Clearing The Air:

A Preliminary Analysis of Air Quality Co-Benefits from Reduced Greenhouse Gas Emissions in Canada

Prepared for
The David Suzuki Foundation

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Contents

1. Introduction

The David Suzuki Foundation publication, *Canadian Solutions*: *Practical and Affordable Steps to Fight Climate Change* (DSF, 1998), was prepared in collaboration with the Pembina Institute for Appropriate Development and outlined a number of greenhouse gas emission reduction actions that would be both 'practical and affordable.' *Canadian Solutions* preceded the work of the sector-based Issue Tables under the National Climate Change Process (NCCP) and anticipated a number of the actions and measures that have since been assessed by the Issue Tables to be feasible.

The NCCP's Analysis and Modelling Group (AMG) has a mandate to integrate the recommendations and data of the various Issue Tables and estimate the overall GHG emission reductions of the feasible actions and measures, including the environmental and health co-benefits of emission reductions of other pollutants that would accompany the GHG reductions. Co-benefits are indirect effects of reducing GHG emissions, as compared with the direct effects of reducing the GHG contribution to global warming and its impact on climate change. The direct effects are the subjects of an extensive literature. We do not address the direct effects in this study.

The NCCP's Integrative group has the task of synthesizing the analysis and modelling results and the priority options from each Issue Table into a draft national implementation strategy to meet requirements of the 1997 Kyoto Protocol. The AMG will not report the results of its studies until later in 2000. In the meantime, in order to inform the discussion of the recommendations of the Issue Tables, the David Suzuki Foundation contracted with Alchemy Consulting to prepare a preliminary analysis of the environmental and health co-benefits of air quality improvements resulting from a small number of specific GHG emission reduction measures. The selected actions are either described in *Canadian Solutions* or are closely related to actions recommended there.

Co-benefits of greenhouse gas emission reductions may include all of the following—

- Associated emission reductions of common (criteria) air contaminants (CACs), leading to improved air quality (with selected examples of the impacts)—
  - Reduced smog precursors (avoided health, crop & forest damage)
  - Reduced acid rain precursors (avoided ecosystem damage)
  - Improved visibility (longer visual range, clearer atmosphere, positive impact on tourism)
  - Reduced materials damage from air contaminants (soiling and deterioration of buildings, ozone damage to vehicle tires and other rubber products)
- Reduced human exposure to toxic air contaminants (possibly related to lung cancer)
- Avoided flooding and other land requirements (lower demand for hydroelectricity & other generating facilities)
- Avoided community impacts (lower demand for transportation infrastructure, developed land use).

- Improved energy efficiency of the economy generally (job creation in existing industries due to improved efficiency and in new energy efficiency industries, recycling of dollars formerly spent on fossil fuels).

This study addresses only the potential air quality benefits from reduced emissions of CACs. Many other general economic benefits noted above would accompany the improved energy efficiency and enhanced community development that will result from measures to reduce greenhouse gas emissions, but these are beyond the scope of this exercise.

Objective of this study

The main purpose of this work is to demonstrate the potential for significant co-benefits arising from air quality improvements that result from measures to reduce greenhouse gas emissions. These benefits must not be ignored in assessing Canada's greenhouse gas reduction options.

Related Work

Each of the 14 Issue Tables in the NCCP[1] was instructed to prepare an analysis of the environmental and health co-benefits that would accompany the proposed GHG emission reductions—in the form of estimated emission reductions of common air contaminants (CACs) and other avoided environmental impacts that could be estimated. One task of the AMG is to estimate the emission reductions of GHGs and CACs across the large number of recommended actions and measures proposed by the issue tables. Another task is to place a common valuation on the avoided impacts. The latter task is controversial, since the currency of the valuation is the estimated avoided economic and social damage expressed in dollars, so that the result can be compared with the economic and social direct costs of implementing the actions and measures proposed by each issue table. Examples of damages that are valued in this kind of analysis include the following partial list—

- actual cost of emergency room and hospital visits for respiratory and cardiac illness made worse by air pollution
- estimated value of reduced life expectancy due to exposure to fine particles and ozone pollutants
- actual cost of lost days of work due to respiratory illness related to air pollution.

Cost-benefit analysis (CBA) of emission reductions (and consequent air quality improvement) and other forms of environmental improvement has developed over the past 40 years, but it is still an approximate science. Nonetheless, benefit evaluation is an essential partner to analysis of implementation costs in modern regulatory impact analysis in Canada and the US.[2] A brief summary of some examples of recent applications of cost-

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[1] See the NCCP website: <http://www.nccp.ca/> for a complete listing of the sector issue tables and other information relating to the process that took place between early 1998 and late 1999.

[2] The US Office of Management and Budget (OMB) specifies that regulatory impact analysis must include monetized benefits estimated according to a 'best practices' directive under Executive Order 12866, January 1996. Draft recommended practice in Canada is similar—see *Framework for Application of Socio-*

benefit analysis in the two countries is presented here to place the work of the AMG and the preliminary analysis of *Canadian Solutions* and this report in context.

The most relevant of the published US studies is a 1997 report by Resources for the Future (RFF), *The Benefits of Reduced Air Pollutants from Greenhouse Gas Mitigation Policies*.[3] This study estimated that the likely monetized benefit of CAC reductions associated with GHG reductions would range from $10 to $32 (CDN) per tonne of CO_2 reduced. RFF is generally considered to be a relatively conservative organization in these matters. They have been influential in promoting cost-benefit analysis as an element of regulatory reform in the US and have contributed to peer review panels for the major CBA analyses that have been carried out for US acid rain control policies and the Clean Air Act.[4]

The retrospective and prospective CBA assessments of the US Clean Air Act (CAA) and its 1990 amendments have produced a highly evolved and sophisticated analytical framework for CBA over the course of several years of methodology development and analysis.[5] The basic conclusion of the studies reported to date is that the monetized benefits of emission reductions under the requirements of the CAA and its amendments greatly exceed the implementation costs—both past and future. These studies have been overseen by a peer panel of the US Environmental Protection Agency's Scientific Advisory Board and have been thoroughly vetted in open public hearings and vigorous debate. The methodology that has been developed has served as the basis for the analytical framework used in Canada for analysis of costs and benefits of air quality improvement—including the proposed methodology to be used by the AMG in analysing co-benefits of GHG reductions in Canada.[6]

The guidance given by the AMG to the Issue Tables for carrying out their analyses of environmental and health-related co-benefits of GHG emission reductions derives from an earlier CCME document: *Framework for the Application of Socio-Economic Analyses*

Economic Analyses in Setting Environmental Standards, Economic Integration Task Group, Canadian Council of Ministers of the Environment, July 1998.

