



---

Year 2006

UCD—ITS—RR—06—02

---

# Impact of Canada's Voluntary Agreement on Greenhouse Gas Emissions from Light Duty Vehicles

Nicholas P. Lutsey

**Impact of Canada's Voluntary Agreement on  
Greenhouse Gas Emissions from Light Duty Vehicles**

Research Report  
UCD-ITS-RR-06-02

January 9, 2006

Nicholas P. Lutsey  
Institute of Transportation Studies  
University of California, Davis  
One Shields Ave.  
Davis, CA 95616  
[nplutsey@ucdavis.edu](mailto:nplutsey@ucdavis.edu)

## **ABSTRACT**

On April 5, 2005, a voluntary agreement between the automobile industry and government officials of Canada was reached to commit to greenhouse gas emission reductions through the year 2010. This report compares Canada's voluntary agreement with other voluntary and mandatory greenhouse gas reduction programs around the world in terms of what technologies are likely to be deployed and how much vehicle fuel consumption is likely to improve. It investigates various methods and measurement approaches for implementing the agreement, incorporating the potential effects of criteria pollutant emission reductions, fuel use modifications (including the effects of lower sulfur fuels and ethanol), and vehicle technology adoption (including mobile air conditioning systems). The findings of this study suggest that the decisions of the official MOU oversight committee on how to credit various existing automobile technology trends could substantially impact total emission reductions and the deployment of fuel efficiency technology in Canada. Based on the committee's determinations, Canada's voluntary agreement could result in substantially improved fuel economy, or it could have little or no effect. This analysis raises broader questions regarding the efficacy and effectiveness of voluntary agreements, relative to regulatory initiatives.

## TABLE OF CONTENTS

<b>ABSTRACT .....</b>	<b>ii</b>
<b>TABLE OF CONTENTS .....</b>	<b>iii</b>
<b>ABBREVIATIONS.....</b>	<b>iv</b>
<b>LIST OF TABLES AND FIGURES.....</b>	<b>v</b>
<b>INTRODUCTION .....</b>	<b>1</b>
<i>Background.....</i>	<i>1</i>
<i>Research Objectives.....</i>	<i>2</i>
<b>ANALYSIS.....</b>	<b>3</b>
<i>Reference Case .....</i>	<i>4</i>
<i>Greenhouse Gas Reduction Mechanisms.....</i>	<i>4</i>
Rated Test-Cycle Vehicle Efficiency .....	5
Nitrous Oxide and Methane Emissions .....	8
Increased Ethanol Mix in Gasoline .....	12
“On-Road” Vehicle Efficiency.....	16
Mobile Air Conditioning Systems.....	19
<b>RESULTS.....</b>	<b>23</b>
<i>Summary and Range of Greenhouse Gas Reduction Implementation Strategies.....</i>	<i>23</i>
“Full Mix” Greenhouse Gas Reduction Implementation Scenario .....	24
“All New Efficiency” Greenhouse Gas Reduction Implementation Scenario .....	25
Range of Potential Greenhouse Gas Reduction Implementation Scenarios .....	27
<i>Potential Impact of Greenhouse Gas Reduction Crediting on Actual Reductions.....</i>	<i>28</i>
<i>Comparison of Greenhouse Gas Reduction Initiatives.....</i>	<i>29</i>
<b>CONCLUSIONS.....</b>	<b>30</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>32</b>
<b>REFERENCES .....</b>	<b>33</b>

## ABBREVIATIONS

ACEA:	Association des Constructeurs Européens D'Automobiles
CAFC:	Company Average Fuel Consumption
CAFE:	Corporate Average Fuel Economy
CARB:	California Air Resources Board
CEC:	California Energy Commission
CH <sub>4</sub> :	Methane
CO <sub>2</sub> :	Carbon dioxide
CO <sub>2</sub> e:	Carbon dioxide equivalent
CVMA:	Canadian Vehicle Manufacturers' Association
DOT:	Department of Transportation (United States)
E10:	Motor fuel with 10% ethanol and 90% gasoline (by volume)
ECMT:	European Conference of Ministers of Transport
EEA:	Energy and Environmental Analysis, Inc.
EEP:	Ethanol Expansion Program
EPA:	Environmental Protection Agency (United States)
EU:	European Union
GHG:	Greenhouse gas
GWP:	Global warming potential
HFC:	Hydrofluorocarbon
IEA:	International Energy Agency
Km:	Kilometer
MAC:	Mobile air conditioning
MLIT :	Ministry of Land, Infrastructure and Transport (Japan)
MOU:	Memorandum of Understanding
MT :	Million tonnes (metric)
MY:	Model year
N <sub>2</sub> O:	Nitrous oxide
NESCCAF	Northeast States Center for a Clean Air Future
NHTSA:	National Highway Traffic and Safety Administration
NLEV:	National Low Emission Vehicle
NMOG:	Non-methane organic gases
NO <sub>x</sub> :	Oxides of nitrogen
NRCan:	Natural Resources Canada
R-134a:	Refrigerant 134a (1,1,1,2-Tetrafluoroethane, C <sub>2</sub> F <sub>4</sub> H <sub>2</sub> )
R-152a:	Refrigerant 152a (1,1- Difluoroethane, C <sub>2</sub> F <sub>2</sub> C <sub>4</sub> )
SAC:	Standardization Administration of China
SFTP:	Supplemental Federal Test Procedure
THC:	Total hydrocarbons
TPMS:	Tire pressure monitoring system

## LIST OF TABLES AND FIGURES

### *Tables:*

Table 1. Summary of Emission-Reduction Mechanisms for Implementation of Canada GHG MOU .....	23
Table 2. Effect of GHG Emission-Reduction Credit from Various GHG Implementation Strategies on Required New Vehicle Rated Carbon Dioxide Emission Rate .....	27

### *Figures:*

Figure 1. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case and MOU Agreement Reductions.....	3
Figure 2. Reference, Actual, and Forecast Fuel Consumption for New Light Duty Vehicles in Canada for Model Years 1996 through 2010.....	7
Figure 3. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Updated and Expected New Vehicle Fuel Efficiency Improvements, and MOU Agreement Reduction Level.....	8
Figure 4. Light Duty Vehicle Oxides of Nitrogen (NO <sub>x</sub> ) and Hydrocarbon (HC) Standards by Model Year.....	9
Figure 5. Average Light Duty Vehicle Methane (CH <sub>4</sub> ) Emission Rate from 1998 to 2010 .....	11
Figure 6. Average Light Duty Vehicle Nitrous Oxide (N <sub>2</sub> O) Emission Rate from 1998 to 2010 .....	11
Figure 7. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Estimated Tier 2 N <sub>2</sub> O and CH <sub>4</sub> Emissions Reductions, and MOU Agreement.....	12
Figure 8. Light Duty Vehicle Gasoline and Ethanol Use .....	14
Figure 9. Fuel Greenhouse Gas Content With Increased Ethanol Content.....	15
Figure 10. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Increased Ethanol Mixing, and MOU Agreement.....	15
Figure 11. Assumed Improvement in On-Road Fuel Consumption Degradation Factor for New Vehicles and Across Entire Light Duty Fleet.....	18
Figure 12. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, “On-Road” Improvements, and MOU Agreement.....	18
Figure 13. New Light Duty Vehicle Greenhouse Gas Emissions – Reference and With MAC Improvements, 2000-2010 .....	22
Figure 14. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Estimated Mobile Air- Conditioning System Emissions Reductions, and MOU Agreement .....	22
Figure 15. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case with “Full Mix” of GHG Reduction Mechanisms and the MOU Agreement Target .....	24
Figure 16. Reference, Actual, and Required Additional Fuel Efficiency Improvements for New Light Duty Vehicles for “All New Efficiency” GHG Reduction Scenario.....	26
Figure 17. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Adjusted Reference Case, "All New Efficiency" GHG-Reduction Scenario, and the MOU Agreement Target .....	26
Figure 18. Actual MOU GHG Emission Reduction Requirements After Considering the Crediting of Various Ongoing Emission Reduction Mechanisms .....	28
Figure 19. Comparison of National Fuel Consumption and Greenhouse Gas Emission Initiatives (Based on An and Sauer, 2004).....	29

## INTRODUCTION

### *Background*

On April 5, 2005, the Canadian automobile industry signed a Memorandum of Understanding (MOU) with the Government of Canada to reduce greenhouse gas (GHG) emissions from vehicles. The Canada MOU is the latest of numerous initiatives around the world aimed at reducing GHG emissions from automobiles. In part inspired by Kyoto Protocol emission reduction commitments, many countries have adopted a variety of rules, policies, and agreements to improve vehicle fuel economy. In Europe, a voluntary agreement by automakers calls for a 25% reduction in the carbon dioxide (CO<sub>2</sub>) emission rate of light duty vehicles between 1995 and 2008 (ACEA, 2004). Standards in Japan require fuel economy improvements of approximately 23% between 1995 and 2010 (MLIT, 2001). China has enacted fuel consumption standards for new light duty vehicles for the first time (SAC, 2005). California's proposed climate change standard would reduce climate change emissions by about 30% for vehicles by model year 2016 (CARB, 2004). Eight U.S. states are committed to the California regulation, and others have expressed interest. In addition, non-CO<sub>2</sub> initiatives are aimed at mitigating GHG emissions from mobile air-conditioning systems in Europe and in California (EU, 2004; CARB, 2004).

The Canada MOU commits major auto manufacturers and the Government of Canada to cooperate to reduce light duty vehicle GHG emissions in the year 2010 by 5.3 million metric tonnes (MT) of carbon dioxide equivalent (CO<sub>2</sub>e) emissions relative to a reference case (NRCan, 2005a). The parties agreed to lower interim emission reductions for years 2007 to 2009 and agreed to meet to establish and update the reference case as needed. As part of the agreement, the auto industry is to offer, market, and deploy GHG emission reduction technologies to vehicle consumers, and the government will lead various programs to encourage consumer awareness and education about vehicle maintenance and vehicle purchasing options that result in GHG emission reductions.

The climate change initiative is a departure from the standard practice in Canada of controlling automobile emissions and fuel efficiency by adhering to regulatory actions in the United States. Historically, Canada's automobile emissions and fuel efficiency characteristics are set to be consistent with, or harmonized with, the comparable light duty vehicle standards set forth by the U.S. Environmental Protection Agency and the U.S. Department of Transportation's National Highway Traffic and Safety Administration. Canada's adoption of U.S. emissions and fuel consumption levels is generally formalized by a series of MOU agreements between the Canadian Government and the automotive industry trade associations. Examples of such MOUs are those for adoption of fuel consumption targets consistent with U.S. Corporate Average Fuel Economy (CAFE) standards, U.S. Tier 1 emission standards (model years 1994-2000), the U.S. National Low Emission Vehicle program (2001-2003), and U.S. Tier 2

emissions standards (2004-2009) (NRCan, 2005b). Also consistent with U.S. Tier 2 standards regarding gasoline sulfur content, the Canadian Government passed regulations to phase in low-sulfur fuel (30 parts per million average) as part of the *Canada Environmental Protection Act* of 1999 (Environment Canada, 1999).

The voluntary GHG agreement was announced in the media as a victory for the environment and for the auto industry. It was championed as an expedient and effective way to reduce GHGs, bypassing contentious rules in favor of a voluntary measure that neither forces specific technology, adds new regulations, nor imposes fines for non-compliance. Then Natural Resources Minister, Hon. John Efford, commented, “This is a good deal for the economy, the environment and consumers” (Canadian Press, 2005). Ford of Canada Chief Executive Officer and chair of the Canadian Vehicle Manufacturers’ Association, Joe Hinrichs, cited industry’s long history of producing more environmentally friendly vehicles and stated, “We remain committed to doing our fair share to reduce GHG emissions while contributing to economic growth” (Canadian Press, 2005). Environmental group representatives praised the commitment, estimating that it would increase fuel economy by 25%, stating it would offer consumers “greater choice of efficient, low-emitting cars in the very near future,” and predicting that it could strengthen efforts in the U.S. to reduce GHG emissions from light duty vehicles (Plungis and Mayne, 2005).

### ***Research Objectives***

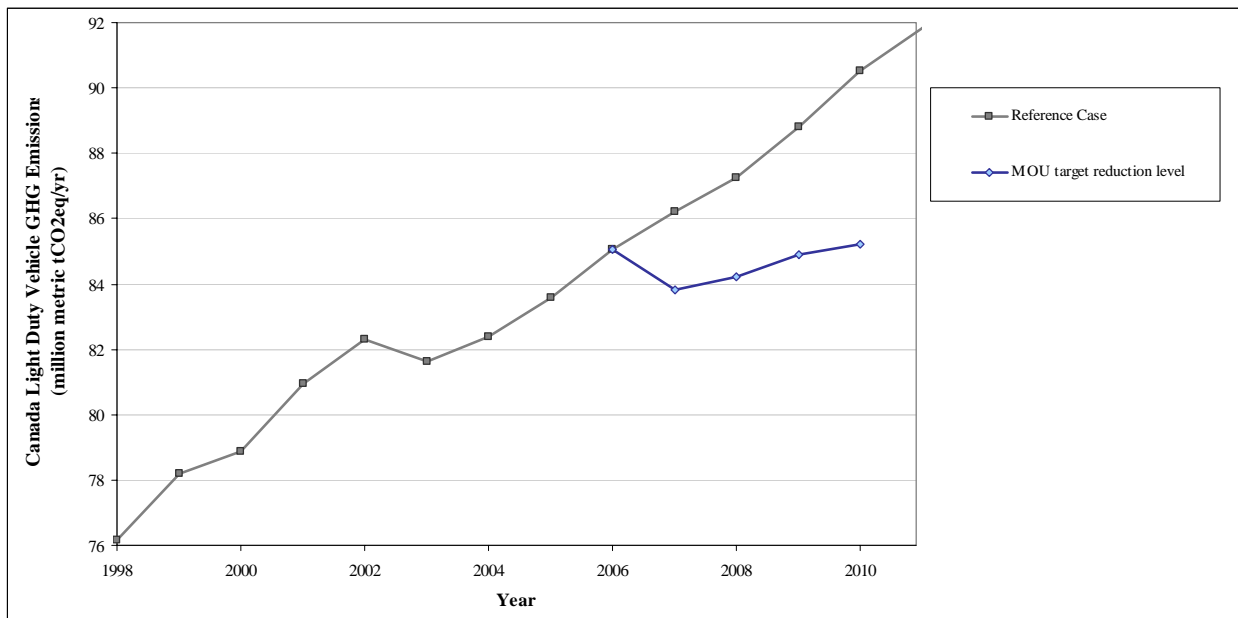
Although the MOU was heralded as a “win-win” situation, making sense of the agreement and what exactly it means for new vehicles was left unresolved. With the agreement framed in terms of an overall sector emissions tonnage reduction (i.e., 5.3 MT of CO<sub>2</sub>-equivalent emissions in the year 2010), questions remain about what effect the MOU really would have. How much of the GHG reductions would take place anyway as a result of already scheduled reductions in vehicle criteria emissions? How much effect will the agreement have on new vehicles relative to changes and improvements already planned? And what is the benchmark: how does this new agreement compare with other light duty vehicle initiatives around the world, especially in Europe and Japan? California-like targets (i.e., 30% CO<sub>2</sub>-equivalent emission rate reduction) were under consideration previous to the MOU agreement (Bustillo, 2005; Ljunggren, 2005); how does the Canada agreement compare with the California initiative?

This report quantifies the possible effects of the voluntary agreement on GHG emissions from light duty vehicles through 2010. The potential impacts of various implementation designs are investigated to examine the effect of different assumptions. These insights and findings could assist the official MOU oversight committee, the “Joint GHG MOU Committee,” in designing the emission reduction crediting process, and the development of voluntary agreements more generally.



