A Long Hard Road

Reducing GHG Emissions in Canada’s Road Transportation Sector by 2050
Abstract & Highlights: A Long, Hard Road: Reducing GHG Emissions in Canada’s Road Transportation Sector by 2050
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Preface

It is widely maintained that to prevent catastrophic climate change from occurring, developed countries must reduce their emissions by 80 per cent relative to 1990 levels. In Canada, greenhouse gas emissions levels are increasing and much of this growth has resulted from the transportation sector, in which road transportation emissions account for the largest share. This report intends to provide an evidence-based view of the contribution that road transportation might practically make to achieving the “80 by 50” target in Canada. The report develops two cases that examine the potential emissions reductions that could result from a broad range of trends and technologies: a reference case and a continuous improvement case. The cases highlight that even with aggressive assumptions, Canada would still need to make significant adjustments to achieve the target. Given that many of the options that exist to further reduce emissions are associated with high unit abatement costs, future emissions reductions may reach a practical or economic limit before the 80-by-50 target is achieved.
CONTENTS

i EXECUTIVE SUMMARY

Chapter 1
1 Introduction

Chapter 2
6 Overview of Canada’s GHG
7 Total Emissions Levels
8 Road Transportation Emissions

Chapter 3
15 Government Initiatives to Reduce GHG Emissions From Road Transportation in Canada
18 Greenhouse Gas Emissions Standards
22 Government Actions to Promote Biofuel Production
28 Low-Carbon Fuel Standards
29 Government Actions to Promote Alternative Technology Cars
32 Urban Planning
39 Greening Government

Chapter 4
42 Voluntary Initiatives to Reduce GHG Emissions From Freight Transportation in Canada
43 Fuel Economy
44 Fuel Economy Technologies
49 Barriers to Technology Adoption

Chapter 5
52 Alternative Fuels and Vehicle Technologies
53 Technology Descriptions
60 GHG Emissions Reductions
62 UpStream Emissions Considerations
65 Emissions Reductions Comparisons With Prior Studies
68 Infrastructure Requirements
77 Cost Comparison
81 Conclusions

Chapter 6
82 Options to Reduce Road Transportation GHG Emissions in Canada
83 Analytical Framework
86 Technology Penetration Rates
88 Scenarios
103 Assembling the Pieces

Chapter 7
106 The Cost of Road Transportation GHG Mitigation
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EXECUTIVE SUMMARY

A Long, Hard Road: Reducing GHG Emissions in Canada’s Road Transportation Sector by 2050

At a Glance

- Reducing Canadian road transportation emissions to 80 per cent below 1990 levels would require a reduction of 117.5 megatonnes of carbon dioxide equivalent (Mt CO$_2$e) from 2013 levels (a target of 19.5 Mt). The options considered here would reduce GHG emissions by 65.8 Mt or more, leaving Canada at least 51.7 Mt above the target.

- Achieving those further cuts would require Canadians to make significant adjustments, including attitudinal and behavioural changes.

- These reductions are often associated with unit abatement costs in excess of $100 per tonne.
The international community has widely embraced limiting global warming to two degrees Celsius (2°C) above pre-industrial levels as a way to prevent dangerous levels of climate change from occurring.

It is commonly believed that this target requires a stabilization of the amount of carbon dioxide (CO₂) in the atmosphere at 450 parts per million. In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) suggested that to achieve this concentration, developed countries would need to reduce their emissions by 80 per cent relative to 1990 levels. Between 1990 and 2013, transportation emissions have accounted for nearly one-half of the growth of Canada’s emissions levels, with road transportation accounting for the largest share of transportation emissions. Reducing Canadian road transportation emissions by 80 per cent relative to 1990 levels would require a decline of approximately 117.5 megatonnes of carbon dioxide equivalent (Mt CO₂e) from 2013 levels. The purpose of this report is to provide an evidence-based view of the contribution that road transportation might practically make to achieving the 80-by-50 target in Canada.

Despite voluntary and regulatory initiatives that have reduced the emissions intensity of passenger and freight transportation, emissions levels have continued to rise in Canada. This is because Canada’s vehicle stock is growing at a rate that outpaces emissions reductions and consumer preferences for passenger vehicles are shifting from cars to more emissions-intensive light trucks. Achieving the 80-by-50 target will require actions that break the link between GDP, population, and road transportation activity.

Road transportation activity can be broken down into two components: how people and freight travel (mode choice) and how far they travel (activity level). Municipal governments, with the support of the federal and provincial governments, have attempted to influence mode choice through the development of transportation and municipal development plans. These plans outline projects intended to encourage people to...
switch from travelling in single-occupant vehicles to other modes of travel that include walking, cycling, or public transit. While governments have implemented initiatives to reduce transportation activity levels, they have focused their efforts on reducing the energy intensity of road transportation. Initiatives include developing vehicle tailpipe emissions standards, increasing the supply of and demand for biofuels, and encouraging the purchase of alternative technology vehicles.

In addition to government policies and regulations, the voluntary actions of private fleets also reduce emissions from road transportation. Fuel is a large portion of operating costs for fleets, so they have an incentive to reduce their fuel consumption to increase their profit margins. Technologies that improve the combustion efficiency of a truck’s engine or reduce the effect of drag or friction can result in fuel savings. However, some firms choose not to install these technologies due to inconsistent regulations between jurisdictions, unacceptable payback periods, and a lack of confidence in available vehicle technologies.

While many of the actions of governments and private firms have focused on improving the fuel efficiency of traditional vehicle technologies, alternatives to conventional internal combustion engines exist. These include vehicles that run on fuels such as biofuel blends, liquefied petroleum gases, natural gas, or electricity. The use of these fuels can reduce the GHG intensity of road transportation. The long-term impact of these technologies is sensitive to the assumptions made regarding future market penetration rates. Given that many of these technologies have been commercially available for a relatively short period, there is a limited historical basis for the assumptions regarding their future success.

This report develops two cases to examine the potential emissions reductions that are possible from a broad range of trends and technologies: a reference case and a continuous improvement case. The reference case projects emissions reductions up to 2050, using existing vehicle patterns, fuel choices, and regulations. While emissions levels decline steadily through 2025—the last model year to which light-duty emissions standards apply—by 2050, road transportation emissions
will have risen to within 12 per cent of current levels. The continuous improvement case makes the same assumptions as the reference case for population and GDP levels, but reflects two additional trends: declining distances travelled per vehicle and improved fuel efficiency.

The near-term outcome of the continuous improvement case is similar to that of the reference case; emissions will decline steadily through 2025. Beyond that, the rate of decline flattens, with total road transportation emissions dropping to 86 million tonnes by 2050, just 12 per cent below the 1990 level of 97.7 Mt.

Incremental emissions reductions could result from a greater market penetration of alternative vehicle technologies and modal shifts away from single-occupancy vehicles. These incremental reductions may reduce emissions enough to offset road transportation activity increases that arise from growing GDP and population. However, they are unsuccessful in achieving an 80 per cent reduction relative to 1990 levels. Furthermore, in the case of passenger vehicles, with very few exceptions, the abatement costs for these technologies exceed a cost of carbon of $100 per tonne. While alternative vehicle technologies may result in financial savings for heavy-duty vehicles, the lack of fuelling infrastructure serves as a barrier to increased adoption.

Even accounting for reduced distances travelled per vehicle, improvements in vehicle efficiency, greater market penetration of alternative technology vehicles, and modal shifts, by 2050, projected emissions from road transportation range from 71.2 to 76.5 Mt, which is 51.7 to 57 Mt higher than what the 2°C target requires. In reality, the reductions identified are not additive; for example, increasing the market share of electric vehicles reduces the impact of improving the fuel efficiency of conventional vehicles. Consequently, it is important to bear in mind how policies interact with one another, and that they are not necessarily additive. To achieve the 80-by-50 target, Canada will need to implement a coordinated approach that, in addition to focusing on technological improvements, includes initiatives that reduce demand for road transportation. For a summary of the report’s findings, see Table 1.
If it is based on an 80 per cent reduction from 1990 emissions, the path to a low-carbon future for road transportation in Canada requires actions beyond those included in Table 1. It will be important to continue our current path of continued focus and improvement in vehicle performance. However, as conventional vehicles continue to become less emissions-intensive, some of the benefits of alternative vehicle technologies may be eroded. The combined impacts of vehicle improvements and alternative technologies are not additive, suggesting that government policies, programs, and incentives must be updated as circumstances change.

Of course, the most fuel- and emissions-efficient passenger- or freight-kilometre is the one not travelled. Canada’s cities are focused on improving public transit, encouraging alternative transportation, and designing or redesigning urban spaces to reduce the need for transportation. These are long-term prospects.

With respect to freight, a continued focus on reducing energy losses will strengthen performance. In addition, improvements in the adoption rate of new technologies could reduce emissions faster than projected in this analysis.

Table 1
Findings Summary

<table>
<thead>
<tr>
<th></th>
<th>Mt CO₂e</th>
<th>vs. 1990 (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road transportation emissions (1990)</td>
<td>97.7</td>
<td>–</td>
</tr>
<tr>
<td>Road transportation emissions (2013)</td>
<td>137.0</td>
<td>+40.2</td>
</tr>
<tr>
<td>Road transportation emissions (2050—Reference case)</td>
<td>120.7</td>
<td>+23.5</td>
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<tr>
<td>Road transportation emissions (2050—Continuous improvement case)</td>
<td>86.2</td>
<td>−11.8</td>
</tr>
<tr>
<td>Road transportation emissions (2050—Additional market penetration case)</td>
<td>71.2 to 76.5</td>
<td>−27.1 to −21.7</td>
</tr>
<tr>
<td>80-by-50 target</td>
<td>19.5</td>
<td>−80</td>
</tr>
<tr>
<td>Remaining reductions required to meet target</td>
<td>51.7 to 57.0</td>
<td>–</td>
</tr>
</tbody>
</table>

Sources: Environment Canada; The Conference Board of Canada.
On balance, one of the key questions is just that: balance. The options exist to enable significant reductions in Canada’s road transportation GHG emissions. However, many of them are expensive. Even as unit abatement costs are reduced, future emissions reductions may well reach a practical or economic limit before the reductions identified in this report can be achieved.
CHAPTER 1

Introduction

Chapter Summary

- Global warming of 2°C above pre-industrial levels is widely believed to be the threshold of dangerous climate change.

- It is widely maintained that this threshold corresponds to stabilizing the atmospheric concentration of carbon dioxide (CO$_2$) to 450 parts per million.

- The Intergovernmental Panel on Climate Change (IPCC) has suggested that achieving this atmospheric concentration would require developed countries to reduce their emissions by 80 per cent relative to 1990 levels.

- Canada’s emissions levels are increasing; between 1990 and 2013, nearly half of this growth resulted from the transportation sector.

- Road transportation emissions account for the largest share of transportation emissions.
In order to keep the earth from warming greater than two degrees Celsius (2°C) above pre-industrial levels, it is widely believed that by 2050, industrialized countries will need to reduce their greenhouse gas emissions by 80 per cent from 1990 levels. Between 1990 and 2013, transportation emissions accounted for almost one-half of the growth in Canada’s total emission levels, with road transportation comprising the largest share of transportation emissions. Consequently, focusing mitigation efforts on emissions from Canada’s road transportation sector will be essential to achieving this target. The purpose of this report is to analyze the potential pathways to reducing greenhouse gas emissions from road transportation in Canada.

Many countries have embraced the 2°C target, including signatories of the United Nations Framework Convention on Climate Change (UNFCCC), which Canada joined in 1992. This target-based approach to climate was established in the 1990s, when researchers proposed that 2°C delineated the boundary between climate change impacts that would result in social and economic disruption, and those that would not.

The UNFCCC suggests that to restrict climate change to the 2°C limit, it is necessary to stabilize the atmospheric concentration of carbon dioxide (CO₂) at 450 parts per million. In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) proposed that

2 United Nations Framework Convention on Climate Change (UNFCCC), *Cancun Climate Change Conference*.
3 UNFCCC, *Canada*.
4 Randalls, “History of the 2°C Climate Target,” 600.
5 UNFCCC, *Fast Facts and Figures*. 
this concentration corresponded to an 80 to 95 per cent reduction in emissions from industrialized countries, relative to 1990 levels.\textsuperscript{6} While the IPCC did not intend for its models to be prescriptive,\textsuperscript{7} many countries and organizations chose to incorporate them into their climate change policies, including the European Union.\textsuperscript{8}

The IPCC has also identified a global “carbon budget,” which refers to the amount of carbon dioxide that can be released into the atmosphere and still restrain climate change to 2°C.\textsuperscript{9} Cumulative global emissions must not exceed 3,670 gigatonnes (Gt) of CO\textsubscript{2} to limit warming to this threshold.\textsuperscript{10} As of 2011, 1,890 Gt CO\textsubscript{2} have already been released—over half of the budget.\textsuperscript{11}

Annual greenhouse gas (GHG) emissions are continuing to grow, globally reaching 49.5 Gt of carbon dioxide equivalent (CO\textsubscript{2}e) in 2010, exceeding any previous level.\textsuperscript{12} The current pace of GHG emissions is incompatible with achieving the 2°C target.\textsuperscript{13} If governments intend to achieve this goal, deep emissions cuts across sectors will be necessary, including across the transportation sector.

\textbf{Carbon Dioxide Equivalent (CO\textsubscript{2}e)} is a unit that is used to compare different greenhouse gas emissions based on the ratio of their global warming potential (GWP) to CO\textsubscript{2}. GWP refers to the warming impact of a greenhouse gas over a set period (typically 100 years). CO\textsubscript{2}e describes the amount of CO\textsubscript{2} that would result in the same GWP as a specified quantity of a greenhouse gas.\textsuperscript{14}

7 Halsnæs and others, “Framing Issues,” 130.
8 European Commission, \textit{A Roadmap for Moving to a Competitive Low Carbon Economy}, 3.
9 Intergovernmental Panel on Climate Change (IPCC), 2013, “Summary for Policymakers,” 27.
10 With a probability >66%.
11 Intergovernmental Panel on Climate Change (IPCC), 2012, “Summary for Policymakers,” 27.
13 Ibid., 114.
In Canada, transportation emissions account for approximately 28 per cent of total emissions, with road transportation comprising the majority. Reducing total GHG emissions by 80 per cent, relative to 1990, would require a reduction of 603.4 megatonnes (Mt) CO$_2$e from 2013 levels. Correspondingly, an 80 per cent reduction in Canada’s road transportation emissions would require a reduction of approximately 117.5 Mt CO$_2$e from 2013 levels. (See Chart 1.) While voluntary and regulatory initiatives have reduced the carbon intensity of road transportation, reducing emissions levels will be more challenging, as increases in passenger and freight activity have the potential to overtake reductions resulting from mitigation measures.

The objective of this report is to provide an evidence-based view of the contribution that road transportation might practically make toward a Canadian goal of an 80 per cent reduction in GHG emissions by 2050.

16 Ibid.
17 Ibid.
18 Sims and others, "Transport," 603.
The analysis is based primarily on existing studies and includes:

- a summary of Canada’s historical emissions levels (Chapter 2);
- an overview of current government policies and regulations (Chapter 3);
- an outline of current voluntary initiatives in Canada’s freight sector (Chapter 4);
- a synopsis of alternative vehicle and fuel technologies (Chapter 5);
- an overview of potential paths to reducing road transportation emissions in Canada (Chapter 6);
- an examination of the costs associated with emissions reductions (Chapter 7);
- a summary of conclusions and recommendations (Chapter 8).
CHAPTER 2

Overview of Canada’s GHG

Chapter Summary

• Regulatory, policy, and voluntary initiatives have reduced the GHG intensity of passenger transportation (CO$_2$/km) and freight transportation (CO$_2$/tonne-km).

• Despite decreasing GHG intensity levels, total emissions levels from road transportation have continued to rise.

• Emissions levels from road transportation are increasing due to the growing size of Canada’s vehicle stock and shifting consumer preferences for passenger vehicles.

• Significant reductions in road transportation emissions levels will require initiatives that break the link between growing GDP, population levels, and road transportation activity.
Due to the large size of their emissions share, lowering Canada’s road transportation emissions will be a critical lever for reducing Canada’s total GHG emissions to 80 per cent below 1990 levels. Achieving this target poses a significant challenge; while voluntary and regulatory initiatives have reduced the GHG intensity of road transportation (which will be discussed in chapters 3 and 4), these improvements have been outpaced by other factors.

These factors include:

- the growing size of Canada’s vehicle stock;
- the increasing vehicle-kilometres and tonne-kilometres travelled;
- changing consumer preferences.

Consequently, achieving the 80-by-50 target will require initiatives that are capable of reducing road transportation emissions, even as GDP and population continue to grow. This theme will be discussed further in Chapter 6.

**Total Emissions Levels**

In 1990, total GHG emissions in Canada totalled 613 Mt.\(^1\) In 2013, total emissions amounted to 726 Mt, an increase of 113 Mt.\(^2\) (See Chart 2.) The majority of increases in emissions occurred prior to 2005.\(^3\) During the 2000s, provincial governments began implementing climate change action plans that intended to reduce GHG emissions, and many of the initiatives contained in these plans were implemented prior to 2004.\(^4\) This fact is important, as it suggests that government efforts to reduce GHG emissions may have had a positive impact on reducing total emissions.

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2. Ibid.
4. Ibid.
Transportation emissions accounted for nearly half of the change in total emissions between 1990 and 2013, increasing by 56 Mt.\textsuperscript{5} Transportation emissions include domestic air, road, off-road, rail, and marine transportation.\textsuperscript{6} Of these GHG sources, road transportation is the largest source, accounting for 67 per cent of transportation emissions in 2013.\textsuperscript{7}

### Road Transportation Emissions

In 2013, road transportation emissions accounted for approximately 19 per cent of total emissions in Canada, up from 16 per cent in 1990.\textsuperscript{8} Road transportation emissions can be broken down into vehicle types based on weight and fuel type. (See Table 2.) Emissions levels have increased for the majority of vehicle categories, with light-duty gasoline vehicles, which decreased by 27 per cent between 1990 and 2013, being the notable exception.\textsuperscript{9} (See charts 3 and 4.) While the emissions levels of light-duty diesel trucks also declined, they account for a much smaller share of emissions.\textsuperscript{10}

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\textsuperscript{6} Ibid.

\textsuperscript{7} Ibid.

\textsuperscript{8} Natural Resources Canada, \textit{Comprehensive Energy Use Database}.

\textsuperscript{9} Ibid.

\textsuperscript{10} Ibid.
Table 2
Vehicle Classifications

<table>
<thead>
<tr>
<th>Gross vehicle weight</th>
<th>Fuel type</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–8,500 lb.</td>
<td>Gasoline</td>
<td>Light-duty gasoline vehicle</td>
</tr>
<tr>
<td>0–8,500 lb.</td>
<td>Diesel</td>
<td>Light-duty diesel vehicle</td>
</tr>
<tr>
<td>0–8,500 lb.</td>
<td>Gasoline</td>
<td>Light-duty gasoline passenger truck</td>
</tr>
<tr>
<td>0–8,500 lb.</td>
<td>Diesel</td>
<td>Light-duty diesel passenger truck</td>
</tr>
<tr>
<td>0–8,500 lb.</td>
<td>Gasoline</td>
<td>Light-duty gasoline freight truck</td>
</tr>
<tr>
<td>0–8,500 lb.</td>
<td>Diesel</td>
<td>Light-duty diesel freight truck</td>
</tr>
<tr>
<td>8,501–33,000 lb.</td>
<td>Gasoline</td>
<td>Medium-duty gasoline freight truck</td>
</tr>
<tr>
<td>8,501–33,000 lb.</td>
<td>Diesel</td>
<td>Medium-duty diesel freight truck</td>
</tr>
<tr>
<td>33,001 lb.+</td>
<td>Diesel</td>
<td>Heavy-duty diesel freight truck</td>
</tr>
</tbody>
</table>

Sources: Natural Resources Canada; The Conference Board of Canada.

Chart 3
Road Transport Emissions by Vehicle Type—Passenger Vehicles
(Mt CO₂e)

Sources: Natural Resources Canada; The Conference Board of Canada.
While the total level of transportation emissions has increased, the intensity of transportation emissions, measured as grams of CO\(_2\)e per passenger-kilometre (g CO\(_2\)e/passenger-km) or grams of CO\(_2\)e per tonne-kilometre (g CO\(_2\)e/tonne-km), has decreased. Canada’s population grew at a compound annual rate of 1 per cent between 1990 and 2012.\(^{11}\) Over this same period, the emissions intensities of passenger cars and trucks decreased at an annual rate of 1.2 and 0.7 per cent, respectively.\(^{12}\) (See Chart 5.) Concerning freight transportation, Canada’s GDP grew at a compound annual rate of 2.4 per cent between 1990 and 2012.\(^{13}\) During this time, the emissions intensities of light-, medium-, and heavy-duty freight trucks declined by an annual rate of 1.3, 1.4, and 0.5 per cent, respectively.\(^{14}\) (See Chart 6.)

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\(^{11}\) Statistics Canada, CANSIM table 109-5345.  
\(^{12}\) Natural Resources Canada, Comprehensive Energy Use Database.  
\(^{13}\) Statistics Canada, CANSIM table 380-0064.  
\(^{14}\) Natural Resources Canada, Comprehensive Energy Use Database.
Despite decreasing emission intensities for both passenger and freight vehicles, road transportation emissions levels continue to rise. In part, this is due to the growth of Canada’s vehicle stock. (See Chart 7.) As Canada’s GDP and population grow, the Canadian vehicle stock expands. Due to having more cars on the road, total vehicle-kilometres (V KT) increases, which results in additional emissions. (See charts 8 and 9.)
Chart 7

Canadian Vehicle Stock
(number of vehicles, millions)

Sources: Natural Resources Canada; The Conference Board of Canada.

Chart 8

Total Vehicle Kilometres Travelled by Vehicle Type—Passenger Vehicles
(billions of passenger-km)

Sources: Natural Resources Canada; The Conference Board of Canada.
In addition to growing in size, the composition of the Canadian vehicle stock is shifting. In 1990, cars made up 80 per cent of passenger vehicles, while passenger trucks, which include pickup trucks, vans, and SUVs, comprised the remaining 20 per cent. By 2013, the make-up of passenger vehicles had changed significantly: Cars’ vehicle share dropped to 63 per cent, while passenger trucks’ share increased to 37 per cent. (See Chart 10.) Because passenger trucks generally consume more fuel than cars, this shift in consumer preferences dampens the gains made by voluntary and government initiatives that reduce road transportation’s emissions intensity.

Sources: Natural Resources Canada; The Conference Board of Canada.
In sum, there are increasingly more vehicles on Canadian roads, which results in additional driving, culminating in elevated total emissions levels. Shifts in consumer preferences have accelerated this trend, and voluntary and government initiatives to lower the emissions intensity of road transportation have not been sufficient to decrease total emissions levels. Achieving significant reductions in Canada’s road transportation emissions will require initiatives that break the link between GDP, population growth, and road transportation activity.
CHAPTER 3

Government Initiatives to Reduce GHG Emissions From Road Transportation in Canada

Chapter Summary

• Governments have attempted to reduce road transportation emissions by focusing on four areas: activity level, infrastructure and mode choice, energy efficiency, and fuel carbon content.

• Government initiatives have focused on energy efficiency and infrastructure/mode choice.

• Initiatives that reduce the emissions intensity of passenger and freight travel include the development of emissions standards for light- and heavy-duty vehicles, increasing the supply of and demand for biofuels, and incentivizing the purchase of alternative technology vehicles.

• Municipal governments have attempted to influence mode choice through the development of integrated transportation and municipal development plans, which encourage people to use more sustainable modes of transportation.
Direct government activities account for only a small share of Canada’s road transportation emissions. However, governments do make regulations, provide public infrastructure, lead by example, and inform the public on the implications of their transportation choices. In performing these roles, governments have access to tools that include legislation, regulation, investment, financial support, and communication.

Governments in Canada have implemented a broad range of initiatives in their attempts to reduce GHG emissions from road transportation. To better understand how these initiatives work, road transportation emissions can be considered in four basic categories, as defined by the Intergovernmental Panel on Climate Change.¹

1. activity level
2. infrastructure and mode choice
3. energy efficiency
4. fuel carbon content

Road transportation activity is typically measured in passenger-kilometres or tonne-kilometres, depending on whether the activity is moving people or moving freight. Population; economic activity (GDP); geography (primarily the geographic dispersion of population or goods production); and climate are among the key drivers of road transportation activity. Behaviour also plays a key role, through decisions such as whether to travel or how and when to ship goods.

