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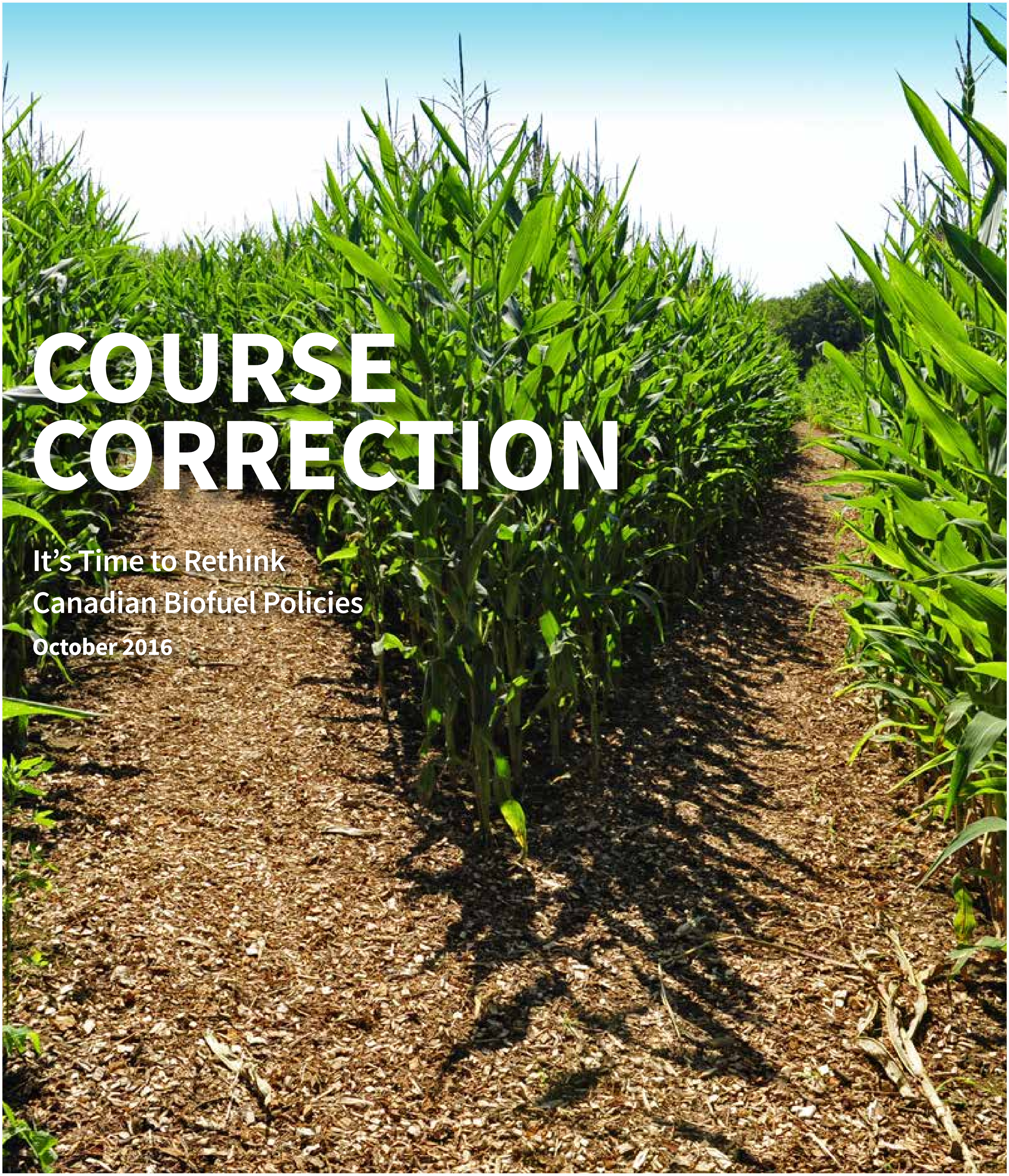

COURSE CORRECTION

It's Time to Rethink Canadian Biofuel Policies

October 2016

CANADA'S ECOFISCAL COMMISSION

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ACKNOWLEDGMENTS

Canada's Ecofiscal Commission acknowledges the advice and insights provided by our Advisory Board:

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We also acknowledge the contributions to this report from the Commission's staff: Jonathan Arnold, Antonietta Ballerini, Dale Beugin, Jason Dion, Annette Dubreuil, and Alexandra Gair. We thank Dr. Ross McKitrick at the University of Guelph and Jeremy Moorhouse at Clean Energy Canada for their valuable comments on a preliminary draft of the report. We also thank the range of stakeholders that attended our workshop for their helpful input. Finally, we extend our gratitude to McGill University and the University of Ottawa for their continued support of the Commission.

Canada's Ecofiscal Commission recognizes the generous contributions of the following funders and supporters:

Peter Gilgan Foundation
IVEY foundation
KTG PUBLIC AFFAIRS
Max Bell Foundation
The J.W. McConnell Family Foundation / La fondation de la famille J.W. McConnell
METCALF FOUNDATION
NORTH GROWTH FOUNDATION
SUNCOR ENERGY
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Fondation familiale Trottier Family Foundation

EXECUTIVE SUMMARY

Canada is on the verge of a significant shift in climate policy. Governments across the country are implementing new policies to help achieve our greenhouse gas (GHG) emissions targets. By 2017, roughly 60% of Canadian GHG emissions will be covered by provincial carbon pricing regimes. These new policies present an opportunity to revisit some existing older policies, and to make course corrections as necessary.

This report considers one set of existing policies: those that support *biofuels* for the transportation sector. Biofuels—such as ethanol and biodiesel—are a renewable alternative to fossil fuels for vehicles. To what extent have biofuel policies achieved their objectives, including reducing GHG emissions? At what cost have these emissions reductions been realized? And which policies best complement a carbon price in transforming our transportation system away from fossil fuels?

To help answer these difficult questions, this report assesses the economic and environmental case for biofuel mandates and production subsidies in Canada.

Biofuel policies in Canada have had limited success, at high costs

Biofuel policies initially appeared to provide a practical opportunity to achieve multiple objectives: reduced GHG emissions, increased opportunities for rural communities, improved air quality, and accelerated development of next-generation biofuels. But to what extent were these outcomes achieved?

