ANALYSIS OF MEASURES FOR REDUCING
TRANSPORTATION SECTOR GREENHOUSE GAS
EMISSIONS IN CANADA

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ABSTRACT

This study examines the problem of reducing greenhouse gas (GHG) emissions from the Canadian transportation sector. Reductions are necessary due to the potential impact of these gases on the global climate regime. Canada has agreed, under the Kyoto Protocol, to reduce emissions from all sectors to 6% below 1990 levels between 2008 and 2012. Considering the wide range of measures available for transportation sector GHG reduction, decision-makers will require estimates of both the potential emission reductions and the costs or benefits associated with a variety of measures.

In response to these information requirements, a simulation model of the Canadian transportation sector has been built. The finished product has since been incorporated into the Canadian Integrated Modelling System (CIMS), a set of economic and energy models developed at the Energy Research Group at Simon Fraser University. The transportation component of CIMS is an energy demand model. Unlike most other models of its kind, this model combines behavioural realism with technological explicitness in a hybrid approach.

The transportation component of CIMS was used in this analysis to test individual measures affecting the personal and freight transportation sectors, as well as a package of measures applied to personal transportation. Measures addressed efficiency improvements, fuel switching, mode switching, load factor increases, and overall activity reductions within the sector.

Annual carbon dioxide (CO₂) emission reduction estimates were obtained for each of the measures. The package of measures tested was found to achieve just over half of the reductions required to meet Canada’s Kyoto target as applied to the transportation sector. Emission reductions were much smaller for the individual measures.

Annual costs or benefits per tonne of CO₂ reduced were also calculated for all of the personal transportation sector measures. According to the expected resource costing methodology employed, all individual measures, except for one measure involving fuel
switching, were found to result in net benefits. The package of measures also resulted in
a net saving. However, the cost results presented in this report must be very carefully
interpreted in their application to policy decision making. Infrastructure and
administration costs, as well as some of the important intangible costs seen by consumers
are missing from the accounts. In addition, benefits may decrease should increased
measure stringency be necessary in order to reach the Kyoto target.
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1. Introduction

1.1 Background

Greenhouse gas (GHG) emissions pose a threat to human society and to the environment due to their potential effect on the global climate regime. Canada is now part of an international agreement to reduce these emissions, and has committed to a 6% reduction from 1990 levels between 2008 and 2012. In order to achieve a significant level of mitigation, it will be necessary to consider options that target the transportation sector, because this sector has such a significant impact on overall emission levels in Canada.

Sectoral analysis reveals the key factors that contribute to transportation sector emissions. Actions for reducing emissions may be formulated that correspond to these factors. Realizing actions will require the implementation of various policies by government. Policy options include direct action by government, information, regulation, and financial incentives and disincentives.

1.1.1 Greenhouse Gases and Global Warming

GHGs occur naturally in the atmosphere where they act to absorb outgoing radiation, thereby warming the surface of the earth (IPCC, 1996b). This phenomenon is referred to as the greenhouse effect. Atmospheric concentrations of the GHGs are currently rising due to human activities such as the burning of fossil fuels, deforestation, and the raising of livestock. These increased concentrations may result in higher mean global temperatures; a rise in sea levels; changes in agricultural yields, forest cover, and water resources; as well as a potential increase in the damages caused by storms (IPCC, 1996a). The social, ecological, and economic consequences of these effects could be devastating.

In 1997, the international community responded to the GHG problem by negotiating the Kyoto Protocol to the United Nations Framework Convention on Climate Change. As part of this agreement, Canada made a commitment to reduce emissions to
6% below 1990 levels during the period between 2008 and 2012. The Analysis and Modelling Group of the National Climate Change Process (AMG, 1999) notes that a 26% gap exists between their projection of what emissions would otherwise be in 2010 and the emission level required to meet the Kyoto target in this year.

1.1.2 Greenhouse Gases and Transportation

The AMG (1999) identifies eight major sources of GHG emissions: residential, commercial, industrial, transportation, fossil fuel industries, electricity generation, agroecosystems, and wastes / others. In 1997, transportation was the largest of these, accounting for 25% of overall emissions. This share is maintained over time, according to AMG forecasts, with emissions at 26% in 2010. Transportation emissions are projected to rise 34% between 1990 and 2010. Because of the significant impact of this sector, Canada must implement mitigation strategies targeting transportation if it is to responsibly address the GHG problem.

GHGs emitted from transportation include carbon dioxide (CO\(_2\)), methane (CH\(_4\)), and nitrous oxide (N\(_2\)O). The most predominant of the three is CO\(_2\), accounting for 94% of transportation GHG emissions in Canada in 1997 on a CO\(_2\) equivalent basis (according to calculations performed on data reported in AMG, 1999).

1.1.3 Factors Contributing to Transportation Sector Emissions

An informed effort to reduce GHG emissions from the transportation sector will require an understanding of the underlying components that determine emission levels. In their 1996 paper, Scholl et al. discuss the effects of several factors on CO\(_2\) emissions from passenger transport: activity (the total amount of passenger kilometres travelled (pkt)), modal structure (the allocation of pkt between various modes of transportation), energy intensity (the energy required to travel one pkt using a given mode), and fuel mix (the proportion of vehicles using various types of fuel). Energy intensity may be broken down further into fuel intensity (energy required to travel one km in a vehicle) and load factor (the number of people per vehicle).
Using the information provided by Scholl et al, a decomposition equation may be derived that describes the effect of six components on GHG emissions from passenger transport:

\[
GHG = T_{pkt} \times \frac{M_{pkt}}{T_{pkt}} \times \frac{M_{vkt}}{M_{pkt}} \times \frac{E}{M_{vkt}} \times \frac{FT}{E} \times \frac{GHG}{FT}
\]

where \(T_{pkt}\) = total passenger kilometres traveled, \(M_{pkt}\) = passenger kilometres traveled using a given mode of transport, \(M_{vkt}\) = vehicle kilometres traveled using a given mode of transport, \(E\) = energy used, and \(FT\) = fuel type. The first term in the equation represents activity, the second modal structure, the third the inverse of load factor, the fourth fuel intensity, the fifth fuel mix, and the sixth a conversion factor to transform fuel use into GHG emissions.

The same factors impact GHG emissions from the freight transportation sector. Activity within this sector would not be measured in pkt, however. For the purpose of this study, freight transport activity is measured in tonne kilometres travelled (tkt). The term load factor refers to the number of tonnes per vehicle in this case.

### 1.1.4 Actions to Reduce Transportation Sector Emissions

Based on the equation outlined above, GHG emissions from the transportation sector may be reduced through the following methods: a reduction in personal or freight transportation activity, a shift towards less GHG intensive modes of travel,\(^1\) an increase in the load factor associated with one or more modes of travel, a reduction in the fuel intensity (increase in the efficiency) associated with one or more modes of travel, or a shift in fuel mix towards less GHG intensive fuels.

These options for reducing emissions may be referred to as *actions*. In a recent report, the Energy Research Group (ERG, 1998) defined actions as, “Changes in

---

\(^1\) Within the personal transportation sector, using public transit, cycling, or walking is considered to be less GHG intense than travelling by car or light duty truck; while within the freight transportation sector, rail is less intense than trucking.
equipment acquisition, equipment use rates, lifestyle choices, or resource management that change net GHG emissions from what they otherwise would be.”

1.1.5 Measures (Policy + Action)

Mitigative actions, such as those described in the preceding section, generally do not occur on their own; some form of intervention is required. A policy is defined as some effort by government. The combination of one or more policies to induce one or more actions is referred to as a measure (ERG, 1998).

\[
\text{Measure} = \text{Action} + \text{Policy}
\]

There are a wide variety of policy options available. These may be divided into four general categories: direct action by government, information, regulation, and financial incentives and disincentives. These categories are discussed below in the context of mitigating GHG emissions from the transportation sector.

Direct Action by Government

Many buildings, vehicles, major facilities, and infrastructure are government owned and controlled. Public authorities therefore have the power to achieve certain actions directly through their own management decisions. Strategic investment may also encourage certain actions. The enhancement of public transit service and infrastructure and the establishment of regional cycling networks make switching to these modes a more attractive option. Investment in research and development may allow for fuel efficiency improvements and better options for fuel switching. Furthermore, once an alternative fuel option has been refined, widespread acceptance will require a significant investment in refuelling infrastructure.

Information

Governments and other agencies commonly use information programs in order to promote certain types of behaviour such as quitting smoking, driving safely, and
recycling. This approach is certainly applicable to achieving reductions in GHG emissions from the transportation sector. Within the personal transportation sector, for example, activity may be reduced through the promotion of telecommuting (the option of working from home). Information campaigns may also be used to facilitate and promote carpooling, thereby increasing the average load factor for passenger vehicles. Improved efficiency in both the personal and freight sectors may result from programs that educate members of the public with respect to the fuel efficiencies of various types of vehicles, and the economic and environmental benefits of efficient technologies.

Regulation

Regulatory policies involve the establishment of rules limiting the technological and behavioural options available to firms and individuals. Technological regulations might take the form of efficiency, fuel, or emission standards. In California, a series of 1990 regulations established emission standards for new passenger vehicles (Bunch et al., 1993). Requirements that only transit or high occupancy vehicles use certain traffic lanes, on the other hand, regulate behaviour in order to encourage mode switching and increased load factors. Regulation could also be used to influence the actions of developers, thereby affecting land use patterns. Mixed land use zoning allows for reduced activity levels within the personal transportation sector because of the close proximity of important destinations.

Financial Incentives and Disincentives

It is also possible to alter behaviour through the use of financial incentives and disincentives. A tax on CO₂ emissions, for instance, would act as a broad based disincentive to such emissions. By targeting the problem directly, this policy would encourage all of the actions outlined in section 1.1.4: activity reduction, mode shifting, increased load factor, increased efficiency, and fuel switching. Road pricing (i.e. tolls), as well as increased parking charges discourage passenger vehicle travel in general (especially for vehicles with only one occupant), thereby reducing activity, causing mode switching, and increasing load factor. A tax might also be applied to purchases of inefficient vehicles so as to contribute to an overall increase in fuel efficiency of the new
vehicle fleet. The tax could either add to general revenue or be structured as a revenue neutral feebate. Feebates would involve taxing purchases of inefficient vehicles, while providing rebates for purchases of more efficient ones.

Any type of taxation tends to be very unpopular with both industry and the public, however. As a result, tradable emission schemes have been implemented in the electricity sector as an alternative to taxation. These programs involve the initial distribution of pollution emission permits to individual firms, and the subsequent trading of these permits on a competitive market. Under the U.S. Acid Rain Program, electric utilities currently trade permits for the discharge of SO$_2$ (Conrad and Kohn, 1996). Tradable emission schemes are theoretically identical to taxation (IPCC, 1996a); however, their implementation should not encounter the level of resistance met by taxation. Tradable emission programs could also be applied to GHG emissions from the transportation sector. For freight transport, this type of program would follow the model already established in the electricity sector. In the case of personal transportation, the model would require significant modification.

Incentives may be especially useful in achieving short-term actions within the freight transportation sector where regulation is challenging politically. In the area of land use, rewards could be offered to developers who are willing to establish mixed use rather than strictly residential neighbourhoods. Financial incentives may also be used to influence the behaviour of individual consumers. For instance, subsidized transit fares provide a financial incentive for mode switching.

1.2 The Problem

The diversity of actions and policies outlined above indicates that decision-makers are faced with a wide variety of potential measures for reducing GHG emissions from the Canadian transportation sector. These decision-makers will require some form of guidance in determining what measure or measures to implement in order to meet international commitments such as the abatement target set in Kyoto, as well as domestic goals. Information in the form of estimates of the emission reductions that may be
achieved under key measures, as well as the costs associated with these reductions will certainly be necessary.

### 1.3 The Objectives

The objectives of this research project are as follows.

1. To build a simulation model of the Canadian transportation sector that is capable of generating GHG emission and cost estimates over time.

2. To use this model to estimate the $\text{CO}_2^2$ emission reductions that could be achieved under a variety of relevant measures.

3. To estimate the costs and benefits associated with these emission reductions.

The term *simulation model* is used here because the goal of the modelling effort is to investigate the impact of alternate states of reality on key output variables. In this case, the alternate states of reality being simulated are different government policy choices that impact GHG emissions.

### 1.4 Modelling Transportation Energy Demand

Because GHG emissions from the transportation sector are primarily a result of energy use, an energy demand model will be built for the purpose of this analysis. (Emission levels will be derived from energy demand through the application of emission factors.) The following section therefore provides a review of the field of energy demand modelling. Two divergent approaches – the “top-down” and “bottom-up” methodologies – are described. (Jaccard *et al.* (1996) and Nyboer (1997) provide a more thorough account of these paradigms.) The current trend in transportation energy demand modelling is to combine the two strategies, moving towards hybridization. There are very few hybrid transportation models in existence: one is the NEMS TRAN model maintained by the U.S. Department of Energy, another is the CIMS transportation model, built in order to meet the objectives of this study.
1.4.1 Top-down Modelling

Under the top-down paradigm, econometric equations are constructed that relate demand for a given form of energy to certain key explanatory variables such as past levels of consumption of that energy form, the price of that energy form, the price of other energy forms, the prices of substitutes for energy such as capital and labour, and gross domestic product. The parameter values for these equations are estimated based on historical information in the form of time-series and / or cross-sectional data, and may therefore be statistically tested.

Top-down models are characterized by a high degree of behavioural realism, because the historical data they incorporate reflects the actual decisions of individual consumers and firms in response to changing conditions. These models therefore have the capacity to forecast future energy use with a high degree of accuracy, as long as future conditions do not deviate significantly from those observed in the past.

The range of conditions where econometric relationships hold is a matter of debate. Dahl’s work indicates that gasoline demand elasticities remain constant over a wide variety of conditions (1982); and that much of the inconsistencies across estimates from one study to another can be explained by the type of model used, the time period associated with the elasticity (monthly, quarterly, or yearly), and the type of data used (1986). Other researchers, however, believe that the relationships that affect energy demand may be significantly altered in the future due to factors such as the emergence of new technologies, the implementation of new regulations, and higher energy price regimes.

Dahl (1982) provides a detailed list of previous work on gasoline demand modelling, including many early studies that could be classified as following the top-down methodology. Current research into the demand for transportation energy, however, generally takes an approach that is too disaggregate to be considered strictly top-down.

\[ CO_2 \] is used as a proxy for GHGs in general for the purpose of this analysis.
1.4.2 Bottom-up Modelling

Bottom-up models are technologically explicit: they forecast energy demand by simulating the evolution and use of stocks of technologies that consume energy in the economy. Technologies “compete” to provide shares of exogenously determined service demands based on their life cycle costs (LCCs), as well as technology-specific constraints. In a strictly bottom-up approach, LCCs would include only tangible, technical-economic costs.

Because bottom-up models deal explicitly with end use technologies, they are more suited than top-down models to exploring the effects of new technological developments on future levels of energy consumption. For example, a bottom-up model of the transportation sector could be used to simulate energy consumption under scenarios where super-efficient vehicles or vehicles that run on alternative, low GHG emitting fuels gain a significant share of the overall market. The historical information embedded in a top-down model may no longer be relevant in such cases, because the technologies in question were not part of the economic landscape during the period of data collection.

Bottom-up models, however, are lacking in the behavioural realism associated with top-down models. In making purchase and mode choice decisions, consumers and firms are faced with intangible as well as tangible costs and benefits. The element of risk associated with an emergent technology may represent an intangible cost, for example. Transaction costs are also associated with gathering information on unfamiliar technologies. In addition, benefits may be attached to the attributes of certain technologies: benefits that are not fully accounted for when all technologies are portrayed as providing identical services. For example, although the technical-economic costs associated with public transit are lower than those associated with the passenger vehicle, consumers continue to prefer the latter mode, as they perceive private vehicles as providing them with a higher level of service. While the full spectrum of factors affecting decision-making are incorporated into top-down models through the use of historical market data, bottom-up models tend to consider only technical-economic costs. This
aspect of bottom-up modelling makes it more suitable to normative analysis (forecasting energy use under conditions where consumers and firms ought to minimize technical-economic costs over time) than positive analysis (forecasting likely levels of energy use).

Transportation sector energy demand is modelled using a bottom-up approach within the linear programming model MARKAL (MARKet ALlocation). MARKAL differs from a traditional bottom-up model in that service demand levels are affected by the costs associated with the provision of these services, rather than being set exogenously (GREIGE and GERAD, 1998; HALOA Inc., 2000). Like other bottom-up models, however, MARKAL does not account for intangible costs, and behavioural realism is not emphasized.

1.4.3 Hybridization in Transportation Modelling

Top-down models tend to produce high cost estimates for reducing energy use and resultant GHG emissions, while bottom-up models generally indicate that small costs or even benefits are associated with such reductions (Grubb et al., 1993; Wilson and Swisher, 1993; IPCC, 1996a; Nyboer, 1997). A hybrid approach to modelling energy demand has the capacity to resolve the cost issue by combining the behavioural realism of a top-down model with the technological explicitness of a bottom-up model.

Top-down transportation energy demand models have been moving towards hybridization in recent years. Increasing disaggregation has allowed these models the potential for incorporating greater technological detail. The first step in this process was the adoption of a “components” approach to modelling gasoline demand within the personal transportation sector. A components methodology might, for example, calculate gasoline demand based on estimates of the average distance travelled per car, the average efficiency of the car fleet, and the number of cars in the fleet. The components of gasoline demand may be modelled using aggregate data or disaggregate, household level data. Dahl (1982) and Gallini (1983) take an aggregate approach to modelling the components of gasoline demand. The Inter Fuel Substitution and Demand model used by
Natural Resources Canada (1997) relies on a similar methodology for forecasting transportation energy demand.

Train (1986) notes that econometric modelling is increasingly focused on the actions of individual decision-makers. This is a logical progression because these actions form the basis of all economic activity. Greater availability of survey data on households and firms has added to the feasibility and accuracy of this methodology. Modelling decisions at the household or individual level has required the development of new techniques, however. For example, while regression is well suited to analysing continuous variables (such as the aggregate demand for automobiles), alternative methods such as qualitative choice analysis are required in order to deal with the discrete choices made by households (such as the choice of whether or not to purchase a car).

