particulate emissions as estimated for this study,[43] so that direct particulate emissions are also incorporated into the baseline. Changes in CO emissions are substantial, but the effects of CO are of lesser magnitude than those associated with NOx and VOC and have not been evaluated explicitly in this study.

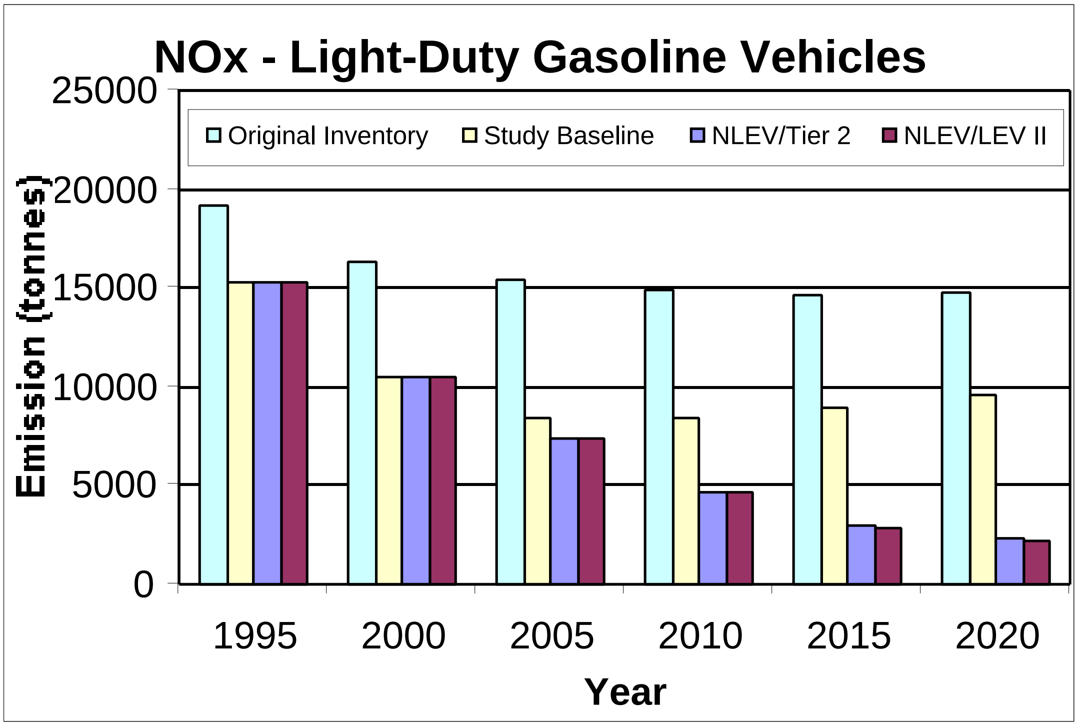
The following graphics and tables show the estimated emission reductions from the study baseline and the relative reductions of vehicle fleet emissions and total inventory for each scenario for NOx, VOC and CO.

It is clear from the graphs that although the LEV II exhaust NMOG standard is significantly lower than the Tier 2 exhaust NMOG standard, the relatively large evaporative component common to each reduces the contrast between the total NMOG emissions under the two standards.

---

[43] The US EPA PART 5 model that was used for the current inventory appears to account adequately for future emission factors under the new standards.

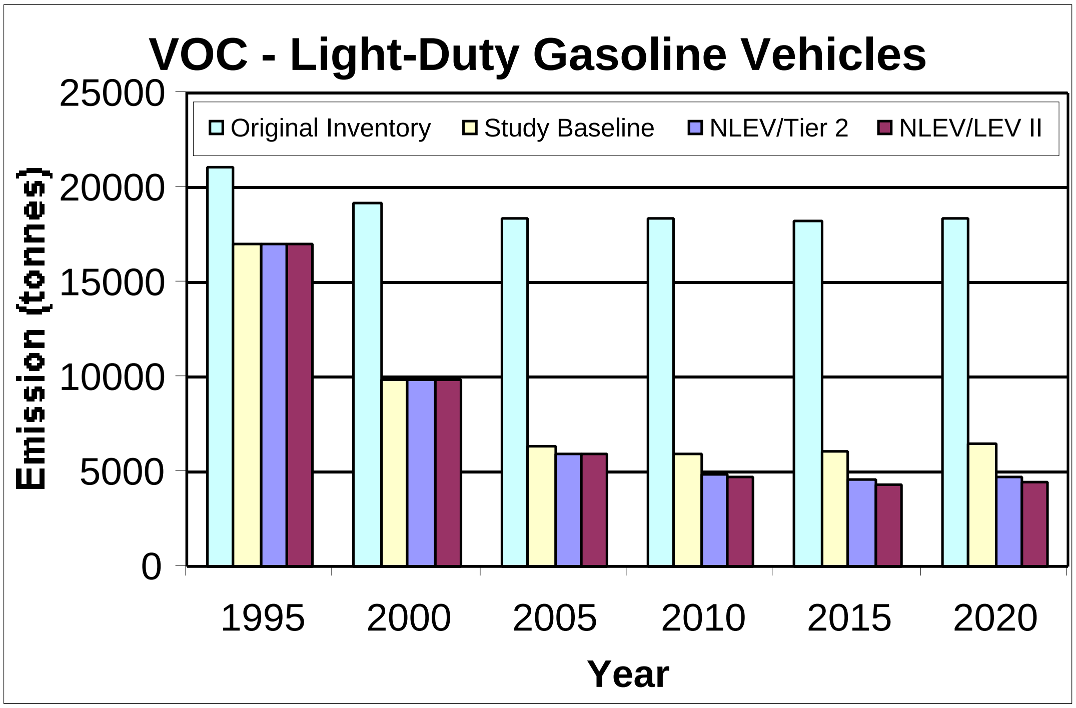
Baseline, Tier 2 & LEV II Emissions - NOx



NOx Reductions from Study Baseline (Compared with All On-Road Vehicles and Total All Sources)

Year	LDGV NLEV/Tier 2			LDGV NLEV/LEV II		
	Reduction tonnes/y	% Vehicle Inventory	% Total Inventory	Reduction tonnes/y	% Vehicle Inventory	% Total Inventory
2005	1089	8	3	1077	8	3
2010	3772	30	10	3765	29	10
2015	5953	44	15	6069	45	15
2020	7174	50	17	7356	51	18

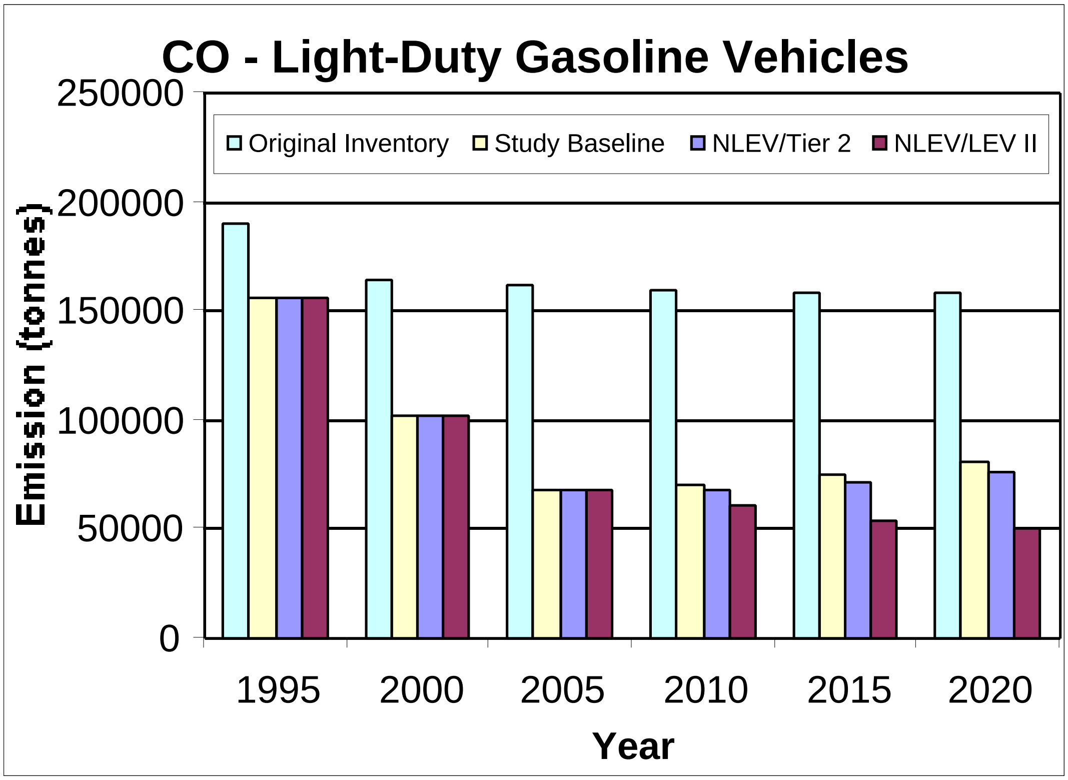
Baseline, Tier 2 & LEV II Emissions - VOC



VOC (NMOG) Reductions from Study Baseline (Compared with All On-Road Vehicles and Total All Sources)

Year	LDGV NLEV/Tier 2			LDGV NLEV/LEV II		
	Reduction tonnes/y	% Vehicle Inventory	% Total Inventory	Reduction tonnes/y	% Vehicle Inventory	% Total Inventory
2005	394	5	1	401	6	1
2010	1067	15	2	1188	17	2
2015	1524	21	3	1746	24	3
2020	1774	23	3	2074	27	4

Baseline, Tier 2 & LEV II Emissions - CO



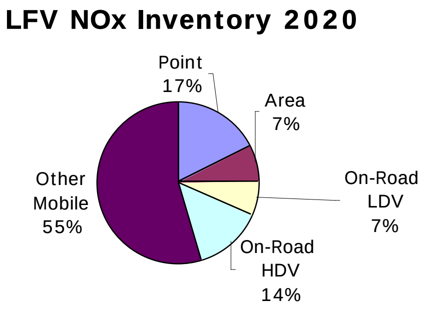
CO Reductions from Study Baseline (Compared with All On-Road Vehicles and Total All Sources)

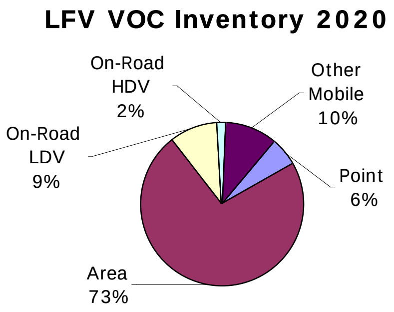
Year	LDGV NLEV/Tier 2			LDGV NLEV/LEV II		
	Reduction tonnes/y	% Vehicle Inventory	% Total Inventory	Reduction tonnes/y	% Vehicle Inventory	% Total Inventory
2005	198	<1	<1	521	<1	<1
2010	1906	3	2	8810	12	8
2015	3414	4	3	21887	27	19
2020	4227	5	3	30158	35	24

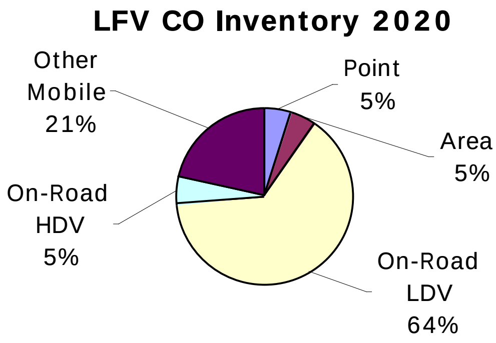
The detailed data behind the graphs are provided in Appendix B. Additional data for the other pollutants not shown here that were calculated using this model may also be found in Appendix B.

These graphs show the essential features of the differences between the impacts of the Tier 2 and LEV II standards for the purposes of this report. Both scenarios are well below the projections for the current vehicle fleet, as reflected in the Study Baseline in the figures. The most pronounced difference is the change between the original baseline and the revised baseline. A further significant emissions reduction is achieved by the implementation of the Tier 2 emissions standards particularly for NOx. The differences between Tier 2 and LEV II, except for CO, are relatively small, as shown. Also as shown, Tier 2 actually outperforms LEV II in NOx emissions in the implementation transition years (2004-2009).

The current projections of the LFV emission inventory indicate the following relative contributions of the major source sectors for 2020 when Tier 2 emission reductions are taken into account.







For comparison, the on-road LDV fleet contributed 31%, 26% and 85% to the LFV NOx, VOC and CO inventories, respectively, in 1995.

3.1.2 Additional measures

Transit buses

Table 3.1 presents a compilation of emission test data for transit buses (exhaust emissions based on the CBD test cycle). The main source of this information is the US DOE's National Renewable Energy Laboratory (NREL) and its Alternative Fuel Transit Bus Evaluation Program. Environment Canada testing of DDC 6V71 and 6V92 diesels is shown, as are the test results for the Orion diesel-electric hybrid.

There is difficulty in estimating emission factors for current engines and engine technology. Emission standards for diesel engines were changed in 1996 and again in 1998, and there are no published test data for current new in-use engines. Since the available test data refer to vehicles meeting the 1991 standard (the typical in-use fleet), better data for the currently available diesel technology would have been preferred.

Table 3.1 shows the test results for the 'without after-treatment' data. Particulate traps and catalytic treatment offer a diesel engine-specific approach to improving the emission characteristics. For example, the US EPA has a program that they assess to be cost-effective to improve the particulate emissions of the existing US transit bus fleet (Urban Bus Retrofit Rebuild Program). The consultants believe that the appropriate basis of comparison of NGV with diesel is without diesel after-treatment, since NGV requires no after-treatment, and experience with diesel emissions after-treatment technology has been mixed.[44] It should be noted that this approach ignores a number of mitigating features of currently available or soon-to-be-available diesel transit bus, such as the following items pointed out by stakeholders: (1) buses meeting the 2004 standards are now available for purchase; (2) the 2007 standards should result in lower NOx and PM emissions; (3) special, low-sulphur diesel fuel for transit buses is now available (probably less than 50 ppm eventually); (4) more effective after treatment systems are being installed and may be standard equipment on most HDVs by 2007.

Table 3.1 provides three emissions estimates for current engines – Sypher (1997)[45], Levelton (1999)[46] and the 'Study Estimate.' The 'Study Estimate' is the consultant's best estimate for current in-use engines and engine technologies. These factors are used in the emission reduction and cost-effectiveness calculations.

---

[44] After-treatment adds capital cost to the diesel bus, and the maintenance and operating experience with after-treatment systems to-date has been inconclusive.

[45] Sypher:Mueller International Inc. (1997) *BC Transit Fuel Choice Study*, submitted to Crown Corporation Secretariat, Government of British Columbia, April 1997

[46] Levelton Engineering Ltd. (1999) *Alternative and Future Fuels and Energy Sources for Road Vehicles*, prepared for the Transportation Issue Table, National Climate Change Process, prepared by Levelton Engineering in association with $(S\&T)^2$ Consulting, BC Research and Constable Associates Consulting, July 1999.

Table 3.1. Transit Bus Emission Data (Chassis Dynamometer Testing - Central Business District Test Cycle)

Emission Test Results (g/mi)

Engine/Test Location/ Year/ Number of Buses Tested	**PM****	**NOx**	**HC***	**CO**
Diesel				
Cummins L10/ Miami,FL/ 1990/ 7	1.99	22.0	1.90	23.5
Cummins L10/ Tacoma,WA/ 1991/ 9	1.74	24.6	2.40	11.2
DDC 6V-92/ St. Paul,MN/ 1991/ 9	1.05	25.3	3.30	9.5
DDC 6V-92/ Miami,FL/ 1990/ 6	2.53	26.7	2.10	16.0
DDC 6V71&6V92/ Env Canada/ 1990&91/ 7	2.26	24.5	2.40	16.9
DDD S50, Atlanta,GA/ 1994/ 3	0.66	31.5	0.12	5.2
Natural Gas				
Cummins L10(240G)/ Miami,FL/ 1991/ 7	0.01	29.0	20.60	15.8
Cummins L10(240G)/ Tacoma,WA/ 1991/ 11	0.01	30.4	9.30	21.8
Cummins L10(260G)/ New Yoek,NY/ 1993/ 10	0.03	12.0	16.10	1.6
Cummins L10(260G)/ Tacoma,WA/ 1994/ 5	0.02	11.2	15.50	0.7
DDC S50G, Atlanta,GA/ 1996/ 10	0.03	20.8	15.80	9.0
Hybrid				
Navistar T444, Environment Canada	0.32	10.7	0.22	1.78
Ballard Fuel Cell				
Assumed	0	0	0	0

Sources: NREL (1996), SAE 973203, Environment Canada (personal communication - Greg Rideout, 1997)

* Natural gas-fuelled buses emit significantly more HC than diesel buses; however, 88-95% is methane, which is essentially unreactive photochemically and does not contribute materially to smog formation. Diesel bus emissions include almost no methane. Normally, diesel bus HC emissions are compared with natural gas NMHC emissions. Hybrid bus data from Environment Canada - MSED, Report 97-26771-3.

** PM emissions can be further reduced from diesel buses by using particle traps. NGV buses do not require particle traps.

Table 3.1 (continued)

Estimated Emissions for 2000 (g/mi)

	PM	NOx	HC*	CO
Diesel				
Sypher – low (worst technology)	1.70	36.0	2.40	32.00
Sypher – likely (probable technology)	0.09	31.0	0.10	3.20
Sypher – high (best technology)	0.09	24.0	0.10	3.20
Levelton - 2000**	1.16	33.5	3.37	20.35
Levelton - 2010**	0.56	21.4	3.17	19.12
Study Estimate	0.60	25.0	2.00	5.00
Natural Gas				
Sypher – “low”	0.02	14.4	1.73	0.30
Sypher – “likely”	0.07	12.4	0.75	7.60
Sypher – “high”	0.09	14.9	0.73	7.30
Levelton - 2000**	0.04	16.8	0.51	2.05
Levelton - 2010**	0.03	10.7	0.48	1.91
Study Estimate	0.02	12.0	0.50	2.00
Hybrid				
Levelton - 2000**	0.69	19.9	2.00	12.14
Levelton - 2010**	0.31	11.8	1.75	10.58
Study Estimate	0.30	12.0	1.50	4.00
Ballard Bus	-	-	-	-

Sources: Sypher (1997), Levelton (1999)

* For Diesel and Hybrid, HC factors are THC, for Natural Gas factors are NMHC.
** These data represent the estimated on-road emissions for the transit fleet for the years indicated. The 2010 data are a surrogate for the on-road fleet that will consist mainly of new vehicles put into service in the next few years.

The ‘Study Estimate’ considered and integrated the following:

- Diesel engines. The DDC S50 is a new engine and most closely represents engines meeting the current (1998) standards.
- Natural gas engines. The Cummins L10 260G is a certified engine showing significant NOx emission improvement over the earlier L10 240G engine and represents good current natural gas engine.
- Hybrid engines. The Environment Canada test results for the Orion hybrid prototype form the basis for the 2000 hybrid estimate.

Table 3.2 shows the forecast emission reductions. The data shown in Table 3.2 were used for cost-effectiveness analysis.

Table 3.2. Emission Reductions for Transit Buses

Estimated Emissions (g/mi) for 2000

	PM	NOx	HC (NMHC)	CO
Study Estimates				
Diesel	0.60	25.0	2.00	5.00
Natural Gas	0.02	12.0	0.50	2.00
Hybrid	0.30	12.0	1.50	4.00
Ballard Bus	0	0	0	0

Source: Table 3.1

Estimated Emissions per Bus over Lifetime of Bus (tonnes)

	PM	NOx	HC (NMHC)	CO
Diesel	0.52	21.56	1.73	4.31
Natural Gas	0.02	10.35	0.43	1.73
Hybrid	0.26	10.35	0.10	3.45
Ballard Bus	-	-	-	-

Note: Lifetime mileage for transit bus - 1,380,000 km (Years 1-6 @ 90,000 km/y; years 7-20 @ 60,000 km/y, averaging 69,000 km/y over 20 years)

Estimated Emission Reduction per Bus Compared to Diesel (lifetime tonnes)

	PM	NOx	HC (NMHC)	CO
Diesel	-	-	-	-
Natural Gas	0.50	11.21	1.29	2.59
Hybrid	0.26	11.21	1.63	0.86
Ballard Bus	0.52	21.56	1.73	4.31

It is important in assessing these emission data to recognize that many important factors that influence in-use performance have been neglected, such as the performance of state-of-the-art diesel technology (including both engines and fuels) and the performance of alternatives over the long term. It should be noted that a recent preliminary study by the Harvard School of Public Health, Center for Risk Analysis comparing diesel and natural gas fuels for heavy trucks[47] concluded that on balance, “the choice to use diesel or natural gas fuels in heavy trucks is not straightforward.” The continuing study is addressing environmental impacts (including GHGs), health, safety, truck performance and costs. Presumably, their conclusion applies to these fuels for buses as well.

ACORP

Table 3.3 shows the estimated emission reductions for ACORP as it currently operates. The analysis indicates that for 2000 (taken as the year for which cost-effectiveness is estimated below), ACORP would account for emission reductions of 44 tonnes of VOC and 28 tonnes of PM in that year.[48]

The five sections of Table 3.3 were derived as follows. The first section shows the baseline emissions of the heavy-duty diesel vehicle (HDDV) fleet as taken from the Study Baseline used in this report. These are essentially the most recent GVRD inventory data, since none of the other measures analysed for this study changed the HDDV emissions.

The second section of Table 3.3 shows the estimates of the excess emissions attributable to a ‘smoking’ heavy duty diesel vehicle as estimated by Sierra Research in their feasibility study for ACORP (see footnote 20). These estimates are the incremental emissions above the fleet average (section 1 of the table) which are attributable to vehicles that are likely to be stopped and tested by the on-road ACORP surveillance vans.

The third section of Table 3.3 shows the equivalent tonnages corresponding to section 2 of the table as calculated from section 1 of the table. The fourth section of the table shows Sierra Research’s estimates of the percentages of the excess emissions likely to be picked up by an ACORP type of program. The reductions are attributed to the effect of repairs carried out in response to ACORP requirements.