Based on our estimates, biofuel policies have indeed reduced GHG emissions. Overall, our analysis suggests that average annual emissions reductions over the 2010–2015 period were roughly 3 Mt. To help put this estimate in perspective, emissions reductions from biofuel policies represent approximately 5.1% of Canada's agricultural emissions, 1.5% of Canada's transportation emissions, or 0.4% of Canada's total GHG emissions.

These emissions reductions have been very costly. Using our estimates of both fiscal and consumer costs, we estimate that the cost of reducing emissions with ethanol policies was approximately $180 to $185 per tonne, and $128 to $165 per tonne with biodiesel policies. Further, these estimates represent a lower bound: if we use less optimistic estimates for the life-cycle emissions of biofuels, the estimated cost of ethanol policies increases to $238 to $284 per tonne, and $189 to $596 per tonne for biodiesel policies.

Emissions reductions from these policies are very costly relative to the social cost of carbon, estimated at $41 per tonne. They are also very costly relative to the costs of emissions reductions expected under carbon pricing—at either today's low carbon prices or higher future prices. In terms of the costs to the overall economy, emissions reductions from biofuel policies are more than five times larger than those driven by the current carbon tax in British Columbia.

Other potential benefits associated with biofuel policies appear unlikely to justify these high costs. Biofuel policies may provide benefits to some Canadian farmers and biofuel producers, but these benefits are offset by adverse impacts on other farmers and other sectors of the economy. According to the federal government's own cost–benefit analysis for its renewable fuel mandate, economic costs exceeded benefits.

We also find that increased use of ethanol and biodiesel has had a negligible impact on reducing air pollution. This is partly because of the small blending levels of biofuels, but also because some biofuels can actually increase emissions of certain pollutants.

Finally, these policies have had little impact on the development and scaling up of next-generation biofuels. First-generation ethanol and biodiesel still account for nearly all biofuels produced in Canada. In addition, projections by the International Energy Agency (2016) and United States Department of Agriculture (2015) suggest that biofuel production and consumption in Canada will remain flat in the short to medium term in the absence of new and effective government policies.

Now is the time to rethink biofuel policies

Biofuel policies were developed at a time when policymakers believed these policies could deliver on their objectives. A new understanding and the current policy context, however, suggest a need—and provide an opportunity—for changing course. Consider four points.

First, as this report shows, we now have a much clearer idea about the modest benefits and relatively high costs of biofuel policies. We conclude that biofuel policies have not performed well against their stated objectives. New policies should take account of this experience.

Second, many of the provincial and federal production subsidies are scheduled to expire in 2017-18, marking an opportunity to adjust policy.

Third, governments are implementing or beginning to implement carbon pricing policies. This policy framework is still emerging across the country, but the prospect of a pan-Canadian carbon price changes the policy context in a crucial way, especially regarding which complementary policies are best suited to achieve emissions reductions.

Fourth, flexible and lower-cost alternative policies to support biofuels are emerging. The low-carbon fuel standard in British Columbia and the zero-emission vehicle standard in California are two examples of flexible policies that take advantage of market mechanisms to deliver a more cost-effective approach than do existing policies. These policies specifically target reductions in the carbon intensity of vehicles and fuels—providing incentives for low-carbon technologies and disincentives for high-carbon technologies.

Canadian governments can chart a new policy course

This report makes four recommendations to provincial and federal governments, all with the goal of using climate policies that drive GHG emissions reductions at the lowest cost to consumers, industry, and government. If followed, these recommendations will change incentives and market outcomes. While the recommended adjustment will reduce costs of policy overall, it may increase costs for specific firms and sectors. As a result, throughout the following recommendations, we stress the importance of easing the transition to alternative policies by considering these distributional impacts.

RECOMMENDATION #1: Provincial and federal production subsidies should be terminated, as initially planned.

Canadian biofuel policies were integral to building domestic capacity to meet federal and provincial fuel mandates, but they were an expensive way to achieve emissions reductions. When compared with other policies, especially carbon pricing, biofuels are clearly not the most cost-effective approach to reducing GHG emissions.

Beyond the relatively high costs of production subsidies, basic principles of subsidy design suggest that support be transitional rather than permanent; subsidies should provide support for emerging technologies to help them become competitive without creating a need for ongoing public funding. First-generation biofuels have now received more than two decades of substantial public support. If producing biofuels in Canada still proves uneconomic, there is a clear indication that additional support for the industry is not a good use of public funds.

The transition away from production subsidies will be assisted by the fact that firms benefiting from these subsidies knew from the outset that they would end in 2017-18, and could thus plan accordingly. In fact, the majority of recipients through the federal production subsidy program stopped receiving payments in 2015, so the transition is already well underway.

Nevertheless, as production subsidies come to an end, governments may experience pressure to renew them to ensure the fuel mandates are met with domestic rather than imported biofuels. They should resist this pressure, given the high costs of these subsidies and potential cost advantages in biofuel production in other jurisdictions. If governments seek to support rural economic development, they could explore alternative policies that create fewer undesirable distortions in agricultural markets.

RECOMMENDATION #2:
Provincial and federal governments should phase out renewable fuel mandates.

Renewable fuel mandates will represent the biggest form of government support for biofuel policies once production subsidies end in 2017-18. These policies have been costly for consumers, who pay a premium when filling their tanks at fuelling stations.

Fuel mandates have also inhibited the development of emerging low-carbon technologies, and this has implications for achieving cost-effective emissions reductions. Decarbonizing the transportation sector will surely involve many different and competing technologies; the technologies that prove the most effective and economically viable should win the day. Only through this competition of ideas will the most cost-effective technologies emerge.

Instead of providing equal incentives to any and all emerging technologies, existing renewable fuel mandates only benefit the biofuels sector—a subset of available and potential technologies. In addition, most fuel mandates in Canada do not create incentives for biofuels based on their carbon content. Because higher-carbon biofuels (first-generation) are typically cheaper and more readily available than lower-carbon biofuels, renewable fuel mandates send a weak incentive for next-generation biofuels and no incentive whatsoever for other vehicular or fuel technologies.