## ANALYSIS

Figure 1 shows the Reference Case light duty vehicle GHG emissions with respect to MOU target emission reductions. The Reference Case is based on official Canada data (NRCan, 1999), and each potential GHG-reduction mechanism would result in a vertical drop from this Reference in the figure toward the MOU target emission reduction levels in years 2007 through 2010. The key characteristics of the Reference Case are discussed in the subsection below. In the following subsection, this report identifies the key technologies that could be deployed to meet the GHG emission reductions and quantifies their potential contribution toward the MOU emission targets. To meet the MOU-designated emission reductions for the entire light duty vehicle fleet, industry could receive emission reduction credit for verified reductions in several different areas: rated vehicle CO<sub>2</sub> emission rate, mobile air-conditioning systems, exhaust emissions of N<sub>2</sub>O and CH<sub>4</sub>, lower GHG fuel properties, and actual “on-road” CO<sub>2</sub> emission rate (which could be independent of laboratory-derived rated CO<sub>2</sub> emissions). In addition, the likelihood of the deployment of each these GHG emission-reduction technologies independent of the MOU is assessed in the GHG reduction mechanism subsection. In the “Results” section, various combinations of the GHG emission-reduction mechanisms are considered to explore the full range of possibilities of the impact of the MOU.



**Figure 1. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case and MOU Agreement Reductions**

## ***Reference Case***

As established by the Canada MOU, the official reference case for the agreement is based upon the 2010 forecast in Study 3 of the Canadian government's Transportation Climate Change Issues Table 1999, titled *Road Vehicle & Fuels Technology Measures Analysis* (EEA, 1999). The assumptions of that study in turn are based on the vehicle characteristics and emissions forecasts from *Canada's Emissions Outlook: An Update* by Natural Resources Canada (NRCan, 1999). More fundamentally, these reference case GHG emissions are based on estimates of vehicle use (kilometer/year), vehicle stock characteristics (including new vehicle sales and retirement), and GHG emission factors. These variables differ by vehicle type (passenger cars, light trucks), fuel type (gasoline or diesel), calendar year, and vehicle model year. The relevant GHG emissions included are carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), hydrofluorocarbons (e.g., HFC-134a), and other gases that are equated to an equivalent value (CO<sub>2</sub>e).

The Reference Case for GHG emissions in 2010 is to be updated periodically from the 1999 values by the MOU oversight committee according to the principles described in the MOU. As the oversight committee monitors the MOU implementation in future years, it will differentiate between exogenous and endogenous variables. The exogenous variables are those considered to be outside of direct industry control and therefore will change the reference case GHG emissions. These variables include technical variables (e.g., global warming potential of emissions, fuel carbon content), total vehicle sales, vehicle sales mix (cars vs. light trucks), vehicle travel, and vehicle retirement rates. There are countless ways in which the exogenous variables can change as the MOU is monitored through 2010; however, changes in these variables, being both unpredictable and unlikely to significantly affect the analysis, are not considered here. The focus of the analysis is on endogenous variables, such as new vehicle rated GHG emissions (grams per mile CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O), air-conditioning system refrigerant type, fuel-GHG properties, and the vehicle "on-road" fuel consumption correction factor. These variables are to be monitored and credited as they contribute toward the industry's GHG reduction targets (Reilly-Roe, 2005).

## ***Greenhouse Gas Reduction Mechanisms***

Investigated here are the nearest-term low-GHG-emitting vehicle technologies – those that are either in the marketplace now (in small numbers) or are set to phase in to new light duty vehicles (by government regulation and/or voluntary industry introduction) in the next five years. In this section we investigate the technical literature, regulatory measures both within and outside of Canada, and industry press releases on

low-GHG emissions technologies. Examined here for deployment in Canada's vehicle fleet through 2010 are potential GHG emission improvements in five main areas: (1) rated test-cycle vehicle efficiency, (2) methane and nitrous oxide emission reductions resulting from Tier 2 criteria pollutant regulations, (3) increased ethanol mixing in gasoline, (4) actual "on-road" fuel efficiency, and (5) mobile air conditioning systems. For each of these technology areas, the impact of the deployment on vehicle GHG emissions in the Canada light duty fleet is quantified. In this section, each of the technology areas is discussed individually. In the "Results" section, the impact of the deployment of combinations of these technologies towards meeting the MOU-established emission reductions is examined.

### **Rated Test-Cycle Vehicle Efficiency**

One of the more evident approaches to be applied by automakers to meet the GHG reduction pact is the deployment of technologies that improve the fuel efficiency of vehicles. Many studies have assessed technologies for light duty vehicles to improve vehicle efficiency in order to increase fuel economy and reduce GHG emissions (e.g., Austin et al, 1999; DeCicco et al, 2001; EEA, 2001; NRC, 2002; Plotkin et al, 2002; Weiss et al, 2000). Engineering-economic studies of this nature generally apply emerging technologies to new vehicles in vehicle simulations on test cycles, such as the U.S. Federal Test Procedure "city" and "highway" cycles. Smaller magnitude, near-term changes in efficiency – those considered for this study – involve incremental (i.e., not hybrid gas-electric or alternative fuel vehicles) vehicle modifications that are already emerging in the marketplace. Such technology packages that yield up to 20% reduction in CO<sub>2</sub> emission rates include combinations of engine (variable valve lift/timing, gasoline direct injection, cylinder deactivation) and transmission (5- and 6-speed automatic and automated manual transmissions) technologies.

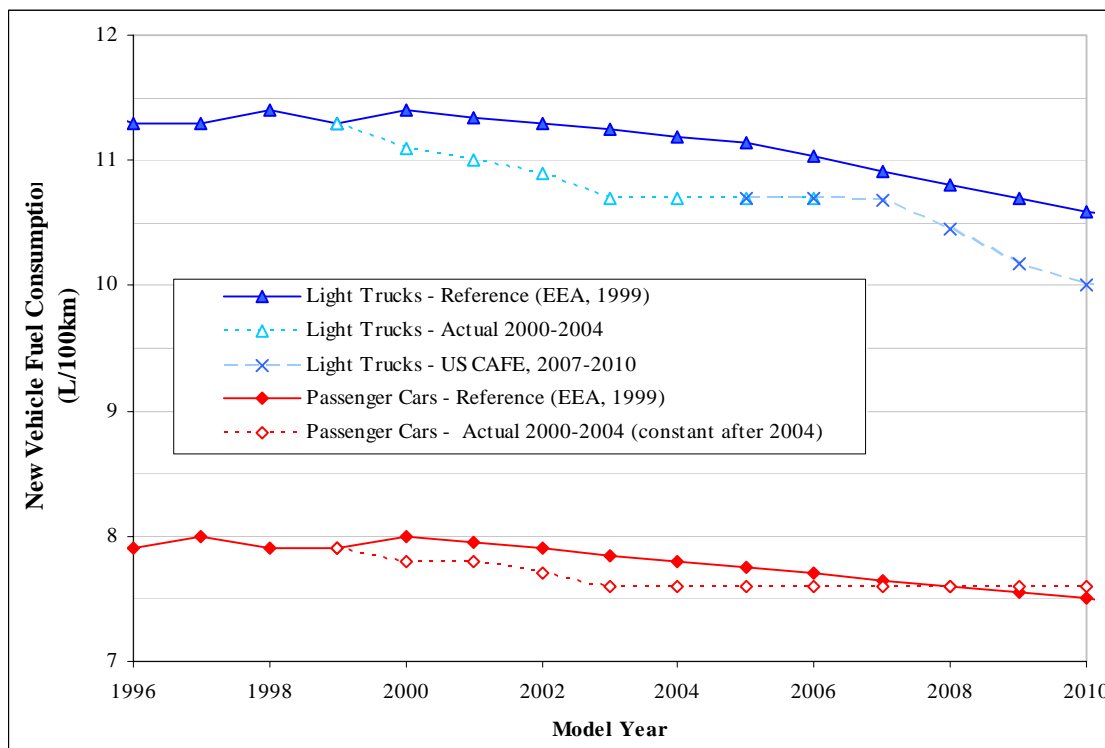
For this study, advances in two types of light duty vehicle fuel economy – test-cycle and actual "on-road" – are considered for potential GHG emission reductions. This distinction is used because these two factors are treated as separate endogenous variables that are to be accounted for independently toward fleet emission reduction goals in the Canada MOU. Test-cycle measurements are used by regulators to determine compliance by vehicle suppliers with regulatory fuel economy or emission standards. With these tests, year-to-year new vehicle changes in emissions and fuel economy are reported by automakers and are easily validated. On the other hand, "on-road" or "in-use" efficiency improvements differ from regulatory test cycle standards in that they generally reflect vehicles, old or new, that are already on the road; can be altered by driver education initiatives; and can be evaluated from surveys and data collection on vehicle use over time. Potential in-use fuel efficiency-related emission reductions are addressed in the "On-Road" subsection, below.

Several trends and developments are pertinent to the discussion of what fuel efficiency advances in the Canada light duty fleet are likely through 2010. First, Canada's light duty fleet (both passenger cars and light trucks) have consistently done better than their Company Average Fuel Consumption (CAFC) targets, which are equivalent to the U.S. light duty Corporate Average Fuel Economy (CAFE) regulations. The Canadian auto industry has consistently been committed to achieving CAFC targets. As a result of various factors (such as lower average income, higher average fuel prices, and differing vehicle purchasing preferences) average new vehicle fuel consumption values in Canada are well below comparable U.S. values. For example, new vehicle fuel consumption (measured in L/100km) in 2004 for Canada is lower than for the U.S. (7% for cars, 5% for light trucks). Second, light truck fuel economy increases in the U.S. CAFE system will also affect Canadian new light truck fuel consumption. Canadian vehicle manufacturers are committed to improvements in new vehicle fuel consumption to stay on par with U.S. light truck fuel economy standards through model year 2007. New U.S. light trucks standards for model years 2008 through 2010 have also been proposed (NHTSA, 2005b). Based on historical trends, near identical product offerings in the U.S. and Canada, and ties between U.S. manufacturing and Canada sales, the Canada light truck market would presumably have fuel economy at least as high as the new proposed U.S. light truck CAFE values for model years 2008 through 2010.

In determining compliance with the voluntary agreement, the Canadian auto industry could be credited for GHG reductions for the already achieved (model years 2000-2004) fuel efficiency improvements as well as from the future light truck improvements related to U.S. light truck CAFE standard increases. The case for awarding credit to the manufacturers for improvements in years prior to the signing of the 2005 MOU agreement is based on the idea that Canadian government officials and industry representatives began discussions on establishing more stringent fuel efficiency targets as early as year 2000. And, because the actual vehicle fuel consumption for model years 2000 through 2004 has been significantly lower than the official reference case which was forecasted in 1997, it is not perfectly clear whether the baseline will be adjusted for the up-to-date fuel consumption values or whether industry will be credited with the earlier-than-MOU-agreement reductions. It is conceivable that the automakers started working toward deploying and marketing low-GHG technologies before the actual signing (and not simply that Canadian consumers chose lower fuel consumption vehicle models). However, considering that historical trends of actual new vehicle fuel consumption have consistently been below CAFC targets independent of the MOU agreement, it is also plausible that these fuel consumption levels would have occurred regardless.

Figure 2 shows the official Natural Resources Canada (NRCan) "Reference Case" fuel consumption data for passenger cars and light trucks for 1996 through 2010. Also shown are actual model year 2000 to

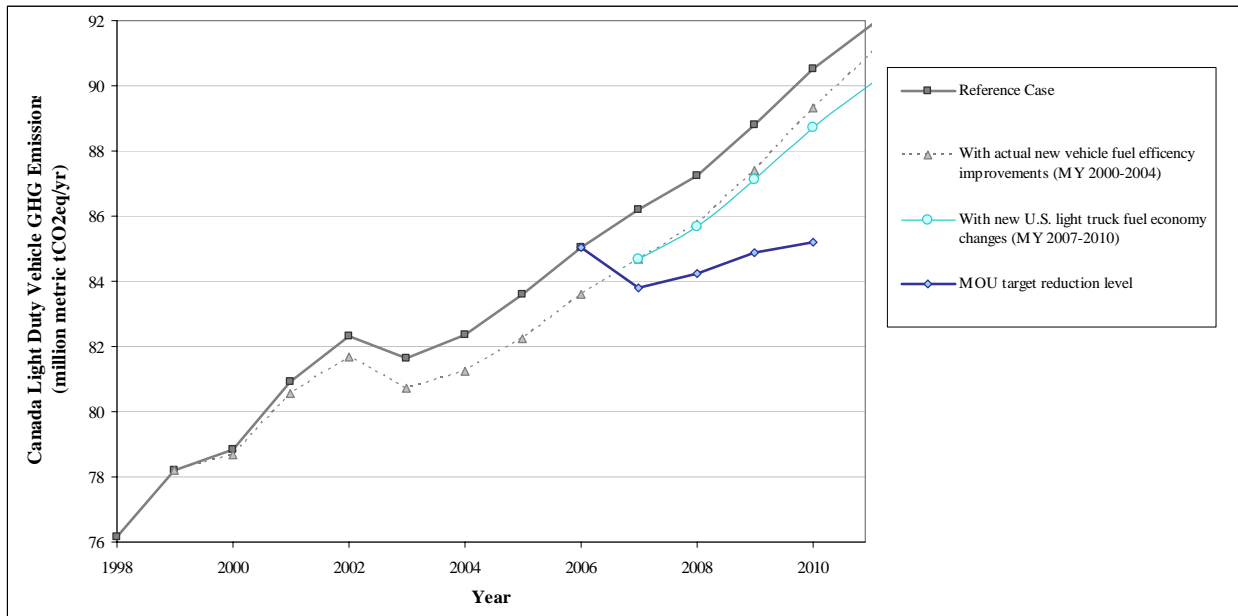
2004 fuel consumption data, which are below the reference case data for these model years. The largest difference between the reference and actual new vehicle fuel consumption is in the year 2003, when actual values are about 4% (4.8% for light trucks and 3.2% for passenger cars) lower than for the reference case. Beyond model year 2004, it is assumed that new passenger car fuel consumption will remain constant (with no planned CAFE or CAFC changes). New light truck fuel consumption will be at or below values from the latest NHTSA rulemaking for light trucks 2005 through 2010. Therefore, average light truck fuel consumption remains constant from present values until model year 2007, after which the light truck CAFE standard becomes more stringent. This change to conform with light truck CAFE results in an increase in light truck fuel economy from 22.0 to 23.5 miles per gallon (or a decrease in fuel consumption from 10.7 to 10.0 L/100 km) between model years 2007 and 2010.



**Figure 2. Reference, Actual, and Forecast Fuel Consumption for New Light Duty Vehicles in Canada for Model Years 1996 through 2010**

Figure 3 shows the effect of actual and expected test cycle fuel consumption improvements on the Canadian light duty fleet GHG emissions as the new vehicles are deployed into, and accumulate miles within, the automobile fleet through 2010. The inclusion of the effect of the lower fuel consumption rate of model year 2000 through 2004 vehicles reduces calendar year 2010 GHG emissions by 1.21 million metric tonnes (MT) of carbon dioxide equivalent (CO<sub>2</sub>e) emissions. This 1.21 MT CO<sub>2</sub>e reduction, if counted against the Canada MOU target of 5.3 MT CO<sub>2</sub>e, would be equivalent to 23% of the needed reductions. Including the effect of the U.S. CAFE standard increase for model years 2007 through 2010

light trucks reduces GHG emissions by 0.59 MT CO<sub>2</sub>e in year 2010, equivalent to 11% of the necessary 2010 reductions.