The fifth section of Table 3.3 shows the estimated reductions (tonnes/year) that are attributable to the operation of an ACORP type of program. The reductions are calculated by applying the percentage capture in section 4 to the excess emission estimates in section 3. The estimated emission reductions shown in section 5 of the table are used to estimate the cost-effectiveness of ACORP.

---

[47] Harvard Center for Risk Analysis, **Risk in Perspective** newsletter, *Fuelling Heavy Duty Trucks: Diesel or Natural Gas?*, Volume 8, Issue 1, January 2000. Summary of Phase 1 of a study sponsored by Navistar International.

[48] Diesel particulate matter consists almost exclusively of PM_{10}, and a high percentage of that is $PM_{2.5}$.

Table 3.3. Emission Reductions of ACORP

Study Baseline - HDDV Emissions (tonnes per year)	VOC	CO	NOx	PM
2000	709	4927	5862	299
2005	599	4821	6217	220

Source: 'Study Baseline' calculated for this study

Excess HDDV Emissions (%)*	VOC	CO	NOx	PM
2000	13%	NA	6%	19%
2005	11%	NA	8%	17%

* Estimated excess relative emissions above normal (baseline) characteristic of a smoking vehicle.
Source: Sierra Research report (see footnote 20)

Excess HDDV Emissions (tonnes per year)	VOC	CO	NOx	PM
2000	88.6	NA	322.4	55.3
2005	65.9	NA	497.4	37.4

Emission Reduction (from Excess Emissions) for Focused Smoke Patrol (%)	VOC	CO	NOx	PM
2000	50%	0%	0%	50%
2005	50%	0%	0%	50%

Source: Sierra Research report (see footnote 20)

Reductions with Focussed Smoke Patrol (tonnes per year)	VOC	CO	NOx	PM
2000	44.3	0.0	0.0	27.7
2005	32.9	0.0	0.0	18.7

Scrap-It

Emissions

The 1997 evaluation of the Scrap-It pilot program established emissions reduction factors for the different incentives selected by owners scrapping a vehicle. As part of the pilot program, 63 of the scrapped vehicles were tested at the AirCare® laboratory using the EPA FTP-75 driving cycle; it is this information for actual scrapped vehicles that determines the emissions reduction estimates.

Table 3.4 presents the baseline emission data and the calculation of the emission reductions and cost-effectiveness.

Table 3.4. Expanded Scrap-It Program: Basic Information

Benchmark Emissions[49]	**HC**	**CO**	**NOx**
	g/km		
Scrap-It Vehicle (as an SOV)	4.98	33.37	1.54
Transit Pass (per passenger-km)	0.05	0.50	0.24
New Vehicle (as SOV)	0.15	2.00	0.20
Used Vehicle (as SOV)	0.60	5.50	0.60
Bicycle (as SOV)	0.00	0.00	0.00

Source: 1997 Scrap-It Evaluation Report

Incentives Chosen	**Number**	**Percent**
Transit Pass	123	32.3%
New Vehicle	56	14.7%
Used Vehicle	35	9.2%
Bicycle	166	43.6%
Vanpool	1	0.3%

Source: Current Scrap-It Program statistics

---

[49] Typical commuter distances were used for each incentive using the base emission rates shown here. See 1997 Scrap-It Evaluation Report. SOV is a single occupant vehicle.

The bicycle incentive is the most popular chosen—44 percent of owners scrapping vehicles chose it.[50] From an emission reduction perspective, a bicycle is a zero emission vehicle provided the bicycle is used for the same transportation uses as the scrapped vehicle. If the bicycle is used occasionally for recreational purposes, then some other transportation alternative (transit, new or used automobile) is the appropriate alternative for comparison.

Vanpools (one owner chose this alternative) and natural gas vehicles (zero chosen) have not been popular incentives.

Greenhouse gas emission reductions

Of the measures and programs evaluated in this study, only the transit bus and Scrap-It measures have associated greenhouse gas emission reduction data available. The LDGV programs (NLEV, Tier 2 and LEV II) and ACORP do not address greenhouse gases explicitly. Thus, detailed analysis of comparative GHG emissions was not possible, and comparison of the available data for transit buses and Scrap-It would not be helpful in the context of this study.

The Transportation Issue Table in the Canadian National Climate Change Process has issued its Options Paper and is conducting a national consultation on the analysis and recommendations. This document and supporting documents commissioned by the Transportation Issue Table provide a more thorough analysis of transportation technologies and their greenhouse gas implications than could be included here.[51]

3.2 Air quality[52]

PM_{10}

PM_{10} monitoring data show a remarkable consistency across the LFV region.[53] Individual station averages and detailed statistical characteristics vary little from Kitsilano to Hope. Current levels are also remarkably low for such an urbanized region. Current (1997-98) annual average levels for both the western and eastern portions of the LFV (as defined above) are approximately 13 $\mu g/m^3$ and differ little from station to station. For this reason, the analysis of effects was based on a single average concentration change for the entire region.

The emission reduction estimates shown in Section 3.1 indicate a substantial reduction in going from the baseline to NLEV/Tier 2 emissions, but a much smaller incremental

---

[50] The bicycle incentive was reduced from $900 to $500 in May 1999, and the rate at which the bicycle incentive was chosen dropped from 60% to 25% of participants.

[51] *Transportation and Climate Change: Options for Action. Options Paper of the Transportation Climate Change Table*, November 1999.

[52] Only the emission reductions associated with the NLEV/Tier 2 and NLEV/LEV II scenarios were used to estimate changes in air quality and, subsequently, to estimate health effects impacts.

[53] See *Lower Fraser Valley Ambient Air Quality Report 1998*, GVRD Air Quality Department and FVRD, September 1999.

reduction in going from that scenario to LEV II for the principal pollutants NOx and VOC.

The following table (Table 3.5) shows the forecast PM_{10} concentrations and reductions for the NLEV-Tier 2 scenario relative to the study baseline[54] for full future implementation of the measures in the GVRD and FVRD Air Quality Management Plans. The estimated incremental improvement attributable to implementation of the LEV II requirements is shown in the table in terms of percent improvement upon NLEV-Tier 2.

The most significant feature of these results is the very small predicted incremental improvement in PM_{10} between the NLEV/Tier 2 scenario and the NLEV/LEV II scenario. This difference reflects the magnitudes of the estimated emission reductions of the contributing pollutants.[55] Note that LEV II would result in a smaller reduction in PM_{10} than Tier 2 in the early years of the programs, since the LEV II NOx emissions are a little higher than for Tier 2 because of timing of some requirements.

The graphic that follows the table shows the historical actual values and the forecast scenario values of the average PM_{10} concentration for the Lower Fraser Valley.[56]

Table 3.5. Estimated Regional Average PM_{10} Concentration Reductions

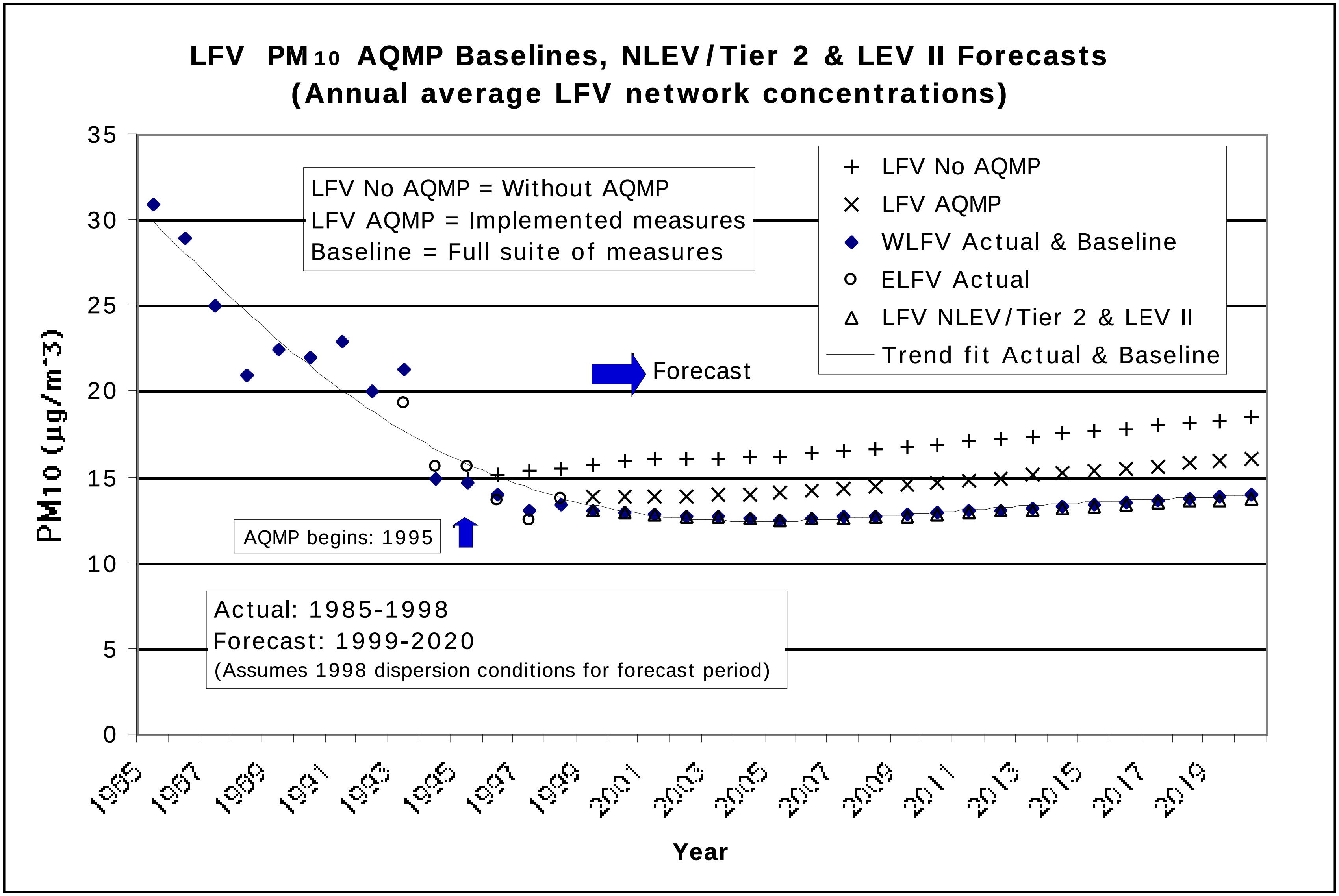
Year	**Baseline** ($\mu g/m^3$)	**Baseline ⇒ Tier 2** ($\Delta\mu g/m^3$)	**Tier 2 Reduction from Baseline** (%)	**Tier 2 ⇒ LEV II** ($\Delta\mu g/m^3$)	**Ratio LEV II/ Tier 2** (%)
2005	12.6	- 0.04	0.3%	~ 0	- 0.2%
2010	12.9	- 0.12	0.9%	- < 0.01	3%
2015	13.5	- 0.19	1.4%	- 0.01	5%
2020	14.0	- 0.22	1.6%	- 0.01	6%

---

[54] Equivalent to Scenario C in the GVRD Backcast-Forecast revisions of 1998, with the new vehicle emissions estimates substituted for the on-road vehicles portion of the original inventory.

[55] Contributing pollutants are directly emitted PM_{10} plus secondary contributions from SO_2 (sulphates), NOx (nitrates) and VOCs (secondary organic aerosol). As noted earlier, only secondary NOx and VOC products contribute to the PM_{10} reductions shown for Tier 2 and LEV II scenarios, since changes in the direct emissions and direct and secondary sulphates have been taken into the baseline.

[56] Recall that there is little difference between the current and forecast concentrations between the urban and rural parts of the Valley.


LFV PM10 AQMP Baselines, NLEV/Tier 2 & LEV II Forecasts
(Annual average LFV network concentrations)
PM10 (µg/m^3)
35
30
25
20
15
10
5
0
LFV No AQMP = Without AQMP
LFV AQMP = Implemented measures
Baseline = Full suite of measures
+ LFV No AQMP
× LFV AQMP
◆ WLFV Actual & Baseline
○ ELFV Actual
△ LFV NLEV/Tier 2 & LEV II
Trend fit Actual & Baseline
Forecast
AQMP begins: 1995
Actual: 1985-1998
Forecast: 1999-2020
(Assumes 1998 dispersion conditions for forecast period)
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
Year

Supplementary secondary aerosol modelling[57]

A significant question arises regarding whether the atmospheric chemistry of the region would change appreciably as a result of the reductions by 2020 in total regional emissions of SOx (9% reduction), NOx (14% reduction) and VOC/NMOG (2% reduction) estimated by this study.[58] If the chemistry changed materially, estimates of changes in the secondary components of PM_{10} (i.e., sulphates, nitrates and organic aerosol) might be significantly in error based on current model factors. Prof. Sara Pryor of Indiana University performed preliminary photochemical model simulation for reduced emissions of the production of secondary aerosol constituents. She used the ISOPART model that she and colleagues had developed for application to the LFV in association with the REVEAL studies. The input reductions used to bound the estimated reductions were SOx (-9%), NOx (-25%) and VOC (-25%) relative to the 1993 inventory currently used in the model.

Based on the ISOPART results, the following elasticities relating changes in emissions to changes in ambient concentrations may be derived:

Precursor and secondary aerosol constituent	**ISOPART elasticities adjusted for background** (% change, ambient / % change, emissions)
SO_2 Sulphate	0.4
NOx Nitrate	1.1
VOC SOA[59]	0.6

The values in the table have been called elasticities by analogy with terminology used in economics for percentage change in demand per percentage change in price, for example. Here we use the term to define the % change in ambient concentration of each secondary component of PM10 (Δ µg/m^3) relative to the % change in emission quantity (Δ t/year) of the primary, directly emitted precursors. The third column of the table shows the values derived from Prof. Pryor's modelling results adjusted to account for the different treatment of background PM_{10} concentration in our analysis compared with hers. Our basic model assumes that each elasticity coefficient is equal to 1.0, i.e., that a 1% change in emission of a primary precursor leads to a 1% change in the ambient concentration of the secondary product component of PM_{10}.

---

[57] Based in part on a report prepared for this study by Prof. Sara C. Pryor, Indiana University: *Application of the ISOPART model to assess vehicle emission control measures,* September 1, 1999.

[58] The atmospheric chemistry of the airshed depends on the net total emission from all sources, so the reductions from the vehicle emission measures must be added to the total emission inventory for all other sources for this analysis.

[59] SOA = secondary organic aerosol

The input data provided to Prof. Pryor bracketed the emission reductions estimated in this study, so the results relate directly to our analysis. These results indicate that even with dramatic reductions in emissions of the precursors (10% for SOx and 25% for each of NOx and VOC from 1993 emission levels), the relative conversion to secondary aerosol is affected by not more than a factor of two.

The data in the above table have not been used explicitly in our analysis, but rather, the range of conversion factors from primary pollutants to secondary aerosol has been incorporated implicitly into the uncertainty distribution for changes in PM_{10} concentrations in the probabilistic uncertainty analysis that is described in Chapter 4.

One of the features of the above data is the relatively greater conversion of NOx to nitrate compared with the other two constituents. This is consistent with other information about the potential shift of the atmospheric chemistry regime toward enhanced nitrate formation as sulphur emissions in the airshed decrease and the influence of non-anthropogenic (i.e., biogenic) sources of both SOx and VOC.[60] These results are interpreted as confirming our basic approach to estimating nitrate and SOA from changes in NOx and VOC emissions.

Ozone

The reductions in NOx and VOC (NMOG) emissions shown in Section 3.1 for the NLEV/Tier 2 scenario compared with the revised baseline are substantial. Based on the UAM-V 1993 episode results for the four locations cited earlier, the estimated emission reductions could produce slight increases in peak ozone concentrations at Kitsilano, Pitt Meadows and Surrey East—a few ppb from 1993 levels by 2020. In contrast, the UAM-V results imply a possibly significant reduction in peak ozone at Abbotsford—about 45 ppb from 1993 levels by 2020. The result for Abbotsford is taken to represent the eastern part of the airshed, as defined earlier. The data for the eastern Valley are shown in the following table (Table 3.6).

---

[60] See, for example, *Atmospheric Science Expert Panel Report*, Joint Industry/Government Study of Sulphur in Gasoline and Diesel Fuels, August 1997 and J.J. West, A.S. Ansari and S.N. Pandis, *Marginal $PM_{2.5}$: Nonlinear Aerosol Mass response to Sulfate Reductions in the Eastern United States*, J. Air & Waste Management Assoc. **49**:1415-1424 (1999).

Table 3.6. Ozone concentration changes for NLEV/Tier 2 and NLEV/LEV II in the eastern LFV (at Abbotsford as surrogate)

Year	**Estimated absolute peak concentration** (ppb)	**Tier 2 & LEV II Mean peak hour conc. reduction*** (ppb)
1993-1995	100	
2000	61	
2001	60	<1
2005	57	0.8
2010	56	1.6
2015	55	3.3
2020	55	4.1

*Obtained by scaling the absolute peak concentration as described in Section 2.6.

The data in the last column are used to evaluate the effects of the changes in ozone concentration. They are the result of scaling the current average peak concentrations at eastern Valley ozone monitoring stations for the period 1995-1998 on days when the 24-hour average concentration was 25 ppb or greater. The mean peak hour value was 45 ppb on these days (the ‘effective’ days for response calculations) for an average of 60 days per year. The estimated typical reductions in peak hour ozone were scaled down by the ratio of the current mean peak hour value on the selected days (45 ppb) to the estimated current absolute peak concentration (61 ppb). This procedure matches the air quality data to the health effects metric, which is based on the change in mean peak hour ozone level.

These data suggest that most of the reduction in peak ozone for the eastern Valley since 1993-95 has already taken place, ostensibly, in part, as a result of emission reductions from the introduction of Tier 1 vehicle emission standards and other AQMP measures in the period 1993-1998. The NOx-VOC-ozone graph for the eastern Valley (see Appendix D) for the current emission regime is quite flat, i.e., peak ozone is relatively insensitive to changes in either NOx or VOC (NMOG).

These statements are true only if the modelling results are a reasonably accurate representation of reality. At present, they are the best data available. The profile of the emission inventories of NOx and VOC do indicate a sharp decline during this period, especially when estimated with the updated emission model used for this study. If the response of peak ozone to these declines is as suggested by the UAM-V results, the predicted ozone trend is consistent with the emission inventory. The ozone monitoring data have been reviewed only for the period 1995-98, so a possible trend in peak ozone at Abbotsford, that might parallel the full set of estimates made here, has not been analyzed.

Network average peak ozone levels are not declining so drastically (and are not expected to).[61]

The forecast reductions in NOx emissions, especially, for the western (urban) part of the Valley appear to lead to small increases in peak ozone in the urban areas because of modifications of the ozone formation chemistry and enhanced destruction of ozone formed in the eastern Valley and recycled into the western Valley. The NOx-VOC-ozone graphical surfaces for the urban region estimated by UAM-V modelling are quite flat, even for substantial changes in emissions such as are estimated here, indicating relative insensitivity of peak ozone to either NOx or VOC changes. If the urban concentrations really do increase slightly by the end of the study period (by an average of perhaps 1 or 2 ppb over the whole study period), the slightly increased exposure to ozone of the 90% of the people who live in the western part of the region could partially offset the reduced exposure of the 10% of the people who live in the eastern part of the region. This possibility suggests a plausible lower bound of near zero net effect attributable to ozone concentration changes.

For the purposes of this report, the small changes in peak ozone concentrations estimated for the urban areas are assumed to be essentially zero, and the changes estimated for the eastern part of the region are taken to be substantial enough to be non-zero. Thus, the evaluation of effects and benefits reported here is based on reduced ozone exposure of residents of the eastern Valley as estimated in Table 3.6.

The incremental emission reductions found for LEV II implementation would lead to a very small further peak ozone reduction in the eastern Valley. The emission change, however, is so small that the change in ozone would be effectively zero. For the purposes of this study, the effect on ozone of LEV II implementation is treated is non-significant.

3.3 Cost-effectiveness

3.3.1 Light-duty gasoline vehicles

The cost-effectiveness calculations were based on total individual light-duty vehicle (passenger car) emissions of NOx, VOC (NMOG) and CO over the life of the vehicle. The fleet average factors for LDGVs in 2005 were considered to be the NLEV/Tier 1 baseline. Factors used from the emission model results were 0.40 g/km NMOG and 0.38 g/km for NOx. Tier 2 emissions are based on fleet average emission factors in 2020. Factors used were 0.24 g/km NMOG and 0.08 g/km NOx. LEV II emission factors for 2020 are 0.22 g/km NMOG and 0.07 g/km NOx. These emission model factors were chosen to approximate in-use estimates of tailpipe and evaporative emissions, rather than referring to the emission standards. The passenger car is assumed to have a life of 10 years averaging 15,000 km/year.

The preliminary cost-effectiveness estimates, and comparisons with other programs, are shown below:

---

[61] Network annual average ozone levels have been rising very slowly over the past few years.

Comparison of Preliminary Cost-Effectiveness Values

Programs	Incremental Vehicle Costs (Retail) $Cdn per tonne of (NMOG + NOx + CO/7)
Tier 2 (compared to NLEV/Tier 1)**	$1,630 ($1,740*)
LEV II (compared to Tier 2)	$3,830 ($33,330*)
AirCare®[62]	$3,200 - $4,300*
Scrap-It (Pilot)[62]	$2,200 ($3,800*)

* Excluding CO

** Depending on how the emission reduction benefits are allocated between NLEV and Tier 2, the Tier 2 cost-effectiveness value could be twice as high. See summary of US EPA's estimates below.

It should be noted that the table shows only selected transportation-related measures—some of the implemented emission reduction measures in the GVRD Air Quality Management Plan, for example, have lower (i.e., better) cost-effectiveness values than the measures discussed here. The above indicates that the Tier 2 program is the most cost-effective of the programs shown. The LEV II cost effectiveness (i.e., LEV II compared to Tier 2) is high, in fact significantly higher than AirCare® or Scrap-It, if the contribution of CO reductions is excluded, i.e., considering NMOG + NOx reductions only.