Lastly, similar to the reasons for not renewing production subsidies, no targeted support for industry should last forever. Renewable fuel mandates were implemented with no defined cut-off dates, which runs counter to basic principles of prudent government support.

Yet, there is value in having a smooth policy transition. Renewable fuel mandates have provided stable demand for the biofuels industry, a relatively small group of producers and farmers. Some biofuel companies may have been established with the expectation that renewable fuel mandates would continue indefinitely. Policies should therefore be gradually phased out over the span of several years to ensure that industry has sufficient time to adjust. Most importantly, the final two recommendations will help ensure that clear incentives still exist for low-carbon transportation technologies, including biofuels.

RECOMMENDATION #3:
Provincial and federal governments should continue to work toward an increasing pan-Canadian carbon price.

The development of carbon pricing in Canada is changing the landscape for climate policy. Federal and provincial governments continue to work toward achieving a pan-Canadian carbon price, which we argue is the most effective and cost-effective way to achieve Canada's climate targets. Achieving a broad-based carbon price in Canada will shift the incentives for developing and deploying low-carbon technologies. In particular, it will increase the value of technologies—including some biofuels—that can deliver more GHG emissions reductions at a lower cost. The Ecofiscal Commission therefore continues to support Canadian governments in their pursuit of establishing carbon pricing as the best overall policy tool to achieve Canada's climate targets.

RECOMMENDATION #4:
As part of the policy transition, governments should complement carbon pricing with flexible performance standards and broad funding for research and development.

By itself, a pan-Canadian price on carbon may not be enough to meet Canada's emissions-reduction targets. One key factor is market failures that inhibit the development of low-carbon technologies. Such barriers may be particularly relevant for decarbonizing transportation, where few alternatives to fossil fuels exist and where infrastructure can create barriers to the deployment of new technologies.

To make the shift to low-carbon transportation, complementary policies may be required in the short term. Provincial and federal governments should replace renewable fuel mandates with flexible performance standards. Low-carbon fuel standards, for example, can offer a cost-effective approach to transitioning to new technologies—extending incentives beyond biofuels to other low-carbon fuels. Other flexible performance standards, such as zero-emission vehicle standards, should also be considered as valuable complementary policies.

As governments implement broad carbon prices that increase in stringency over time, the flexible performance standards should be gradually phased out. Once a carbon price high enough to generate significant reductions in GHGs is established, the need for these complementary transportation regulations will diminish. The low-carbon fuel standards in both British Columbia and California were implemented over a 10-year period, which may be a satisfactory transition period while the carbon price increases in stringency.

Finally, governments should understand the potential interactions between flexible performance standards and a carbon price. For jurisdictions with a carbon tax, the implications are clear: complementary policies will drive additional emissions reductions. However, jurisdictions with cap-and-trade systems should understand that additional policies will not necessarily lead to additional emissions reductions. These interactions can be complex, but are nevertheless extremely important for designing and implementing performance standards.

In addition to introducing flexible performance standards, provincial and federal governments should continue to fund research and development of low-carbon transportation technologies. This will help complement a pan-Canadian carbon price and flexible performance standards by bridging the gaps between discovering, testing, and scaling up new technologies that are currently too costly for private firms to pursue or deploy.

Considering the smaller environmental footprint of next-generation biofuels, and their potential for bigger GHG emissions reductions, next-generation biofuels may be a worthwhile candidate for continued R&D support. Yet the transition to a low-carbon transportation sector will likely involve many different emerging technologies. Government support for R&D should therefore be aimed across the spectrum of emerging transportation technologies, rather than just at next-generation biofuels.

CONTENTS

1 INTRODUCTION

Canadian governments have implemented a range of policies to support the production and consumption of biofuels. These policies—including production subsidies and renewable fuel mandates—were intended to reduce greenhouse gas (GHG) emissions, increase rural economic opportunities, improve air quality, and accelerate the development of next-generation biofuels (Environment Canada, 2010; Government of Ontario, 2006; NRCan, 2014). The extent to which these policies have achieved these ambitious objectives, and at what cost, is the focus of this report. We assess the economic and environmental case for Canadian biofuel policies and explore potential opportunities for shifting toward new policies that better fit the current policy context.

Biofuels have been used to power cars and trucks for more than a century. But only in the last few decades have biofuels—primarily ethanol and biodiesel—been viewed as a source of economic and environmental benefit. Ethanol and biodiesel are made from renewable biomass, and can be used in most internal combustion engines when mixed with petroleum fuels.

Since the mid-2000s, Canadian governments have implemented policies that boosted the production and use of biofuels. These policies include production subsidies, tax credits and exemptions, grants and low-interest loans, and renewable fuel mandates. Some of these programs and policies have expired or are about to do so, but a number of important policies remain in place today.

Government biofuel policies were designed to support both sides of the market: they supported Canadian supply through production subsidies and ensured minimum levels of consumer demand through renewable fuel mandates. Together, these policies assisted nearly all stages of the biofuel supply chain—from the research lab to the fuel pump—and were designed to achieve diverse, and sometimes competing, policy objectives.

This report looks both backwards and forward. Looking at past performance, to what extent have biofuel policies achieved these varied objectives? And to what extent have these policies been cost-effective? Looking to the future, to what extent do new, emerging carbon pricing policies reduce the need for biofuel policies in Canada? If carbon pricing alone is insufficient to achieve governments' emissions reduction targets, is the current mix of policies the most effective and cost-effective approach moving forward?

Four main findings emerge from our analysis.

First, Canadian biofuel policies have reduced GHG emissions, but have done so at a high cost relative to other policy options, such as carbon pricing. Even the much deeper emissions reductions that Canada requires over time could be achieved at lower costs than what is possible with current biofuel policies. Further, our assessment of these policies is quite sensitive to estimates of life-cycle emissions: less optimistic estimates suggest they achieve fewer emissions reductions at even higher average costs.

Second, biofuel policies have had mixed success in achieving other objectives. Alternative policies aimed specifically at each objective are more likely to succeed.