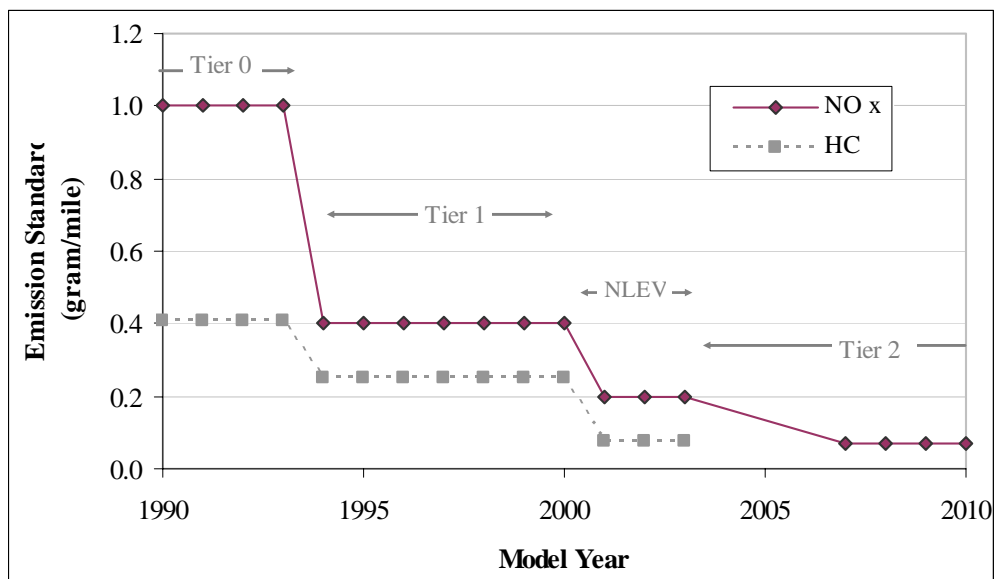
**Figure 3. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Updated and Expected New Vehicle Fuel Efficiency Improvements, and MOU Agreement Reduction Level**

### Nitrous Oxide and Methane Emissions

Greenhouse gas emission reductions from U.S. and Canada automobiles are likely to result from the U.S. Environmental Protection Agency’s Tier 2 emission program which reduces vehicle exhaust emissions of the criteria pollutants oxides of nitrogen (NO<sub>x</sub>) and hydrocarbons (HC). Tier 2 rules, finalized in 1999, lower tailpipe emissions of NO<sub>x</sub> by 77% for passenger cars and 95% for light trucks from Tier 1 emission levels and are to be phased in on new vehicles from model years 2004 to 2009. The more stringent tailpipe emission standard is coupled with a 90% reduction in the standard for gasoline sulfur content to 30 parts per million (ppm) in the year 2006 (U.S. EPA, 1999). Likewise, Canadian emissions levels are set to reduce in line with the U.S. Tier 2 emission and low-sulfur gasoline standards according to the 1999 *Canada Environmental Protection Act* (Environment Canada, 1999; NRCan, 2005c; GM Canada, 2005). Because nitrous oxide (N<sub>2</sub>O), a species of NO<sub>x</sub> in vehicle exhaust, is a GHG, the Tier 2 emission standards with low-sulfur fuel will indirectly result in GHG emission reductions. Potential reductions of hydrocarbons, and namely their GHG component methane (CH<sub>4</sub>), are also analyzed in this section.

Figure 4 shows the phase in by model year of NO<sub>x</sub> and HC emission standards. The National Low Emission Vehicle (NLEV) standards served as a transition between the Tier 1 standards and the phasing

in of Tier 2 standards from model years 2004 through 2009. The emission-reduction technologies required to meet the Tier 2 standards include engine control and design as well as improved aftertreatment systems. To meet the Tier 2 requirements, Kenney (1999) discusses two technology approaches: improved aftertreatment system performance and increasing exhaust gas recirculation with engine controls via variable cam phasing with improved aftertreatment. Similarly, MECA (2003) discusses the advanced aftertreatment catalyst systems together with engine operating strategies currently being used to achieve Tier 2 emissions compliance. A pilot study of on-road N<sub>2</sub>O emissions suggests that average emission levels are about 20 milligram/kilometer, or 0.03 grams/mile, suggesting that on-road emissions rates are in line with this regulatory level (Behrentz et al, 2004). A technology assessment for the proposed California GHG regulations neither anticipated, nor sought regulations for, more stringent N<sub>2</sub>O emission levels for new vehicles beyond model year 2010, when Tier 2 standards would be fully phased in (CARB, 2004).



**Figure 4. Light Duty Vehicle Oxides of Nitrogen (NO<sub>x</sub>) and Hydrocarbon (HC) Standards by Model Year**

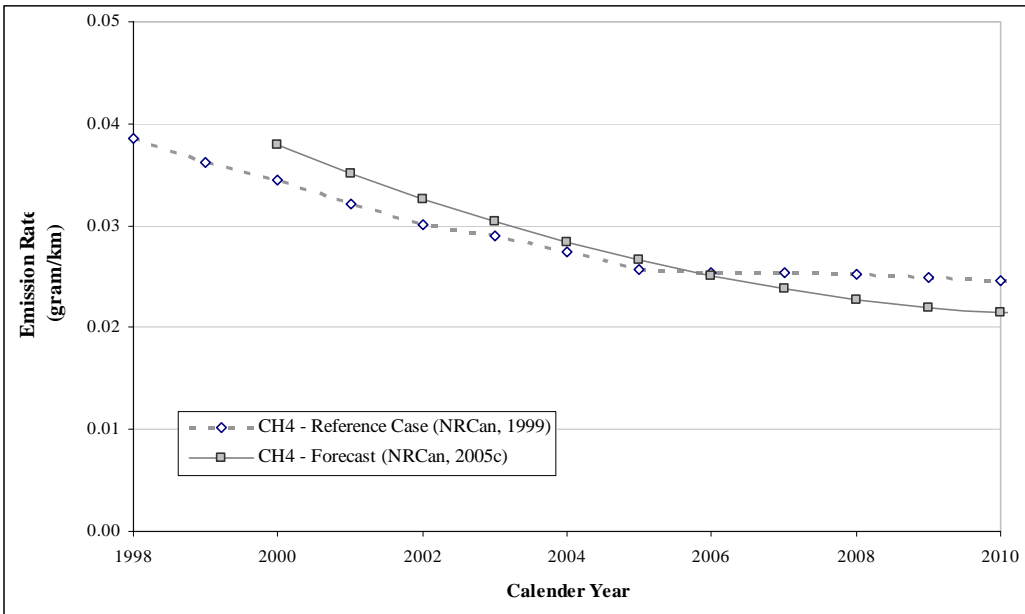
At present, it is uncertain whether or not emission reductions from Tier 2 regulations will be credited toward the Canada MOU 2010 GHG reduction target. The issue is not directly addressed in the MOU statement, and there are conflicting statements from industry in various media sources on the issue of crediting reductions from N<sub>2</sub>O emissions. In one news story on the MOU signing, an auto industry executive was cited as “adamant that there is ‘no double billing for NO<sub>x</sub>,’ allowed per the agreement” (IWP, 2005). However, a different industry statement implies that the Canadian auto industry expects to be credited with GHG emission reductions for their action in response to the Tier 2 criteria pollutant emission regulations; in a statement on automaker voluntary commitments to climate change, the industry commits to “Continued introduction of Tier 2 level emissions control systems which reduce N<sub>2</sub>O

emissions from new vehicles and, in conjunction with cleaner fuels, the N<sub>2</sub>O emissions of the entire fleet” (CVMA, 2005). The counterpoint to including these reductions holds that the Tier 2 emissions reductions were established in 1999 and would occur regardless of the signing of the Canada MOU on GHG emissions. As above in the fuel efficiency subsection, the GHG emission reduction impact from new vehicles of model year 2000 and later is considered.

Although tested gram-per-mile tailpipe N<sub>2</sub>O and CH<sub>4</sub> emissions will likely be reduced substantially from Tier 2 emissions vehicles entering the fleet, the effect of these emissions trends for GHG emissions in the Canadian fleet are not perfectly characterized. Here, emissions trends for Canadian vehicle N<sub>2</sub>O and CH<sub>4</sub> emissions are estimated from NRCan’s emissions data program, GHGenius version 3.0 (NRCan, 2005c). This program uses exhaust emissions data from the U.S. EPA’s MOBILE 6.2C emissions inventory and modeling tool, which does incorporate the phasing in of Tier 2 emissions vehicles with low sulfur fuel. These emissions forecasts are compared in this section against the official MOU Reference Case emission levels (from NRCan, 1999) to determine likely near-term GHG emission reductions.

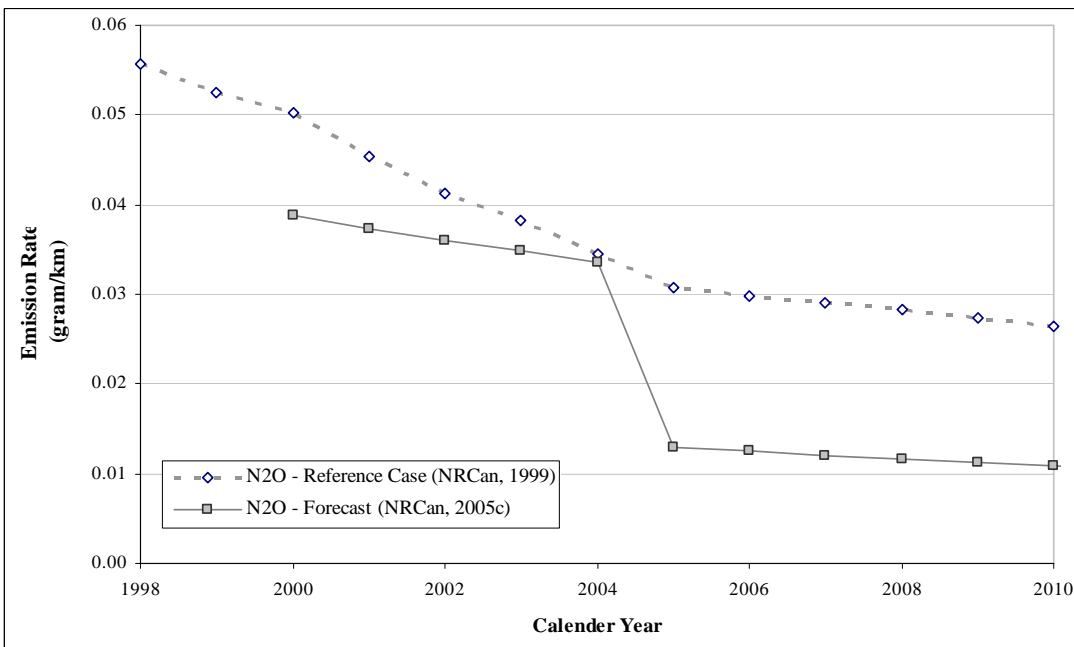
The reference and forecasted Tier 2 emission rates are shown by calendar year in Figure 5 (for CH<sub>4</sub>) and Figure 6 (for N<sub>2</sub>O). For both CH<sub>4</sub> and N<sub>2</sub>O, a gradual downward trend in vehicle emissions is shown as vehicles with Tier 2 technology (engine controls and/or improved catalysts) are phased into the fleet. Little difference is seen between the reference and forecasted CH<sub>4</sub> emissions in Figure 5, as the Tier 2 regulations for model year 2004 and beyond replace the standards for total hydrocarbons (THC) with standards for non-methane organic gases (NMOG). With the small differences shown in Figure 5’s reference and forecasted gram-per-mile curves, it is conceivable that differences are the result of data errors between the two sources (NRCan, 1999 and NRCan, 2005c).





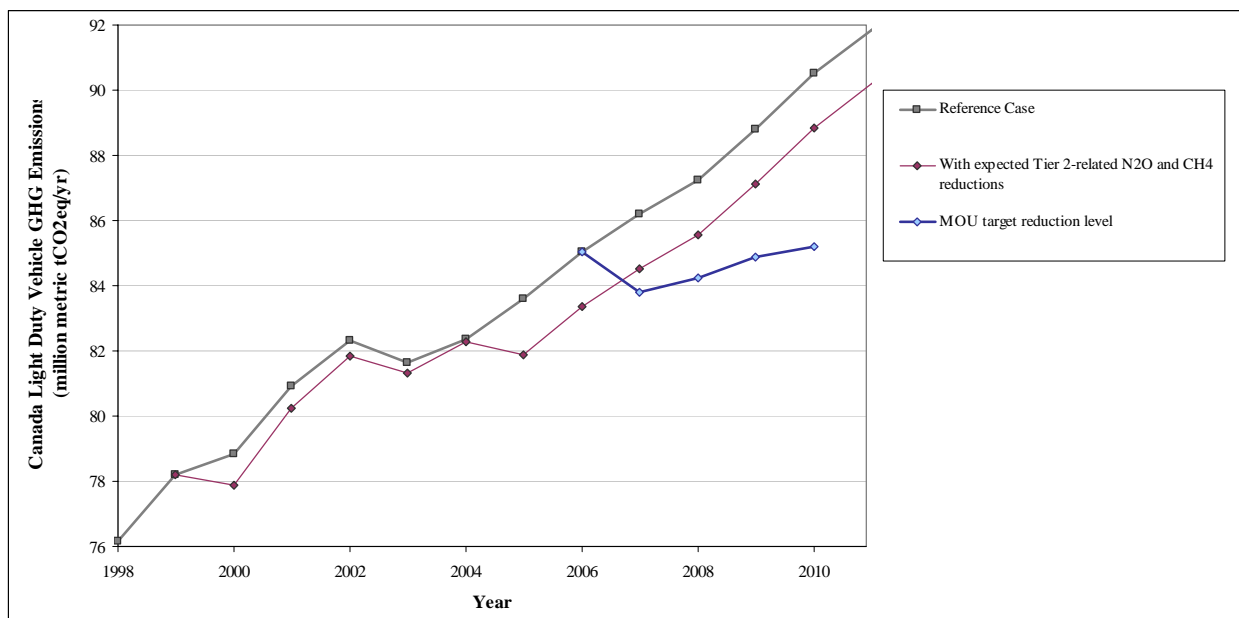
**Figure 5. Average Light Duty Vehicle Methane (CH<sub>4</sub>) Emission Rate from 1998 to 2010**

As shown in Figure 6, the N<sub>2</sub>O reference case appears to exclude the impacts of both the introduction of the NLEV vehicle (model year 2000-2003) and Tier 2 (model year 2004 and later) emission reduction technology. Also noteworthy in Figure 6 for N<sub>2</sub>O is the abrupt drop for calendar year 2005 emissions; this sharp decline is based on the emission reductions that result from regulatory shift to low-sulfur fuels (from an average of 300+ ppm to 30 ppm). For years 2005 through 2010, average gram-per-mile light duty vehicle N<sub>2</sub>O emissions are estimated to be 58-59% below their reference case emission levels.



**Figure 6. Average Light Duty Vehicle Nitrous Oxide (N<sub>2</sub>O) Emission Rate from 1998 to 2010**

Figure 7 shows the effects of model year 2000 and later N<sub>2</sub>O and CH<sub>4</sub> emissions reductions on the Canada light duty fleet's GHG emissions through 2010. In the year 2010, these Tier 2 emissions reductions are estimated to contribute a 1.65 MT CO<sub>2</sub>e reduction toward the 5.3 MT CO<sub>2</sub>e target, equivalent to approximately 31% of the MOU agreement 2010 target reduction. The vast majority of these Tier 2 reductions, 98.6%, are from N<sub>2</sub>O reductions, which are estimated to have larger gram-per-mile reductions from the reference emissions (Fig. 6) and have a higher global warming potential than methane.