[3] D. Burtraw and M. Toman, Resources for the Future, Discussion Paper 98-01-REV, Washington, DC, November 1997.

[4] D. Burtraw and E. Mansur, *Environmental Effects of SO_2 Trading and Banking*, Environmental Science & Technology 33(20), 3489-3494 (1999) ; D. Burtraw, A. Krupnick, E. Mansur, D. Austin and D. Farrell, *The Costs and Benefits of Reducing Acid Rain*, Resources for the Future, Discussion Paper 97-31-REV, September 1997. A more general discussion of CBA methodology can be found in R.J. Kopp, A.J. Krupnick and M. Toman, *Cost-Benefit Analysis and Regulatory Reform: An Assessment of the Science and the Art*, Resources for the Future, Discussion Paper 97-19, January 1997.

[5] Retrospective study: *The Benefits and Costs of the Clean Air Act, 1970 to 1990*, Report prepared for US Congress by US Environmental Protection Agency, October 1997; Prospective study: *The Benefits and Costs of the Clean Air Act, 1990 to 2010*, EPA Report to Congress, November 1999.

[6] The Canadian approach is currently being assessed by an expert working group under the auspices of the Royal Society of Canada, through the Network for Environmental Risk Assessment & Management (NERAM) based in the University of Waterloo's Institute for Risk Research (IRR).

in Setting Environmental Standards.[7] Two AMG documents guided the issue tables: *Framework for the Analysis of Environmental and Health Impacts* and *Guide for the Assessment of Environmental and Health Effects of Climate Change Measures.*[8] The approach was evaluated in a workshop under the auspices of the Climate Change Economic Analysis Forum (CCEAF) in May 1999.[9]

The workshop provided a strong critique of the methods and assumptions proposed by AMG, but the principal points of disagreement were inputs and parameters used in the models rather than the underlying methodologies. That is, the fundamental validity of evaluating benefits in a context that can be compared with implementation costs of GHG reduction measures was not a significant issue. At this workshop, Peter Nagelhout of the US EPA summarized the preliminary co-benefits evaluation that his agency has carried out for GHG mitigation measures. EPA's analysis shows that each ton of carbon mitigated yields on average between $11 and $55 (USD) in health and environmental co-benefits (equivalent to $5 to $25 CDN per tonne of CO_2)—comprising combined cost savings and the avoided social damage value of reduced co-pollutants (CACs).[10] Note that the range of EPA's estimates is very similar to that estimated by Resources for the Future as cited above.

A recently developed damage cost model for power plants in the US[11] provides relevant estimates of avoided damage values of reduced emissions of the CACs for Boston and its region. These values are transferable to eastern Canadian urbanized regions that are of population density to Boston's (i.e., Toronto, Montreal, and generally, the Windsor-Quebec City corridor). This research found the following values for avoided public health damages—

- PM_{10}: $20,000 CDN / tonne
- SO_2: $1,300 CDN / tonne (including secondary particulate sulphates)
- NOx: $1,300 CDN / tonne (including secondary particulate nitrates and ozone)
- CO_2: $5.60 CDN / tonne (direct benefit of avoided global public health impact).

These values are very similar to those estimated in various studies of Canadian urban areas which quantify the economic value of avoided emissions.[12] The researchers suggest that adding upstream emissions and non-public health damages (such as acid rain,

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[7] Canadian Council of Ministers of the Environment, September 7, 1998.

[8] Analysis and Modelling Group, National Climate Change Process, February 16, 1998 (both documents).

[9] Assessment of Health and Environmental Impacts of Climate Change Mitigation Workshop, Calgary, AB, May 3-4, 1999. Sponsored by Conference Board of Canada and the Canadian Energy Research Institute on behalf of the Analysis and Modelling Group of the NCCP.

[10] *Recommendations and Workshop Overview Report* on the workshop referenced in the previous footnote, prepared by CCEAF, September 24, 1999.

[11] J.I. Levy, J.K. Hammitt, Y. Yanagisawa and J.D. Spengler, *Development of a New Damage Function Model for Power Plants: Methodology and Applications*, Environmental Science & Technology, 33(24), 4364-4372 (1999).

[12] See, for example, *Economic Analysis of Air Quality Improvement in the Lower Fraser Valley*, prepared for BC Ministry of Environment, Lands & Parks by BOVAR-Concord Environmental, November 1995.

ecosystem damage and visibility impairment, as noted in the previous section) would increase these estimates by as much as 50%. These values are useful in assessing the avoided damages in urban areas from the CAC reductions estimated in this report and in comparing the estimated damage values based on the more generic model that provided our core estimates (described below).

A recent Canadian evaluation (monetization) of the benefits of air quality improvement in relation to reducing the sulphur content of Canadian gasoline and diesel fuels provides a reference case for relating the GHG co-pollutant emission reductions estimated in the issue table studies to their avoided damage valuation. The sulphur study covered seven major Canadian urban areas.[13] Estimated damage values are reasonably consistent with the recent Harvard estimates given above.

This brief and limited review of the background information is intended to demonstrate that the analysis carried out in this study is supported by a substantial literature on the valuation of avoided health and environmental damage attributable to reduced emissions of air contaminants.

Context of this report

The purpose of this study is to estimate the potential benefits to air quality improvement—and their social valuation—of some of the actions and measures proposed by selected issue tables, whose sectors relate to actions proposed in *Canadian Solutions*. The selected issue tables are: Electricity, Transportation, Municipalities and Buildings. The selected actions and measures from *Canadian Solutions* that correspond to measures proposed in the Option Papers released by these issue tables are—

Transportation (Transportation Issue Table)

- Fuel economy standards for vehicles
- Phased increases in fuel taxes
- Actions to increase the use of alternative modes of transportation

Electricity Generation (Electricity Industry Issue Table)

- Fuel switching (e.g., coal to less carbon intensive fuels)
- Adopting a 10% renewable energy portfolio standard

Residential/Commercial Buildings (Municipalities and Buildings Issue Tables)

- Cost-effective energy efficient retrofits of homes and commercial buildings

[13] *Health and Environmental Impact Assessment Panel Report*, Joint Industry/Government Study of Sulphur in Gasoline and Diesel Fuels, Study Secretariat, April 1998. The impact assessment was based on emission reduction estimates made by the Study's Atmospheric Science Expert Panel, of which one of the authors was a member.