Third, the multiple objectives underpinning biofuel policies can sometimes compete. Emerging next-generation biofuels based on non-crop feedstocks, for example, might have the potential to reduce more GHG emissions, but also have limited benefits for farmers and rural areas. Yet existing policies may actually disadvantage these new biofuel technologies relative to conventional, crop-based biofuels. International trade also poses a potential conflict in objectives: importing biofuels might drive more emissions reductions at lower cost, but provides smaller economic gains for Canadian biofuel producers.

Fourth, Canada now has an opportunity to correct its policy course toward more cost-effective approaches. Policymakers have new information on the costs and effectiveness of biofuel policies based on years of evidence and experience. New approaches can draw on lessons from both domestic and international experience. They could customize new policy approaches to align with today's policy context, explicitly considering how policies can best complement the emerging pan-Canadian pattern of carbon prices.

As a result of these findings, this report argues that provincial and federal governments should seize this opportunity to change course on biofuel policy. It recommends that production subsidies for biofuels should be terminated, as initially planned, and that renewable fuel mandates should be phased out. As part of this policy transition, the report encourages provincial and federal governments to continue developing a pan-Canadian carbon price with steadily increasing stringency, and to complement the carbon price for several years with flexible performance standards for transportation.

If implemented, these changes will provide stronger incentives for reducing emissions, and at a lower cost than existing policies. The extent to which biofuels are produced and used in this new policy environment will depend on how their life-cycle GHG emissions compare with those for petroleum fuels, and also on how they compare in terms of cost with emerging low-carbon fuel and vehicle technologies.

The remainder of this report is organized as follows: Section 2 provides an overview of biofuels and biofuel policies in Canada. It describes the policy context in which biofuel policies were first implemented, as well as how the context has changed over time. Section 3 assesses biofuel policies in terms of how well they have reduced GHGs, including the costs of these reductions. It finds that biofuel policies represent an expensive approach to GHG policy relative to alternatives. Section 4 assesses the extent to which biofuel policies have achieved other major policy objectives, including economic development, improved air quality, and development of next-generation biofuels. It finds little compelling evidence that biofuel policies have achieved these objectives. Section 5 discusses the new policy context in Canada and considers how alternative approaches might complement provincial carbon pricing policies. Finally, Section 6 concludes with our recommendations.

2 BIOFUELS AND ASSOCIATED POLICIES

This section provides an overview of biofuels and biofuel policies in Canada. It sets the stage for our assessment of these policies and the options moving forward. Our focus is on biofuel economics and policy. While we do not delve deeply into the science and engineering of biofuel production, we summarize some of the fundamentals in Box 1.

Box 1: A Primer on Biofuels

Although *liquid biofuels* can refer to any liquid fuel made from renewable biomass, ethanol and biodiesel are the main biofuels used for transportation in Canada. Ethanol is blended with gasoline; biodiesel is blended with diesel.

Ethanol

- Nearly all ethanol produced in Canada is *first-generation* (i.e., made from agricultural feedstocks) (USDA, 2015). Corn is the primary feedstock for producing ethanol in Ontario and Quebec, while wheat is the primary feedstock in Western Canada.
- *Next-generation* ethanol can be produced from a range of non-food feedstocks, such as wood waste, perennial grasses, algae, or even solid waste. But producing next-generation ethanol is significantly more complex and expensive compared with first-generation ethanol (Hughes et al., 2010).
- Ethanol, whether first- or next-generation, contains roughly two-thirds of the energy of gasoline, meaning that ethanol typically offers lower vehicle mileage than gasoline in existing vehicle fleets (Knoll et al., 2009; Larsen et al., 2009; NRCan, 2013).
- Most vehicles can use ethanol blends of only 10% to 15%. Unless cars are specifically made for higher blends of ethanol-gasoline such as E85 (called flex-fuel vehicles), high concentrations of ethanol can cause internal damage to cars, particularly for older models (Larsen et al., 2009).

Box 1 continued

Biodiesel

- *First-generation* biodiesel is produced using feedstocks such as vegetable oils (e.g., soybeans or canola), recycled grease, or animal fats. Approximately 55% of biodiesel feedstocks in Canada are from canola crops, with the remaining 45% derived from tallow (animal fats) and recycled grease (USDA, 2015).
- The technology to produce first-generation biodiesel is well established (called transesterification). Biodiesel can be safely blended with diesel fuel in ratios between 5% and 20% and used in most vehicles without requiring modifications (USEIA, 2016a), but can have limited application in colder climates because of gelling.
- *Next-generation* biodiesel can be produced using a range of feedstocks and technological processes; however, the most common type is "renewable diesel." This can be made from the same feedstocks as first-generation biodiesel, but uses a different refining process (called hydrotreating) that gives it a similar molecular composition to petroleum diesel. Renewable diesel can be used in regular diesel engines at blend ratios as high as 100% (USEIA, 2016b). Canada does not currently produce renewable diesel, but does import this fuel from other countries.