**Figure 7. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Estimated Tier 2 N<sub>2</sub>O and CH<sub>4</sub> Emissions Reductions, and MOU Agreement**

### Increased Ethanol Mix in Gasoline

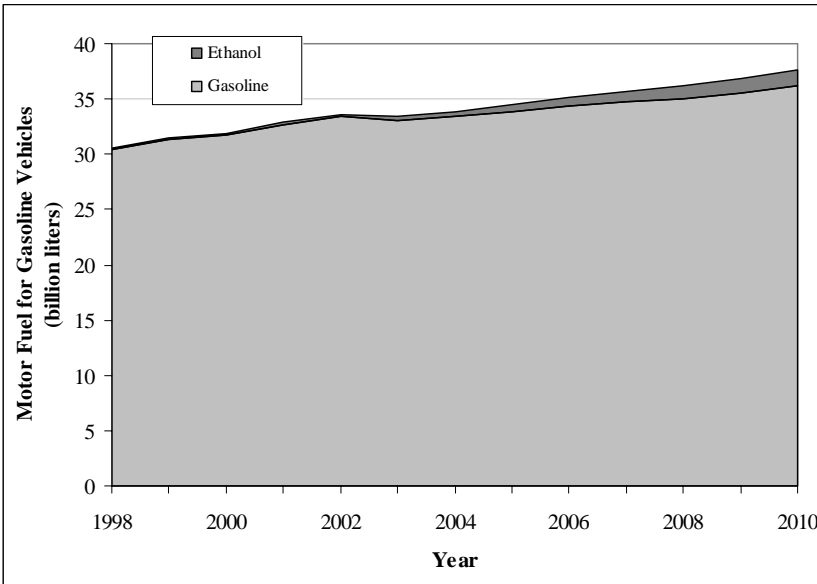
The increased use of ethanol in motor gasoline has the potential to reduce GHG emissions from the light duty vehicle sector. Ethanol derived from agricultural crops is a renewable fuel that harnesses CO<sub>2</sub> from the atmosphere to store energy in a chemical form that can be used to produce liquid fuels for vehicles. The net cycle of growing and harvesting crops, transporting and chemically converting the crop to usable fuel for vehicles, and combusting the fuel for motor vehicle propulsion can offer net GHG reductions, depending on crop feedstock and process characteristics. There are two primary methods of producing ethanol – from grain-based (generally corn-derived) and cellulose-based (from a variety of sources). Significant energy and GHG reduction can result from the introduction of grain-based corn ethanol and cellulosic ethanol into transportation fuels, and mixing ethanol into motor gasoline to up to 15% of the blended volume can be done without vehicle modifications.

Although there has been a lingering debate over the life-cycle energy efficiency and overall climate change emission impacts of utilizing grain as a fuel feedstock, recent studies indicate that improved technology has made today's corn-derived ethanol a net GHG benefit. One leading study from U.S. Department of Energy's Argonne National Laboratory suggests that present corn-based ethanol production technology improves GHG emissions to the tune of 12-19% per unit volume of ethanol in an E10 (10% ethanol, 90% gasoline) blend compared with gasoline. The same study's "corn-based, near-future" scenario indicated benefits of 24.1-26.4% GHG reduction per unit volume ethanol in E10 blended gasoline (Wang et al, 1999). Natural Resources Canada states that GHG reductions of up to 40% are achievable with the use of ethanol (derived from grains such as corn and wheat) in place of conventional motor gasoline (NRCan, 2004). Greater life-cycle GHG emission reductions at higher costs are available with the potential future use of cellulosic (instead of grain-based) ethanol; however, because of the short timeframe (i.e., through 2010) of this analysis on the Canada MOU and the current prototype-plant-stage of cellulosic ethanol technology, cellulosic ethanol is not considered here.

It is uncertain whether or not increased ethanol blending in gasoline will be officially considered for potential GHG reductions toward the MOU. The MOU oversight committee has not weighed in on this issue, but automotive industry press releases routinely list the use of increased alternative fuels such as ethanol as one of the approaches the industry is taking to help reduce automobile GHG emissions to meet the voluntary agreement with the Government of Canada. Listed along with efforts on deploying advanced lower fuel consumption technologies, the "Canadian Automotive Industry has voluntarily agreed to... develop and introduce... alternative fuel compatible vehicles" and "encourage the expanded use of alternative fuels, such as ethanol" (CVMA, 2005). However, a statement from a Canadian Government official suggests that increased ethanol blending is outside of the purview of the MOU agreement. A Natural Resources Canada official states, "Credit for the use of E-10 fuel cannot be applied to the 5.3 Mt target as increased production and use of ethanol fuel is being attributed to the government's Ethanol Expansion Program or related measures" (Khanna, 2005). Although the government official's language indicates that ethanol is unlikely to be included, the fact that some efforts have been made by automakers to accommodate ethanol blending (e.g., vehicle modifications that are minimal for E10 and more substantial for E85-compatible vehicles), and that automakers could therefore make a case to include ethanol as a GHG reduction mechanism, suggests that the prospect of expanded ethanol blending counting toward the MOU target should be assessed in this report.

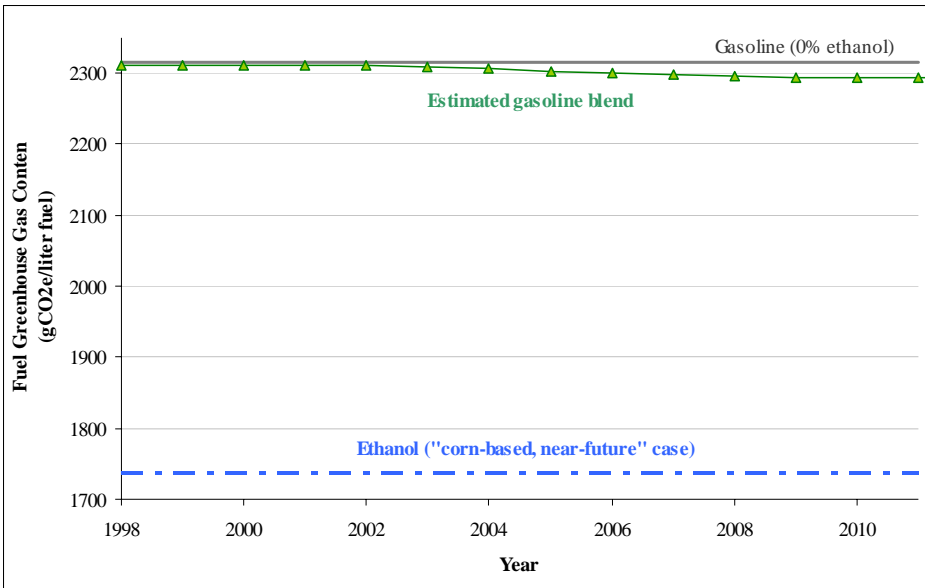
Canada launched its Ethanol Expansion Program (EEP) in 2003 to drastically increase the ethanol content in motor gasoline as part of Canada's climate change action plan. The EEP would increase ethanol production from 200 million liters in 2002 to 1.4 billion liters in 2010, increasing the percentage of E10

from approximately 7% to 35% over that period (NRCan, 2005d). For this analysis, the ethanol expansion from 2002 to 2010 is assumed to be linear. This increase, from 0.6% to 3.7% of the total gasoline mix, is shown with respect to the reference case gasoline use in light duty vehicles in Figure 8.



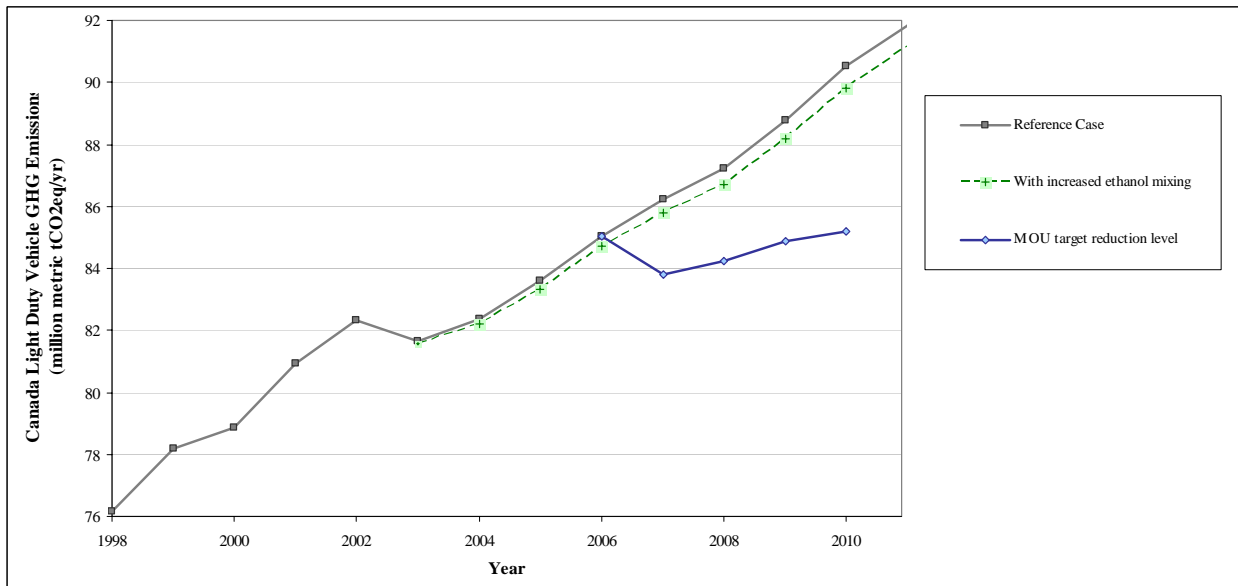
**Figure 8. Light Duty Vehicle Gasoline and Ethanol Use**

The life-cycle emission benefits from the “corn-based near-future” ethanol case in Wang et al (1999) are applied to the motor fuel mix changes to estimate the GHG emission benefits of the EEP program on light duty vehicle from 2000 to 2010. Although NRCan (2004) reports higher GHG benefits (“up to 40%” compared to Wang et al’s 24.1-26.4%) from corn-based ethanol, it does not readily pinpoint research sources and methods, so its values were not applied to this analysis. Using the official MOU reference case fuel GHG content of 2311 gram CO<sub>2</sub> per liter of motor fuel and an average 0.6% ethanol-99.4% gasoline mix in 2002, the change of the fuel GHG content is estimated as the increased ethanol quantity is added to gasoline. Based on Wang et al (1999), ethanol’s equivalent life-cycle GHG per volume is estimated to be 25% lower than for gasoline, or 1736 gram CO<sub>2</sub>e per liter. The change in the fuel GHG content with the ethanol expansion from 0.6% to 3.7% is shown in Figure 9.



**Figure 9. Fuel Greenhouse Gas Content With Increased Ethanol Content**

Light duty fleet GHG emissions impacts of the increased ethanol content in motor gasoline through the year 2010 are shown in Figure 10. The estimated effect of the ethanol program is to reduce GHG emissions by 0.68 MT CO<sub>2</sub>e in the year 2010. This is equivalent to 12.8% of the total 5.3 MT CO<sub>2</sub>e emission reduction target.



**Figure 10. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Increased Ethanol Mixing, and MOU Agreement**

## **“On-Road” Vehicle Efficiency**

Vehicle emissions testing is generally conducted on idealized test simulations that underestimate real-world “on-road” fuel consumption and emissions (and overestimate fuel economy in miles-per-gallon). Along with the investigation above of the GHG-reduction potential of laboratory-derived test-cycle vehicle efficiency improvements, potential CO<sub>2</sub>-emission reductions that result from real-world vehicles on the road (that are not necessarily recognized by new vehicle lab testing) are assessed here. From very early in CAFE testing, it was known that there was a gap between actual “on-road” fuel economy and lab-tested fuel economy (McNutt et al, 1982). Adjustment factors were put forward by U.S. EPA to decrease tested “highway” fuel economy by 22% and tested “city” fuel economy by 10% (Hellman and Murrell, 1984). Applying these adjustments decreases average tested fuel economy by approximately 15% to establish more accurate metrics for new vehicle fuel economy information for consumers and for use in public policy evaluations (however, the corrections are not used in official regulatory testing for CAFE standards). Research studies (see e.g., Mintz et al, 1993) and many media articles since have suggested that the “on-road” vs. tested fuel economy gap is widening. Official U.S. DOE estimates for future on-road energy use in light duty vehicles assume correction factors for both passenger cars and light trucks of about 20% (EIA, 2005). The Canada MOU reference baseline also assumes an average 20% fuel consumption correction (NRCan, 1999).

The difference between test cycle and actual “on-road” fuel economy is receiving considerably more attention lately because of the potential that the difference between the regulatory test and actual fuel use (and CO<sub>2</sub> emissions) is widening. To the extent that “on-road” correction factor is widening, or increasing above 1.20, actual CO<sub>2</sub> emissions and fuel consumption are increasing with respect to official vehicle test data. Conversely, if the “on-road” factor is decreasing, there is an improvement in fuel and emissions characteristics in vehicles on the road. In 1996, the U.S. EPA revised the Federal Test Procedure to include a Supplemental Federal Test Procedure (SFTP), which took into account real-world vehicle conditions such as aggressive driving and air conditioning operation. Fully phased in by model year 2002, the SFTP program is designed to ensure that “off-cycle” criteria pollutant (e.g., NO<sub>x</sub> and NMOG) emission rates are not substantially higher than test-cycle emission rates. However, there has not yet been a corresponding inclusion of more representative real-world conditions into CO<sub>2</sub> and fuel economy vehicle testing; although a Congressional measure seeks to change this for the sake of fuel economy labeling accuracy (U.S. Congress, 2005).

For this analysis, several measures that could impact “on-road” vehicle CO<sub>2</sub> emissions from light duty vehicles in Canada from years 2000 through 2010 are considered, including ongoing regulatory measures and government programs. The ongoing U.S. EPA SFTP program could result in reducing the fuel

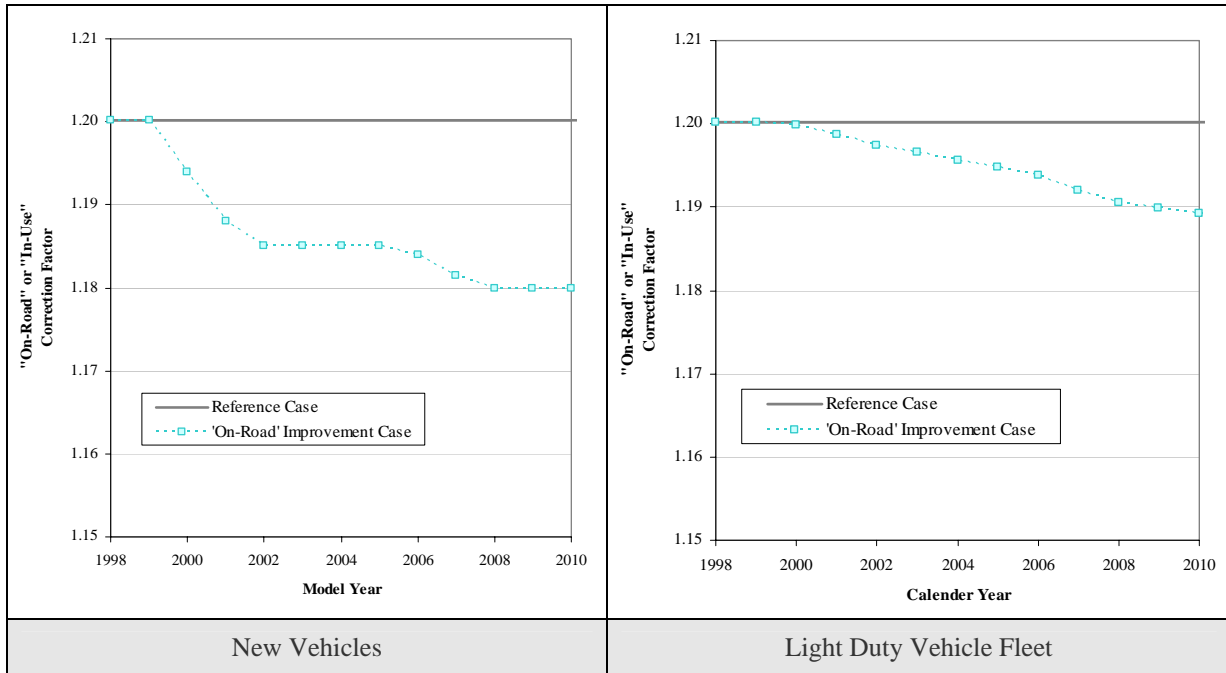
economy “shortfall.” Early 1990s EPA testing led to a better understanding how off-cycle emissions and fuel use differed from officially testing, and eventually led to the formulation of the SFTP program. One EPA paper suggests that revisions in the federal testing procedure could indirectly have an impact on reducing the in-use fuel economy shortfall by 1-2% (German, 1997). The SFTP program phased in emissions standards for new vehicles of model years 2000 to 2002 phased in at 40-80-100% of light duty vehicle sales).