The issue tables each provided estimates in their respective *Options Paper* of the emission reductions of common air contaminants that would accompany the GHG reductions for each of these actions or measures. Our analysis provides a preliminary estimate of avoided social damage costs of the air quality improvements that these emission reductions will produce.

The following table shows how the actions analysed in this study relate to those proposed in *Canadian Solutions* and to issue table actions.

Table 1. Relationship of measures assessed in this report to *Canadian Solutions* and the respective Issue Table's *Options Paper*

Action/Measure(s) (this report)	*Canadian Solutions*	Issue Table Action/Measure(s)
Transportation:		
Fuel economy standards for vehicles	"Improved and mandatory fuel economy standards for vehicles"	Transportation Table: Road Vehicles & Fuels, harmonized target (Canada/US), 25% by 2010 from present actual fleet average
Phased increases in fuel taxes	"Phased increases in gasoline and diesel taxes"	Transportation Table: Fuel taxes - road gasoline & diesel (10¢/L)
Actions to increase use of public transit	"Actions to increase the use of alternative modes of transportation"	Transportation Table: Passenger (Promising Measures) Package
Electricity Generation:		
Fuel switching	"Level playing field for low-carbon energy sources"	Electricity Table: Package of measures to achieve Base -6% Scenario (least cost)
Renewable energy portfolio standard	"Adopting a 10% renewable energy portfolio standard by 2010"	Estimated as incremental to Electricity Table -6% Base Scenario
Community Buildings:		
Energy efficient retrofits	"Cost-effective energy efficient retrofits of Canadian homes … and commercial buildings"	Municipalities/Buildings Tables: Community Buildings Measures Package

2. Key Findings

The following key findings are the main conclusions of this preliminary study. Similar findings should result from the more thorough and definitive analysis that is being carried out by the NCCP's AMG and Integrative Group.

1. Appreciable reductions in CACs would result from the implementation of the selected measures analyzed here—

   - vehicle fuel economy standards
   - fuel taxes
   - increased public transit
   - fuel switching in electricity generation
   - more renewable resources in electricity generation
   - community building energy efficiency improvement retrofits.

   These measures are a very small sample from the large number of measures proposed in the Issue Table Options Papers.

2. The six measures evaluated in this study would achieve CO_2 reductions of 68 million tonnes/year in 2010—9% of the projected national total in 2010 of 748 million tonnes per year and 36% of the estimated reduction of 187 million tonnes per year in 2010 necessary to meet Canada's Kyoto commitment.

3. The CO_2 reductions would be accompanied by estimated CAC emission reductions of 220,000 tonnes per year of SO_2 (9% of the Canadian national emission inventory of SO_2) and 140,000 tonnes per year of NOx (7% of the NOx national inventory). For comparison, the SO_2 reduction is several times greater than the effect of reducing the sulphur content of gasoline to meet the new Canadian standard (10,000 t/y), and the NOx reduction is somewhat larger than the effect of implementing the new (Tier 2) vehicle emission standards (about 66,000 t/y). These reductions would contribute significantly to enabling Canada to meet requirements of current and future North American acid rain and smog management agreements.

4. The avoided damage value of improved air quality resulting from the CAC reductions is estimated to be $1.2 billion/year in 2010, with a range of $340 million to $2.2 billion/year.

5. The environmental and health co-benefits of CAC reductions are estimated to be of similar value to the direct benefits of avoided global damage by the greenhouse gases themselves. That is, the total direct plus indirect benefits of GHG reductions could be double the value of the indirect co-benefits estimated here.

6. Significant portions of the total estimated air quality co-benefit would accrue to both urban and rural regions of Canada. In this analysis, about 30% of the total value of the co-benefits would be in rural areas and 70% in urban areas. This nominal split is not exclusive, since all measures contribute both urban and rural air quality benefits.

7. Much more detailed and definitive analysis will need to be carried out to reach more precise estimates of the potential scope and value of the air quality (and other) co-benefits that will result from implementing national GHG emission reductions. The analysis reported here is preliminary and applies to a small sample of possible measures.

3. Methodology

Our analysis makes use of readily available data from publicly released Options Papers of the respective Issue Tables, with supporting data from other recent Canadian and US estimates of air quality co-benefits of GHG emission reductions. The emission reduction estimates of common (or criteria) air contaminants (CACs) by the various Issue Tables were taken at face value, with the exception of the Transportation Table's data, some of which were modified as noted below. Different methodologies were used by the Issue Tables to estimate CAC reductions, which undoubtedly led to some inconsistencies. For the purposes of this analysis these potential inconsistencies are not thought to be material to the conclusions. The actions or measures that have been selected for analysis here do not overlap in their effect on GHGs or CACs, so double-counting is not an issue.

The estimates of CAC reductions for the Issue Tables (generally provided by a different consultant or committee) did not fully take into account the potential reduction in emissions of CACs that would be brought about by other regulatory initiatives, such as, the planned new vehicle emission standards (NOx, VOCs, CO), controls for reducing emissions of precursors of acid rain (SO_2, NO_X) or smog (NO_X, VOCs), or reductions of emissions of air toxics (PM, VOCs). Such reductions will affect the future baseline against which additional CAC reductions achieved due to GHG reductions should be measured. A systematic adjustment for all possible future baseline scenarios has not been made in this analysis. Again, this omission is not thought to affect the conclusions of this study materially. It is important to note that the CAC reduction co-benefits of GHG management are complementary to these air emission reduction programs.

Transportation Emissions

The CAC reductions estimated for the Transportation Table do not appear to have taken account of the reduced sulphur content of gasoline (and eventually diesel fuel) that will be required by pending Canadian (and US) regulations. The SO_2 reductions provided in the Transportation Table's *Options Paper* are likely overstated for this reason. A possible overestimation of the SO_2 reductions from some transportation measures is taken into account in our analysis. It is now also known that the current version of the national mobile source emission model (MOBILE 5C) significantly overestimates light-duty gasoline vehicle NOx, VOC and CO emissions. The current model also does not take into account the new US emission standards for light-duty vehicles (to be harmonized with Canada).[14]

Other adjustments to the CAC reduction estimates presented in the Transportation Table's Options Paper have been made to account for known omissions. For example, for several measures that lead ostensibly to no change in vehicle-kilometers-travelled (VkT

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[14] The required adjustments to the current mobile source emission model and the effect of the Tier 2 standards on the vehicle fleet emission inventory in the Lower Fraser Valley have been evaluated in a recent report: *BC Clean Transportation Analysis Project: Final Report,* prepared by Alchemy Consulting Inc., Levelton Engineering Ltd. and Constable Associates Consulting Ltd. for a consortium of public and private sector agencies, dated January 2000. Available from BC Ministry of Environment, Lands & Parks, Air Resources Branch. Posted on the Branch's website: http://www.elp.gov.bc.ca/epd/epdpa/ar/vehicle/. The results of this study have been assumed to apply to the national light-duty gasoline vehicle fleet in our analysis.

or VkmT), such as the fuel efficiency improvement measure that we have selected, the Table's estimates indicate no change in CAC emissions. This is not plausible based on simple physical principles, as indicated in the following.