For comparison, the US EPA has calculated cost-effectiveness values for Tier 1, NLEV and Tier 2 as follows.[63]

US EPA Cost-Effectiveness Estimates

Program	$US/tonne (NOx+NMOG)
Tier 1 (re Tier 0)	$1,788 - $2,430
NLEV (re Tier 1)	$2,045
Tier 2 (re NLEV)	$1,759

The EPA numbers are not directly comparable with our estimates since different methodologies are used. EPA calculates emission reductions on a discounted basis over a vehicle lifetime of 25 years, as well as determining a weighted average of all vehicle categories (not just LDGVs). The latter explains, in part, why EPA's estimate for Tier 2 is greater than our estimate for LDGVs alone. Considering how approximate all of these values are, the agreement is reasonable.

---

[62] Cost-effectiveness values for AirCare and Scrap-It are taken from: Scrap-It Program Steering Committee (1997), *Evaluation of the Scrap-It Pilot Program*, August 1997.

[63] *Tier 2/Sulphur Draft Regulatory Impact Analysis*, US EPA Office of Mobile Sources, April 1999. Similar values appear in the EPA's cost-effectiveness analysis for the Final Tier 2 Rule, December 1999, but they were not included in our analysis.

The cost data are very preliminary at this stage of analysis. The main point of the above results is that Tier 2 appears to fall into a category that is generally considered cost-effective among air quality management measures for NOx and VOC. LEV II appears to be in a category that is generally considered to be not cost-effective (i.e., greater than $10,000 per tonne)[64] for NOx and VOC (NMOG). The evaluation of NLEV/Tier 2 is merely to place the cost-effectiveness of LEV II in context, since NLEV/Tier 2 vehicles will automatically reach the BC market (i.e., NLEV/Tier 2 vehicles will be the normal new vehicles in the future) and no regulatory decision regarding their implementation is needed. It is reasonable to use the cost-effectiveness values excluding CO for comparison of programs (as in the EPA's analysis summarized above), since CO is generally considered to be a material contributor to smog formation only in areas with severe photochemical smog formation potential such as Southern California. CO in the LFV is not a priority concern either directly or as a smog precursor.

3.3.2 Additional measures

Transit buses

Three sources of cost/price estimates were consulted for new transit bus purchases: (1) estimates provided by TransLink, (2) information provided by Orion Bus to Levelton Engineering in May 1999, and (3) a study by the US General Accounting Office.[65]

Cost-effectiveness calculations for NGV, hybrid and Ballard engine technologies are based on the added price (cost) of a new bus relative to a diesel bus. Differences in operating and maintenance costs among the four technologies have not been addressed in this analysis. Other factors such as shown in the following table were not evaluated.

Some examples of future potential cost factors not evaluated

Factor	Alternatives	Diesel
Fuelling infrastructure capital cost	✓	
Parts cost & inventory	✓	
Operator training	✓	
Fuel efficiency & future fuel cost	✓	✓
Engine reliability	✓	
Emission control system cost & reliability	✓	✓
Fuel or equipment purchase incentives	✓	

---

[64] See the GVRD Stage 2 AQMP detailed documentation of costs and cost-effectiveness of measures, as well as more recent data in *Greater Vancouver and Fraser Valley Air Quality Management Plan Discussion Paper: Issues, Policies and Approaches*, May 1999.

[65] US GAO (1999). Op.cit., p.10.

The alternatives to diesel are low-volume or demonstration technologies at present and do not achieve economies of scale. A Levelton study for the Transportation Climate Change Issue Table provided current prices for transit buses and ‘optimistic’ prices based on high production volumes. Both prices are shown in Table 3.7 for comparison, but only the current prices should be used in comparing alternatives, since the optimistic prices are speculative estimates based on experience with other similar technologies of what volume production may be able to achieve. Production volume would undoubtedly bring prices down, perhaps by the relative amounts shown.

Table 3.7. Cost-Effectiveness Data for Transit Buses

Price (Cost) of New Transit Buses*

	Per Bus		**Additional Over Diesel**	
	Current	Optimistic	Current	Optimistic
Diesel	$390,000	$390,000	-	-
Natural Gas	$460,000	$430,000	$70,000	$40,000
Hybrid	$520,000	$450,000	$130,000	$60,000
Ballard	$800,000	$490,000	$410,000	$100,000

* Current bus costs - TransLink, Orion, GAO; Optimistic - Levelton (1999)

Cost-Effectiveness ($/tonne)				
	PM+NMHC+NOx+CO/7		**PM Only**	
	Current	Optimistic	Current	Optimistic
Natural Gas	$5,230	$2,970	$139,930	$79,960
Hybrid	$9,830	$4,540	$502,415	$231,884
Ballard	$16,790	$4,100	$792,271	$193,237

* CO emissions are discounted by a factor of 7 to reflect its relative contribution to ozone formation compared with NOx and NMHC.

All things considered, a conclusive statement cannot be made about the cost-effectiveness of the transit bus alternatives. More detailed analysis is required to reach a definitive assessment.

ACORP

The start up cost for ACORP is estimated at $522,000 and annual operating cost at $404,000. There is no cost recovery for ACORP, i.e., no fees are charged for an HDDV failing the SAE J1667 test. ACORP generates revenue, however, since the ACORP peace officers issue tickets under the Motor Vehicle Act, the Commercial Transportation Act, the Motor Carrier Act and the Transportation of Dangerous Goods Act. Fines issued for the first six months of the program totaled $31,192 and are estimated at $60,000 per year. Assuming the initial start-up cost is spread over five years, the annual cost of ACORP is about $450,000 per year. Table 3.8 shows the cost effectiveness data for ACORP.

Table 3.8. Cost-Effectiveness Data for ACORP*

ACORP Statistics (per year)	
Trucks Observed	28,000
Trucks Stopped	2,800
Trucks Tested	1,400
Trucks Failed/Repaired	933

	Costs ($/y)		**Cost -Effectiveness ($/tonne)**	
			PM+HC	**PM Only**
ACORP	$450,000		$6,253	$16,270

* Cost-effectiveness based on emission reduction estimate for 2000

ACORP should be considered to be reasonably cost-effective, since it targets only PM and HC and gets no credit for NOx or CO in this analysis.

<u>Scrap-It</u>

Table 3.9 shows the data for determining the cost-effectiveness for a program that scraps 1000 vehicles per year. The total cost of the program is $835,000 per year ($100,000 to administer the program and $735,000 of incentives).

If bicycles are considered as zero emission vehicles, the cost effectiveness for HC plus NOx (excluding CO) is $3,414 per tonne; if a used car is the actual alternative chosen by an owner taking the bicycle incentive, the cost-effectiveness for HC plus NOx (excluding CO) is $3,625.

The real value of Scrap-It is the removal of a high polluting vehicle from the road. All of the replacement alternatives (incentives) are relatively low pollution, hence, the relatively small difference in the cost-effectiveness value between considering a bicycle as a zero emission vehicle compared to being replaced by a used car (1989 and newer).

Table 3.9. Cost-Effectiveness Data for Scrap-It

Emission Reductions Per 1000 Vehicles Scrapped*

	HC	CO	NOx
	tonnes		
Transit Pass	62.1	414.2	16.4
New Vehicle	28.2	398.5	7.8
Used Vehicle	15.7	99.9	3.4
Bicycle at zero emissions	84.7	567.5	26.2
Bicycles at used vehicle emissions	74.5	473.9	22.1
Total (bicycles at zero emissions)	190.7	1480.0	53.8
Total (bicycles at used vehicle emissions)	180.5	1386.5	49.7

* Based on 13,101 km/y and 3 years remaining life.

Costs per 1000 Vehicles Scrapped (per year)

Costs	
Program overhead	$100,000
Transit Pass	$249,627
New Vehicle	$112,205
Used Vehicle	$45,932
Bicycle*	$326,772
Total	$834,535

* Calculation based on $750 per bicycle, the initial cost to the program.

Cost-Effectiveness ($/tonne)

Pollutants	Bicycle@Zero	Bicycle@Used Vehicle
HC+NOx	$3,414	$3,625
HC+NOx+CO/7*	$1,830	$ 1,949

* CO emissions are discounted by a factor of 7 to reflect its relative contribution to ozone formation compared with NOx and NMHC (NMOG)

Summary of Cost Effectiveness Estimates for All Measures

The following table (Table 3.10) brings the results of the previous sections together for easier comparison.

Table 3.10. Cost-Effectiveness Summary

Measure/Program	Scale	Total Quantity of Pollutants (t or t/y)		Cost-Effectiveness
		NOx+NMHC+CO/7	PM	($/t)
LDGV (NLEV/Tier 2)	LFV Fleet (2020)	8,948* (9,550) t/y	N/A	$1,700* ($1,600)
LDGV (LEV II)	LFV Fleet (2020)	480* (4,190) t/y	N/A	$33,000* ($3,800)
Transit Buses (lifetime)				
NGV	100 buses	13 t	50	$5,230**
Hybrid	100 buses	13 t	26	$9,830**
Ballard	100 buses	24 t	52	$16,790**
ACORP	2 vans (2005)	33 t/y	28	$6,250***
Scrap-It	1000 vehicles/y	450 t/y	N/A	$1,800-$3,600

* Excluding CO. Values in brackets include CO reductions. Passenger cars only.
** Current prices, including NOx, NMHC, CO and PM.
*** Including HC and PM only.

As noted earlier, the cost-effectiveness values in the final column are very approximate, especially for the transit bus alternatives. The conclusions that may be drawn from this table are that NLEV/Tier 2 and Scrap-It appear to be the most cost-effective measures analyzed, and that ACORP is reasonably cost-effective considering its target pollutants and the fact that it gets no credit for NOx or CO reductions in our analysis.

As a final comment on this section, cost-effectiveness analysis does not address the benefit side of the ledger. Benefits were not estimated for the additional transportation measures, so the subsequent analysis does not provide any further information to place the cost-effectiveness estimates for these measures in a cost-benefit context. For example, the transit bus alternatives and ACORP measures reduce PM emissions, which contributes little to the cost-effectiveness values but would be more heavily weighted in a cost-benefit analysis.

3.4 Health and other effects[66]

The changes in PM_{10} and ozone concentrations shown above were used to calculate estimated health outcomes over the study period. The following table (Table 3.11) shows these outcomes for NLEV/Tier 2 emission reductions for the “central” (best) estimates of concentration-response coefficients in the model. They show the expected pyramid of larger numbers of less severe outcomes and smaller numbers of more severe outcomes.

Detailed descriptions and definitions of the outcomes may be found in the AQVM documentation.

Table 3.11. Summary of hypothetical avoided health outcomes (2004-2020) – NLEV/Tier 2

Pollutant & Outcome	Number of Outcomes*
	Central estimate
PM_{10}	
Acute respiratory symptom days	800,000
Restricted activity days	300,000
Asthma symptom days	30,000
Bronchitis cases (children)	3,000
Emergency room visits	2,000
New chronic bronchitis cases	300
Cardiac hospital admissions	20
Respiratory hospital admissions	20
Mortality (premature deaths)	20
Ozone	
Acute respiratory symptom days	60,000
Minor restricted activity days	30,000
Asthma symptom days	10,000
Asthma emergency room visits	30
Respiratory hospital admissions	10
Mortality (premature deaths)	2

* Data are significant only to one figure.

The numbers shown are the totals for the period 2004-2020, the effective period for Tier 2 or LEV II. It may be argued that the effects of the NLEV program should be separated

---

[66] See Disclaimer and Appendix G for a summary of CPPI’s position on this material.

from the combined effect of the NLEV/Tier 2 scenario. For the purposes of this study, it is assumed that the NLEV program effectively rolls over into the Tier 2 program after 2003, i.e., they form a single, continuous scenario as treated here, since they define the normal new vehicles that BC residents will be able to buy. This is described in Sections 2.3 and 2.4. The incremental effects of the additional LEV II emission reductions are essentially proportional to the relative incremental emission reductions, i.e., about 4% of the Tier 2 values.

3.5 Monetized benefits[66]

The health effects shown in Table 3.11 were used as the basis of calculating the hypothetical avoided damage benefit of the reduced number of incidences of the outcomes listed in the table. Again, the AQVM documentation may be consulted for the monetary values and their basis for the various outcomes. The detailed spreadsheets for all of the calculations are available to the sponsors.

The following table (Table 3.12) shows the estimated, hypothetical avoided damage benefits for the case of the “central” concentration-response coefficient set. It should be emphasized that these costs include both direct, actual health care costs (avoided hospitilaztions, asthma treatments, etc.) and avoided damage costs based on values from databases on what people reveal about their willingness to pay for risk reduction.

The principal feature of this table is the estimated average annual benefit of about $10.7 million for Tier 2. Almost all of it (93%) is contributed by the PM_{10} benefit.

The corresponding average annual benefit for the period for NLEV/LEV II is $11.1 million, 4% greater than NLEV/Tier 2. This is an monetized benefit of implementing NLEV/LEV II of about $0.4 million per year over the 17 years ($7 million for the study period).

Table 3.12. Monetized hypothetical health damage benefits (central estimate): NLEV/Tier 2 Scenario

Year	PM_{10}	Ozone	Total
2005	$2.3 million	$200,000	$3 million
2010	$8.3 million	$340,000	$9 million
2015	$14 million	$730,000	$15 million
2020	$18 million	$1 million	$19 million
Total NLEV/Tier 2 (2004-2020)	$170 million	$9 million	$180 million
Average annual benefit (2004-2020)			$10.7 million

The complete dataset includes an estimate for each year of the period.

4.0 Uncertainty Analysis

Estimates of the uncertainty range for each of the parameters identified in Section 2.9 were analyzed using the Crystal Ball® (Version 4.0b) Monte Carlo simulation software. The details of the form of uncertainty estimated for each parameter are shown in Appendix F. For the concentration-response factors and outcomes valuation, the uncertainty range and weightings specified in AQVM (as of 1998) were used for the most part (see Appendix F). The mortality valuation (value of a statistical life) distribution was taken from the 1995 economic analysis study for this region. For the emissions and air quality parameters, new estimates of uncertainty distributions were created. A simulation of the overall uncertainty distribution focused on the single integrating forecast result: the average annual monetized benefit over the period 2004-2020 for each of the scenarios (NLEV/Tier 2 or NLEV/LEV II). The following depiction of the result for NLEV/Tier 2 of a simulation with 5,000 iterations shows the probability distribution for the full range of possible values, i.e., the probability that any particular value is the best estimate. The table following the graphic shows selected percentile points in the distribution.

Figure 4.1. Tier 2 Average Annual Benefit Statistical Distribution

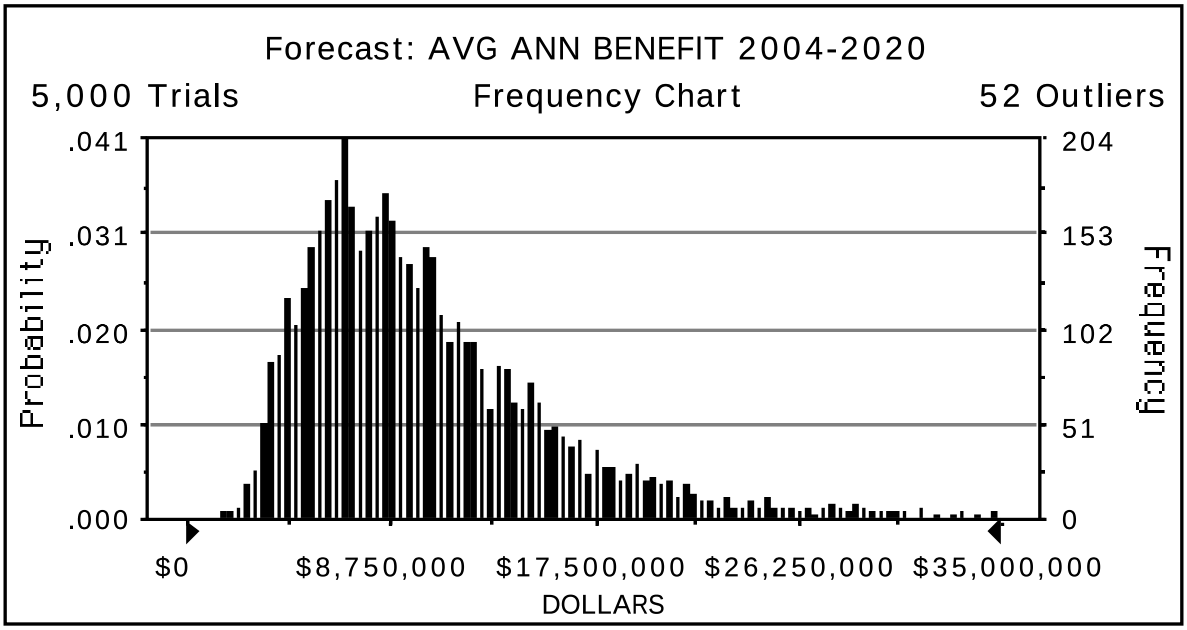


Table 4.1. Selected Percentiles of NLEV/Tier 2 Benefit Distribution

Percentile	Value
0% (Lowest value)	$1 million
5%	$4 million
10%	$5 million
50% (Median)	$9 million
Mean	**$11 million**
90%	$18 million
95%	$22 million
100% (Highest value)	$170 million

The mean value in this simulation is close to the "central" value quoted earlier. The distribution of values for the LEV II is, of course, similar, with a mean value of $11 million—roughly 4% greater than the Tier 2 estimate.

The broad form of the distribution—two orders of magnitude from minimum to maximum—emphasizes the approximate nature of the overall estimate when the major sources of uncertainty are taken into account. At the 5th and 95th percentile points in the above distribution, the average annual benefit of the emission reductions estimated for the NLEV/Tier 2 scenario could range from $4 million to $22 million per year. This range is from a factor of 3 lower than the mean to a factor of two greater than the mean.

Other monetizable factors

Previous estimates of economic value of air quality improvement in the LFV have evaluated additional factors, such as crop damage attributable to ozone exposure, visibility impairment by fine particles and global climate change (greenhouse gas) effects. These factors have not been evaluated explicitly for this analysis, but some comments are in order.

The reduction in ozone exposure in the eastern Lower Fraser Valley attributable to the emission reductions documented in this study would lead to reduced exposure of agricultural crops. The 1995 cost-benefit analysis study concluded that avoided crop damage associated with peak ozone concentration reduction about twice as great as that estimated for the NLEV/Tier 2 scenario would have a benefit of about $1 million/year. For the purposes of this study, we may assume on a *pro rata* basis that the new vehicle emission standards would have a value about one-half of the earlier estimate, or $0.5 million/year.

The estimated reduction in regional mean fine particle concentration found for this study is small, but we can estimate its value relative to earlier estimates. The 1995 cost-benefit study found an hypothetical benefit of $9 million per year (1994-2020) for the mean annual visual range improvement attributable to all of the measures in the 1994 GVRD

Air Quality Management Plan.[67] The 1997 Sulphur in Fuels study found a 0.2 µg/m^3 reduction in PM_{10} or $PM_{2.5}$ in the region due to reducing the primary and secondary sulphate from reduced sulphur in gasoline and diesel fuels. That reduction in fine particle concentration was assessed to result in a non-significant change in visual range which was not valued in the total benefit.[68] The reduction in PM_{10} or $PM_{2.5}$ that has been estimated for the NLEV/Tier 2 scenario in this study is similar to the reduction found for the Sulphur in Fuels study, i.e., about 0.2 µg/m^3. On this basis, the change in visual range attributable to NLEV/Tier 2 is assumed to be not significant as well. This suggests that the annual benefit from reduced fine particle concentration associated with the NLEV/Tier 2 scenario is much less than the estimate for the whole GVRD AQMP cited above, therefore, small relative to the other benefits estimated above.

The analysis described here does not address any potential greenhouse gas emission reductions associated with either the core measures or the additional measures. Therefore, we do not comment on any potential climate change avoidance benefit.

Other qualitative factors

The other factors in uncertainty that were noted in Section 2.9 have not been analyzed formally, but they would add further to the breadth of the uncertainty distribution. It does not appear that including them in the formal analysis would change the basis for any conclusions about the relative benefits of Tier 2 and LEV II that may be drawn from the above results.

One of the other factors listed that deserves brief discussion here is the potential effect of the use of MMT (methylcyclopentadienyl manganese tricarbonyl) as an octane enhancer in Canadian gasoline. The EPA emission models do not account for MMT effects. At issue is whether MMT affects emissions of CO, NOx, VOC and PM either directly or through modification of engine or emission control performance. The various factors may positively or negatively affect emissions. The literature on the subject is sparse. A rough estimate of direct PM emissions can be made based on the maximum dosage allowed in Canadian gasoline, 18 mg Mn/L. If all of the manganese were converted to manganese dioxide, this dosage would correspond to a tailpipe PM emission factor of about 3 mg/km for a typical LDGV. Such an emission would increase the total PM emission factor (tailpipe plus brake and tire wear) from an LDGV by about 20%. The Atmospheric Science Expert Panel in the 1997 Canadian national study of sulphur in fuels (see footnote 23) concluded on this basis that the possible incremental direct PM emission was probably not significant. The available data on the effect of MMT on NOx emissions suggested to the same Expert Panel that an emission reduction credit of 9% should be applied to MOBILE 5C/Complex emission estimates due to MMT use in Canadian gasoline relative to US gasoline. This fuel quality issue is quite complicated and cannot

---

[67] The mean visual range improvement was 5.5 km based on a mean PM_{10} concentration change of about 3 µg/m^3 over the period.

[68] The visual range estimation methodology used in the 1997 study was more quantitative than that used in the 1995 study and considered to be consistent with the best current practice. The earlier estimates, however, were based on fine particle concentration changes relative to much higher base levels than we are currently experiencing. A definitive result awaits re-analysis of the reductions based on current emission inventory and air quality data.

be resolved here. It does not appear that it would affect the results and conclusions of this study materially and is therefore not developed more fully. Whether MMT is on balance beneficial or detrimental to LDGV tailpipe emissions remains an unresolved issue for the purposes of this study.