2.1 THE ECONOMICS OF BIOFUELS

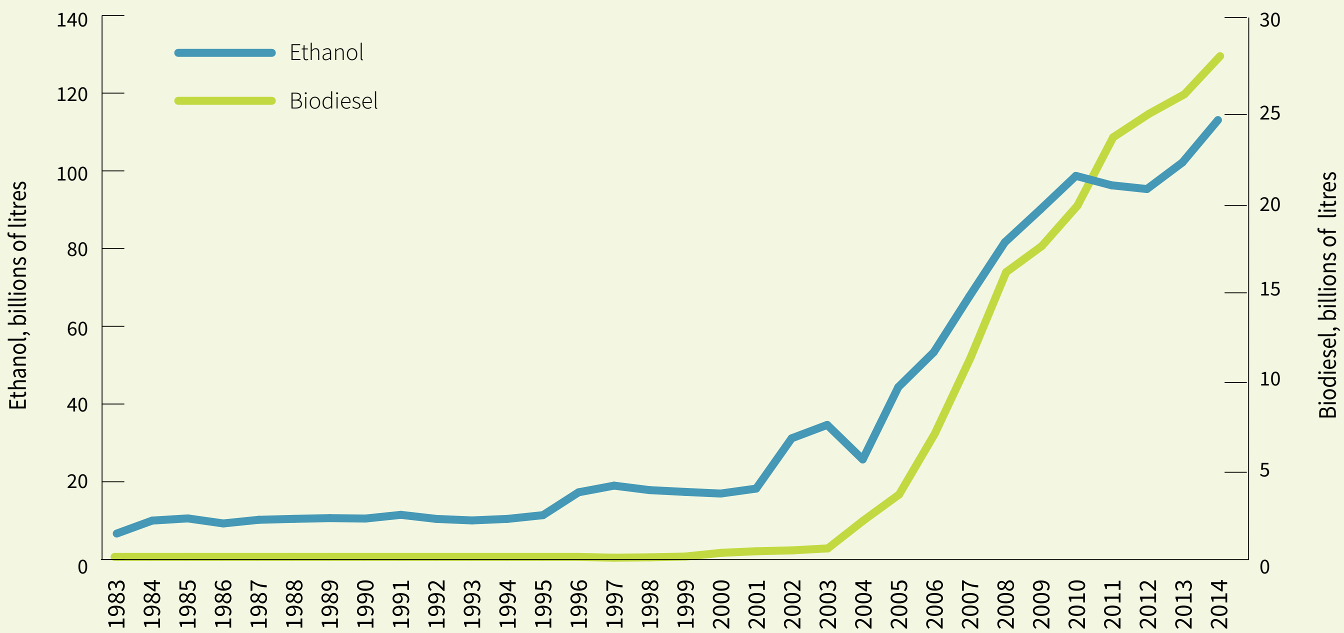
Where does Canada currently stand in terms of biofuel production, and what are the associated costs? This section provides an overview of the current state of the biofuel markets and, in particular, the industry in Canada.

Global production of biofuels has grown rapidly, but still accounts for a small share of transportation fuel

The major oil price shocks in the 1970s sent a price signal to find cheaper and domestically produced alternatives to petroleum. Since these shocks, a nascent biofuels industry has taken root across North and South America, Europe, and parts of Asia. Levels of research and development, often tied with government support, were relatively modest during the 1980s and 1990s, resulting in small volumes of global biofuels production. During the 1983–2000 period, biodiesel production volumes remained close to zero, while ethanol production volumes increased from 10 billion to 20 billion litres (see Figure 1).

The early 2000s marked a significant shift in policy and saw a dramatic increase in the production and use of biofuels. Aggressive government policies were implemented in several countries, such as the United States, Brazil, France, and Germany, and included a wide range of support policies—including production subsidies and renewable fuel mandates. As Figure 1 illustrates, the increase in global production closely followed the introduction of expansive government policy during the early 2000s.

Figure 1: Global Biofuels Production, 1983–2014



The global production of ethanol and biodiesel increased sharply with the introduction of government policies in the early 2000s. The volume of ethanol production is roughly four to five times larger than biodiesel primarily because blending mandates for ethanol are typically larger than for biodiesel, and also due to the relatively high production costs of biodiesel.

Source: OECD–FAO, 2016.

Despite the rapid growth of biofuels production early this century, these fuels account for only a small share of total transport fuels—approximately 2% in 2012 (IEA, 2014).[1] Petroleum-based fuels still account for roughly 93% of total transport fuels (IEA, 2014), a share that has been relatively constant for several decades. (The remaining 5% of transportation fuels consist of electricity and natural gas.) The United States, Brazil, the European Union, and Indonesia are among the biggest biofuel producers in the world.

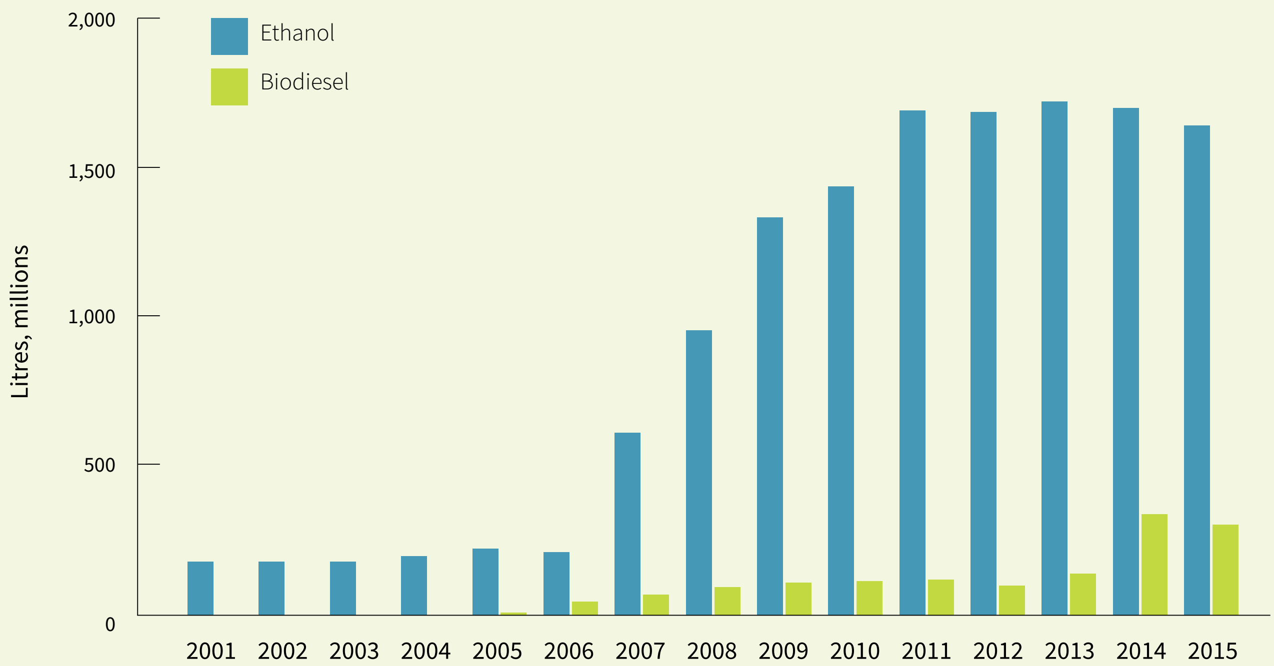
Canada is a small player in the global biofuels market

Within the global market for biofuels, Canada is a relatively small producer and is a net importer. Canada produced roughly 1.7 billion litres of ethanol and 0.3 billion litres of biodiesel in 2014, which together represented 2% of world production (REN21, 2015).