New regulations from the U.S. Department of Transportation’s National Highway Traffic and Safety Administration mandating tire pressure monitoring technology onboard new vehicles also have the potential to improve in-use CO<sub>2</sub> emissions. The new tire pressure monitoring systems (TPMSs) would warn drivers if tires were significantly under-inflated for improved vehicle safety, but the measure also has indirect fuel usage benefits (NHTSA, 2005a). The TPMS-equipped vehicles are set to phase into the fleet in model years 2006 through 2008 at 20-70-100% of light duty vehicle sales. The estimated improvement that results from the tire regulation in average on-road fuel use rate is 0.5% when the measure is fully phased in. TPMS technology is mentioned in the GHG MOU (NRCan, 2005a). A statement by the Canadian auto industry suggests that tire pressure monitoring systems is one method for which it intends to be credited for MOU GHG emission reductions (CVMA, 2005).

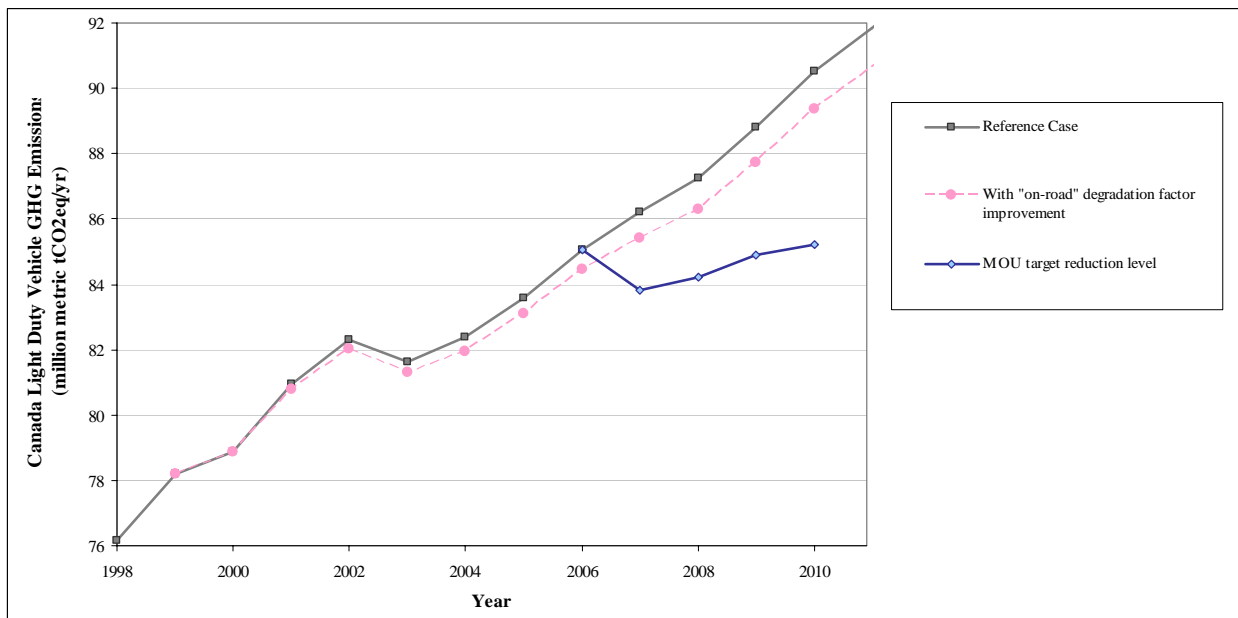
In addition, there is the possibility that public outreach campaigns by the Canadian government could impact the driving habits and fuel consumption awareness of Canadian drivers and thus significantly impact the in-use fuel use factor. Natural Resources Canada is conducting a consumer education campaign on fuel efficiency purchase and maintenance decisions in its “One-Tonne Challenge” program to engage consumers in low-GHG decisions (NRCan, 2005e). U.S. EPA has continually done public information and outreach campaigns on how vehicle users, through driving style, travel behavior, and vehicle maintenance, can improve their real-world fuel economy (U.S. EPA, 1994). In addition, numerous studies have assessed the potential to improve in-use fuel use and CO<sub>2</sub> emissions through efficiency technologies, improved vehicle maintenance, driver education, and other measures (see e.g., CEC and CARB, 2003; ECMT, 2004). However, the impacts in the areas of driver education and vehicle maintenance are more speculative, and it would be difficult to verifiably quantify such GHG-reduction impacts within the 2010 timeframe. As a result, such measures are not included in this investigation.

Figure 10 depicts the estimated model year and calendar year effects of the SFTP and tire pressure monitoring system regulations on the in-use fuel consumption correction factor. Shown against the reference case in-use factor of 1.20, the improved in-use factor improves to 1.185 in model years 2000 through 2002, corresponding to the 1.5% percent SFTP improvement discussed above. The factor further

reduces to 1.18 due the 0.5% improvement caused by the deployment of tire monitoring systems in model years 2006 to 2008. Also shown in Figure 10 is the corresponding calendar year fleet phase-in of these vehicles. The resulting fleet GHG emissions are shown in Figure 11. In 2010, this factor contributes a 1.12 MT CO<sub>2</sub>e reduction, equivalent to 21.2% of the total 5.3 MT CO<sub>2</sub>e emission reduction target.



**Figure 11. Assumed Improvement in On-Road Fuel Consumption Degradation Factor for New Vehicles and Across Entire Light Duty Fleet**



**Figure 12. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, ‘On-Road’ Improvements, and MOU Agreement**



## Mobile Air Conditioning Systems

Trends in government programs, regulations, and industry reports on new technology developments in North America and Europe suggest that the use of advanced mobile air conditioning (MAC) system technologies will see widespread adoption in the next decade. The U.S. EPA Supplemental Federal Test Procedure (SFTP) program instituted new vehicle test-cycle guidelines to include air conditioning operation in the emissions testing (U.S. EPA, 1996). A U.S. Senate bill has considered incorporating air conditioning testing into fuel economy labeling to more accurately represent real-world fuel use (U.S. Congress, 2005). California's proposed GHG regulation allows for credits for improved MAC systems to count toward required GHG reduction for model year 2009 and later standards (CARB, 2004). The European Union has set forth regulations to reduce GHG emissions associated with automobile MAC systems to contribute to future Kyoto Protocol reduction targets (EU, 2004). In response to these regulatory initiatives, technology developers, such as Visteon, Behr, and Delphi, and various automakers are planning near-term introductions of low-GHG MAC systems.

Greenhouse gas reductions from MAC systems can result from two main technologies: (1) Refrigerant (i.e., hydrofluorocarbon R-134a) GHG emission reductions from lower leak components, charge reduction, or an alternative refrigerant, and (2) Improved MAC system efficiency to reduce fuel consumption and tailpipe CO<sub>2</sub> emissions. The analysis in this section utilizes the work by researchers and regulators at U.S. EPA, in California, and Europe to assess baseline emissions, advanced technologies, and potential GHG emission reductions.

The contribution of hydrofluorocarbon refrigerant leakage to GHG emissions has received considerable attention recently in U.S. and Europe (Schwarz and Harnisch, 2003; CARB, 2004). Reductions in refrigerant emissions can result from improvements in the recovery and recycling of the refrigerant from vehicles, reductions in leakage from vehicles, and by replacing the refrigerant with an alternative system. Because recycling of the conventional hydrofluorocarbon (HFC) refrigerant R-134a from vehicles is already mandatory in the U.S. and Canada, we focus here on "on-vehicle" aspects of the air conditioning compressor system. The current refrigerant for new light vehicles, R-134a, has a relatively high global warming potential (GWP) of 1300, compared to low-GWP replacement alternative refrigerants such as R-152a (GWP=120) and carbon dioxide (GWP=1). Earlier studies (see, e.g., Bhatti, 2003) indicated that costs and environmental benefits of enhanced higher-efficiency R-134a systems were vastly preferable to any alternative refrigerant system. However, more recent work suggests low-leak, reduced charge, higher system efficiency MAC systems using R-152a are a promising technology with GHG emissions, energy use, and manufacturing advantages (Baker et al, 2003; Ghodbane et al, 2003).

Ongoing regulatory initiatives directed at improving refrigerant HFC emissions associated with light duty automobiles will largely dictate the prevailing MAC technology. The market in Europe, in connection with joint regulatory-industry deliberations over reducing emissions to contribute to overall Kyoto Protocol reductions, is set to (a) phase in lower-leak MAC systems in all new vehicles by 2011, and (b) phase out R-134a for new vehicles between 2011 and 2017 (EU, 2004). In the proposed California climate change regulations for vehicles, the technology assessment assumes the use of a lower-leak system with the use of refrigerant R-152a, to be fully deployed across new light duty vehicles by model year 2016 (CARB, 2004).

Estimates for this study on the GHG reduction potential of MAC systems by model year 2010 are based on the CARB (2004) technology assessment that formulates the emission-reduction credits to be granted for given MAC system improvements for the California GHG standards. The CARB regulatory research, based primarily on a study by NESCCAF (2004), concludes that “low leak” technology (including multiple O-rings at pipe and hose connections, ultra-low permeability barriers for hoses in contact with the refrigerant, and multiple-lip compressor shaft seals) can cut in-use leakage by 50%, equivalent to reducing vehicle GHG emissions by 3.0 grams CO<sub>2</sub>-equivalent per mile. The same study reports that switching new vehicles from HFC-134a to HFC-152a offers a potential reduction of 8.5 grams CO<sub>2</sub> equivalent per mile (91% of direct MAC emissions), and switching to CO<sub>2</sub> as a refrigerant resulted in a 9 gram per mile reduction (99% of direct MAC emissions). Supplanting the conventional R-134a with an alternative (e.g., R-152a, CO<sub>2</sub>, etc) system is unlikely for the short timeframe (i.e., through model year 2010) of this analysis; however, the deployment of the “low-leak” system in new vehicles is considered for model years 2007 through 2010.

Fuel usage from automobile air conditioning systems has been well studied and documented in recent years (see, e.g., Welstand et al, 2003; Johnson, 2002). Improved efficiency MAC systems offer potential GHG emissions by reducing the accessory load on the engine while driving, thereby reducing fuel consumption and exhaust CO<sub>2</sub> emissions. Primary low-GHG MAC system technology components include variable displacement compressors (VDCs), improved control systems, improved heat transfer condensers and evaporators, and external vehicle solar load reduction.

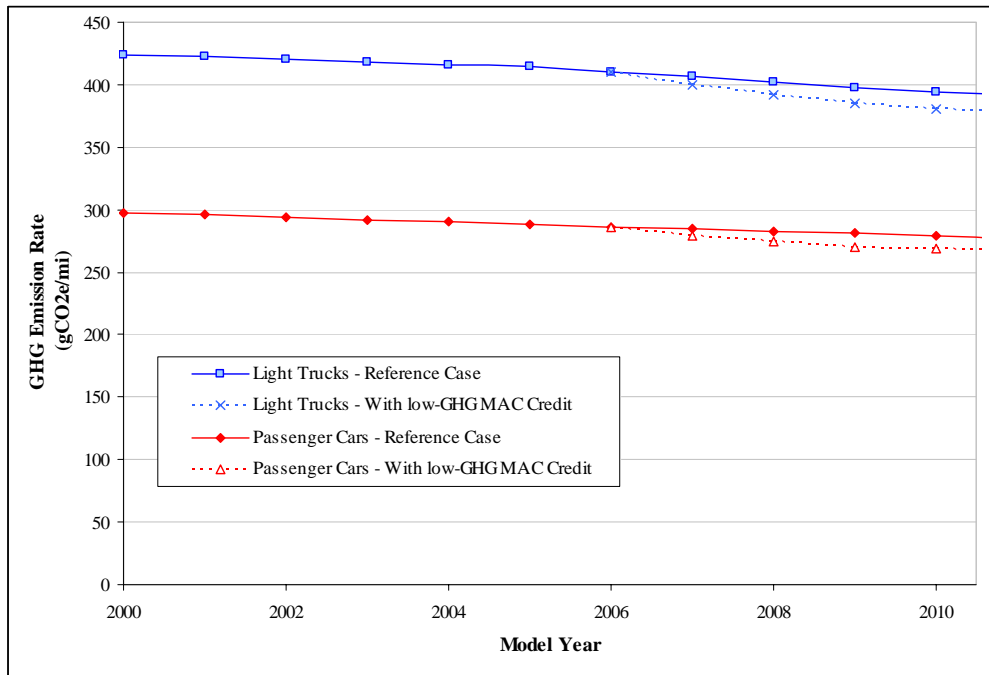
Focus for this analysis is centered on the use of variable displacement compressors and improved control systems, due to these technologies’ likely nearer-term deployment and verifiable emission reductions. The auto industry’s interest and near-term commitment to reducing MAC system fuel consumption is shown in the growing technical literature on recent MAC advances in externally-controlled MAC systems

and the use of variable displacement compressors. Conventional MAC systems have fixed speed compressors with a constant refrigerant flow and on-off cycling. Externally controlled compressors that more tightly manage the operation of the MAC systems' according to various conditions (e.g., ambient air, recirculation mode, solar radiation) offer substantial GHG reductions, and the addition of variable displacement compressors and cabin air recirculation further enhance the GHG benefits. Such advanced MAC systems are currently available; VDCs are being used in smaller cars in Europe (CARB, 2004) and have been demonstrated by numerous auto industry companies, including Delphi, Toyota, Mitsubishi, and Fiat (Benouali, et al 2003; Forrest and Bhatti, 2002; Martini et al, 2003; Mitsubishi, 2004; Watanabe, 2004).

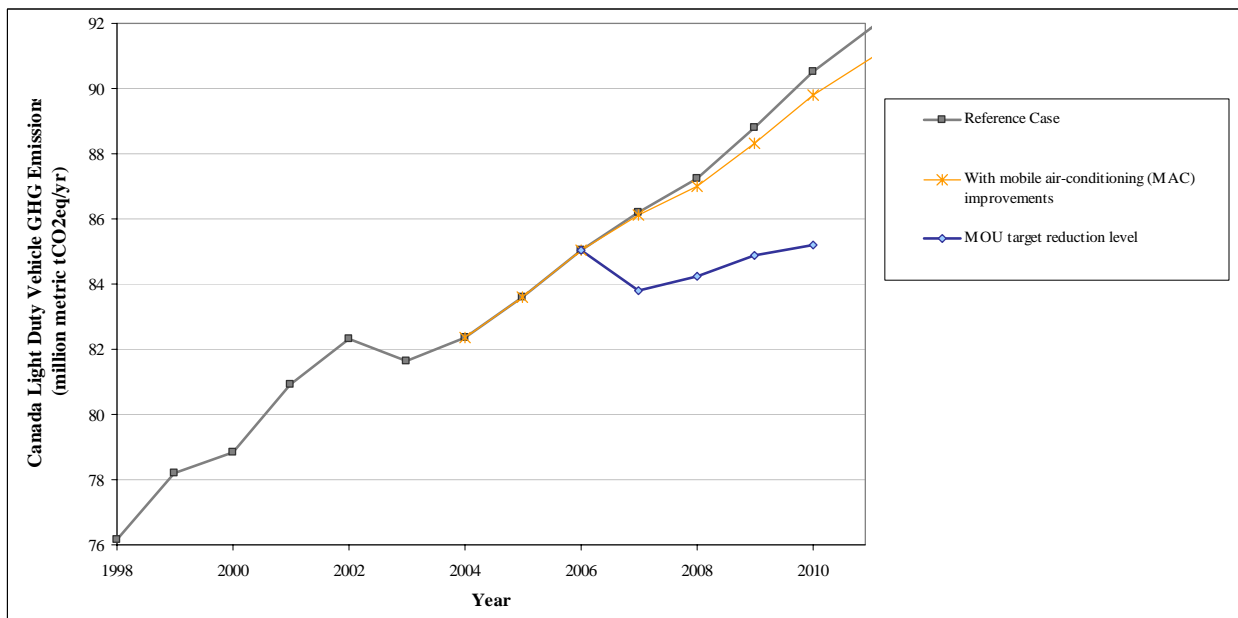
Assessment here of the impacts of potential MAC efficiency improvements on Canada fleet wide GHG emissions is based on the emission reduction credit system of the proposed California GHG regulations for vehicles. In the California standards, upgrading to a MAC system with an externally-controlled variable displacement compressor with improved air recirculation is estimated to reduce 7.5 grams CO<sub>2</sub>e per mile for passenger cars and 10.0 grams CO<sub>2</sub>e per mile for light trucks (which on average have somewhat larger air conditioning loads and larger compressors than passenger cars) (CARB, 2004).