Fuel efficiency improvement reduces the amount of fuel burned per VkT, so SO_2 emissions, and undoubtedly carbonaceous particle and VOC emissions, will be reduced proportionately. This is because sulphur and carbon are inherent constituents of the fuel and hence will be emitted more or less proportionately to the quantity of fuel burned per distance travelled.[15] One can presume that since CO_2 emissions are reduced by better fuel efficiency, carbonaceous PM emissions will be as well (the principal constituent of gasoline and diesel exhaust PM is carbon). VOC emissions (unburned fuel, also mostly carbon) would also be reduced by better fuel efficiency, but the effect is not as definitive. Thus, only NO_X of the CACs is likely to be little affected directly by better fuel efficiency, since its emissions are related more to combustion conditions and post-combustion controls than to fuel quantity.

In addition to the argument in the previous paragraph, one can speculate that improvements in vehicle fleet fuel efficiency will be accompanied by a general reduction in weight and engine power over the fleet—and that this will in turn result in lower emissions of CACs as well. A cursory review of NRCan's EnerGuide ratings of new vehicles (see website: http://autosmart.nrcan.gc.ca/fuel_e.cfm) shows that there is a strong inverse correlation between vehicle size (weight) and fuel efficiency. Current tailpipe emission standards for CACs (NO_X, VOCs, CO) are specified as manufacturer's fleet average values. Within this specification is hidden the fact that lighter vehicles with smaller engines generally emit lower levels of CACs per km than heavier vehicles with larger engines (shown by motorists' everyday experience with AirCare® tests, for example). Under the new Tier 2 standards that are about to be implemented in the US[16] beginning in model year 2004 (and the California LEV II standards to start in the same year), the different emission levels across the vehicle fleet are much clearer.

The Tier 2 standards specify a series of 'bins' into which each manufacturer will have to certify its vehicle model lines to achieve a corporate fleet sales average emission limit. Each Tier 2 'bin' has a different set of CAC emission requirements. Some models will be certified to 'bins' with very low emissions and some will be certified to 'bins' with quite high emissions (nevertheless, lower than current Tier 1 vehicles). There will not be a strict correlation between vehicle weight and engine size and the level of emissions, but it can be assumed to be true enough for the purposes of our analysis. Thus, vehicle fleet fuel efficiency improvements will not only result in the CAC benefit due to reduced fuel quantity passing through the engine described in the previous paragraph, but they will also result in significant additional CAC emission reductions per VkT because of a likely shift in the 'bin' profile of the fleet, i.e., a shift toward lighter—but not necessarily smaller—vehicles, if fuel efficiency standards or targets are set.

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[15] This is a simple conservation of matter argument. 25% less sulphur and carbon being processed by the engine must lead to more or less proportionate reductions in the sulphur- and carbon-containing combustion products—CO_2 as well as those by-products cited here.

[16] In all likelihood, Canadian vehicle emission standards will be harmonized with the US Tier 2 standards on the same time schedule.

We prefer to base our analysis on future CAC emission reductions within a Tier 2 fleet rather than using current emission levels (Tier 1 and older vehicles)—this is a more realistic view of the future that also provides a more conservative estimate of co-benefits. The following table illustrates the spread of emission values across the Tier 2 fleet.

Table 2. Summary of Tier 2 emission rates for all light-duty gasoline vehicles and possible assignments to size (weight) classes (g/km)[17]

Tier 2 Bin#	Vehicle Type(s)[18]	NO_X	NMOG[19]	CO	PM
7	HLDTs	0.12	0.08	2.6	0.01
6	LLDTs	0.06	0.06	2.6	0.01
5	PCs (full size)	0.04	0.06	2.6	0.01
4	PCs (mid/small)	0.04	0.03	1.3	0.006
3	PCs (small/mid)	0.02	0.04	1.3	0.006
2	HEV, etc.	0.01	0.01	1.3	0.006
1	ZEV	0.00	0.00	0.00	0.00

The full fleet average is represented approximately by the bin #5 emission rates. For the purposes of our analysis, a plausible assumption is that implementation of a 25% fuel efficiency improvement requirement would have the spin-off effect of reducing both NOx and NMOG emissions by a factor of two (0.04 g/km and 0.06 g/km, respectively, to 0.02 and 0.03 g/km) by effectively dropping each class down one bin in the above table. The effect would be achieved similarly by moving the heaviest classes in the table down one bin as by moving the middle classes down one bin (i.e., a 50% reduction in NOx and NMOG emissions, so the effect is not limited to the lighter classes). It must be emphasized that this assumption is not supported by any design or test data, since the vehicles have not yet been built to meet either the CAC exhaust standards or the fuel efficiency improvement requirement. There are vehicles already on the road today, however, that meet both the bin 3, 2 and 1 CAC emission levels (e.g., California ULEV

[17] The final, useful life standards are shown in the table (180,000 km). These standards will be implemented for the lighter classes for model year 2004 and phased in for the heavier classes by 2009. Interim standards that apply to the heavier weight classes are not shown, nor are standards for the first 80,000 km. More details may be found in a recent report (see footnote 14).

[18] This characterization, which is not part of the Tier 2 standard, is very rough, since engine technologies will undoubtedly cross size classes, but it should not introduce significant distortion into our analysis. HLDTs = heavy light-duty trucks (including SUVs, for example); LLDTs = light light-duty trucks (including minivans and smaller SUVs, for example); PCs = passenger cars; HEV = hybrid electric vehicles and similar very low emission vehicles; ZEV = zero emission vehicles (primarily electric vehicles).