As illustrated in Figure 2, production levels of biofuels, particularly ethanol, increased rapidly from 2006 to 2011, which corresponded with a period of aggressive support from federal and provincial governments. Many of the government policies for biodiesel lagged behind those for ethanol, which helps explain why growth in biodiesel production occurred later. Since 2011, production levels of ethanol have plateaued, while the production of biodiesel nearly doubled in 2013-14 due to the opening of a new facility in Alberta, with an annual capacity of 265 million litres of canola-based biodiesel (Pratt, 2014).

[1] Expressed in energy-equivalent units. Since biofuels contain less energy per litre than do fossil fuels, a greater volume is required to produce the same amount of energy.

Figure 2: Canadian Production of Ethanol and Biodiesel, 2001–2015



Ethanol production increased rapidly over the 2006–2011 period, whereas production of biodiesel increased later. Ethanol production is significantly larger than biodiesel production for several reasons: (1) diesel consumption is roughly two-thirds of gasoline consumption, providing a larger market for ethanol blending; (2) renewable fuel mandates are higher for ethanol (5% to 8.5%) than for biodiesel (2% to 4%); and (3) biodiesel is more expensive to produce than ethanol and petroleum fuels. Note that one of the only sources of publicly available data on Canadian biofuels is from the U.S. government.

Sources: USDA (2006, 2015); USEIA (2016c).

Despite the recent growth of biodiesel production, overall levels of biofuel production are expected to remain relatively flat in the short to medium term, largely because the major government policies and programs have ended or are scheduled to end in 2017-18 (IEA, 2016; USDA, 2015). We return to the future outlook of the industry in Section 5.

Compared with other biofuel-producing countries, Canada has relatively high production costs for ethanol and biodiesel (AAFC, 2011). Crops grown in Canada offer lower feedstock yields compared with those in tropical countries such as Brazil, Indonesia, and Malaysia, where higher-yield crops, including sugarcane and palm oil, are grown (Worldwatch Institute, 2007; IEA–ETSAP & IRENA, 2013). Nearly all feedstocks used to produce ethanol in Canada are starch crops, which require higher amounts of energy to process than sugarcane ethanol. Other costs, such as labour and land, may also be higher in Canada than in other countries.

In terms of market structure, the biofuels industry is relatively diffuse with many small and local producers that claim biofuels as their sole business (Laan et al., 2011). Aside from some firms that may benefit from being a single biofuel producer in a geographic region, there appears to be a competitive North American market for biofuels—reflected by extensive cross-border trade between the

Box 2: A Snapshot of the Canadian Biofuels Industry

Ethanol

- 15 ethanol producers with a total annual capacity of roughly 1,800 million litres; most plants operate at or near capacity (USDA, 2015).
- Roughly 60% of ethanol production capacity is located in Ontario.
- Top 5 producers, by production capacity: Greenfield (27%), Suncor (24%), Husky (16%), IGPC Ethanol (10%), Terra Grain Fuels (9%).
- The industry has consolidated over the past decade, and there is some degree of integration between the ethanol and petroleum industries.

Biodiesel

- 14 biodiesel producers with a total annual capacity of roughly 740 million litres.
- Facilities operated at an average of 61% of total capacity from 2007 to 2015 (USDA, 2015).
- Over 80% of biodiesel production capacity is located in Ontario and Alberta.
- Top 5 producers, by 2015 production capacity: Archer Daniels Midland (33%), Atlantic Biodiesel (21%), Biox Canada Ltd. (8%), Methes Energies Canada (7%), Rothsay Biodiesel (6%).
- Future growth of the biodiesel industry may be constrained by scarce and expensive feedstock (USDA, 2015).

United States and Canada and small price differentials between the two countries.[2] Compared with the fossil fuel industry, the biofuels industry in Canada is less concentrated and less vertically integrated, and relies on petroleum producers to purchase and blend biofuels at retail fuel stations. See Box 2 for a snapshot of the biofuel industry in Canada.

Production costs for biofuels are typically higher than for petroleum fuels

The cost of producing biofuels is highly dependent on the feedstock type, processing inputs, soil quality, crop yield, labour, and region (De Gorter et al., 2014; Worldwatch Institute, 2007). But when all production costs are considered (in the absence of government support), ethanol and biodiesel are typically more expensive to produce than petroleum fuels on a per litre basis. The one exception to this is sugarcane ethanol (produced primarily in Brazil), which can be produced at a lower cost, owing to the higher yields from sugarcane crops and lower processing costs (IEA, 2013).

Table 1 illustrates the wide range in production costs for each type of fuel when all factors of production are considered, and also demonstrates how production costs respond to changes in crude oil prices. These production costs include costs of feedstock, energy and other input, capital, fuel storage and refuelling, operating and maintenance, and fuel transport (IEA, 2013); these costs do not include taxes or subsidies.

[2] This is based on comparing the Canadian (wholesale) price of biofuels with prices from several key U.S. biofuel-producing states. Generally, the price of biofuels is slightly higher in Canada, which may be due to higher transportation costs.

Table 1: Production Costs of Fuels per 100 km at Different Crude Oil Prices

Fuel Type	Production Costs (for driving 100 km, in $US)		Increase in Cost From Higher Oil Price
	$60/bbl	$150/bbl	
Gasoline	$6.05	$15.13	150%
Corn Ethanol	$9.78	$17.75	81%
Sugarcane Ethanol	$6.91	$14.01	103%
Lignocellulosic Ethanol	$11.82	$29.43	149%
Diesel	$5.63	$14.06	150%
Canola Biodiesel	$10.40	$21.49	107%

This table shows the costs of producing the volume of fuel required to drive 100 kilometres (normalizing by distance allows for comparison between gasoline and diesel replacements). Production costs of biofuels are usually higher than for gasoline and diesel in the IEA's current technology scenario, with the exception of sugarcane ethanol (typically produced in Brazil). Because biofuel production requires varying amounts of fossil fuels for farming and processing feedstocks, production costs rise with oil prices, but by less than the increase in costs for gasoline and diesel.