Sensitivity analysis

The Crystal Ball® software also calculates the sensitivity of the forecast result (Mean Annual Monetized Benefit) to each of the input assumptions. Uncertainty distribution assumptions were defined for thirty-one input parameters, as stated above and shown in Appendix F. The following table shows the ten assumptions that contributed the most to the overall statistical variance of the simulation for NLEV/Tier 2.

Table 4.2. Summary of Benefit Sensitivity to Statistical Uncertainty Assumptions

Assumption (Parameter uncertainty distribution)	**Contribution to Variance (%)**
PM_{10} concentration change	28
Chronic bronchitis valuation	18
PM_{10} chronic bronchitis concentration-response coefficient	15
Value of a statistical life (VOSL)	15
PM_{10} mortality threshold level	14
PM_{10} mortality concentration-response coefficient	6
PM_{10} reduced activity days concentration-response coefficient.	2
Reduced activity days valuation	1
PM_{10} acute respiratory symptoms concentration-response coefficient	1
Ozone mortality concentration-response coefficient	1

The sensitivities depend, of course, on the details of the specified uncertainty distribution for each parameter, as well as the algebra of the model. Considering these somewhat arbitrary limitations, the dominance of PM_{10} factors in the end result for the estimated benefit is reflected in the dominance of uncertainty in those parameters in the statistical variance of the forecast distribution. The overall uncertainty in the change in PM_{10} concentration, which was estimated to have a range of a factor of three from lowest to highest, is the principal contributor to the overall uncertainty as measured by the total statistical variance. The broad VOSL distribution has a relatively smaller effect.

5.0 Conclusions

Key Findings

The following are the principal findings of the study.

1. The emission model developed for this study has allowed a significant update to estimates of emissions from the Lower Fraser Valley vehicle fleet—leading to a more accurate database. The new results indicate a significant reduction in the estimated emissions of CO, NOx and VOC (NMOG) of the current fleet compared with earlier estimates throughout the study period (1995-2020).[69] The principal source of the downward revisions is significantly improved vehicle performance deterioration factors. The following table shows the adjustments to the original light-duty gasoline-fuelled vehicle fleet[70] inventory for NOx and VOC that were determined in this study for 1995 and 2020:

Revisions to Original LDGV Inventory to Produce New Study Baseline

Pollutant	**Year**	**Original Inventory** (tonnes/year)	**Study Baseline** (tonnes/year)	**Percent Reduction** (%)
NOx	1995	19,151	15,345	20
	2020	14,830	9,537	36
VOC (NMOG)	1995	21,025	16,971	19
	2020	18,428	6,536	65

2. The following table summarizes the scenario results for 2020 for the light-duty, gasoline-fuelled vehicles in the on-road fleet.[71]

---

[69] CO results are included in the body of the report for completeness. The CO reductions, although considerable, were not evaluated further for potential impacts because of the apparent weak association with health effects. CO itself is not a priority regional air quality issue, and it does not contribute appreciably to formation of particulate matter or ozone. Vehicle CO emissions are also being reduced by other measures than the ones evaluated here. The CO data are omitted from the Summary.

[70] Vehicles with gross vehicle weight, GVW, less than 8,500 lbs. Excluding the small number of light-duty diesel-fuelled vehicles in the existing fleet.

[71] NLEV standards were not evaluated separately—only in combination with Tier 2 or LEV II. Each scenario was treated as a continuous transition from current standards to Tier 2 or LEV II. NLEV vehicles contribute to emission reductions between 2001 until Tier 2 or LEV II is phased in fully. Some of the emission reductions during the transition years are attributable to NLEV vehicles, but by 2020, the fleet is essentially all Tier 2 vehicles or all LEV II vehicles.

LDGV Emission Baseline and Scenario Reductions in 2020

	LDGV	**LDGV NLEV/Tier 2**			**LDGV NLEV/LEV II**			
	Study Baseline (t/y)	Emission (t/y)	Reduction (t/y)	% Red. (%)	Emission (t/y)	Cumulative Reduction (t/y)	Incremental Reduction (t/y)	Incr. % Red. (Δ%)
NOx	9,537	2,363	7,174	75%	2,181	7,356	182	2%
VOC	6,536	4,762	1,774	27%	4,462	2,074	300	5%

3. The incremental reductions in emissions of NOx and VOC for the LEV II implementation scenario are small in comparison with the Tier 2 reductions—a few percent of the Tier 2 reductions (as shown in the last column of the summary table).
4. By 2020, emissions of NOx and VOC from the on-road light-duty vehicle fleet would comprise about 7% and 9%, respectively, of the total regional emission inventory of these pollutants, compared with 31% and 26%, respectively, in 1995.
5. The effects on air quality of implementing NLEV and Tier 2 would be—
   - lower regional PM_{10} levels in 2020 by about 0.2 µg/m^3 on annual average (relative to a forecast 14 µg/m^3)
   - lower average peak ozone levels in the eastern part of the Lower Fraser Valley in 2020 by about 4 ppb (relative to a forecast peak of about 60 ppb)
   - no measurable effect on ozone levels in the urban (western) part of the region—possibly a slightly detrimental effect.
6. Corresponding reductions in health effects outcomes for reaching the Tier 2 emission levels occur for both PM_{10} and ozone—including on average about 1 premature death per year over the period 2004-2020. Most of the avoided health effects are attributable to lower PM_{10} ambient concentrations.
7. The central estimate of the monetized benefit of hypothetical avoided health effects of implementing NLEV and Tier 2 averages $11 million per year over the period 2004-2020, 93% of which is due to lowered PM_{10}. The annual benefit reaches $19 million in 2020.
8. The hypothetical health effects benefit of the additional emission reduction that would be achieved by implementing NLEV and LEV II would be about $0.4 million per year on average over the period. This is about 4% of the NLEV and Tier 2 benefit.

9. The incremental direct consumer costs of the two programs are estimated to be[72]—
   - $120 per new passenger car purchased for Tier 2 (relative to NLEV/Tier 1) and
   - $270 per new passenger car purchased for LEV II (relative to NLEV/Tier 1).
10. The corresponding incremental cost-effectiveness values for passenger cars are (very approximately)—
    1. $1,700/tonne of (NOx +VOC) for Tier 2 relative to NLEV/Tier 1 and
    2. $33,000/tonne of (NOx + VOC) for LEV II relative to Tier 2.

    The Tier 2 value compares favourably with the cost-effectiveness of other measures in the GVRD and FVRD Air Quality Management Plans, including other transportation-related measures. The LEV II value would place it in a category generally considered to be not cost-effective.
11. A rough estimate of the annual consumer cost of implementing Tier 2 is about $34 million per year, given the new vehicle purchase premiums cited above (9) and approximately 150,000 new light- and medium-duty passenger vehicles purchased each year in the LFV region. This is a partial and approximate statement of annual consumer costs, but the central estimates of estimated purchase costs and average benefits are approximately in balance within the significant uncertainties in both quantities. Taking the relative LEV II costs for passenger cars as applying to the new purchase fleet, the estimated incremental consumer cost of LEV II (compared with NLEV/Tier 1, as above) would be about $75 million per year.
12. There are major uncertainties in the values of all of the parameters that make up the bottom lines of this analysis. It is believed that the relative numbers—differences between various baseline and scenario estimates—are reasonably sound. In particular, the relative difference between vehicle emissions in the Tier 2 and LEV II implementation scenarios is believed to be acceptably accurate, since consistent, up-to-date emission modelling was used for both. Statistical uncertainty analysis indicates that the range of the monetized health benefit, for example, could be a factor of 2 or more larger to a factor of 3 or more smaller than the central value cited above (7). The Tier 2 and LEV II cost estimates in (11) are probably accurate to within ±50%
13. For the additional measures analyzed, the cost-effectiveness of emission reductions varies significantly—
    - Transit buses: The available data do not permit a definitive statement about the cost-effectiveness of the alternatives to diesel transit buses. All of the alternatives to conventional diesel transit buses are currently less cost-effective than

---

[72] Illustrative cost estimate for passenger cars only. Other classes of vehicles, such as SUVs and light and medium-duty trucks, are included in the programs, but available cost estimates are very approximate. The final Tier 2 rule cost-effectiveness analysis by EPA suggests incremental costs for the heavier classes of vehicles of less than about twice the passenger car cost for light trucks and less than 3.5 times the passenger car cost for medium-duty passenger vehicles. For our purposes, we can assume that the new vehicle purchases consist of about 50% passenger cars, 25% light-duty trucks and 25% medium-duty passenger vehicles (heavy SUVs, etc.).

NLEV/Tier 2 and other measures considered, but may be more cost-effective than NLEV/LEV II. The estimates are based on partial analysis that considers only capital costs and ignores operating, maintenance and fuel costs. A more complete analysis is required.

- ACORP. Cost-effectiveness for this program is good, considering that it targets PM and HC reductions only.
- Scrap-It Program. Cost-effectiveness is good (comparable with NLEV/Tier 2) based on the costs of the full package of incentives.

Conclusions

1. The principal conclusion to be drawn from this study is that future vehicles conforming to the Tier 2 standard will eventually lower emissions from the BC motor vehicle fleet considerably (particularly SUVs and light- and medium-duty trucks). Implementing the California LEV II standards would produce relatively small incremental emission reduction benefits at a cost per tonne of pollutants in a range that is generally considered not cost effective.
2. With the revisions to the light-duty fleet emission inventory reported here and the implementation of the NLEV/Tier 2 scenario, the LDGV portion of the mobile source sector will become a relatively minor contributor to the total regional emission inventories of NOx and VOC (NMOG) by 2020.
3. Of the additional measures analysed, only the Scrap-It program is comparable with NLEV/Tier 2 in cost-effectiveness. Alternatives to diesel buses appear to be less cost-effective than Tier 2, but based on preliminary analysis, may be potentially more cost-effective than LEV II on a cost/tonne of pollutants basis.

Data Gaps and Future Work

The next steps to substantiate the findings of this study or fill data gaps, for subsequent action by the sponsors or others are as follows—

1. It is strongly advised that the vehicle emission estimates be redone when the US EPA's MOBILE 6 model becomes available. The preliminary estimates based on the adapted MOBILE 5b model (which incorporates many of the inputs that will go into MOBILE 6) should not be relied on as definitive. EPA indicates currently that a preliminary version of the model should be released by fall 2000. The new model will have, among other enhancements, capability to better model any fuel quality-related factors that have not been addressed here.
2. Better, Canadian-specific consumer cost and program implementation data for future low emission vehicles in BC are required to determine the accurate cost-effectiveness of the programs. This also true for alternative heavy-duty vehicles.
3. The implications of the revised emission inventory for the current ongoing development of the UAM-V modelling system need to be assessed, including the impacts of the estimated emission reductions on both ozone and fine particle

concentrations. Estimates from this study based on earlier UAM-V results may be significantly in error.

4. The potential implementation of stringent low emission vehicle requirements in the eastern US states (possibly equivalent to LEV II) should be tracked through continued contact with NESCAUM, since opening such a large market to low emission vehicles would undoubtedly influence the cost-effectiveness of bringing them into Canada.

Glossary

Term	Definition
ACORP	AirCare On-Road Program for inspection of heavy-duty diesel vehicles
AIAMC	Association of International Automobile Manufacturers of Canada
AirCare®	BC's vehicle inspection and maintenance program under the auspices of ICBC and TransLink
AirCare II	Upgraded version of AirCare® beginning in fall 1999
AQVM	Air Quality Valuation Model developed for Environment Canada and Health Canada
BER	Base emission rates for the MOBILE series of models; initial ('zero kilometer') emission rates before applying modifying factors
CARB	California Air Resources Board of the California Environmental Protection Agency
CBD	Central business district simulated test cycle for urban buses
CO	Carbon monoxide
CO_2	Carbon dioxide (a greenhouse gas)
CPPI	Canadian Petroleum Products Institute
CVMA	Canadian Vehicle Manufacturers' Association
EMME2	Transportation network model used by GVRD
EPA	Environmental Protection Agency, United States
FVRD	Fraser Valley Regional District
GVRD	Greater Vancouver Regional District
GVW	Gross vehicle weight
HC	Hydrocarbon
HDDV	Heavy-duty diesel vehicle
ICBC	Insurance Corporation of British Columbia
ISOPART	Lagrangian model for simulating secondary particle formation in the atmosphere
LDGT	Light-duty gasoline-fuelled trucks (two classes: LDGT1, LDGT2)
LDGV	Light-duty gasoline fuelled vehicles; passenger cars and trucks less than 8,500 pounds gross vehicle weight; US EPA classes LDGV, LDGT and MC
LEV	Low emission vehicle exhaust emission standards for California (various years); also generic term for this class of vehicle
LEV II	Low Emission Vehicle exhaust and evaporative emission standards for light- and medium-duty vehicles for MY 2004- in California
LFV	Lower Fraser Valley; includes GVRD and FVRD
MC	motorcycles

Glossary (continued)

Term	Definition
MY	(vehicle) model year
NESCAUM	Northeast States for Coordinated Air Use Management
NGV	Natural gas-fuelled vehicle
NLEV	National Low Emission Vehicle program in the US
NMHC	Non-methane hydrocarbons; see VOC
NMOG	Non-methane organic gases; see VOC
NOx	Nitrogen oxides (nitrogen dioxide, NO_2, and nitric oxide, NO, taken together)
NRCan	Natural Resources Canada (Federal Government Department)
OEHHA	Office of Environmental Health Hazard Assessment, California Environmental Protection Agency
Pacific '93	Intensive field research program in atmospheric chemistry of the LFV carried out in the summer of 1993
PART 5	US EPA computer model for estimating particulate emissions from a vehicle fleet
PM	Generic term for airborne particulate matter, regardless of particle size
PM_{10}, $PM_{2.5}$	Size classifications of airborne particulate matter, specifying whether particles are less than or equal to 10 or 2.5 millionths of a meter (micron), respectively, in equivalent aerodynamic diameter
REVEAL	Regional Visibility Experimental Assessment in the Lower Fraser Valley; visibility monitoring and characterization research program operated by BC MELP and FVRD in 1993-4.
REVEAL II	Follow-on program to REVEAL operated by the FVRD in 1994-5.
RFG	Reformulated gasoline: gasoline meeting US requirements for specified components and properties
RVP	Reid vapour pressure-fuel vapour pressure determined by a specific test procedure
SAE	Society of Automotive Engineers
Scrap-It	BC program for early retirement of older light-duty vehicles
SFTP	Supplemental Federal Test Procedure: US EPA driving cycle emission certification procedure
SOA	Secondary organic aerosol
SO_2	Sulphur dioxide; also SO_X
SOV	Single occupant vehicle (as compared with HOV, high-occupancy vehicle)
SULEV	Super-ultra low emitting vehicle; California vehicle class
SUV	Sport-utility vehicle
Tier 0	Light-duty vehicle emission standards for MY 1988-
Tier 1	Light-duty vehicle emission standards for MY 1994-

Glossary (continued)

Term	Definition
Tier 2 (Bin # …)	Low emission vehicle exhaust and evaporative emission standards for light- and medium-duty vehicles in areas of the continental US outside of California for MY 2004- (Bin number identifies one of a number of vehicle weight and design classes)
TransLink	Operating brand name of the Greater Vancouver Transportation Authority, the Regional Transportation Network
UAM-V	Urban Airshed Model - Variable grid. An Eulerian photochemical dispersion and chemical transformation model.
ULEV	Ultra-low emitting vehicle; California vehicle class
VkmT or VkT	Vehicle kilometers travelled; base quantity used in emission models
VOC	Volatile organic compounds; in this report taken as equivalent to non-methane hydrocarbons, NMHC, and non-methane organic gases, NMOG
ZEV	Zero-emitting vehicle, e.g., an electric vehicle or equivalent

APPENDICES

A. Terms of Reference

B. Emission supporting data

C. Air quality supporting data

D. Effects and benefits supporting data

E. Cost-effectiveness supporting data

F. Uncertainty analysis supporting data

G. Summary of CPPI position on air quality valuation models

APPENDIX A:
Terms of Reference

TERMS OF REFERENCE

"CLEAN TRANSPORTATION ANALYSIS"

1 BACKGROUND

The Clean Transportation Analysis is being conducted to assess the benefits of a number of transportation-related initiatives in the Lower Fraser Valley. The core objective is to support a decision by the Province of British Columbia in the early fall of 1999 to evaluate appropriate motor vehicle emission standards for BC for the period from 2004-2020. Analyses will include:

- an estimation of emission reductions from implementation of the proposed U.S. EPA and California emission standards for the period from 2004 to 2020,
- an estimate of related ambient air quality improvements in the Lower Fraser Valley, and
- an estimate of health and other benefits from air quality improvements.

Additional measures to be assessed include fuel quality effects, the SCRAP program, AirCare onRoad Program, and the purchase of alternative fuel buses (Ballard, Compressed Natural Gas, etc.).

To date, five partners have committed to fund this project:

- Ministry of Environment, Lands and Parks
- GVRD (Air Quality Department)
- Environment Canada
- Canadian Petroleum Products Institute (CPPI)
- Canadian Vehicle Manufactuers' Association (CVMA)

Other potential partners who have yet to confirm their participation are:

- Association of International Automobile Manufacturers of Canada (AIAMC)
- TransLink

The funding partners constitute the project coordinating committee.

The consulting team selected by the project coordinating committee consists of:

- Dr. Robert Caton
  Alchemy Consulting Inc.
  222-1628 West First Avenue
  Vancouver, BC V6J 1G1 (Consultant)

- Mr. Wayne Edwards, P.Eng.
  Mr. Rob Dunlop, P.Eng.
  Levelton Engineering Ltd.
  150-12791 Clarke Place
  Richmond, BC V6V 2H9 (Subcontractor)

- Mr. Sandy Constable
  Constable Associates Consulting Inc.
  1628 West First Avenue
  Vancouver, BC (Subcontractor)

The selection of this team of consultants is based on their extensive national and regional experience with conducting similar analysis. Recent relevant experience includes national work on air quality benefits of fuel quality changes and greenhouse gas benefits of a variety of transportation measures, as well as extensive work in the region: the 1995 air quality cost/benefit study, the 1998 inventory and forecast update, the 1999 air quality strategic framework discussion paper, and peer review work. No other group is believed able to assemble comparable expertise and deliver the planned analysis in the required timeframe.

2 STATEMENT OF WORK

Without limiting the general scope of work, the consultant shall carry out all work as outlined below and designated [C]. These refer to the core tasks that are to be documented in draft reports by September 27, 1999. The core results are needed by this date so that the Province can support a decision this Fall on appropriate motor vehicle emission standards for B.C.

Work items designated [ES] refer to the "expanded scope" items that are targeted to be complete and documented in the revised draft reports by October 31, 1999, should additional partner funding become available. These items are specifically excluded from the scope of work of this contract at this time. Should additional partner funding become available, this contract may be amended to add these tasks to the scope of work, at an additional cost of $18,000 plus GST. Such contract amendment would be at the sole discretion of the GVRD.

All work delegated by the Consultant to subcontractors, and payment to them for same, shall be the sole responsibility of the Consultant.

1. [C] Review and select the most appropriate vehicle emission model for the project including the following possibilities:

- CVMA/CCME modified ('Canadianized') MOBILE5b model
- MOBILE 6ß (full release MOBILE 6 will not be ready in time)
- EPA-modified MOBILE 5b/T2 to enable analysis of Tier 2 implementation
- MOBILE 5C (modified and enhanced to accommodate current requirements)
- PART 5 (adjusted output) results from GVRD inventory and Sulphur-in-Fuels Study will be used to estimate PM emissions. No new primary PM emission modelling is planned.

Alternatively (or additionally), base analysis for BC on analyses carried out by others, e.g., US EPA, CARB, etc. That is, use meta-analysis and synthesis of available studies rather than formal BC-specific model analysis.[1] This may be particularly useful in the

---

[1] For example, spreadsheets developed by CARB comparing Tier 2 and LEV II fleet-average emission factors are in-hand.

short term to get as preliminary answer, leaving more detailed analysis for later when better tools would be available.

2. [C] Estimate emissions from the light duty vehicle fleet[2] in the LFV for the years 1995, 2000, 2005, 2010, 2015 and 2020[3], considering the following emission scenarios—

- Baseline, consisting of GVRD's "Implemented AQMP" emission levels (GVRD Scenario B), with the addition of the effects of the recent federal fuel sulphur regulations - adjusted to take into account Scrap-It, AirCare II and any other committed initiatives in-progress; adjusted to take into account harmonization with US vehicle emission regulation timing starting with the 2001 model year (US federal NLEV[4] and Tier 2 implementation).

- Incremental emission reductions from implementation of California LEV II regulations. Scenarios[5] for partial implementation of the proposed CAL regulations and related actions, e.g., NMOGs-only[6], full LEV II, ZEV, ultra-low sulphur fuel or other fuel quality specifications, etc.

- Predict future motor vehicle emissions in the region based on the same VKT forecast as used in Scenarios A and B in the GVRD 'backcast-forecast' exercise for the 1995 inventory (Levelton Engineering, 1998)[7].

3. [C] Forecast emission reductions for each scenario analyzed in Item 2 relative to the selected baseline.

4. [ES] Forecast reductions in greenhouse gas emissions (if any anticipated) resulting from the scenarios. This task refers to additional measures beyond the LD fleet analysis, not to the LD fleet analysis. See Task 9 below. Comment on any interactions (especially conflicts) between tailpipe standards and fuel efficiency standards

5. [C] Using the predicted emission reductions for motor vehicles, develop forecasts of total emissions in the LFV airshed. The forecast of emissions other than from light duty vehicles will be as estimated previously in the 1995-2020 GVRD forecast study (Levelton Engineering, 1998).

6. [C] Review available approaches to estimating relation of ozone levels in the LFV to changes in precursor emissions. If possible, use available results from regional UAM-V modelling to develop an appropriate methodology for predicting changes in peak ozone levels and hours of elevated ozone exposure as a function of changes in NOx and VOC

---

[2] Defined initially as the LDV (PC), LDT1 and LDT2 classes – no intention to expand scope to encompass CAL LEV II inclusion of MDV classes at this time.

[3] Or other choices of key years as determined in scoping consultations.