Infrastructure and mode choice refer to the level and types of transportation infrastructure we can access and how we choose to use them. The level of infrastructure determines whether moving people or freight by a certain mode is even an option. Infrastructure availability

¹ Sims and others, “Transport.”
influences, but does not determine, decisions such as mode choice. Infrastructure also includes the relationship between land-use planning and transportation planning in an urban setting.

“Energy efficiency” refers to the energy consumed per unit of activity considered (e.g., litres per 100 kilometres or litres per tonne-kilometre). It is determined by the vehicle technology, the energy content of the fuel, and driving behaviour.

It is possible to reduce the emissions intensity of transportation activities by reducing the carbon in the fuel. This may be accomplished with a very limited behavioural change in the case of blending biofuels into gasoline or diesel, which are burned in an internal combustion engine (ICE). It may also require more fundamental changes, such as replacing an internal combustion engine vehicle with an electric vehicle.

Government initiatives have been implemented to influence each of these categories, although energy efficiency and infrastructure have been addressed most actively and perhaps most broadly. This chapter summarizes recent initiatives by Canada’s federal and provincial governments that include:

- vehicle tailpipe emissions standards: light- and heavy-duty vehicles (energy efficiency, fuel carbon content);
- promoting biofuels production (energy efficiency, fuel carbon content);
- vehicle incentives (energy efficiency, fuel carbon content);
- urban planning (activity level, infrastructure and mode choice);
- greening government (activity level, energy efficiency).

Each group of initiatives is presented in terms of current initiatives, their basic structure, the cost (where available), the intended environmental outcome, and the actual outcome to date (although this is not often known).
Greenhouse Gas Emissions Standards

Tailpipe emissions standards reduce GHG emissions levels by limiting the average GHG intensity of a vehicle manufacturer’s fleet in a given model year, measured in grams of CO$_2$e per mile. As opposed to incentives that promote the use of alternative technology vehicles, these standards are more flexible in that they allow the market, rather than the government, to choose the appropriate technology path.

Prior to regulating GHG emissions, Canada implemented regulations that set standards for the emission of volatile organic compounds, carbon monoxide, nitrogen oxides, particulate matter, and other air pollutants. The federal government also implemented regulations that limited the sulphur content of gasoline and diesel. Canada’s Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations were the first regulations to specifically limit GHG emissions in the road transportation sector.

Canada’s current emissions standards, shown in Table 3, grow increasingly stringent with each model year and align with standards developed by the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). Canada has historically mirrored the United States’ approach to emissions standards, ensuring a harmonized standard across North America. For additional details on the evolution of emissions standards, refer to Appendix A.


Light-Duty Vehicle Emissions Standards: 2011–16
The Government of Canada anticipates that the regulations will result in a cumulative reduction of 92 Mt of CO$_2$e over the lifetime of the regulated vehicles.\(^4\) The government predicts that achieving this reduction will cost approximately $4.2 billion,\(^5\) and that vehicle manufacturers will spend approximately $3.6 billion on incremental technology.\(^6\) The majority of these costs are expected to be passed on to consumers in the form of a higher sticker price. Consumers, however, benefit from increased fuel savings, allowing for a payback period that averages less than 1.5 years.\(^7\) The government estimates that the total social and private benefits\(^8\) attributable to the regulations will be approximately $13.4 billion,\(^9\) resulting in a net benefit of approximately $9.2 billion.\(^10\) This information is shown by model year (MY) in Table 4.

Table 3

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Initiative</th>
<th>Model years</th>
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<tr>
<td>Canada</td>
<td>Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations</td>
<td>2011–16</td>
</tr>
<tr>
<td>Canada</td>
<td>Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations</td>
<td>2017–25</td>
</tr>
<tr>
<td>Canada</td>
<td>Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations</td>
<td>2014–18</td>
</tr>
</tbody>
</table>

Sources: Federal Regulations; The Conference Board of Canada.

\(^5\) Ibid.
\(^6\) Ibid.
\(^7\) Ibid.
\(^8\) In this chapter, many of the measures include both social and private costs and benefits. In subsequent chapters and in the modelling analysis, only private costs and benefits are examined.
\(^10\) Ibid.
Calculating the Benefits of Policies and Regulations That Address Climate Change

In Canada, all “significant regulatory proposals” must be accompanied by a cost-benefit analysis. The federal government uses the social cost of carbon as a way of evaluating the economic benefits of regulations that address climate change. The social cost of carbon refers to the damage, expressed in dollars, that results from the emission of a metric ton of CO$_2$e into the atmosphere. Given that different models will result in distinct outcomes, there is no universally accepted value for the cost of carbon. While the cost of carbon is not definitive, it is still an important concept, as it narrows the cost differential between the status quo and alternative, less carbon-intensive, scenarios.


Over the lifespan of the 2017–25 vehicle cohort, the government estimates that the regulations will result in a reduction of 174 Mt of CO$_2$e. Similar to the first iteration of light-duty emissions standards, the government estimates that industry will pass incremental costs onto consumers. The payback period to offset this cost increase ranges from

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11 Treasury Board of Canada Secretariat, Canadian Cost-Benefit Analysis Guide.
12 United States Environmental Protection Agency (U.S. EPA), The Social Cost of Carbon.
one to three years. To see a breakdown of anticipated costs and benefits by model year, refer to Table 5. Currently, it appears that neither the U.S. nor the Canadian government has announced an intention to develop light-duty vehicle emissions standards beyond 2025.

### Table 5

**Costs and Benefits of the 2017–25 Light-Duty Vehicle Emissions Standards**

(2012 C$ millions)

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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs</td>
<td>241</td>
<td>471</td>
<td>694</td>
<td>904</td>
<td>1,105</td>
<td>1,458</td>
<td>1,795</td>
<td>2,117</td>
<td>2,443</td>
<td>11,226</td>
</tr>
<tr>
<td>Total benefits</td>
<td>1,367</td>
<td>2,803</td>
<td>4,217</td>
<td>5,572</td>
<td>6,925</td>
<td>8,085</td>
<td>9,242</td>
<td>10,398</td>
<td>11,647</td>
<td>60,257</td>
</tr>
<tr>
<td>Net benefit</td>
<td>1,126</td>
<td>2,333</td>
<td>3,523</td>
<td>4,668</td>
<td>5,821</td>
<td>6,627</td>
<td>7,447</td>
<td>8,282</td>
<td>9,204</td>
<td>49,031</td>
</tr>
</tbody>
</table>

*MY = model year

Source: Government of Canada.

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**Heavy-Duty Vehicle Emissions Standards**

Canada’s heavy-duty vehicle emissions standards apply to on-road vehicles with a gross vehicle weight greater than 8,500 lb. intended for sale in Canada.\(^{14}\) The government estimates that over the lifetime of the vehicles from 2014–18 model years, the regulations will result in a reduction of 19.0 Mt of CO\(_2\)e.\(^{15}\) Similar to the light-duty emissions standards, the majority of the costs associated with the standards are due to upgrading vehicle technology to comply with the regulations. Most likely, manufacturers will increase their prices to recover these costs. However, the resulting fuel savings are anticipated to more than offset the effect on vehicle owners. For a detailed breakdown of anticipated costs and benefits of the regulations by model year, refer to Table 6.


\(^{15}\) Ibid., 921.
In October 2014, the federal government issued a notice of intent to develop regulations that govern the emissions from on-road heavy-duty vehicles post-2018 model year. The next steps to implementing new regulations include stakeholder consultations, which will assist in the drafting of proposed regulations. As has been the case historically, the federal government intends to work in close coordination with the EPA and NHTSA to ensure the development of common national standards between Canada and the United States. In June 2015, the EPA and NHTSA published proposed standards, building on current regulations, that would apply beginning in 2021 through to 2027.

### Government Actions to Promote Biofuel Production

Biofuels offer a potential avenue to reduce emissions from road transportation, as they are generally less carbon-intensive than gasoline or diesel, which are the largest sources of transportation fuel in

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Costs and Benefits of the 2014–18 Heavy-Duty Vehicle Emissions Standards (2010 C$ millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MY* 2014</td>
</tr>
<tr>
<td>Total costs</td>
<td>166</td>
</tr>
<tr>
<td>Total benefits</td>
<td>793</td>
</tr>
<tr>
<td>Net benefit</td>
<td>627</td>
</tr>
</tbody>
</table>

*MY = model year

Source: Government of Canada.

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17 Ibid.
18 Ibid.
20 Coad and Bristow, *Ethanol’s Potential Contribution to Canada’s Transportation Sector*, 45.
Biofuels are not without their limits; many warranties do not allow for the use of fuel blends above E10 or B20. Additionally, when compared to pure petroleum diesel, in cold weather, biofuel blends tend to gel at higher temperatures. However, these effects can be addressed by “fuel additives and engine block or fuel filter heaters.”

Despite these limitations, the provincial and federal governments have attempted to increase the market share of biofuels. The measures include:

- tax exemptions and credits
- loans and grants
- volumetric production incentives
- renewable fuel requirements

After the introduction of a federal renewable fuel standard, the consumption of biofuels in Canada has increased to the point that consumption exceeds production. To make up for this difference, Canada relies on biofuel imports, which are sourced primarily from the United States. (See charts 11 and 12.) Consequently, reducing GHG emissions through the increased use of biofuels would require either additional domestic production capacity or increased imports.

Canadian governments have recently focused on increasing the production of second-generation biofuels. First-generation biofuels, which are sourced from food crops, have been associated with negative effects on food security and the environment. In contrast, next-generation biofuels, which are sourced from alternative feedstocks,

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21 Statistics Canada, CANSIM table 405-0002.
22 Searle and others, *Technical Barriers to the Consumption of Higher Blends of Ethanol*, 5; *Biodiesel, OEM Information*.
23 Transport Canada, *Biodiesel*.
24 Ibid.
25 United States Department of Agriculture (U.S. DoA), *Canada Biofuels Annual 2014*.
26 Ibid.
are not subject to the same issues.\textsuperscript{28} However, to penetrate the market, next-generation biofuels will need to become cost-competitive with first-generation biofuels.\textsuperscript{29}

\textbf{Chart 11}
\textbf{Canadian Ethanol Fuel Consumption vs. Fuel Production}
(\textit{millions of litres})

\textbf{Chart 12}
\textbf{Canadian Renewable/Bio Diesel Fuel Consumption vs. Fuel Production}
(\textit{millions of litres})

\textsuperscript{28} Ibid.

\textsuperscript{29} Des Rosiers, \textit{A Canadian Perspective on Global Biofuels Developments}. 
Renewable Fuel Standards
Canada’s federal renewable fuel standards require transportation fuel producers and importers to ensure that gasoline and diesel contain an average renewable fuel content of at least 5 per cent and 2 per cent, respectively. Some provinces differ from the federal blending requirements for ethanol and biodiesel. (See Table 7.) Over a 25-year period, the federal government anticipates that the federal regulations will result in a 47.4 Mt reduction of CO$_2$e, representing a benefit of $1.1 billion. The government estimates that costs to achieve these reductions will total approximately $4.8 billion. Consequently, the federal government anticipates the regulations to result in a net cost of approximately $3.7 billion.

Table 7
Current Renewable Fuel Standards (per cent)

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Ethanol</th>
<th>Bio-diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>5.0</td>
<td>2.0</td>
</tr>
<tr>
<td>British Columbia</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Alberta</td>
<td>5.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>7.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Manitoba</td>
<td>8.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Ontario</td>
<td>5.0</td>
<td>2.0*</td>
</tr>
</tbody>
</table>

* increasing to 3 per cent between January 1, 2016, and December 31, 2016, and 4 per cent after December 31, 2016

Sources: Renewable Fuels Regulations; Renewable and Low Carbon Fuel Requirements Regulation; Renewable Fuels Standard Regulation; Ethanol Fuel (General Regulations); The Renewable Diesel Act; Ethanol General Regulation; Biodiesel Mandate for Diesel Fuel Regulation; Ethanol in Gasoline; Greener Diesel—Renewable Fuel Content; Requirements for Petroleum Diesel Fuel.

30 Environment Canada, Federal Renewable Fuels Regulations.
31 Ibid.
32 Ibid.
33 Ibid.
The federal government has not announced any intention to increase federal blending requirements. However, the national ethanol and biodiesel blend rates for on-road use currently exceed the federally mandated level for both ethanol and biodiesel. (See Chart 13.) The U.S. Department of Agriculture suggests that this may be due to the low price of ethanol, the over-blending of biofuel in B.C. to meet the province’s Low-Carbon Fuel Standard regulation, and provincial mandates that exceed federal blending requirements.34

Chart 13
Canadian On-Road Blend Rate
(per cent)

Sources: U.S. Department of Agriculture; The Conference Board of Canada.

Tax Credits, Loans, and Grants
To date, government incentives have not resulted in a level of production capacity that can meet domestic demand. The federal government ceased making additional commitments under its ecoEnergy program in 2013, citing that Canadian biofuel producers “[had] not been able to produce and sell the large quantities of fuel that were forecasted.”35 Despite the discontinuation of the majority of incentive programs, a handful of current initiatives continue to exist. (See tables 8–10.)

34 U.S. DoA, Canada Biofuels Annual 2014.
35 Lane, “Ottawa Shuts Down Biofuels Subsidy Program.”
### Table 8
**Current Biofuel Tax Credits**

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Initiative</th>
<th>Amount</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quebec</td>
<td>Tax Credit for the Production of Ethanol</td>
<td>Maximum of $0.185 per litre, subject to monthly production caps and the price of crude oil</td>
<td>2006–18</td>
</tr>
<tr>
<td>Quebec</td>
<td>Tax Credit for the Production of Cellulosic Ethanol</td>
<td>Maximum of up to $0.15 per litre, subject to a monthly production cap and the price of ethanol</td>
<td>2011–18</td>
</tr>
</tbody>
</table>

Source: Finances Québec.

### Table 9
**Current Biofuel Loan Programs**

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Initiative</th>
<th>Amount</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>NexGen Biofuels Fund</td>
<td>Up to 40 per cent of eligible project costs</td>
<td>2007–27</td>
</tr>
</tbody>
</table>

Source: Natural Resources Canada.

### Table 10
**Current Biofuel Grant Programs**

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Initiative</th>
<th>Amount</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>ecoENERGY for Biofuels</td>
<td>Fixed declining incentive rate: $0.10–$0.03 per litre for ethanol</td>
<td>2008–17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fixed declining incentive rate: $0.26–$0.04 per litre for biodiesel</td>
<td></td>
</tr>
</tbody>
</table>
| Alberta      | Bioenergy Producer Credit | First 150 million litres:  
• First-generation ethanol: $0.10 per litre  
• Second-generation ethanol: $0.14 per litre  
• Biodiesel: $0.13 per litre  
Production in excess of 150 million litres:  
• First-generation ethanol: $0.06 per litre  
• Second-generation ethanol: $0.09 per litre  
• Biodiesel: $0.09 per litre | 2011–16 |

(continued ...)

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Low-Carbon Fuel Standards

Low-carbon fuel standards (LCFSs) attempt to reduce GHG emissions from road transportation by setting a fuel carbon intensity limit. The carbon intensity of a fuel refers to the amount of carbon dioxide equivalent that a fuel releases into the atmosphere during its life cycle, for each unit of energy consumed. Life-cycle measurements include emissions that occur during production through to those that occur upon combustion, capturing the process from well to wheels. Carbon intensity is measured in terms of grams of carbon dioxide equivalent for each megajoule of energy produced (g CO$_2$e/MJ).

In 2007, California was the first jurisdiction to establish an LCFS; it called for a 10 per cent reduction in the carbon intensity of California’s transportation fuels by 2020. In 2007, both Ontario and British Columbia committed to implementing a LCFS that mirrored California’s

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target.\textsuperscript{38} To date, Ontario has not implemented an LCFS.\textsuperscript{39} In contrast, in 2008, British Columbia passed the Renewable and Low Carbon Fuel Requirements Regulation, which came into force in 2010 and echoed California’s target.\textsuperscript{40} British Columbia is currently the only jurisdiction in Canada that has implemented a low-carbon fuel standard. In 2012, the use of low-carbon and renewable fuels resulted in a total avoidance of 904,868 tonnes of CO\textsubscript{2}e in the province.\textsuperscript{41}

**Government Actions to Promote Alternative Technology Cars**

In Canada, demand for mobility is amplifying: From 1999 to 2014, total road motor vehicle registrations increased by 38 per cent.\textsuperscript{42} Over this same period, net sales of gasoline rose by 13 per cent and net sales of diesel by 39 per cent.\textsuperscript{43} This increased demand for diesel and gasoline has contributed to Canada’s growing road transportation emissions. Consequently, governments have provided incentives toward the purchase of vehicles that may result in the emission of fewer GHGs. While a handful of provinces once offered rebates and tax exemptions for natural gas vehicles,\textsuperscript{44} government incentive programs currently focus on gasoline hybrid and electric vehicles.

Electric vehicles (EVs), a vehicle category that includes plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), have the potential to result in fewer GHG emissions than a comparable internal combustion engine vehicle that runs on diesel or gasoline. The extent

\textsuperscript{38} Office of Governor Edmund G. Brown Jr., *Governor Schwarzenegger Signs Agreement With British Columbia Premier Campbell*; Office of Governor Edmund G. Brown Jr., *Governor Schwarzenegger Joins Ontario Premier McGuinty*.


\textsuperscript{40} Renewable and Low Carbon Fuel Requirements Regulation.


\textsuperscript{42} Statistics Canada, CANSIM table 405-0004.

\textsuperscript{43} Statistics Canada, CANSIM table 405-0002.

\textsuperscript{44} Marbek, *Study of Opportunities for Natural Gas in the Transportation Sector*, 13.
of GHG reductions that are possible from increasing the market share of electric vehicles is dependent on the carbon intensity of the electrical grid and the size, load, and driving pattern of a vehicle.45

There are factors that inhibit the widespread adoption of EVs, namely their purchase cost and range. When compared to a conventional vehicle (CV), the purchase cost of an EV is typically higher, and the cost is positively correlated with the range of the car.46 In the case of battery electric vehicles, which cannot be refuelled by liquid fuels, consumers often express “range anxiety,” as the battery range of EVs is typically less than CVs.47 Federal and provincial governments have implemented vehicle and charging station incentive programs to induce consumer adoption of EVs and reduce hurdles that stand in the way of purchases.

**Vehicle Purchase and Lease Rebates**

In Canada, the first wave of incentives originated with provincial governments. Before the implementation of the federal government’s ecoAUTO rebate program in 2007, five Canadian provinces (British Columbia, Manitoba, Ontario, Quebec, and Prince Edward Island) had already implemented incentive programs.48 Since the conclusion of these programs, only three out of the five provinces that initially offered purchase or lease rebates continue to do so. (See Table 11.) Additionally, the composition of vehicles that are eligible for rebates has changed; hybrid vehicles qualify for only one of the rebate programs. The potential GHG emissions reductions of hybrid electric vehicles are smaller than that of PHEVs and BEVs, due to their lower fuel economy.49 While it is too early to report on British Columbia’s program, as of June 2015, Ontario’s program had awarded 3,414 rebates.50 Additionally,

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45 Hongrui and others, “A New Comparison.”
46 Egbue and Long, “Barriers to Widespread Adoption of Electric Vehicles.”
47 Ibid.
48 Chandra, Gulati, and Kandlikar, “Green Drivers or Free Riders?” 81–82.
50 Ontario Ministry of Transportation, *Cars Are EVolving.*
in the 2013–14 fiscal year, Quebec awarded 1,326 rebates toward the purchase/lease of an electric vehicle and 772 rebates toward the purchase/lease of a hybrid vehicle.\footnote{Ministère de l’Énergie et des Ressources naturelles, \textit{Rapport annuel de gestion 2013–2014}, 58.}

### Table 11

Current Vehicle Purchase/Lease Rebates

<table>
<thead>
<tr>
<th>Province</th>
<th>Rebate amount</th>
<th>Time frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>Point-of-sale rebate up to $5,000 for eligible clean energy vehicles ($6,000 for hydrogen fuel cell vehicles)</td>
<td>Phase 2: April 1, 2015–March 31, 2018 (or when program funding is depleted)</td>
</tr>
<tr>
<td>Ontario</td>
<td>Rebate ranging from up to $5,000 to $8,500 for the purchase/lease of eligible PHEVs or BEVs</td>
<td>Implemented in 2010 (until 10,000 rebates have been granted)</td>
</tr>
<tr>
<td>Quebec</td>
<td>Rebate ranging from up to $500 for eligible hybrid vehicles and up to $4,000 or $8,000 for eligible BEVs and PHEVs</td>
<td>2012–16 (or until 15,000 rebates for vehicles have been granted)</td>
</tr>
</tbody>
</table>

Sources: CEV for BC; Ontario Ministry of Transportation; Ministère des Resources.

### Charging Station Rebates

Given that the provinces reserve the highest rebates for battery electric vehicles, it is not surprising that the majority of provinces that currently offer vehicle purchase/lease rebates also provide home charging system rebates. (See Table 12.) Battery electric vehicles rely exclusively on battery packs that must be charged by plugging into an electrical outlet between trips.\footnote{Egbue, \textit{A Socio-Technical Analysis of Widespread Electric Vehicle Adoption}, 11.}
Vehicle Scrapping Programs

Vehicle scrapping programs are intended to reduce GHG emissions related to road transportation by removing older, high-emitting vehicles from the Canadian fleet. Owners of eligible vehicles can scrap their automobile in exchange for an incentive. A current government-funded vehicle scrapping program is British Columbia's Scrap-It Program. In operation since 1996, the Scrap-It program currently accepts vehicles from any model year.\textsuperscript{53} Incentives include the choice of up to $3,000 toward the purchase of an electric vehicle, $1,000 toward a replacement vehicle, or $400 toward a bike.\textsuperscript{54} Between April 1996 and May 2015, 38,901 vehicles have been scrapped, and the program claims to have reduced carbon emissions by 881,731 tonnes.\textsuperscript{55}

Urban Planning

The programs described above address vehicle efficiency or the carbon content of fuels. From the IPCC framework, we know that the availability of transportation infrastructure and consumer decisions regarding the use of that infrastructure also influence GHG emissions. Urban infrastructure policies have the potential to influence citizen's lifestyle and behavioural choices, which in turn impact GHG emissions levels from

\textsuperscript{53} BC Scrap-It Program, \textit{The BC Scrap-It Program}.
\textsuperscript{54} BC Scrap-It Program, \textit{Incentive Choices}.
\textsuperscript{55} BC Scrap-It Program, \textit{Key Program Metrics}.
road transportation. In general, the greater the distance that individuals live from the places they work and play, the less likely it is that they will use active modes of transportation such as walking or cycling or take public transit. Individuals are also more likely to use these modes of transportation in areas where it is convenient and safe to do so. 56

These observations about the relationship between transportation and the urban environment inform policies that seek to change the transportation mode share of cities. “Mode share” refers to the percentage of travellers using a particular kind of transportation. Transportation plans often support climate change goals by encouraging a shift toward more sustainable modes of transportation, which result in fewer GHG emissions.

The process of redistributing modal shares is challenging; compared to motorized vehicles, walking and bicycling are slower over longer distances. 57 Abundant parking and low operating costs enhance the convenience of private vehicle travel. 58 In contrast, users of more sustainable modes of transportation must contend with inconveniences that include poor weather, hilly terrain, and road characteristics that do not encourage cycling or walking, such as bad lighting, noise, poor aesthetics, or a lack of crosswalks. 59 Additionally, factors such as socio-economic class and concerns over personal safety may prevent individuals from adopting more sustainable transportation practices. 60

Provincial and municipal transportation plans attempt to overcome these challenges and reduce solo automobile travel.

The following observations are not exhaustive of the strategies that provinces and municipalities are currently implementing. Instead, they focus on the efforts of five of Canada’s most populated cities: Calgary, Vancouver, Montréal, Ottawa, and Toronto. (See Table 13.)