Proponents of the use of household data to model gasoline demand point out that there is a relationship between decisions on vehicle holdings (how many vehicles to own, how efficient should these vehicles be) and vehicle usage (how much should each vehicle be driven) at the household level (Berkowitz et al., 1990; Eltony, 1993). Because the components of gasoline demand are linked at the household level, they cannot be accurately modelled using aggregate data.3 Mannering and Train (1985) provide a review of developments in the household-based approach to modelling automobile demand between 1980 and 1985; while Train (1986), Berkowitz et al. (1990), Hensher et al. (1990), and Eltony (1993) provide more recent examples of the application of this approach to the transportation sector.

The components approach to modelling transportation energy demand requires that modellers deal explicitly with vehicle efficiency levels. This development has encouraged a level of technological sophistication not associated with the standard top-down methodology. Eltony (1993), for example, models two components of the overall fuel efficiency of new cars: efficiency within car classes (as determined by

---

3 This is not to say that models using aggregate data cannot address relationships between the components of gasoline demand, only that they cannot do so at the household level.
manufacturers) and the distribution of sales across these classes (as determined by consumers).

The Transportation Sector Model of the National Energy Modeling System (NEMS TRAN), maintained by the U.S. Department of Energy, has been identified as a transportation energy demand model that is a hybrid. NEMS TRAN combines behavioural realism with technological explicitness to such an extent that it may no longer be classified as either top-down or bottom-up. Within the model, energy demand is estimated separately for major modes of transportation. A special emphasis is placed on light duty vehicles, due to their overwhelming impact on the sector. In order to estimate light duty vehicle fuel consumption, a simulated demand for personal travel is combined with simulated stock efficiency. The penetration of the passenger vehicle market by alternative fuelled vehicles is also addressed (U.S. Department of Energy, 1998).

Within NEMS TRAN, light duty vehicle travel demand is estimated from fuel price, personal income, and population projections. Future new vehicle fuel efficiency levels are simulated on the basis of three major factors: technological improvements within market classes, changes in acceleration performance within market classes, and changes in the mix of market classes sold. Technological improvements are simulated from the point of view of the manufacturer, based on the availability and cost effectiveness of a wide array of component technologies capable of improving vehicle efficiency. The consumer perspective is used to determine the other two types of changes. Market shares for alternative fuelled vehicles are generated based on fuel efficiency and fuel price estimates. The parameter values used within the alternative fuel sub-model of NEMS TRAN were derived from the results of a stated preference survey (U.S. Department of Energy, 1998).

Behavioural realism in technology modelling is most often achieved through the use of revealed preference (RP) information. Over time, the value placed by consumers on various commodities or attributes is revealed through their purchasing behaviour. Alternative fuelled vehicles tend to differ from conventional vehicles in terms of
attributes such as range and fuel availability. Information on consumer preferences with respect to these attributes is required for behaviourally realistic modelling. However, because alternative fuelled vehicles are, for the most part, emerging technologies not yet available for mainstream consumption, the requisite RP data does not exist. This lack of information has prompted researchers to begin to collect stated preference (SP) data instead.

The SP approach involves presenting survey respondents with information on the attributes of hypothetical products and then eliciting their preferences for these products. Statistical procedures are applied to the survey data in order to attach values to the attributes under investigation. Bunch et al. (1993) provide a description of the SP approach that they use to determine consumer preferences for the attributes of clean-fuel vehicles. Golob et al. (1997) model vehicle use at the household level according to vehicle type using both RP and SP data.

A simulation model of the Canadian transportation system was built in order to meet the objectives of this study. This model has since been integrated into the Canadian Integrated Modelling System (CIMS), developed at the Energy Research Group (ERG) at Simon Fraser University. Like NEMS TRAN, the transportation energy demand component of CIMS is a hybrid model. Few other models of this type exist. CIMS incorporates the behavioural realism of top-down modelling into a technologically explicit framework by adding key behavioural parameters to its technology competition procedure.

Within the CIMS transportation model, a discount rate is used to represent elements of cost risks, transaction costs, and option value. This discount rate was derived from parameters used in NEMS TRAN. Intangible cost parameters have also been incorporated into the Canadian model. These parameters account for positive or negative attributes that are not reflected in the technical-economic costs of technologies. Intangible cost parameters have been estimated based on both efficiency and fuel type.

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4 NEMS TRAN incorporates the results of this study into its alternative fuel sub-model.
NEMS TRAN sources and values were also used in the estimation of the intangible cost parameters. The discount rate and the intangible cost parameters associated with efficiency levels have a basis in observed market behaviour, and may therefore be considered RP parameters. The intangible costs associated with attributes related to fuel type were, for the most part, derived from SP information. A full description of the hybrid methodology used to build the CIMS transportation model is provided in the following section.
2. Methodology

2.1 CIMS

The transportation model built as part of this study has now been incorporated into the Canadian Integrated Modelling System (CIMS), a model developed by the Energy Research Group (ERG) at Simon Fraser University. CIMS is a simulation model: it was designed to provide information to decision makers on the potential effects of various government policy alternatives intended to affect technological evolution. The system consists of an Energy Demand Model, an Energy Supply and Conversion model, and a Macro-Economic Model linked by a Global Data Structure. CIMS was recently used by the Canadian government to evaluate GHG emission reduction options as part of its National Climate Change Implementation Process (ERG / M.K. Jaccard and Associates, 2000). A diagram of CIMS is shown in Figure 2-1 below.
The link between the Energy Demand Model and the Energy Supply and Conversion Model of CIMS represents the interaction that occurs between sectors that use energy (residential, commercial, industry, and transportation) and sectors that produce or transform energy (electricity generation, fossil fuel supply, oil refining, and natural gas processing). CIMS iterates between decisions occurring within the Energy Demand Model and decisions occurring within the Energy Supply and Conversion Model until energy prices and energy demand have stabilized at equilibrium.

The link between the Energy Demand Model and the Macro-Economic Model represents the indirect effect of changes in the costs of providing energy services on the structure of the economy (intermediate and final product demands) and on total economic output. This is an especially important feature of CIMS because technology choices may impact the costs of providing energy services.
The CIMS Energy Demand Model is comprised of a residential model, a commercial model, an industrial model, and a transportation model. Until recently, the CIMS Energy Demand Model existed in isolation, and was referred to as the Intra-Sectoral Technology-Use Model (ISTUM). This prototype demand model was made up of a residential model (ISTUM-R), a commercial model (ISTUM-C), and an industrial model (ISTUM-I). A transportation model (ISTUM-T) was built for the purpose of this study and was operated as a stand-alone model in order to generate the results reported here. As the project neared completion, however, all of the demand components had been integrated into CIMS.

There are two main implications of operating the transportation model in partial equilibrium apart from the rest of CIMS. First, the lack of integration between energy demand and energy supply makes it difficult to estimate full cycle GHG emissions. Full cycle emissions for a given fuel type include not only the emissions associated with actually burning the fuel at the point of end use, but also those associated with generation or extraction of the fuel and with any necessary refining processes. The emission forecasts generated by the CIMS transportation model alone generally include end use emissions only, because there is no link to energy supply. Second, separation from the Macro-Economic Model means that a change in the cost of providing transportation services that may be incurred as a result of government GHG mitigation policy will not automatically result in a change in the level of demand for these services.

5 The process for calculating the emission reductions associated with measures, however, accounts for the emissions associated with electricity generation (these emissions are referred to as indirect emissions). See section 2.3.2 for an explanation of this methodology.

6 In order to simulate measures involving taxation, a reduction in service demand has been applied externally to the model. The two measures affected are the CO2 Tax and the Diesel Tax. A complete description of these (and all other measures) may be found in sections 2.4.1 and 2.4.2.
2.2 *The CIMS Transportation Model*

The structure of the CIMS transportation model is described below with the aid of a flow diagram, followed by an explanation of the process for simulating technology stock evolution within the model. A final section documents the inputs provided to the model.

Each of the demand components of CIMS, including transportation, is composed of seven regional models (the Atlantic provinces are combined into one model). Output is therefore available both on a regional level and on a national level. As this study is national in scope, the results of the regional models have been aggregated for presentation in the Results section.

2.2.1 *Flow Diagram of the CIMS Transportation Model*

Each of the demand components of CIMS functions by tracking overall demand for a particular energy service through a series of general categories down to individual technology stocks. The flow diagrams shown in Figures 2-2 and 2-3 illustrate the categories of transportation service included in CIMS, as well as the technologies available to supply these services. General categories of service demand are referred to as nodes and are represented by boxes. Each node has been assigned a number for modelling purposes. These numbers are also included in the figures so that nodes may be easily identified within the text. The technologies available at each node are listed below that node.

Three main categories of demand for transportation services are included in CIMS: personal transportation, freight transportation, and offroad transportation. In urban areas, demand for personal transportation services is met by passenger vehicles (cars and trucks), buses, rapid transit, and walking and cycling. Passenger vehicles may be single occupancy (SOVs) or high occupancy (HOVs). In regions outside urban areas, services are provided by passenger vehicles and buses, as well as air and rail travel. Marine, air, road, and rail vehicles provide freight transportation services.
Demand for freight transportation is measured in tonne kilometres travelled (tkt). Demand for personal transportation is measured in passenger kilometres travelled (pkt). The demand for passenger vehicle travel at nodes 10 and 14 in Figure 2-2 is met by node 20 in Figure 2-3. In the transition from nodes 10 and 14 to node 20, pkt are converted to vehicle kilometres travelled (vkt). This conversion is achieved using load factors (assumptions regarding the number of passengers per vehicle).

Passenger vehicles are defined as either cars or trucks, and are categorized by age (old, recent, or new), as well as by fuel type and efficiency. Available within CIMS are conventional gasoline fuelled passenger vehicles, vehicles that run on other fuels currently in use (other fuels), and vehicles that run on alternative fuels that are not yet on the market or that are just beginning to enter the market (alternative fuels).

For the purpose of this study, non-gasoline fuelled vehicles are defined as follows: methanol vehicles run on a blend of 85% methanol to 15% gasoline, ethanol vehicles run on a blend of 85% ethanol to 15% gasoline, electric vehicles run off an onboard battery, electric hybrid vehicles run off an onboard battery recharged by a small onboard internal combustion engine, and hydrogen vehicles run off a hydrogen fuel cell.

In order for CIMS to function, the total demand for transportation services in a base year must be allocated between the available nodes and technologies as accurately as possible. A base year is a year in the recent past that data is available for. The year 1995 was used as the base year for this study.
Figure 2-2 Flow diagram of the CIMS transportation model (nodes 1-19 & 34)
2.2.2 Simulation of Technology Stock Evolution

The CIMS demand models, including transportation, track the evolution and use of technology stocks over time according to five basic steps: growth in demand, retirement, technology acquisition, retrofit, and generation of output. These steps are followed at five-year increments over the simulation period in order to generate fuel...
consumption, emission, and cost output for that year. For this analysis, a simulation period extending from 2000 until 2015 has been used.

*Growth in Demand*

In each year of the simulation period, growth forecasts are used to estimate the increase or decrease in demand for transportation services at each node within CIMS relative to the previous simulation year (or to the base year for the year 2000).

*Retirement*

Once a new level of demand has been specified at each node for the year in question, a portion of the technology stock is retired. Retirement within CIMS is almost entirely a function of time, and is based on information on technology lifetimes. If the remaining stock at a given node is in excess of what is required to meet demand, an additional portion of the stock is retired. If remaining stock is insufficient, technology acquisition to meet outstanding demand is distributed among the available technologies. This process is described below.

*Technology Acquisition*

The acquisition of new technologies to meet outstanding demand at a node may be either exogenous or endogenous. In the exogenous case, demand is allocated according to a ratio generated outside the model. In the endogenous case, market shares are determined through internal competition of the technology choices.

Allocation is endogenous at the nodes representing new cars and trucks (nodes 28-33), and exogenous at all other nodes. This is because the data required for endogenous competition was generally unavailable. Also, in some cases, the increase in model complexity that would be necessary in order to allow for endogenous competition would not be acceptable given the expected improvement in model performance.

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7 See Jaccard and Nyboer (1997) and Nyboer (1997) for additional detail on the CIMS Energy Demand Model. Note that these documents were written when the CIMS Energy Demand Model existed in isolation, and was referred to as ISTUM.
Endogenous Technology Competition

The acquisition of new cars and trucks is simulated endogenously to the transportation component of CIMS through a technology competition process that relies primarily on estimates of annualized life cycle costs (LCCs). In order to mimic the decision making behaviour of individual consumers as closely as possible, the LCC estimation procedure attempts to take into account the key factors considered by individuals when making purchase decisions. These factors include technical-economic costs, transfers between government and individual consumers, cost risks, transaction costs, option value, and the intangible costs associated with certain technology specific attributes. This combination of factors may be referred to as the perceived private costs faced by the consumer.

Technical-economic costs incorporated into the annualized LCC estimates calculated by the CIMS transportation model include the yearly operating, maintenance, and fuel costs (including transfers to government in the form of taxes), as well as the capital costs of passenger vehicle technologies. In their raw form, as inputs to the LCC calculation, these technical-economic costs are the same risk free costs that would be used in a standard bottom-up model. A discount rate is used to spread the initial capital costs of technologies out over their expected lifetimes.

Discount rates can be portrayed as consumer time preference. Time preference is the general preference exhibited for consumption in the present as opposed to consumption at some point in the future, or the preference for incurring costs in the future as opposed to the present. Discounting increases the importance of present expenditures and benefits relative to those in the future. Examples of future benefits associated with vehicle ownership would include the fuel cost savings enjoyed by owners of more efficient vehicles or vehicles using cheaper alternatives to gasoline. Because novel technologies such as alternative fuelled vehicles tend to have higher capital costs than established technologies, discounting makes purchases of these technologies less likely.

A social discount rate is the weighted average of the net-of-inflation returns to saved and invested capital. The social discount rate represents a technical-economic cost
associated with purchasing a vehicle: in making this purchase, the consumer foregoes the returns they would have received had they saved or invested their capital instead.

In the model, setting the discount rate at a rate higher than the social discount rate allows the modeller to capture elements of cost risks, transaction costs, and option value within the discount rate as well. This is because the new technologies that are penalized by discounting due to their high capital costs are the same technologies that higher risks and transaction costs, as well as lower option values, are associated with.\(^8\) Technologies that are new on the market tend to be have higher failure risks and higher risks of increases in operating costs than established technologies. High transaction costs are also associated with these technologies. This is because extra time is required on the part of the consumer in order to gather information, and because novel technologies may also be more difficult to acquire. Option value refers to the value placed on the ability to respond to change by consumers. Emerging technologies have lower option values because their higher capital costs mean that they take longer to pay off.

Passenger vehicle technologies may have positive and negative attributes from the point of view of the consumer that are not reflected in their purchase price. For example, vehicles that run on alternative fuels tend to have the disadvantage of limited range and fuel availability. Because of these negative attributes, an individual switching from a conventional vehicle to an alternative fuelled vehicle may suffer a loss in consumers’ surplus. This means that the consumer would have been willing-to-pay a premium for a conventional vehicle with higher range and fuel availability even though that premium is not actually reflected in the cost of the conventional technology. Given the importance of consumers’ surplus to decision making, the values associated with key attributes have

\(^8\) The drawback to this approach is that capital cost is not a perfect indication of cost risks, transaction costs, and option value. For example, two new technologies may have the same capital cost, while one may have a much higher risk of failure. This distinction would be lost using the methodology described here. A goal for future application of the CIMS transportation model is to incorporate technology-specific risk information. This is accomplished within the model by assigning different discount rates to different technologies.
been monetized within the CIMS transportation model, and included in the capital costs of the various technologies as intangible cost parameters.

New passenger vehicle technologies, such as vehicles that run on electricity or hydrogen, often have extremely high capital costs when they are first introduced on the market. The intangible cost parameters that act as adders to their capital costs are also large. As a technology achieves greater market penetration, however, costs usually decline. Within the transportation component of CIMS, the capital costs, including any intangible cost parameters, associated with emerging passenger vehicle technologies are therefore allowed to decline with increasing market share according to a pre-specified function.

The procedure described above for generating annualized LCCs results in a unique estimate for each competing technology. Relative costs, however, are actually variable due to aspects such as regional differences in energy prices; imperfect information on technical-economic costs; and differences between individuals in terms of how they perceive cost risks, transaction costs, option value, and intangible cost attributes. This variability is accounted for in CIMS through the probabilistic simulation of technology competition. A technology's market share of the demand for new stock is a probabilistic function (logistic curve) of its LCC cost relative to competing technologies. Thus, the cheapest technology captures most, but not all of the market (Nyboer, 1997).

Node Competition

Acquisition of technologies may be either exogenous or endogenous to CIMS. The allocation of demand between nodes, on the other hand, is generally accomplished in an exogenous fashion (using growth rates and information on how demand was allocated in the base year). This is because the demand categories represented by nodes are usually considered to be distinct enough from each other so as not to be in direct competition. For example, within the transportation sector, urban areas are not considered to be directly competing with rural areas for a share of the overall demand for personal transportation. Even in cases where nodes may, in fact, be in direct competition, our understanding of how this competition occurs is often not advanced enough to allow for
the process to be modelled with confidence. For example, public transit companies must compete with passenger vehicles to supply a share of the overall demand for personal transportation services in urban areas; however, the determinants of market share for each of these service categories are not well understood.

The allocation of demand between new passenger vehicles using gasoline, other fuels, and alternative fuels (see nodes 25 and 27 in Figure 2-3), however, is determined through an endogenous node competition. This is because passenger vehicles are assumed to provide the same basic service regardless of fuel type. A node competition follows the same procedure outlined above for technology competition. Annualized LCCs are calculated for each node by taking a weighted average of the LCCs of the technologies available at that node.

Retrofit

In the other CIMS demand sub-models, a slightly modified technology acquisition process is available to account for the possibility of retrofitting existing stocks. Use of the retrofit option was not necessary for this study, although the capacity may be activated for future projects.