Source: Adapted from IEA (2013).

Because of the high production costs, combining biofuel production with other value-added products is becoming more common. Such facilities are called biorefineries, which can produce a wide range of co-products, most notably dried distiller grains from ethanol plants and glycerine from biodiesel plants. Producing and selling these co-products can help diversify revenue streams and make the industry less vulnerable to changes in the price of oil (Canadian Renewable Fuel Association, 2015). The gains from selling these co-products are incorporated in the cost estimates in Table 1.

2.2 BIOFUEL POLICIES IN CANADA

We define *biofuel policies* as government measures providing economic or financial support to the production or consumption of biofuels. These range from renewable fuel mandates (which require minimum amounts of biofuels to be blended with petroleum fuels), production subsidies, interest-free loans, and research grants. Similar to the definition used by the OECD, we include all policies that (1) keep consumer prices below market levels, (2) keep producer prices above market levels, or (3) reduce costs for both producers and consumers by providing direct or indirect support (OECD, 2006).

Canadian governments have had multiple motivations for implementing biofuel policies (Environment Canada, 2010; Government of Ontario, 2006; NRCan, 2014). Producing and consuming more biofuels could generate social and economic benefits through reducing GHGs, provide new opportunities for rural communities, reduce air pollution, and encourage the development of a domestic biofuels industry. We examine in sections 3 and 4 the extent to which these objectives have been achieved.

Biofuel policies in Canada have targeted both supply and demand

Canadian governments have supported the biofuels industry since the 1980s. Federal and provincial governments have implemented various policies that (1) specifically encourage domestic production capacity and (2) increase the overall market demand from consumers (Campbell et al., 2016). Table 2 illustrates the various ways support has been provided.

Most supply-side biofuel policies have ended or are scheduled to end soon

Production subsidies—one of the biggest support mechanisms—are scheduled to end in 2017-18 at both the federal and provincial levels. These subsidies were introduced by the federal government and five provinces in the mid-2000s and replaced the exemption of biofuels from fuel taxes. Their purpose was to directly support *domestic* biofuel production, unlike fuel-tax exemptions that also benefited importers. The goal was to generate enough domestically produced biofuel to meet the demand stimulated by the renewable fuel mandates (Campbell et al., 2016).

Table 2: Types of Biofuel Policies Used in Canada

	Target of Policy	Policy Instrument	Examples
Supply-Side Measures	**Research and Development** Support the development of new biofuel technologies	Low-interest loans, research grants, research partnerships	**Federal:** Sustainable Development Technology Canada is one of the biggest sources of R&D support for biofuels in Canada. The SD Tech Fund, for example, has allocated $915 million, though not exclusively to biofuels (from 2001 to 2021).
			Provincial: The Alberta Biorefining Commercialization and Market Development Program provided funding for early development project costs. From 2007 to 2009, it allocated more than $16 million to ethanol and biodiesel projects.
	Demonstration and	Low-interest loans, capital/research grants	**Federal:** The NextGen Biofuels Fund provides financial assistance to biofuel companies that are near the demonstration and commercialization phase of development. The approved federal contribution is $500 million over the 2007–2027 period.
			Provincial: The BC Bioenergy Network helps fund research, development, demonstration, and deployment of new bioenergy technologies that could be applied in British Columbia. The provincial government made a one-time contribution of $25 million.
	Production Encourage domestic production of biofuels	Excise tax concessions, import tariffs, tax exemptions, production subsidies, feedstock subsidies, market price support	**Federal:** The ecoEnergy Program provides volume-based subsidies to biofuel producers. The program runs from 2008 to 2017 and has a multi-year budget of $1.5 billion. Payments started at $0.10 per litre of ethanol and $0.26 per litre of biodiesel, and decline over time.
			Provincial: Five provinces provide production subsidies to biofuel producers. The biggest program is Ontario's Ethanol Growth Fund, which runs from 2005 to 2016 and pays producers up to $0.11 per litre of ethanol.
Demand-Side Measures	**Consumption** Encourage domestic consumption of biofuels	Renewable fuel mandates, low-carbon fuel standards, flex-fuel vehicle requirements	**Federal:** The Renewable Fuel Regulations were implemented in 2010-11 and require that gasoline and diesel contain 5% and 2% renewable fuel content, respectively.
			Provincial: Five provinces implemented renewable fuel mandates between 2005 and 2011, requiring that gasoline and diesel contain between 5% and 8.5%, and 2% and 4% renewable fuel content, respectively. The B.C. government introduced its Low-Carbon Fuel Standard in 2008, which requires a scheduled reduction in GHG emissions per unit of transportation fuel. It is the only standard of its kind in Canada.

Should production subsidies end in 2017-18, some supply-side policies will remain. Funding through government programs or agencies, such as Sustainable Development Technology Canada, will continue to provide upstream support for developing new technologies. Similarly, accelerated depreciation,[3] and import tariffs[4] are also expected to remain in place, but will likely have a small impact on the Canadian production of biofuels.

Demand-side policies will soon represent the biggest form of government support

Assuming the major supply-side subsidies are not extended, renewable fuel mandates will be the largest form of government support for the biofuels industry, post-2018. These mandates require petroleum fuels to be blended with minimum amounts of biofuels, and are an increasingly common tool to encourage the use of biofuels. In total, more than 50 countries have implemented biofuel blending targets or mandates, in addition to similar policies at the sub-national level (IEA, 2011). Renewable fuel mandates in Canada were implemented at the national level and in five provinces. While the mandated blending requirements differ across jurisdictions, each is administered in a similar way.

Table 3 provides an overview of existing fuel mandates in Canada. The federal renewable fuel mandate for gasoline, for example, requires fuel suppliers to blend a minimum of 5% ethanol with gasoline, while the mandate for diesel requires suppliers to blend a minimum of 2% biodiesel with diesel fuel. Some provincial blending mandates have increased over time, and Table 3 lists the most recent changes.