58 Ibid.
59 Ibid.
60 Ibid.
Cities are increasingly integrating land use and transportation planning to support modal shifts; transportation plans assume that urban densification will increase the probability that individuals will choose more sustainable modes of transportation. By locating trip generators such as schools, shopping complexes, and job centres close to one another, mixed-use development limits the distance between the places that people live, work, and play. Placing transit stations in closer proximity to these trip generators results in a greater number of users within walking distance, which can increase ridership and decrease the distance and number of trips taken in single-occupancy vehicles.61

61 Cervero and Kockelman, “Travel Demand and the 3Ds.”
By integrating land-use and transportation plans, cities can “manage the scope and nature of urban travel demand” and reduce the impact of congestion.62 Consequently, if reducing GHG emissions is an objective of these plans, land-use and transportation planning must be integrated. Underscoring this principle, Calgary’s Transportation Plan was developed in tandem with its Municipal Development Plan63 following a 2006 City Council request that the two processes be unified.64

The design of a city’s buildings can also influence an individual’s transportation decisions. People will often opt to drive rather than walk, cycle, or take transit because they feel unsafe using those options.65 Vancouver’s plan intends that buildings will feature large window fronts on the main level to address this concern. In effect, this places additional “eyes on the street,”66 which can improve the sense of personal security of pedestrians. Incorporating land-use planning and urban design principles can increase the likelihood that people will choose sustainable modes of transportation to navigate the city. Calgary’s plan focuses on designing “complete streets” that improve the safety and comfort of cyclists and pedestrians.67 Complete streets include design elements such as wider sidewalks, green infrastructure, and traffic calming measures.68 These measures allow pedestrian traffic to move unobstructed, minimize the impact of traffic and noise on pedestrians and cyclists, and reduce vehicle operating speeds.69

These plans also intend to limit the negative land-use impacts associated with vehicle use. Parking lots are an especially ineffective use of land; vehicle use results in a larger land-use footprint “than a typical

63 City of Calgary, *Calgary Transportation Plan*.
64 City of Calgary, *An Introduction to Plan It Calgary*, 4.
68 Ibid.
69 Ibid.
urban resident uses for housing, jobs, and commercial activities.” Consequently, Calgary intends to limit the availability of parking in areas where “high quality” modes of transportation, such as light-rail transit or bus rapid transit (BRT), exist. Where parking facilities remain, the plan gives priority to “preferred parkers” that include carpool/car share participants, cyclists, motorcycles, and scooters. Ottawa intends to reduce the impact of surface parking by encouraging shared parking lots and the construction of multi-level parking lots, rather than single-level surface lots. Similarly, Toronto intends to limit the supply of non-ancillary parking and to encourage the sharing of parking spaces among uses that have different peaking times throughout the day.

**Improving Public Transportation**

Historically, transit riders have contended with unsatisfactory and slow trips; transit systems have often served relatively few destinations, resulting in inefficient trip chains, and have maintained low levels and frequency of service. For public transit to occupy a greater modal share, it must become an attractive alternative to private vehicle use. Drivers often report feeling more in control in their vehicles; there is a perception that public transit is unreliable and results in large expenditures of time and effort to successfully navigate.

Travel time and reliability significantly impact an individual’s transportation mode decisions; individuals prefer to be able to travel directly to their destinations, and to be comfortable while doing so. Transportation plans seek to implement a variety of measures to improve

71 City of Calgary, *Calgary Transportation Plan*, 3–41.
72 Ibid.
73 City of Ottawa, *Transportation Master Plan*, 32.
75 Brown, Werner, and Kim, “Personal and Contextual Factors Supporting the Switch to Transit Use,” 141.
76 Beirão and Sarsfield Cabral, “Understanding Attitudes Towards Public Transport and Private Car,” 482.
user experience, increase transit ridership, and reduce car dependence. To accomplish this, the plans focus on increasing the connectivity, reliability, and frequency of transit services. Calgary intends to ensure that during peak periods in primary transit corridors, “combined service frequency will be every 10 minutes or better” and will operate at least 15 hours a day, seven days a week. By maintaining this standard, Calgary’s plan ensures that a variety of trips are supported, not just those to and from work or school.

Measures that prioritize the movement of public transit vehicles over other traffic can also improve public transit’s travel time. Priority measures are relatively inexpensive to implement and can stimulate additional demand for transit services by improving their performance. Montréal’s transit plan includes the development of a bus rapid transit network that operates on reserved lanes. Calgary intends to use transit signal priority (TSP) systems to cut trip times by increasing the duration of green lights and shortening the duration of red lights for transit vehicles. Queue jumps, which allow for transit vehicles to bypass long vehicle queues at intersections, are often implemented in tandem with signal priority measures. Calgary also intends to remove non-essential bus stops to reduce route runtimes, which allows for an increase in trip frequency and capacity.

Facilitating intermodal travel may also increase public transit ridership. Specifically, it has the potential to increase the number of “non-captive users,” or individuals who could otherwise use a private vehicle to make their trip. Intermodal trips refer to trips that involve more than one mode of transportation. Municipalities can equip transit stations with

77 City of Calgary, Calgary Transportation Plan, 3-12.
78 Ibid.
79 Seattle Department of Transportation, Seattle Transit Master Plan Briefing Book, 7–33.
80 Ville de Montréal, Transportation Plan 2008, 19.
81 City of Calgary, Calgary Transportation Plan, 3–14.
82 Seattle Department of Transportation, Seattle Transit Master Plan Briefing Book, 7–33.
83 City of Calgary, Calgary Transportation Plan, 3–14.
84 Transport Canada, Intermodal Transit Stations, 1.
Public transit is a major budget item for municipalities, which do not have access to the same tax bases as their provincial or federal counterparts.

Amenities that encourage users to access transit services via alternative modes of transportation such as cycling or walking. Improving the quality of “pedestrian infrastructure” within a transit station’s catchment area encourages riders to access public transit by foot. Measures can include improving the curb appeal of pedestrian walkways, installing ladder stripe crosswalks at busy intersections (which improve crosswalk visibility), and ensuring that pedestrian walkways are well-lit. Additionally, municipalities can implement policies that encourage riders to access stations by bike, which also increases the catchment area of a station. To increase ridership, cities can provide ample bicycle parking at transit stations and install bicycle racks on transit vehicles.

While municipal governments are often tasked with implementing transportation plans, they receive funding from other levels of government. For the 2014–15 fiscal year, Transport Canada forecast that combined federal and provincial/territorial expenditures on transit would total $3.62 billion. Since 2005, federal per capita spending has declined. Some provinces, such as Quebec, Manitoba, and British Columbia, have increased provincial per capita expenditures over the same period. Public transit is a major budget item for municipalities, which do not have access to the same tax bases as their provincial or federal counterparts. In the wake of declining per capita expenditures, municipal governments must balance funding for infrastructure and operating costs carefully, which may constrain the expansion of public transportation infrastructure.

85 Ibid.
86 Transport Canada, Transportation in Canada 2014: Statistical Addendum, 22.
87 Transport Canada, Transportation in Canada 2014: Statistical Addendum, 22; Statistics Canada, CANSIM table 051-0001.
89 Ibid.
Active Transportation
To encourage individuals to walk and bike, either for a portion or the complete duration of a trip, transit plans focus on creating environments that are pedestrian-and cyclist-friendly. Similar to public transit, individuals will be more likely to choose to walk or cycle if it is a convenient mode of transportation. Consequently, the plans prioritize building pedestrian walkways and cycling paths that increase the level of connectivity between destinations, are well maintained and supplied with amenities such as benches and bicycle parking, and feel safe to users.

Greening Government
To support federal and provincial greenhouse gas reduction targets and to lead by example, provincial and federal governments are implementing policies to reduce the emissions footprint of government operations. Governments have implemented green procurement policies to reduce the emissions intensity of government vehicles and have introduced anti-idling policies to curb unnecessary emissions. Governments are also encouraging their employees to reduce their private vehicle use by using more sustainable methods of transportation to commute to work. In some instances, governments are eliminating the need for their employees to commute entirely by allowing employees to work remotely.

Green Procurement
In Canada, governments have implemented a variety of green procurement approaches. Some provinces have set purchase targets for hybrid or alternative fuel vehicles, while others encourage the purchase of fuel-efficient vehicles. An issue that arises with this kind of procurement policy is that many provinces have not defined what constitutes a fuel-efficient vehicle. Some provinces have clarified this ambiguity by implementing a fuel-efficiency standard for their government fleets. A notable feature of New Brunswick’s policy is that
it is dynamic; executive vehicle purchases must be within 10 per cent of the most fuel-efficient full-size vehicle in its class.\footnote{90} As vehicle fuel efficiency improves, the standard will become stricter.

These initiatives have had limited success. In 2002, Alberta set a target of purchasing or leasing 100 hybrid or alternative fuel vehicles over a course of three years.\footnote{91} By 2012, the provincial fleet included 3,100 vehicles, only 87 of which were hybrids.\footnote{92} Saskatchewan is currently working toward attaining an average fuel efficiency of 8.22 litres per 100 kilometres.\footnote{93} In 2011–12, the province came the closest to meeting its objective, with an average fuel efficiency of 9.87 litres per 100 kilometres.\footnote{94} By 2013–14, this amount had grown to 10.94 litres per 100 kilometres.\footnote{95}

### Anti-Idling

In a Canadian survey on driving habits and behaviour, it was discovered that during winter’s coldest months, Canadian drivers idled their vehicles approximately eight minutes per day.\footnote{96} Cumulatively, this represents over 2.2 million litres of wasted fuel and 5 million kilograms of greenhouse gases.\footnote{97} Governments have implemented anti-idling policies that are targeted at public servants to reduce these unnecessary emissions. In addition to anti-idling policies that apply to government vehicles, governments have attempted to educate their employees to increase awareness about the negative impact of idling. Both British Columbia

\footnote{90} Communications New Brunswick, Government Adopts New “Green” Vehicle Policy.
\footnote{91} Government of Alberta, Albertans & Climate Change, 21.
\footnote{92} Government of Alberta, Greening Government Strategy, 9.
\footnote{94} Ibid.
\footnote{95} Ibid.
\footnote{96} Natural Resources Canada (NRCAN), Why Do Canadians Idle?
\footnote{97} Ibid.
and Saskatchewan have launched anti-idling tool kits on their public service intranet portals. The tool kits underscore the importance of avoiding unnecessary idling and provide tips to drivers.

**Telecommuting**

Another mechanism that several government departments have implemented to “green” government operations is to minimize travel by the public service. By encouraging employees to telecommute, governments can reduce transportation-related greenhouse gas emissions. Telecommuting refers to the practice of employees working from home, or a location other than their usual office, with the support of technology that allows them to host video conferences. This policy could result in GHG reductions by decreasing the vehicle-kilometres travelled by employees.
Chapter Summary

- Fuel occupies a large share of operating costs for private vehicle fleets. Consequently, these fleets have an incentive to reduce fuel consumption to increase their profit margins.

- Existing vehicle technologies can improve the combustion efficiency of an engine and reduce the impact of drag and friction on a vehicle, all of which result in fuel savings.

- Due to inconsistent regulations between provinces, payback periods in excess of 1.5 years, and uncertainty regarding possible fuel consumption reductions, some firms may choose not to voluntarily install these technologies on their vehicles.
In addition to government initiatives, the voluntary actions of truck fleets also reduce emissions from road transportation. Many fleets voluntarily install technology that improves the fuel economy of their rigs. A vehicle’s fuel economy indicates how efficiently a vehicle can convert fuel into mechanical energy; a higher fuel economy results in lower GHG emissions. Despite possible reductions in fuel consumption, some firms may choose not to install these technologies in the absence of regulations. Fleets often cite market, regulatory, and behavioural hurdles as barriers to adoption. While provincial and federal incentive programs were implemented to assist firms overcoming market and behavioural hurdles to installing fuel-saving technologies, these programs have since been discontinued.

**Fuel Economy**

While Canadian truck manufacturers are legally obligated to comply with federal heavy-duty emissions standards, the trucking industry has also voluntarily implemented additional measures to reduce their emissions profile. Given fuel’s large share of operational expenses, firms have an incentive to increase the fuel economy of their vehicle fleet. In 2010, fuel costs totalled 20 per cent of operating costs for local trucking carriers and 17 per cent of operating costs for long-distance carriers.\(^2\)

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Improving the aerodynamics of rigs and trailers with highway duty cycles offers the largest area for potential improvement.

The impact of fuel-saving technology will vary depending on the duty cycle of a vehicle. Duty cycles refer to how a “certain type of vehicle is used in [its] targeted application.” For example, the duty cycles of long-haul trucks are characterized by high-speed operation on highways, with few stops. In contrast, local trucks will operate at lower speeds in urban environments and stop more frequently. Firms purchase their vehicles with the intention of completing jobs efficiently and minimizing costs. Whereas “passenger cars are typically purchased based upon their interior passenger and cargo volume ... trucks tend to be selected for a specific duty cycle.”

**Fuel Economy Technologies**

Engine losses account for over half of total energy loss in both urban and highway heavy-duty vehicles; however, the next-largest possible gains from technological improvements vary between vehicles with different duty cycles. (See Chart 14.) For heavy-duty vehicles with urban duty cycles, the second-largest component of energy losses is due to inertia and braking. Consequently, the hybridization of these vehicles could result in significant fuel economy improvements through regenerative braking. In contrast, because highway duty cycles do not involve frequent acceleration or deceleration, this technology would result in only modest gains. Instead, improving the aerodynamics of rigs and trailers with highway duty cycles offers the largest area for potential improvement. The following paragraphs describe several technologies that fleets may install on their vehicles to improve fuel economy. The potential fuel savings that may result from these technologies are detailed in Table 14.

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7 Ibid.
Engine

The majority of heavy-duty trucks are fuelled by diesel. Engines are not 100 per cent efficient: Some of the energy is lost as waste heat, so technologies that reduce waste heat, or capture it and convert it into additional power, can improve the fuel economy of heavy-duty trucks. These technologies include thermal insulation, turbo compounding, and bottoming cycles. Improving an engine’s combustion process through the use of low-viscosity oil, real-time combustion control systems, and improved fuel injection systems can also reduce fuel consumption.

9 NRCAN, Transportation Sector–Canada.
10 National Research Council of the National Academies, Technologies and Approaches to Reducing the Fuel Consumption, 53.
11 Ibid., 54.
Another inefficiency that reduces heavy-duty fuel economy is using a truck’s engine to power its accessories. By electrifying engine-powered accessories, these accessories can operate more efficiently, or only when needed, whereas engine-driven accessories result in a constant “parasitic demand.”12 Accessory electrification can be accomplished through the use of an electric turbocompound or hybridization.13

Table 14
Heavy-Duty Fuel Economy Technologies (per cent)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reduction in fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine</strong></td>
<td></td>
</tr>
<tr>
<td>Bottoming cycle system</td>
<td>Up to 10</td>
</tr>
<tr>
<td>Mechanical turbocompound system</td>
<td>2.5–5</td>
</tr>
<tr>
<td>Electric turbocompound system</td>
<td>3–10</td>
</tr>
<tr>
<td>Low-viscosity engine oil</td>
<td>1–2</td>
</tr>
<tr>
<td>Real-time combustion control system</td>
<td>1–4</td>
</tr>
<tr>
<td>Improved fuel injection system</td>
<td>1–4</td>
</tr>
<tr>
<td>Accessory electrification</td>
<td>2–5</td>
</tr>
<tr>
<td><strong>Hybridization</strong></td>
<td></td>
</tr>
<tr>
<td>Hybridization</td>
<td>5.5–10</td>
</tr>
<tr>
<td><strong>Vehicle body</strong></td>
<td></td>
</tr>
<tr>
<td>Side skirt</td>
<td>1–7</td>
</tr>
<tr>
<td>Underbody device</td>
<td>1–6</td>
</tr>
</tbody>
</table>

(continued... )

12 Ibid.

13 Cooper and others, *Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption*, 90.
Hybridization

As mentioned, the electrification of engine accessories can be accomplished through vehicle hybridization. The nature of long-haul trucks’ duty cycles, which are characterized by relatively constant speeds, has led to a limited uptake of hybridization technology.\(^\text{14}\) However, arterial highways, whose grade “provide[s] regenerative braking opportunities,” often comprise a considerable portion of long-haul truck routes.\(^\text{15}\) Consequently, hybridization can result in a fuel consumption reduction for long-haul trucks. This amount is even greater for trucks with multi-day routes that are required to idle overnight as the driver rests.

Vehicle Body

As a heavy-duty truck drives down a road, it is working to overcome forces that affect its speed, including air resistance, otherwise known as drag. As a vehicle’s speed increases, so does drag. This has implications for long-haul heavy-duty trucks whose duty cycles are characterized by high-speed highway driving. By improving the aerodynamics of truck rigs and trailers, drag can be reduced, which

\(^{14}\) National Research Council of the National Academies, Technologies and Approaches to Reducing the Fuel Consumption, 134.

\(^{15}\) Ibid.
improves fuel economy. Consequently, the following aerodynamic technologies will result in greater cost savings for heavy-duty trucks that operate primarily on a highway environment, as compared to those that operate in urban settings.\textsuperscript{16}

A study conducted by the International Council on Clean Transportation (ICCT) found that side skirts, which reduce drag on the undercarriage of a trailer, had the largest market penetration rate of all of the aerodynamic technologies studied. While underbody devices are alternatives to side skirts, they occupy a smaller market share.\textsuperscript{17} Boat tails, which reduce the speed of air that passes over the roof and sides of the trailer, have also seen limited uptake. The study also found that gap reducers that minimize air flow disruptions between the tractor and trailer had the lowest adoption rates, due to the existence of alternatives that don’t require the installation of aerodynamic technology.\textsuperscript{18}

**Tires**

In addition to air resistance, heavy-duty trucks must contend with the force of gravity and friction. “Rolling resistance” refers to the impact of these two forces, as a tire flattens and generates friction while it rolls. The ICCT study found that the majority of tires sold to fleets were low rolling resistance (LRR) tires.\textsuperscript{19} A trade-off of LRR tires noted by study participants was reduced traction in heavy snow and icy road conditions.\textsuperscript{20} A second tire option is single wide-base (SWB) tires, which can be substituted for a dual tire set. With SWB tires there are only two side walls to flex, rather than four, resulting in less weight and reduced inertia.\textsuperscript{21}

\textsuperscript{16} Sharpe and Roeth, *Costs and Adoption Rates of Fuel-Saving Technologies for Trailers in the Canadian On-Road Freight Sector*, 14.

\textsuperscript{17} Ibid.

\textsuperscript{18} Ibid., 17.

\textsuperscript{19} Ibid., 18.

\textsuperscript{20} Ibid., 18.

\textsuperscript{21} Ibid., 18.
Barriers to Technology Adoption

While improved fuel economy offers a financial incentive to install these technologies, there are a number of barriers that reduce or prevent firms from realizing this incentive. These hurdles reduce the impact of voluntary technological improvements on reducing GHG emissions from road transportation.

Regulatory Barriers

The maximum size and weight of heavy-duty trucks falls under provincial jurisdiction. In an effort to standardize these regulations, a memorandum of understanding (MOU) was established in February 1988 stipulating that vehicles that complied with the size and weight restrictions detailed in the MOU would be able to travel freely between provinces. Because provinces are still able to allow for larger weights and dimensions or additional vehicle configurations, this regulatory framework led to a patchwork of inconsistent regulations.

Prior to December 2013, truck fleets were only able to install boat tails up to two feet in length. Fleets that installed full-length boat tails could use them south of the Canadian border, but were not able to extend them on Canadian highways. The federal government eventually modified its Motor Vehicle Safety Act to allow the use of full-length boat tails, but it was not until October 2014 that the MOU was amended to increase the allowable size of rear-mounted aerodynamic devices. Despite beginning

22 Task Force on Vehicle Weights and Dimensions Policy, Heavy Truck Weight and Dimension Limits for Interprovincial Operations in Canada, 3.
23 Ibid., 5.
27 Task Force on Vehicle Weights and Dimensions Policy, Heavy Truck Weight and Dimension Limits for Interprovincial Operations in Canada, 3.
testing of this technology in Canada in 2007,\textsuperscript{28} due to the misalignment of federal and provincial regulations, the fuel-saving opportunity of boat tails was not fully realized for a number of years.

Similarly, while SWB tires were introduced to the market in 2000, as of June 2015, only three provinces have amended their legislation to establish load parity between SWB tires and conventional dual tires.\textsuperscript{29} Discrepancies between allowable loads between tire types result in decreased hauling/payload capacity, which puts fleets that use SWB at a disadvantage compared to those that don’t. These inconsistencies reduce the market penetration of SWB tires.

**Market Barriers**

Given that fuel savings technologies result in additional costs for heavy-duty vehicle owners, to make an investment in them, they must obtain a return. As such, the fuel savings that result from these technologies must be larger than the cost of installing the technology. The timeline for this to occur varies between fleets; while private fleets have historically replaced their trucks after a period of three years, owner-operators replace their trucks close to every six years.\textsuperscript{30} In a study commissioned by the International Council for Clean Transportation, the typical expectation for a payback period was approximately half of the ownership cycle.\textsuperscript{31} Given that a large proportion of heavy-duty trucks in Canada are in private fleets,\textsuperscript{32} according to these expectations, many fleets would expect a payback period of approximately 1.5 years to allow for a return on investment on improving the fuel efficiency of a truck.\textsuperscript{33} Because this expected payback period is shorter than the actual payback

\textsuperscript{28} Today’s Trucking, Canadian Truckers to Get More Boat Tail Options.

\textsuperscript{29} Michelin Canada, Encouraging Sustainable Mobility for Canada’s Trucking Industry.

\textsuperscript{30} Sustainable Development Technology Canada, Transportation—Industrial Freight Transportation, 94.

\textsuperscript{31} Roeth and others, Barriers to the Increased Adoption of Fuel Efficiency Technologies, 6.

\textsuperscript{32} Transport Canada, Canadian Vehicle Use Study.

\textsuperscript{33} Similar payback periods were found by the National Research Council of the National Academies. See pp. 7 and 151 of Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.
period of many technologies, this may inhibit market adoption. Another consideration arises for improvements that are made to a trailer: The owner of the trailer may not be the same as the owner of the truck. In these instances, whether or not a trailer owner will make an investment in fuel-saving technology will depend on whether or not he can recover the cost of his investment.

Attitudinal Barriers
In two separate ICCT studies, skepticism regarding the claims of technology manufacturers, poor testing results, and word of mouth negatively impacted the adoption rate of fuel-saving technologies. Fleets reported that, in practice, the fuel consumption reductions often did not live up to the promises of manufacturers. This inconsistency may be due to the testing process: In lab settings, technologies are subjected to constant highway speeds; however, in actual duty cycles, technologies encounter variable speeds, which may reduce efficiency improvements. Until a technology can substantially penetrate the market, it is more difficult for fleets to verify the claims of technology manufacturers. Even in instances where there is early adoption of a particular technology, information is often disseminated via word of mouth and anecdotally, possibly reducing a firm's confidence in a technology, which may limit the further adoption of a technology.

34 National Research Council of the National Academies, *Technologies and Approaches to Reducing the Fuel Consumption*.
35 Roeth and others, *Barriers to the Increased Adoption of Fuel Efficiency Technologies*; Sharpe and Roeth, *Costs and Adoption Rates of Fuel-Saving Technologies for Trailers*.
37 Roeth and others, *Barriers to the Increased Adoption of Fuel Efficiency Technologies*, 56.
38 Ibid.
CHAPTER 5

Alternative Fuels and Vehicle Technologies

Chapter Summary

- A number of alternatives to traditional internal combustion engines exist, including vehicles that run (in whole or in part) on biofuels, liquefied petroleum and natural gases, and electricity.

- These alternatives have the potential to result in lower emissions when compared to conventional vehicles and fuels.

- Infrastructure and higher upfront capital costs serve as barriers to higher market penetration rates.
Previous chapters have discussed a variety of policies and measures that provincial and federal governments, as well as private organizations, have taken to reduce emissions from Canada’s road transportation sector. By and large, these efforts have reduced GHG emissions by encouraging improvements in the fuel consumption of conventional internal combustion engines (ICEs), reducing vehicle weights, and improving aerodynamics. Other initiatives have focused on encouraging drivers to switch to alternative fuel vehicles (AFVs) such as vehicles running on natural gas or electricity.