Generation of Output

The final step in the CIMS demand modelling process is the generation of fuel consumption, end use emission, and cost output. Generally, output is derived by taking the sum of the outputs associated with individual technologies for the year in question. A more detailed description of how this procedure is carried out within the transportation sector model is given below.

Fuel Consumption

Once overall demand for transportation services has been allocated amongst available technologies in a given year, the fuel consumed by each technology is determined based on fuel efficiency and service demand provided (the amount of fuel required per unit of service for each technology is multiplied by the stocks of that
technology). Aggregate consumption levels are then determined by summing over all technologies.

Fuel consumption output from the CIMS transportation model has been calibrated to estimates provided by the Analysis and Modelling Group of the National Climate Change Process in Canada’s Emissions Outlook: An Update (AMG, 1999). Calibration was achieved for the base year (1995), as well as over the forecast period for a Business-as-Usual (BAU) case where no action is taken to mitigate GHG emissions. Calibration in the base year was within 5% for overall energy use as well as by fuel type for major fuels. The year 2010 was chosen to represent calibration over the forecast period. Calibration in the year 2010 was within 10% for overall energy use as well as by fuel type for major fuels. The calibration results are shown in Appendix A.

End Use Emissions

The CIMS transportation model (like all of the other demand sub-models of CIMS) produces end use emissions as output. Integration with the Energy Supply and Conversion Model is necessary for the generation of full cycle emissions.

End use emissions of GHGs and other pollutants are determined within the transportation model by multiplying the service demand allocated to each technology by the magnitude of emissions produced for each unit of service provided by that technology. Emission levels attributed to the individual technologies are then summed to give an estimate of the total emissions generated by the sector in that year.

It is possible to generate emission forecasts for many types of pollutants using the transportation component of CIMS; however, this study focuses on CO₂ as a proxy for all GHG emissions. In the case of CO₂, emissions per unit of service are calculated by combining the fuel efficiency of the technology in question with the CO₂ end use emission factor associated with the fuel type used by that technology.

Costs

Costs are determined in a similar fashion to the other types of output within CIMS. The cost associated with a specific technology in a given year is calculated by
multiplying the service demand allocated to that technology by the annualized LCC incurred per unit of service demand supplied. Costs are then summed over the available technologies.

The annualized LCCs calculated within CIMS are a representation of the perceived private costs faced by the consumer. Reliance on annualized LCCs for the calculation of costs means that the raw cost output of the CIMS transportation model is also an account of perceived private costs. If other cost accounts are required, the raw cost output may be further manipulated to provide such costs.

The annualized LCC estimates provided by the transportation model do not include intangible cost parameters associated with transit technologies or with carpooling (the HOV technology), because reliable estimates of the consumers’ surplus associated with these modes (relative to the passenger vehicle) were not available. This is a missing element of perceived private costs. There are likewise no intangible costs associated with reduced levels of activity within the model. Infrastructure and administration costs are not associated with technologies as part of the LCC calculation because these costs are not directly borne by the consumer and therefore do not affect private decisions with respect to technology acquisition and use.

Annualized LCCs for freight technologies are not estimated within CIMS. This omission was due to a lack of accurate data on the costs associated with the various freight modes. Therefore, cost estimates generated within the model do not include the cost of meeting the demand for freight transportation services. Likewise, costs are not estimated for the offroad sector.

2.2.3 Input Assumptions

A variety of inputs are necessary to the function of the CIMS transportation model. Key assumptions and their sources are discussed below.

Base Year Demand Allocation

In order for the transportation component of CIMS to function according to the five steps described in section 2.2.2, demand for transportation services must first be
allocated between all nodes and technologies for the base year (1995). This allocation was based on the following sources: AMG (1999), Dunphy and Fisher (1996), Hall (1994), Natural Resources Canada (1997), Statistics Canada (1998, website), (1995a), (1995b), (1995c), (1995d), Transport Canada(a) (website), (b) (website), and (c) (website). Supplemental information was also provided by BC Transit, the Greater Vancouver Regional District, and Natural Resources Canada.

Demand Growth Forecasts

Forecasts of growth in the demand for transportation services are required in the first step of the modelling process employed by CIMS. Future demand levels are exogenously supplied to the model using forecasts generated by the AMG (1999).

Cost Variance Parameter

Under the endogenous competition procedure used to acquire new passenger vehicle technologies in the CIMS transportation model, a technology’s share of the outstanding service demand available at a given node is determined as a probabilistic function (logistic curve) of its annualized LCC relative to that of competing technologies. As a result, the cheapest technology captures most but not all of the new market for a given service demand category. This methodology is used to account for the LCC variability that exists in reality.

Within CIMS, the slope of the probabilistic function is determined by the cost variance parameter. As the value of this parameter is increased, the slope of the logistic curve also increases, and the market share captured by the cheapest technology becomes larger. As the value of the cost variance parameter is decreased, slope decreases, and the cheapest technology loses market share to more expensive technologies. Therefore, if perceived cost is assumed to be invariable, a high value should be assigned to the cost variance parameter, while if perceived cost is assumed to be highly variable, a low value should be assigned.

For the purpose of this study, the cost variance parameter was set to its default value of 10. At the default value, where there is a 15% difference in the LCCs of two
technologies, about 80% of the market for new stock will be captured by the cheaper technology. The default value was determined by Nyboer (1997) for the industrial sector through consultations with analysts and experts, as well as an examination of market reports.9

Fuel Prices

The CIMS transportation model requires province by province fuel price forecasts for transportation fuels over the period 2000-2015. Transportation sector price forecasts for gasoline and diesel were supplied by the AMG (1999). AMG price forecasts were also used for electricity; however, commercial rates were used in this case because rates for the transportation sector were not available. Prices for liquefied petroleum gas (LPG) or propane were supplied by Natural Resources Canada (1997). Again, commercial rates were used. Fuel prices for compressed natural gas (CNG), methanol, ethanol, and hydrogen were calculated from gasoline prices using information on the relative costs of transportation fuels reported by the U.S. Department of Energy (1998). Because the transportation component of CIMS was operated in partial equilibrium for the purpose of this analysis, fuel prices are not influenced by levels of demand for fuel. This simplification should not create too much of a problem, however, because most prices are primarily affected by the U.S. and international markets. The fuel price inputs included fuel taxes.

Technology Capital Costs

Capital costs were assigned to the transportation technologies that supply personal transportation services within CIMS. These capital costs are a factor in the annualized LCC calculation that is used in determining the cost output of the model. The LCC estimates are also integral to the endogenous technology competition process used to allocate market share for new cars and trucks between available technologies (this acquisition process is described in section 2.2.2). The capital costs of new passenger

9 See Jaccard and Nyboer (1997) and Nyboer (1997) for a thorough explanation of the implications of using different values for the cost variance parameter.
vehicles were carefully researched in order to make this competition process as realistic as possible. Table 2-1 below shows the capital cost assumptions for these vehicles.

Table 2-1 Capital cost assumptions for new passenger vehicles

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Capital Cost (1995$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Efficiency Gasoline</td>
<td>17,370</td>
</tr>
<tr>
<td>Low Efficiency Gasoline</td>
<td>24,520</td>
</tr>
<tr>
<td>Propane</td>
<td>26,110</td>
</tr>
<tr>
<td>Diesel</td>
<td>25,820</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>26,630</td>
</tr>
<tr>
<td>Methanol</td>
<td>26,740</td>
</tr>
<tr>
<td>Ethanol</td>
<td>26,540</td>
</tr>
<tr>
<td>Electric</td>
<td>54,610</td>
</tr>
<tr>
<td>Electric Hybrid</td>
<td>57,950</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>139,990</td>
</tr>
</tbody>
</table>

1 All cost inputs to CIMS (as well as all cost outputs from the model) are in 1995 Canadian dollars.

2 Capital cost assumptions for electric, electric hybrid, and hydrogen vehicles include an estimate of the net present value of the costs associated with battery and fuel cell replacements required by these vehicles. Battery and fuel cell replacement costs are included in the information on price premia published by the U.S. Department of Energy (1998).

The cost estimates for high and low efficiency gasoline passenger vehicles were obtained from a report documenting a transportation energy demand model for the province of Ontario (Hall, 1994). Capital costs are higher for low efficiency vehicles because many of these vehicles are high performance sport and luxury vehicles.

Capital cost estimates for non-gasoline fuelled vehicles were obtained by adding price premia to the capital cost of a conventional gasoline vehicle. These premia were

10 The cost estimates reported by Hall (1994) were converted to 1995 dollars using Canadian consumer price indices.

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derived from information provided in the model documentation report for the Transportation Sector Model of the National Energy Modeling System (NEMS TRAN) maintained by the U.S. Department of Energy (1998).

*Technology Intangible Cost Parameters*

Intangible cost parameters are used in the CIMS transportation model to adjust the capital costs of passenger vehicle technologies. These parameters allow consumer behaviour to be simulated more accurately because they represent attributes that do not affect technical-economic costs, but that do result in differences in consumers’ surplus. Intangible cost parameters associated with undesirable attributes are added to the capital cost, while those associated with desirable aspects are subtracted. Attributes associated with both efficiency level and with fuel type have been monetized for the purpose of this analysis. Intangible cost parameters are not applied to the capital costs of other modes of transportation (such as public transit and carpooling), because reliable estimates of the consumers’ surplus associated with these modes (relative to the passenger vehicle) have not been found.

The intangible cost parameters associated with different efficiency levels of new gasoline passenger vehicles are shown in Table 2-2 below.

**Table 2-2 Intangible cost parameters associated with efficiency levels**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Intangible Cost Parameter (1995$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Efficiency Gasoline Car</td>
<td>$7,020</td>
</tr>
<tr>
<td>Low Efficiency Gasoline Car</td>
<td>-$3,660</td>
</tr>
<tr>
<td>High Efficiency Gasoline Truck</td>
<td>$6,120</td>
</tr>
<tr>
<td>Low Efficiency Gasoline Truck</td>
<td>-$3,820</td>
</tr>
</tbody>
</table>

The parameters shown in Table 2-2 account for changes in vehicle performance relative to a vehicle of average efficiency. Performance was represented by horsepower in the derivation of the intangible cost parameters. High efficiency vehicles tend to have lower than average horsepower. The parameters associated with the high efficiency
vehicles are therefore positive, representing costs to the consumer that are not included in the capital costs of the vehicles. Low efficiency vehicles tend to have higher than average horsepower. The parameters associated with low efficiency vehicles are therefore negative, representing benefits to the consumer that offset the higher capital costs of these vehicles.

The dollar values shown in Table 2-2 were calculated using a relationship between horsepower and efficiency taken from the documentation report for NEMS TRAN (U.S. Department of Energy, 1998), and were calibrated in order to generate overall new passenger vehicle efficiency levels for cars and trucks matching those reported by the AMG (1999). The Inter Fuel Substitution and Demand model used by the AMG and Natural Resources Canada forecasts new passenger vehicle fuel efficiency either through exogenous estimation or through the use of an econometric equation relating past and current gasoline prices to efficiency levels (Natural Resources Canada, 1997). Because both methods rely on revealed preference (RP) information, the intangible cost parameters associated with efficiency are RP parameters.

There are also intangible cost attributes associated with fuel type. Bunch et al. (1993) have identified vehicle purchase price, fuel cost, range, fuel availability, and emissions level as the most important fuel related factors influencing vehicle choice. Purchase price and fuel cost are monetary costs that have already been incorporated into the technology competition procedure of the CIMS transportation model. With respect to emissions level, Bunch et al. state that special care must be taken in interpreting this attribute. NEMS TRAN uses all of the attributes listed by Bunch et al. to determine choice between vehicle fuel types with the exclusion of the emissions attribute. This attribute is not considered to be a significant input (U.S. Department of Energy, 1998). Likewise, emissions level is not included as an intangible cost attribute related to fuel type in the transportation component of CIMS. This leaves range and fuel availability.

The range and fuel availability attributes associated with each of the fuel types available in the CIMS transportation model have been estimated and then monetized. Range and fuel availability estimates were derived using information provided as model
documentation for NEMS TRAN (U.S. Department of Energy, 1998). Monetary values were then assigned to the various levels of range and fuel availability according to trade-off curves presented by Bunch et al. (1993). These curves were generated using a stated preference (SP) model; therefore, the intangible cost parameters associated with fuel type are SP parameters.

Table 2-3 below presents the final intangible cost parameters associated with the range and fuel availability of passenger vehicles. These parameters are added to capital costs, representing the decreased range and lower fuel availability associated with many alternative fuelled vehicles as compared to conventional gasoline vehicles.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Intangible Cost Parameter (1995$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Propane Passenger Vehicle</td>
<td>0</td>
</tr>
<tr>
<td>Diesel Passenger Vehicle</td>
<td>0</td>
</tr>
<tr>
<td>Natural Gas Passenger Vehicle</td>
<td>3,640</td>
</tr>
<tr>
<td>Methanol Passenger Vehicle</td>
<td>6,060</td>
</tr>
<tr>
<td>Ethanol Passenger Vehicle</td>
<td>2,420</td>
</tr>
<tr>
<td>Electric Passenger Vehicle</td>
<td>13,340</td>
</tr>
<tr>
<td>Electric Hybrid Passenger Vehicle</td>
<td>4,850</td>
</tr>
<tr>
<td>Hydrogen Passenger Vehicle</td>
<td>16,970</td>
</tr>
</tbody>
</table>

When the CIMS transportation model was run with the range and fuel availability intangible cost parameters as the only parameters related to fuel type, however, the results showed a penetration rate for diesel vehicles far in excess of what is known to exist in reality. The excessive penetration of these vehicles could indicate that the power function parameter is set at too low a level, causing the importance of the difference in annualized LCCs between gasoline and diesel vehicles (gasoline vehicles have lower LCCs) to be less important than it should be in the market share calculations. Another explanation for this problem is that the range and fuel availability attributes do not fully
account for the non-monetary costs associated with either diesel vehicles in particular or alternative fuels in general.

Diesel vehicles may have initially gained a high level of market share within the CIMS transportation model due to the fact that vehicle emission levels were not included as an attribute. Furthermore, the Bunch et al. study that was used to define and monetize attributes related to fuel type does not address diesel vehicles -- only “clean” alternatives to gasoline (electricity, methanol, ethanol, natural gas, and propane) were considered. Intangible cost attributes that are only relevant for diesel vehicles would therefore be missing from the study, and from the estimated intangible cost parameters.

It is also possible, however, that there are barriers associated with the purchase of any alternative to the gasoline vehicle that were not identified by Bunch et al. The authors of this study conducted a SP survey in order to investigate consumer preferences with respect to the attributes that distinguish clean fuel vehicles from conventional gasoline vehicles. The results of the survey were analysed using a nested multinomial logit model. This model included variables representing vehicle purchase price, fuel cost, range, emissions level, and fuel availability; as well as constants associated with various types of alternative fuelled vehicles. The constants account for consumer preferences not explained by model variables. While the t-statistics associated with the coefficients for the five variables were all highly significant, the constants associated with dedicated alternative fuelled vehicles (vehicles that do not have the ability to switch between different fuel types) were not significantly different from zero. These results suggested that no critical variables had been omitted from the study.

Despite these statistical results, it is still possible that an important factor distinguishing gasoline vehicles from the alternatives has been omitted. SP surveys are always open to the criticism that there is a discrepancy between how respondents say they would behave and how they actually do behave. Consumers may be less sensitive to cost risks when responding to a survey than they would be in practice. In the hypothetical context of the survey they may put aside a general preference for gasoline vehicles. Also, the survey administered by Bunch et al. supplied consumers with information on the
characteristics of hypothetical gasoline and alternative fuelled vehicles – information that could not be accessed by ordinary consumers without incurring significant transaction costs. Although both cost risks and transaction costs are partly addressed by the discount rate in this analysis, the rate chosen may not fully capture these cost elements. A general preference for gasoline vehicles, on the other hand, has not been addressed so far.

The area of intangible cost parameters associated with fuel type certainly warrants further investigation. For the purpose of this analysis; however, an additional intangible cost parameter was simply added to the capital cost of all non-gasoline passenger vehicles. This parameter was adjusted upwards until diesel fuel use was calibrated to Canada’s Emissions Outlook (AMG, 1999). Calibration was achieved once the parameter reached a value of $10,000.

Discount Rate

As part of the CIMS annualized LCC calculation, a discount rate is used to spread the initial costs of technologies (capital costs including intangible cost parameters) out over their expected lifetimes. For the purpose of this analysis, a 30% discount rate was applied to personal transportation technologies. This rate is higher than the social discount rate. A higher discount rate has been used in order to capture elements of cost risks, transaction costs, and option value.

The 30% discount rate referred to above was derived from assumptions used by the U.S. Department of Energy within the NEMS TRAN model. Within the Light Duty Vehicle Model of NEMS TRAN, the cost effectiveness of component technologies to improve fuel efficiency is determined as part of the procedure used to simulate the overall efficiency of new vehicles. In order to calculate cost effectiveness, the expected present value of fuel savings associated with each technology is added up over a four year time period using a discount rate of 8% (U.S. Department of Energy, 1998; Chien, pers. comm.). This combination of discount rate and time period was applied to the LCC calculation within the CIMS transportation model, and is equivalent to applying a
discount rate of 30% over the full life span assumed for passenger vehicles.\textsuperscript{11} The discount rate is considered to be an RP parameter in this case, because it is based on observed market behaviour with respect to time preference.

\textit{Declining Cost Function}

Within the CIMS transportation model, the up-front costs (capital costs plus intangible cost parameters) associated with emerging passenger vehicle technologies are allowed to decline with increasing market share according to a pre-specified function requiring 3 inputs: 1) current market share of the technology, 2) an estimate of the lowest cost that may ultimately be attained by the technology relative to its current cost, and 3) an estimate of the proportion of market share that must be captured before this ultimate cost is achieved. The market share that the ultimate cost is reached at is referred to as the maturity parameter.

The declining cost function is applied to all non-gasoline fuelled passenger vehicle types in the transportation component of CIMS. The costs associated with high efficiency gasoline vehicles are also allowed to decline slightly, representing improvements in vehicle performance at constant efficiency levels. Such improvements are expected to occur over time as a result of continuing technological development. Table 2-4 below shows the assumptions made with respect to the declining cost function.