[4] Taken as equivalent to CAL LEV I for 2001-2003.

[5] Approximately 3-4 scenarios planned.

[6] That is, specification of NMOG emissions only, without specifiying NOx, etc. explicitly, as in current BC MVER Reg.

[7] Incorporates updated growth parameters for the region (see Levelton, 1998).

(NMOG) emissions. Interface with Environment Canada's UAM-V development and application program where possible.

[C]: Default is to interpolate and extrapolate from (possibly) revised data from 1997 Sulphur-in-Fuels Study and 1995 BC Clean Vehicles and Fuels Study.[8]

[C]: Adapt UAM V and other data to create new parameterized NOx-NMOG-ozone diagrams (*a la* earlier EKMA diagrams for the region).

7. [C] Review the available models and results for predicting secondary particle formation and concentration (nitrates, sulphates, secondary organic aerosol), focusing on—

- Lagrangian box model developed for the LFV region in the 1997 Sulphur in Fuels Study by Prof. Spyros Pandis, Carnegie Mellon University
- ISOPART Lagrangian plume model being developed by Prof. Sara Pryor, Indiana University
- Develop new data, if existing database is not adequate.

8. [C & ES] Predict the change in ambient peak ozone and mean fine particle concentrations (secondary pollutants) using the selected models for each of the motor vehicle scenarios. Predict the ambient mean concentration changes of the primary gaseous and particulate pollutants: NOx, SO_2, CO, PM and VOC (NMOG)[9] using emission rollback models that have been applied previously in the region.[10]

9. [ES] Develop definitions and results of additional measures proposed by sponsors, such as TransLink initiatives: Ballard buses, the AirCare ACORP program for HDVs, older vehicle scrappage program (Scrap-It), and Natural Gas buses

10. [C] Summarize recent, available cost data for the LD vehicle emission standard scenarios and develop cost-effectiveness values. New cost data will not be generated. US EPA and CARB existing analyses will be the principal sources.[11]

11. [C] Estimate monetized benefits (health effects, visibility, others) in terms of avoided damages resulting from air quality improvements for each of the motor vehicle regulation scenarios using the basic methodology used for the LFV cost-benefit studies (1994/5, 1997), with updates of key parameters. Interface with the Environment Canada program to implement AQVM where possible.

---

[8] With any required updates.

[9] Possibly including 'toxics' as treated in earlier studies [ES]

[10] See 1994 & 1995 cost-benefit studies for the region and 1995 Cleaner Vehicles and Fuels Benefits for BC analysis (BOVAR-Concord, 1994, 1995a,b). Assume relative changes in ambient concentrations of primary pollutants directly proportional to relative changes in emissions.

[11] Sponsors expected to provide data or any special insight or requirements here.

[ES] Develop a Multiple Account Evaluation (MAE) framework to take into account other than monetizable benefits systematically.[12]

12. [C & ES] Estimate uncertainty of air quality changes and benefits using, for example, a Monte Carlo statistical treatment of the data (e.g., using Crystal Ball®, as done for 1995 CBA and 1997 Sulphur-in-Fuels Study).

13. [C & ES] Prepare a comprehensive report on the findings of all tasks.

14. [ES] Develop work plan for any additional tasks to be carried out beyond the short-term requirements to evaluate the proposed revisions to the BC Vehicle Emission Reduction Regulation (TransLink and other sponsor tasks, such as support of development of anticipated new GVFV AQMP) – Phase2.

In addition, the consultant will be expected to attend interim project meetings with the project coordinating committee as required.

3 REQUIREMENTS FOR THE STUDY REPORT

The report will be produced in two volumes. Volume 1 shall include Emissions, Air Quality Impacts, and Costs. Volume 2 shall include the Air Quality Benefits. The following number of reports are to be submitted by the dates shown in Section 5.2.

(i) Eight copies of draft reports
(ii) Eight copies of final reports
(iii) Two unbound camera-ready copies of final reports including the front and back covers.

An electronic copy in Microsoft Word 97 for the reports, and any electronic data files used in this study (eg. Mobile 5b input and output files, air quality model input files) shall be provided on disk.

4 CONTRACT ADMINISTRATION

This contract will be administered by Mr. John Newhook, and all invoices and administrative issues should be forwarded to his attention at the following address:

Mr. John Newhook, P.Eng.
Air Quality Management
Air Quality Department
Greater Vancouver Regional District
4330 Kingsway, Burnaby, B.C.
Canada V5H 4G8

---

[12] See 1994 & 1995 LFV CBA studies and *Greater Vancouver and Fraser Valley Air Quality Management Plan Discussion Paper: Issues, Policies and Approaches*, Alchemy Consulting & Levelton Engineering, May 1999.

In addition, Mr. Kelly Der, P. Eng., at the same address as above, will provide technical input to the project on behalf of the GVRD.

The project will be reviewed on a periodic basis by members of the project coordinating committee referred to in Section 1.

5 PROJECT SCHEDULES AND DELIVERABLES

5.1 The total funding available for this project is $50,000 (Cdn), including 7% GST.

5.2 The schedule for the project is:

Submission of draft reports "Emissions, Air Quality Impacts, and Costs (Volume 1)" and "Air Quality Benefits (Volume 2)" These draft reports include the "core" tasks discussed in Section 2.	September 27, 1999
Submission of revised draft reports "Emissions, Air Quality Impacts, and Costs" and "Air Quality Benefits". (These versions of the draft reports will include the "expanded scope" activities discussed in Section 2, should this contract be revised to include those tasks).	October 31, 1999
Submission of Final Reports	November 30, 1999

Appendix B: Emissions supporting data

1. Introduction

This appendix contains details of the methods used to calculate the study baseline emissions and the emissions if the NLEV/Tier 2 or the NLEV/LEV II programs were implemented in BC. The emission results for these three cases are also tabulated for reference. A discussion of the results is presented in the main body of the report.

The study area includes the motor vehicles operating in the Lower Fraser Valley (LFV). The LFV area used in this study is identical to that used in the previous emission inventory studies and extends from the US-Canada border north to Lions Bay, and from Bowen Island East to Hope.

The main focus of the emission analysis conducted in this study was the development of estimates for NO_x, VOC and CO emissions from light duty gasoline motor vehicles. This group includes passenger cars, light duty trucks (includes vans, SUVs and trucks) and motor cycles. Related analysis was conducted to also estimate emissions of SOx and particulate matter (total, PM10 and PM2.5) from this group of vehicles. Emissions for heavy duty gasoline and diesel trucks as well as light duty diesel vehicles were outside the scope of the study and the emission estimates were not changed from the existing 1995-2020 emission forecast. For ease of use of the emission results, the earlier estimates of emissions from heavy duty vehicles and from light duty diesel vehicles have been included in this section of the Appendix. For information on the methods used to develop the emission estimates for these vehicles the reader is referred to the 1995-2020 emission forecast study (Levelton, 1998).

Motor vehicles as a group are a large source of emissions in the Lower Fraser Valley, comprising in 1995 approximately 88% of the CO, 48% of the NO_x, 31% of the VOC, 14% of the SO_x, 11% of the $PM_{2.5}$ and 8% of the PM_{10} emitted from all anthropogenic sources (point, area and mobile) inventoried in the Lower Fraser Valley (Levelton, 1998, Scenario B; emission reduction measures implemented as of end of 1997).

2.0 Methodology

2.1 General Approach to Estimating Emissions from Motor Vehicles

Vehicle emissions are typically estimated by multiplying a base quantity times an emission factors as shown in the following simple equation:

$$\text{Emission (g)} = \text{vehicle kilometers of travel (VkmT)} \times \text{emission factor (g/VkmT)} \qquad (1)$$

For the 1995 LFV inventory forecast, the VkmT data for each EPA vehicle class was estimated by the GVRD using the EMME2 transportation model to develop the estimate of total VkmT by year allowing for growth in the region, together with a distribution of VkmT across vehicle classes developed from 1995 ICBC data on vehicle registrations. The distribution of VkmT across vehicle classes was assumed to be constant over the 1995-2020 period.

Various methods have been used to develop the estimates of emission factors for each pollutant included in the existing 1995-2020 forecast of emissions in the LFV. Emission factors used to develop the forecast of CO, NOx and VOC emissions were estimated using the US EPA MOBILE 5C model, which was the latest version of this model available when the inventory was prepared in 1998. Emission factors for particulate matter (total, PM_{10} and $PM_{2.5}$) were estimated using the US EPA PART5 model. In the case of SO_x, emission factors were estimated by mass balance, assuming 98% of the sulphur in the fuel is emitted as SO_2 gas, with the remainder emitted as particulate matter. The following sections explain the methods used to update the emission factors for three cases considered in this study: study baseline; implementation of NLEV followed by US EPA Tier 2 standards; implementation of NLEV followed by California LEV II standards.

2.2 Base Quantity Data

The VkmT values developed previously by the GVRD reflect the mix of vehicles on the road in 1995. The distribution of vehicle kilometers traveled used in the existing1995-2020 emission forecast is as follows:

Percent of Vehicle miles traveled (VkmT)									
LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	LDVs	HDVs
67.1	20.4	5.8	0.3	0.7	0.8	4.2	0.6	95.5	4.5

LDGV, light duty gasoline vehicles (passenger cars).
LDGT1, light duty gasoline trucks, 0-2,720 kg (0-6,000 lbs.) GVW. This includes vans and trucks.
LDGT2, light duty gasoline trucks, 2,721-3,856 kg (6,000-8,500 lbs.) GVW. This includes trucks and SUVs.
HDGV, heavy duty gasoline vehicles, greater than 3,856 kg (> 8,500 lbs.) GVW.
LDDV, light duty diesel vehicles (passenger cars)
LDDT, light duty diesel trucks (types 1 and 2 as above)
HDDV, heavy duty diesel vehicles, greater than 3,856 kg (> 8,500 lbs.) GVW.
MC, motorcycles.

There has been an increasing shift in new cars sales to larger vehicles such as trucks and sport utility vehicles. With time, this is changing the on-road fleet significantly from what was determined for the 1995 LFV emission inventory. The significance of the shift in VkmT distribution was investigated using data provided by Natural Resources Canada for BC on the on-road vehicle stock, distances traveled and survival fractions by age of vehicle. This data was used to estimate the distribution of distance traveled by on-road gasoline passenger cars and light duty trucks gasoline vehicles. These results are shown below and compared to the VkmT used in the 1995-2020 LFV emission forecast and re-used in this study (note that the distribution is assumed constant in the emission forecast):

Vehicle Category	Latest NRCan Data for BC 1997 Fleet **		Used for the 1995-2020 LFV Emission Forecast**
	VkmT (Million km)	%	%
Cars	17,000	64.9	71.9
Light duty Trucks (LDGT1&2)	9,180	35.1	28.1
Total for these categories only**	26,100	100.0	100

** The VkmT distribution shown applies only to the listed categories, not the full vehicle fleet.

The NRCan data for BC show passenger car VkmT have decreased and light duty truck VkmT have increased since preparation of the data for the LFV forecast. The impact of the trend is likely continuing to shift the on-road fleet distribution. The significance of this shift in VkmT on the emissions estimated in this study that have been based on the previously developed VkmT distribution is discussed in the results section of this report.

Almost all base quantity information needed to model emission factors for motor vehicles using the MOBILE model were assumed to be the same as used previously for the 1995-2020 LFV emission forecast. This includes meteorological inputs, gasoline RVP, vehicle speeds and vehicle fleet characteristics. Using the modelling options available in the MOBILE model (see below) light duty vehicles were assumed to use US conventional gasoline in 1995 and 2000 and US reformulated gasoline in 1995 and later years. Gasoline sulphur content was assumed to decrease as follows: 1995-1999, 330 ppm sulphur; 2000-2004, 150 ppm and 2005 -2020, 30 ppm.

2.3 CO, NOx, and VOC Emission Factors

2.3.1 The Model - Modified MOBILE 5b Tier 2 Evap

MOBILE 5C is a Canadianized version of the US EPA MOBILE 5A model. However, its default basic emission rates (BERs) do not include the proposed Tier2 and LEV II standards, it can only handle up to 12 user-supplied BERs, which is not sufficient to model the Tier2 and LEV II phase-in requirements, and it does not have the capability to predict emission factors for future Canadian gasoline sulphur contents. Consequently, the MOBILE 5C model is not suitable for the present study.

The US EPA is developing the MOBILE 6 model, which will include new correlations for predicting emissions from on-road vehicles that have been developed from a large body of vehicle test data, as well as capabilities to model emissions with the existing and proposed Tier 2 standards. However, the MOBILE 6 model will not be available until the Fall of 2000, at the earliest. The US EPA developed and released a modified version of the MOBILE 5B model called MOBILE 5B-Tier 2evap (released June 1999) that it used for analysis of the proposed Tier 2 standards. This model addresses the problems indicated above regarding the MOBILE 5C model and incorporates an option that enables prediction of emissions assuming Tier 2 evaporative standards have been implemented. This version of the model was used in this study to generate emission factors for CO, NOx and VOC.

2.3.2. Vehicle Classes

The Mobile model deals with eight different classes of vehicles, of which LDGV, LDGT1 and LDGT2 are pertinent to the present study. The MOBILE definition of these three vehicles is provided below, together with EPA Tier 2 and California LEV II equivalence:

	LDGV	LDGT1	LDGT2
Definition	Light-duty vehicles	Light-duty truck 1	Light-duty truck 2
In MOBILE		< 6000 lb GVW	6000–8500 lb GVW
Equivalent to		EPA - LDT1 & 2	EPA LDT3 & 4
Equivalent to		CA - LDT1 & 2	CA – MDV1 & 2

The definitions used in the MOBILE model were used by the GVRD in the 1995 LFV emission forecast.

2.3.3. Annual Mileage Accumulation Rates (MR)

Emission factors depend on the vehicle age and mileage accumulated. The default MRs used in the earlier emission forecast were based on the US national data. The MR data used in the present study are the BC averages (1997 data) supplied by NRCan for LDGV, LDGT1 and LDGT2, and the model default values for the remaining vehicle types.

2.3.4. Vehicle Registration Age Distribution (MY)

Emission factors vary significantly with model year (MY) as a result of advances of emission control technology. The in-use fleet is a mixture of vehicles of different ages. The registration age distributions used by the GVRD in the 1995 emission forecast have been used in the present study for all modelled vehicles types.

2.3.5. Basic Emission Rates (BERs)

The MOBILE 5B Tier 2 evap model generates emission factors by correcting the basic emission rates using parameters such as fuel properties, local climate, speed, etc. The BERs are expressed as a linear function of mileage, consisting of a zero-mile level (ZML) and one or two deterioration rates (DR1 and DR2). Where two DRs are applied, the model requires the user to supply the kink mileage (point at which the slope in the line changes) above which DR2 takes effect. The model can handle up to 25 BERs per pollutant per vehicle type, with the maximum number of BERs being 3 x 8 x 25 = 600. The BERs for LDGV, LDGT1 and LDGT2 were compiled in the present study, while model defaults are used for the rest of the vehicle types.

The vehicles in Canada and the US had different emission standards and control technologies between MY 1980 and 1987. Since 1988, the vehicle emission characteristics were essentially the same. Beginning with the 1998 vehicle model year, Canadian emission standards and test procedures were formally harmonized with those applicable in the US under the Environmental Protection Agency (EPA)[1]. The BERs used in the present study were taken from MOBILE5C for MY80-87 and from EPA documents prepared in support of their development of the MOBILE 6 model for all later vehicle model years.

2.3.5.1 Base BERs (BBERs)

Base values for the basic emission rates (BBERs) indicate BERs for fuels with 30 ppm sulfur. Koupal (1999a) reported the methodology that will be used in MOBILE 6 for the BBERs for vehicles of different emission standards. These BBERs are disaggregated into running emissions (when the engine and catalyst are fully warmed up) and start emissions (before fully warmed up). MOBILE 6 will also distinguish between "normal" emitters, "high" emitters, and "repaired" emitters. The present study only considers the "normal" emitters, based on the simplifying

---

[1] Canada Gazette, Part II, Regulations Amending the Motor Vehicle Safety Regulations, Vol. 131, No 17.

assumption that the emissions from high and repaired emitters are almost all off-set by the supplementary federal test procedure (SFTP)standards that will be implemented.

The SFTP standards require manufacturers to control emissions from vehicles under aggressive driving conditions, specifically, when operated at high speed/acceleration (US06 test cycle), at high ambient temperature and with air conditioning loads (SC03 test cycle). SFTP requirements will be phased-in over three years starting with the 2000 model year for passenger cars and light duty trucks. The phase in for heavy light duty vehicles starts with the 2002 model year. Modelling of the effect of SFTP on vehicle emissions would involve considerably more complexity and difficulty because of the additional phase in requirements, the need to develop algorithms to relate test results to on-road emissions, and the additional level of standards.

Conceptually, the SFTP attempts to off-set the effects of air conditioner use and aggressive driving behaviour, which lead to higher emission rates than that predicted using correlations developed by the EPA for "normal" emitter vehicles. From review of the emission factors reported by Koupal (1999a), the SFTP will result in almost total reduction in the emissions from aggressive driving and air conditioner use, and this simplifying assumption has been used in the present study. The modeling results reported in this study are based on emission correlations developed by the EPA for the normal emitter vehicles and assumes these fairly represent emissions from the total vehicle fleet. The emission estimates developed with this approach are anticipated to be somewhat lower than actual.

For vehicles certified to Tier1 standards, the BBERS were derived directly from updated test emissions. For LEVs (including NLEV, Tier2, and LEV II), as correlations for these vehicles do not yet exist, the BBERs were estimated according to the following equations:

$$\mathrm{ZML}_{(\mathrm{VEH})} = \mathrm{ZML}_{(\mathrm{Tier1})}{*}\mathrm{LEV}_{(50)}\,/\mathrm{Tier1}_{(50)} \qquad (2)$$

$$\mathrm{DR}_{(\mathrm{VEH})} = \mathrm{DR}_{(\mathrm{Tier1})}{*}\ \mathrm{LEV}_{(50)}\,/\mathrm{Tier1}_{(50)} \qquad (3)$$

where the subscript (VEH) represents LDGVs, LDGT1s, and LDGT2s certified to NLEV, Tier 2 and LEV II standards. $\mathrm{LEV}_{(50)}$ and $\mathrm{Tier1}_{(50)}$ indicate the LEV and Tier1 emission standards, respectively, at 50,000 miles. The ZML and DR1 for fuels with 30 ppm sulfur were given in Tables 1 and 2 of Koupal (1999a) for normal FTP composites of NO_x and HC (NMHC for Tier 1 and NMOG for LEVs).

For vehicle model years 88-93, the MOBILE 6 BBERs were developed from correlating vehicle emission test data. As the emission levels are a function of fuel delivery technology type, the BBERs were developed as weighted averages. The technology weighting factors were given in Koupal (1999a). This same reference also reports NO_x and THC the running ZML and DR1[2] and start emissions (g). The FTP composite emission rates are calculated from the equation:

$$\text{FTP Composite (g/mile)} = \text{Running} + (0.43{*}\text{Start} + 0.57{*}0.16{*}\text{Start})/7.5 \qquad (4)$$

Where 7.5 = total miles in LA4; 0.43/0.57 = relative weightings of cold start and hot start; and 0.16 = ratio of hot start emissions (i.e. following 10 min soak) to cold start emissions.

---

[2] As from the diagrams presented at the Mobile6 Workshop (Enns, 1999) and in Koupal and Rykowski, (1999). Note that all DR1s listed in Table A-1 of the reference have been calculated as emission increase/1000 miles, not by definition as increase/10,000 miles. The DR1 values used in the present study are the correct values.

Data used to develop the ZML and DR1 of CO are taken from the Mobile 6 Workshop papers: Enns (1999) for MY88-93; and Koupal (1999b) for Tier1 and later model years. The same methodology used for NO_x and HC BBERs is used also for BBERs for CO.

In overview, the standards used to develop BBERs are summarized as follows:

Specific Emission Standards Used to Develop BBERs *

	LDVs	LDGT1	LDGT2	Mobile Classes
Tier0	LDVs	LDTs	LDTs	EPA classes
Tier1	PC/LDT1	LDT2	LDT4	EPA classes
NLEV	PC/LDT1	LDT2		CA classes
Interim Tier2**			MDV1	CA classes
Tier2	PCs/LDTs	PCs/LDTs	PCs/LDTs	EPA classes
LEV II	PCs/LDTs	PCs/LDTs	PCs/LDTs	CA classes

* Distribution of light duty trucks between LDT1 and LDT2 is not available; nor is distribution between LDT3 and LDT4.

** Interim Tier2 standards are not available for CA MDV2.

2.3.5.2 Exhaust Emission Standards

Emission standards vary with vehicle model year (MY): Tier 1 was introduced in MY1994; voluntary NLEV will be introduced in MY2001; and Tier 2 will be introduced in MY2004. BBERs change with MY accordingly. However, new emission standards are usually phased-in over a period of time. During the phase-in model years, vehicles registered are certified to different standards, with a minimum percentage of the fleet to the newer standards according to the governmental phase-in requirements. The BBERs developed for these model years are the weighted averages.

Existing emission standards pertinent to this study are summarized in Table B-1, The Tier 2 and LEV II emission standards are summarized in Tables B-2 an B-3. The new car fleet NMOG standards that manufacturers must meet under the LEV II program, and which have been used to calculate the phase-in percentages for LEV II, are given in Table B-4. For modeling purposes the LEV II evaporative standards have been assumed to be equivalent to the Tier 2 evaporative standards built into the MOBILE 5B Tier 2 evap model available for this study.

BIN 5 standards are assumed to be the Tier 2 fleet average, while the LEV II average standards are based on a distribution among LEV2, ULEV2 and SULEV2 standards that satisfy the fleet average NMOG requirements. The phase-in program is dictated by NO_x emission reduction for Tier 2, but by NMOG emission reduction for LEV II.