The two MAC technologies are assumed to be deployed on new vehicles of model year 2007 and later. As described above, the lower-leak (multiple O-rings at connections, ultra-low permeability barriers, and multiple-lip compressor shaft seals) system is credited with 3.0 grams per mile CO<sub>2</sub>e reduction for each new vehicle so equipped. The increased efficiency MAC system (VDC, external controls, recirculation) is credited with a 7.5 (for passenger cars) and 10.0 (for light trucks) gram per mile CO<sub>2</sub>e reduction for new vehicles so equipped. The deployment of these technologies in the figures below is set for gradual phase-in over 2007 to 2010 model years to correspond with the timing of the European directive (that limits leakage of refrigerant systems) and to precede by two years the California regulation (for the 2012 "near-term" standards that promote low-leak and high-efficiency MAC systems).

Figure 13 shows the impact of the two MAC technology advances, a lower-leak refrigerant HFC-134a and an improved efficiency MAC system, on new vehicle GHG emissions. These two technologies together are estimated to result in 10.5 (for cars) and 13.0 (for light trucks) grams per mile CO<sub>2</sub>e reduction credit. The majority, approximately 75%, of this reduction is from the improved MAC efficiency technology. Deployment of these MAC technologies is set at 50-75-100% for new light duty vehicles from 2007 to 2009. The resulting fleet GHG emission reductions are shown below in Figure 14. In the year 2010, the low-GHG air conditioning system technologies are estimated to contribute to a 0.71 MT CO<sub>2</sub>e reduction, or 13% of the overall 2010 MOU target.



**Figure 13. New Light Duty Vehicle Greenhouse Gas Emissions – Reference and With MAC Improvements, 2000-2010**



**Figure 14. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Estimated Mobile Air-Conditioning System Emissions Reductions, and MOU Agreement**

## RESULTS

### *Summary and Range of Greenhouse Gas Reduction Implementation Strategies*

Table 1 gives a summary of the GHG emission reduction mechanisms investigated in this report, their estimated potential emission reductions toward the 5.3 MT CO<sub>2</sub>e target if credited, and brief descriptions of the technology deployed in their respective timeframes. With the prevailing uncertainty about which mechanisms from these will be credited as reductions toward the MOU target, combinations of these mechanisms are explored. Results here are highlighted for (1) a “Full Mix” strategy, where all of the mechanisms are implemented and credited toward the MOU, (2) an “All New Efficiency” strategy, where none of the mechanisms are credited toward the MOU reduction targets (i.e., where achievement of the 5.3 MT CO<sub>2</sub>e target will require new, additional vehicle fuel efficiency technologies), and (3) a range of scenarios bracketed between the above two approaches. In each case, if the considered scenario does not result in compliance with the 5.3 MT CO<sub>2</sub>e MOU emission reduction target, the necessary additional fuel efficiency technology is applied to the scenario to achieve the MOU target.

**Table 1. Summary of Emission-Reduction Mechanisms for Implementation of Canada GHG MOU**

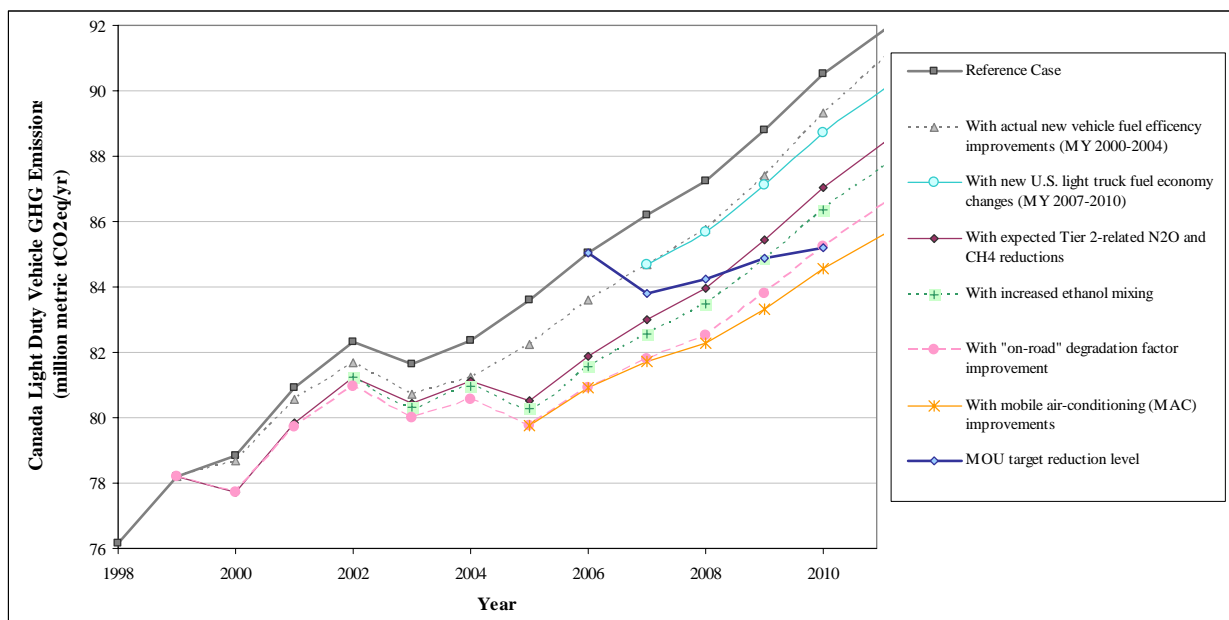
<b>Greenhouse Gas Reduction Mechanism</b>	<b>Potential Emission Reduction in 2010<sup>a</sup> (MT CO<sub>2</sub>e)</b>	<b>Percent of MOU Target Reduction in 2010<sup>a</sup></b>	<b>Description of GHG Reduction Mechanism</b>
Actual fuel consumption, MY 2000-2004	1.21	22.8%	The Reference Case included fuel consumption data for new vehicles from 2000-2004 that was greater than the actual fuel consumption when the MOU was signed in 2005. Actual model year 2004 fuel consumption is 4% lower than the Reference Case.
U.S. Light Truck CAFE, MY 2005-2010	0.59	11.1%	With Canada's fuel consumption targets harmonized to the U.S. corporate average fuel economy regulations, fuel consumption (in L/100km) of model year 2010 light trucks would decrease by 5% compared to the Reference Case.
Tier 2, low-sulfur N <sub>2</sub> O and CH <sub>4</sub> emissions, 2000-2010	1.66	31.3%	Tier 2 criteria pollutant regulations with low-sulfur fuel regulations decrease N <sub>2</sub> O gram/mile emissions by 58-59% for 2005 and later.
Increased ethanol fuel mixing, 2002-2010	0.68	12.8%	Canada's Ethanol Expansion Program (EEP) increases ethanol mixing from 0.6% to 3.7% (by volume) of blended gasoline from 2002 to 2010.
On-road correction factor, MY 2000-2010	1.12	21.2%	Indirect improvements due to emissions and safety programs: Supplemental Federal Test Procedure (SFTP) program for criteria emission reductions reduce "on-road" fuel use by 1.5% and the tire pressure monitoring systems, per pending safety regulations, reduce "on-road" fuel use by 0.5%.
Mobile air conditioning (MAC) technologies, MY 2007-2010	0.71	13.4%	Phase-in of low-leak, higher-efficiency air conditioning systems comparable to upcoming California and Europe initiatives over model years 2007 to 2010.

<sup>a</sup> Note that the reductions and percents from all of the mechanisms are not strictly additive when combined in various scenarios

## “Full Mix” Greenhouse Gas Reduction Implementation Scenario

Figure 15 shows the impact of crediting all of the discussed GHG-reduction mechanisms (actual and expected fuel consumption improvements, Tier 2 criteria pollutant emission reductions, increased ethanol mixing in gasoline, improved “on-road” fuel efficiency, and advanced air conditioning technology) toward the MOU-directed emission reduction targets through 2010. Applying all of the potential low-GHG technologies simultaneously for this “Full Mix” strategy is more than sufficient to achieve the 2010 emission reduction targets. That is, no additional fuel efficiency technology would be required under this scenario to reach the MOU target emission reduction level. All of the mechanisms together equate to a 5.5 MT CO<sub>2</sub>e reduction, 13% greater than the MOU agreement’s target.

By accepting all of the GHG reduction mechanisms discussed here, the “Full Mix” scenario represents the prospect that the MOU oversight committee would take the most liberal definition of what is to be credited with GHG reductions. That is, Figure 15 represents granting credits for all initiatives that reduce GHG emissions regardless of (a) whether the reductions were the result of outdated reference case projections or involve technologies already deployed at the time of the MOU signing (e.g., applying actual model year 2000-2004 improvements), (b) whether the reductions were set to occur due to previous agreements or standards or were highly likely to occur regardless of the MOU (e.g., Tier 2 emissions, “on-road” correction factor improvements, harmonized fuel consumption rates with U.S. CAFE, Ethanol Expansion Program), and (c) whether they are the result of regulations crafted for reasons other than climate change (Tier 2 standards for criteria pollutants, tire monitoring systems for safety).

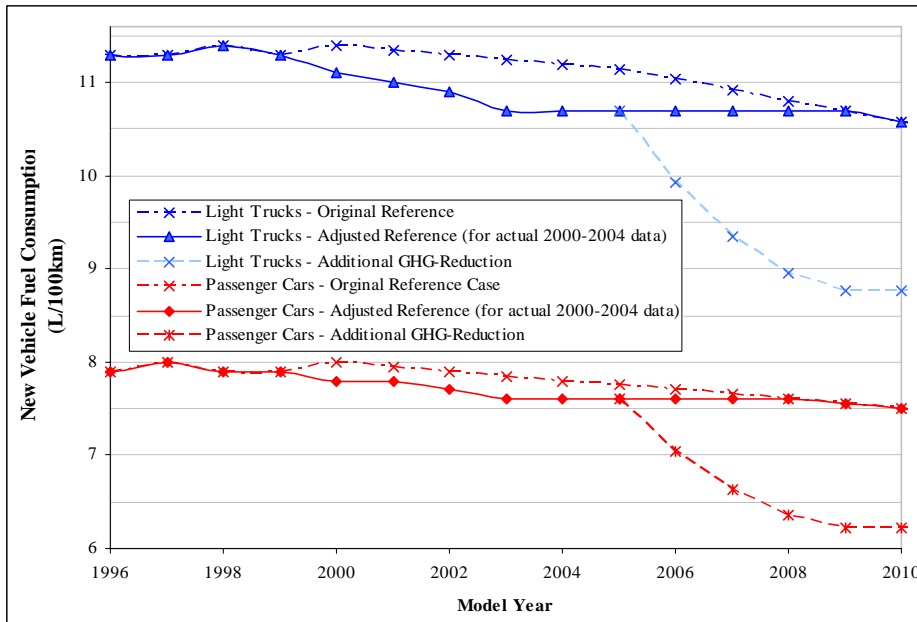


**Figure 15. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case with “Full Mix” of GHG Reduction Mechanisms and the MOU Agreement Target**

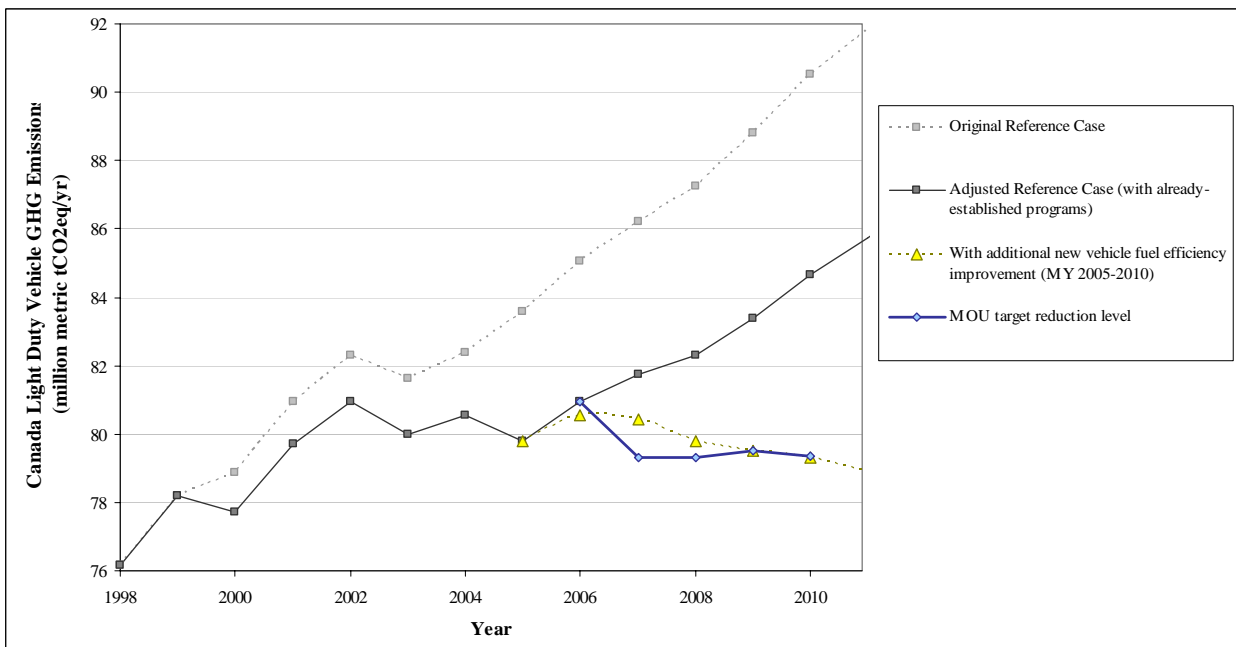
## **“All New Efficiency” Greenhouse Gas Reduction Implementation Scenario**

For the “All New Efficiency” scenario, it is assumed that all of the 5.3 MT CO<sub>2</sub>e emission reduction in 2010 is achieved by the deployment of more fuel efficient vehicles (with improved rated test-cycle fuel consumption rates). For this scenario, it is assumed that the baseline reference case would be adjusted downward to reflect the impacts of each of the GHG reductions that are already scheduled to occur from 2000-2010 as discussed in the sections above. This scenario represents a stricter definition of which reductions are to be credited, i.e., where reductions that result from actions that are likely to not have occurred without the signing of the MOU are counted.

The reference case GHG emissions were adjusted to properly account for current new vehicle fuel consumption data (through model year 2004). After this adjustment, the average fuel consumption of new vehicles was decreased until the industry achieved 5.3 MT of new CO<sub>2</sub>e emissions reductions in 2010. Figure 16 shows the required fuel consumption improvements required for this “fuel efficiency only” approach. For both passenger cars and light truck vehicle types, a reduction of new vehicle fuel consumption of 18.1% from the actual 2004 fuel consumption levels, with the phase-in implemented between 2005 and 2009, is sufficient to achieve the MOU targets for 2009 and 2010. This is equivalent to raising average new vehicle fuel economy by 5.8 miles per gallon (6.8 mpg for cars, 4.9 mpg for light trucks). The resulting fleet GHG reductions are shown with respect to the MOU target emissions in Figure 17. Note that although the 2009 and 2010 targets are met, due to the slow phase-in of these new vehicles and retirement of older vehicles with higher fuel consumption vehicles from the fleet, the interim 2007 and 2008 MOU targets are not met in the “All New Efficiency” scenario.