\textsuperscript{11} The life span assumed for passenger vehicles within the CIMS transportation model is 16 years. This estimate was taken from Hall (1994).
Table 2-4 Declining cost function parameters

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Ultimate / Current Cost</th>
<th>Maturity Parameter (Proportion of Market Share)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Efficiency Gasoline Car</td>
<td>0.96</td>
<td>1.0</td>
</tr>
<tr>
<td>High Efficiency Gasoline Truck</td>
<td>0.97</td>
<td>1.0</td>
</tr>
<tr>
<td>Propane Passenger Vehicle</td>
<td>0.96</td>
<td>0.5</td>
</tr>
<tr>
<td>Diesel Passenger Vehicle</td>
<td>1.00</td>
<td>0.5</td>
</tr>
<tr>
<td>Natural Gas Passenger Vehicle</td>
<td>0.96</td>
<td>0.5</td>
</tr>
<tr>
<td>Methanol Passenger Vehicle</td>
<td>0.92</td>
<td>0.5</td>
</tr>
<tr>
<td>Ethanol Passenger Vehicle</td>
<td>0.92</td>
<td>0.5</td>
</tr>
<tr>
<td>Electric Passenger Vehicle</td>
<td>0.60</td>
<td>0.5</td>
</tr>
<tr>
<td>Electric Hybrid Passenger Vehicle</td>
<td>0.57</td>
<td>0.5</td>
</tr>
<tr>
<td>Hydrogen Passenger Vehicle</td>
<td>0.24</td>
<td>0.5</td>
</tr>
</tbody>
</table>

* Within CIMS, the market share captured by a technology is defined as its share of the service demand at the node it is directly connected to in the flow diagram. Therefore, a maturity parameter of 0.5 for a propane car, for example, indicates that the ultimate cost of this car will be reached when it gains 50% of the market for cars that run on “other fuels” (see node 29).

The ratios of ultimate cost to current cost for non-gasoline fuelled vehicles were estimated using ultimate capital cost assumptions reported by the U.S. Department of Energy (1998). The ratios for high efficiency gasoline vehicles were set at reasonable levels so as to achieve calibration over time to the overall new passenger vehicle efficiency levels for cars and trucks reported in Canada’s Emissions Outlook (AMG, 1999).12 The maturity parameter was set to its default value of 0.5 for the non-gasoline-

12 Although the costs associated with high efficiency vehicles were allowed to decline in order to achieve calibration to the Outlook, this approach may be criticized as it encourages increased efficiency over time. Alson et al. (1996) point out that, in the past, transportation energy demand models have tended to over predict future vehicle fuel economy.
fuelled vehicles. This parameter was adjusted up to 1, however, for the high efficiency gasoline cars and trucks, because these are not emerging technologies.

In order to demonstrate how assigning different values to the declining cost function parameters affects costs as market shares increase, the function is plotted for high efficiency gasoline cars and electric passenger vehicles in Figures 2-4 and 2-5 respectively.

**Figure 2-4 Declining cost of high efficiency gasoline cars with increasing market share**

![Graph showing declining cost of high efficiency gasoline cars](image)

High efficiency gasoline cars have been assigned an ultimate to current cost ratio of 0.96 and a maturity parameter of 1. Figure 2-4 shows how capital cost (including the intangible cost parameter) will decline from a current value of $24,390 to an ultimate value of 23,410 with increasing market share according to these parameters. The graph appears almost flat because cost is falling only slightly (does not fall below 96% of current cost) over the entire range between 0% market share and 100% market share. The declining cost function is not meant to have too large of an impact on the cost of high efficiency vehicles because these are not emerging technologies.
Electric vehicles have been assigned an ultimate to current cost ratio of 0.60 and a maturity parameter of 0.5. Figure 2-5 shows how capital cost (including the intangible cost parameter) will decline from a current value of $88,860 to an ultimate value of $53,320 with increasing market share according to these parameters. The graph falls relatively steeply for electric vehicles because their costs decline substantially (to only 60% of what they were before) by the time they gain 50% of the market. The declining cost function significantly impacts the cost of electric vehicles because these are emerging technologies.

Although the best available estimates with respect to declining costs have been used in this study, the costs associated with non-gasoline fuelled vehicles may decline faster than anticipated. Initiatives to reduce vehicle emissions in the U.S. (at the federal level, as well as within the state of California) should expand the market for clean-fuelled vehicles, potentially reducing costs. Furthermore, government investment may increasingly favor fuel switching over efficiency improvements due to concerns about the so-called “rebound” effect. Under this effect, increased efficiency levels would lead to a growth in transportation activity due to decreased fuel costs (Greene, 1992; Jones, 1993).
Furthermore, some analysts have proposed very sharp cost decreases under the argument that the market for passenger vehicles will be completely transformed upon the introduction of one or a few alternative fuelled vehicle technologies, “flipping” away from gasoline vehicles and towards these more innovative options. If such a transformation were to occur, costs would fall to much lower levels at smaller market shares.

*Technology Fuel Efficiencies*

In order for the CIMS transportation model to generate fuel consumption output, each of the technologies in the model must be assigned a fuel efficiency. The efficiency estimates associated with new passenger vehicle technologies are especially important because these technologies are acquired endogenously on the basis of annualized LCCs. Efficiency influences fuel costs, that, in turn, have an impact on annualized LCCs. The fuel efficiency assumptions for new passenger vehicles are shown in Table 2-5 below. Estimates are expressed in common units (GJ of fuel consumed per vehicle kilometre travelled) to facilitate comparison between vehicle types.
### Table 2-5 New passenger vehicle fuel efficiency

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Fuel Efficiency (GJ/vkt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Efficiency Gasoline Car</td>
<td>0.0017</td>
</tr>
<tr>
<td>Low Efficiency Gasoline Car</td>
<td>0.0052</td>
</tr>
<tr>
<td>High Efficiency Gasoline Truck</td>
<td>0.0029</td>
</tr>
<tr>
<td>Low Efficiency Gasoline Truck</td>
<td>0.0064</td>
</tr>
<tr>
<td>Propane Car</td>
<td>0.0022</td>
</tr>
<tr>
<td>Propane Truck</td>
<td>0.0030</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>0.0032</td>
</tr>
<tr>
<td>Diesel Truck</td>
<td>0.0044</td>
</tr>
<tr>
<td>Natural Gas Car</td>
<td>0.0039</td>
</tr>
<tr>
<td>Natural Gas Truck</td>
<td>0.0054</td>
</tr>
<tr>
<td>Methanol Car(^1)</td>
<td>0.0033</td>
</tr>
<tr>
<td>Methanol Truck</td>
<td>0.0046</td>
</tr>
<tr>
<td>Ethanol Car</td>
<td>0.0047</td>
</tr>
<tr>
<td>Ethanol Truck</td>
<td>0.0065</td>
</tr>
<tr>
<td>Electric Car</td>
<td>0.0013</td>
</tr>
<tr>
<td>Electric Truck</td>
<td>0.0018</td>
</tr>
<tr>
<td>Electric Hybrid Car(^2)</td>
<td>0.0026</td>
</tr>
<tr>
<td>Electric Hybrid Truck</td>
<td>0.0036</td>
</tr>
<tr>
<td>Hydrogen Car</td>
<td>0.0035</td>
</tr>
<tr>
<td>Hydrogen Truck</td>
<td>0.0049</td>
</tr>
</tbody>
</table>

\(^1\) Note that methanol and ethanol vehicles are consuming GJ of a blended fuel comprised of 85% alcohol to 15% gasoline.

\(^2\) Note that electric hybrid vehicles are consuming GJ of gasoline, not electricity.

Fuel efficiency assumptions for the high and low efficiency gasoline vehicles were chosen so as to encompass a normal range of efficiency for these vehicles. Efficiency estimates for all other vehicle categories were derived according to a two step process. First, information provided in the model documentation report for NEMS TRAN
(U.S. Department of Energy, 1998) was used to calculate the relative efficiency of each vehicle type relative to a gasoline vehicle. These coefficients were then applied to the average new gasoline car and truck efficiencies for 1995 provided by Natural Resources Canada (1997). Additional information from the Electric Vehicle Association of Canada (1998) was used to generate an efficiency figure for hybrid electric vehicles.

**CO₂ End Use Emission Factors**

A CO₂ emission factor was required for each type of fuel consumed within the CIMS transportation model in order to calculate overall end use emissions for the sector. These emission factors are shown in Table 2-6 below.

With the exception of the ethanol emission factor, all of the factors reported in Table 2-6 refer to end use emissions. The emission factor reported for ethanol is a full cycle emission factor. Only by using a full cycle emission factor is it possible to represent the advantage of ethanol as a biomass fuel. About 95% of the ethanol fuel produced in the U.S. is derived from corn (U.S. Department of Energy, 1998). Because corn absorbs carbon from the atmosphere during its growing stage, net CO₂ emissions associated with the use of corn derived ethanol have been estimated to be zero (Environmental Protection Agency, 1990).

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13 It is also possible to derive methanol from biomass sources; however, methanol was not considered to be a biomass fuel for the purpose of this analysis, because natural gas is currently its primary source (U.S. Department of Energy, 1998).
Table 2-6 CO₂ end use emission factors by fuel type

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>End Use Emission Factor (tonnes CO₂/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0.0681</td>
</tr>
<tr>
<td>LPG (Propane)</td>
<td>0.0599</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.0706</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.0487</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.0394</td>
</tr>
<tr>
<td>Ethanol*</td>
<td>0.0000</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.0000</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.0000</td>
</tr>
<tr>
<td>Aviation Turbo Fuel</td>
<td>0.0710</td>
</tr>
<tr>
<td>Marine Heavy Fuel Oil</td>
<td>0.0740</td>
</tr>
</tbody>
</table>

* The emission factor reported for ethanol is actually a full cycle emission factor.

The CO₂ emission factor for methanol was derived using information from the Energy Information Administration (EIA, 1994; EIA, website). Electricity and hydrogen were assigned emission factors of zero, because these fuels do not result in any CO₂ emissions at the point of end use. For all of the other fuels, end use emission factors were supplied by the AMG.

2.3 Analysis of Measures

The CIMS transportation model has been used to analyse a range of measures aimed at reducing GHG emissions from the Canadian transportation sector. This section addresses the Business-as-Usual scenario that is used as a comparison for evaluation, defines two types of emission reductions that are reported for the measures, provides a discussion of several means of accounting for the costs of GHG reduction measures, and explains how expected resource cost estimates were calculated in this analysis.
2.3.1 Business-as-Usual Forecast

The effects of measures were determined relative to a Business-as-Usual (BAU) case where no action is taken to mitigate GHG emissions. The transportation component of CIMS generates its BAU forecast when the input assumptions are as described in section 2.2.3. All of the measures addressed by this study result in a decrease in CO₂ relative to BAU. For some measures, there is a net cost associated with this decrease, while for others a net benefit is the result. If the total cost of supplying transportation services under a given measure is higher than in the BAU case, a net cost is assigned to the measure; while if the opposite is true, a net benefit is reported.

2.3.2 Emission Reductions

Two categories of emission reductions are addressed in this report: direct emission reductions and total emission reductions. Direct CO₂ emission forecasts are generated within the transportation component of CIMS according to the end use emission factors shown in Table 2.6. Direct emission reductions are determined by comparing the direct emissions associated with a measure to direct emissions under BAU assumptions.

In some cases, a measure will result in a reduction in direct emissions accompanied by an increase in electricity use. This is the case for measures that promote the use of cars, buses, and rapid transit services powered by electricity. Electricity may be generated using hydropower, or by burning fossil fuels. The latter option results in GHG emissions. Therefore, when the demand for electricity increases as a result of a measure, emission factors are applied to that increase. These emission factors are based on the method used to make up the difference between BAU electricity demand and the increased level of demand under the measure -- or marginal demand. For example, if hydroelectricity was used to meet marginal demand, the emission factor would be zero, while a relatively high emission factor would be applied if diesel fuel was burnt to produce the electricity. Resulting emissions are referred to as indirect emissions. If electricity use decreases as a result of a measure, the same emission factors are applied to determine the indirect emission reduction associated with that measure.
Table 2-7 presents, by province and by forecast year, the CO₂ emission factors associated with marginal electricity demand. The sources used to generate marginal electricity are also shown.

**Table 2-7 CO₂ emission factors for and sources of marginal electricity demand (tonnes CO₂/GJ electricity)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
<td>0.0993 (natural gas)</td>
</tr>
<tr>
<td>Alberta</td>
<td>0.1505 (natural gas)</td>
<td>0.1505 (natural gas)</td>
<td>0.1505 (natural gas)</td>
<td>0.0993 (natural gas)</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>0.1505 (natural gas)</td>
<td>0.1505 (natural gas)</td>
<td>0.1505 (natural gas)</td>
<td>0.0993 (natural gas)</td>
</tr>
<tr>
<td>Manitoba</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
</tr>
<tr>
<td>Ontario</td>
<td>0.1505 (natural gas)</td>
<td>0.1505 (natural gas)</td>
<td>0.1505 (natural gas)</td>
<td>0.0993 (natural gas)</td>
</tr>
<tr>
<td>Quebec</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
<td>0.0000 (hydro)</td>
</tr>
<tr>
<td>Atlantic</td>
<td>0.1393 (NA)</td>
<td>0.1393 (NA)</td>
<td>0.1393 (NA)</td>
<td>0.0701 (NA)</td>
</tr>
</tbody>
</table>

The information in table 2-7 was provided by the AMG. The marginal emission factors supplied for the Atlantic provinces were aggregated using a weighted average based on electricity consumption in each province (across all sectors). Electricity consumption estimates were taken from AMG (1999) forecasts.

Total emission reductions are calculated by subtracting the indirect emissions associated with a measure from the direct emission reductions achieved. If indirect emissions are reduced as a result of a measure, this reduction is added to the direct

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14 The AMG provided forecasts of the marginal fuel displaced by lower electricity demand and gave the CO₂ conversion factors associated with each fuel. For the purpose of this study, that information was applied to both lower and higher levels of demand for electricity compared to BAU.
emission reduction. Total CO₂ emission reductions therefore take into account emissions resulting from marginal electricity generation.

2.3.3 Costs and Benefits

The raw cost output of the CIMS transportation model is basically a representation of the perceived private costs associated with meeting the demand for personal transportation services under a given simulation. (Although some perceived costs are missing, such as the intangible costs associated with transit technologies and carpooling, as well as those incurred when overall levels of transportation activity are reduced.) By comparing the cost output obtained when simulating a measure with that obtained under BAU assumptions, it is therefore possible to estimate the net cost or benefit of the measure in terms of perceived private costs.

There are however, other means of accounting for costs. Expected resource costs represent the expected financial flows within society as a whole that are associated with a measure. These costs include technical-economic costs, as well as government infrastructure and administration costs. Transfers are excluded. Certain intangible costs must also be included in an account of expected resource costs. Cost risks, transaction costs, option value, and attribute specific intangibles all contain an element of expected resource costs; however, a portion of these costs are not associated with financial flows and are not real resource costs.

Cost risks and transaction costs are higher with technologies that are new on the market, and these are real resource costs. Yet, a portion of the risk and transaction costs perceived by the consumer are not real resource costs because consumers may have a tendency to overestimate these intangibles. To the extent that option value is a response to a real risk of change in the future, this is a real resource cost as well. Again, any overestimation of this risk does not translate into a real resource cost. Finally, the intangible costs associated with technology specific attributes may be attached to real resource costs such as time costs, or they may simply represent a perceived difference in the quality of service derived from one attribute as compared to another.
Costs may also be accounted for in terms of social welfare costs. Social welfare costs are equivalent to expected resource costs, except that all changes in consumers’ surplus are accounted for. This means that all intangible costs associated with technology specific attributes are included, even those that have no link to real resource costs.

An expected resource cost account has been used for the purpose of this analysis to express the costs associated with various GHG mitigation measures. Accounting for costs in this way is a necessary first step in the policy evaluation process. Expected resource costs provide a good indication of whether or not measures are attractive financially, and are generally required as a starting point for further macroeconomic analysis.

Because the CIMS transportation model produces output in the form of perceived private costs, however, accounting for expected resource costs required some modification of raw cost output. In order to generate resource costs estimates, transfers (including all fuel taxes and changes in capital costs due to feebate schemes) were excluded, the discount rate applied to personal transportation technologies was lowered to 20%, the intangible cost parameters associated with efficiency levels were removed, and the intangible cost parameter of $10,000 associated with all non-gasoline passenger vehicles was halved. Note that these changes only apply to the reporting of costs. All of the simulations were still run using the input assumptions described in section 2.2.3.

In lowering the discount rate to 20%, it was assumed that the 30% discount rate used during the simulations may be broken down as follows: 1/3 representing the social discount rate (a technical-economic cost and therefore a real resource cost); 1/3 attributable to the real resource cost portion of cost risks, transaction costs, and option value; and 1/3 attributable to the overestimation of these risk and cost factors by the consumer. Because the last component of the discount rate is not a real resource cost, it is removed, leaving only a 20% discount rate.

The intangible cost parameters associated with efficiency levels were also removed. These parameters represent losses or gains in performance relative to a hypothetical vehicle of average efficiency. Because the change in consumers’ surplus that
results from a change in vehicle performance does not translate into any kind of financial flow, the efficiency parameters do not have resource cost implications. Consumers simply perceive a difference in service quality. The intangible cost parameters associated with range and fuel availability were not removed for the purpose of cost accounting, however. This is because a loss of range or fuel availability results in a loss of time, and this is a real resource cost. Owners of vehicles with low range must refuel more often, while owners of vehicles that use low availability fuels must spend more time searching for refuelling stations.

The intangible cost parameter of $10,000 associated with all non-gasoline passenger vehicles was added to achieve calibration. This parameter represents all of the intangible costs that may apply to non-gasoline vehicles and that are not encompassed by the 30% discount rate or by the range and fuel availability parameters: cost risks and transaction costs (these are at least partially accounted for by the discount rate), as well as a general preference for gasoline vehicles. It was assumed that 50% of this parameter represented the real resource cost portion of cost risks and transaction costs, plus any portion of the consumers’ surplus associated with gasoline vehicles that is attributable to a financial flow (such as an extra time cost associated with alternative fuelled vehicles). The other 50% would therefore represent the overestimation of risk and cost factors by consumers, as well as the portion of the consumers’ surplus associated with gasoline vehicles that has no link to financial flows. This latter portion was removed from the cost output for reporting purposes.