In this chapter, we will review the major alternatives to using conventional petroleum fuels (gasoline and diesel). These include vehicles running on biofuel blends (namely, ethanol and biodiesel) or liquefied petroleum gases (LPGs, such as propane); hybrid electric vehicles (HEVs); plug-in hybrid electric vehicles (PHEVs); battery-electric vehicles (BEVs); fuel cell electric vehicles (FCEVs); and vehicles run using compressed or liquefied natural gas (CNG and LNG, respectively). This will include a brief discussion of each technology, including the available and required infrastructure necessary for refuelling, as well as limitations relative to ICE technology. We then compare the current costs of the various technologies and discuss their potential 2050 penetration rates.

**Technology Descriptions**

**Biofuels**

Biofuels are fuels that are derived from living or recently living organic material. Major vehicle biofuels include ethanol and biodiesel, both of which can be mixed in small proportions into conventional ICEs or used in higher proportion mixes in specially designed ICEs. Like petroleum
fuels, biofuels also emit GHGs upon combustion. However, their effects on atmospheric carbon differ substantially. Petroleum fuels are derived from carbonized fossils, and the carbon they release upon combustion has remained trapped within the earth for millions of years. Thus, combusting these fuels results in a net increase in atmospheric carbon. Biofuels, on the other hand, are derived from recently living organic matter, typically vegetation. When a plant grows, it “fixates” atmospheric carbon, pulling it out of the atmosphere to generate organic compounds. When the plant dies, this carbon is released back into the atmosphere as the plant decomposes. Therefore, over the course of a plant’s life cycle, there is no net change in atmospheric carbon. This principle extends to the use of biofuels. Because the materials used to derive ethanol and biodiesel come from recently living organic matter, the carbon released into the atmosphere upon combustion was only recently fixed, and so the emissions are non-net, since the material combusted recently fixed the carbon out of the atmosphere. The production and distribution of these fuels both require energy, and the vegetation grown to produce biofuels may displace other vegetation that would similarly fixate atmospheric carbon.

Currently, the Government of Canada requires that 5 per cent of fuel in the gasoline pool be composed of ethanol and 2 per cent of diesel be composed of biodiesel. At these concentrations, biofuels can be used in all conventional ICES. For higher concentrations of ethanol, there are vehicles available on the market with specialized engines that can run on gasoline mixtures composed of up to 83 per cent ethanol (typically referred to as E85). All diesel engines sold in the U.S. can use biodiesel in blends of up to 5 per cent (called B5), and many manufacturers produce vehicles that can use blends of up to 20 per cent biodiesel (B20). However, biodiesel can gel at low temperatures (more so than petroleum diesel), and it can increase wear and tear on some engine parts, particularly the seals and hoses. As a result, biodiesel is typically blended and sold in low proportions of 5 per cent or less. High-ethanol

fuel blends also exhibit poorer performance in cold conditions, and so the ethanol component of E85 tends to be decreased during winter months to as little as 51 per cent.\(^3\) Both of these biofuels have a lower energy density than their petroleum counterparts (ethanol more so than biodiesel), and so reduce vehicles’ range and increase the volume of fuel consumed.

Biofuels can be produced in a number of ways. First-generation biofuels (the most commonly available) are produced by extracting oils from food crops such as corn (for ethanol) and canola (for biodiesel).\(^4\) Second-generation fuels are produced from non-food crops, such as wood, and from other forms of biomass, such as organic waste. Third-generation fuels are produced from crops that are engineered specifically for biofuel generation (e.g., certain types of algae). Fourth-generation biofuels use biomass materials similar to second- and third-generation fuels, but utilize a process to capture and store additional carbon so that the use of biofuels will have a negative effect on net atmospheric carbon. The more recent methods tend to produce biofuels with lower net carbon emissions, but are considerably more expensive.

It should be noted that the above biofuels are produced using a transesterification process that yields glycerol as a by-product. A more recently developed hydroprocessing technique allows the generation of hydrogenation-derived renewable diesel (HDRD) from the same biological feedstocks used in transesterification. The by-products of HDRD generation are carbon monoxide, carbon dioxide, and propane (which can be captured and used).\(^5\) Compared with transesterification-based biodiesel, HDRD has better cold-weather performance and can be generated with refining technology currently used for petroleum diesel. However, it tends to be more capital-intensive than transesterification-based biofuel processing, and so prices for HDRD are typically higher.

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3 Alternative Fuels Data Center, \textit{E85 Specification}.
5 ÉcoRessources Consultants, \textit{Study of Hydrogenation Derived Renewable Diesel}, i.
than biodiesel. HDRD has been produced in large volumes in the U.S. and Europe for several years, and Canada now imports large volumes to meet the federally established biofuel requirements.

Liquefied Petroleum Gas Vehicles
LPG vehicles (typically) use internal combustion engines to combust propane that has been liquefied for compact storage. Per unit of energy, propane emits fewer GHGs than conventional liquid petroleum fuels. Unlike biofuels, however, liquefied petroleum gas cannot be combusted by conventional ICE engines (although these can be converted to work with LPG). Similarly, liquefied petroleum gas cannot be purchased at conventional fuelling stations. Additionally, because LPGs have a lower energy density than gasoline or diesel fuel, LPG vehicles have shorter ranges than vehicles using conventional petroleum fuels (for comparably sized fuel tanks).

Hybrid Electric Vehicles
HEVs rely on two sources of energy: conventional petroleum fuel (either gasoline or diesel, combusted by an internal combustion engine); and kinetically generated electricity (usually generated when the brakes are applied) that is stored in batteries. These vehicles typically have both an ICE and an electric motor. By using regenerative braking technology, they are able to make use of kinetic energy that would otherwise be wasted. They are thus able to achieve a higher fuel efficiency than conventional ICE vehicles, particularly when driving in city conditions where there is a lot of stopping and starting. This in turn reduces their GHG emissions, as electricity produces no GHG emissions during consumption. They have driving ranges that are comparable to those of conventional ICE vehicles.

6 Ibid., ix, 57.
7 Doray, Why Have the Options for Renewable Diesel Been More Problematic?
8 Alternative Fuels Data Center, Hybrid Electric Vehicles.
Plug-In Hybrid Electric Vehicles

Similar to HEVs, PHEVs rely on both an electric motor and an internal combustion engine and are powered by both electricity and petroleum fuel. Unlike HEVs, however, they do not rely solely on regenerative braking to generate electricity. Instead, they can be plugged into the grid to charge their batteries, which are generally larger than those of their HEV counterparts. As a result, most PHEVs can be driven for some distance (typically 10 to 40 miles, or 16 to 64 kilometres, in current models) without requiring any petroleum fuel. They run free of GHG emissions when operating solely on battery power (referred to as charge-depleting, or Cd, mode) and have reduced emissions outside of this range (due to the regenerative braking). While they can fill up on petroleum fuel at traditional petroleum fuelling stations, their batteries must be charged by plugging them into the grid, either in standard 110 V sockets or at dedicated high-voltage charging stations installed in users’ homes and some parking lots. It should be noted that the batteries in all PHEVs (as well as those used in HEVs and BEVs) gradually lose charge capacity with use, which means that their potential driving range decreases over time. Charging times for PHEVs vary with the power available from the charging outlet (generally either 110 or 220 V), the size of the on-board battery, and the capacity of the charger. MY 2014 PHEVs sold in the U.S. have charging times that range from only 40 minutes (for the Honda Accord Plug-in Hybrid, with a 29 kWh battery) to 5 hours (the Cadillac ELR, with a 41 kWh battery), but are generally from 2 to 4 hours.9

Battery Electric Vehicles

BEVs have no onboard internal combustion engine, and so rely entirely on electricity to power their electric motors. Like PHEVs, these vehicles are charged by plugging them into the electricity grid through standard sockets or dedicated charging stations. However, because these vehicles do not have ICEs or fuel tanks, they have larger-capacity batteries than their PHEV counterparts, and so a larger (electric) driving

range (although a shorter range than when gasoline is included in the PHEVs’ ranges). The driving range of BEVs varies substantially across models, based predominantly on the size of the battery and the weight of the vehicle. Temperature also plays an important role, as cold temperatures can reduce the driving range of BEVs.\textsuperscript{10} The smallest MY2014 vehicle available in the U.S., the Smart fortwo, has a range of only 68 miles (110 kilometres).\textsuperscript{11} The largest range is achieved by the Tesla Model S, which is able to travel up to 265 miles (460 kilometres) on its 85 kWh battery. While these ranges are shorter than those of conventional ICE vehicles and other types of hybrid vehicles, BEVs run with zero tailpipe emissions all the time. Their larger batteries have longer charging times by necessity; they require between 3.5 and 12 hours, but typically between 6 and 8 hours, to charge.\textsuperscript{12} It is worth noting that the use of commercially available charging stations that use direct current (DC, as opposed to the alternating current (AC) charging stations typically installed in private homes) can reduce charge times substantially, providing 50 to 70 miles (80 to 113 kilometres) of electric range in only 20 minutes.\textsuperscript{13}

**Fuel Cell Electric Vehicles**

FCEVs, like BEVs, are driven by an electric motor. The primary difference is the source of the energy used by the motor. Rather than storing energy in a battery, FCEVs use fuel cells that generate electricity by using compressed hydrogen (typically). The hydrogen reacts with oxygen, generating energy and producing only water and heat as by-products, so no GHGs are emitted during use. Their range is larger than that of most BEVs—the only model sold publicly in the U.S. has a range of 230 miles (370 kilometres).\textsuperscript{14} Unlike BEVs, FCEVs can be

\textsuperscript{10} Stevens, “FleetCarma Digs Deep Into Cold-Weather EV Data.”
\textsuperscript{11} U.S. DoE, *Model Year 2014*, 34.
\textsuperscript{12} Ibid.
\textsuperscript{13} Alternative Fuels Data Center, *Developing Infrastructure to Charge Plug-In Electric Vehicles*.
quickly refuelled in under 10 minutes,\textsuperscript{15} and so with sufficient refuelling infrastructure would be more appropriate for longer trips. However, hydrogen fuelling stations are currently few and far between. In the U.S., there are only 12 public fuelling stations: 10 in California, 1 in South Carolina, and 1 in Connecticut.\textsuperscript{16} In Canada, there are currently only 2 hydrogen fuelling stations usable by consumers—both in the Greater Vancouver regional district (in British Columbia). While there are 2 additional refuelling facilities located in Toronto, Ontario, and Trois-Rivières, Quebec, they are used only for research and do not function as retail outlets.

Natural Gas Vehicles

While the combustion of natural gas (NG) creates carbon emissions, natural gas emits fewer GHGs than conventional petroleum fuels per unit of energy. Thus, by using natural gas to power vehicles, GHG emissions can be reduced. Because NG is gaseous in its natural state, it has a very low energy density. Therefore, in order to allow natural gas vehicles (NGVs) sufficient driving range, it must be either compressed (down to less than 1/100th of its original volume) or liquefied (thereby increasing its energy density substantially). Per volume, liquefied natural gas has over twice the energy density of compressed natural gas, making LNG preferable for longer trips.\textsuperscript{17} However, the process of liquefying natural gas is more complicated than simply compressing it. While CNG can be produced at any conventional fuelling station with access to natural gas and a compressor installed, LNG requires a special liquefaction plant that can cool the gas to –160°C and must remain in insulated containers to maintain this temperature subsequently.

Even after being condensed or liquefied, natural gas is less energy-dense than either gasoline or diesel fuel. As a result, NGVs must either be equipped with larger fuel tanks or have a reduced driving range. This is particularly the case with CNG vehicles. This is somewhat offset, however, by their higher energy efficiency.

\textsuperscript{15} Alternative Fuels Data Center, \textit{Fuel Cell Electric Vehicles.}\n\textsuperscript{16} Alternative Fuels Data Center, \textit{Hydrogen Fueling Station Locations.}\n\textsuperscript{17} Bright Hub Engineering, \textit{LNG, CNG and LPG.}
There are several models of CNG vehicles currently available, but only heavy-duty trucks are sold with LNG engines. Vehicles (both light-duty and heavy-duty) with traditional ICEs can be converted to use CNG, but conversions to use LNG are performed less frequently because LNG requires specialized fuel storage tanks.

In general, compressed natural gas is preferable for vehicles or fleets that typically travel short distances. The low energy density of CNG limits its usefulness for long trips, but CNG is more widely available and cheaper than LNG, so is otherwise preferable. When long-distance travel is required, LNG trucks are more widely used, as they can travel more than twice as far as CNG counterparts with comparably sized fuel tanks before they need to refuel.

**GHG Emissions Reductions**

The various types of fuels and technologies discussed above can reduce GHG emissions in several ways: using combustion fuels with lower carbon intensities; using electricity (which does not produce emissions when consumed); or offsetting the downstream emissions through upstream carbon sequestration. Here, we compare the GHG emissions reductions achievable across each of the technologies discussed above.

For passenger vehicles, we have estimated emissions reductions using GHGenius, a road transportation energy use and emissions model developed by (S&T)² Consultants Inc., and used by Natural Resources Canada as well as the provincial governments of Ontario, Alberta, and British Columbia.¹² This model compares life-cycle emissions and energy use across a multitude of technologies and vehicle fuels and contains Canada-specific data, such as electricity generation emissions intensity. While real-world observations for GHG emissions from different vehicle technologies have been reported, fuel consumption rates vary heavily across vehicle models and characteristics as well as environmental conditions, making direct comparisons from across

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¹² (S&T)² Consultants Inc., *GHGenius*.
different studies difficult. Using GHGenius, we were able to estimate GHG emission reductions across vehicle fuels and technologies while holding such external variables constant, and compared the results with those reported in the literature for each technology. See Table 15 for the estimated reduction in tank-to-wheels (TTW) and well-to-wheels (WTW) emissions for each alternative fuel technology when compared

Table 15
GHG Emissions Reductions From Alternative Fuel Technologies (per cent)

<table>
<thead>
<tr>
<th>Fuel/technology</th>
<th>Tank-to-wheels emissions reduction</th>
<th>Well-to-wheels emissions reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>vs. gasoline vs. diesel</td>
<td>vs. gasoline vs. diesel</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0 vs. –26</td>
<td>0 vs. –33</td>
</tr>
<tr>
<td>Diesel</td>
<td>20 vs. 0</td>
<td>25 vs. 0</td>
</tr>
<tr>
<td>Ethanol (E85)</td>
<td>6 vs. –18</td>
<td>16 vs. –12</td>
</tr>
<tr>
<td>Biodiesel (B100)</td>
<td>8 vs. –4</td>
<td>95 vs. 94</td>
</tr>
<tr>
<td>LPG</td>
<td>9 vs. –14</td>
<td>22 vs. –4</td>
</tr>
<tr>
<td>Gasoline hybrid</td>
<td>34 vs. 16</td>
<td>33 vs. 10</td>
</tr>
<tr>
<td>Diesel hybrid</td>
<td>50 vs. 37</td>
<td>53 vs. 37</td>
</tr>
<tr>
<td>PHEV (85 per cent of distance on charge depleting mode)</td>
<td>89 vs. 87</td>
<td>61 vs. 48</td>
</tr>
<tr>
<td>PHEV (40 per cent of distance on charge depleting mode)</td>
<td>61 vs. 50</td>
<td>47 vs. 30</td>
</tr>
<tr>
<td>BEV</td>
<td>100 vs. 100</td>
<td>68 vs. 57</td>
</tr>
<tr>
<td>FCEV</td>
<td>100 vs. 100</td>
<td>30 vs. 7</td>
</tr>
<tr>
<td>CNG</td>
<td>10 vs. –13</td>
<td>17 vs. –11</td>
</tr>
<tr>
<td>LNG</td>
<td>10 vs. –13</td>
<td>8 vs. –22</td>
</tr>
</tbody>
</table>

Notes: Table 15 shows typical tank-to-wheels and well-to-wheels GHG emissions reductions from various alternative fuel technologies relative to vehicles using conventional gasoline and diesel ICEs, modelled using GHGenius, for light-duty vehicles. These reductions are measured as the per cent reduction in CO₂e relative to gasoline and diesel ICE vehicles per 100 km. Estimates are based on Canadian default parameters, with adjustments made to diesel consumption to better reflect observed fuel consumption rates; other parameters were left at default settings. For PHEVs, we estimated GHG savings under two sets of assumptions: one where 85 per cent of the total distance was travelled in charge-depleting mode, and another where only 40 per cent of the total distance was travelled in charge-depleting mode.

Source: The Conference Board of Canada.

19 For a discussion on this, see Tong, Jaramillo, and Azevedo, “Comparison of Life Cycle Greenhouse Gases,” 7124.
to conventional gasoline and diesel light-duty vehicles. The TTW phase refers to the emissions that result from vehicle operation, whereas the WTW phase, in addition to these emissions, also includes those that result from fuel production, processing, and delivery.

Looking at TTW emissions, there are stark differences across the different technologies. The biofuels have low reductions in tailpipe emissions (and even an increase relative to diesel). The TTW emissions reductions achieved by LPG vehicles are comparable. HEVs show a substantial increase, slightly larger than the reductions achievable through use of the NG technologies. BEVs and FCEVs, of course, have no TTW emissions. PHEVs stand out with reductions of over 80 per cent of emissions when run primarily in CD mode. The emissions reductions achievable by PHEVs are, though, heavily dependent on the amount of driving that occurs under battery power. Their emissions reductions are much smaller when they are run in CD mode for only 40 per cent of their total distance.

**UpStream Emissions Considerations**

While we have reported estimates of the net reduction in GHG emissions after taking upstream emissions into account (reported as well-to-wheels emissions reductions), it should be noted that these estimates are less reliable than those of the tailpipe emissions because these can vary enormously across time and between different regions, depending on the energy sources used to generate the fuels used by each technology. Additionally, since these estimates are relative to upstream emissions estimates for gasoline and diesel fuels, these values will also differ based on the type and source of oil(s) used to produce gasoline and diesel fuel, the distance the fuels must be transported prior to use, and other related factors.
Biofuels

Biofuels are the most problematic technology for which to estimate upstream emissions, as these upstream emissions depend on the source of the biofuel (e.g., corn vs. sorghum vs. algae), since different sources have different input requirements (such as fertilizer) and require different amounts of energy for processing. For example, Wang and others found that ethanol produced from corn (a first-generation biofuel crop) reduced lifetime GHG emissions by 19 to 48 per cent relative to gasoline, but that ethanol produced from miscanthus grass (a second-generation crop) reduced emissions by over 100 per cent.\(^{20}\)

The resulting indirect land use change (ILUC) from biofuel production can also have a substantial impact on net emissions. If biofuels are grown on land that was previously forested, for example, then they can result in a net increase in atmospheric carbon once deforestation is taken into account.\(^{21}\) The extent to which this occurs is a topic of heavy debate, and varies between jurisdictions and biofuel crops. A review conducted by Ahlgren and Di Lucia found that CO\(_2\)e emissions attributable to ethanol produced from corn, for example, was estimated to vary from around 10 g/MJ of ethanol to over 80 g/MJ.\(^{22}\) The lower end of this range corresponds to a reduction of GHG emissions of around 40 per cent (relative to gasoline), but the upper estimates result in emissions increases of over 100 per cent. While available evidence indicates that there is no net change on land use in Canada resulting from biofuel production, and little observed in the U.S.,\(^{23}\) the range of potential impacts on net emissions needs to be born in mind, as the impacts of ILUC in North America could grow if biofuel crop production increases substantially.

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\(^{20}\) Cai and others, “Life-Cycle Energy Use and GHG Emissions of Production of Bioethanol.”

\(^{21}\) See, for example, Searchinger and others, “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases,” 1238.

\(^{22}\) Ahlgren and Di Lucia, “Indirect Land Use Changes of Biofuel Production.”

\(^{23}\) Daynard and Daynard, What Are the Effects of Biofuels and Bioproducts on the Environment, 34–35.
PHEVs and BEVs
These vehicle technologies, which rely on charging vehicle batteries from the electricity grid, will have upstream emissions that change with the source of electricity generation. While we have adjusted our estimates to reflect Canada’s average GHG emissions intensity from electricity generation, this is unlikely to remain constant between 2015 and 2050. If Canada reduces its reliance on fossil fuels for power generation, particularly in heavily reliant provinces such as Alberta, Saskatchewan, and Nova Scotia, the GHG reductions achievable through these technologies will increase. It is worth emphasizing that provinces that continue to generate electricity using carbon-intensive means (i.e., fossil fuel consumption) will not achieve a significant reduction to net GHG emissions through the use of PHEVs and BEVs, as the reduction in downstream emissions will be largely offset by the combustion of fossil fuels to produce electricity.

Fuel Cell Electric Vehicles
FCEVs, as noted previously, typically rely on hydrogen to generate electricity. The upstream emissions resulting from this technology therefore depend on the methods used to generate hydrogen. Currently, hydrogen is typically generated from natural gas, resulting in GHG emissions. However, it is also possible (albeit more expensive) to generate hydrogen from lower emission sources, such as algae, or through water hydrolysis (using low-emission electricity). While we have assumed that natural gas is used as the source for hydrogen, if hydrogen generated in the future comes from low-emission sources, then the upstream emissions for this vehicle technology could be dramatically reduced.

24 National Research Council of the National Academies, Transitions to Alternative Vehicles and Fuels, 56.
Natural Gas Vehicles

Natural gas has long been touted as a cleaner alternative to conventional vehicle fuels, but it is not clear that substantive net GHG emission reductions can be achieved through the use of this fuel. While the GHGenius model shows reduced tailpipe emissions from LNG, another transportation energy use model (called GREET, developed by the Argonne National Laboratory) also suggests that when upstream emissions are included, the use of liquefied natural gas increases net GHG emissions. Similar estimates have recently been reported by Tong, Jaramillo, and Azevedo, who explored the use of CNG and LNG in medium- and heavy-duty vehicles. They report that emissions from these technologies have been underestimated in prior research, primarily due to the underestimation of methane released during natural gas extraction, and due to incomplete combustion of natural gas in vehicle engines. In this study, they estimated GHG emissions from a variety of fuel technologies, for a variety of medium- and heavy-duty trucks. After taking the increased methane emissions into account, they found that total life-cycle emissions from both CNG and LNG were higher than that of traditional diesel ICEs for Class 8 tractors and transit buses, with no net change for CNG when used by Class 6 box trucks. However when compared with diesel produced from oil sands oil, the natural gas technologies look more favourable, with reduced GHG emissions in all these vehicles, except for transit buses using LNG.

Emissions Reductions Comparisons With Prior Studies

The emissions reductions we have estimated for light-duty vehicles using GHGenius generally compare well to estimates reported in other research. Lipman and Delucchi compared well-to-wheels emissions reductions from several technologies considered here (HEVs, PHEVs, BEVs, and FCEVs) from across seven studies (with U.S.-based

26 Argonne National Laboratory, Argonne’s GREET.

27 Tong, Jaramillo, and Azevedo, “Comparison of Life Cycle Greenhouse Gases.”
estimates), and the results here for each technology are comparable. HEVs were found to reduce emissions by 28 to 43 per cent compared to gasoline vehicles (vs. 33 per cent reported here); PHEVs reduced emissions by 32 to 59 per cent (vs. 57 per cent here); BEVs reduced emissions by 25 to 40 per cent (vs. 68 per cent here); and FCEVs were estimated to reduce emissions by 30 to 55 per cent (vs. 30 per cent here). The largest difference observed with our GHGenius results is from BEVs, but given that Canada has a lower electricity generation emission intensity than the U.S., the lower value we report here was expected.

For biofuels, as noted previously, the impact on WTW GHG emissions varies widely across studies, depending on assumptions about the sources of the biofuels and their estimated ILUC. From 2011–13, the large majority of the global ethanol supply was derived from first-generation crops (grains, cereals, and sugars). By 2023, cellulosic (second-generation) ethanol is predicted to account for only 5 per cent of global ethanol production, and the bulk (over 80 per cent) will still come from cereals and sugars. Looking at biodiesel, over 80 per cent is produced from vegetable oils. By 2023, this too will have changed little, with biomass still accounting for less than 5 per cent of production. Canada’s production of both ethanol and biodiesel, which already is insufficient to meet national demand, is predicted to increase only marginally during this time period. This indicates that if Canadian consumption of biofuels increased substantially in the short term, biofuels could well be imported from larger producers such as the U.S., Brazil, and Singapore.

Collectively, these data suggest that the emissions reductions achievable through biofuels will remain comparable to the levels observed in first-generation fuels, rather than the higher reductions that are achievable via electric vehicles.