Table B-1 Current and Past Exhaust Emission Standards (g/mi)

Vehicle	NOx		THC		CO	
	50 k mi.*	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.
LDGV						
Tier 0	1.0	1.2	0.41	0.80	3.4	10
Tier 1	0.4	0.6	0.25	0.31	3.4	4.2
NLEV	0.2	0.3	0.075	0.09	3.4	4.2
LDGT1						
Tier 0	1.0	1.7	0.41	0.80	3.4	10
Tier 1	0.7	0.98	0.32	0.40	4.4	5.5
NLEV	0.4	0.5	0.1	0.13	4.4	5.5
LDGT2						
Tier 0	1.0	1.7	0.41	0.80	3.4	10
Tier 1	1.1	1.153	0.39	0.56	5.0	7.3

* k mi. and is an abbreviation for 1000 miles.

Table B-2 Proposed Interim and Tier 2 Exhaust Emission Standards by Bin Category (g/mi)

Bin No.	NOx		NMOG		CO		PM	
	50 k mi.*	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.
Light Duty Gasoline Vehicles								
7	0.14	0.20	0.100	0.125	3.4	4.2	-	0.02
6	0.11	0.15	0.075	0.090	3.4	4.2	-	0.02
5**	0.05	0.07	0.075	0.090	3.4	4.2	-	0.01
4	0.05	0.07	0.040	0.055	1.7	2.1	-	0.01
3	-	0.04	-	0.070	-	2.1	-	0.01
2	-	0.02	-	0.010	-	2.1	-	0.01
1	-	0.00	-	0.000	-	0.0	-	0.0
Interim Standards for LDV/LLDTs								
5	0.4	0.6	0.125	0.156	3.4	4.2	-	0.06
4**	0.2	0.3	0.075	0.090	3.4	4.2	-	0.06
3	0.2	0.3	0.04	0.055	1.7	2.1	-	0.04
2	0.05	0.07	0.075	0.090	3.4	4.2	-	0.01
1	-	0.00	-	0.00	-	0.0	-	0.0
Interim Standards for HLDTs								
5	0.40	0.60	0.160	0.230	3.4	4.2	-	0.06
4	0.20	0.30	0.140	0.180	3.4	4.2	-	0.06
3**	0.14	0.20	0.125	0.156	3.4	4.2	-	0.02
2	0.05	0.07	0.075	0.090	3.4	4.2	-	0.01
1	-	0.00	-	0.00	-	0.0	-	0.0

* k mi. and is an abbreviation for 1000 miles.

** Used as fleet average standards

Table B-3 LEV I and LEV II Exhaust Emission Standards by Vehicle Emission Category (g/mi)

Vehicles	NOx		NMOG		CO		PM**	
	50 k mi.*	100 k mi.	50 k mi.	100 k mi.	50 k mi.	100 k mi.	50 k mi.	100 k mi.
LEV I and Tier 1 Exhaust Emission Standards								
Light Duty Gasoline Passenger Cars and Trucks								
Tier 1	0.4	0.6	0.25	0.31	3.4	4.2	0.08	-
TLEV	0.4	0.6	0.125	0.156	3.4	4.2	-	0.08
LEV	0.2	0.3	0.075	0.090	3.4	4.2	-	0.08
ULEV	0.2	0.3	0.04	0.055	1.7	2.1	-	0.08
Light Duty Gasoline Trucks (3751-5750 lbs.)								
Tier 1	0.7	0.97	0.32	0.40	4.4	5.5	0.08	-
TLEV	0.7	0.9	0.16	0.20	4.4	5.5	-	0.10
LEV	0.4	0.5	0.10	0.13	4.4	5.5	-	0.10
ULEV	0.4	0.5	0.05	0.07	2.2	2.8	-	0.05
	50 k mi.	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.
Medium Duty Vehicles (3751-5750 lbs.)								
Tier 1	0.7	0.97	0.32	0.46	4.4	6.4	-	0.10
LEV	0.4	0.5	0.16	0.23	4.4	6.4	-	0.10
ULEV	0.4	0.5	0.10	0.143	4.4	6.4	-	0.05
SULEV	0.2	0.3	0.05	0.072	2.2	3.2	-	0.05
Medium Duty Vehicles (5751-8500 lbs.)								
Tier 1	1.1	1.53	0.39	0.56	5.0	7.3	-	0.12
LEV	0.6	0.9	0.195	0.28	5.0	7.3	-	0.12
ULEV	0.6	0.9	0.117	0.167	5.0	7.3	-	0.06
SULEV	0.3	0.45	0.059	0.084	2.5	3.7	-	0.06
LEV II Exhaust Emission Standards								
Light Duty Gasoline Passenger Cars and Trucks (< 8500 lbs.)								
	50 k mi.	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.	50 k mi.	120 k mi.
LEV	0.05	0.07	0.075	0.090	3.4	4.2	-	0.01
ULEV	0.05	0.07	0.04	0.055	1.7	2.1	-	0.01
SULEV	-	0.02	-	0.01	-	1.0	-	0.01

* k mi. is an abbreviation for 1000 miles.

** diesel fuel only

Table B-4LEV II Fleet Average NMOG Exhaust Emission Requirements

Vehicle Model Year	Fleet Average NMOG (g/mi)*	
	All Passenger Cars, LDTs 0-3750 lbs. LVW	LDTs 3751 lbs. LVW - 8500 lbs. GVW
2001	0.070	0.098
2002	0.068	0.095
2003	0.062	0.093
2004	0.053	0.085
2005	0.049	0.076
2006	0.046	0.062
2007	0.043	0.055
2008	0.040	0.050
2009	0.038	0.047
2010	0.035	0.043

* 50,000 mile durability vehicle basis

2.3.5.3 Phase-out and Phase-in Timing Assumptions for Standards

NLEV standards have been assumed to apply to 100% of the vehicles sold in BC in 2001-2003 inclusive. Compliance with the NLEV program is presently voluntary in Canada and no formal commitments have been made to comply with these standards as of completion of this study. It appears reasonable for this study that substantial compliance with the NLEV program will occur in BC, and this has been assumed.

Phase-in provisions are include in the proposed EPA Tier 2 standards and have been used in the analysis for this study. Some changes to this phase-in program are possible by the time the Tier 2 program is legislated.

Table B-5 summarizes the percentage of new vehicles meeting interim and final emission standard that are assumed to be sold in each year. The phase-in percentages are shown for each of the vehicle classes used in the MOBILE model, namely, LDGV, LDGT1 and LDGT2. Similarly, the phase-in percentages for the LEV II standards are summarized in Table B-6. The phase-in percentages for LEV II were calculated so that the resulting new vehicle fleet meets the NMOG fleet requirement given previously in Table B-4. These phase-in percentages were also applied to CO and NO_x emission standards.

Both Tier 2 and LEV II offer large decreases in emission standards for NMOG and NO_x from current Tier 1 standards that have been in effect since 1994. The fleet average NMOG standard specified under the LEV II program is lower than the Tier 2 NMOG standard. The mix of vehicle technologies that satisfy the LEV II fleet NMOG average (many technology combinations are possible) will also yield fleet CO exhaust emission standards that are significantly lower, and fleet NO_x standards that are slightly lower than the Tier 2 standards.

Table B-5 Vehicle Phase-out and Phase-in Percentages for Current Standards and Future Interim and Tier 2 Standards

Vehicles and Technologies	Pre 1994	1994	1995	1996	1997 to 2000	2001 to 2003	2004	2005	2006	2007	2008	2009	2010 to 2020
LDGV													
Tier 0	100	60	20	0									
Tier 1		40	80	100	100								
NLEV						100	75	50	25	0			
Tier 2 + evap*							25	50	75	100	100	100	100
LDGT1													
Tier 0	100	60	20	0									
Tier 1		40	80	100	100								
NLEV						100							
Interim							75	50	25	0			
Tier 2 + evap*							25	50	75	100	100	100	100
LDGT2													
Tier 0	100	100	100	50									
Tier 1				50	100	100							
Interim 1							75	50	25	0			
Interim 2							25	50	75	100	50	0	
Tier 2 + evap*											50	100	100

* The phase-in of Tier 2 standards are as specified in the proposed rules.

Table B-6 Vehicle Phase-out and Phase-in Percentages for Current Standards and Future Interim and LEV II Standards

	Pre 1994	1994	1995	1996	1997 to 2000	2001 to 2003	2004	2005	2006	2007	2008	2009	2010 to 2020
LDGV													
Tier 0	100	60	20	0									
Tier 1		40	80	100	100								
NLEV						100	45	35	27.5	20	12.5	7.5	0
LEV II + evap*							55	65	72.5	80	87.5	92.5	100
LDGT1													
Tier 0	100	60	20	0									
Tier 1		40	80	100	100								
NLEV						100	74	58	33	21	12	7	0
LEV II + evap*							26	42	67	79	88	93	100
LDGT2													
Tier 0	100	100	100	50									
Tier 1				50	100	100							
LEV I							74	58	33	21	12	7	0
LEV II + evap*							26	42	67	79	88	93	100

* The phase-in percentages for 2004 and later years are calculated to achieve the fleet LEV II NMOG requirements. The phase-in percentages determined for NMOG are then also applied to CO and NO_x.

2.3.5.4 Corrections for the Effects of Fuel Sulfur

Modern emission control technologies rely on catalysts. As a strong catalyst-poison, sulfur can severely deactivate catalysts. The current MOBILE models do not have the capacity to estimate sulfur impacts on emissions. Consequently, the adjustment factors developed by the US EPA for their analysis of Tier 2 impacts has been applied externally to correct the BBERs to account for emission differences between the 30 ppm sulfur level (in Indolene or Phase II RFG) and actual sulfur levels of in-use fuels. However, BERs for MY 80-87 are taken from MOBILE 5C without sulfur correction, though the influence of these vehicles is small of the latter part of the forecast period. BERs for the later MY vehicles are calculated with BBERs corrected for sulfur impact.

Local gasoline in 1995 contained approximately 300 ppm sulfur. New regulations have been proposed that the sulfur level will be reduced to 150 ppm after 2000 and 30 ppm after 2005. The sulfur correction factors for these three sulfur levels (note that the EPA correction for 330 ppm sulphur has been applied for the local case of 300 ppm) are provided in Table 9 of Koupal (1999a) for NOx and HC emissions under Tier 0, Tier1, NLEV and Tier2 standards for LDVs and LDTs. The sulfur correction factors for CO have been taken from data presented at the MOBILE 6 Workshop (Rao, 1999; Koupal, 1999b).

Thus, BERs vary not only with vehicle model year (MY) but also with calendar year (CY).

2.3.5.5 Conventional Gasoline, Reformulated Gasoline and Non-Sulfur Corrections

In developing BERs for the present study, fuel sulfur effects were isolated to allow the assessment of changes in sulfur level only. The effects of all other fuel characteristics are accounted for using non-sulfur fuel factors developed for conventional gasoline and US reformulated gasoline. For pre-Tier 1 vehicles, non-sulfur fuel effects derived by the EPA for the MOBILE 5B fuel corrections using the Complex Model were applied. For Tier 1 and later vehicles, these factors were generated using results the EPA developed using the Complex Model for Tier 0 vehicles with Port fuel injection and three-way catalyst technology. With the total fuel corrections, sulfur factor times non-sulfur factor, the “target” BERs are obtained:

$$\text{Target BERs} = \text{BBER*S\_factor*Non\_S\_factor} \qquad (5)$$

The non-sulfur factors were given in Table 10 of Koupal (1999a) and Table 9 of Koupal and Rykowski (1999).

2.3.5.6 Correction for Fuel Sulphur Effect Imbedded in Mobile 5B

The above BERs can not be input directly into the modified MOBILE 5B model, as the model contains out of date fuel corrections that EPA did not disable. Therefore, the fuel corrections already imbedded in MOBILB 5b were backed out by making corrections to the BERs. Table 9 of Koupal and Rykowski (1999) provided the total fuel corrections already in MOBILE 5B. The final “adjusted” BERs that are used in this study with the Modified MOBILE 5b Tier 2 evap model were developed by dividing the target BERs by the reported MOBILE 5b total fuel correction factors:

$$\text{BER} = \text{BBER*S\_factor*Non\_S\_factor/ MOBILE5b\_fuel\_factor} \qquad (6)$$

2.3.5.7 Emission reduction from AirCare

The MOBILE model was run assuming no inspection and maintenance program was in effect and hence the emission factors need to be corrected to reflect the emission reductions that are achieved by the AirCare program.

The effect of the AirCare program on emissions from light duty vehicles was applied to the emission factors estimated by the MOBILE model using the same emission reduction factors for CO, NO_x and VOC that were applied in the forecast/backcast of the1995 LFV emission inventory (Levelton, 1998). The potential effects of AirCare II on the future vehicle emissions were not able to be evaluated. The emission reductions achieved by AirCare relative to the estimates modelled assuming that no inspection and maintenance program was in effect were assumed to be constant for the 1995-2020 period at the following rates:

CO	26.5%
VOC	19.1 %
NOx	2.3 %

2.3.5.8 Factors not Considered

MOBILE 5B default tampering rate were assumed. More complicated factors, such as aggressive driving (AGD), air conditioning (A/C), “high” emitters (malfunction) and “repaired” emitters, and the SFTP were not considered individually. However, there is evidence (Koupal, 1999a) that the effects of the negative factors (Aggressive driving, A/C, high emitters) are largely offset by the SFTP. Thus, it is not expected that the overall results should not be affected significantly by this simplification.

2.4 SO_x Emissions

Excluding particulate sulphur compounds, SO_x emissions from motor vehicles are proportional to the sulphur content of the fuel and the amount of the fuel burned. This relationship was used in the 1995-2020 LFV emission forecast (Levelton, 1998) to estimate the emissions of SO_x from all vehicle categories. The earlier results for light duty gasoline vehicles were updated in this study to reflect the future changes in gasoline sulphur content over the forecast period. As in the earlier emission inventory, 2% of the sulphur input to the vehicle in the fuel was assumed to be converted to particulate matter, with the balance being converted to SO_2. The gasoline sulphur contents assumed for the calculation of emissions in this study are as follows:

Year	Gasoline Sulphur (ppm w/w)
1995	300
2000	150
2005	30
2010	30
2015	30
2020	30

Since SO_x emissions from light duty motor vehicles are not dependent on emission standards, the annual emissions are the same for the study baseline and the Tier 2 and LEV II programs considered in this study.

2.5 Particulate Emissions

Particulate emission factors used in the 1995-2020 forecast (Levelton, 1998) were determined for motor vehicles using the US EPA PART5 model. Emission factors predicted by this model were corrected for the difference between the model's default fuel sulphur content and the local fuel sulphur content. The model predicts emission factors for total particulate, PM10 and PM2.5 segregated into the following source components: organic; sulphate particulate; brake wear; and tire wear.

The emission factors determined in the earlier emission forecast were adjusted to reflect the effect of future reductions in gasoline sulphur content. The same sulphur values were used as described above for SOx emission factors. The adjustment involved multiplying the PART5 emission factor for suphate particulate by the ratio of the local gasoline sulphur content to the default value used by PART5 (340 ppm), then combining the contribution from all source components.

3.0 Emission Results for Motor Vehicles

Tables B-7 and B-8 present the study baseline emissions. Tables B-9 and B-10 summarize the emission results for motor vehicles developed in this study for the NLEV/Tier 2 and NLEV/LEV II cases, respectively. A discussion of these results is provided in the main body of the report. Table B-11 summarizes the emission reduction achieved with the NLEV/Tier 2 and NLEV/LEV II standards relative to the study baseline.

Table B-7 Study Baseline Emissions for Motor Vehicles (With AirCare)

LDGV Annual emissions (tonnes)							
Year	CO	VOC	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$
1995	156186	16971	15345	729	374	364	218
2000	101657	9863	10475	392	306	299	151
2005	68564	6293	8418	84	298	290	129
2010	70388	5940	8389	90	322	314	142
2015	75340	6118	8899	95	353	344	156
2020	81079	6536	9537	98	380	371	168
LDDV Annual Emissions (tonnes)							
1995	167	89	242	14	48	48	42
2000	148	73	195	16	37	37	32
2005	150	71	184	15	28	27	23
2010	160	76	198	17	27	27	23
2015	174	82	216	18	30	29	25
2020	189	89	237	17	32	32	27
HDV Annual emissions (tonnes)							
1995	5651	866	6114	97	420	419	371
2000	4927	709	5862	92	299	293	274
2005	4821	599	6217	103	220	159	170
2010	5062	592	6842	115	193	135	146
2015	5527	622	7528	126	192	133	144
2020	5983	666	8150	136	206	144	154
All Vehicle Annual emissions (tonnes)							
1995	162004	17925	21701	840	842	831	631
2000	106733	10645	16533	500	642	629	457
2005	73535	6963	14818	203	546	477	322
2010	75610	6607	15429	221	542	476	311
2015	81041	6822	16643	239	575	507	325
2020	87252	7292	17924	251	618	547	349

Table B-8 Summary of Study Baseline (Updated GVRD Scenario B) Sector Emissions

Source Sector	Annual Emissions (tonnes)					
	1995	2000	2005	2010	2015	2020
CO						
Point	4492	5503	5613	5741	5866	6000
Area	5293	5472	5553	5496	5516	5547
Mobile						
On-road	162004	106733	73535	75610	81041	87252
Other	17481	20029	21591	22982	24428	25865
Total	189270	137737	106292	109829	116851	124664
NOx						
Point	9186	6854	6887	7030	7120	7214
Area	4189	4526	4636	4417	4394	4386
Mobile						
On-road	21701	16533	14818	15429	16643	17924
Other	13973	15060	15984	16757	17636	18640
Total	49049	42973	42325	43633	45793	48164
VOC						
Point	3582	3720	3964	4276	4536	4817
Area	41123	40700	40822	41646	42829	44152
Mobile						
On-road	17925	10645	6963	6607	6822	7292
Other	3493	3909	4252	4547	4849	5163
Total	66123	58974	56001	57076	59036	61424
SOx						
Point	3337	2651	2666	2944	2959	2974
Area	201	211	215	210	210	211
Mobile						
On-road	840	500	203	221	239	251
Other	1736	1792	1875	1947	2028	2133
Total	6114	5154	4959	5322	5436	5569

Table B-9 Emissions from Motor Vehicles with NLEV/Tier 2 Standards (With AirCare)

LDGV Annual emissions (tonnes)							
Year	CO	VOC	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$
1995	156186	16971	15345	729	374	364	218
2000	101657	9863	10475	392	306	299	151
2005	68366	5899	7329	84	298	290	129
2010	68482	4873	4617	90	322	314	142
2015	71926	4594	2946	95	353	344	156
2020	76855	4762	2363	98	380	371	168
LDDV Annual Emissions (tonnes)							
1995	167	89	242	14	48	48	42
2000	148	73	195	16	37	37	32
2005	150	71	184	15	28	27	23
2010	160	76	198	17	27	27	23
2015	174	82	216	18	30	29	25
2020	189	89	237	17	32	32	27
HDV Annual emissions (tonnes)							
1995	5651	866	6114	97	420	419	371
2000	4927	709	5862	92	299	293	274
2005	4821	599	6217	103	220	159	170
2010	5062	592	6842	115	193	135	146
2015	5527	622	7528	126	192	133	144
2020	5983	666	8150	136	206	144	154
All Vehicle Annual emissions (tonnes)							
1995	162004	17925	21701	840	842	831	631
2000	106733	10645	16533	500	642	629	457
2005	73337	6570	13730	203	546	477	322
2010	73704	5541	11657	221	542	476	311
2015	77627	5298	10690	239	575	507	325
2020	83028	5518	10749	251	618	547	349

Table B-10 Emissions from Motor Vehicles with NLEV/LEV II Standards (With AirCare)

LDGV Annual emissions (tonnes)							
Year	CO	VOC	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$
1995	156186	16971	15345	729	374	364	218
2000	101657	9863	10475	392	306	299	151
2005	68043	5892	7341	84	298	290	129
2010	61578	4752	4624	90	322	314	142
2015	53453	4372	2830	95	353	344	156
2020	50921	4462	2181	98	380	371	168
LDDV Annual Emissions (tonnes)							
1995	167	89	242	14	48	48	42
2000	148	73	195	16	37	37	32
2005	150	71	184	15	28	27	23
2010	160	76	198	17	27	27	23
2015	174	82	216	18	30	29	25
2020	189	89	237	17	32	32	27
HDV Annual emissions (tonnes)							
1995	5651	866	6114	97	420	419	371
2000	4927	709	5862	92	299	293	274
2005	4821	599	6217	103	220	159	170
2010	5062	592	6842	115	193	135	146
2015	5527	622	7528	126	192	133	144
2020	5983	666	8150	136	206	144	154
All Vehicle Annual emissions (tonnes)							
1995	162004	17925	21701	840	842	831	631
2000	106733	10645	16533	500	642	629	457
2005	73014	6563	13742	203	546	477	322
2010	66800	5420	11664	221	542	476	311
2015	59154	5076	10574	239	575	507	325
2020	57094	5218	10567	251	618	547	349

Table B-11 Reduction in Annual Emissions from Light Duty Motor Vehicles relative to the Study Baseline for NLEV/Tier 2 and NLEV/LEV II

Year	CO	VOC	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$	NO_x+VOC+CO/7
Reduction in Annual Emissions with NLEV/TIER2 (tonnes)								
1995	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0
2005	198	394	1088	0	0	0	0	1510
2010	1906	1066	3772	0	0	0	0	5110
2015	3414	1524	5953	0	0	0	0	7965
2020	4225	1773	7174	0	0	0	0	9551
Total	9743	4757	17988	0	0	0	0	24136
Reduction in Annual Emissions with NLEV/LEV II (tonnes)								
1995	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0
2005	521	400	1077	0	0	0	0	1552
2010	8810	1187	3765	0	0	0	0	6211
2015	21887	1746	6069	0	0	0	0	10942
2020	30159	2074	7357	0	0	0	0	13739
Total	61377	5408	18268	0	0	0	0	32444

References

CARB (1999), “Proposed California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles”.

Enns, P. (1999), “Modeling Deterioration of Running and Start Emissions in 1981-93 Light Duty Vehicles”, Mobile6 Workshop, June 1999.

Koupal, J.W. (1999a), “Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards”, EPA420-R-99-005.

Koupal, J.W. (1999b), “Basic Exhaust Emission Rates for Tier1 and Later LDVs and LDTs”, Mobile6 Workshop, June 1999.