[19] Non-methane organic gases—essentially equivalent to the commonly-used VOC.

and SULEV vehicles, HEVs and ZEVs), and have very high fuel efficiency (5.5 L/100 km or better, compared with a current fleet average of about 10 L/100 km).[20]

A plausible assumption is that implementation of a 25% fleet average fuel efficiency improvement requirement (by whatever means it is brought about) would achieve the effect of moving 50% of the new vehicle fleet into emission categories that would produce an emission reduction in CACs of 50% (essentially moving down one bin in the above table). This is equivalent to reducing the average fleet emissions of the key CACs (NOx and NMOG) by 25%. This is the approximate estimate used in our analysis of the Transportation Table's fuel efficiency target measure in place of the Table's assumption (unsubstantiated) that there would be no change in CAC emissions associated with a 25% improvement in fleet fuel efficiency.

There is no question that moving the fleet average fuel efficiency by the target amount will not be easy, but it has been done before (in response to the 'oil crisis' of the early 70s)[21] and can be done again. The impediment is not technology, but markets. The fuel efficiency measure is categorized as 'Promising' by the Transportation Table.

The reductions estimated here are in addition to reductions of the carbon-containing portion of the CAC emissions that would result from burning less fuel (as noted above). The following table (Table 3) summarizes the estimated relative emission reductions that would result from the 25% fuel efficiency improvement measure. The values in Table 3 should be taken as optimistic—but plausible—estimates of the potential efficacy of the 25% fuel efficiency improvement measure. The relative reductions would characterize the light-duty vehicle fleet after a complete turnover (about 10 years). We assume that this would have happened by 2010.

Considering the rapid advance of cost-competitive hybrid electric vehicle technology (HEVs)—including feasible designs for the heaviest light-duty vehicle classes[22]—the reductions shown in Table 3 must be considered to be feasible. Hybrid electric technology would achieve better than a 25% GHG reduction in conjunction with CAC reductions at least as great as those shown in Table 3. Either way, the question is not whether these reductions can be achieved cost-effectively, but when.

Table 3. Estimated combined emission reduction of lower fuel consumption and lighter vehicles resulting from meeting 25% fuel efficiency improvement

[20] Data supporting these assumptions are readily available on the NRCan EnerGuide website cited earlier, where the fuel efficiency of essentially every model year 2000 vehicle for sale in Canada is documented. The correlation between vehicle size and fuel efficiency is documented in detail in a US Environmental Protection Agency report: *Light-Duty Automotive Technology and Fuel Economy Trends Through 1999.* Report EPA 420-R-018, September 1999, US EPA Office of Air and Radiation. Details may also be found in the Transportation Table's *Foundation Paper*, December 1998. The EPA document shows that if the 1986 fleet average weights and 0-60 mph acceleration specifications had been maintained, passenger car fuel efficiency would be 18% better than it is today, and light-duty truck fuel efficiency would be 25% better than it is today (i.e., the vehicle fleet has become generally heavier and more powerful).

[21] Average fuel efficiency of North American new passenger cars doubled between 1973 and 1988—5% per year improvement—but has remained flat since that time.

[22] See F. An, F. Stodolsky, A. Vyas, R. Cuenca and J. Eberhardt, *Scenario Analyis of Hybrid Class 3-7 Heavy Vehicles*, SAE 2000 World Congress, Detroit, MI, March 6-9, 2000. Technical Paper 2000-01-0989.

Pollutant	Fuel reduction (%)	Weight reduction (%)	Total reduction (%)
SOx	25	0	25
NOx	0[A]	25	25
NMOG[23]			
Exhaust	25	25	50
Evaporative[B]	12.5	0	12.5
Weighted average	19	12.5	31
Fine PM ($PM_{2.5}$)	25	0	25

A) Lowering fuel sulphur content may lower NOx emissions by about 9% in Tier 1 technology passenger cars, but the effect on the Tier 2 future fleet is not known.
B) Assume that the measure is 50% effective in reducing evaporative emissions.

Emissions for other measures

CAC reductions associated with the other Transportation measures in Table 1 are used as estimated by the Transportation Table (with any necessary adjustments for fuel sulphur content and CAC inventory corrections, as noted above). Estimated CAC emission reductions for the Electricity Generation and Community Buildings measures listed in Table 1 were used as provided by the respective issue tables in their Options Papers.

Baseline emissions

The following table (Table 4) shows the 1995 Canadian emission inventory by province of the principal CACs that are associated with vehicle emissions, with the relative contribution of the light-duty gasoline vehicles (LDGV) broken out.

Environment Canada’s forecast of NOx and VOC emissions through 2010 indicates that these emissions will not change substantially between 1995 and 2010—falling slightly and then rising slowly again. The values in the table do not necessarily match provincial or municipal data due to differences in methodology and base quantity data, but they provide a consistent basis for cross-country analysis of the measures being assessed here.

The recently announced commitment to require lower sulphur content of Canadian gasoline will lower the relative contribution of LDGVs to the SO_2 inventory. Recent analysis of NOx and VOC emissions from the light-duty vehicle fleet using up-to-date analytical tools indicates that the estimated contribution from LDGVs has been overestimated in the past, requiring adjustment of the Table 4 values.[24] In addition, as suggested earlier in this report, the new Tier 2 vehicle exhaust emission requirements which have just been promulgated in the US and which will be harmonized with

[23] Exhaust and evaporative components of NMOG emissions are currently each about 50% of total NMOG emissions. Evaporative emissions will eventually comprise most of NMOG emissions.

[24] See footnote 14.

Canadian requirements, will reduce the contribution of the LDGV fleet to the inventory compared with the values in Table 4.

Table 5 provides a suggested set of adjusted values to be used as the basis for our analysis of future implementation of emission reduction measures.