**Figure 16. Reference, Actual, and Required Additional Fuel Efficiency Improvements for New Light Duty Vehicles for “All New Efficiency” GHG Reduction Scenario**



**Figure 17. Light Duty Vehicle Greenhouse Gas Emissions – Reference Case, Adjusted Reference Case, "All New Efficiency" GHG-Reduction Scenario, and the MOU Agreement Target**



## Range of Potential Greenhouse Gas Reduction Implementation Scenarios

The intent of the above two subsections, the “Full Mix” and “All New Efficiency” scenarios, was to bound the potential approaches that industry could undertake to meet the Canada MOU-established targets. These two implementation scenarios reflect the boundaries of policy determinations regarding how industry compliance with the target emission reductions might be accomplished, and they produce two very different results in terms of the MOU’s impact on new vehicle fuel consumption and CO<sub>2</sub> emission rate. Because of the prevailing uncertainty about which GHG emission reduction mechanisms the automakers will be granted credit for, a range of intermediate scenarios was also analyzed. Table 2 shows the results of various combinations of the six potential GHG emission reduction mechanisms that fall between the two boundary scenarios above. Note that there are other possible intermediate range scenarios than those shown. Shown in the last column of the table is the required average level of improvement in test-cycle CO<sub>2</sub> emission rate from model year 2004 to 2010 that would have to occur to meet the 2010 MOU emission targets for each scenario.

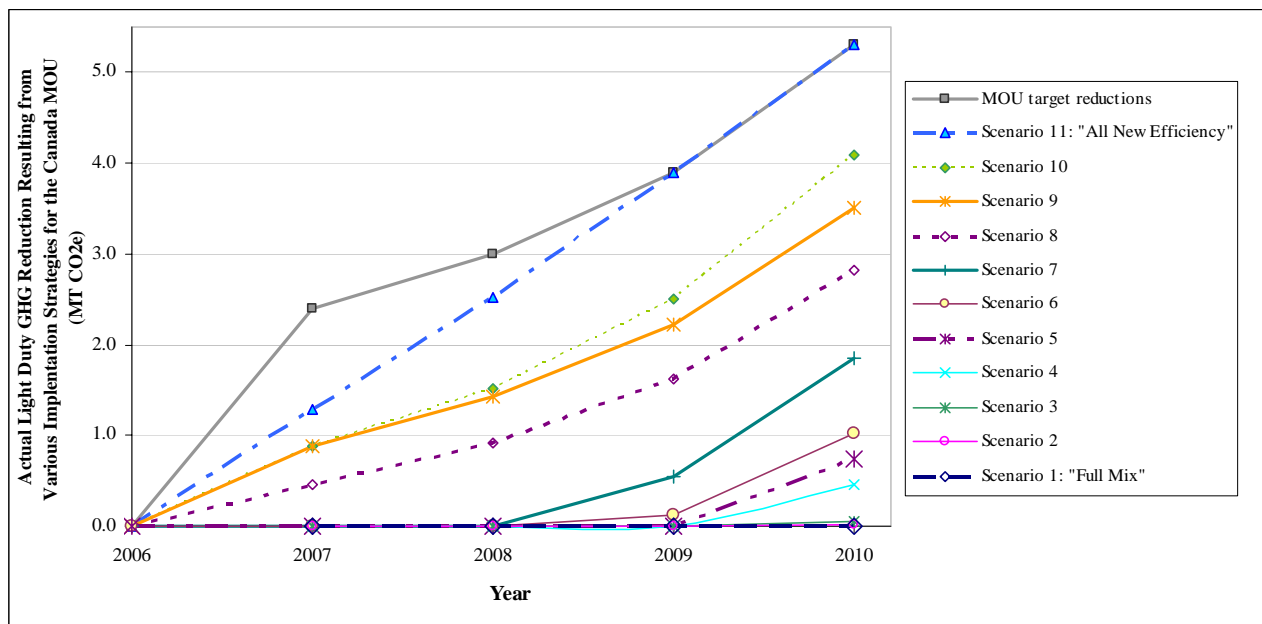
**Table 2. Effect of GHG Emission-Reduction Credit from Various GHG Implementation Strategies on Required New Vehicle Rated Carbon Dioxide Emission Rate**

Scenario	Potential Areas of GHG Emission Reduction Credit Applied to Scenario						Average Change in Test-Cycle CO <sub>2</sub> Emission Rate in Light Duty Vehicles Needed to Meet MOU Target from Model Years 2004 to 2010 (After Various Areas of GHG Emission Reduction Credit are Applied)
	Actual 2000-2004 Fuel Use	US CAFE Light Trucks, 2005-2010	Tier 2 N <sub>2</sub> O/CH <sub>4</sub> Emissions	Ethanol Blending Increase	“In-Use” Factor	Mobile Air Conditioning	
1. Full Mix	X	X	X	X	X	X	(none)
2. Mix	X	X	X		X	X	-0.1%
3. Mix	X	X	X	X	X		-0.2%
4. Mix	X	X	X	X		X	-1.6%
5. Mix	X	X	X		X		-2.6%
6. Mix	X	X		X	X	X	-3.6%
7. Mix	X	X	X				-6.5%
8. Mix	X	X		X			-9.8%
9. Mix	X	X					-12.2%
10. Mix	X						-14.0%
11. All New Efficiency							-18.1%

**Potential Impact of Greenhouse Gas Reduction Crediting on Actual Reductions**

If combinations of the GHG mechanisms would have occurred regardless of the signing of the Canada GHG MOU, the findings of Table 2 (and the corresponding decisions of the oversight committee) have significant repercussions on the amount of actual GHG emission reductions that are caused by the MOU. As GHG mechanisms that already would have occurred are granted credit toward the MOU, the incremental 2010 emission reductions that it actually achieves become less than the official 5.3 MT CO<sub>2</sub>e target (assuming that industry does not over-comply with the reduction targets by deploying more vehicle efficiency than necessary). More specifically, for each GHG reduction resulting from some other established program that is credited toward the MOU target emission reductions, the effectiveness of the MOU in further reducing GHG emissions from automobiles is diminished by the amount of that GHG reduction.

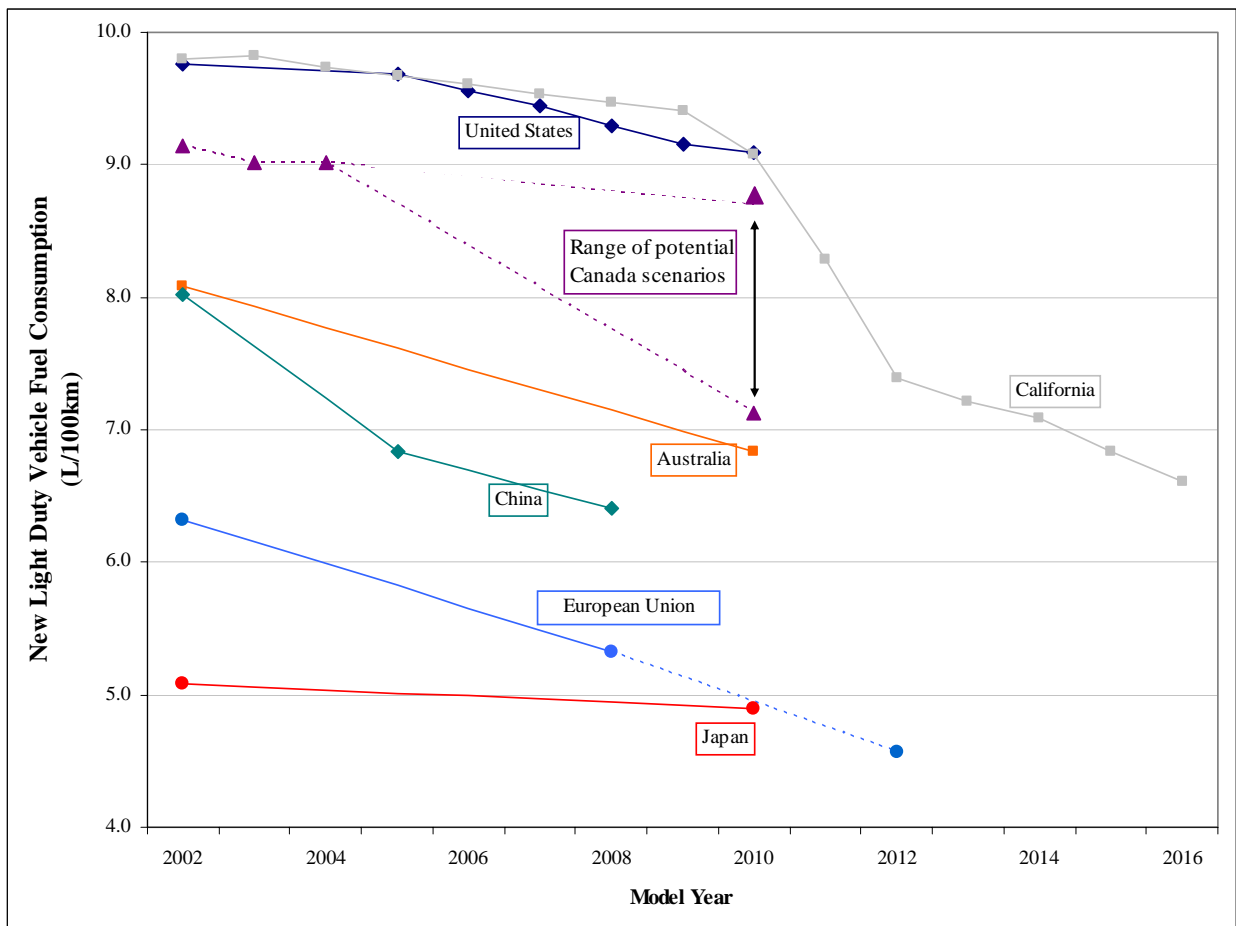
Figure 18 graphically illustrates Table 2’s results, showing the effects of various GHG crediting scenarios on actual reductions (assuming industry does not choose to deploy more efficiency/low-GHG technology than is needed to comply with the MOU). To ensure that the MOU reduction for 2010 is achieved and that 5.3 MT CO<sub>2</sub>e of *additional* emission reductions actually result from the MOU, the GHG mechanisms that would occur independent of the MOU would have to be incorporated into the official MOU Reference Case by the MOU oversight committee. Of the scenarios discussed in this report, the only one that results in actual incremental GHG emission reductions in 2010 at the level of the MOU’s 5.3 MT CO<sub>2</sub>e commitment is the “All New Efficiency” scenario.



**Figure 18. Actual MOU GHG Emission Reduction Requirements After Considering the Crediting of Various Established Emission Reduction Mechanisms**

### Comparison of Greenhouse Gas Reduction Initiatives

Figure 19 shows the range of effects that the Canada GHG MOU could have on vehicle fuel consumption (measured in L/100km), as compared with fuel consumption and GHG initiatives in other countries. The data in Figure 19 are based upon An and Sauer (2004), which standardizes various countries' standards according to the North American vehicle testing cycle. The range of impacts over the 2004 to 2010 timeframe is from 3% to 18%, as estimated in this analysis. Note that the above Table 2 reports a 0% to 18% potential change in fuel consumption (and CO<sub>2</sub> emission) rate. The difference between these two lower-bound values is caused by the CO<sub>2</sub> emissions effect of the U.S. light truck CAFE standard increase (and corresponding reduction in the Canada CAFC goal) that is likely to occur independent of the Canada GHG MOU.



**Figure 19. Comparison of National Fuel Consumption and Greenhouse Gas Emission Initiatives (Based on An and Sauer, 2004)**

## CONCLUSIONS

The chief purpose of this study was to better understand the likely results of the recent Canadian Memorandum of Understanding (MOU) on greenhouse gas (GHG) emissions from automobiles. This analysis sought to analyze available GHG reduction technologies that could be deployed to achieve the MOU-established 5.3 MT CO<sub>2</sub>e reduction target in 2010. Key technologies were identified, deployment schedules of these technologies were approximated, and emissions reduction potential of the technology deployment was estimated for the 2000-2010 timeframe.

Several implementation mechanisms for the Canada MOU have been highlighted, ranging from (a) an approach where GHG emission reductions attributable to other current initiatives, such as increased ethanol mix in fuel, lower sulfur fuel and criteria pollutant emission policy, and previous model year (2000-2004) fuel consumption, are all credited toward the MOU target to (b) a strategy that employs all new vehicle efficiency technology to meet the necessary GHG emission reductions. In the former “Full Mix” scenario, the MOU target could be achieved with little or no new vehicle fuel consumption improvement (beyond ongoing trends) from model year 2004 to 2010. The latter “All New Efficiency” strategy results in an 18% fuel consumption and CO<sub>2</sub> emission rate reduction for new vehicles from model year 2004 to 2010 for the MOU target reductions to be achieved. Where between the low (0%) and high (18%) new fuel efficiency improvements that new 2010 vehicles will end up depends on the crediting of potential GHG reduction mechanisms discussed in this report. It is true that if the Canada light duty vehicle fuel consumption improved by 25% by 2010, the goals of the MOU GHG agreement would be met in 2010, as media at the time of the signing of the MOU agreement reported. However, it is also true that if industry is credited with certain emission reductions that result from ongoing trends and already-adopted regulations, only minimal fuel efficiency improvements by 2010 would be required to meet the 2010 MOU emission reduction targets.

Some of the GHG-reduction mechanisms discussed in this report are quite likely, probable, or near certain to occur and would affect Canada’s GHG emissions within the 2010 timeframe independent of the signing of the Canada MOU on GHG emissions. The actual model year 2000 to 2004 fuel consumption improvements, for instance, had already happened at the time of the signing of the MOU yet may be counted toward the MOU targets due to the outdated data inherent in the reference case. Improvements in light truck fuel consumption in the 2007 through 2010 model years would almost certainly have occurred without the MOU due to the harmonization of Canada’s CAFC targets to the more stringent U.S. CAFE regulations for light trucks for those model years (and due to a history in Canada of achieving lower-than-CAFC-targeted fuel consumption levels). Nitrous oxide emissions reductions that are the result of Tier 2 emissions technology and low-sulfur fuel were also established independent of, and set in motion earlier

than, the GHG MOU. Existing on-road fuel efficiency improvements caused by the Supplemental Federal Test Procedure (SFTP) program and U.S. safety regulations for tire monitoring systems could both incidentally improve GHG emissions, and might also be credited toward the MOU. The use of advanced mobile alternative air conditioning (MAC) systems is considered by the regulatory agencies of California and Europe as a mechanism to reduce light duty vehicle fuel use and GHG emissions within the next decade, so it is plausible that these technologies would enter the marketplace regardless of the MOU.

Determination of which of these GHG mechanisms would have occurred irrespective of the MOU is crucial to the determination of the true impact of the MOU as a GHG mitigation initiative. The question arises as to whether the intent of the MOU is to *witness* a 5.3 MT CO<sub>2</sub>e emission reduction or to *actually be responsible for causing* a 5.3 MT CO<sub>2</sub>e emission reduction. It is apparently possible for the MOU agreement to be met with little or no actual impact on GHG emissions from Canada's fleet. If the MOU oversight committee decides to credit each of the mechanisms discussed, the primary role of the Canada GHG MOU would be to simply re-label a series of already-established programs as a GHG reduction initiative. If, on the other hand, the intent of the Canada GHG MOU is to generate 5.3 MT CO<sub>2</sub>e of *new* emission reductions, then the oversight committee would have to opt to not include already-established programs (for fuel consumption, criteria pollutants, safety, etc.) in the crediting of industry's progress toward the MOU emission targets.

Canada's auto industry has a history of harmonizing its own vehicle emissions and safety standards to the United States' regulations. If the recently signed MOU on GHG emissions is truly a commitment to initiate a departure from the federal inaction on climate change emissions in the United States, the oversight committee would have to opt to not credit the already-established vehicle fuel and technology trends.