Once the raw cost output of the CIMS transportation model was modified in order to remove costs that are not real resource costs, the net cost or benefit associated with a measure was estimated by comparing the total (adjusted) cost of supplying transportation services under that measure with the total (adjusted) cost under BAU assumptions.

The intent of this costing methodology was to represent expected resource costs, however, there are certain resource cost elements that are missing from the results. The net cost or benefit associated with a measure does not include infrastructure and administration costs. Intangible cost parameters have not been assigned to transit
technologies or to carpooling within the CIMS transportation model. There are also no intangible cost estimates associated with reduced levels of activity within the sector. Any portion of these intangible costs that corresponds to a real resource cost is therefore missing from the reported costs.

Other types of costs that are not incorporated into the results presented in this report include impacts due to macroeconomic changes in employment levels or degree of economic activity. Benefits due to reduced emission levels (such as slowing of climate change and improved air quality) are not calculated either. Because the cost output of the transportation model does not include the cost of meeting the demand for freight transportation services, net costs and benefits are calculated for personal transportation sector measures only.

2.4 Measures Tested

The CIMS transportation model was used to evaluate twelve measures aimed at reducing GHG emissions from the Canadian transportation sector. A variety of sources were relied upon to aid in the process of defining these measures: BC Greenhouse Gas Forum (1998), City of Vancouver (1996), Compass Resource Management and ERG / M.K. Jaccard and Associates (1998), David Suzuki Foundation and Pembina Institute (1998), ERG (1998), Hughes (1991), Jaccard et al. (1997), Michaelis and Davidson (1996), and Scholl et al. (1996). Additional, unpublished information was also provided by the Transportation Sub-Committee of the BC Greenhouse Gas Forum and the Energy Policy Branch of Ontario. The final selection of measures includes those that were most commonly identified in the relevant literature. The degree of stringency associated with each measure was set so as to make the measure as ambitious as possible given current political constraints as well as constraints inherent to the measure itself.

The following sections describe the action and policy component of each of the twelve measures tested. Nine of these measures address the personal transportation sector, while three address the freight transportation sector. The emphasis, in terms of both number of measures and associated magnitude of change, is clearly on the personal
transportation sector. This bias is generally reflected in the sources cited above; the personal transportation sector tends to be perceived as more flexible and less closely tied to a healthy economy.

2.4.1 Personal Transportation Sector Measures

Nine measures were applied to the personal transportation sector for the purpose of this study. The first eight are individual measures assumed to occur independently of each other. The final measure was designed in order to show the effect of several individual sub-measures packaged together. The measures are described in Tables 2-8 and 2-9 below.
<table>
<thead>
<tr>
<th>Measure 1</th>
<th>Efficiency Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy</strong></td>
<td>An efficiency standard is used to improve new passenger vehicle fuel efficiency. The standard requires the average fuel efficiency of new cars to be 7.0L/100km in 2005, 6.0 in 2010, and 5.0 in 2015. The average fuel efficiency of new trucks is required to be 10.5L/100km in 2005, 9.5 in 2010, and 8.5 in 2015.</td>
</tr>
<tr>
<td><strong>Action</strong></td>
<td>Compliance with the standard.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measure 2</th>
<th>Efficiency Feebate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy</strong></td>
<td>New cars and trucks are divided into 3 efficiency categories -- high, medium, and low. High efficiency vehicles are awarded a rebate of 7% of the capital cost of the vehicle at the time of purchase. A fee of 7% is applied to the capital cost of low efficiency vehicles. There is no change in price for medium efficiency vehicles.</td>
</tr>
<tr>
<td><strong>Action</strong></td>
<td>Determined internally to the CIMS transportation model.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measure 3</th>
<th>Fuel Switching Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy</strong></td>
<td>A fuel switching standard is used to achieve greater penetration of zero emission passenger vehicles (electric and hydrogen vehicles). Under this standard, the percentage of new cars and trucks having zero emissions is required to be as follows: 5% in 2005, 10% in 2010, and 20% in 2015.</td>
</tr>
<tr>
<td><strong>Action</strong></td>
<td>Compliance with the standard.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measure 4</th>
<th>Fuel Switching Feebate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy</strong></td>
<td>A fee or rebate is applied to purchases of new cars and passenger trucks based on the average amount of CO₂ emitted per km travelled for that fuel type. This program results in a fee of 10% of the capital cost for gasoline and diesel vehicles, and 5% for natural gas and electric hybrid vehicles. There is no change in the price of propane and methanol vehicles. A rebate of 5% of the capital cost is awarded to ethanol vehicles, while the rebate for hydrogen vehicles is 10%. The fee or rebate applied to electric vehicles ranges between a 10%</td>
</tr>
</tbody>
</table>

---

15 Electric and hydrogen vehicles are referred to as zero emission vehicles because the emissions associated with batteries and fuel cells are negligible. Hybrid electric vehicles are not included in this category.
fee and a 10% rebate depending on the emissions associated with electricity generation in the province in question.\textsuperscript{16}

**Action**
Determined internally to the CIMS transportation model.

**Measure 5 Program to Encourage Public Transit Use**

**Policy**
Within each province, a policy program is designed and implemented to achieve a mode switch from passenger vehicles to public transit. Elements of these programs may include the following: enhanced bus and rapid transit service and infrastructure, the designation of transit only lanes, policies to encourage development along transit corridors, the subsidization of transit fares, information and education, the restructuring of parking charges, the use of road pricing (tolls) to discourage private vehicle use, and pay-per-use vehicle insurance.

**Action**
Within urban areas, between the years 2000 and 2015, the passenger vehicle share of passenger kilometres travelled (pkt) decreases 1.5% per year. Corresponding increases of 1% in the bus share of pkt and 0.5% in the rapid transit modal share occur.\textsuperscript{17}

**Measure 6 Program to Encourage HOV Use**

**Policy**
Within each province, a policy program is designed and implemented to achieve higher load factors for passenger vehicles in urban areas. Elements of these programs may include the following: initiatives to facilitate and promote carpooling, the restructuring of parking charges, the designation of high occupancy vehicle (HOV) lanes, and the use of road pricing / tolls to discourage single occupant vehicle (SOV) use.

**Action**
Within urban areas, between the years 2000 and 2015, the SOV share of pkt decreases 1.5% per year. There is a corresponding increase in the HOV share.

**Measure 7 Program to Reduce Urban Activity**

**Policy**
Within each province, a policy program is designed and implemented to reduce personal transportation sector activity in urban areas.

\textsuperscript{16} The level of the fee or rebate applied to electric vehicles was based on the average emissions associated with generating one unit of electric energy in each province in the base year. This information was provided by the Energy Research Group (ERG). The methodology must be distinguished from that used to determine indirect emissions. Indirect emissions are based on the emissions associated with marginal electricity generation. Average emissions are used here because charges for electricity use are usually based on average costs rather than marginal costs.

\textsuperscript{17} In provinces where rapid transit is unavailable, an annual increase of 1.5% occurs in the bus share of pkt.
Elements of these programs may include the following: the promotion of telecommuting, mandatory trip reduction bylaws for large employers, the restructuring of parking charges, the use of road pricing / tolls to reduce demand, pay-per-use vehicle insurance, and the use of development standards and incentives to increase land use density and use mix.

<table>
<thead>
<tr>
<th>Action</th>
<th>Personal transportation sector activity within urban areas is reduced by 5% in 2005, 10% in 2010, and 15% in 2015 from BAU.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure 8</td>
<td><strong>CO₂ Tax</strong></td>
</tr>
<tr>
<td>Policy</td>
<td>A CO₂ tax of 120 $/tonne CO₂ is applied to fuel purchases within the personal transportation sector from the year 2000 on.¹⁸ (This tax results in about a 50% increase in the price of gasoline relative to BAU.)</td>
</tr>
<tr>
<td>Action</td>
<td>There is a decrease from BAU in the distance travelled by cars and light trucks of 2.5% in the year 2000, rising to 10% in 2015.¹⁹</td>
</tr>
</tbody>
</table>

¹⁸ The tax is applied according to the emission factors shown in Table 2-6. Electricity consumption is also taxed based on the _average_ emissions associated with generating one unit of electric energy in each province in the year in question. This information was provided by ERG. The methodology must be distinguished from that used to determine indirect emissions. Indirect emissions are based on the emissions associated with _marginal_ electricity generation. Average emissions are used here because charges for electricity use are usually based on average costs rather than marginal costs.

¹⁹ Decreased levels of travel in the event of a CO₂ tax were calculated by applying fuel price elasticities of demand for light duty vehicle (LDV) travel to the 50% increase in the price of gasoline. A short run elasticity of -0.05 and a long run elasticity of -0.2 were used. These elasticity estimates were obtained from the U.S. Department of Energy (Chien, pers. comm.). The short run elasticity was applied immediately (in the year 2000). Travel demand was then reduced incrementally until the year 2015 when the long run elasticity was applied. (The 16-year period starting in the year 2000 and ending in the year 2015 represents the lifetime of a passenger vehicle.) The following two equations show how the short run and long run elasticity estimates used correspond to the assumed percentage changes.

\[
\text{ShortRunElasticity} = \frac{\%\Delta LDVTravel}{\%\Delta Fuel \ Price} = \frac{-2.5}{50} = -0.05
\]

\[
\text{LongRunElasticity} = \frac{\%\Delta LDVTravel}{\%\Delta Fuel \ Price} = \frac{-10}{50} = -0.2
\]

It is assumed that the reduction in distance travelled by passenger vehicles is not replaced through the use of other modes such as public transit.
Passenger vehicle efficiency and fuel switching effects are determined internally to the CIMS transportation model.
Table 2-9 Measures Package applied to the personal transportation sector

<table>
<thead>
<tr>
<th>Measure 9</th>
<th>Measures Package</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sub-Measure 1</strong></td>
<td>Efficiency Feebate</td>
</tr>
<tr>
<td><strong>Policy / Action</strong></td>
<td>As described under measure 2.</td>
</tr>
<tr>
<td><strong>Sub-Measure 2</strong></td>
<td>Fuel Switching Standard</td>
</tr>
<tr>
<td><strong>Policy / Action</strong></td>
<td>As described under measure 3.</td>
</tr>
<tr>
<td><strong>Sub-Measure 3</strong></td>
<td>CO₂ Tax</td>
</tr>
<tr>
<td><strong>Policy / Action</strong></td>
<td>As described under measure 8.</td>
</tr>
<tr>
<td><strong>Sub-Measure 4</strong></td>
<td>Integrated Strategy for Urban Transportation Management</td>
</tr>
<tr>
<td><strong>Policy</strong></td>
<td>The Program to Encourage Public Transit Use (see measure 5), the Program to Encourage HOV Use (see measure 6), and the Program to Reduce Urban Activity (see measure 7) are combined into an Integrated Strategy for Urban Transportation Management. The three programs are combined because they incorporate many of the same elements.</td>
</tr>
<tr>
<td><strong>Actions²⁰, ²¹</strong></td>
<td>Within urban areas, between the years 2000 and 2015, the passenger vehicle share of pkt decreases 1% per year. Corresponding increases in the bus and rapid transit modal shares occur. Within urban areas, between the years 2000 and 2015, the SOV share of pkt decreases 1% per year. There is a corresponding increase in the HOV share. Personal transportation sector activity within urban areas is reduced by 2.5% in 2005, 5% in 2010, and 7.5% in 2015.</td>
</tr>
</tbody>
</table>

²⁰ The effect of the CO₂ tax on modal shares and activity levels was taken into account prior to the application of these changes.

²¹ These actions are modified versions of the actions associated with the component programs. The actions associated with the Integrated Strategy are smaller than those associated with the individual measures. This adjustment was made to account for the overlapping effects of the three programs, as well as the CO₂ Tax.
2.4.2 Freight Transportation Sector Measures

The three measures that were applied to the freight transportation sector are described in Table 2-10 below. All of the freight transportation sector measures are assumed to occur independently of other measures.

Table 2-10 Measures applied to the freight transportation sector

<table>
<thead>
<tr>
<th>Measure 1</th>
<th>Incentive Program for Road Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy</td>
<td>A voluntary incentive program with industry is initiated to improve the efficiency of road freight vehicles.</td>
</tr>
</tbody>
</table>
| Action        | The efficiency of road freight vehicles improves such that, by the year 2000, the average fuel efficiency of new light/medium diesel trucks is 18.5 L/100km and the average fuel efficiency of new heavy diesel trucks is 35.0 L/100km.  

<table>
<thead>
<tr>
<th>Measure 2</th>
<th>Incentive Program to Encourage Rail Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy</td>
<td>A voluntary incentive program with industry is initiated to encourage a mode switch from road freight transport to rail freight transport.</td>
</tr>
<tr>
<td>Action</td>
<td>The number of freight tonne kilometres travelled (tkt) by road decreases to 15% below BAU over the period from 2000 to 2015. These tkts are transported by rail instead.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measure 3</th>
<th>Diesel Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy</td>
<td>A new tax is implemented that causes a 25% increase in the price of diesel relative to BAU from the year 2000 on.</td>
</tr>
</tbody>
</table>
| Action        | This price change results in a decrease from BAU in freight tkt of 0.2% in the year 2000, rising to 3.2% in 2015.  

---

22 Under BAU assumptions, the average fuel efficiency of new light/medium diesel trucks in the year 2000 is 21.1 L/100km. The corresponding efficiency for heavy diesel trucks is 40.0 L/100km.

23 The assumptions regarding decreased freight tkt in the event of a diesel tax were calculated by applying a long run diesel price elasticity of freight movement in North America of -0.21 to the 25% increase in the price of diesel. This elasticity estimate was reported by Michaelis and Davidson (1996). (The estimate was made using the International Energy Agency (IEA) world energy model.) Application of the elasticity estimate would result in a long run decrease in freight movement of 5.25% as shown by the equation below.
3. Results and Discussion

3.1 Business-as-Usual CO₂ Emissions

The CO₂ emission levels forecast using the Canadian Integrated Modelling System (CIMS) transportation model in the Business-as-Usual (BAU) case are shown in Table 3-1 below. The table also compares these results to forecasts provided in Canada’s Emissions Outlook: An Update (CEOU) (AMG, 1999). The two sets of results are very close because fuel consumption within CIMS was calibrated to the Outlook (see Appendix A).

Table 3-1 Business-as-Usual CO₂ emissions (kt) for the Canadian transportation sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CEOU</td>
<td>168,000</td>
<td>178,000</td>
<td>189,000</td>
<td>204,000</td>
</tr>
<tr>
<td>CIMS</td>
<td>170,425</td>
<td>178,553</td>
<td>190,628</td>
<td>206,514</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>-1.4%</td>
<td>-0.3%</td>
<td>-0.9%</td>
<td>-1.2%</td>
</tr>
</tbody>
</table>

3.2 Annual CO₂ Emission Reductions

Annual CO₂ emission reductions are presented for the nine measures affecting personal transportation as well as the three measures affecting freight transportation.²⁴

The long run is assumed to be 25 years in this case. A 5.25% decrease over 25 years works out to about a 0.2% decrease per year. Because the diesel tax begins to take effect in the year 2000, the decrease in freight movement is 3.2% by the year 2015. Although the IEA elasticity estimate used here may represent a scenario where both mode switching and demand reduction are allowed to occur, the estimate is being applied to the CIMS transportation model with freight mode shares held constant.

²⁴ The changes in fuel consumption that are associated with the measures are not presented as part of the results, given that the focus of this study is on emissions. Appendix B, however, provides the interested reader with fuel use changes associated with the Measures Package in 2010 (relative to BAU).
Emission reductions are calculated relative to the CIMS BAU emissions shown in Table 3-1 above. Emission reductions are reported on an annual rather than a cumulative basis: they refer to the CO₂ emission reduction in the forecast year indicated not the cumulative reduction from the present up until that year. The following sections present the direct emission reductions, the indirect emissions, and the total emission reductions associated with each of the measures addressed in this study.

Each measure is simulated by itself, assuming the others do not occur. One cannot sum the emission reductions associated with individual measures because they are interdependent. For example, the effect of a fuel switching standard depends on the fuel efficiency of the existing fleet, and this, in turn, would be affected by an efficiency standard. The Measures Package provides an estimate of emission reductions that may be achieved by combining measures.

The magnitude of the emission reduction reported for a given measure is not necessarily indicative of the relative merit of that measure. This is because the reported reductions are a function of the degree of stringency assigned to each measure as part of this modelling exercise. Although the measures have been carefully defined in order to be as realistic and as instructive as possible, they do not necessarily represent the true extent of what could be achieved using a given approach. For example, the Efficiency Standard might have required higher levels of efficiency. Had that been the case, the emission reductions associated with this measure would have been larger.

### 3.2.1 Direct Emission Reductions

CO₂ emission reductions resulting from a decrease in fossil fuel use associated with a given measure are defined as direct emission reductions. Direct CO₂ emission reductions for the measures affecting the personal transportation sector are shown in Table 3-2 below. Direct emission reductions for the freight transportation sector are not shown. As there are no indirect emissions associated with the freight transportation measures analysed, direct emission reductions are equal to total emission reductions for
this sector. Total emission reductions for the both personal and freight transportation sector measures are presented in section 3.2.3.