Table 4. Summary of 1995 National CAC Emission Inventory (tonnes/year)

Prov	NOx			VOC			SO2		
	Prov Ttl	LDGV	%LDGV	Prov Ttl	LDGV	%LDGV	Prov Ttl	LDGV	%LDGV
BC	263,914	31,568	12.0	262,807	40,476	15.4	176,111	1,112	0.6
AB	653,319	30,733	4.7	762,732	44,123	5.8	608,100	666	.01
SA	214,491	9,640	4.5	416,287	15,162	3.6	131,100	210	.02
MB	109,073	12,157	11.1	237,633	18,756	7.9	365,475	256	.01
ON	555,884	94,471	17.0	822,122	113,826	13.8	632,762	5,589	0.9
QC	383,144	72,057	18.8	487,076	94,257	19.4	373,647	2,670	0.7
NB	62,657	8,825	14.1	65,436	11,601	17.7	115,542	210	0.2
NS	73,060	7,944	10.9	78,932	10,083	12.8	167,071	191	0.1
NF	42,658	4,012	9.4	52,895	4,902	9.3	65,014	97	0.1
PEI	7,977	1,510	18.9	9,836	2,006	20.4	2,547	36	1.4
10 Prov	2,366,177	272,917	11.5	3,195,756	355,192	11.1	2,637,369	11,037	0.4

Table 5. Summary of Adjusted National CAC Emission Inventory for 2010 (tonnes/year)[25]

Prov	NOx			VOC			SO_2		
	Prov Ttl	LDGV	%LDGV	Prov Ttl	LDGV	%LDGV	Prov Ttl	LDGV	% LDGV
BC	242,763	10,417	4.3	233,664	11,333	4.9	175,110	111	0.06
AB	632,728	10,142	1.6	730,963	12,354	1.7	607,521	87	0.01
SA	208,032	3,181	1.5	405,370	4,245	1.0	130,917	27	0.02
MB	100,928	4,012	4.0	224,129	5,252	2.3	365,252	33	0.01
ON	492,588	31,175	6.3	740,167	31,871	4.3	627,397	224	0.04
QC	334,866	23,779	7.1	419,211	26,392	6.3	371,111	134	0.04
NB	56,744	2,912	5.1	57,083	3,248	5.7	115,343	11	0.01
NS	67,738	2,622	3.9	71,672	2,823	3.9	166,893	13	0.01
NF	39,970	1,324	3.3	49,366	1,373	2.8	64,924	7	0.01
PEI	6,965	498	7.2	8,392	562	6.7	2,514	3	0.1
10 Prov	2,183,323	90,063	4.1	2,940,018	99,454	3.4	2,626,981	649	0.02

Valuation of emission reductions

A critical factor in determining the economic value of avoided damages due to CAC emission reductions is whether they occur in urban or rural areas. Reductions in urban areas will have a greater health impact because of the much greater number of people exposed (effect of population density). Reductions in both urban and rural areas would reduce impacts of long-range transported pollutants, such as smog (ozone) damage of agricultural crops and forests and acid rain damage to forests and aquatic ecosystems. The scope of this study did not permit systematic modelling of the effect of emission changes on local air quality in each region of Canada, therefore, specific regional valuation of the avoided impacts across Canada could not be undertaken.

Our approach is to use the typical avoided damage valuation for air quality co-benefits in the US, per tonne of CO_2 reduced, as a surrogate for this value in Canada. This choice is justified on the basis of the following factors:

- Population and natural ecosystem geographic distribution across the US is similar to that across the most densely populated portions of Canada (i.e., within 200-300 km of the US border).
- The US studies were carried out on a scale and at a level of comprehensiveness that have not been matched in Canada (and could not be approached for this study).
- The US studies have been thoroughly peer reviewed and publicly debated.

[25] Adjusted data assume implementation of Tier 2 vehicle exhaust standards according to the current US schedule, re-modelling of LDGV fleet emissions using improved tools (equivalent to MOBILE 6) and implementation of Canadian low-sulphur gasoline requirements. The rest of the emission inventory is assumed to be flat between 1995 and 2010, approximately as forecast by Environment Canada.

- The tools available to carry out such detailed analysis in Canada are not as advanced as their US counterparts.

The valuation parameter is a single, averaged monetary value across all pollutants and a reasonably large selection of impacts which is assumed to apply on average to the more populated parts of Canada where air quality impacts would have their greatest damage value. The main impacts of the CAC reductions are characterized by this single, averaged valuation parameter.

In keeping with the limited scope of this study, we have performed a simple apportionment of the co-benefits between urban and rural areas. Effects that occur primarily in rural areas are valued at the low end of the range of damage values, and effects that occur primarily in urban areas are valued at the higher end of the estimated range. This is the simplest way to account for geographic and demographic variability of impacted receptors.

4. Results

<u>Emission Reductions</u>

The following table (Table 6) summarizes the CAC emission reductions for the measures for which data may be taken directly from each Issue Table's *Options Paper.* The results for the remaining measure—fuel efficiency improvement—are summarized in a second table below. Table 6a shows adjustments to the Transportation Table estimates attributable to recent regulatory events (low-sulphur fuel and Tier 2 standards) and improved light-duty vehicle fleet emission modelling. It has been assumed that the Table's emission reduction estimates could be scaled down in proportion to the adjustments to the base LDGV emission inventory, since reduced usage in the light-duty fleet is the principal target of these measures.

Table 6. Summary of GHG & CAC emission reductions by measure (as reported by Issue Table)

Measure	GHGs	CAC Reductions in 2010 (tonnes/year)				
	(MT)	SOx	NOx	VOC	PM[A]	CO
Transportation[C]						
Road fuel tax	4.7-10.3	974	41,081	14,327	1,800	82,136
Incr. public transit	10.1	792	21,146	14,190	1,295	130,395
Electricity Gen.						
Fuel switching	28	189,000	72,000	NA	17,000[D]	NA
10% Renewable energy[B]	9	34,500	18,000	NA	2,200[E]	NA
Community Bldgs.						
Energy efficiency	7.5	75	11,263	343	2,634	NA

A) Includes primary PM and secondary PM for Electricity Generation, primary PM only for others. In this report, 'PM' may be taken to mean PM_{10} or $PM_{2.5}$, since essentially all of particulate emissions associated with the measures analyzed here are fine particles.
B) Incremental above the fuel switching measure (Electricity Table -6% Base Case). Incremental emission reductions assumed to be 10% of the residual baseline national power generation emission inventory for CO_2, SOx, NOx and $PM_{2.5}$ (i.e., residual after applying the fuel switching measure).
C) Assumes that measures in the 'passenger' transit package are independent (additive) and that the package is in turn independent of the fuel tax measure—as assumed by the Transportation Table.
D) 8,000 t/y primary; 9,000 t/y secondary.
E) 1,000 t/y primary; 1,200 t/y secondary.

Fuel efficiency measure emission reductions

Two versions of a 25% improvement in fleet average fuel efficiency were analyzed by the Transportation Table. Both of them assumed that Canadian targets would be harmonized with US targets—a realistic constraint. The less stringent measure would see the 25% improvement relative to the current target for 2010, and the other version would be relative to the current actual fleet average. They lead to slightly different GHG reductions because of the difference in the two targets. We base our analysis on a 25% improvement in the current actual fleet average, which is related to the current national emission inventory.