Koupal, J.W., and Rykowski, R.A. (1998), “Methodology for Modifying Mobile5b in the Tier 2 Study”, EPA420-R-98-004.

Levelton, 1998, “Forecast and Backcast of 1995 LFV Emission Inventory”, prepared for the GVRD by Levelton Engineering Ltd., May.

Rao, T. (1999), “Effects of Sulfur on Exhaust Emissions”, Mobile6 Workshop, June 1999.

APPENDIX C: Air quality supporting data

BC Clean Transportation Analysis Project – 1999

Outline of Air Quality Analysis Model: PM and Ozone

- Build baseline emissions from GVRD & FVRD1 (WLFV & ELFV) total emission inventories (less on-road mobile source contribution); add back in on-road mobile source emissions as calculated by MOBILE 5b/T2/v.2 and PART 5 (as modified for GVRD/FVRD inventory Backcast-Forecast study in 1998). Pollutants: CO, SOx, NOx, VOC, $PM_{10}/PM_{2.5}$[1]. Period: 1995-2020.
- Build scenario emissions from (1) scaled for NLEV/Tier 2, LEV II, etc. emission factors.
- Calculate changes in PM_{10} primary emissions & secondary PM precursor emissions from (1) and (2).
- PM_{10} calculations:

$$[PM_{10}]_{GVRD} = \sum_i K_i \cdot E_{iGVRD} + [PM_{10}]_{background}$$

(annual average, based on annual emissions)

Calibrate algebraic model by solving the above equation with the known current PM_{10} concentration (1997-98) and emitted quantities from the current GVRD & FVRD emission inventories.

In the above equation,

$$K_i = \frac{f_i \quad ([PM_{10}]_{GVRD} - [PM_{10}]_{background})}{E_{iGVRD}} = \text{airshed local dispersion factor}$$

where *fi* is the fractional contribution to the total ambient PM_{10} loading made by component *i*. *Ei* is the emission inventory amount for the *i*th component.

In our model, the components of PM_{10} are

- direct point and area source emissions
- direct motor vehicle emissions (tailpipe, brake & tire wear)
- re-entrained soil (road dust and agricultural sources)
- secondary sulphates formed from SO_2 gaseous emissions
- secondary nitrates formed from gaseous NOx emissions
- secondary organic aerosol formed from gaseous VOC (NMOG) emissions.

Each of the *fi* for the WLFV and ELFV is estimated from detailed chemistry of local PM_{10} and $PM_{2.5}$ samples and source apportionment studies that have been carried out for the region and analogous apportionments made in similar urban regions. That is, f_i

---

[1] Cannot do much with $PM_{2.5}$ effects based on current ambient data or effects concentration-response data.

is the fractional contribution of each inventory category to current [PM_{10}], based on source apportionment studies, ambient chemistry and emission inventory arguments.

Assume: $Ki_{GVRD} = Ki_{ELFV}$ and that Ki does not change throughout the forecast period. This is equivalent to assuming that overall regional dispersion does not change over the period and that the relationship between emission points and monitors does not change. See attached printout of spreadsheet tables for data.[2]

PM_{10} in the eastern Valley is dominated by sources in the western Valley, so an adjustment is made in terms of a transfer coefficient as shown in the following equation:

$$[PM_{10}]_{ELFV} = \sum_i K_i \cdot E_{iELFV} + K_T\left([PM_{10}]_{GVRD} - [PM_{10}]_{background}\right) + [PM_{10}]_{background}$$

$$K_T = \frac{\left([PM_{10}]_{ELFV} - [PM_{10}]_{background}\right) - \sum_i K_i \cdot E_{iELFV}}{\sum_i K_i \cdot E_{iGVRD}} = \text{GVRD} \quad \text{ELFV transfer coefficient}$$

The Ei's (the individual pollutant emission amounts) are functions of time (the inventory forecast), so the forecast concentrations change with time accordingly.

- PM_{10} health effects risk metric for both mortality and morbidity outcomes is change in daily 24-hour [PM_{10}]. Monitoring data are available for each station (past 4 years' data used): currently 8 assignable to GVRD (urban sites) and 5 to ELFV (not along strict GVRD/FVRD boundary). Calculate number of days at each station for each year (1995-1998) during which 24-hour averages were > threshold (arbitrarily definable). Average over monitoring period. Future number of days > threshold at each site (or for eastern and western parts of LFV region, depending on how significant station-to-station variations turn out to be) scaled according to ratio of forecast annual average [PM_{10}] to base year's average [PM_{10}]. Forecast number of days when [PM_{10}] exceeds a threshold * change in exposure from baseline to scenario (µg/m^3*persons) => number of effects outcomes.
- PM_{10} concentration-response threshold issue: Calculate results for range of possible threshold values (e.g., 0, 15, 20 µg/m^3 24-hour average) – sensitivity & uncertainty analysis. The model assumes no threshold for morbidity effects and accommodates possible threshold levels for mortality effects, consistent with the literature. In the case of a threshold being applicable, the number of days on which the response is effective is defined as the mean number of days per year of station monitoring data on which the 24-hour average concentration exceeds the threshold. Averages to be

---

[2] Ki's will be modified to take into account the recent secondary aerosol formation elasticities estimated from new modelling performed by Prof. S. Pryor (report, 1 Sep 99).

calculated separately for the eastern and western portions of the valley (ELFV & WLFV, respectively).

- Ozone calculations. Health effects metric is change in daily maximum hourly concentration. In the absence of a threshold (response indicated down to below current background level in LFV), annual effect = 365 * typical or average daily effect, or a smaller number of "effective days." In our model, the number of days on which the ozone concentration maximum is influenced by changes in anthropogenic emissions is estimated by counting only the days on which the 24-hour average for that day exceeds 25 or 35 ppb, an arbitrarily selected range of 'background' levels on days with significant regional ozone formation potential. This selected set of days is defined as the number of "effective days" in the ozone model.

  Use composite of old EKMA NOx-VOC-ozone isopleth data from GVRD AQMP Stage 1 (1980 meteorology; 1985-2005 emissions) and analogous UAM-V results for 1985 & 1993 meteorology and emissions. Estimate range of possible changes in peak 1-hour ozone concentration based on forecast changes in NOx & VOC emissions. Scale change in mean maximum hourly [ozone] for each LFV station (or GVRD & ELFV sub-regions, as for PM_{10}) by estimated change in mean peak hour ozone from baseline to scenario emissions.[3]

RB Caton

27 Sep 99

---

[3] On "effective days" only.

BC CTA Benefits Study-1999
PM10 Exposure Scenarios

PM10 inventory apportionment model

	GVRD				ELFV							
Contaminant	Fraction of Ambient PM10	Baseline Conc. 1997-8	Emissions 1998	Klocal 1998	Fraction of Ambient PM10	Baseline Conc. 1997-8	Emissions 1998	Klocal 1998	ISOPART elasticities (S.Pryor) (%/%)	Equiv elasticities adj for background contrib. (appl to var. portion only)	Default elasticities (base case)	
PM10	1.00	13.30			1.00	13.15						
Primary PM10 (non-soil, EC)	0.27	2.47	8,065	3.067E-04	0.19	1.73	1,894	3.067E-04				
Vehicles Direct PM10 # (EC etc)	**0.15**	1.40	563	2.478E-03	**0.15**	1.37	70	2.478E-03				
'Soil' (Road Dust+Agri)	0.25	2.33	9,859	2.358E-04	0.16	1.46	1,897	2.358E-04				
SOx ((NH4)2SO4)*,**	0.11	1.02	5,172	1.978E-04	0.17	1.51	311	1.978E-04	0.309	0.442	1.0	[Multiply ΔSOx values by this factor]
NOx (NH4NO3)**	0.10	0.97	39,028	2.478E-05	0.16	1.43	4,341	2.478E-05	0.786	1.124	1.0	[Multiply ΔNOx values by this factor]
VOC (SOA, OC)***	0.12	1.12	38,703	2.883E-05	0.18	1.65	19,552	2.883E-05	0.449	0.642	1.0	[Multiply ΔVOC values by this factor]
Checks	1.00	9.30			1.00	9.15						

* Based on REVEAL II, marine S may contribute significant % of ambient SO4 (here, included in Background)

** Particulate form of SOx and NOx = ammonium sulphate and ammonium nitrate, resp.

*** Some gaseous VOCs contribute to organic carbon (OC) portion of SOA in PM10.

exhaust + brake & tire wear (approx. 50/50 split ~1995-2000)

GVRD profile is 1995 CBA (starting point), NOx & VOC(SOA) scaled upward based on ELFV data.

NOx & SOA portions = GVRD SO4/ELFV SO4*ELFV NO3 & SOA, respectively.

Klocal ELFV assumed = Klocal GVRD (I.e., characteristic of airshed)

ELFV apportionment based on REVEAL II chem. analysis; assumes all SOA & OC of anthropogenic origin-modified by ISOPART elasticities.

Assumptions:

Sulphate, nitrate, SOA fractions for ELFV scaled from REVEAL II results (PM2.5=>PM10, etc.)

Soil for ELFV based on % contribution to REVEAL II PM2.5 (=6.7%) * PM10/PM2.5 % ratio in 1995 inventory for [Road Dust + Agri] (=2.3)

Veh. Direct for ELFV est. = GVRD value.

GVRD measured conc (1997-8).	ug/m3	**13.3**	
Expected PM10 in ELFV from local sources:	ug/m3	5.93	
ELFV Measured concentration (1997-8):	ug/m3	**13.2**	
Transport factor of GVRD PM10 to ELFV, KT:		0.775964	
GVRD Background Concentration	ug/m3	**4**	[Mean Min 1998 VIAA = 5.1; Hope Arpt = 3.5]

See CBA AQ model, pages B-14 - B-16, "Economic Analysis of Air Quality Improvement in the Lower Fraser Valley"
(Volume 2: Appendices A, B, C), BOVAR-Concord, August 1995.

Carbon monoxide dispersion ratios (supplementary model):

		LFV				
Basis	Regional Background Conc. (µg/m3)	On-road Vehicle Emissions (t/y)*	Total emissions (t/y)	Avg Total Conc. (µg/m3)	Avg Local Conc.-veh. (µg/m3)	Klocal (vehicles) (µg/m3 per t/y)
CO 1995	160	162003	183614	749	520	3.208E-03
CO 1996	160	149078	171039	698	469	3.145E-03
CO 1997	160	137184	159501	697	462	3.367E-03
CO 1998	160	126238	148918	658	422	3.344E-03
CO 1990 (Levelton backcast)	160	293583	317411	1140	906	3.087E-03
S in Fuels Study data (1990)	160	304700	335573	1140	890	2.920E-03

* Using revised Scenario B baseline for the on-road fleet from this study for 1995-1998

Avg. Klocal 1995-1998 = 3.266E-03
StDev 1.07E-04
Rel SD 3.27%

BC CTA Project - Appendix D: Effects and valuation supporting data

Concentration-response factors for health effects - BC Clean Transportation Analysis Project, 1999

Factors taken from AQVM Manual (1996) or ASEP Health Effects report (1997), except as noted. Reviewed for consistency with CEPA/FPAC WGAQOG, 1999 (+ CWS material for PM & ozone).

Daily risk factors for unit change in pollutant concentration (except for CO, SO4 and toxics, as noted)

Pollutant	Range	Bronchitis*	W	LRD*	W	ARSs++	W	RADs**	W	MRADs	W	ASDs***	W	CHAs	W	RHAs	W	ERVs	W	AERVs	W	Symptoms+	W	CB/CRD****	W	Mortality	W	Concentration Units
Sulphur Dioxide	low																											ppm
(CBA, annual)	central																											ppm
	high																											ppm
Nitrogen Dioxide	low																											ppm
(CBA, annual)	central																											ppm
	high																											ppm
Carbon monoxide	low													0	33%													ppm (annual mean)
(annual risk, POP>65)	central													2.76E-04	33%													ppm (annual mean)
	high													6.74E-04	33%													ppm (annual mean)
Ozone	low					7.00E-05	25%			1.93E-05	25%	1.06E-04	33%	NA		9.70E-09	33%	NA		2.90E-08	25%	NA				0	40%	ppb (daily high hour)
	central					1.37E-04	50%			4.67E-05	50%	1.88E-04	50%	NA		1.20E-08	33%	NA		4.30E-08	50%	NA				2.00E-09	40%	ppb (daily high hour)
	high					2.04E-04	25%			7.40E-05	25%	5.20E-04	17%	NA		1.43E-08	33%	NA		5.80E-08	25%	NA				5.00E-09	20%	ppb (daily high hour)
PM10	low	8.00E-04	25%			2.20E-04	25%	8.00E-05	33%	NA		9.00E-05	33%	5.00E-09	25%	6.40E-09	33%	3.20E-07	25%	NA		NA		3.00E-05	25%	9.00E-09	40%	µg per cubic meter
	central	1.60E-03	50%			4.60E-04	50%	1.60E-04	33%	NA		1.60E-04	50%	6.60E-09	50%	7.80E-09	50%	6.50E-07	50%	NA		NA		6.10E-05	50%	1.80E-08	50%	µg per cubic meter
	high	2.40E-03	25%			7.00E-04	25%	2.50E-04	33%	NA		5.40E-04	17%	8.20E-09	25%	3.26E-08	17%	9.70E-07	25%	NA		NA		9.30E-05	25%	6.60E-08	10%	µg per cubic meter
Sulphate (FPM)	low			2.70E-03	25%	4.60E-02	25%	1.55E-02	25%			3.30E-01	25%	1.00E-05	25%	1.30E-05	25%	8.40E-05	25%	NA		NA		7.06E-05	25%	1.14E-05	22%	µg/m3, annual mean
(annual risk)	central			4.40E-03	50%	1.41E-01	50%	2.68E-02	50%			6.60E-01	50%	1.30E-05	50%	1.60E-05	50%	1.10E-04	50%	NA		NA		1.35E-04	50%	2.54E-05	67%	µg/m3, annual mean
	high			6.20E-03	25%	2.32E-01	25%	3.81E-02	25%			9.90E-01	25%	1.70E-05	25%	1.80E-05	25%	1.20E-04	25%	NA		NA		2.00E-04	25%	5.70E-05	11%	µg/m3, annual mean
Toxics (NMOG)	low																									0		
Mobile+++	central																									4.37748E-05		risk per tonne
(CBA, annual risk)	high																									4.37748E-05		
Toxics (NMOG)	low																									0		
Fuel Marketing+++	central																									7.23851E-06		risk per tonne
(CBA, annual risk)	high																									7.23851E-06		
Toxics (PM10)	low																									0		
Diesel Particulate+++	central																									0.00073155		risk per tonne
(CBA, annual risk)	high																									0.00073155		

W = probability weighting to be applied re uncertainty - from AQVM & ASEP

Current base annual mortality rate (risk) =	6.70E-03	Basis of annual risk estimates
Current base daily mortality rate (risk) =	1.84E-05	Basis of daily risk estimates

*** Children, POP<18; POP<20 used for this study (AQVM database)**

**** POP>=18; Non-asthmatics (94%); 93% used for this evaluation.**

***** POP with asthma (6%); 7% used for this evaluation, since % is increasing.**

******POP>=25**

+ Annual outcomes. "Symptoms" are the sum of headaches, sore throats, eye irritation, mild coughs, MRADs and chest discomfort. Previous LFV CBA usage (1994 & 1995 studies).

++ Non-asthmatic POP (94%); 93% used for this evaluation

+++ US EPA, 1993; not evaluated for this study.

Adjustments to resulting outcomes (AQVM formulae, to avoid double counting):
Net ERVs = ERVs - RHAs
Net RADs = RADs - (% adult POP)*[(5.7*RHAs) + (5.6*CHAs) + (Net ERVs) + (ASDs)]
Net ARSs - ARSs - RADs (PM10)
Net MRADs = MRADs - ASDs
Net ARSs = ARSs - MRADs (ozone)

BC CTA Project - Appendix D: Effects & valuation supporting data

Economic values of health outcomes

Range	**Bronchitis**	**LRD***	**ARSs**	**RADs**	**MRADs**	**ASDs**	**ERVs**	**AERVs**	**CHAs**	**RHAs**	**CB/CRD**	**MORT**		**CANC**	
	1994 $CDN	1994 $CDN	1994 $CDN	1994 $CDN	1994 $CDN	1994 $CDN	1994 $CDN	1994 $CDN	000 1994 $CDN	000 1994 $CDN	000 1994 $CDN	000 000 1994 $CDN	W		000 000 1994 $CDN
low (W=0.33)													0.33		
POP>=65 years												2.3		Non-fatal	0.149
POP<65												3		Fatal	2.5
Age-weighted	180	180	7	35	22	18	300	300	4.2	3.3	175	2.4		Average	1.6
central (W=0.34)													0.5		
POP>=65 years												3.8		Non-fatal	0.297
POP<65												5		Fatal	4.2
Age-weighted	360	360	14	75	36	49	600	600	8.3	6.5	291	4		Average	2.6
high (W=0.33)													0.17		
POP>=65 years												7.5		Non-fatal	0.594
POP<65												10		Fatal	8.3
Age-weighted	540	540	21	110	60	81	900	900	12.5	9.8	466	7.9		Average	5.2

* Assume same as child bronchitis

(Taken from AQVM Manual and Sulphur in Fuels Env & Health Panel report, 1997)

Other values

Visibility
(AQVM Manual) Household willingness to pay (HHWTP)/year = b*ln(VR2/VR1)
Total VIS damage value = SUM(HHWTP*HH) (C$1994)

	b	5% improv	10% improve
low	120	$6	$13
central	190	$10	$20
high	260	$13	$27

Climate change
(ignore for this study)

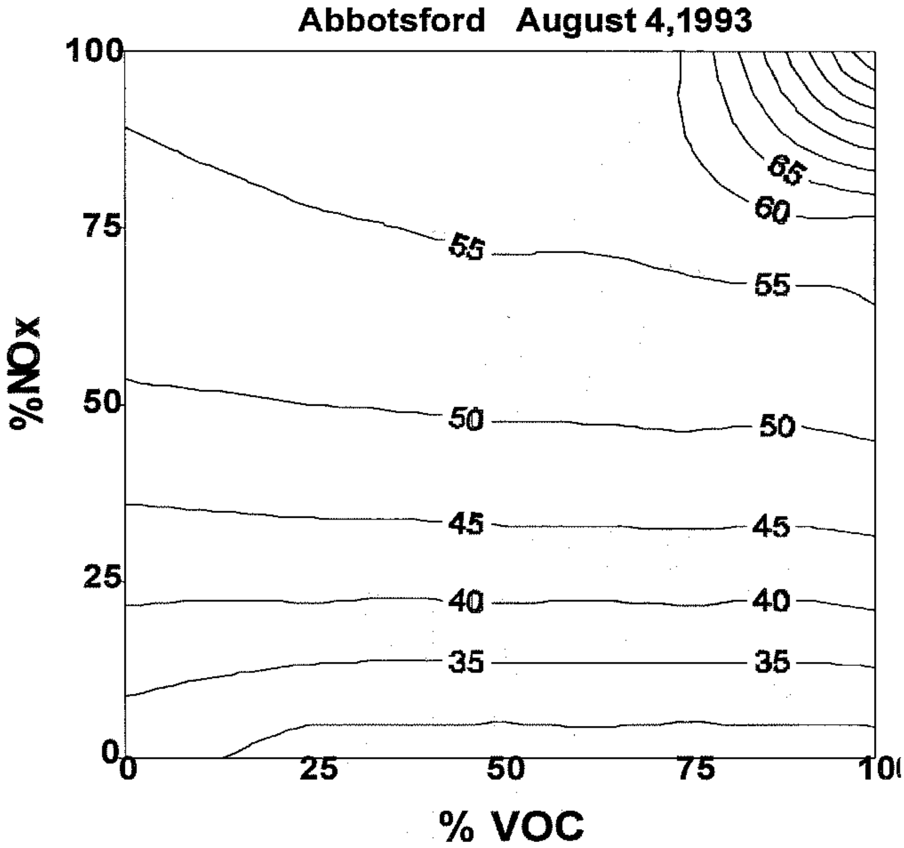
	$/t CO2e C$1994
low	15
central	25
high	50

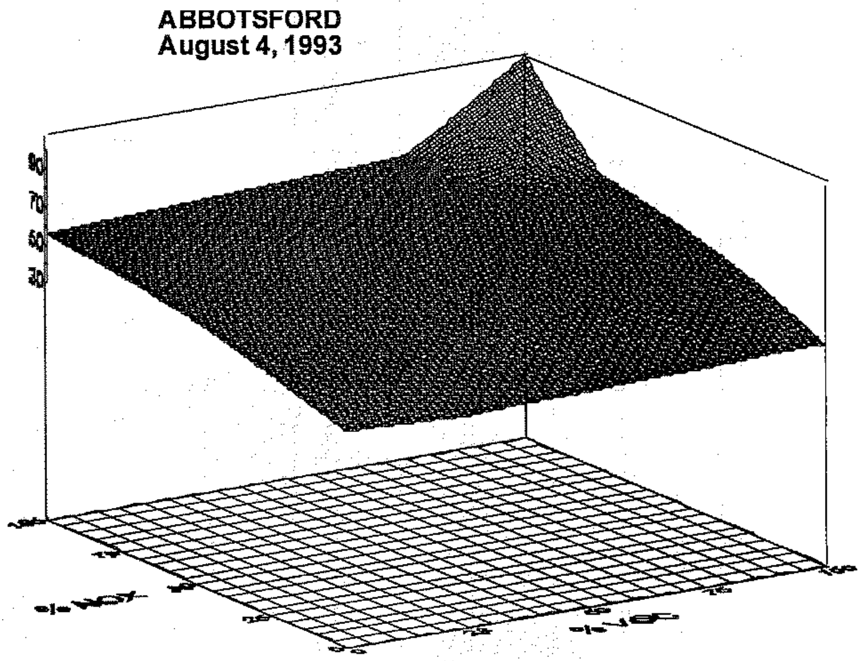
Materials Ignore for this study

Ozone crop damage Pro-rate (scale) earlier CBA results (1994/5)

UAM-V 3-D NOx-VOC-Ozone
Isopleth Plot for Abbotsford

(Axis labels are percentage of full emission inventory values of NOx or VOC. Emission reductions are calculated relative to 100% for each pollutant. The ozone isopleth surface represents the peak hour ozone concentration for each pair of NOx and VOC values as estimated by UAM-V for this episode day.)