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30 Ibid.
LPG vehicles, or those running propane, are expected to achieve emissions reductions compared to gasoline vehicles. Energetics Inc. estimates WTW GHG emission reductions on the order of 20 to 25 per cent in light-duty vehicles and 18 per cent in medium-duty vehicles, similar to the 20 per cent reported here. For school buses (falling into the heavy-duty vehicle category), the emissions reductions are estimated at around 17 per cent compared to gasoline, but are actually marginally higher than for buses running diesel engines.

Emissions associated with NGVs depend on the type of natural gas used (compressed vs. liquefied) and a variety of factors associated with extraction and transportation. Rosenfeld and Jackson estimated that the use of compressed natural gas could reduce emissions in heavy-duty engines by 15 to 29 per cent (compared with diesel fuel), while emissions reductions from liquefied natural gas range from 7 to 28 per cent. More recently, Ou and Zhang estimated similar emissions reduction ranges of 10 to 20 per cent and 5 to 10 per cent. While our estimates reported in Table 15 show a net increase in emissions when used by light-duty

35 Calculated from Rosenfeld and Jackson, Life-Cycle Cost Model and Pollutant Estimator, 10.
While the AFV technologies all have the potential to play a role in reducing GHG emissions from Canada’s road transportation sector, we currently lack the infrastructure to support these technologies. Vehicles, when using GHGenius to estimate emissions from heavy-duty vehicles, we observed emissions reductions that fell within these ranges (17 per cent and 9 per cent, respectively, for CNG and LNG).

**Infrastructure Requirements**

While the AFV technologies all have the potential to play a role in reducing GHG emissions from Canada’s road transportation sector, we currently lack the infrastructure to support these technologies if they were able to achieve high penetration rates. Below, we discuss the infrastructure upgrades that would be required to deploy these technologies on a large scale.

**Biofuels**

As noted above, biofuels are currently included in Canada’s conventional fuel stock—ethanol is blended in with gasoline and biodiesel is blended in with conventional diesel. Because vehicles can be refuelled with biofuels in the same way as petroleum fuels, no additional refuelling infrastructure would be required to increase the share of biofuels in Canada’s fuel stock. However, there would likely need to be increases in other forms of infrastructure in order to produce, blend, and transport biofuels in much larger quantities.

First, new facilities would have to be constructed to convert biomass into biofuels. Again, the feedstock used for biofuels generation will have an impact on the infrastructure required. Second-generation biofuel feedstocks, such as switchgrass, are bulkier than the grain-based first-generation feedstocks, and thus are more expensive to transport. This results in diseconomies of scale for the production of second-generation biofuels. As a result, smaller, decentralized processing facilities would likely need to be constructed close to the crops that they use as a feedstock in order to be economical. While long-distance

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transport of biofuels (after processing) could occur via existing pipeline infrastructure, new pipelines would need to be built or existing pipelines modified and dedicated solely to ethanol transportation. Ethanol can become contaminated with water and other residual substances when transported through non-dedicated pipelines, which compromises engine performance.\textsuperscript{39,40} New “feeder” pipeline infrastructure would also be needed to transport the biofuels from the (numerous) conversion facilities to the larger petroleum distribution system currently in place. Alternatively, biofuels could be transported by truck or rail, but the unit costs of transporting oil by rail or truck are much higher than by pipeline.\textsuperscript{41}

In addition to the increase in transportation infrastructure required to accommodate a large increase in biofuel use, there would need to be an increase in farming infrastructure to produce the feedstock necessary to generate biofuels. Without large increases in biofuel feedstock crop yields, Canada would need to increase the farmland dedicated to biofuels production substantially in order to have biofuels make up a large component of the fuel stock.

### Liquefied Petroleum Gases

LPG vehicles can be filled at fuelling stations that sell propane. Such stations are readily available in most provinces (except Newfoundland and Labrador), albeit less so than conventional gas stations.\textsuperscript{42} While these stations are likely to sell propane in small volumes (for use with barbecues, for example) their dispensing equipment could be upgraded to handle higher turnover and more easily accommodate vehicle refuelling.\textsuperscript{43} While there is already substantial fuelling structure available,

\textsuperscript{39} Alternative Fuels Data Center, \textit{Ethanol Production and Distribution}.

\textsuperscript{40} Whims, \textit{Pipeline Considerations for Ethanol}.

\textsuperscript{41} For example, it has been estimated that it costs US$5 to transport a barrel of crude oil by pipeline, but US$10–US$15 to transport a barrel of oil by rail. See Frittelli and others, \textit{U.S. Rail Transportation of Crude Oil}, 7.

\textsuperscript{42} cdnauto.org, \textit{Propane Map}.

\textsuperscript{43} Alternative Fuels Data Center, \textit{Propane Fueling Infrastructure Development}.
the supply of propane within Canada could be a barrier to widespread adoption of LPG vehicles. In 2014, Canada exported roughly 5.2 million cubic metres of propane.\textsuperscript{44} This amounts to about 134 petajoules (PJ) of energy,\textsuperscript{45} or 5 per cent of the road transportation sector's 2012 energy consumption. While LPG vehicles may never achieve a penetration rate higher than 5 per cent, this fuel is produced in much smaller quantities than natural gas in Canada, meaning that supply is much more likely to be an issue for this vehicle technology.

**Hybrid Electric Vehicles**

Because HEVs rely only on conventional fuels as an external fuel source, no additional infrastructure is required for their use or uptake. The electricity they use is generated kinetically, and so these vehicles would not increase the use of the electricity grid. Also, because they consume fewer conventional fuels, their uptake would simply reduce pressure on the current petroleum fuel infrastructure.

**PHEVs and BEVs**

PHEVs and BEVs are charged by plugging into the electricity grid. The uptake of these vehicle technologies would thus necessitate two additional forms of infrastructure: refuelling (recharging) infrastructure (chargers to plug vehicles into) and electricity grid infrastructure (to ensure sufficient capacity during charging times).

As noted above, electric vehicles, and PHEVs in particular, have relatively short ranges and thus need to be recharged frequently. While the built-in chargers can typically be plugged into standard 110 V electrical sockets, many owners purchase a charging station, or electric vehicle service equipment (EVSE), which increases the voltage and amperage so that owners can charge their vehicles more quickly while they are at home.\textsuperscript{46}

\textsuperscript{44} National Energy Board, 2014 Propane and Butanes Exports Summary.
\textsuperscript{45} Calculated from National Energy Board, Energy Conversion Tables.
\textsuperscript{46} Conway, Is It Easy to Charge an Electric Car?
To maximize the emissions reductions realized by the use of PHEVs, it would be beneficial to have charging stations available outside of owners’ homes. Some businesses and organizations already provide charging stations; Mountain Equipment Co-op, for example, provides charging stations in the parking lot of its North Vancouver location.\(^{47}\)

Commercial charging stations would also need to be available to allow drivers to recharge during midday, or to allow BEVs to travel distances further away than their battery range would allow.

Importantly, the draw of a BEV or a PHEV on the electricity grid is fairly substantial, and varies across different types of chargers. Chargers with higher voltages are able to charge vehicles more quickly, but also put increased strain on the electricity grid, by concentrating the power consumed into a shorter period of time. Similarly, vehicles with larger batteries will take longer to charge, and increase the draw on the system for a longer period of time. The time when vehicles are charged also matters, as charging vehicles during the middle of the night (while at home), when electricity consumption is lowest, would strain the electricity grid less than charging during the middle of the day (while at work, for example, or partway through a long-distance drive) during the peak electricity consumption period.

To demonstrate the scale of the potential impact of BEVs and PHEVs on the electricity grid, we employed Natural Resources Canada’s PEV Charge Impact Model.\(^{48}\) This model estimates the draw on the grid resulting from the use of BEVs and PHEVs. Users can specify the proportion of the light-duty vehicle fleet that comprises PHEVs and BEVs, and after specifying a few parameters, estimate the draw on the power grid that would occur during each hour of a typical weekday.

The model suggests that the 2015 nationwide weekday electricity draw typically varies from a low of 57 GW at 4 a.m. to a high of 78 GW at 6 p.m., without considering the use of electric vehicles. It estimates the

\(^{47}\) Mountain Equipment Co-op, *North Vancouver.*

\(^{48}\) NRCAN, *PHEV-CIM/PEV-CIM.*
maximum capacity of the grid to be 98 GW. For illustrative purposes, we estimated the impact of electric vehicles on the grid draw with the following assumptions:

1. Fifty per cent of the light-duty vehicle fleet consists of BEVs and PHEVs vehicles (for a total of 10,900,000 electric vehicles).
2. Drivers have a typical weekday commute of 6 kilometres (each direction) and some evening driving activity.
3. A typical vehicle’s power draw is comparable to those of three representative vehicles, weighted equally:
   - a Chevrolet Volt (a compact PHEV)
   - a Toyota Prius Plug-in (a mid-size PHEV)
   - a Tesla Model S (a full-size BEV)
4. Charging patterns are as follows:
   - Forty per cent of drivers charge their vehicles at home during off-peak hours.
   - Forty per cent of drivers charge their vehicle at home, as soon as they arrive home.
   - Twenty per cent of drivers charge their vehicle as soon as they arrive at work in the morning and again as soon as they arrive home after work.

Running the model with the above parameters suggests that an electric vehicle fleet of this size would increase the grid load by a maximum of 23 GW around 6 p.m.—29 per cent higher than the typical peak load of 78 GW. This puts the total draw at 6 p.m. at 101 GW, about 3 GW above the 2015 capacity. Grid draw resulting from electric vehicles is predicted to increase substantially at other times of the day as well, but by smaller amounts, and during times when the base load is smaller, and so the loads remain below the 98 GW capacity.

It should be born in mind that this result is demonstrative, and not predictive, and that the results are strongly dependent on the input parameters (specified above). The length of the weekday commute (6 kilometres), for example, is shorter than the national median commute distance of 7.6 kilometres, and so this result could underestimate the

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potential impact on the electricity grid. The impacts will also differ across provinces and smaller regions, where the difference between peak draw and grid capacity may differ substantially. For example, limiting the model to the Charlottetown region, which has a base grid load very close to its capacity, shows that the charging of electric vehicles increases the peak load at 6 p.m. by 56 per cent, and that the demand for power exceeds grid capacity at many times throughout the day: 1–2 a.m., 9–10 a.m., 5–8 p.m., 9 p.m., and 11 p.m. Despite the variability between regions, the results of this model show that a widespread adoption of electric vehicles could have significant impacts on Canada’s electricity consumption, necessitating investments in capacity that would otherwise be unnecessary.

Beyond additional capacity, additional distribution infrastructure, in the form of transformers, would also likely be necessary. Transformers serve to lower the voltage of electricity to be consumed by local businesses and households after it has been transported over long distances across high-voltage transmission lines. So, not only would many regions of Canada need additional production capacity, they would also need additional transformers to distribute the much higher electricity loads that would occur during peak consumption periods. Again, the extent to which additional distributional capacity is necessary would vary considerably between regions depending on a variety of factors.

A study conducted in Toronto found that the bulk of potential electric vehicle owners would tend to charge their vehicles during periods of peak demand, and that on extremely hot days when air conditioners are running, having as few as three to four electric vehicles charging simultaneously could overload a typical transformer serving 19 homes. However, this result was highly influenced by the charger capacity of the electric vehicles. In this scenario, the vehicles were assumed to have a charger capacity of 20 kW, which would permit a quick AC charge, but would be slower than some of the commercially available DC chargers,

50 Pollution Probe, *Electric Mobility Adoption and Prediction (EMAP): Toronto*, 55.
51 Ibid., 56.
which can have capacities exceeding 120 kW. The currently available Tesla Model S, for example, has a default charger capacity of 9.6 kW, but this can (optionally) be doubled to 19.2 kW.\footnote{Calculated from Tesla, 
\textit{Models}.} Findings for the city of Ottawa are comparable, with a typical seven-home transformer being predicted to overload if two or more electric vehicles were charging during peak hours on extremely hot days.\footnote{Pollution Probe, \textit{Electric Mobility Adoption and Prediction (EMAP): Ottawa}, 63.}

These studies indicate that the uptake of electric vehicles could necessitate substantive investment in new production capacity and electricity distribution infrastructure in order to ensure that electricity is provided continuously and reliably.

**Fuel Cell Electric Vehicles**

Hydrogen, the fuel used by FCEVs, has a well-established production, transmission, and distribution system, as it has long been used as an industrial feedstock.\footnote{International Energy Agency, \textit{Technology Roadmap: Hydrogen Fuel Cells}, 12.} However, so far it has seen little use as a transportation fuel, and there is currently almost no hydrogen refuelling infrastructure established in Canada. Of all the AFV technologies discussed here, FCEVs face the greatest hurdles in terms of infrastructure and fuel availability.

Unlike AFVs powered by biofuels or electricity, FCEVs cannot piggyback off existing refuelling infrastructure used for other purposes. Therefore, establishing accessible refuelling infrastructure will be pivotal to any wide-scale adoption of this technology. Although Canada has no readily usable refuelling infrastructure, it is currently available in other jurisdictions, including California, Germany, Japan, and Korea. Because of its low energy density, hydrogen is more expensive to transport and store than other vehicle fuels (on a per Btu basis). It has been suggested that using fuel cells to power fleet vehicles (such as school buses or
refuse trucks, which return to a central location each day) may help to establish some initial refuelling infrastructure, in order to ensure high utilization rates of the refuelling equipment.56

Beyond providing fuelling stations for FCEVs, additional infrastructure would likely be required to supply these stations with hydrogen. While small stations with capacities of 50 to 100 kilograms per day (enough to fuel 10 to 20 light-duty vehicles) could rely on trucking (compressed) gaseous hydrogen for supply, larger stations that would be necessary for wide-scale FCEV use would require the trucking of liquefied hydrogen or access to pipelines, unless hydrogen were to be produced on-site, which would increase production costs.56 Although these methods of transportation are cheaper than trucking compressed hydrogen, constructing pipelines involves high upfront costs and the liquefaction of hydrogen is expensive, making it economical only over long distances.57

**Natural Gas Vehicles**

Public compressed natural gas refuelling stations are operational in Canada, but are not widespread. These stations currently operate in five provinces. There are 11 stations in B.C., 11 in Alberta, 7 in Saskatchewan, 5 in Ontario, and 2 in Quebec.58 Liquefied natural gas fuelling stations are even more limited. There are 3 publicly accessible stations in Quebec, with 2 in Ontario,59,60 2 in Alberta,61 and 2 in British Columbia. Several additional stations are planned in B.C., Alberta, and Ontario.

55 Ibid., 15.
57 U.S. DoE, *Hydrogen Distribution and Delivery Fact Sheet*.
58 Canadian Natural Gas Vehicle Alliance, *Natural Gas Refuelling Stations*.
59 Fleets & Fuels, *Gaz Métro & GE for Natural Gas Trucks*.
60 ENN Canada, *Find a Location Near You*.
61 Today’s Trucking, *Shell Opens Even More Natural-Gas Fuelling Stations*. 
If natural gas vehicles were to play a substantive role in reducing road transportation GHG emissions, the number of fuelling stations would have to increase dramatically and include coverage that is much less concentrated than the current distribution. This would be easier to achieve with compressed natural gas than liquefied natural gas. While CNG must be stored in pressurized tanks, compressors can be installed relatively easily anywhere with access to gaseous natural gas. Additionally, it is not always necessary to store CNG. CNG vehicles can be refuelled directly from compressors through “time fill” dispensers if the refuelling time is not an issue. Such dispensers work best with vehicle fleets such as school buses and refuse trucks that can be refuelled overnight at a central location.\(^{62}\) This saves money on storage facilities, but refuelling takes a very long time because it is limited by the rate of CNG compression, and so is not practical for public refuelling stations. For passenger vehicle refuelling infrastructure, it would be necessary to install storage tanks for CNG so that it can be compressed in advance, and “fast fill” dispensers that can refuel vehicles at roughly the same rate as typical gasoline or diesel dispensers.

Liquefied natural gas requires more specialized equipment than CNG (in order to achieve liquefaction) and is therefore much more expensive to produce. Further, special training and safety equipment is necessary simply to refuel an LNG vehicle. Finally, because cryogenic tanks are required to store LNG at very low temperatures, the use of LNG as a vehicle fuel makes sense only on large trucks, which have sufficient space for the bulky cryogenic fuel storage tanks.\(^{63}\) Because the LNG market is thus limited to heavy-duty vehicles, this limits the potential demand for LNG, which will in turn reduce the amount of LNG refuelling infrastructure that could be installed profitably. It is therefore likely that LNG technology will remain somewhat hampered by the relative unavailability of refuelling infrastructure.


\(^{63}\) LNG tanks are 70 per cent larger than diesel tanks for an equivalent amount of energy. See TIAX, *U.S. and Canadian Natural Gas Vehicle Market Analysis*, 1.
While the current infrastructure is insufficient to permit large-scale adoption of NGV technology, Canada already has a sufficient supply of natural gas to accommodate a huge increase in national consumption. In 2014, Canada exported over 76 billion cubic metres of natural gas.\textsuperscript{64} This volume is much smaller than Canada’s peak natural gas exports of around 107 billion cubic metres (achieved in 2007), but it is equivalent to over 2,900 PJ of energy,\textsuperscript{65} more than all the energy consumed by the entire road transportation sector in 2012.\textsuperscript{66} Therefore, if the refuelling infrastructure was constructed, Canada should not have a difficult time ensuring adequate supply of NG fuels.

\section*{Cost Comparison}

The AFV technologies reviewed in this chapter have very different costs associated with them. From an end-user perspective, there are three primary costs to be concerned with: upfront (purchase) cost, maintenance cost, and fuel cost.

To compare the costs of owning and operating vehicles using each AFV technology, we used the AFLEET model developed by the Argonne National Laboratory for the U.S. Department of Energy.\textsuperscript{67} By including purchase cost, fuel consumption rates, average distances travelled, and fuel prices, this tool can estimate vehicle use costs on a per kilometre basis.

We ran this model with default purchase price and fuel efficiency parameters, but updated the fuel costs\textsuperscript{68} and changed the assumed annual travel distance to reflect average travel distances reported by

\begin{itemize}
\item \textsuperscript{64} National Energy Board, \textit{2014 Natural Gas Exports and Imports Summary}.
\item \textsuperscript{65} Calculated from National Energy Board, \textit{Energy Conversion Tables}.
\item \textsuperscript{66} Roughly 2,600 PJ. From Natural Resources Canada, \textit{Transportation Sector—Canada}.
\item \textsuperscript{67} Argonne National Laboratory, \textit{Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool}.
\item \textsuperscript{68} Taken from U.S. Energy Information Administration (U.S. EIA), \textit{Annual Energy Outlook 2015}, Table A3; and U.S. DoE, \textit{Alternative Fuel Price Report, April 2015}.
\end{itemize}
Natural Resources Canada. Because AFLEET does not estimate costs for FCEVs, we included an estimate of costs from research conducted at the National Renewable Energy Laboratory in Detroit, Michigan. Energy prices are forecast by the U.S. Energy Information Administration, but because they include taxes, we estimated the tax component of each fuel and subtracted these from the fuel costs. As a final adjustment, we added in an estimated cost for charging stations typically used by PHEVs and BEVs. In Table 16, we show an estimate of the cost (in nominal 2013 U.S. dollars) of owning and operating passenger cars running the light-duty vehicle technologies discussed here, measured over the total lifetime cost of each vehicle. We have also included the costs for operating conventional ICE cars for comparison purposes.

69 NRCAN, Transportation Sector—Canada.
70 Melaina, Sun, and Bush, Retail Infrastructure Costs Comparison for Hydrogen and Electricity Light Duty Vehicles.
71 Taxes were estimated based on data from the U.S. EIA, Federal and State Motor Fuel Taxes; Alternative Fuels Data Center, Alternative Fuel Excise Tax; Tax Foundation, State and Local Sales Tax Rates in 2014; and the United States Census Bureau, Population Estimates.
73 Costs for vehicles running on biodiesel were only estimated for vehicles using B20, as there are no vehicles on the market (either light- or heavy-duty) that operate using pure (B100) biodiesel.
When averaged over the lifespan of the vehicles, some of the alternative fuel vehicle technologies have costs that are comparable to that of conventional internal combustion engine vehicles. All AFV technologies, however, do appear to be more costly than either gasoline or diesel ICE vehicles, even after taking into account the lower fuel costs for most of these technologies. Over the life cycle of the vehicles, the cost increase for owning an AFV instead of a gasoline vehicle ranges from 1 to 18 per cent. The vehicles that stand out in this analysis are the FCEVs and BEVs. With an estimated operating cost of over $29 per 100 kilometres, these technologies are considerably more expensive than any other. In the case of FCEVs, this reflects both the high

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<th>Fuel/technology</th>
<th>Purchase cost</th>
<th>Fuel cost</th>
<th>Repair and maintenance costs</th>
<th>Total lifetime cost</th>
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<td>68,180</td>
<td>6</td>
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<td>PHEV (85 per cent of distance in CD mode)</td>
<td>36,530</td>
<td>6,861</td>
<td>28,780</td>
<td>72,171</td>
<td>12</td>
</tr>
<tr>
<td>PHEV (40 per cent of distance CD mode)</td>
<td>36,530</td>
<td>10,804</td>
<td>28,780</td>
<td>76,114</td>
<td>18</td>
</tr>
<tr>
<td>BEV</td>
<td>39,653</td>
<td>5,990</td>
<td>29,614</td>
<td>75,256</td>
<td>17</td>
</tr>
<tr>
<td>FCEV</td>
<td>26,682</td>
<td>20,534</td>
<td>27,367</td>
<td>74,583</td>
<td>16</td>
</tr>
<tr>
<td>CNG</td>
<td>27,000</td>
<td>11,844</td>
<td>27,367</td>
<td>66,212</td>
<td>3</td>
</tr>
</tbody>
</table>

Notes: Table 16 illustrates the estimated costs of owning and operating passenger vehicles with various fuel technologies. Costs are measured in undiscounted nominal 2013 U.S. dollars and include the upfront purchase cost, the fuel cost, and the maintenance costs. Costs were modelled using AFLEET and fuel prices forecast by the U.S. Energy Information Administration, with taxes subtracted. For FCEVs, which are not included in the AFLEET model, costs were estimated manually using data from the Alternative Fuels Data Center and the National Research Council of the National Academies. Vehicles were assumed to have a 16-year life and travel approximately 16,000 km per year. The purchase price of PHEVs and BEVs include the cost of a high-voltage charging station. Maintenance costs for HEVs, PHEVs, and BEVs include the cost of a replacement battery.

Source: The Conference Board of Canada.
The cost of PHEV ownership is comparable to that of BEVs and FCEVs.

purchase price of FCEVs and the high cost of hydrogen fuel. FCEVs, along with ethanol-powered vehicles, are the only AFV technologies included in the analysis with a higher fuel cost than gasoline, after taking into account the different fuel efficiencies. BEVs, on the other hand, are hampered by the cost of replacing their built-in batteries. The cost of PHEVs is also worth some attention. Similar to the emissions reductions achievable with PHEVs, the costs are also heavily impacted by driving behaviour. Individuals who drive 85 per cent of their mileage in CD mode can expect to save $4,000 over the life of the vehicle compared to drivers who drive under battery power 40 per cent of the time. The latter driving pattern makes the cost of PHEV ownership comparable to that of BEVs and FCEVs.

It should be noted that the above estimates are based on 2013 vehicle purchase prices. As a result, economies of scale and production efficiencies that could be achieved for the various AFV technologies as they increase in prevalence have not been taken into consideration. Additionally, these costs were estimated only for passenger cars and thus do not take into account the different costs associated with other vehicle types. Because most of the technologies discussed here have fuel costs that are lower than gasoline or diesel, AFVs that typically average greater annual distances will achieve lower costs per 100 kilometres, as the purchase price of the vehicle has a smaller impact in the full life-cycle costs. Thus, while the model shows increased costs for all passenger AFVs, when looking at freight heavy-duty vehicles, some AFV technologies appear to be cheaper than their conventional diesel counterparts (data not shown).