Table 3-2 Direct CO₂ emission reductions (kt) for the Canadian personal transportation sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency Standard</td>
<td>0</td>
<td>5,176</td>
<td>11,417</td>
<td>20,891</td>
</tr>
<tr>
<td>Efficiency Feebate</td>
<td>5,927</td>
<td>11,287</td>
<td>15,288</td>
<td>17,803</td>
</tr>
<tr>
<td>Fuel Switching Standard</td>
<td>0</td>
<td>1,583</td>
<td>4,114</td>
<td>9,003</td>
</tr>
<tr>
<td>Fuel Switching Feebate</td>
<td>1,464</td>
<td>2,907</td>
<td>3,980</td>
<td>4,709</td>
</tr>
<tr>
<td>Program to Encourage Public Transit Use</td>
<td>0</td>
<td>1,657</td>
<td>3,443</td>
<td>5,721</td>
</tr>
<tr>
<td>Program to Encourage HOV Use</td>
<td>0</td>
<td>3,591</td>
<td>7,631</td>
<td>12,640</td>
</tr>
<tr>
<td>Program to Reduce Urban Activity</td>
<td>0</td>
<td>2,332</td>
<td>4,962</td>
<td>8,219</td>
</tr>
<tr>
<td>CO₂ Tax</td>
<td>5,480</td>
<td>10,823</td>
<td>15,697</td>
<td>20,165</td>
</tr>
<tr>
<td>Measures Package</td>
<td>9,809</td>
<td>23,452</td>
<td>34,948</td>
<td>45,874</td>
</tr>
</tbody>
</table>

3.2.2 Indirect Emissions

CO₂ emissions attributed to electricity use are referred to as indirect emissions. Indirect emissions for the measures affecting the personal transportation sector are shown in Table 3-3 below (only those measures resulting in changes in indirect emissions are shown). Negative numbers indicate increases in indirect emissions, while positive numbers indicate decreases. Indirect emissions have been calculated on an annual basis relative to BAU. The three measures affecting the freight transportation sector do not result in any indirect emissions, as these measures do not cause any substitution of electricity for fossil fuels.
Table 3-3 Indirect CO₂ emissions (kt) for the Canadian personal transportation sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Switching Standard</td>
<td>0</td>
<td>-484</td>
<td>-1,283</td>
<td>-2,125</td>
</tr>
<tr>
<td>Program to Encourage Public Transit Use</td>
<td>0</td>
<td>-332</td>
<td>-724</td>
<td>-986</td>
</tr>
<tr>
<td>Program to Reduce Urban Activity</td>
<td>0</td>
<td>12</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td>Measures Package</td>
<td>0</td>
<td>-657</td>
<td>-1,418</td>
<td>-1,963</td>
</tr>
</tbody>
</table>

The Fuel Switching Standard results in a large increase in indirect emissions because this measure requires the purchase of more electric powered passenger vehicles. The Program to Encourage Public Transit Use causes a switch from passenger vehicles to public transit. Because some public transit is fuelled by electricity (trolley buses and rapid transit), this measure also results in an increase in indirect emissions. As the Measures Package incorporates both of the measures noted above, this measure too causes indirect emissions to increase.

Indirect emissions are also associated with the Fuel Switching Feebate; however, these emission levels are so small that they would round to zero if shown in Table 3-3. The low indirect emissions resulting from this measure indicate that only a very small increase in purchases of electric fuelled vehicles is anticipated. Although the Fuel Switching Feebate acts to promote alternatives to gasoline and diesel passenger vehicles, other alternatives such as propane, natural gas, methanol, and ethanol remain much cheaper than the electric vehicles following the application of the Feebate. In provinces where CO₂ emissions are associated with electricity generation, the program actually leads to an increase in the capital cost of electric powered vehicles.

The CO₂ Tax also results in levels of indirect emissions too small to show up in Table 3-3. Again, this is due to the fact that the market share captured by electric passenger vehicles increases only slightly under this measure. Despite changes in fuel
prices, most consumers continue to avoid electric powered vehicles due to their prohibitively high capital costs. Furthermore, the tax will cause the cost of electricity to increase in provinces where emissions are associated with generation.

The Program to Reduce Urban Activity results in a small decrease in indirect emissions. With this measure comes a decrease in all forms of urban transportation including public transit. Because some public transit vehicles are powered by electricity, the indirect emissions associated with electricity use decline under this measure.

### 3.2.3 Total Emission Reductions

Total emission reductions represent the emission reductions achieved once emissions associated with electricity generation are taken into account. Total emission reductions are calculated by subtracting the indirect emissions associated with a measure from the direct emission reductions achieved. Total CO₂ emission reductions are shown below in Table 3-4 for personal transportation and in Table 3-5 for freight transportation. Figures 3-1, 3-2, and 3-3 show the results graphically. These are annual emission reductions relative to BAU. Measures are simulated in isolation.

To put these numbers in perspective, if the Canadian transportation sector were to achieve the Kyoto target of a 6% reduction from 1990 levels by 2010 for CO₂ emissions, a reduction of approximately 59,000 kt from the CIMS BAU forecast would be necessary in 2010. ²⁵

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²⁵ This figure was calculated based on the assumption that 1990 CO₂ emissions from the Canadian transportation sector were 140 Mt as reported by the AMG (1999).
## Table 3-4 Total CO₂ emission reductions (kt) for the Canadian personal transportation sector

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency Standard</td>
<td>0</td>
<td>5,176</td>
<td>11,417</td>
<td>20,892</td>
</tr>
<tr>
<td>Efficiency Feebate</td>
<td>5,927</td>
<td>11,287</td>
<td>15,288</td>
<td>17,803</td>
</tr>
<tr>
<td>Fuel Switching Standard</td>
<td>0</td>
<td>1,098</td>
<td>2,832</td>
<td>6,878</td>
</tr>
<tr>
<td>Fuel Switching Feebate</td>
<td>1,464</td>
<td>2,907</td>
<td>3,979</td>
<td>4,709</td>
</tr>
<tr>
<td>Program to Encourage Public Transit Use</td>
<td>0</td>
<td>1,324</td>
<td>2,719</td>
<td>4,734</td>
</tr>
<tr>
<td>Program to Encourage HOV Use</td>
<td>0</td>
<td>3,591</td>
<td>7,631</td>
<td>12,640</td>
</tr>
<tr>
<td>Program to Reduce Urban Activity</td>
<td>0</td>
<td>2,345</td>
<td>4,989</td>
<td>8,257</td>
</tr>
<tr>
<td>CO₂ Tax</td>
<td>5,480</td>
<td>10,823</td>
<td>15,697</td>
<td>20,164</td>
</tr>
<tr>
<td>Measures Package</td>
<td>9,809</td>
<td>22,795</td>
<td>33,531</td>
<td>43,911</td>
</tr>
</tbody>
</table>
Figure 3-1 Total CO₂ emission reductions under individual measures applied to the Canadian personal transportation sector

In terms of the individual measures, the Efficiency Standard, the Efficiency Feebate, and the CO₂ Tax appear to have the greatest impact in terms of CO₂ reductions. The Program to Encourage Public Transit Use, the Program to Encourage HOV Use, and the Program to Reduce Urban Activity affect urban areas only and are therefore less likely to have a large impact relative to the other measures. Of these three urban measures, the HOV measure has the greatest impact.
Figure 3-2 Total CO2 emission reductions under the Measures Package applied to the Canadian personal transportation sector

As would be expected, the Measures Package results in the largest emission reductions by far. However, because there are overlaps and interdependencies between its components, the emission reductions achieved are much smaller than the summed effects of the individual constituent measures.

Table 3-5 Total CO2 emission reductions (kt) for the Canadian freight transportation sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Incentive Program for Road Efficiency</td>
<td>1,000</td>
<td>1,519</td>
<td>1,981</td>
<td>2,354</td>
</tr>
<tr>
<td>Incentive Program to Encourage Rail Transport</td>
<td>0</td>
<td>1,468</td>
<td>3,099</td>
<td>4,914</td>
</tr>
<tr>
<td>Diesel Tax</td>
<td>99</td>
<td>626</td>
<td>1,206</td>
<td>1,842</td>
</tr>
</tbody>
</table>
Figure 3-3 Total CO2 emission reductions for the Canadian freight transportation sector

![Graph showing CO2 reductions for different measures over time]

* Measure names are abbreviated as follows: Incentive Program for Road Efficiency = Rd Eff, Incentive Program to Encourage Rail Transport = Rail, and Diesel Tax = Dsl Tax.

Discussion around measures to reduce GHG emissions from the transportation sector tends to be biased towards the personal transportation sector. The results presented above reflect this bias: there are fewer measures affecting freight, and the emission reductions associated with these measures are small in relation to those affecting the personal transportation sector. Of the freight measures, the Incentive Program to Encourage Rail Transport was found to have the greatest impact in terms of CO2 reductions.

3.3 Annual Cost per tonne of CO2 Reduced

The annual cost per tonne of CO2 reduced has been estimated for each of the measures affecting the personal transportation sector. Cost per tonne estimates are not provided for the freight measures, as accurate data on the costs associated with the four freight modes was unavailable.
The costs and benefits reported here have been calculated using an *expected resource cost* accounting procedure (see section 2.3.3 for a full explanation of cost derivation). Missing from the account of expected resource costs are infrastructure and administration costs, as well as the real resource cost portion of the intangible costs associated with taking public transit, carpooling, or reducing personal transportation sector activity altogether. The implications of these omissions are addressed through an analysis of uncertainty in the following section. Providing resource cost estimates required some modification of the cost output of the CIMS transportation model, because this output is basically a representation of *perceived private costs*.

Following modification of the raw cost data, the net cost or benefit associated with each measure was calculated by comparing the total cost of supplying transportation services under that measure with the total cost under BAU assumptions. Cost per tonne estimates were then determined by dividing the net cost or benefit observed in a given year by the total emission reduction achieved in that year. The result is an annual rather than a cumulative figure: cost per tonne results are based on costs and emission reductions in the year indicated, *not* on cumulative costs and reductions from the present up until that year.

The magnitude of the emission reduction estimates presented in this report is not necessarily indicative of the relative merit of the measures under analysis. This is because the reported reductions are a function of the degree of stringency associated with each measure, as set by the modeller. When the cost per tonne of CO\textsubscript{2} reduced is estimated for a measure, however, this link is broken. Cost per tonne estimates may therefore be used to interpret the relative merit of actions or measures in terms of cost effectiveness.

A distinction must be made here between cost effectiveness and political acceptability. A measure may result in a large net benefit in terms of expected resource costs, yet still meet serious opposition from members of the public. An efficiency standard, for instance, should be associated with a net benefit under a resource cost accounting procedure, due to the lower capital and fuel costs associated with higher efficiency vehicles. This benefit, however, would not encompass the loss in consumers’
surplus that would occur due to lower vehicle performance. This loss in consumers' surplus could cause the public to reject the measure.

Annual cost per tonne estimates for the measures affecting personal transportation are shown in Table 3-6 below. The same results are presented graphically in Figures 3-4 and 3-5. Costs are shown as positive numbers and benefits as negative numbers.

Table 3-6 Annual cost (95$) per tonne of CO₂ reduced from the Canadian personal transportation sector

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency Standard</td>
<td>0</td>
<td>-529</td>
<td>-528</td>
<td>-538</td>
</tr>
<tr>
<td>Efficiency Feebate</td>
<td>-498</td>
<td>-531</td>
<td>-530</td>
<td>-542</td>
</tr>
<tr>
<td>Fuel Switching Standard</td>
<td>0</td>
<td>6,548</td>
<td>1,723</td>
<td>1,759</td>
</tr>
<tr>
<td>Fuel Switching Feebate</td>
<td>-421</td>
<td>-463</td>
<td>-464</td>
<td>-479</td>
</tr>
<tr>
<td>Program to Encourage Public Transit Use</td>
<td>0</td>
<td>-2,190</td>
<td>-2,362</td>
<td>-2,249</td>
</tr>
<tr>
<td>Program to Encourage HOV Use</td>
<td>0</td>
<td>-1,381</td>
<td>-1,404</td>
<td>-1,401</td>
</tr>
<tr>
<td>Program to Reduce Urban Activity</td>
<td>0</td>
<td>-1,378</td>
<td>-1,400</td>
<td>-1,399</td>
</tr>
<tr>
<td>CO₂ Tax</td>
<td>-808</td>
<td>-849</td>
<td>-892</td>
<td>-956</td>
</tr>
<tr>
<td>Measures Package</td>
<td>-673</td>
<td>-561</td>
<td>-810</td>
<td>-785</td>
</tr>
</tbody>
</table>
The Efficiency Standard and the Efficiency Feebate both result in a benefit per tonne of CO₂ reduced. This is because the more efficient passenger vehicle technologies have lower capital costs and lower annual fuel costs than the less efficient technologies. Also, the intangible cost parameters associated with efficiency levels have been removed from the cost estimates, as they do not represent real resource costs. These parameters effectively increase the costs associated with efficient vehicles and decrease the costs associated with inefficient vehicles.

The Fuel Switching Standard is the only measure that was found to incur a net expected resource cost. This standard leads to purchases of zero emission vehicles (electric and hydrogen) -- novel technologies with very high initial capital costs, as well as high intangible cost parameters associated with range and fuel availability. An additional intangible cost parameter of $5,000 is also included in the capital cost of each new electric or hydrogen vehicle (half of the original intangible cost parameter associated with all non-gasoline passenger vehicles). These high up-front costs are magnified by the
20% discount rate applied for the purposes of accounting for costs. For hydrogen vehicles in particular, yearly fuel costs are also very high.

The cost associated with the Standard decreases significantly from a high of $6,548 per tonne in 2005, the year the measure takes effect. This is the effect of declining costs. After the year 2005, as the Standard drives increased penetration, the costs associated with zero emission vehicles fall significantly, according to the parameters of the declining cost function. Due to this potential for variation in costs over time, it might be beneficial in future projects to calculate the net present value of future costs instead of annual costs alone.

The results reported for the Fuel Switching Standard would suggest that switching to zero emission vehicles is not a very cost-effective way to reduce CO₂ emissions. Although the best available estimates with respect to costs have been used in this study, the costs associated with electric, hydrogen, and other non-gasoline fuelled vehicles may decline faster than anticipated, making the actual cost of fuel switching lower than estimated here. It is even conceivable that the market for passenger vehicles will be completely transformed upon the introduction of one or a few alternative fuelled vehicle technologies, “flipping” away from gasoline vehicles and towards these more innovative options. If such a transformation were to occur, costs would fall to much lower levels at smaller market shares. This possibility is addressed in the analysis of uncertainty in the following section.

In contrast to the Fuel Switching Standard, the Fuel Switching Feebate results in a benefit per tonne of CO₂ reduced. This is because the main effect of the Feebate is actually an efficiency improvement, and such improvements, as was shown by the results of the Efficiency Standard and the Efficiency Feebate, lead to net benefits.

Under the Fuel Switching Feebate, a 10% fee is added to the capital costs of all new gasoline passenger vehicles. The capital cost of a high efficiency gasoline vehicle, under BAU assumptions, is $17,370, while the capital cost of a low efficiency gasoline vehicle is $24,520. A fee of $1,737 is therefore added to the capital cost of high efficiency vehicles, while a fee of $2,452 is added to the cost of the low efficiency
vehicles. Because the monetary value of the fee is greater for the low efficiency vehicles, the Feebate makes these vehicles less attractive relative to high efficiency vehicles. The high efficiency vehicles therefore gain a greater portion of market share than under BAU assumptions, causing the overall efficiency of the fleet to improve.

The unexpected result of the Fuel Switching Feebate indicates that the CIMS transportation model is much more sensitive to price signals that encourage efficiency evolution than to price signals that encourage fuel switching. Fuel switching is difficult to induce due to the high costs associated with non-gasoline fuelled vehicle technologies.

A very large cost saving is forecast for the Program to Encourage Public Transit Use. This is simply because the technical-economic costs associated with travelling one passenger kilometre (pk) by public transit are lower than those associated with travelling one pk in a car or a truck. However, the infrastructure costs associated with providing expanded public transit services have not been included in the cost estimates provided here. Furthermore, intangible cost parameters have not been assigned to transit technologies within the CIMS transportation model. Any portion of the intangible cost associated with public transit use that corresponds to real resource costs (time losses, increased frequency of illness for transit users) is therefore missing from the reported costs. Due to these omissions, it is probably safe to assume that expected resource benefits have been overestimated for this measure.

Significant net benefits are also reported for the Program to Encourage HOV Use and the Program to Reduce Urban Activity. In the case of the HOV measure, this is again the result of reduced technical-economic costs. The Program to Reduce Urban Activity results in a cost saving simply because there are fewer transportation services provided under this measure. However, intangible cost parameters have not been assigned to carpooling for the purpose of this study. Neither are there intangible cost estimates associated with reduced levels of activity within the personal transportation sector. Some portion of these intangibles will most likely represent real resource costs, again leading to an overestimation of benefits.
There are three actions associated with the CO\(_2\) Tax: improved passenger vehicle fuel efficiency, fuel switching, and a reduction in the demand for travel by passenger vehicles. Fuel efficiency improvements are realized because gasoline prices increase with the implementation of the tax, making high efficiency gasoline vehicles more attractive to the consumer. Fuel switching occurs because the tax results in higher price jumps for the conventional fuels (gasoline and diesel), making alternative fuelled vehicles more attractive. Reduction in travel demand is applied externally to the transportation component of CIMS as fuel prices rise (a short run fuel price elasticity of demand for light duty vehicle travel of -0.05 was used, along with a long run elasticity of -0.2). Efficiency improvements and reductions in the demand for transportation services result in net benefits under the analytical framework used in this study, while fuel switching results in a net cost.

The Tax was found to have a net benefit, indicating that the costs associated with fuel switching are overwhelmed by the benefits associated with efficiency improvements and reduced levels of travel demand in this case. The level of net benefit achieved increases over the forecast period. This trend is seen because the reduction in demand for passenger vehicle travel associated with the CO\(_2\) Tax grows larger over time. Again, the real resource cost portion of the intangible cost associated with reducing personal transportation sector activity levels is not included in the cost analysis presented here.
The Measures Package was composed of the Efficiency Feebate, the Fuel Switching Standard, and the CO$_2$ Tax; as well as an Integrated Strategy for Urban Transportation Management. The Integrated Strategy, in turn, was made up of modified versions of the Program to Encourage Public Transit Use, the Program to Encourage HOV Use, and the Program to Reduce Urban Activity. The actions associated with the three programs making up the Integrated Strategy are smaller than the actions associated with the programs when they are simulated in isolation. This adjustment was made to account for the overlapping effects of the programs, as well as the CO$_2$ Tax. The policies and actions associated with each element of the Measures Package are described in detail in Table 2-9.