This analysis provokes broader questions regarding the implementation and effects of voluntary agreements, as compared with the issuance of regulatory initiatives as a means to substantive emission reductions. Of course, the voluntary approach does have the key advantages of avoiding mandates, fines, costly compliance testing and government oversight, and the potential for lawsuits. However, it is likely that an industry signing on to such an agreement possesses a firm understanding of how the implementation of the agreement can be met and additional critical knowledge of how other initiatives (including those indirectly related) could contribute to the target reductions. It is plausible that an industry could use a voluntary agreement as a way to recharacterize already-adopted measures and trends, thus scoring environmental public relations benefits with little or no additional effort or new resources expended on technologies or other means to achieve incremental emission reductions.

## **ACKNOWLEDGEMENTS**

The author would like to thank the William and Floral Hewlett Foundation for its support of this work, and Hal Harvey, Environment Program Director, for his insights and leadership. Thanks to Kenneth Colburn of Symbiotic Strategies for his guidance and critical review of this report. The valuable comments of Dan Sperling are gratefully acknowledged.

## REFERENCES

- An, F. and A. Sauer 2004. *Comparison of Passenger Vehicle Fuel Economy and GHG Emission Standards Around the World*. Prepared for the Pew Center on Global Climate Change. December.
- An, F., J. DeCicco, and M. Ross, 2001, "Assessing the Fuel Economy Potential of Light Duty Vehicles," *Society of Automotive Engineers Technical Paper Series*. 2001—01-2482. Warrendale, Penn.
- Association des Constructeurs Européens D'Automobiles (ACEA), 2004. "ACEA's CO<sub>2</sub> Commitment." [www.acea.be/ACEA/brochure\\_co2.pdf](http://www.acea.be/ACEA/brochure_co2.pdf). Accessed July 15.
- Austin, T.C., R.G. Dulla, and T.R. Carlson. 1999. *Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles*. Prepared for Committee on Road Vehicle Technology and Fuels, Natural Resources Canada. Sacramento, Calif.: Sierra Research, Inc. July.
- Baker, J.A., M. Ghodbane, L.P. Scherer, P.S. Kadle, W.R. Hill, S.O. Anderson, 2003. "R-152a Refrigerations System for Mobile Air Conditioning." *Society of Automotive Engineers Technical Paper Series*. 2003-01-0731. Warrendale, Penn.
- Behrentz, E., R. Ling, P. Rieger, and A.M. Winer, 2004. "Measurements of Nitrous Oxide Emissions from Light-Duty Motor Vehicles: A Pilot Study." *Atmospheric Environment*, **38**: 4291-4303.
- Benouali, J., D. Clodic, and C. Malvicino, 2003. "Possible Energy Consumption Gains for MAC Systems Using External Control Compressors." *Society of Automotive Engineers Technical Paper Series*. 2003-01-0732. Warrendale, Penn.
- Bhatti, M.S., 1999. "Enhancement of R-134a Automotive Air Conditioning System." *Society of Automotive Engineers Technical Paper Series*. 1999-01-0870. Warrendale, Penn.
- Bustillo, M., 2005. "Canada Considers Copying California's Greenhouse Gas Law." <http://www.latimes.com/news/local/state/la-me-canada18jan18,1,74890.story?coll=la-news-state>. *Los Angeles Times*. January 18.
- California Air Resources Board (CARB), 2004. *Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles*. <http://www.arb.ca.gov/regact/grnhsgas/isor.pdf>. Accessed October 22, 2005. August 6.
- California Energy Commission (CEC) and California Air Resources Board (CARB), 2003. *Reducing California's Petroleum Dependence*. Appendix C, Attachment B. Publication # 600-03-005SD. May.
- Canadian Press, 2005. "Canadian Automakers Hail Agreement to Reduce Greenhouse Gases." <http://www.canada.com/businesscentre/story.html?id=def09b63-ba76-494a-9b42-9864cd1b2940>. Accessed October 17, 2005. April 5.
- Canadian Vehicle Manufacturers Association (CVMA), 2005. "CVMA: Current Issues: Climate Change." <http://www.cvma.ca/eng/issues/climatechange.asp>. Accessed October 11, 2005.
- DeCicco, J., F. An, and M. Ross. 2001. *Technical Options for Improving the Fuel Economy of US Cars and Light Trucks by 2010-2015*. Washington, D.C.: American Council for an Energy-Efficient Economy. April.
- Energy and Environmental Analysis, Inc.(EEA), 1999. "Canadian Transportation Table Study 3: Road Vehicle and Fuels Technology Measures Analysis." [http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/vehicle\\_technology/study3/Final\\_Report/Final\\_Report.htm](http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/vehicle_technology/study3/Final_Report/Final_Report.htm). Accessed October 12, 2005. Arlington, Virginia. September.
- Energy and Environmental Analysis, Inc. (EEA). 2001. *Technology and Cost of Future Fuel Economy Improvements for Light-Duty Vehicles*. Draft Final Report. Prepared for the National Academies National Research Council Committee on Impact and Effectiveness of Corporate Average Fuel Economy Standards.

- Environment Canada, 1999. "Sulphur in Gasoline Regulations (SOR/99-23)." *Canada Environmental Protection Act*. [http://www.ec.gc.ca/ceparegistry/regulations/g2-13313\\_r1.pdf](http://www.ec.gc.ca/ceparegistry/regulations/g2-13313_r1.pdf). Accessed October 20, 2005. June 4.
- European Conference of Ministers of Transport (ECMT), 2005. *Technology and Policies to Improve Vehicles In-Use Fuel Economy*. Organisation for Economic Co-Operation and Development. May 9.
- European Union (EU), 2004. "Climate Change: Commission Welcomes Political Agreement in the Council to Reduce Emissions of Fluorinated Greenhouse Gases." <http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/1231&format=HTML&aged=0&language=EN&guiLanguage=en>. Accessed October 25, 2005. October 14.
- Forrest, W.O. and M.S. Bhatti, 2002. "Energy Efficient Automotive Air Conditioning System", *Society of Automotive Engineers Technical Paper Series*. 2002-01-0229. Warrendale, Penn.
- General Motors Canada (GM Canada), 2005. "Vehicle Emissions & Fuels." [http://www.gmcanada.com/inm/gmcanada/english/about/Environment/environment\\_Tailpipe.html](http://www.gmcanada.com/inm/gmcanada/english/about/Environment/environment_Tailpipe.html). Accessed October 18, 2005.
- German, J., 1997. "Federal Test Procedure Revisions and Real-World Emissions." *Transportation, Energy, and Environment: How Far Can Technology Take Us?* Eds. J. DeCicco and M. DeLucchi. Washington D.C.: American Council for an Energy-Efficient Economy. pp. 51-73
- Ghodbane, M., L Scherer, J. Baker, and P. Kadle, 2003. "Potential Applications of R-152a Refrigerant in Vehicle Climate Control." *Society of Automotive Engineers Technical Paper Series*. 2003-04-0005. Warrendale, Penn.
- Hellman, K.H. and J. D. Murrell, 1984. "Development of Adjustment Factors for the EPA City and Highway MPG Values." *Society of Automotive Engineers*. 840496.
- Inside Washington Publishers (IWP), 2005. "Canada, Automakers Reach Historic Pact on Greenhouse Gas Emissions." March 24.
- Kenney, T.E., 1999. "Partitioning Emissions Tasks Across Engine and Aftertreatment Systems." *Society of Automotive Engineers Technical Paper Series*. 1999-01-3475. Warrendale, Penn.
- Khanna, P., 2005. Natural Resources Canada. Personal communication. December 5.
- Johnson, V.H., 2002. "Fuel used for vehicle air conditioning : A State-By-State Thermal Comfort-Based Approach." *Society of Automotive Engineers Technical Paper Series*. 2002-01-1957. Warrendale, Penn.
- Ljunggren, D. 2005. "Canada Split Over Restrictions of Car Emissions." [http://www.metronews.ca/reuters\\_national.asp?id=52818](http://www.metronews.ca/reuters_national.asp?id=52818). *Reuters*. January 25.
- Manufacturers of Emission Controls Association (MECA), 2003. *Tier 2/LEV II Emission Control Technologies for Light-Duty Gasoline Vehicles*. [http://www.meca.org/galleries/default-file/Tier2813final\\_a.pdf](http://www.meca.org/galleries/default-file/Tier2813final_a.pdf). Accessed October 22, 2005. Washington, D.C. August.
- Martini, S., M. Magini, S. Mola, G. Lo Presti, C. Malvicino, J. Benouali, D. Clodic, G. Caviasso., and A Tarzia, 2003. "High-Efficiency Air Conditioning – Improving Comfort and Reducing Impact on Fuel Consumption." *Society of Automotive Engineers Technical Paper Series*. 2003-04-0023. Warrendale, Penn.
- McNutt, B.D., R. Dulla, R. Crawford, H.T. McAdams, N. Morse, 1982. "Comparison of EPA and On-Road Fuel Economy – Analysis Approaches, Trends and Imports," *Society of Automotive Engineers*. Paper 820788, Warrendale, Penn. June.
- Ministry of Land, Infrastructure and Transport (MLIT), 2001. "Interim Report on Target Standards for Fuel Consumption" [http://www.mlit.go.jp/english/mot\\_news/mot\\_news\\_981014/mot\\_news\\_981014\\_2.html](http://www.mlit.go.jp/english/mot_news/mot_news_981014/mot_news_981014_2.html) Accessed July 15.



- Mintz, M.M., A.D. Vyas., and L.A. Conley, 1993. "Difference between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?," Paper 931104, 72<sup>nd</sup> Annual Meeting of the Transportation Research Board, Washington DC, January.
- Mitsubishi Motors, 2004. "Development of Energy-Saving Air Conditioner Control System for New Compact Vehicles." *Society of Automotive Engineers of Japan*. Technical Paper 20034297
- National Highway Traffic and Safety Administration (NHTSA), 2005a. *Federal Motor Vehicle Safety Standards; Tire Pressure Monitoring Systems; Controls and Displays; Final Rule*. U.S. Department of Transportation. 49 CFR Parts 571 and 585. April 8.
- National Highway Traffic and Safety Administration (NHTSA), 2005b. *Preliminary Regulatory Impact Analysis: Corporate Average Fuel Economy and CAFE Reform for MY 2008-2011 Light Trucks*. U.S. Department of Transportation. August.
- National Research Council (NRC), 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. National Academy of Sciences. Washington, D.C.: National Academy Press.
- Natural Resources Canada (NRCan), 1999. *Canada's Emissions Outlook: An Update*. <http://www.nrcan.gc.ca/es/ceo/update.htm>. Accessed October 12, 2005. December 21.
- Natural Resources Canada (NRCan), 2004. "Benefits: Societal and Economic Benefits." <http://oee.nrcan.gc.ca/transportation/fuels/ethanol/benefits.cfm?attr=8>. Accessed October 26, 2005. September 24.
- Natural Resources Canada (NRCan), 2005a. "Memorandum of Understanding between the Government of Canada and the Canadian Automotive Industry Respecting Automobile Greenhouse Gas Emissions." [http://www.nrcan-rncan.gc.ca/media/mous/2005/20050405\\_e.htm](http://www.nrcan-rncan.gc.ca/media/mous/2005/20050405_e.htm). Accessed October 5, 2005. Updated April 6.
- Natural Resources Canada (NRCan), 2005b. "Backgrounder: The Government of Canada's Voluntary Agreements with the Automotive Industry." [http://www.nrcan-rncan.gc.ca/media/newsreleases/2005/200522b\\_e.htm](http://www.nrcan-rncan.gc.ca/media/newsreleases/2005/200522b_e.htm). Accessed October 20, 2005. Updated April 5.
- Natural Resources Canada (NRCan), 2005c. "GHGenius Downloads." <http://www.ghgenius.ca/downloads.php>. GHGenius, Version 3.0. Accessed Oct 12, 2005. September 28.
- Natural Resources Canada (NRCan), 2005d. "Backgrounder: Ethanol Expansion Program." [http://www.nrcan.gc.ca/media/newsreleases/2005/200550a\\_e.htm](http://www.nrcan.gc.ca/media/newsreleases/2005/200550a_e.htm). Accessed October 29, 2005. July 7.
- Natural Resources Canada (NRCan), 2005e. "Your Guide to the One-Tonne Challenge." <http://www.climatechange.gc.ca/onetonne/english/tips/tipsCarFull.asp?classID=2> and <http://www.climatechange.gc.ca/onetonne/english/tips/tipsCarFull.asp?classID=1>. Accessed October 27, 2005. October 27.
- Northeast States Center for a Clean Air Future (NESCCAF), 2004. Reducing Greenhouse Gases from Light-Duty Vehicles. Interim Report. <http://bronze.nescaum.org/committees/mobile/rpt040316ghglightduty.pdf>. Accessed March 15.
- Plungis, J. and E. Mayne, 2005. "Automakers Go Green in Canada, Curbing Emissions." *The Detroit News*. <http://www.detnews.com/2005/autosinsider/0504/09/B01-141349.htm>. April 6.
- Reilly-Roe, P., 2005. "Voluntary Commitment by the Motor Vehicle Industry to Reduce GHG Emissions in Canada – Part of Canada's Climate Change Plan." 10th Biennial Conference on Transportation Energy and Environmental Policy. Asilomar, California. Aug. 25.
- Plotkin, S., D. Greene, K.G. Duleep. 2002. *Examining the Potential for Voluntary Fuel Economy Standards in the United States and Canada*. ANL/ESD/02-5, Argonne National Laboratory, U.S. Department of Energy. Argonne, Illinois.

- Schwarz, W. and J. Harnisch, 2003. *Establishing the Leakage Rates of Mobile Air Conditioners*. Prepared for the European Commission. B4-3040/2002/337136/MAR/C1. [http://europa.eu.int/comm/environment/climat/pdf/leakage\\_rates\\_final\\_report.pdf](http://europa.eu.int/comm/environment/climat/pdf/leakage_rates_final_report.pdf). Accessed October 22, 2005. April 17.
- Standardization Administration of China (SAC), 2005. "Announcement of Newly Approved National Standards of P.R. China" <http://www.sac.gov.cn/cgi-bin/english/showbulgbe.asp?id=665&year=2004&num=9&tnums=71&cnt=8&pdate=2004-9-13>. Accessed November 14, 2005.
- U.S. Congress, 2005. "Fuel Economy Truth in Labeling Act." Senate Bill S. 835IS. 109<sup>th</sup> Congress. <http://thomas.loc.gov/cgi-bin/query/z?c109:S.836>. Accessed October 24, 2005. April 18.
- U.S. Environmental Protection Agency (EPA), 1994. *Tips to Save Gas and Improve Mileage*. EPA- 420-F-92-004. <http://www.epa.gov/otaq/consumer/17-tips.htm>. Accessed October 26, 2005.
- U.S. Environmental Protection Agency (EPA), 1996. *Regulatory Impact Analysis (Final Rule): Federal Test Procedure Revisions*. <http://www.epa.gov/otaq/regs/ld-hwy/ftp-rev/ftp-ria.pdf>. Accessed October 24, 2005. August 15.
- U.S. Environmental Protection Agency (EPA), 1999. "Tier 2 Vehicle and Gasoline Sulfur Program Final Rule." Accessed October 11, 2005. <http://www.epa.gov/tier2/finalrule.htm>. December.
- Wang, M., C. Saricks, and D. Santini, 1999. "Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions." Argonne National Laboratory, U.S. Department of Energy. ANL/ESD-38. January. Argonne, Illinois
- Watanabe, T., 2004. "Concept of Fuel Consumption Rate Improvement for A/C Operation." *Society of Automotive Engineers of Japan*. 20045539.
- Weiss, Malcolm A., John B. Heywood, Elisabeth M. Drake, Andreas Schafer, and Felix F. AuYeung. 2000. *On the Road in 2020: A Life-Cycle Analysis of New Automobile Technologies*. Energy Laboratory Report # MIT EL 00-003. Massachusetts Institute of Technology (MIT). October.
- Welstand, J.S., H.H. Haskew, R.F. Gunst, and O.M. Bevilacqua, 2003. "Evaluation of the Effects of Air Conditioning Operation and Associated Environmental Conditions on Vehicle Emissions and Fuel Economy." *Society of Automotive Engineers Technical Paper Series*. 2003-01-2247. Warrendale, Penn.