Additionally, these costs are based on estimated U.S. costs, for vehicle ownership, fuel prices, and maintenance costs. While we have excluded fuel taxes, to better reflect the societal cost of vehicle operation, the various cost components may differ somewhat in Canada.
Conclusions

In this chapter, we have reviewed the major AFV technologies that are currently on the market. These include biofuels used in conventional ICE vehicles, propane vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, fuel cell vehicles, and vehicles powered by natural gas, either compressed or liquefied. Each technology has different impacts on upstream and downstream GHG emissions, as well as different infrastructure requirements and vehicle operational costs. Additionally, some vehicle technologies, such as liquefied natural gas, are better suited to larger vehicles like heavy-duty trucks, while others, such as the various electric vehicle technologies, are better suited to passenger vehicles. While various organizations have explored possible 2050 scenarios with different vehicle penetration rates, it is currently unclear which of the major AFV technologies are likely to establish a strong foothold in Canada’s vehicle fleets by 2050.
CHAPTER 6
Options to Reduce Road Transportation GHG Emissions in Canada

Chapter Summary

- Using a vintaged capital stock approach, this chapter examines potential GHG reductions that could arise from different transportation trends and technologies.

- Existing vehicle patterns, fuel choices, and regulations will result in a decline in road transportation emissions levels until 2025. After this point, emissions levels will increase and, by the late 2040s, will exceed current levels.

- Assuming declining distances travelled per vehicle and improved fuel efficiency results in a similar outcome to the reference case, increasing transportation activity will offset fuel efficiency gains once existing regulations cease to require continuous improvement for each model year.

- Incremental improvements could result from a greater market penetration of alternative vehicle technologies, or additional modal shifts. However, this would offset only the growth in transportation activity that results from increasing GDP and population levels.
Analytical Framework

The previous chapters have examined a range of policy and technology options that could help Canada reduce GHG emissions from road transportation. This chapter considers the potential contributions that various combinations of those options might make toward meeting the goal of an 80 per cent reduction in GHG emissions from their 1990 level. The reduction target is to be accomplished by 2050. As road transportation GHG emissions were 97.7 megatonnes of CO$_2$e in 1990, emissions would need to be reduced from 137 Mt in 2013 to 19.5 Mt in 2050. Although this is the target that would stabilize atmospheric greenhouse gas concentrations, Canada has not officially committed to a long-term goal. The current official target is a 30 per cent reduction from the 2005 level by 2030. Given the 2005 emissions of 132 Mt for road transportation, a 30 per cent reduction would result in 92 Mt in 2030.

The options for reducing GHG emissions can be analyzed based on the IPCC framework identified in Chapter 3. The framework includes four major categories: activity level, mode choice, energy efficiency, and the carbon content of the fuel. Activity level refers to the level of transportation demand. This is primarily driven by growth in population and economic output. As both drivers continue to increase through time, any kind of reduction in future GHG emissions will require a fundamental change in the relationships between population, GDP, and transportation of goods and people. Since the oil price shocks of the 1970s created incentives to reduce energy consumption, the link between energy...
and economic activity has been difficult to break. At most it has been weakened by improved energy efficiency. This is true in road transportation just as it is in other sectors.

Most of the options to reduce transportation demand require changes in behaviour to be effective, and some of the options overlap with mode choice and land-use decisions. Reducing activity levels presents a significant challenge in Canada as society continues to evolve around private automobiles and as commodity exports continue to grow. Reducing activity levels reduces emissions primarily by encouraging people to reduce their overall travel. Government programs in this area focus on communication.

Mode choice and transportation infrastructure are strongly related. The shift from private automobiles to public transit can reduce GHG emissions directly, provided that the trip distance remains constant and the emissions per passenger-kilometre are reduced. Higher public transit ridership for a given level of transit vehicles reduces the GHGs per kilometre travelled. Increasing ridership can also have a spillover benefit for private automobiles to the extent that it reduces congestion.

Of course, the lowest emitting transit modes are walking and cycling. Efforts to influence mode choice must address behavioural inertia and the convenience advantage that private vehicles offer. Mode choice and supporting infrastructure are key considerations when integrating land-use plans and transportation plans in an urban community. Most of the government initiatives in this area are administered at the municipal level.

Given the challenges associated with encouraging commuters to switch to lower emitting modes, and given the continuing growth in freight transportation, governments have focused strongly on the energy efficiency of transportation. The tailpipe emissions regulations discussed in Chapter 3, together with manufacturer fuel efficiency standards, are examples of programs that target energy efficiency. Most of the voluntary initiatives discussed in Chapter 4 for medium and large trucks also fall into this category. They have the advantage of not requiring substantial
changes in behaviour. Purchasing the technology achieves the emissions reduction without changing the activity level. Gasoline-electric hybrid vehicles provide the strongest example of this kind of initiative.

Reducing the carbon content of fuels has historically been about biofuels production and use. Chapter 3 reviews numerous initiatives to increase the share of ethanol and biodiesel in transportation fuels. More recently, emerging electric vehicle technologies have been added to the mix. Several Canadian provinces rely on hydropower and wind for almost all of their electricity generation. As a result, electric vehicles in those provinces are ultra-low emission vehicles. The electricity consumed accounts for very low GHG emissions. One province, British Columbia, has introduced low carbon fuel regulations that set an upper bound on the carbon content of transportation fuels sold in the province.

This report uses a vintaged capital stock approach to examine the potential GHG benefits of a broad range of trends and technologies. This methodology is widely used for analyzing patterns of energy use and emissions levels over time. The starting point is a reference case that represents trends in vehicles in use, vehicle use (passenger-kilometres or tonne-kilometres), fuel consumption, and related emissions over the period from 1990–2012. Historical performance is tracked for nine vehicle types: passenger automobiles, light-duty passenger trucks, motorcycles, light-duty freight trucks, medium-duty freight trucks, heavy-duty freight trucks, school buses, urban transit buses, and inter-city buses. Energy use for each vehicle type is divided between gasoline, diesel, propane, ethanol, and natural gas as appropriate.

The Conference Board of Canada’s long-term outlooks for population and GDP are used, together with statistical relationships to project vehicle requirements from 2013 through 2050. For each vehicle type, the model uses a vintaged capital stock methodology, and tracks vehicles based on their model year. Each year a fixed percentage of vehicles on the road is retired based on historical vehicle lifespans. New vehicle purchases are calculated to replace retired vehicles and accommodate
growth in the total stock. This approach facilitates modelling current and proposed tailpipe emissions standards and allows simple tracking of the penetration of new technologies and fuels.

The gradual penetration of new technologies, together with unit abatement costs, can then be used to develop a simple abatement cost curve for the emissions-reducing options considered.

**Technology Penetration Rates**

The vehicle fleet in operation has an average life that can vary from 12 years (for most buses) to 15 years (passenger vehicles) or as long as 30 years (heavy-duty transportation). Only a small portion of the vehicle fleet purchased in any year will be retired through accident, mechanical failure, or other reasons in each subsequent year. Further, improvements in fuel efficiency and emissions take place gradually, with small increments in each model year.

New vehicle technologies are often adopted rather slowly by the market as consumers gain experience and as the vehicles overcome market barriers. Most importantly, new technologies are not typically adopted faster than old technologies wear out and are replaced. This is particularly true for expensive purchases such as vehicles.

The rate of market uptake, or market penetration rate, is a key unknown for some of the options considered. In particular, technologies with which consumers have little or no experience can produce very different emissions impacts depending on the assumptions made for market penetration. The limited historical record makes it difficult to find a basis for such assumptions. Plug-in electric vehicles provide an example. They are very new to the market, and currently stand where gasoline-electric hybrids stood just 20 years ago. Early adopters are beginning to embrace the technology, but the rate of acceptance among consumers in general is still uncertain.
A simple example will illustrate the importance of this theme. In 2012, WWF-Canada published a report examining the potential of electric vehicles to reduce GHG emissions.\textsuperscript{1} Its analysis considered three scenarios for the growth in electric vehicles in Canada: 15 per cent annual growth, 25 per cent annual growth, and 35 per cent annual growth. All scenarios were measured over a 13-year period ending in 2025, starting from an initial 12,000 electric vehicles at the end of 2012. In 2013, WWF published an update to the report, indicating that there were only 4,059 electric vehicles on the road and comparing Canada’s performance to that of Norway and California. The update shows that 3.1 per cent of vehicle sales in Norway and 2.9 per cent of vehicle sales in California are electric.\textsuperscript{2}

Simple calculations can show the importance of these assumptions to the end results. Table 17 considers the number of electric vehicles on the road at the end of 2025 based on an initial count of 4,059 vehicles at the end of 2012 and the various growth rates. In addition to the electric vehicle counts, we have included the share of total passenger vehicles that would be electric based on our calculations of the total vehicle fleet. For the calculations based on 3 per cent of vehicle sales, we have also relied on our estimate of the number of vehicles sold each year. The table also shows the impact of extending each assumption through 2035 to demonstrate the longer-term impact of growth rate assumptions compared with a constant share of new vehicle sales.

\begin{itemize}
  \item \textsuperscript{1} WWF-Canada, \textit{Greenhouse Gas Reduction Potential of Electric Vehicles}.
  \item \textsuperscript{2} WWF-Canada, \textit{Transportation rEVolution}, 5.
\end{itemize}
As the table illustrates, the assumption made regarding technology penetration is particularly important to the long-term result obtained. The lack of historical record for some of the technologies considered increases the uncertainty surrounding their future success.

### Scenarios

There are numerous options to reduce road transportation GHGs in Canada, making the number of possible combinations quite large. Sensitivities around key assumptions make the task of describing future reduction paths even more complex. This report examines two basic cases, then layers on additional potential trends. The two basic cases are a reference case and a continuous improvement case. All cases treat 2012 as the most recent historical year because greenhouse gas emissions detail is available for that year.

### Reference Case

The reference case represents a continuation of existing vehicle patterns, fuel choices, and regulations. The vehicle stock is based on the stock that existed at the end of 2012, adjusted each year for vehicle retirements and vehicle purchases. Retirements are based on historical trends in vehicle lifespan, and purchases are based on the current year’s vehicles required, minus the previous year end stock, plus current year retirements. The current year’s vehicle requirements are based on

<table>
<thead>
<tr>
<th>Growth assumption</th>
<th>Number of electric vehicles in 2025</th>
<th>Electric share of total vehicles in 2025 (per cent)</th>
<th>Electric share of total vehicles in 2035 (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 per cent annual growth</td>
<td>24,975</td>
<td>0.17</td>
<td>0.58</td>
</tr>
<tr>
<td>25 per cent annual growth</td>
<td>73,833</td>
<td>0.49</td>
<td>3.94</td>
</tr>
<tr>
<td>35 per cent annual growth</td>
<td>200,797</td>
<td>1.34</td>
<td>23.12</td>
</tr>
<tr>
<td>3 per cent of vehicle sales</td>
<td>266,926</td>
<td>1.79</td>
<td>2.09</td>
</tr>
</tbody>
</table>

Source: The Conference Board of Canada.
econometric modelling that links the number of vehicles to population and GDP. Vehicle stocks, distances travelled, passenger-kilometres, freight tonne-kilometres, fuel consumption, and emissions per vehicle (based on model year) are tracked for the following vehicle types in each province: passenger cars, light-duty passenger trucks, light-duty freight trucks, medium-duty freight trucks, heavy-duty freight trucks, school buses, transit buses, inter-city buses, and motorcycles.

The reference case reflects current Canadian tailpipe emissions standards for both cars and trucks. For light-duty passenger vehicles, these standards require continuous reductions in tailpipe emissions through model year 2025. From 2026 onward, emissions per litre of fuel consumed are held constant at the 2025 model year level. For trucks, the emissions regulations currently in force require improvements through model year 2018. Emissions intensity is held constant for subsequent years in the reference case.

Table 18 shows the reference case assumptions for vehicles on the road, Table 19 shows the emissions intensity trends, and Chart 15 shows the long-term trend in road transportation emissions by vehicle type.

Table 18
Reference Case Vehicle Stock in Operation
(number of vehicles, 000s)

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>2000</th>
<th>2012</th>
<th>2020f</th>
<th>2030f</th>
<th>2040f</th>
<th>2050f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>10,684</td>
<td>11,921</td>
<td>13,715</td>
<td>16,185</td>
<td>18,882</td>
<td>22,120</td>
</tr>
<tr>
<td>Light-duty passenger trucks</td>
<td>4,615</td>
<td>7,182</td>
<td>8,311</td>
<td>9,871</td>
<td>11,572</td>
<td>13,625</td>
</tr>
<tr>
<td>Light-duty freight trucks</td>
<td>1,430</td>
<td>2,247</td>
<td>2,621</td>
<td>3,136</td>
<td>3,699</td>
<td>4,380</td>
</tr>
<tr>
<td>Medium-duty trucks</td>
<td>600</td>
<td>1,290</td>
<td>1,475</td>
<td>1,676</td>
<td>2,138</td>
<td>3,003</td>
</tr>
<tr>
<td>Heavy-duty trucks</td>
<td>289</td>
<td>397</td>
<td>485</td>
<td>599</td>
<td>738</td>
<td>903</td>
</tr>
<tr>
<td>School buses</td>
<td>47</td>
<td>51</td>
<td>56</td>
<td>62</td>
<td>67</td>
<td>73</td>
</tr>
<tr>
<td>Transit buses</td>
<td>23</td>
<td>30</td>
<td>33</td>
<td>37</td>
<td>40</td>
<td>43</td>
</tr>
<tr>
<td>Inter-city buses</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>373</td>
<td>853</td>
<td>818</td>
<td>901</td>
<td>975</td>
<td>1,059</td>
</tr>
</tbody>
</table>

f = forecast
Source: The Conference Board of Canada.
The number of medium-duty trucks showed the strongest increase from 2000 to 2012 rising by 115 per cent. The projection shows a much slower growth rate through 2050 based on population and GDP growth. Light-duty passenger vehicles (cars and trucks combined) represent the largest vehicle counts at a combined 19.1 million vehicles in 2012. The shift from autos to mini-vans and pickup trucks that began in the 1990s is assumed to have largely played out. The result is that both categories grow at similar rates into the future. Heavy-duty trucks are also expected to show strong growth as Canada’s economy continues to produce, consume, and trade goods.

The trend in emissions intensity partially offsets the long-term impact of continuous growth in the vehicle stock. For most vehicle types, there was about a 10 per cent improvement in emissions per VKT between 2000 and 2012, even though total emissions increased over most of that period. Looking forward, the improvements mandated under current tailpipe emissions regulations would be fully implemented by 2025 for light-duty vehicles and 2018 for medium- and heavy-duty vehicles. Improvements in the average emissions intensity shown in the table continue as older vehicles are replaced by more efficient, less emissions-intensive vehicles. This impact is stronger for light-duty vehicles.

### Table 19

**Reference Case Emissions Intensity Trends**

(grams CO$_2$e per VKT)

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>2000</th>
<th>2012</th>
<th>2020f</th>
<th>2030f</th>
<th>2040f</th>
<th>2050f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>218.7</td>
<td>200.0</td>
<td>153.7</td>
<td>102.7</td>
<td>98.9</td>
<td>98.5</td>
</tr>
<tr>
<td>Light-duty passenger trucks</td>
<td>304.1</td>
<td>277.6</td>
<td>220.4</td>
<td>143.1</td>
<td>135.1</td>
<td>134.7</td>
</tr>
<tr>
<td>Light-duty freight trucks</td>
<td>307.5</td>
<td>259.9</td>
<td>206.3</td>
<td>133.6</td>
<td>126.2</td>
<td>126.1</td>
</tr>
<tr>
<td>Medium-duty trucks</td>
<td>636.9</td>
<td>578.8</td>
<td>545.5</td>
<td>526.3</td>
<td>521.6</td>
<td>521.6</td>
</tr>
<tr>
<td>Heavy-duty trucks</td>
<td>912.2</td>
<td>830.6</td>
<td>781.4</td>
<td>750.6</td>
<td>742.2</td>
<td>740.6</td>
</tr>
<tr>
<td>Transit buses</td>
<td>917.3</td>
<td>822.2</td>
<td>813.9</td>
<td>786.3</td>
<td>782.4</td>
<td>782.4</td>
</tr>
</tbody>
</table>

f = forecast

Source: The Conference Board of Canada.
vehicles because they have a shorter service life and the required model year improvements are more aggressive and are extended over a longer period.

Chart 15
Reference Case Road Transport Emissions
(Mt CO₂e)

Source: The Conference Board of Canada.
Based on reference case assumptions, road transportation GHG emissions would be reduced by almost 20 per cent from their 2005 level by 2025.

The emissions projection shown in Chart 15 reflects the reference case assumptions. Total emissions decline from 132.4 Mt in 2013 to 105 Mt in 2025 as a result of the current tailpipe emissions regulations combined with a continuation of trends in vehicle purchases per capita and freight movement per million dollars of GDP. Emissions from freight movement remain fairly constant as the emissions improvements that are required through 2018 model years apply only to new vehicles and are barely sufficient to offset the growth in freight. Longer term, freight-related emissions continue to rise. Light-duty vehicles show a noticeable reduction from 83 Mt in 2013 to 54.4 Mt in 2025 as tailpipe emissions standards take their effect. In the longer term, even though vehicle efficiency stays at the 2025 level for subsequent model years, population increases are offset by the retirement of older, inefficient vehicles and light-duty vehicle emissions remain constant, reaching 54.6 Mt by 2050.

The reference case can be characterized as a case in which existing emissions standards are continued as currently stated and are fully met. It does not include further transitions in the composition of the vehicle fleet or in mode choice. However, based on reference case assumptions, road transportation GHG emissions would be reduced by almost 17 per cent from their 2005 level by 2025, putting Canada well on its way to the 2030 target. However, the reference case points clearly to the need for further actions in the longer term.

The reference case can be considered pessimistic in that it assumes a continuation of existing conditions plus currently legislated improvements. It does not reflect incremental voluntary actions by the freight sector, changes in vehicle preference, or any continuous improvement in vehicle efficiency beyond that currently embodied in regulation. However, it clearly demonstrates that without further action road transportation GHG emissions will fall modestly in the short term, then rise gradually in the longer term. This does not meet the long-term goal of an 80 per cent reduction.
Continuous Improvement Case
The continuous improvement case embodies what some might view as a more realistic future. It is based on the same demographics as the reference case with regard to population, GDP, and the number of vehicles on the road in each category. However, it reflects two important trends: declining distances travelled per vehicle and continuously improving emissions intensity. For heavy-duty trucks, the regulated improvement in tailpipe emissions is extended through 2027 based on similar requirements to those proposed in the U.S. as Phase 2. This requires approximately a 2 per cent annual reduction in tailpipe emissions from new trucks in each model year from 2018 through 2027. Once the regulatory period ends (beginning in 2026 for light-duty vehicles and 2028 for trucks and buses), all gains achieved are retained and an incremental 1 per cent per year improvement in emissions intensity is imposed. This is consistent with historical trends prior to tailpipe standards. The continuous improvement case also assumes a 1 per cent per year decline in the average kilometres travelled per vehicle for all light-duty vehicles as well as for heavy-duty trucks. This assumption is based on the historical trend and is applied from the beginning of the outlook period. The impact of the continuous improvement assumptions on emissions intensity is shown in Table 20.

Table 20
Continuous Improvement Case Emissions Intensity Trends
(grams CO$_2$e per VKT)

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>2000</th>
<th>2012</th>
<th>2020f</th>
<th>2030f</th>
<th>2040f</th>
<th>2050f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>218.7</td>
<td>200.0</td>
<td>153.7</td>
<td>97.9</td>
<td>85.1</td>
<td>76.7</td>
</tr>
<tr>
<td>Light-duty passenger trucks</td>
<td>304.1</td>
<td>277.6</td>
<td>220.4</td>
<td>136.7</td>
<td>116.2</td>
<td>104.8</td>
</tr>
<tr>
<td>Light-duty freight trucks</td>
<td>307.5</td>
<td>259.9</td>
<td>206.3</td>
<td>133.6</td>
<td>126.2</td>
<td>117.8</td>
</tr>
<tr>
<td>Medium-duty trucks</td>
<td>636.9</td>
<td>578.8</td>
<td>536.5</td>
<td>437.7</td>
<td>381.6</td>
<td>345.3</td>
</tr>
<tr>
<td>Heavy-duty trucks</td>
<td>912.2</td>
<td>830.6</td>
<td>767.5</td>
<td>621.7</td>
<td>543.0</td>
<td>490.0</td>
</tr>
<tr>
<td>Transit buses</td>
<td>917.3</td>
<td>822.2</td>
<td>800.5</td>
<td>654.1</td>
<td>572.4</td>
<td>520.5</td>
</tr>
</tbody>
</table>

f = forecast
Source: Natural Resources Canada; The Conference Board of Canada.
The continuous improvement case shows a greater reduction in emissions intensity for heavy-duty vehicles than for passenger vehicles, primarily because the current standards require less improvement. The proposed heavy-duty regulations would accelerate the pace of improvement and sustain it over a longer period of time. As shown in the table, the average passenger car or light-duty truck on the road in 2050 would produce only 38 per cent of the emissions of the average car on the road in 2012 per kilometre travelled. Heavy-duty transport trucks would produce 59 per cent of the 2012 emissions per kilometre travelled in 2050.

Road transportation emissions for the continuous improvement case are shown in Chart 16. As in the reference case, emissions continue to decline from the beginning of the outlook period (2013) until 2025, reaching 100 Mt. This is because the reference case and continuous improvement case are based on very similar assumptions during that period, with the primary difference being extended improvements in heavy-duty vehicles post-2018. In the longer term, as emissions improvements proceed at a slower pace and as older vehicles continue to be retired, total emissions continue to decline to 86.2 Mt in 2050. This suggests that continuing the historical trend of 1 per cent annual reduction in vehicle travel along with a 1 per cent annual reduction in emissions intensity of travel is sufficient to more than offset the growth pressures from ever-rising activity variables. Light-duty vehicle emissions in this case fall from 83 Mt in 2013 to 54 Mt in 2025 and 42.5 Mt in 2050. For trucks and buses, emissions fall very slightly from 49.2 Mt in 2013 to 45.9 Mt in 2025 and 43.8 Mt in 2050.

Although there are many additional steps that can be taken on a voluntary basis to improve fuel efficiency, or steps that include vehicle choice, mode choice, and carbon fuel intensity, it is clear that the continuous improvement case represents a situation where the growth in emissions turns into a decline over the next decade and that, in the absence of aggressive long-term measures, the decline continues at a very modest pace. The continuous improvement case results in 2050 road transportation emissions that are almost 12 per cent below the
1990 level, hence well above the 80 per cent reduction standard. The remaining sections of this chapter examine some of the key options for further improvement and measure their potential impact based on penetration rate assumptions and the potential emissions savings described in chapters 4 and 5. The impacts are measured as increments to the continuous improvement case.

Source: The Conference Board of Canada.
Light-Duty Vehicle Options and Impacts

Plug-In Electric Vehicles

This technology is still in the early stages of market commercialization, with only 4,059 vehicles on the road in 2012. The market penetration rate is therefore highly uncertain. For this report, we have chosen three illustrative cases. In each case, the percentage of total vehicle sales allocated to this technology rises from its current level of just over 0.5 per cent to 3 per cent, 5 per cent, and 10 per cent, respectively. For the first two cases, the increase occurs over 5 years and for the latter it is spread over 10 years. In all three cases, the number of electric vehicles on the road is based on cumulative sales less retirements.

Electric vehicle retirements are based on a 10-year life. Table 21 shows the penetration for electric passenger cars and the resulting emissions reductions for all three cases. Table 22 presents the same information for light-duty passenger trucks. The GHG reductions are estimated based on all electricity being produced from renewable energy and, therefore, overstate the savings that would actually be achieved in some provinces. The overstatement becomes less important after 2030, as coal-fired generation is retired and lower emitting sources emerge in the provinces that currently rely on coal.