In order to simulate the Measures Package, market shares were exogenously reserved for zero emission vehicles in accordance with the Fuel Switching Standard. The distance travelled by passenger vehicles was also exogenously manipulated, to mimic the service demand reduction assumed to occur under the CO$_2$ Tax. The urban component of
overall personal transportation activity was then further reduced, representing implementation of the modified Program to Reduce Urban Activity. Market shares were adjusted to simulate the modified versions of the Program to Encourage Public Transit Use and the Program to Encourage HOV Use.

Following these exogenous changes, the CIMS transportation model was run with altered capital costs for high and low efficiency passenger vehicles, as dictated by the Efficiency Feebate; and with altered fuel prices in accordance with the CO2 Tax. Changes in the efficiency of the passenger vehicle fleet due to the Feebate and the Tax were endogenously determined as a result. A minimal degree of endogenous fuel switching also took place; however, this potential was limited because most fuel shares had been set exogenously in order to simulate the Fuel Switching Standard.

The results obtained indicate that, by employing several measures together, a large reduction in emissions may be achieved through a diversity of actions without financial penalty. Despite the inclusion of the Fuel Switching Feebate, a very costly measure when simulated by itself, the Measures Package results in a net benefit per tonne of CO2 reduced throughout the forecast period. However, certain caveats must be taken into account when considering the cost result for the Measures Package. These caveats pertain to the omission of infrastructure and administration costs, as well as the lack of intangible costs associated with public transit technologies, carpooling, and reduced personal transportation sector activity within the CIMS transportation model.

3.4 **Analysis of Uncertainty with Respect to Emission Reduction Costs**

The expected resource cost estimates presented in the previous section are associated with a degree of uncertainty. Three key factors have been identified as contributing to this uncertainty: 1) infrastructure and administration costs are not included in the expected resource cost estimates, 2) the real resource cost portions of the intangible costs associated with public transit use, carpooling, and reduced levels of personal transportation sector activity are missing, and 3) there is uncertainty around the parameters assigned to the declining cost function for the purpose of this analysis.
Cost uncertainty is addressed here by focusing on the cost per tonne estimate provided for the Measures Package in the year 2010 (the mid-point of the Kyoto deadline). The sensitivity of this result to changes corresponding to the three factors identified above is investigated. Only the Ontario component of the CIMS transportation model was used. This simplification made the analysis easier to perform, and should not compromise the integrity of the results, because the cost estimate in question is almost the same for Ontario ($820 per tonne CO$_2$ reduced) as for the entire country ($810 per tonne).

3.4.1 Infrastructure and Administration Costs

The lack of infrastructure and administration costs is rectified by adding an annual estimate for these costs to the 2010 Measures Package result. This estimate includes the following expenditures:

- $306 million per year for improved urban transportation in Toronto,\(^{26}\)
- $15 million per year for public transit projects in other regions of Ontario, and
- $15 million per year for other policy administration costs (personnel, facilities, advertising, and materials).

These expenditures add to an annual total of $336 million.

3.4.2 Real Resource Cost Portion of Intangibles

Certainly, there are significant intangible costs associated with using public transit, carpooling, and making overall reductions in personal transportation sector activity. If there were not, the technical-economic savings associated with these actions

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\(^{26}\) A New Approach to Funding Urban Transportation in Canada (IBI Group, 1998) estimates the increase in annual expenditures that would be required to achieve more sustainable urban transportation within the top three Census Metropolitan Areas (CMAs) of Canada (Toronto, Montreal, and Vancouver) at $668 million. According to 1996 data from Statistics Canada (website), Toronto represents about 45.8% of the population of the top three CMAs. Therefore, assuming that per capita transportation costs are uniform across the top CMAs, the annual cost attributable to Toronto is $306 million.
would have made them attractive enough for government policy to be unnecessary. A portion of the intangibles in question is associated with real resource costs. For example, travel times are increased under public transit and carpooling options, while public transit users may also become ill more frequently. These costs are missing from the expected resource cost estimates that have been presented so far in this report. This problem was addressed by running the Measures Package with the actions associated with the Integrated Strategy at half strength, as indicated in Table 3-7 below. When fixed infrastructure and administration costs are added to the results of this run, the benefits associated with the Measures Package will decline.

Table 3-7 The Integrated Strategy for Urban Transportation Management under original and half strength assumptions

<table>
<thead>
<tr>
<th></th>
<th>Integrated Strategy for Urban Transportation Management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy</strong></td>
<td>The Program to Encourage Public Transit Use, the Program to Encourage HOV Use, and the Program to Reduce Urban Activity are combined into an Integrated Strategy for Urban Transportation Management. The three programs are combined because they incorporate many of the same elements.</td>
</tr>
<tr>
<td><strong>Original Actions</strong></td>
<td>Within urban areas, between the years 2000 and 2015, the passenger vehicle share of pkt decreases 1% per year. Corresponding increases in the bus and rapid transit modal shares occur. Within urban areas, between the years 2000 and 2015, the SOV share of pkt decreases 1% per year. There is a corresponding increase in the HOV share. Personal transportation sector activity within urban areas is reduced by 2.5% in 2005, 5% in 2010, and 7.5% in 2015.</td>
</tr>
<tr>
<td><strong>Actions at Half Strength</strong></td>
<td>Within urban areas, between the years 2000 and 2015, the passenger vehicle share of pkt decreases 0.5% per year. Corresponding increases in the bus and rapid transit modal shares occur. Within urban areas, between the years 2000 and 2015, the SOV share of pkt decreases 0.5% per year. There is a corresponding increase in the HOV share. Personal transportation sector activity within urban areas is reduced by 1.25% in 2005, 2.5% in 2010, and 3.75% in 2015.</td>
</tr>
</tbody>
</table>
3.4.3 Declining Cost Function

Although the best available estimates with respect to declining costs have been employed in this study, a significant degree of uncertainty remains around the parameters assigned to the declining cost function. Should market transformation or market flipping occur with the introduction of one or a few alternative fuelled technologies, costs will fall to lower levels at smaller market shares than previously assumed. In order to address this possibility, the Measures Package was simulated under a new set of assumptions with respect to declining costs for electric and hydrogen passenger vehicles, as shown below in Table 3-8. The ultimate to current cost ratios were set to levels such that the up-front costs (capital costs plus intangible cost parameters) of the zero emission vehicles are allowed to fall to just slightly above those associated with conventional gasoline vehicles. In addition, the ultimate costs are now reached twice as quickly (the maturity parameter has been halved).

Table 3-8 Declining cost function parameters under original and market transformation assumptions

<table>
<thead>
<tr>
<th></th>
<th>Ultimate / Current Cost</th>
<th>Maturity Parameter (Proportion of Market Share)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original Assumptions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Passenger Vehicle</td>
<td>0.60</td>
<td>0.5</td>
</tr>
<tr>
<td>Hydrogen Passenger Vehicle</td>
<td>0.24</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Market Transformation Assumptions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Passenger Vehicle</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Hydrogen Passenger Vehicle</td>
<td>0.15</td>
<td>0.25</td>
</tr>
</tbody>
</table>

3.4.4 Results of the Uncertainty Analysis

Under original assumptions, the Measures Package was found to result in a net benefit per tonne of CO₂ reduced. This benefit is diminished through the addition of infrastructure and administration costs, and the effect is enhanced by setting the actions
associated with the Integrated Strategy for Urban Transportation Management at half strength. These changes are therefore combined in order to produce a low estimate of benefits. Alteration of the parameters of the declining cost function to simulate market transformation, on the other hand, results in an increase in the benefit estimated for the Package. This change is simulated to provide a high estimate of benefits. Finally, all three changes are simulated together to combine the low and high estimates.

Table 3-9 Cost in 2010 (95$) per tonne of CO₂ reduced under the Measures Package

<table>
<thead>
<tr>
<th>Original Estimate of Net Benefit</th>
<th>Low Net Benefit Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Infrastructure and administration costs included, Integrated Strategy actions at half strength)</td>
</tr>
<tr>
<td>-820(^*)</td>
<td>-660</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High Net Benefit Estimate</th>
<th>Combination of Low and High Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Market transformation assumptions)</td>
<td></td>
</tr>
<tr>
<td>-894</td>
<td>-752</td>
</tr>
</tbody>
</table>

\(^*\) This number is slightly different from the number reported in section 3.3. The number reported in section 3.3 was for all of Canada, while the number reported in Table 3-9 is for Ontario only.

The results of the uncertainty analysis show that a significant benefit in terms of expected resource costs is still associated with the Measures Package even once infrastructure and administration costs have been added, and the actions associated with the Integrated Strategy halved. Furthermore, an even higher net benefit may be achieved if the passenger vehicle market is transformed by the introduction of zero emission vehicles running on fuels like electricity and hydrogen.

These results may seem counterintuitive: if such large net benefits are associated with reducing GHG emissions from the Canadian personal transportation sector, why is mitigation even an issue? It would appear that we can achieve significant reductions and realize financial savings at the same time. Remember, however, that an expected resource cost accounting procedure has been used here. Reported costs represent expected
financial flows within society. The overestimation of intangible real resource costs (cost risks, transaction costs, and option value) by the consumer are not included. More importantly, expected resource costs do not address losses in consumers’ surplus that are not associated with financial flows. It is anticipated that such losses would be significant under the Measures Package evaluated here.

The use of passenger vehicles allows individuals to travel in a private, comfortable environment where they enjoy a variety of amenities (air conditioning, stereo system, coffee cup holder). Their vehicles make them feel free, independent, powerful, and sexy. Measures that affect the types of vehicles people drive, act to increase public transit and HOV use, or encourage reduced sectoral activity will therefore result in important losses in consumers’ surplus.

The estimation of expected resource costs is a necessary first step in the policy evaluation process. These costs provide policy makers with a good indication of whether or not measures are attractive financially, and may lead to further analysis of macroeconomic consequences. Resource costs do not, however, provide a very good representation of true costs to society. Nor do they indicate whether or not a measure will be acceptable politically, because unaccounted for losses in consumers’ surplus may result in public outrage. A social welfare cost account, on the other hand, would acknowledge all losses in consumers’ surplus, providing the full compliment of information necessary for decision making with respect to transportation sector GHG mitigation policy.
4. Conclusion

4.1 Summary

This study has examined the problem of reducing GHG emissions from the Canadian transportation sector. Canada has made an international commitment, under the Kyoto Protocol, to reduce its GHG emissions to 6% below 1990 levels sometime between 2008 and 2012. Because the transportation sector has such a significant impact on overall emissions, measures addressing this sector must be considered if a serious attempt at mitigation is to be made. Considering the wide range of measures available, decision-makers will require estimates of both the potential emission reductions and the costs or benefits associated with a variety of measures.

In response to these information requirements, a simulation model of the Canadian transportation sector was built and used to test eight individual measures and one package of measures affecting the personal transportation sector, as well as three individual measures affecting the freight transportation sector. This model has since been incorporated into the Canadian Integrated Modelling System (CIMS), a set of economic and energy models housed at the Energy Research Group at Simon Fraser University and used by the Canadian government for climate change policy analysis. This project may therefore also be viewed as a partial equilibrium test of the CIMS transportation model. Direct and total emission reductions have been estimated, along with expected resource costs or benefits for the selected measures. All results are presented relative to a Business-as-Usual case. Although the set of measures evaluated as part of this study is by no means exhaustive, the CIMS model can be used to test additional measures in the future.

Total emission reductions represent the emission reductions achieved once emissions associated with electricity generation are taken into account. The results indicate that in terms of the individual personal transportation measures, total annual CO$_2$ emission reductions in 2010 were greatest under the Efficiency Standard, the Efficiency Feebate, and the CO$_2$ Tax (at 11,417 kt, 15,288 kt, and 15,697 kt respectively). The
Program to Encourage HOV Use had the greatest impact (at 7,631 kt) of the measures affecting urban areas only. It is not possible to sum the emission reductions associated with individual measures due to the interdependencies between them. A Measures Package was therefore applied to the personal transportation sector in order to estimate the emission reduction potential of several measures acting in combination. The Package was estimated to reduce 2010 emissions by 33,531 kt. Of the measures affecting Canada’s freight transportation sector, the Incentive Program to Encourage Rail Transport was found to have the greatest impact (at 3,099 kt).

Annual costs or benefits per tonne of CO₂ reduced were also calculated for each of the measures affecting the personal transportation sector. An expected resource cost accounting procedure was used to estimate costs. Missing from the cost account, however, are infrastructure and administration costs; as well as the real resource cost portion of intangible costs associated with public transit, carpooling, and reducing overall demand for personal transportation sector activity.

Under the resource costing methodology employed, the Program to Encourage Public Transit Use, the Program to Encourage HOV Use, and the Program to Reduce Urban Activity all resulted in very large savings ($2,362, $1,404, and $1,400 per tonne in the year 2010, respectively). The CO₂ Tax was also found to be quite attractive, with an annual benefit of $892 per tonne. The Efficiency Standard, the Efficiency Feebate, and the Fuel Switching Feebate were cost effective (benefits of $528, $530, and $464 per tonne in 2010). (The result for the Fuel Switching Feebate is similar to the result of the efficiency measures due to the fact that the main effect of the Feebate is actually an efficiency improvement.) The Fuel Switching Standard was the only measure to result in a net cost in 2010 ($1,723 per tonne). This measure resulted in purchases of zero emission vehicles with very high up-front costs. Finally, the Measures Package was achieved with a net financial benefit of $810 per tonne.

An uncertainty analysis was carried out on the cost per tonne estimate provided for the Measures Package in 2010. The Ontario component of the CIMS transportation model was used. A low estimate of benefits was generated by adding infrastructure and
administration costs to the results and by setting some of the actions associated with the Package at half strength. Actions were set at half strength in order to address the fact that the real resource cost portions of the intangible costs associated with public transit use, carpooling, and reduced levels of personal transportation sector activity are missing from the results. A high estimate of benefits was also produced, representing a potential state of nature where the passenger vehicle market is transformed upon the introduction of one or a few alternative fuelled vehicle technologies, making fuel switching much cheaper than anticipated. Finally, a combination of the low and high estimates was provided. The Package result was found to be relatively insensitive to these changes – even the low benefits estimate showed significant savings in terms of real resource costs.

4.2 Major Trends in the Results

If the Kyoto target of a 6% reduction from 1990 levels were to be applied to CO₂ emissions from the Canadian transportation sector, a reduction in 2010 of approximately 59,000 kt of CO₂ would be necessary. Reaching such a target was not the goal of this project, as there has been no confirmation of how the overall reduction of 6% will actually be allocated between sectors. Instead, stringency of the measures tested was based on a review of the relevant literature, and on current views as to what is politically acceptable. However, the Kyoto target does give a good indication of the magnitude of reductions that may be necessary.

The results indicate that each of the individual measures evaluated here fall far short of meeting the Kyoto target as applied to transportation. Of course, increases in the stringency of measures, as well as certain adjustments to model input and parameters could result in greater reductions. It is doubtful, however, that any of these changes would be enough to cause one individual measure to emerge as the key to reducing transportation sector emissions.

Furthermore, even the Measures Package applied to the personal transportation sector was found to take care of only just over half of the 59,000-kt reduction referred to above. The freight transportation sector measures tested were found to result in such
small reductions that even if these measures were to be combined with the Package, reductions would not approach 6%.

The cost estimates obtained present a more optimistic picture: there do appear to be options available for reducing CO₂ emissions at a net benefit in terms of real resource costs. All of the personal transportation measures tested for the purpose of this analysis, with the exception of the Fuel Switching Standard, resulted in annual net benefits. The savings associated with some of the measures were quite impressive.

In interpreting these costs, however, it is important to consider three major issues. First, the expected resource costs do not include all costs that are perceived by the consumer. Therefore, a measure that results in a net benefit using a resource cost accounting procedure may have a large cost associated with it because of a loss in consumers’ surplus. As a result, the measure may be very costly socially and politically regardless of apparent benefits. A measure to increase passenger vehicle efficiency might result in a loss in consumers’ surplus due to decreased vehicle performance, for example. A measure that shifts travellers from private vehicles to public transit, on the other hand, might result in a loss due to increased discomfort and decreased privacy.

Second, the cost estimates provided here do not completely represent real resource costs. This is due to the omission of infrastructure and administration costs, as well as the real resource cost portion of certain intangibles. Inclusion of these costs could significantly reduce the estimated benefits associated with many measures, and might even result in net costs being reported.

Third, if the stringency of the Measures Package must be ramped up once the Kyoto target has been allocated amongst the various sectors, the cost picture may change significantly, with a tendency towards increased costs or decreased benefits. The elements of expected resource costs that would be most affected by such a transition would probably be those not included in the initial cost estimates -- infrastructure and administration plus the real resource cost portion of consumers’ surplus.
For instance, it should be possible to achieve a moderate shift to public transit through a relatively small investment in new transit infrastructure, a modest compensation program for individuals willing to make the desired lifestyle changes, or a gentle penalty for those who continue to rely on passenger vehicles. These policies would be aimed at individuals who do not encounter high intangible costs when taking public transit to begin with. Shifts of a much greater magnitude would require higher investments in infrastructure, larger compensation programs, or greater penalties for passenger vehicle use in order to increase transit ridership among individuals who perceive very high costs to be associated with this mode. Cost estimates would be affected because all infrastructure costs, as well as a portion of consumers’ surplus are considered real resource costs.

4.3 Recommendations

The results of this analysis should prove valuable to decision makers currently in the process of designing a strategy for reducing GHG emissions from the Canadian transportation system. Key measures have been analysed in terms of potential emission reductions and resource cost effectiveness. In addition to these results, however, decision-makers will need to consider certain aspects that have been beyond the scope of this study.

Initially, certain negotiation and harmonization efforts will be necessary. The issue of what portion of the Kyoto commitment the transportation sector is responsible for must be resolved; the higher the responsibility for transportation, the greater the scope and stringency required of an overall GHG reduction program. The CIMS model, including the transportation model built for the purpose of this study, was recently used to evaluate trade-offs between sectors under different GHG reduction scenarios as part of the Canadian National Climate Change Implementation Process (ERG / M.K. Jaccard and Associates, 2000). An interprovincial allocation of target emission reductions will also be required. Harmonization with U.S. initiatives may be sought to improve the mitigative
impact and cost effectiveness of efficiency and fuel switching measures, as well as fuel or emission taxation strategies.