Table 6a. GHG & adjusted CAC emission reductions for Transportation measures

Measure	GHGs (MT)	Adjusted CAC Reductions in 2010 (tonnes/year)				
		SOx	NOx	VOC	PM	CO
Transportation						
Road fuel tax	4.7-10.3	57	13,600	4,000	1,800	NA[A]
Incr. public transit	10.1	46	7,000	4,000	1,295	NA[A]

A) An appreciable quantity, but not deemed to be significant in overall valuation - not estimated here.

Although the fuel efficiency data are not used in our analysis, according to the Transportation Table's data, the current fleet average gasoline consumption rates (1996) are 7.9 L/100km for passenger cars and 11.3 L/100km for light trucks.[26] These values extend to a fleet average of just under 10 L/100km. Thus, a 25% reduction is about equivalent to the whole fleet achieving the efficiency of the passenger car portion of the fleet.

For the purposes of this study, we assume that the baseline for comparison of CAC reductions that would accompany the 25% GHG reduction resulting from a 25% improvement in fuel efficiency (consumption rate) is the adjusted 2010 National CAC Emission Inventory, as summarized in Table 5.[27] The reduction in either GHGs or CACs that could be achieved by 2010 is not the full impact of a 25% fuel efficiency improvement, since future targets would refer to new vehicles, and fleet turnover is of the order of 10% per year. By 2020, the reductions in both GHGs estimated by the Issue Table and the CAC reductions estimated here would be significantly greater because of full penetration of the fleet by the new technology.

The estimated CAC reductions resulting from the fuel efficiency measure are shown in Table 7.

Table 7 addresses only the primary portion of emissions from the light-duty vehicle fleet. NOx, VOCs and SOx are all precursors of various secondary products, such as ozone and fine particulate matter, that are produced by chemical reactions in the atmosphere. Several Canadian and US studies have included secondary fine particles and ozone in estimating benefits of avoided damage from these pollutants.[28] Table 8 shows the values of conversion rates of the principal primary gaseous pollutants (NOx, VOC, SOx) that were

[26] The Canadian Company Average Fuel Consumption (CAFC) standards are currently 8.6 L/100km for passenger cars and 11.4 L/100km for light trucks (including, for example, minivans and SUVs).

[27] With the adjustments as noted earlier for recent regulatory events that significantly influence future emission rates.

[28] See footnotes 4, 5, 11 and 13.

used in the Electricity Table's analysis.[29] We use these approximate values here to estimate the secondary fine particle reductions associated with the emission reductions for all measures for which they were not included in the Issue Table's analysis. These values are applicable to the southern, more heavily populated portions of each province where most of the transportation-related emission reductions would take place.

Table 7. GHG & estimated CAC reductions for Transportation fuel efficiency improvement measure relative to estimated 2010 emissions (this study)

Measure	**GHGs (MT/y)**	**CAC Reductions in 2010 (tonnes/year)**				
		SOx (t/y)	**NOx (t/y)**	**VOC (t/y)**	**PM (t/y)**	**CO (t/y)**
Transportation						
Fuel efficiency	5.2-6.5	160	22,500	30,800	Small[A]	NA[B]

A) Most of the PM reduction results from secondary products rather than primary emissions.
B) Large reduction, but not evaluated here, since the avoided damage is estimated to be small relative to the other pollutants.

It must be emphasized that the values in Table 8 are very rough surrogates for the complex atmospheric chemistry that takes place in the various regional airsheds, especially in eastern Canada, where long-range transported pollutants influence local atmospheric chemistry so strongly. The conversion rates in Table 8 are based on up-to-date—but simplified—photochemical modelling of the respective regions, but they can be expected to capture the actual effect only approximately. The important point is that secondary particle formation should not be ignored in estimating the air quality benefits that we are assessing here.

[29] The estimated conversion rates were based on the work of the Atmospheric Science Expert Panel in the Joint Industry/Government Study of Sulphur in Gasoline and Diesel Fuels in 1997. Data are found in the Panel's report (August 14, 1997).

Table 8. Secondary chemical conversion rates for SO_2, NOx and VOCs

Province	Annual average chemical conversion rates (%/year)	
	SO_2 => Sulphate	NOx => Nitrate and VOC => Aerosol
BC	1.6	0.5
AB	0.94	0.3
SA	0.15[A]	0.05[A]
MB	0.15	0.05
ON	5.0	1.7
QC	2.8	0.9
NB	2.4	0.8
NS	4.2	1.4
NF	4.2[B]	1.4[B]
PEI	4.2[B]	1.4[B]
10 Province average[C]	2.4	0.8

A) Assumed to be the same as Manitoba
B) Assumed to be the same as Nova Scotia
C) Emission-weighted

The secondary particle reduction corresponding to the SOx, NOx and VOC reductions shown in Tables 6, 6a and 7, then, are given by the following equation (Equation 1):

[1] Fine $PM_{secondary}$ reduction in 2010 = Total SOx*0.024 + (Total NOx + Total NMOG)* 0.008 = 800 t/y

Secondary PM was estimated only for the Electricity Table measures of those evaluated here, so the above number cannot be compared directly with those in Table 6 (nor with the National Emission Inventory, which accounts only for primary emissions). It is informative to note the potentially significant increase in PM reduction benefit that would result from avoided formation of secondary particles by reducing the primary gaseous emissions.

The CAC reductions shown in Table 7 and Equation [1] are arguably more realistic estimates of CAC reductions that would result from implementing a 25% fuel efficiency improvement than the Transportation Table's estimate of "zero." The additional secondary reduction for all measures (Equation 1) is to be added to the primary emission reductions based on the national inventory (incorporated in Table 9 below).

Summary of emission reductions

Table 9 summarizes the total emission reductions that we have estimated for all six measures. Numbers have been rounded.