Table 21
Impact of Electric Cars

<table>
<thead>
<tr>
<th></th>
<th>2020f</th>
<th>2030f</th>
<th>2040f</th>
<th>2050f</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3 per cent electric vehicle sales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles on the road</td>
<td>160,255</td>
<td>309,878</td>
<td>402,124</td>
<td>485,728</td>
</tr>
<tr>
<td>Electric share of total vehicles (per cent)</td>
<td>1.17</td>
<td>1.91</td>
<td>2.13</td>
<td>2.20</td>
</tr>
<tr>
<td>Mt GHG reduction</td>
<td>0.378</td>
<td>0.419</td>
<td>0.428</td>
<td>0.421</td>
</tr>
<tr>
<td><strong>5 per cent electric vehicle sales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles on the road</td>
<td>273,651</td>
<td>518,750</td>
<td>671,003</td>
<td>809,825</td>
</tr>
<tr>
<td>Electric share of total vehicles (per cent)</td>
<td>2.00</td>
<td>3.21</td>
<td>3.55</td>
<td>3.66</td>
</tr>
</tbody>
</table>

(continued...)
As indicated in the table, the penetration of electric vehicles based on an assumed share of new vehicle sales is lower than the assumed share, even after 35 years. This is due in part to the very slow turnover rate for passenger vehicles and in part to a shorter lifespan for electric vehicles. The case that is based on electric vehicles accounting for 3 per cent of total sales would be the closest to current performance in California and Norway, as indicated in the WWF studies. Using that case as a benchmark, the growth rate of total electric vehicles on the road falls from very high initial levels to a still very respectable 16 per cent in 2020, then trends downward, to 6.8 per cent (compounded annually) between 2020 and 2030; 2.6 per cent annually between 2030 and 2040; and 1.9 per cent annually in the final decade. The more aggressive shares of sales shown in the table would need to be accompanied by greater market support than has been experienced to date. Given that California and Norway have achieved 3 per cent electric vehicle sales through aggressive subsidies that Canada has not broadly adopted, even a 3 per cent sales target in Canada would require support that is currently not available.

Alternative scenarios were considered based on an assumed growth rate for the electric vehicle capital stock, but these penetration rates are more difficult to substantiate. Further, the impact of continuous compounding over long time periods makes them difficult to interpret in the absence of a strong historical example. For example, an assumption of 35 per cent annual growth in the number of electric vehicles on the road is not

<table>
<thead>
<tr>
<th>Table 21 (cont’d)</th>
<th>Impact of Electric Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020f</td>
<td>2030f</td>
</tr>
<tr>
<td><strong>10 per cent electric vehicle sales</strong></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles on the road</td>
<td>353,014</td>
</tr>
<tr>
<td>Electric share of total vehicles (per cent)</td>
<td>2.57</td>
</tr>
<tr>
<td>Mt GHG reduction</td>
<td>0.83</td>
</tr>
</tbody>
</table>

f = forecast
Source: The Conference Board of Canada.
sustainable beyond 2035 because it would require electric vehicle sales that exceed total sales from 2036 onward. A less astronomical, but still very aggressive, rise in the electric vehicle stock could be considered based on 35 per cent growth for the first 5 years, 25 per cent for the next 10 years, and then 15 per cent per year. Under these assumptions, the electric share of the light-duty passenger vehicle stock would not exceed 10 per cent until 2045, but would then double to 20 per cent by 2050. In our view, these kinds of aggressive growth rate cases illustrate clearly the effects of compound growth but do not represent a plausible long-term future for electric vehicle market penetration.

### Table 22

**Impact of Electric Passenger Trucks**

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>2020f</th>
<th>2030f</th>
<th>2040f</th>
<th>2050f</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 per cent electric vehicle sales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles on the road</td>
<td>97,253</td>
<td>188,726</td>
<td>240,459</td>
<td>298,207</td>
</tr>
<tr>
<td>Electric share of total vehicles (per cent)</td>
<td>1.18</td>
<td>1.92</td>
<td>2.12</td>
<td>2.20</td>
</tr>
<tr>
<td>Mt GHG reduction</td>
<td>0.349</td>
<td>0.398</td>
<td>0.395</td>
<td>0.392</td>
</tr>
<tr>
<td>5 per cent electric vehicle sales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles on the road</td>
<td>166,111</td>
<td>315,963</td>
<td>400,073</td>
<td>497,183</td>
</tr>
<tr>
<td>Electric share of total vehicles (per cent)</td>
<td>2.01</td>
<td>3.22</td>
<td>3.56</td>
<td>3.67</td>
</tr>
<tr>
<td>Mt GHG reduction</td>
<td>0.594</td>
<td>0.668</td>
<td>0.664</td>
<td>0.655</td>
</tr>
<tr>
<td>10 per cent electric vehicle sales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles on the road</td>
<td>213,618</td>
<td>588,606</td>
<td>805,043</td>
<td>989,099</td>
</tr>
<tr>
<td>Electric share of total vehicles (per cent)</td>
<td>2.57</td>
<td>5.99</td>
<td>6.99</td>
<td>7.30</td>
</tr>
<tr>
<td>Mt GHG reduction</td>
<td>0.76</td>
<td>1.242</td>
<td>1.302</td>
<td>1.302</td>
</tr>
</tbody>
</table>

*f* = forecast  
Source: The Conference Board of Canada.

Combining the results from tables 21 and 22 indicates that under the assumption of electric vehicles accounting for 3, 5, or 10 per cent of total passenger vehicles sold, GHG emission in 2050 would be reduced by
0.813, 1.356, or 2.696 Mt, respectively. This accounts for 7.3 per cent of total light-duty passenger vehicle emissions in that year for the 10 per cent sales case. The more aggressive growth rate assumption described above would result in a GHG reduction of 7.4 Mt in 2050.

**Gasoline or Diesel Hybrid Electric Vehicles**

These vehicles represent the technology that has the lowest impact on consumer driving habits because they continue to rely on internal combustion engines fuelled by hydrocarbons while extending vehicle fuel economy (hence range), although they do reduce cargo space somewhat. However, the initial vehicle cost is higher and the lifespan is reduced without significant expenditure on battery replacement. As indicated in Chapter 5, gasoline hybrid vehicles typically reduce GHG emissions by 34 per cent and diesel hybrid vehicles by 50 per cent relative to the un-hybridized version of a vehicle. However, gasoline hybrid vehicle sales peaked in Canada in 2012 at approximately 25,000 units, or just over 3 per cent of total sales.\(^3\) Although sales have dropped more recently, returning to 3 per cent of total sales for gasoline hybrids could reduce emissions in 2050 by as much as 0.15 Mt.

**Natural Gas Vehicles**

Compressed natural gas has been available to light-duty vehicle markets for decades, but has struggled to penetrate Canadian markets. The estimated 10 per cent reduction in tank-to-wheels GHG emissions is accompanied by the incremental cost of conversion, a reduction in vehicle range (or a need to continue to operate on gasoline), reduced trunk space because of the natural gas tank, and reduced ongoing engine maintenance (because natural gas burns cleaner than gasoline). Compressed natural gas vehicles require regular fuel system certification for safety reasons. The fuel cost savings will depend on the

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\(^3\) Israel, *Hybrid Cars Still Have a Future.*
relative prices of natural gas and gasoline. Finally, the lack of fuelling infrastructure in Canada creates a barrier for passenger vehicles, making CNG largely an alternative fuel for fleet vehicles.

Broader market acceptance of compressed natural gas as a light-duty vehicle fuel in Canada would depend on reducing the barriers, with fuelling infrastructure, conversion costs, vehicle range, and reduced cargo space representing the most important barriers. A recent study by Marbek\(^4\) suggested that the potential for light-duty natural gas vehicles would be primarily fleets and could take the number of vehicles from 4,800 in 2011 to 45,000 in 2020, a compound annual growth of 28 per cent. However, the postulated growth in the first half of that period has not materialized. Given the long history of modest growth for this technology, conservative assumptions appear justified. Even with natural gas vehicles accounting for 1 per cent of total annual sales, this technology would account for only 0.73 per cent of total light-duty vehicles (261,500 cars and passenger trucks together) and would reduce GHG emissions by 0.027 Mt in 2050. Even this assumption is likely optimistic unless fuelling infrastructure becomes commonplace.

### Mode Switching, Land Use, and Behavioural Change

The potential GHG reduction impacts and costs of mode switching, improved land-use planning, and behavioural change are difficult to quantify, primarily because they require consumers to make changes. Mode shifting has been an important component of transportation planning in Canada’s cities for many years. Transit ridership has increased slowly but steadily and cities continue to focus on getting people out of their cars and onto a bus or train. However, the GHG benefits of this particular mode shift depend strongly on whether commuters shift to buses or trains, and in the latter case, whether the train is powered by diesel or electricity as well as the carbon intensity of the electricity. Using the Natural Resources Canada Office of Energy Efficiency energy end-use data, Table 23 illustrates the fuel intensity and carbon intensity of the alternatives.

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4 Marbek, *Study of Opportunities for Natural Gas in the Transportation Sector.*
The values shown represent historical data and illustrate the progress made in both fuel efficiency and carbon intensity between 1990 and 2012. As the numbers indicate, passenger car and passenger truck emissions per passenger-kilometre travelled have shown greater improvement than transit bus improvements. This is a combination of significant improvements in vehicle fuel efficiency and modest improvements in vehicle occupancy rates. Comparing the carbon intensity of passenger vehicles to that of buses, we also note the impact of higher emissions levels from diesel versus gasoline engines. The table suggests that in 2012 there was no appreciable reduction in carbon intensity that would result from riding a bus rather than driving a car. However, the table does not explicitly reflect other considerations. Although transit buses typically operate at high occupancy rates during rush hour, they are under-utilized the remainder of the day. To the extent that mode shift occurs during rush hour, it would need to be accommodated by adding buses. This is likely to have little or no impact on carbon intensity. However, to the extent that mode shift increases ridership during off-peak hours, the higher utilization of existing buses would reduce their carbon intensity. Additionally, as cities work to increase population density in core areas rather than continuing to add new suburbs, the impact is to bring people closer to

Table 23
Fuel and Carbon Intensity of Passenger Trucks vs. Urban Bus Transit

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Measure (units)</th>
<th>1990</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>Energy intensity (MJ/pkt)*</td>
<td>2.23</td>
<td>1.85</td>
</tr>
<tr>
<td>Passenger car</td>
<td>Carbon intensity (T GHGs/pkt)**</td>
<td>69.00</td>
<td>66.8</td>
</tr>
<tr>
<td>Passenger truck</td>
<td>Energy intensity (MJ/pkt)</td>
<td>2.89</td>
<td>2.32</td>
</tr>
<tr>
<td>Passenger truck</td>
<td>Carbon intensity (T GHGs/pkt)</td>
<td>69.50</td>
<td>66.8</td>
</tr>
<tr>
<td>Transit bus</td>
<td>Energy intensity (MJ/pkt)</td>
<td>1.92</td>
<td>1.61</td>
</tr>
<tr>
<td>Transit bus</td>
<td>Carbon intensity (T GHGs/pkt)</td>
<td>67.70</td>
<td>67.0</td>
</tr>
</tbody>
</table>

* MJ/pkt = megajoules per passenger-kilometre travelled  
** T GHGs/pkt = tonnes of CO2e per passenger-kilometre travelled  
Sources: Natural Resources Canada; The Conference Board of Canada.
their workplace. Urban citizens have shorter commutes and have been demonstrated to rely more heavily on public transit to avoid parking costs and congestion. Finally, should the mode shift from private vehicles to public transit proceed more rapidly than population growth, the net impact could be to reduce congestion. Transport Canada has investigated this issue, although published studies are somewhat dated. In 2006, for example, Transport Canada determined that if all roads in Vancouver, Toronto, and Montréal had been able to operate at 70 per cent or more of the posted speed limit during rush hour, rather than just 50 per cent, GHG emissions in those cities would have been reduced by 1.2 million tonnes.5

Chapter 3 shows the current mode shift targets of three large Canadian cities. Calgary plans to reduce car share from 77 per cent in 2005 to 55 to 65 per cent in 2070, a reduction of at least 12 per cent. The city also plans to increase transit ridership by 6 to 10 per cent over the same period. Ottawa has more modest goals, but over a shorter time frame. However, all three cities with mode share targets intend to increase the mode share for walking or biking.

The mode shift toward walking or biking should reduce or eliminate GHG emissions. To the extent that there is no impact on congestion, elimination is possible. This is the most attractive mode shift available in urban areas in terms of carbon intensity. However, it also requires the greatest commitment and behavioural change on the part of commuters; and municipal targets for improving the share of walking and biking are modest (typically less than a 10-percentage-point shift in the very long term). In order to accommodate and encourage this shift, cities are including dedicated bike lanes, bike paths, and multi-use corridors in urban areas. The investment required can be large.

5 Transport Canada, The Cost of Urban Congestion in Canada, Table 8.
Heavy-Duty Vehicle Options and Impacts

Heavy-duty transportation vehicles have taken numerous actions to voluntarily reduce their GHG emissions. In many cases, these actions also contribute to profitability because they reduce fuel consumption, and hence operating costs (after the initial purchase cost is recovered). Table 14 lists the primary options as well as the resulting fuel savings.

Recent work completed by Pollution Probe and the International Council on Clean Transportation provides a small sample indication of the fuel savings and adoption rates of the trailer technologies. They found that side skirts are the most implemented of the technologies. Their findings are that side skirts improve fuel economy by 1 to 7 per cent and that the trailer suppliers in their survey sell about half of their trailers with this technology. The underbody devices and boat tails provide similar fuel savings but have much lower adoption rates. For low rolling resistance tires, the same survey found that 80 per cent or more of new trailers are equipped and that fleet operators have shown strong acceptance of the technology. Wide-base tires have shown much lower levels of availability, at less than 10 per cent of new trailers.

Assembling the Pieces

This chapter has discussed the main options available to reduce road transportation GHG emissions in Canada. It also presents the potential impact of these measures on emissions in 2050 based on savings per vehicle and assumptions regarding adoption rates. Table 24 summarizes the key impacts. It should be noted that the options presented are not always additive. For example, achieving plug-in electric vehicles’ share of 10 per cent of total vehicle sales and achieving gasoline hybrid vehicles’ share of 3 per cent of total vehicle sales may have a lower probability of success than either of the options on its own. Also, the initiatives shown in the table are measured at the high end of the range considered achievable.

6 Sharpe and Roeth, Costs and Adoption Rates of Fuel-Saving Technologies.
Table 24
Summary of Mitigation Options and Potential Impacts

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Assumed potential</th>
<th>Emissions reduction in 2050 (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug-in electric vehicles</td>
<td>Passenger car share of new sales reaches 10 per cent by 2025</td>
<td>1.394</td>
</tr>
<tr>
<td>Plug-in electric vehicles</td>
<td>Light-duty passenger truck share of new sales reaches 5 per cent by 2025</td>
<td>0.655</td>
</tr>
<tr>
<td>Gasoline hybrid electric vehicles</td>
<td>Passenger car share of new sales increases by 3 percentage points</td>
<td>0.150</td>
</tr>
<tr>
<td>Compressed natural gas vehicles</td>
<td>Passenger car share of new sales at 1 per cent</td>
<td>0.027</td>
</tr>
<tr>
<td>Mode shift</td>
<td>Growth of 5 percentage points in share of passenger-km travelled by bicycle or on foot rather than by car/light truck</td>
<td>1.849</td>
</tr>
<tr>
<td>LNG heavy-duty trucks</td>
<td>5 per cent of heavy-duty trucks on the road in 2050 operate on LNG</td>
<td>1.170</td>
</tr>
<tr>
<td>Trailer streamlining</td>
<td>All trailers on the road in 2050 have side skirts that save 4 per cent fuel on average</td>
<td>0.936</td>
</tr>
</tbody>
</table>

Source: The Conference Board of Canada.

Table 24 is not comprehensive because it does not include all of the reduction options available. Some additional options are beyond the scope of this analysis to quantify, and others are excluded or limited because they have been available for some time, and have not yet penetrated the market significantly. For example, the closer integration of urban land-use planning and transportation planning is beginning to influence road traffic, congestion, and mode choice. However, the road infrastructure and the physical configuration of cities are both long-term constraints. Once roads and suburbs are built, they last for decades and act to constrain the options for further development. Canadian cities are working to increase urban density, improve transit systems, and encourage alternative transportation. Some of these impacts are captured in the options described in this chapter, but the potential is likely understated. Similarly, technologies such as natural gas vehicles, gasoline hybrid vehicles, and some of the heavy-duty trailer options have been available for many years but have shown either gradual market acceptance or even an apparent peak in market penetration.
Although there is much more that can be done, the analysis in this chapter indicates clearly that there is no drop-in solution. The options available will cost society, companies, and individuals to implement. The historical rate of acceptance of these options has been much less than their acceptance must be if Canada is to reduce its road transportation emissions below 1990 levels. Reducing emissions 80 per cent from that benchmark will require remarkable changes in transportation choices. The technology solutions to improve vehicle efficiency, introduce new fuels, and improve traffic flows will accomplish little more than offset the increases that will result from growth in population and economic activity.
Chapter Summary

- On a well-to-wheels basis for passenger vehicles, almost all of the options examined result in abatement costs that are above $100 per tonne. This is substantially higher than the current prices on carbon.

- On a well-to-wheels basis for heavy-duty vehicles, compressed natural gas, liquefied natural gas, and hybridization result in financial savings. However, the cost of vehicle conversion and a lack of fuelling infrastructure serve as barriers to widespread adoption of these technologies in the freight sector.

- For both light- and heavy-duty vehicles, GHG reductions come at the expense of higher initial capital costs. Vehicle purchasers must commit to a higher cost to achieve long-term savings. For both passenger and freight transportation, payout is a critical variable.
The previous chapters have summarized government initiatives to encourage companies and individuals to reduce road transportation greenhouse gas emissions. They have also discussed the technology and policy options available to accomplish the change. But the question remains, at what cost? For many of the options, the unit cost of abatement can be approximated; for others it cannot. This chapter focuses on the cost as measured in the undiscounted life-cycle cost per tonne of greenhouse gas emissions avoided.

Abatement costs are difficult calculations because of the many assumptions required. For the purposes of this report, we have focused on vehicle-related abatement costs and relied primarily on results from the GHGenius model, supplemented by results from AFleet. The former is a Canadian model; the latter uses U.S. data. Because this report is directed to road emissions, we report the tank-to-wheels emissions and well-to-wheels emissions, but exclude emissions related to vehicle manufacture or end-of-life salvage. The tank-to-wheels metrics are the most useful for considering only road emissions, although well-to-wheels emissions capture the fuel-cycle emissions.

The emissions abatement costs that can be reliably quantified are primarily those that relate to alternative fuels or vehicle fuel efficiency. Estimates of the tank-to-wheels abatement costs for light-duty passenger cars and trucks are shown in Table 25. To generate these estimates, we used costs modelled using AFLEET (such as those presented in Table 16) and emissions reductions estimated using GHGenius (such as those presented in Table 15). To calibrate the GHG emissions reductions from GHGenius to real-world observations, we estimated emissions...
reductions per 100 kilometres of driving, using road transportation emissions data from Natural Resources Canada’s Comprehensive Energy Use Database, averaged from 2008–12.¹

Table 25
Tank-to-Wheels Passenger Vehicle GHG Emissions Abatement Costs Relative to Gasoline Vehicles
($ per tonne CO₂e)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Light-duty passenger cars</th>
<th>Light-duty passenger trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline HEV</td>
<td>222</td>
<td>509</td>
</tr>
<tr>
<td>Gasoline PHEV (85 per cent of distance in CD mode)</td>
<td>168</td>
<td>n.a.</td>
</tr>
<tr>
<td>BEV</td>
<td>209</td>
<td>n.a.</td>
</tr>
<tr>
<td>Biodiesel (B20)</td>
<td>162</td>
<td>No emissions reduction</td>
</tr>
<tr>
<td>Ethanol (E85)</td>
<td>1,215</td>
<td>1,352</td>
</tr>
<tr>
<td>Propane</td>
<td>900</td>
<td>609</td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>376</td>
<td>537</td>
</tr>
<tr>
<td>Fuel cell electric vehicle</td>
<td>195</td>
<td>203</td>
</tr>
</tbody>
</table>

Source: The Conference Board of Canada.

The entries in Table 25 indicate that there are several combinations that either are not available or do not reduce emissions on a tank-to-wheels basis. For those that do, none have an abatement cost of less than $100 per tonne. Note that for ethanol, including the well-to-tank emissions in the calculation significantly reduces the abatement cost compared to the tank-to-wheels value cited. This is because of the way we have allocated the carbon content of the fuel. The vehicle-cycle greenhouse gas emissions of ethanol are similar to gasoline and the fuel-production emissions are marginally higher. However, because ethanol is produced from plants that remove carbon dioxide from the

¹ NRCAN, Transportation Sector—Canada.
On a tank-to-wheels basis, biodiesel for cars has the lowest abatement cost.

air, the carbon in the fuel is not considered part of the emissions when emissions are measured on a well-to-wheels basis. The fuel production removes carbon from the air, whereas the fuel consumption puts it back.

All of the technologies shown in Table 25 act by replacing gasoline or diesel with a lower carbon content fuel. The abatement costs show that on a tank-to-wheels basis, biodiesel (B20) for cars has the lowest abatement cost. It should be noted, however, that a large proportion of the emission reductions relative to gasoline is caused simply by switching to diesel, which, as noted in Table 15, is predicted to reduce emissions by 20 per cent. Of the remaining AFVs, the electric vehicle technologies provide the lowest cost GHG reductions. These technologies have higher initial vehicle costs, and high maintenance costs because their batteries must be replaced, but achieve the highest emissions reduction as well. The biofuel options also reduce the carbon intensity of the fuel, but by a lesser amount. The abatement cost of biofuels is incurred primarily to produce the fuel, with some cost in the distribution system and minimal cost in the vehicle. The incremental costs for propane and natural gas vehicles are incurred both in vehicle conversions (or purchase) and fuel delivery infrastructure.

Of course, CO₂ abatement costs for light-duty vehicles have been estimated elsewhere. The Conference Board of Canada, for instance, previously estimated the abatement cost of PHEVs to be around C$800 per tonne CO₂e.² This is substantially higher than our current estimate of US$168 per tonne. However, our current estimate is based on undiscounted costs and assumes an incremental cost of roughly $16,530, whereas the earlier estimate assumed a 5 per cent discount rate and an incremental cost of $21,000. When we applied this discount rate and incremental cost to PHEV vehicles using the AFLEET model, the difference in lifetime costs between a PHEV and a gasoline vehicle increased several times over, which resulted in an abatement cost much closer to the C$800 estimated previously. This indicates that these

² Campbell and Gill, Are We Ready to Step Off the Gas?, 25.
assumptions in particular can have a large impact on the outcome of the analysis. Under a different set of assumptions, the abatement costs could be higher than those reported here.

Table 26 presents abatement costs for the same light-duty vehicle technologies on a well-to-wheels basis. This comparison includes the costs and emissions related to fuel production, fuel delivery, and fuel combustion. The excluded emissions relate to vehicle production and end-of-life disposal. Because Natural Resources Canada does not report the upstream (well-to-tank) emissions for road vehicles, these were estimated based on the tank-to-wheels emissions reported by Natural Resources Canada, grossed up using results from GHGenius, which estimates both well-to-wheels and tank-to-wheels emissions.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Light-duty passenger cars</th>
<th>Light-duty passenger trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline or diesel hybrid electric</td>
<td>171</td>
<td>360</td>
</tr>
<tr>
<td>Gasoline or diesel plug-in hybrid electric</td>
<td>184</td>
<td>n.a.</td>
</tr>
<tr>
<td>Battery electric vehicle</td>
<td>230</td>
<td>n.a.</td>
</tr>
<tr>
<td>Biodiesel (B20)</td>
<td>42</td>
<td>228</td>
</tr>
<tr>
<td>Ethanol (E85)</td>
<td>359</td>
<td>395</td>
</tr>
<tr>
<td>Propane</td>
<td>284</td>
<td>163</td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>167</td>
<td>181</td>
</tr>
<tr>
<td>Fuel cell electric vehicle</td>
<td>492</td>
<td>444</td>
</tr>
</tbody>
</table>

Source: The Conference Board of Canada.

On a well-to-wheels basis, the results for passenger cars remain similar, with biodiesel appearing as the cheapest option and the only technology with an abatement cost below $100 per tonne. It has a lower abatement cost, on a well-to-wheels basis, than on a tank-to-wheels basis because the carbon sequestration is now being accounted for in
the emissions reductions. After biodiesel, the electric technologies show the lowest abatement costs, although the ranking of electric technologies has changed somewhat compared to the tank-to-wheels costs. The emissions intensity for electric vehicles used in GHGenius reflects the carbon intensity of electricity production at a national level. As a result, the abatement costs in provinces that still generate electricity from coal or natural gas would be higher than those stated in the table, and abatement costs in provinces that rely on hydropower, nuclear, or wind generation would be lower than shown in the table. Notably, the fuel cell vehicles rise significantly in abatement costs. This is because hydrogen production uses natural gas as a feedstock and is energy intensive to produce.

The results of the well-to-wheels abatement cost analysis for light-duty vehicles can be compared to similar calculations made by the International Energy Agency (IEA) in 2009 for several of the technologies considered here.3 (See Table 27.)