Analysis of additional cost factors is also a likely prerequisite to the finalization of Canada’s mitigation program for transportation. Federal and provincial government bodies will certainly wish to further investigate the issue of intangible costs associated with losses in consumers’ surplus. These costs are not fully accounted for within expected resource costs, yet they are important, both socially and politically. Costs associated with macroeconomic changes will also require consideration. A tax on CO₂ emissions, for example, might appear to have a much higher societal cost once potential job losses and reduced levels of economic activity are taken into account.

Finally, there may be an interest in evaluating additional measures impacting both personal and freight transportation, and in looking at new variations or stringency levels of the measures that have already been addressed by this analysis.

Although this study does not encompass the full range of conditions that must be considered in order to propose a specific strategy for reducing GHG emissions from the transportation sector, it is possible to make some general recommendations with respect to transportation policy in Canada on the basis of three major trends identified in the results. First, the results indicate that any individual measure will most likely be insufficient to the task reducing emissions to a reasonable target level. Second, even the combination of the Measures Package with all three freight measures would not reach the Kyoto target as applied to the transportation sector. Third, it appears that there are several options for reducing GHG emissions from the personal transportation sector that should result in net benefits, according to an expected resource costing methodology.

4.3.1 Implement a Package of Measures

Given that the individual measures tested here were found to result in such small reductions (relative to potential target levels), it is recommended that a package of measures be implemented. This conclusion is supported by the literature on transportation related GHG emissions: Hughes (1991), Michaelis and Davidson (1996),
and Scholl *et al.* (1996) have all noted the importance of drawing on more than one option for achieving reductions.

Furthermore, it is recommended that all of the factors identified in section 1.1.3 as contributing to GHG emissions from the transportation sector be addressed in any comprehensive program to reduce emissions. These factors (as outlined by Scholl *et al.*, 1996) are: activity, modal structure, fuel intensity or efficiency, load factor, and fuel mix. Each is addressed by the Measures Package that has been applied to the personal transportation sector for the purpose of this analysis. Despite the high cost associated with fuel switching, the results show that such a package may be implemented with a net benefit in terms of expected resource costs.

Besides the increased magnitude of reductions possible under a package approach, there are additional reasons for implementing more than one measure at a time. Schipper and Eriksson (1995) have identified eight “deadly sins of the automobile.” These include safety problems, air pollution, spatial issues, congestion / access, hulks, noise, CO₂ emissions, and energy use.²⁷ Focusing on only one remedy to the GHG problem neglects other important issues and may even exacerbate certain problems. For example, a full switch to a completely “clean” fuel source for transportation would theoretically eliminate the GHG problem for this sector. However, roads and urban sprawl would continue to encroach on wilderness areas, and traffic flow would not be improved.

Individual transportation measures may also have unintended, even counteractive effects. Measures designed to improve vehicle efficiency levels (standards and feebates, for example) may lead to increases in overall transportation activity because of falling driving costs. This “rebound” effect is addressed by Greene (1992) and Jones (1993). A recent article in The Economist provides another example of a potentially paradoxical effect: the construction of a new passenger rail system may cause a shift from bus to rail

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²⁷ Although some of the measures that have been tested here may reduce some of these problems, the benefits associated with such changes have not been calculated for the purpose of this study.
travel, resulting in cutbacks in bus service levels that eventually force bus passengers unable to use the rail system back into their cars. When measures are packaged together, however, the problematic effects of one measure can be cancelled out by the other measures. For example, in a carefully constructed package, measures promoting reduced activity levels would be combined with efficiency measures, hopefully eliminating any potential rebound.

Packages of measures may be designed for the transportation sector in particular, or they may have a broader, more holistic focus. Community Energy Management (CEM) is an example of a more broad-based package. CEM is a strategy for building livable communities with minimal energy requirements, and, in turn, minimal GHG emissions at a given standard of living. Land use planning, transportation management, site design, and local energy supply and delivery planning are all involved (Jaccard *et al.*, 1997).

4.3.2 Do Not Abandon Fuel Switching

It may be tempting to abandon fuel switching as an option for reducing sectoral emissions due to the high costs expected to be associated with this alternative. Such a policy direction is not recommended, however. Fuel switching offers an unlimited potential for reducing GHG emissions from the transportation sector in the long term. This potential must be tapped, as other options for reducing emissions (including efficiency improvements) may not be sufficient to meeting reduction targets such as the one agreed to under the Kyoto Protocol. Even more ambitious targets may be set in the future, strengthening the argument that fuel switching options be given serious consideration. Furthermore, should the intangible costs associated with reducing private passenger vehicle use be much larger than expected, fuel switching may not appear so costly relative to measures that involve switching to public transit, increasing vehicle occupancy, or reducing personal transportation sector activity altogether.

The high costs associated with fuel switching should decline as alternative fuelled technologies begin to gain market share. This potential for decreased costs is captured by
the declining cost function that has been applied to the up-front costs (capital costs plus intangible cost parameters) of non-gasoline fuelled vehicles. It is possible, however, that up-front costs may fall at a faster rate than anticipated. Some analysts have even proposed that the market will be completely transformed upon the introduction of one or a few alternative fuelled vehicle technologies, resulting in much lower costs for fuel switching.

Furthermore, recent findings suggest that action with respect to fuel switching should be taken as soon as possible due to significant time lags associated with the penetration of new technologies into the in-use stock. Knapp (1999) has found the time scale required to achieve significant reductions in carbon emissions from 1990 levels through the penetration of carbon-free road transportation and electricity generation technologies to be on the order of several times the expected lifetime of the existing technologies. This despite his implicit assumption that novel technologies are able to meet current expectations with respect to performance and cost.

Realizing significant emission reductions through fuel switching, however, will most likely demand that a choice be made between potential options (propane, natural gas, methanol, ethanol, electric, hydrogen). The general public will not embrace any alternative until a certain availability threshold is reached, requiring massive investments in infrastructure over a short time frame. This infrastructure barrier virtually eliminates the option of successfully promoting more than one alternative at a time (U.S. Department of Energy, 1998). It is recommended that the question of what fuel switching option to pursue be investigated as soon as possible. Negotiations with the U.S. on this point will be essential.

4.3.3 Include Significant Measures Affecting Freight Transportation

The fact that the Measures Package tested for the personal transportation sector was found to be insufficient to meeting the Kyoto target as applied to transportation suggests that significant GHG emission reductions from the freight sector may be required in the future. The three freight measures evaluated here do not appear stringent
enough to achieve the magnitude of reductions expected to be necessary. These measures were developed using various background information sources that tended to focus mostly on the personal transportation sector. This emphasis is perhaps due to a commonly held assumption that it will be politically difficult and economically damaging to reduce emissions from freight transportation. Despite such reservations, however, serious consideration must be given to the freight sector if significant reductions in transportation emissions are deemed necessary.

4.3.4 Reevaluate Standards for Political Acceptability

The preceding discussion has revealed that the measures developed and tested during the course of this study are generally lacking in terms of emission reduction potential. Because these measures were defined with the intent that they be as stringent as possible given political and inherent constraints, the rather disappointing results obtained using the CIMS transportation model may be indicative of an existing gap between what is perceived to be politically feasible and what is actually required in order to meet our commitments to reduce Canadian GHG emissions. In order to successfully reduce transportation sector emissions to target levels, decision-makers may need to implement measures currently viewed as being politically unacceptable. The acceptability of such measures may always be improved through the use of informational programs or by ensuring that policies are revenue neutral.

4.4 Areas for Further Study

The transportation model built as part of this study has now been incorporated into CIMS. This development has already allowed for a more full equilibrium analysis of GHG mitigation policy to take place through a project completed as part of the Canadian National Climate Change Implementation Process (ERG / M.K. Jaccard and Associates, 2000). This work also involved the evaluation of additional transportation measures.

Future work with CIMS and the CIMS transportation model will continue to take advantage of full equilibrium capabilities, and additional measures and variations of measures will be tested as necessary. It is also suggested that increased sophistication be
incorporated into the efficiency evolution process of the transportation model. In addition, a complete account of all elements of expected resource costs would greatly improve the accuracy of cost estimates. Finally, work should be done to estimate the social welfare costs of measures in order to fully inform the decision making process with respect to GHG mitigation policy within the transportation sector.

4.4.1 Moving from Partial Equilibrium to Full Equilibrium

Running the transportation model developed for this project apart from the rest of CIMS has resulted in two major impacts: 1) because energy demand and energy supply were not connected, end use rather than full cycle GHG emissions were generated as model output, and 2) separation from the Macro-Economic Model of CIMS meant that a change in the cost of providing transportation services did not automatically result in a change in the demand for these services.

Integration into CIMS allows for full cycle emission reductions to be reported. This change would increase the emission reductions and decrease the costs associated with most of the measures that have been evaluated here. With the exception of the Fuel Switching Standard, all of these measures result in reduced emissions because they act to reduce conventional fuel use. Because GHGs are emitted through the production of gasoline and diesel, the full cycle emission reductions associated with reduced fuel use would be even greater than the end use emission reductions that have already been reported. Larger reduction estimates would, in turn, result in decreased cost per tonne estimates. In the case of the Fuel Switching Standard, however, the results would depend on how available alternative fuels are produced. Hydrogen, for example, may be generated in a virtually emission free manner using solar power. If conventional electricity is used, however, emissions may be significant, depending on the full cycle emissions associated with the electricity consumed.

Connection to the Macro-Economic Model would also impact the results. Any measure leading to an increase in the cost of providing transportation services would automatically cause a reduction in the demand for these services, while any measure
leading to a decrease in costs would have the opposite effect. This type of interaction was applied exogenously in order to simulate measures involving taxation for the purpose of this analysis. Additional measures would have been affected, however, had the transportation model been run as part of CIMS. For example, personal transportation sector activity would have been reduced under the Fuel Switching Standard, because this measure results in an increase in the costs of providing transportation services, due to the higher up-front costs of passenger vehicles. Efficiency measures, on the other hand, would have resulted in a “rebound” in sectoral activity due to decreased fuel costs.

4.4.2 Evaluating Additional Measures and Variations of Measures

As part of the ongoing process of formulating a strategy for reducing GHG emissions from the transportation sector in Canada, decision makers may wish to evaluate additional measures as well as new variations or stringency levels of the measures already examined. Looking at the effect of varying stringency levels will be especially important once an emission reduction target for the transportation sector has been established. The CIMS transportation model continues to be available for this type of additional analysis.

4.4.3 Modelling Efficiency

The methodologies used by Eltony (1993) and the U.S. Department of Energy (1998) for modelling new passenger vehicle fuel efficiency have been described in section 1.4.3 of this report. In both cases, overall efficiency is determined on the basis of efficiency levels within vehicle classes, and the distribution of sales across these classes. Technological improvements leading to increases in class fuel economy are modelled from the manufacturer’s point of view, while sales distribution is modelled from the point of view of the consumer.

The current representation of passenger vehicle efficiency within the CIMS transportation model is relatively simplistic due to the time constraints and the relatively broad scope of this modelling exercise. If the opportunity arises at a later date to increase
the level of sophistication with respect to efficiency, however, an approach similar to that described above would be recommended.

4.4.4 A Full Account of Expected Resource Costs

An expected resource cost accounting procedure has been used for the purpose of this analysis; however, certain elements of resource costs are missing from the estimates. Although an uncertainty analysis has partially addressed this problem, future work to fully incorporate expected resource costs would certainly improve the accuracy of the cost estimates generated using the CIMS transportation model.

There will be a need in later work to report the infrastructure and administration costs associated with measures, because these costs are an important component of expected societal resource costs. Inclusion of infrastructure costs will certainly affect measures that increase transit use and promote fuel switching. The modeller should, however, be careful to also include the significant infrastructure costs associated with more conventional modes and technologies (costs of maintaining and extending the road network, for example).

The real resource cost portion of intangible costs associated with public transit and carpooling is also missing from the expected resource cost estimates. Because of this omission, the cost savings reported for the Program to Encourage Public Transit Use, the Program to Encourage HOV Use, and the Measures Package may have been overestimated. Future work is needed to monetize the real resource cost portion of the loss in consumers’ surplus associated with these alternative transportation modes.

In future versions of the CIMS transportation model, it will also be beneficial to account for the real resource cost portion of intangible costs associated with reducing transportation activity levels altogether (as under the Program to Reduce Urban Activity, the CO₂ Tax, and the Measures Package). Future work, especially in linking the transportation model to the CIMS Macro-Economic Model, may allow for the inclusion of such costs.
Finally, cost information is required for the freight transportation technologies within the transportation component of CIMS.

4.4.5 Social Welfare Costs

The previous section notes that the cost results that have been presented in this report are not a perfect representation of expected resource costs. Even if they were, however, additional information would still be required in order to properly inform the policy process. This is because although resource costs provide policy makers with a good indication of whether or not measures are attractive financially, they do not provide a very good indication of true social costs or of political acceptability. Expected resource costs do not fully account for losses in consumers’ surplus that may occur as a result of a measure. A social welfare cost account, on the other hand, would acknowledge all losses in consumers’ surplus, along with the other cost elements encompassed by expected resource costs.

It is suggested that future work be done to estimate the social welfare costs associated with measures for reducing GHG emissions from the transportation sector. Accounting for all social welfare costs will be a challenge, because losses in consumers’ surplus associated with reductions in passenger vehicle use are extremely difficult to monetize, and are poorly understood despite their importance. The challenge must be met however, if we are to make truly informed decisions with respect to transportation sector GHG mitigation policy. Although the expected resource cost results presented in this report are extremely valuable to the policy process, the final piece of the puzzle will be an understanding of full social welfare costs.
Appendix A:

Calibration of Fuel Consumption Output

The fuel consumption output of the Canadian Integrated Modelling System (CIMS) transportation model has been calibrated to Canada’s Emissions Outlook: An Update (CEOU) (AMG, 1999) in the base year (1995), as well as in forecast year 2010. The criteria for calibration were that the CIMS results be within 5% of CEOU in 1995 and within 10% in 2010. CIMS was calibrated to CEOU for all major fuel types. The following fuel types were not included in the calibration procedure: propane, natural gas, methanol, ethanol, hydrogen, aviation gasoline, and marine gasoline. These fuels are responsible for only a small portion of overall energy use, and very little information was available on how consumption estimates were determined by the AMG. Table A-1 compares fuel consumption estimates from CIMS to those of CEOU for the Canadian transportation sector in 1995. Table A-2 compares fuel consumption forecasts for the year 2010.
Table A-1 Calibration of fuel consumption, 1995

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>CEOU (PJ)</th>
<th>CIMS Transportation (PJ)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Road Gas(^1)</td>
<td>1,153.6</td>
<td>1,181.0</td>
<td>-2.4</td>
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<tr>
<td>Off-Road Gas</td>
<td>64.8</td>
<td>64.8</td>
<td>0.0</td>
</tr>
<tr>
<td>On-Road Diesel</td>
<td>444.6</td>
<td>432.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Off-Road Diesel</td>
<td>174.5</td>
<td>174.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.0</td>
<td>2.9</td>
<td>3.3</td>
</tr>
<tr>
<td>Aviation Turbo Fuel</td>
<td>181.0</td>
<td>181.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>Rail Diesel</td>
<td>80.9</td>
<td>80.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Marine Heavy Fuel Oil</td>
<td>56.6</td>
<td>56.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Marine Diesel Fuel Oil</td>
<td>45.2</td>
<td>45.4</td>
<td>-0.4</td>
</tr>
<tr>
<td><strong>Total(^2)</strong></td>
<td><strong>2,246.9</strong></td>
<td><strong>2,249.8</strong></td>
<td><strong>-0.1</strong></td>
</tr>
</tbody>
</table>

\(^1\) Farm motor gasoline use has been included in this category for the purpose of calibration.

\(^2\) Totals do not equal the sum of the individual fuel consumption forecasts because some fuel categories have been excluded from the table.
In the base year, calibration was within 5% for all of the fuels listed, as well as for total energy use. In the year 2010, calibration was within 10% for all fuels except electricity. Total energy use easily met the 10% criterion. Electricity demand increases over time in the CIMS transportation model, while remaining constant over the modelling period in the CEOU forecasts. Electricity is consumed by public transit vehicles in CIMS, and because public transit use is assumed to grow over the forecast period, an increase in electricity demand is seen. Although the CIMS results shown here are for a Business-as-Usual (BAU) case where no action is taken to mitigate GHG emissions, transit use is still assumed to rise due to an overall increase in personal transportation sector activity.
Appendix B:
Changes in Fuel Consumption Associated with the Measures Package

The changes in fuel consumption that are associated with the Measures Package affecting the personal transportation sector are shown in Table B-1 below. Changes are presented relative to the Business-as-Usual (BAU) case for the year 2010.

Table B-1 Changes in fuel consumption (PJ) associated with the Measures Package in 2010

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>Measures Package</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Road Gas</td>
<td>1,347.5</td>
<td>830.8</td>
<td>516.7</td>
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<tr>
<td>Off-Road Gas</td>
<td>80.8</td>
<td>80.8</td>
<td>0.0</td>
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<tr>
<td>On-Road Diesel</td>
<td>584.5</td>
<td>591.1</td>
<td>-6.6</td>
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<tr>
<td>Off-Road Diesel</td>
<td>243.7</td>
<td>243.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Electricity</td>
<td>4.2</td>
<td>18.4</td>
<td>-14.2</td>
</tr>
<tr>
<td>Propane</td>
<td>8.3</td>
<td>5.5</td>
<td>2.8</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>4.2</td>
<td>2.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.5</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.0</td>
<td>25.6</td>
<td>-25.6</td>
</tr>
<tr>
<td>Aviation Turbo Fuel</td>
<td>279.1</td>
<td>279.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Rail Diesel</td>
<td>89.2</td>
<td>89.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Marine Heavy Fuel Oil</td>
<td>62.3</td>
<td>62.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Marine Diesel Fuel Oil</td>
<td>49.7</td>
<td>49.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>2,754.3</td>
<td>2,279.5</td>
<td>474.8</td>
</tr>
</tbody>
</table>
Bibliography


Environmental Protection Agency. April 1990. *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel*.