Table 9. Summary of Local Air Pollution and Greenhouse Gas Emission Reductions by Measure

Measure	GHGs (MT/y)	SOx (t/y)	NOx (t/y)	VOC (t/y)	PM (t/y)
Transportation					
Road fuel tax	4.7-10.3	60	13,600	4,000	1,800
Incr. public transit	10.1	50	7,000	4,000	1,300
Fuel efficiency	5.2-6.5	160	22,500	30,800	small
Electricity Generation					
Fuel switching	28	189,000	72,000	NA	17,000[C]
10% Renewables	9	34,500	18,000	NA	2,200[C]
Community Buildings					
Energy efficient retrofits	7.5	75	11,270	340	2,630
All 6 measures	**68**	**223,500**	**144,000**	**39,000**	**25,700[A]**
% of National Inventory (% of Kyoto requirement)	9% (36%)[B]	9%	7%	1.4%	1%[D]

A) May be assumed to be $PM_{2.5}$ (including 14,700 t/y primary and 11,000 t/y secondary contributions from all measures).
B) Based on NRCan's most recent estimate of the reduction requirement in 2010 as 25% of 748 MT = 187 MT.
C) Including secondary PM.
D) Based on relative reduction of primary $PM_{2.5}$ only.

Clearly, the selected measures are especially effective in reducing SOx and NOx emissions in association with the GHG reductions. These numbers are relatively conservative, since they take into account recent regulatory events that reduce the effect of the measures relative to the Transportation Table's estimates, as noted above.

<u>Valuation of reductions</u>

As noted earlier, we do not propose to apply a detailed air quality improvement valuation model to the CAC emission reductions estimated here. Instead, we use integrated valuations on the basis of unit emission reductions of GHGs, expressed in terms of CO_2 equivalents, from the two US studies cited. We selected reasonable values from the range of estimates from these studies that were relevant to the approach of this analysis.

The following table summarizes the range of values from the US studies with a indication of how these values have been used here. These values are taken from studies that valued a comprehensive set of both health and environmental impacts of reduced CAC emissions and took into account both primary emissions and their secondary products. Very low values from the US studies that addressed a limited set of impacts or pollutants have been omitted.

Table 10. Co-benefit avoided damage valuation estimates for CAC emissions used in this study

Value	Low	Mid/Low	Mid	Mid/High	High
Avoided CAC damage values ($CDN/tonne CO_2)	$5	$10	$18	$25	$32
National average			✔		
Uncertainty limits	✔				✔
Typical rural impacts		✔			
Typical urban impacts				✔	

The damage values in Table 10 cover the estimated values of a wide range of public health impacts (shortened lives, respiratory illness and many other health outcomes that are associated with air pollutants) and non-public health-related impacts (acid rain ecosystem damage, visibility impairment, agricultural crop damage, forest damage) for the CACs associated with the GHG reductions. The values integrate across all types of population exposures and environmental impacts in the US and are assumed to apply directly to average exposures and impacts in the southern portion of Canada.

The values in Table 10 do not account for a truly comprehensive set of outcomes, since socio-economic effects other than direct health and environmental impairment have not been analyzed in detail in the base studies.[30] The higher values in the table take into account avoided administrative costs of regulating the equivalent CAC reductions, but do not include general economic net benefits of energy efficiency and many other potentially valuable social and environmental factors.[31]

The values in Table 10 do not cover the estimated direct public health, social and environmental value of avoided impacts of global warming itself, such as sea level rise, climate change or increased temperatures. It is worth noting that the avoided damage values of the air quality co-benefits shown in Table 10 are similar in value to the commonly used estimated direct benefits of avoided global damage attributed to the greenhouse gases themselves. A typical range of the latter is $10 to $25 CDN (or

[30] See a partial list in the Background section.

[31] Many comprehensive studies of the costs and benefits of GHG mitigation have indicated a long-term net benefit to the US economy of the efficiencies brought about by implementing better, less GHG-intensive technologies and behaviours. One example is the US DOE ‘Five-Lab Study,’ *Scenarios of US Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond*, US Department of Energy, 1997.

more)/tonne of CO_2, which is based on estimates of global damages, not limited to Canada.[32]

For the estimated GHG reduction attributable to the six measures discussed in this report—68 million tonnes of CO_2 in 2010—the national average avoided damage value from Table 10 would place the benefit at $1.2 billion in that year. The low and high ends of the possible range, based on the data in Table 10, would be $340 million/year to $2.2 billion/year.

This gross estimate may be disaggregated approximately into urban and rural components as follows:

The Electricity measures affect mainly rural areas of Canada, since most of the generating capacity is located away from urban centres (there are significant exceptions to this generalization in Alberta and Ontario). Smaller communities in some provinces (for example, Nova Scotia) would also benefit from reduced emissions impact from fuel switching in electricity generation. Using the 'rural' damage value for these emissions from Table 10 ($10/tonne CO_2), the associated emission reductions for the two Electricity measures would be about $370 million/year.

Subtracting the value of the Electricity measures from the estimated total avoided damage leaves about $830 million/year for the avoided urban damages of the Transportation and Community Buildings measures.

The Transportation and Community Buildings measures clearly benefit urban areas and thus have an appreciable effect on avoided health damages. These reductions comprise about 35% of the NOx and VOC reductions associated with the six measures. Using the Harvard study's urban damage value[33] for NOx (VOC assumed to be equal in value) of $1,300 for the 100,000 tonnes/year of NOx and VOC reductions that would occur primarily in urban areas of Canada, the estimated avoided damage benefit would be $130 million/year. The corresponding value of the urban fine particle reductions (primary emissions and associated secondary particles) at $20,000/tonne would be about $130 million/year in 2010. These estimates for the avoided damage of the urban emission reductions may be taken as an estimate of the low end of the avoided damage uncertainty range ($260 million/year, compared with the $830 million/year figure from the previous paragraph). In either case, the benefit is appreciable.

Since the estimated values of the co-benefits and direct benefits appear to be of roughly the same magnitude, if the estimated direct benefit of the GHG reductions of the measures analyzed here were added to the above co-benefit, the total benefit could approximately double.

[32] See, for example, the value cited in the reference cited in footnote 11, as noted earlier—$5.60 CDN/tonne CO_2, as well as IPCC estimates provided in their 1995 Assessment—up to $50 CDN/tonne CO_2 emitted now (*Climate Change 1995: Economic and Social Dimensions of Climate Change,* Working Group III, IPCC, 1996).

[33] See footnote 11.

Summary of results

In summary, the estimated air quality co-benefits in Canada associated with the small number of GHG emission reduction measures assessed here may amount to several hundred million dollars per year in 2010 and beyond, within a fairly broad range of uncertainty. These co-benefits are considerable in the context of the limited scope of potential benefits included in the base studies from which the damage values were taken. Although the uncertainty is significant, these results suggest that a thorough analysis of the potential economic value of co-benefits of greenhouse gas emission reduction measures is an essential element of the integrated analysis of the NCCP's possible measures and options.

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