### Table 27

<table>
<thead>
<tr>
<th>Technology</th>
<th>Abatement cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol (from corn)</td>
<td>75</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>150</td>
</tr>
<tr>
<td>Gasoline HEV</td>
<td>30</td>
</tr>
<tr>
<td>PHEV</td>
<td>180</td>
</tr>
<tr>
<td>BEV</td>
<td>387</td>
</tr>
<tr>
<td>FCEV</td>
<td>464</td>
</tr>
</tbody>
</table>

Note: For abatement costs for PHEVs, BEVs, and FCEVs, which are highly dependent on electricity generation emission intensity, we have reported the costs assuming an electricity generation mix comparable to that of France and Britain, the most comparable jurisdictions with specific estimates. Sources: International Energy Agency; The Conference Board of Canada.

Before making comparisons with our estimates, it should be noted that the IEA’s abatement cost estimates are based on global data that are older than the data we have used here, and assume an oil cost of $60 per barrel. The most notable differences with our estimates are from ethanol and HEVs, which both have much lower abatement costs than those we have estimated. For ethanol, this is likely a result of different assumptions about emissions reductions, as our results from the GHGenius model show only a 16 per cent reduction in emissions for ethanol relative to gasoline vehicles. The estimate for PHEVs is very similar to the cost we have calculated here, as is the abatement cost for FCEVs. While the BEV abatement cost is notably higher than our estimate of $230 per tonne, the cost of BEVs has likely come down since the IEA report was published.

For heavy-duty trucks, the abatement costs on both well-to-wheels and tank-to-wheels are shown in Table 28. The negative abatement cost entries indicate that there is a financial savings associated with emissions reduction. However, diesel hybrid engines are not broadly available to the market or have not been widely accepted. Biodiesel is currently available only at low-blend rates and would need further improvement to avoid operating problems at higher blend rates. The two natural gas technologies are currently handicapped by the upfront vehicle conversion costs and limited fuelling infrastructure. Trucking is a highly competitive industry where the initial cost of vehicle conversion and fuelling infrastructure act as barriers. Furthermore, these abatement cost estimates assume that heavy-duty trucks achieve high mileage over their lifespan, lasting for 28 years (the default assumption in AFLEET) and being driven for roughly 80,000 kilometres per year (the average distance travelled by heavy trucks in Canada during 2008–12). With a shorter lifespan or reduced annual mileage, these abatement costs would be larger. Halving the assumed lifespan, for instance, would make the abatement cost of a diesel hybrid electric vehicle slightly positive, while the natural gas vehicles would lose some (but not all) of their net cost savings.

Calculated based on data from NRCAN, Transportation Sector—Canada.
The previous chapters have discussed the vehicle technologies listed in tables 25 through 28, as well as mode shifts, behavioural changes, and land-use changes. Although actions in these latter categories will contribute to reducing road transportation GHG emissions, quantification of the abatement costs is fraught with challenge. The actual costs as well as the result achieved are specific to the location considered and the nature of the action taken. For example, cycling or walking in Vancouver is perhaps easier to encourage than in another city where weather is more challenging and the population less dense. This report quantifies only the abatement costs for vehicle and fuel technologies.

### Table 28

**Heavy-Duty Truck GHG Emissions Abatement Costs Relative to Diesel Vehicles**

($ per tonne CO₂-e)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Well-to-wheels</th>
<th>Tank-to-wheels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel hybrid electric</td>
<td>–9</td>
<td>–12</td>
</tr>
<tr>
<td>Biodiesel (B20)</td>
<td>133</td>
<td>No emissions reduction</td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>–311</td>
<td>–674</td>
</tr>
<tr>
<td>Liquefied natural gas</td>
<td>–584</td>
<td>–627</td>
</tr>
</tbody>
</table>

Source: The Conference Board of Canada.
CHAPTER 8

Closing the Gap

Chapter Summary

- In addition to the emissions reductions described in the continuous improvement case, there is potential for a further reduction of between 9.7 and 15 Mt per year in road transportation emissions through greater market penetration of alternative technology vehicles, modal shifts, and improved transportation planning.

- Other initiatives will be necessary to achieve the remaining 51.7 to 57 Mt necessary to reach the targeted 80 per cent reduction relative to 1990.

- The options examined will likely achieve half of the required reductions. Behavioural change and a refocused and intensified collaboration will be needed to get the rest of the way to the target.
Canada’s ability to reduce road transportation greenhouse gas emissions rests upon at least three fundamental questions: How much can technology accomplish? What will it cost? How much are we willing to change behaviour?

These are not easy questions, and the analysis presented in this report suggests that the answers will be even more challenging. We know that road transport emissions in 2013 were 39 Mt (40 per cent) higher than in 1990. This means that in order to reduce emissions to just 20 per cent of the 1990 level by 2050, Canada will need to find a way to eliminate 117.5 Mt, or 86 per cent, of its 2013 road transportation emissions. Further, emissions are expected to decline over the next decade as tailpipe emissions standards tighten, then resume a longer-term growth path. With an assumption that vehicle fuel efficiency continues to improve at 1 per cent per year after the tailpipe standards reach their current end date, population and economic growth reassert themselves. The continuous improvement case shown in Chapter 6 shows a continued reduction in emissions over the long term, with total road transportation emissions at 86 Mt in 2050. This is below the 1990 level, but still well above the 80 per cent reduction target.

Vehicle technologies and lower carbon fuels can help reduce that level, as shown in Table 29, along with a range of estimated contributions to GHG reductions.

However unlikely it may be, should all of the changes identified in Table 29 be implemented, the total reduction in GHG emissions in 2050 would range from 9.7 to 15.0 Mt, leaving 51.7 to 57 Mt of reductions to come from other initiatives. Those initiatives could include further adoption of the listed technologies (although the high-end assumptions are already aggressive); reduced transportation demand through avoiding trips; electrification of bus fleets; and other measures not yet in evidence.
Table 29
Estimated Contributions to GHG Reductions

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Minimum potential</th>
<th>Maximum potential</th>
<th>Emissions reduction in 2050 (Mt)</th>
<th>Unit abatement cost ($ per tonne)</th>
<th>Total abatement cost ($ millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug-in electric cars</td>
<td>10 per cent share of new vehicle sales (7.28 per cent of total stock in 2050)</td>
<td>35 per cent for 5 years, 25 per cent for 10 years, then 15 per cent annual growth (20 per cent of total stock in 2050)</td>
<td>1.394–3.829</td>
<td>230</td>
<td>321–881</td>
</tr>
<tr>
<td>Plug-in electric passenger trucks</td>
<td>5 per cent share of new vehicle sales (3.67 per cent of total stock in 2050)</td>
<td>10 per cent share of new vehicle sales (7.3 per cent of total stock in 2050)</td>
<td>0.655–1.302</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Gasoline hybrid electric cars</td>
<td>Double current share of new sales from 3 to 6 percentage points</td>
<td>Double current share of new sales from 3 to 6 per cent</td>
<td>0.3</td>
<td>171</td>
<td>51</td>
</tr>
<tr>
<td>Passenger car CNGs</td>
<td>1 per cent share of new vehicle sales</td>
<td>3 per cent share of new vehicle sales</td>
<td>0.027–0.054</td>
<td>167</td>
<td>4.5–9.0</td>
</tr>
<tr>
<td>Mode shift</td>
<td>Growth of 5 percentage points in active transport share</td>
<td>Growth of 8 percentage points in active transport share</td>
<td>1.85–2.96</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Congestion reduction</td>
<td>Improve commute time speed to 70 per cent of free flow</td>
<td>Improve commute time speed to 70 per cent of free flow</td>
<td>3</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Trailer streamlining</td>
<td>All trailers in 2050 use LNG</td>
<td>8 per cent of trucks in 2050 use LNG</td>
<td>1.4</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Trailer streamlining</td>
<td>All trailers in 2050 have side skirts</td>
<td>Eliminate congestion fuel wasted in Canada's three largest cities</td>
<td>0.6–1.2</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Transit ridership</td>
<td>Reduce public transit fuel consumption by 20 per cent through increased ridership</td>
<td>Reduce public transit fuel consumption by 40 per cent through increased ridership</td>
<td>0.48–0.96</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Source: The Conference Board of Canada.

Table 29 also shows the unit cost of abatement as well as the total cost based on the estimated tonnes of avoided GHG emissions. For technologies that are not yet commercial or for initiatives for which unit costs range broadly, the entry is listed as n.a. Approximately half of the emissions reduction identified in the table can be achieved at costs of $100 per tonne or less. Given that carbon prices in Canada (where they exist) are all $30 per tonne or less, and that around the
world carbon prices are typically $30 per tonne or less, this suggests that the reductions identified are unlikely to be fully achieved without an increased policy commitment to higher carbon prices.

The addition of the measures in Table 29 is also less than perfect. In other words, our analysis has not examined the achievability of these measures in combination. For example, to the extent that plug-in electric vehicles gain market acceptance to the level that their share of new vehicle sales reaches 10 per cent (three times the current level in California and Norway), it is not clear that gasoline hybrid vehicles would still attract enough interest to double their share of sales. Similarly, the estimate of the greenhouse gas reduction from reducing congestion is based on the vehicle mix operating in Canada’s cities in 2012 and would be reduced significantly by a strong trend toward electric vehicles.

Although it is neither predictive nor realistic, it is useful to consider the impact that would result from shifting the entire passenger fleet (cars, light trucks, school buses, and urban transit buses) from their current fuels to electricity generated from renewable sources. This would result in a reduction of 35.2 Mt of GHG emissions in 2050 under the continuous improvement case, still leaving Canada short of its 80 per cent reduction target. A comparison between zero-emissions passenger vehicles and other options such as mode choice, land-use planning, and active transportation is beyond the scope of this report, but could provide some interesting insights. To date, Canadian governments have focused most of their effort and expense on supporting biofuels and energy-efficient transportation technologies, with a lesser focus on land-use planning and urban redesign. The wisdom of this approach represents an interesting research question.

From Table 29 it is clear that achieving an 80 per cent reduction in road transportation emissions will require every initiative that can be pursued. However, the cost of many initiatives is currently high enough to suggest caution. Reducing fuel carbon content, improving vehicle efficiency, electrification, mode shift, and improved land-use planning must all play their roles. In addition, governments can focus efforts on reducing overall transportation demand.
Additional observations can be made with respect to what might constitute a realistic target for road transportation emissions reductions between now and 2050. An 80 per cent reduction from the 1990 level appears to be a target without a concrete plan. As stated, converting all passenger traffic to zero emissions traffic would still leave Canada well short of the goal. Emissions from road freight movement are projected to be 46.4 Mt in 2050. Although there is some potential to reduce freight emissions through mode switching to rail or marine transportation, trucks are the most flexible freight transportation mode available and will always retain a significant market share. The options beyond those stated in Table 26 exist, but their impact is highly uncertain.

It does not appear that, on their own, technological solutions will be adequate to achieve the 80-by-50 goal. This suggests that policies that result in behavioural changes that reduce vehicle-kilometres travelled (VKT) will be required. Several factors influence VKT; many studies have attempted to quantify the effectiveness of public policies on influencing these factors.\(^1\) While various studies have concluded that the policies successfully reduced VKT, there are inherent difficulties in establishing relationships between public policies and VKT. Often, the relationship between factors that influence VKT and VKT are indirect.\(^2\) Further, estimating the impact of a policy is difficult because the data that are collected on VKT are not sufficiently disaggregated.\(^3\) Finally, many of the research designs of these studies were weak.\(^4\) Consequently, some researchers have concluded that “the evidence base for the effectiveness of any type of intervention to reduce car use is weak.”\(^5\)

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1 See Graham-Rowe and others, “Can We Reduce Car Use and, If So, How?”; and Salon and others, “How Do Local Actions Affect VMT?”
2 Salon and others, “How Do Local Actions Affect VMT?” 496.
3 ibid.
4 Salon and others, “How Do Local Actions Affect VMT?” 496; Graham-Rowe and others, “Can We Reduce Car Use and, If So, How?”
5 Graham-Rowe and others, “Can We Reduce Car Use and, If So, How?”, 414.
Based on the data considered, a more modest target of even a 50 per cent reduction in road transportation emissions from their 1990 level will require Canadians to do all they can to rethink their transportation use, will require most if not all available technologies to be implemented, and may require some measures that we don’t yet know about.

**The Path to a Low-Carbon Future for Road Transportation**

This report has examined ongoing efforts, as well as potential future options, to decarbonize Canada’s road transportation sector. The fundamental premise is that Canada’s population, economy, and income levels will continue to grow, and that the transportation of people and goods will continue to contribute to that growth. The challenge is to ensure that the growth is sustainable, particularly with respect to greenhouse gas emissions. Sustainable growth requires Canada to find a balance that enables economic and income growth that does not bring with it ever-increasing greenhouse gas emissions. In fact, those emissions must be substantially reduced to stave off or at least mitigate the impacts of climate change on our society. Although this is a global issue, Canada must take a leadership role.

Historically, economic growth has been a combination of increasing goods production and growth in service industries, with the former being more greenhouse gas-intensive than the latter. However, both goods and services rely on transportation. Since the oil price shocks of the 1970s, reducing the energy intensity of economic activity has been an important policy and cost issue. Since the 1990s, reducing GHG emissions has provided an added incentive to weaken the link between economic growth and energy consumption.

This report has documented many of the government initiatives to reduce GHG emissions from road transportation. To date, they have focused on reducing the fuel and emissions intensity of vehicles (e.g., the tailpipe emissions standards and fuel efficiency standards applied to vehicle manufacturers); reducing the carbon intensity of the fuel used...
(e.g., biofuels and electric vehicle incentives); and influencing mode choice (e.g., active transportation and public transit investments). The private sector has contributed voluntary measures to improve emissions performance, particularly for freight movement. The public has begun to contribute through better transportation choices. And yet the goal appears to be just out of reach.

The evidence points clearly to the opportunity to take a more strategic approach. Canada’s road transportation vision can be more clearly articulated and more strongly linked to the strategic options that will drive the necessary change. Canada’s vision might be to reduce GHG emissions from road transportation by 80 per cent by 2050. If so, intermediate objectives should be set to ensure that we are moving toward the long-term vision. The strategic options can then be examined relative to each other and relative to their cost. The remainder of this chapter provides some basic recommendations in this regard.

**Continue the Focus on Vehicle Performance**

Recent government regulations and industry initiatives have focused strongly on reducing the emissions intensity per kilometre travelled. This is a key area of focus moving forward, and the scenarios in this report show that this effort must continue through 2050. This is an important element of weakening or breaking the link between economic growth, transportation growth, and emissions growth. It is also an area where the best improvements in Canada will likely follow improvements made elsewhere, particularly in the United States.

**Focus More Carefully on Alternative Vehicles**

A continued focus on improving vehicle performance brings with it the dilution of the benefits associated with alternative vehicles. This does not mean that hybrid vehicles, plug-in electric vehicles, natural gas vehicles, or biofuels should not continue to play a role. It simply means that the vehicle options must be considered jointly to ensure the best mix of government and private expenditures. This report has suggested a potential range of benefits that come from alternative technologies,
and has identified that their life-cycle costs make the realistic options. However, the abatement costs for some of these technologies are much higher than the current cost of carbon. As a result, Canadians and their governments are faced with a rather large and complex multi-objective optimization problem.

The mix of incentives, the required investments, consumer preferences, the potential for GHG reductions, and the cost of abatement are all part of the optimization. The historical approach seems to have been based on considering one option and one technology at a time. This leaves unanswered the question of the most effective bundle of options. Government and industry can do much more to understand consumer decision-making, examine combinations of vehicle technologies, and improve the impact of the investments they are making.

**Get People Out of Cars**

The road transportation component of moving people in Canada is all about low-occupancy cars and light-duty trucks. For the past 20 years, consumers have shifted their purchasing decisions away from passenger cars toward passenger trucks (including minivans, crossovers, and sport utility vehicles). This trend has partially offset the benefits of fuel efficiency improvements in both categories. Further, the average distance travelled per vehicle is declining slowly and the average occupancy per VKT remains stubbornly below two. As Canada’s population continues to slowly urbanize and several of Canada’s large cities get larger, congestion continues to grow.

Canada’s cities are working on this issue. They are spending on urban transit systems, but their spending is limited by available tax revenues. This makes it a challenge to grow transit services faster than population grows. Cities are also spending on alternative transit modes (walking and cycling) and on encouraging their use. Some cities are considering addressing congestion through fees, parking costs, and other measures.
As Canada moves toward 2050, the challenge of getting people out of their cars and onto other modes of transportation will remain one of the largest we face. This will require governments, cities, businesses, and people to change the way they think about getting where they need to go.

**Focus on Freight**

The trucking industry has been a leading contributor to growing road transportation emissions, notwithstanding significant improvements in vehicle performance. Although there are emerging options to continue the vehicle improvements, this is a highly competitive industry and the vehicle options may not have developed as rapidly as for light-duty vehicles. The cost-based competition in freight movement means that incremental technologies must be low-cost to penetrate the market. It also means that government support or incentives can play a key role, but only if they are properly designed.

There are numerous areas that can be better understood and perhaps can demonstrate long-term improvement. Focusing freight transportation on low-carbon options rather than the fastest option might provide a partial answer. By this we mean greater reliance on intermodal shipping to take advantage of the lower emissions of rail and marine transportation wherever possible. Improving dispatch practices to keep trucks closer to their load capacity might also contribute. However, both of these options may come at a price to the customer in terms of timing and flexibility. It is not clear that consumers would be willing to accept higher costs, slower delivery, or other inconveniences in return for lower carbon freight transportation.

**Reduce Demand for Transportation**

The most challenging option of all has received almost no attention in this report. Transportation services are a derived demand. This means that we do not consume transportation for its own sake, but because it enables us to consume something else. Mostly we drive to
get somewhere, whether it is work, recreation, shopping, or some other destination. We ship goods for the obvious purpose of moving them from where they are to where they need to be.

The most carbon-effective measures we can take are measures that reduce the demand for transportation. The classic example is for a consumer to make a conscious decision to make one trip per week for groceries rather than several. Working remotely (from home) is another example. The challenge is that reducing demand requires behavioural change, and that is not easy to accomplish. Individuals choose to act to reduce emissions knowing that their actions will benefit society, but may not bring sufficient personal benefit to justify the change based on self-interest alone. Governments can provide incentives, but individuals must make the choices.

Find the Balance
The evidence is clear about at least one thing. To meet an aggressive emissions target for road transportation, Canada will need increased commitment to all of the options we have listed. The commitment needs to become more granular in that defining a broad target and leaving society to work out the details will not be sufficient. Governments, industry, and society must work increasingly as a team to achieve a common goal. Closing the gap would impose costs on Canadian citizens and governments, and given that the options identified are not additive, there would be trade-offs involved. The trade-offs would extend beyond vehicle choice, fuel choice, and mode choice to include behavioural change.

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APPENDIX A

Additional Information on Government Initiatives

Emissions Standards

Light-Duty Vehicles
Prior to 2011, Canada’s approach to reducing GHG emissions from road transportation was voluntary. Consistent with this approach, in 2005 the Government of Canada signed a voluntary memorandum of understanding (MOU) with the Canadian automotive industry that committed industry to reduce GHG emissions from cars and light trucks.\(^1\) In contrast to regulations, the government and industry promoted the MOU as an effective and flexible solution that allowed industry “to select the most appropriate means” to achieve the target.\(^2\) However, while industry introduced several technological improvements that led to an initial decline, total GHG emissions from passenger vehicles and light

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trucks began to rise after 2008. (See Chart 1.) It became apparent that a voluntary approach would not be an effective method of reducing GHG emissions.

Chart 1
Light-Duty Vehicle GHG Emissions in Canada 2005–10
(Mt CO₂e)

Sources: Environment Canada; Government of Canada; The Conference Board of Canada.

In October 2006, the federal government announced its intention to implement new emissions standards for passenger vehicles and light-duty trucks, which would take effect in 2011. In April 2009, the government issued a second notice of intent, initiating the development of these regulations. Originally, the regulations were equivalent to U.S. national fuel economy standards. However, shortly after the Canadian government’s announcement, in September 2009, the NHTSA and the EPA announced a joint proposal to implement new U.S. standards for passenger vehicles and light-duty trucks for the 2012–16 model years. Finalized in April 2010, in addition to fuel economy standards, the regulations implemented increasingly stringent limits for fleet average

5 Ibid., 842.
6 U.S. EPA, EPA and HTSA Propose Historic National Program.
emissions levels. Consequently, to harmonize Canadian and American standards, the federal government modified its proposed regulations to include tailpipe emissions limits.

The government published the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations in October 2010. The regulations apply to vehicle fleets for 2011–16 model years, and grow increasingly stringent each year. Vehicle manufacturers calculate their respective fleet average emission standards on the basis of the size and number of vehicles in their fleet for a given model year. Manufacturers determine the size of the vehicle by its footprint, measured as the distance between a vehicle’s tires multiplied by the distance between a vehicle’s axles.

The government also included compliance flexibilities in the regulations to assist vehicle manufacturers in transitioning to a stricter regulatory environment. These flexibilities included:

- establishing an emissions credit system that would allow manufacturers to accumulate credits to offset emissions deficits in years that they did not achieve their fleet average standard;
- implementing a separate set of standards for small-scale manufacturers;
- providing allowances that reduce fleet average emission values for advanced technology vehicles;
- providing allowances that reduce fleet average emission values for non-conventional technologies that result in GHG emissions reductions.

In October 2010, the federal government released a notice of intent to collaborate with the U.S. government to develop emissions standards applicable to vehicles from model years 2017–25.

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9 Ibid.
10 Ibid., 1876.
regulations were published in September 2014. Similar to the first iteration of regulations, the average fleet emissions targets grow increasingly stringent over subsequent model years; on average, cars must reduce their emissions by 5 per cent annually. The regulations distinguish between the level of difficulty involved in reducing emissions from cars and large light trucks. Consequently, in model years 2017–21, on average, light trucks must decrease their emissions by 3.5 per cent annually, increasing to 5 per cent for model years 2022–25.

The Canadian Vehicle Manufacturers’ Association (CVMA), an industry association whose membership accounts for 65 per cent of vehicles manufactured in Canada, has publicly supported the regulations. The CVMA affirmed that the harmonization of Canadian and American regulations “[takes] advantage of the economies of scale derived from the larger integrated market inherent in the North American automobile industry.” This sentiment was largely echoed in government consultations with stakeholders. While some stakeholders desired a Canada-specific approach in the development of regulations, overall, stakeholders wanted the regulatory certainty of maintaining alignment with U.S. standards. The U.S. will conduct a mid-term review of the regulations in April 2018, at which point the Canadian federal government has committed to further consultations with stakeholders and, if necessary, will take Canada-specific considerations into account.

13 Ibid., 2414.
14 Ibid.
16 Ibid.
Heavy-Duty Vehicles

Building on governments’ efforts to implement harmonized emissions standards for light-duty vehicles, on May 21, 2010, both the Canadian and U.S. governments announced their intention to regulate GHG emissions from heavy-duty vehicles.18 In 2011, the NHTSA and the EPA finalized a Heavy-Duty National Program.19 The program enacted fuel economy and GHG emission standards for heavy-duty vehicles in the United States and was the first of its kind.20 Canada’s Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations, published in April 2012, align with the U.S. program.21 The regulations apply to the 2014–18 model year cohort of on-road vehicles with a gross vehicle weight greater than 8,500 lb. intended for sale in Canada.22

Manufacturers calculate their average fleet emissions targets on the basis of the number of vehicles in the fleet, vehicle weights, and four-wheel drive capabilities.23 Similar to the Canadian standards for light-duty vehicles, the regulations contain an emissions credit system and become progressively restrictive over time. Additionally, the heavy-duty regulations provide vehicle manufacturers with compliance flexibility; manufacturers can receive additional emissions credits for alternative fuel vehicles or innovative technologies that reduce GHG emissions.24 This provision gives vehicle manufacturers a regulatory incentive to increase the market share of low-emissions vehicles. Additionally, manufacturers may exempt a portion of their tractors and vocational vehicles from the regulations between 2014 and 2016.25

18 Environment Canada, Canada Announces Continental Approach; The White House Office of the Press Secretary, Presidential Memorandum.
20 U.S. EPA, EPA and NHTSA Adopt First-Ever Program.
22 Ibid., 968.
24 Ibid.
25 Ibid.
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