JLP Environment Canada 1999

Appendix E: Cost-effectiveness supporting data

Incremental Vehicle Costs

What are the incremental costs for vehicle manufacturers of selling a LEV II vehicle in British Columbia compared to a Tier 2 vehicle, beginning with model year 2004? This is the cost issue.

Although LEV II vehicles will be sold in California, these vehicles in B.C. will be unique because of the need to meet Transport Canada safety regulations. Consequently, there are two components to the incremental (retail) costs for OEMs:

- Incremental costs of manufacturing a LEV II vehicle compared to a Tier 2 vehicle;
- Incremental costs of selling the LEV II vehicle in B.C. (including any safety and other features that may be required to meet Canadian regulations).

Incremental Costs of LEV II Vehicles compared to Tier 2 Vehicles

Both the EPA and the California ARB have performed cost analysis related to the introduction of new emission standards.

The EPA analysis [U.S. Federal Register, Part III – Environmental Protection Agency, 40 CFR Parts 80, 85 and 86, Air Pollution: Tier 2 Motor Vehicle Emission Standards and Gasoline Sulphur Control Requirements; Diesel Fuel Quality Control; Proposed Rules – Thursday, May 13, 1999] estimates the incremental purchase price of a Tier 2 vehicle compared with an NLEV vehicle. Incremental costs below are for Tier 2 to NLEV for vehicle categories LDGV, LDGT1 and LDGT2; and Tier 2 to Tier 1 for vehicle categories LDGT3 and LDGT4.

Estimated Purchase Price Increase Due to Proposed Tier 2 Standards (current $US)

	LDGV	LDGT1	LDGT2	LDGT3	LDGT4
Tailpipe standards:					
Near-term (year 1)	$76	$69	$132	$270	$266
Long –term (year 6 and beyond)	46	43	99	214	209
Evaporative Standard	4	4	4	4	4

Source: Federal Register/Vol. 64, No. 92/Thursday, May 13, 1999/ Proposed Rules/ page 26071

This is the incremental cost of a Tier 2 vehicle compared to an NLEV vehicle, not a Tier 2 compared with a LEV II.

The other cost analysis available is from the California Air Resources Board [Staff Report: Initial Statement of Reasons: Proposed Amendments to the California Exhaust and Evaporative Emission Standards and Test Procedures for Passenger Cars, Light-Duty Trucks and Medium-duty Vehicles ("LEV II") and Proposed Amendments to California Motor Vehicle Certification, Assembly-Line and In-Use Test Requirements ("CAP 2000"), September 18, 1998]. This document includes a cost analysis of LEV II and is based on determining the incremental (retail) costs of ULEV II and SULEV vehicles compared to ULEV I vehicles. The CARB results are as follows:

Incremental Retail Cost of ULEV II and SULEV Vehicles

Compared to a ULEV I Vehicle (current US $)

Category	**ULEV II**	**SULEV**
PC	$71	$131
LDT1	46	105
LDT2	184	279
MVD2	208	-
MVD3	209	-
MVD4	134	-

Source: CARB Staff Report, page II-54

The above comparison is not specifically a LEV II to Tier 2 comparison, but it is probably close[1].

Information from CVMA and AIAMC

CVMA and AIAMC have indicated that they may be able to provide an estimate of the incremental cost (at retail) of a LEV II vehicle compared to a Tier 2 vehicle in B.C. (i.e., an incremental cost including both manufacturing costs and costs related to supplying a LEV II vehicle in BC). At the time of writing the consultants have not received any cost information from CVMA or AIAMC.

---

[1] The federal Clean Air Act requires U.S. EPA to adopt, under certain conditions, more stringent light-duty vehicle emission standards, known as Tier 2 standards after the 2003 model year. These standards may be similar to the current California LEV standards, although U.S. EPA may choose to adopt more stringent standards as needed.

APPENDIX F:

Uncertainty analysis supporting data

(Crystal Ball® Report)

Forecast: AVG ANN BENEFIT 2004-2020 **Cell: D29**

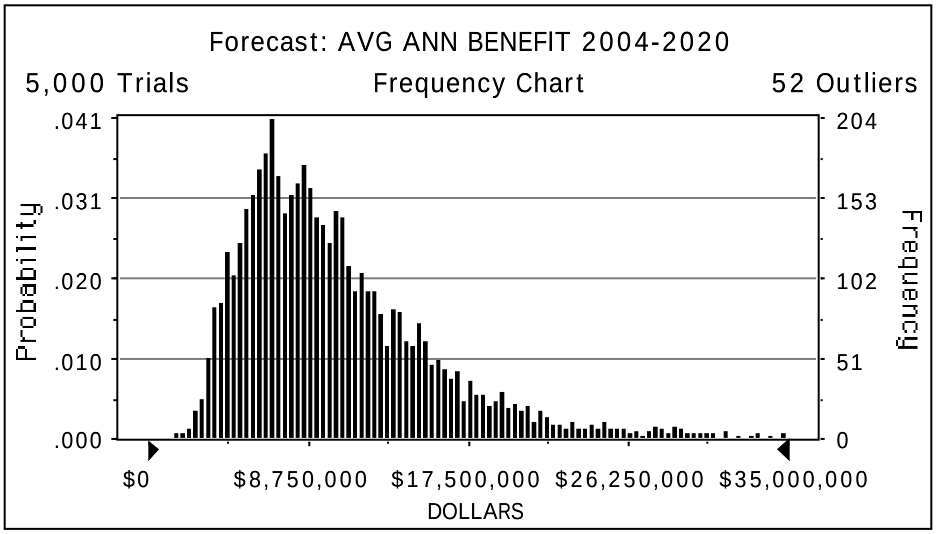
Summary:

Display Range is from $0 to $35,000,000 DOLLARS

Entire Range is from $1,448,107 to $167,371,114 DOLLARS

After 5,000 Trials, the Std. Error of the Mean is $106,389

Statistics:	Value
Trials	5000
Mean	$10,815,396
Median	$9,173,058
Mode	---
Standard Deviation	$7,522,824
Variance	6E+13
Skewness	6.00
Kurtosis	80.64
Coeff. of Variability	0.70
Range Minimum	$1,448,107
Range Maximum	$167,371,114
Range Width	$165,923,006
Mean Std. Error	$106,388.80



Forecast: AVG ANN BENEFIT 2004-2020 (cont'd) **Cell: D29**

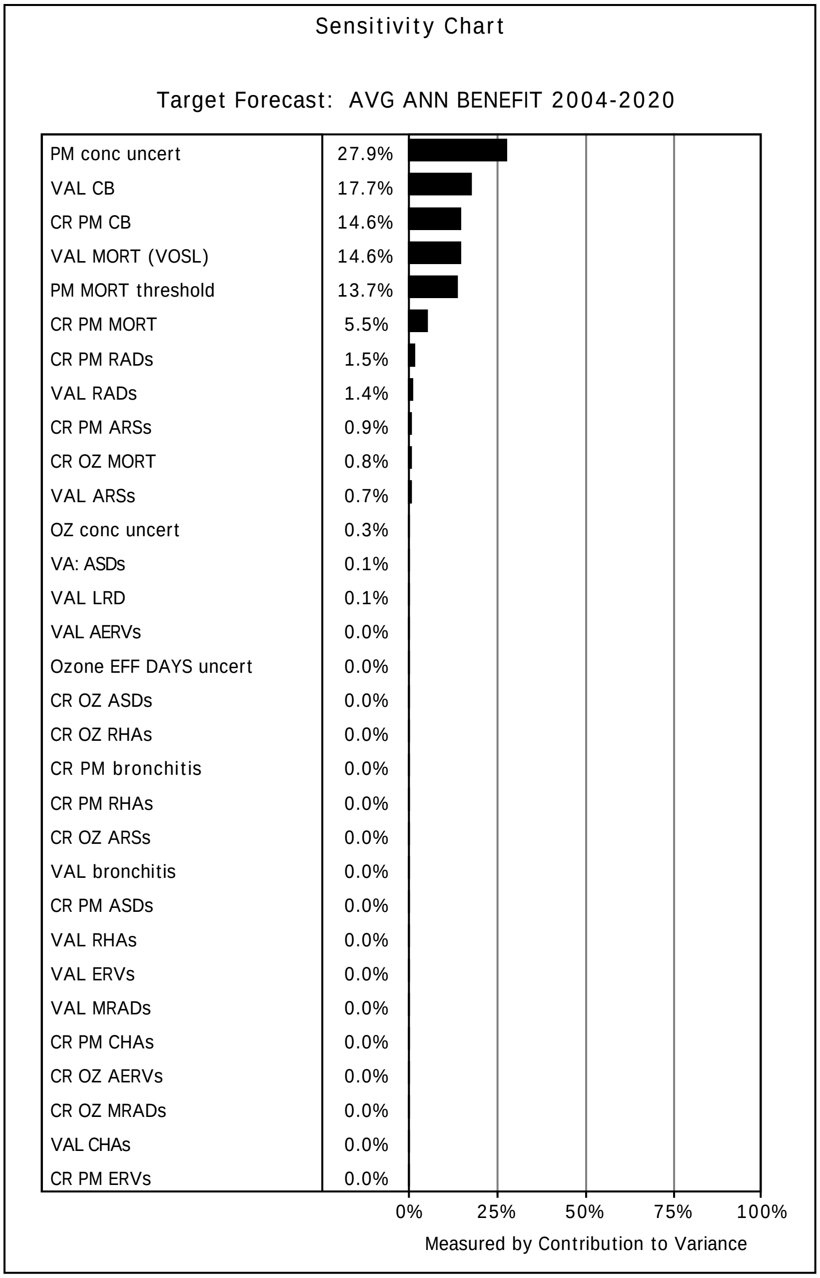
Percentiles:

Percentile	DOLLARS
0%	$1,448,107
5%	$4,056,116
10%	$4,872,235
15%	$5,499,866
20%	$6,081,066
25%	$6,565,853
30%	$7,015,154
35%	$7,568,666
40%	$8,121,681
45%	$8,648,822
50%	$9,173,058
55%	$9,823,103
60%	$10,463,243
65%	$11,148,660
70%	$12,035,234
75%	$13,056,002
80%	$14,211,633
85%	$15,642,192
90%	$17,828,802
95%	$21,701,589
100%	$167,371,114

End of Forecast

Crystal Ball Report

Simulation started on Thu, Nov 11, 1999 at 8:45:07 AM
Simulation stopped on Thu, Nov 11, 1999 at 11:07:27 AM



Assumptions

Assumption: OZ conc uncert **[effects~CTA(XL98&5/CB).xls]ozone - Cell: E57**

Triangular distribution with parameters:

Minimum	0.20
Likeliest	1.00
Maximum	1.50

Selected range is from 0.20 to 1.50

Mean value in simulation was 0.90

Assumption: Ozone EFF DAYS uncert **[effects~CTA(XL98&5/CB).xls]ozone - Cell: I21**

Custom distribution with parameters:		Relative Prob.
Single point	0.50	0.250000
Single point	1.00	0.500000
Single point	2.00	0.250000
Total Relative Probability		1.000000

Mean value in simulation was 1.13

Assumption: PM conc uncert **[effects~CTA(XL98&5/CB).xls]PMexpos - Cell: D56**

Custom distribution with parameters:				Relative Prob.
Continuous range	0.50	to	1.00	0.500000
Right/Left	2.83			
Continuous range	1.00	to	1.50	0.500000
Left/Right	2.83			
Total Relative Probability				1.000000

Mean value in simulation was 1.00

Assumption: PM MORT threshold **[effects~CTA(XL98&5/CB).xls]PMexpos - Cell: M50**

Custom distribution with parameters:

		Relative Prob.
Single point	0.00	0.100000
Single point	10.00	0.100000
Single point	15.00	0.350000
Single point	20.00	0.350000
Single point	25.00	0.100000
Total Relative Probability		1.000000

Mean value in simulation was 15.82

Assumption: VAL bronchitis **[effects~CTA(XL98&5/CB).xls]values - Cell: B13**

Custom distribution with parameters:

		Relative Prob.
Single point	180.00	0.333333
Single point	360.00	0.333333
Single point	540.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 358.49

Assumption: VAL LRD **[effects~CTA(XL98&5/CB).xls]values - Cell: C13**

Custom distribution with parameters:

		Relative Prob.
Single point	180.00	0.333333
Single point	360.00	0.333333
Single point	540.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 361.40

Assumption: VAL ARSs **[effects~CTA(XL98&5/CB).xls]values - Cell: D13**

Custom distribution with parameters:

		Relative Prob.
Single point	7.00	0.333333
Single point	14.00	0.333333
Single point	21.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 13.95

Assumption: VAL RADs **[effects~CTA(XL98&5/CB).xls]values - Cell: E**

Custom distribution with parameters:		Relative Prob.
Single point	35.00	0.333333
Single point	75.00	0.333333
Single point	110.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 72.11

Assumption: VAL MRADs **[effects~CTA(XL98&5/CB).xls]values - Cell: F**

Custom distribution with parameters:		Relative Prob.
Single point	22.00	0.333333
Single point	36.00	0.333333
Single point	60.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 39.46

Assumption: VA: ASDs **[effects~CTA(XL98&5/CB).xls]values - Cell: G13**

Custom distribution with parameters:		Relative Prob.
Single point	18.00	0.333333
Single point	49.00	0.333333
Single point	81.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 49.37

Assumption: VAL ERVs **[effects~CTA(XL98&5/CB).xls]values - Cell: H13**

Custom distribution with parameters:		Relative Prob.
Single point	300.00	0.333333
Single point	600.00	0.333333
Single point	900.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 599.76

Assumption: VAL AERVs **[effects~CTA(XL98&5/CB).xls]values - Cell: I13**

Custom distribution with parameters:		Relative Prob.
Single point	300.00	0.333333
Single point	600.00	0.333333
Single point	900.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 596.10

Assumption: VAL CHAs **[effects~CTA(XL98&5/CB).xls]values - Cell: J13**

Custom distribution with parameters:		Relative Prob.
Single point	4.20	0.333333
Single point	8.30	0.333333
Single point	12.50	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 8.28

Assumption: VAL RHAs **[effects~CTA(XL98&5/CB).xls]values - Cell: K13**

Custom distribution with parameters:		Relative Prob.
Single point	3.30	0.333333
Single point	6.50	0.333333
Single point	9.80	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 6.51

Assumption: VAL CB **[effects~CTA(XL98&5/CB).xls]values - Cell: L**

Custom distribution with parameters:		Relative Prob.
Single point	175.00	0.333333
Single point	291.00	0.333333
Single point	466.00	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 307.27

Assumption: VAL MORT (VOSL) **[effects~CTA(XL98&5/CB).xls]values - Cell: M13**

Lognormal distribution with parameters:

Mean	4.00
Standard Dev.	3.53

Selected range is from 0.60 to 13.50
Mean value in simulation was 3.67

Assumption: CR PM bronchitis **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: C21**

Custom distribution with parameters:		Relative Prob.
Single point	8.00E-04	0.250000
Single point	1.60E-03	0.500000
Single point	2.40E-03	0.250000
Total Relative Probability		1.000000

Mean value in simulation was 1.60e-3

Assumption: CR PM ARSs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: G21**

Custom distribution with parameters:		Relative Prob.
Single point	2.20E-04	0.258993
Single point	4.60E-04	0.489209
Single point	7.00E-04	0.251799
Total Relative Probability		1.000000

Mean value in simulation was 4.59e-4

Assumption: CR PM RADs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: I21**

Custom distribution with parameters:		Relative Prob.
Single point	8.00E-05	0.333333
Single point	1.60E-04	0.333333
Single point	2.50E-04	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 1.64e-4

Assumption: CR PM ASDs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: M21**

Custom distribution with parameters:		Relative Prob.
Single point	9.00E-05	0.369565
Single point	1.60E-04	0.500000
Single point	5.40E-04	0.130435
Total Relative Probability		1.000000

Mean value in simulation was 1.80e-4

Assumption: CR PM CHAs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: O21**

Custom distribution with parameters:		Relative Prob.
Single point	5.00E-09	0.248175
Single point	6.60E-09	0.481752
Single point	8.20E-09	0.270073
Total Relative Probability		1.000000

Mean value in simulation was 6.65e-9

Assumption: CR PM RHAs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: Q21**

Custom distribution with parameters:		Relative Prob.
Single point	6.40E-09	0.372263
Single point	7.80E-09	0.503650
Single point	3.26E-08	0.124088
Total Relative Probability		1.000000

Mean value in simulation was 1.04e-8

Assumption: CR PM ERVs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: S21**

Custom distribution with parameters:		Relative Prob.
Single point	3.20E-07	0.257353
Single point	6.50E-07	0.485294
Single point	9.70E-07	0.257353
Total Relative Probability		1.000000

Mean value in simulation was 6.44e-7

Assumption: CR PM CB **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: Y21**

Custom distribution with parameters:		Relative Prob.
Single point	3.00E-05	0.258993
Single point	6.10E-05	0.489209
Single point	9.30E-05	0.251799
Total Relative Probability		1.000000

Mean value in simulation was 6.19e-5

Assumption: CR PM MORT **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: AA21**

Custom distribution with parameters:		Relative Prob.
Single point	9.00E-09	0.420290
Single point	1.80E-08	0.492754
Single point	6.60E-08	0.086957
Total Relative Probability		1.000000

Mean value in simulation was 1.84e-8

Assumption: CR OZ ARSs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: G18**

Custom distribution with parameters:		Relative Prob.
Single point	7.00E-05	0.251799
Single point	1.37E-04	0.496403
Single point	2.04E-04	0.251799
Total Relative Probability		1.000000

Mean value in simulation was 1.37e-4

Assumption: CR OZ MRADs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: K18**

Custom distribution with parameters:		Relative Prob.
Single point	1.93E-05	0.248175
Single point	4.67E-05	0.496350
Single point	7.40E-05	0.255474
Total Relative Probability		1.000000

Mean value in simulation was 4.65e-5

Assumption: CR OZ ASDs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: M18**

Custom distribution with parameters:		Relative Prob.
Single point	1.06E-04	0.367647
Single point	1.88E-04	0.485294
Single point	5.20E-04	0.147059
Total Relative Probability		1.000000

Mean value in simulation was 2.04e-4

Assumption: CR OZ RHAs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: Q18**

Custom distribution with parameters:		Relative Prob.
Single point	9.70E-09	0.333333
Single point	1.20E-08	0.333333
Single point	1.43E-08	0.333333
Total Relative Probability		1.000000

Mean value in simulation was 1.20e-8

Assumption: CR OZ AERVs **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: U18**

Custom distribution with parameters:		Relative Prob.
Single point	2.90E-08	0.255474
Single point	4.30E-08	0.481752
Single point	5.80E-08	0.262774
Total Relative Probability		1.000000

Mean value in simulation was 4.36e-8

Assumption: CR OZ MORT **[effects~CTA(XL98&5/CB).xls]conc-resp - Cell: AA18**

Custom distribution with parameters:		Relative Prob.
Single point	0.00E+00	0.402597
Single point	2.00E-09	0.402597
Single point	5.00E-09	0.194805
Total Relative Probability		1.000000

Mean value in simulation was 1.77e-9

Appendix G: CPPI Critique of air quality valuation models (AQVM as a particular example)

Prepared by the CANADIAN PETROLEUM PRODUCTS INSTITUTE (CPPI) Oct 1999

How AQVM Works

The Canadian Air Quality Valuation Model (AQVM) is based on the "Damage Function Approach."[1] This approach uses, as its input, a change in environmental quality to estimate the environmental and/or health impacts of the change in question. The "value" of these estimated effects is then monetized by means of the price for marketplace goods and services associated with the impacts, and/or from "dollars" derived from a "Willingness to Pay" basis for non-marketplace benefits (primarily, reduced mortality and improved visibility). These monetized values are then aggregated across effects, populations and time.

What's Wrong with AQVM and Other Valuation Models

1. The controversial nature of the basic methodology has not been acknowledged adequately in the course of the development of AQVM.
2. The change in environmental quality and health impact input data incorporated in the model grossly overstate the real relationships between the two in some cases.
3. The monetization techniques used in AQVM for quantification of non-marketplace benefits are questionable applications of the technique's design functionalities.
4. The model's input is open to subjective manipulation to produce bias in the calculated results. The treatment of input and output data needs to be more transparent.
5. Any environmental initiative that can be associated with a deemed health outcome can artificially produce huge apparent "dollar" benefits when evaluated in AQVM. The inputs and outputs need to be reviewed critically, but the model freezes these values and gives the impression of adequate uncertainty evaluation.
6. The model measures its output in "damage cost dollars" associated with the calculated environmental and health benefits of a contemplated initiative against hard "real dollar" estimates of the implementation costs attached to the proposal, as though the parameters were directly comparable. The model (and other similar valuation models) mixes hard health damage cost expenditures with hypothetical WTP deemed damage cost dollars (that have no commercial value outside the 'walls' of the model) without distinguishing between them. Direct comparison of real and hypothetical values may be used as the basis to convey sensational messages to the public that are wrong, but are nonetheless difficult for politicians to ignore, because of the appearance of being authoritative. An especially contentious parameter here is the value of a statistical life that usually determines most of the benefit.

---

[1] Much of the criticism that follows is applicable to most current environmental cost-benefit valuation models in use in North America. The specific references to AQVM are examples of more general problems with the basic methodology.

7. In our opinion, the peer review process associated with the model when it was introduced was not adequately open and objective. It gives an impression of credibility that is not deserved.
8. The considerable criticism of the AQVM methodology that has been provided in the form of critiques by industry, academics, environmentalists, and other government agencies has not been addressed publicly.
9. AQVM is badly flawed so that it must be used and interpreted judiciously and cautiously as a tool in evaluating public policy, despite the fact that nothing better exists.

What should be done?

A consensus mechanism that does work must be developed.