Table 3: Renewable Fuel Mandates in Canada

Jurisdiction	Ethanol Mandate (Year enacted)	Biodiesel Mandate (Year enacted)
Canada	5% (2010)	2% (2011)
Ontario	5% (2007)	4% by 2017*
Manitoba	8.5% (2008)	2% (2009)
Saskatchewan	7.5% (2007)	2% (2012)
Alberta	5% (2011)	2% (2011)†
British Columbia	5% (2010)	4% (2010)

*The Ontario mandate for biodiesel requires that biodiesels reduce GHGs by a minimum of 70% by 2017. Blending credits are partially based on GHG emissions; biodiesels with higher emission reductions are given more credit (Government of Ontario, 2016a).

†The Alberta policy requires renewable fuels to reduce GHG emissions by at least 25% compared with the equivalent petroleum fuel.

[3] Accelerated depreciation is a tax benefit that allows corporations to receive higher-than-normal returns during the initial years of investment. Laan et al. (2011) note that subsidies from accelerated depreciation were expected to decline in step with the slow-down of new construction of ethanol and biodiesel plants. Most conventional ethanol and biodiesel plants were completed by 2010, therefore reducing the amount claimed under accelerated depreciation allowances.

[4] Canada imposes a tariff of five cents per litre of ethanol on imports from some non-NAFTA countries, including Brazil. The extent to which tariffs discourage imports is unclear; according to Laan et al. (2011), transportation costs are likely a more important import barrier.

Canadian fuel mandates can be met with either domestically produced or imported biofuels. Despite incentives from production subsidies, Canadian facilities have not produced sufficient volumes of biofuels—particularly ethanol—to satisfy federal (and some provincial) fuel mandates. As a result, Canada is a net importer of biofuels.

Some provinces have also implemented supplementary policies to specifically reduce GHG emissions from transportation fuels. Alberta and Ontario require that biofuels reduce emissions by a specified amount in order to count toward compliance with the mandate. Similar policies are used in the United States and the European Union.

In addition to its renewable fuel mandate, British Columbia implemented its Low-Carbon Fuel Standard (LCFS) to complement other biofuel (and transportation) policies. This policy requires fuel suppliers to reduce the average carbon intensity of their fuels over time by a specified amount. Unlike with renewable fuel mandates,

Box 3: The State of Biofuel Policies in Canada

As provincial and federal production subsidies wind down, it is worth examining how Canadian governments plan to move ahead with biofuel policies. Most governments have so far released few concrete details; however, there are some commitments worth mentioning.

Federal: The most recent federal budget (2016-17) does not specifically include any new policies for biofuels. However, the government has earmarked $63 million over 2016-18 for investing in infrastructure for electric vehicles and alternative transportation fuels (Infrastructure Canada, 2016). The federal government has not signalled any changes to its renewable fuel mandates for gasoline and diesel, and has not commented on whether it plans to renew the production subsidies currently scheduled to expire in 2017.

British Columbia: Although the B.C. government has not made any clear policy commitments on biofuels, the Climate Leadership Team, tasked with providing policy advice to the provincial government, made several recommendations in 2015 relevant to biofuels and low-carbon transportation technologies (Climate Leadership Team, 2015). In particular, the team recommended increasing the existing stringency and timeline of the low-carbon fuel standard (from a 10% reduction by 2020 to a 15% reduction by 2030), and creating targets for the sales of light-duty zero-emission vehicles (e.g., 10% by 2020).

Ontario: The province's Ethanol Growth Fund ends in 2016 and has provided nearly $500 million in production support to ethanol producers over its 12-year duration. The Ontario government has not indicated whether the program will expire, as initially planned (Crawley, 2016). More concretely, the government's Climate Action Plan has committed to introducing a new regulation that would require a 5% reduction in life-cycle carbon emissions from gasoline by 2020. The plan also includes $100 to 155 million earmarked for new incentives for fuel retailers to sell more biodiesel and high ethanol blends (Government of Ontario, 2016b).

Quebec: The provincial government is planning to introduce the first zero-emission vehicle standard in Canada (Government of Quebec, 2016). The planned legislation sets a target of having 100,000 registered plug-in vehicles by 2020, and will use a system of tradable permits to encourage producers to maximize the range that electric vehicles can travel on a single charge.

Industry: In addition to these government commitments, industry is actively seeking changes in policy. Renewable Industries Canada (RIC, formerly the Canadian Renewable Fuels Association) recommends that the federal government increase its renewable fuel mandates: from 5% to 10% for ethanol and from 2% to 5% for biodiesel (RIC, 2016). Both RIC and the Advanced Biofuels Canada Association also support the introduction of carbon pricing (RIC, 2016; WCBA, 2015).

fuel suppliers are given the flexibility to comply with the LCFS by using any low-carbon fuel available, not just ethanol or biodiesel. B.C. is currently the only province with an LCFS, which requires a 10% reduction in the carbon intensity of transportation fuels by 2020. This policy was introduced in tandem with its renewable fuel mandate in 2010 and is modelled on a similar policy in California.

Further changes to biofuel policies in Canada may be on the horizon. Box 3 describes potential policy shifts that are not yet fully defined but should also be considered moving forward.

After years of government support, a closer look at biofuel policies is needed

With the exception of Atlantic Canada and the three territories, Canada has introduced a wide array of policies to support the biofuel industry. Although provincial and federal policies differ on the margins, governments have taken a fairly consistent approach to supporting the industry: production subsidies for building a domestic supply of biofuels, and renewable fuel mandates to provide a guaranteed consumer market.

As production subsidies end in 2017-18, we take this opportunity to assess how biofuel policies have performed. The next two sections consider this question by assessing the performance of these policies against the stated policy objectives.

3 ASSESSING BIOFUEL POLICY AS CLIMATE POLICY

Determining whether biofuel policies have achieved their stated objectives is critical for smart policy development; new policy choices should learn from past policy successes and failures. When biofuel support policies were accelerated in the mid-2000s, federal and provincial governments believed biofuels would play a role in meeting emissions-reduction targets, and this henceforth became a core policy objective (Environment Canada, 2010; Government of Ontario, 2006).[5] Biofuel policies were introduced to achieve other policy objectives as well, which we examine in Section 4.

The effectiveness of biofuel policies reflects the extent to which they have reduced GHG emissions. In particular, emissions reductions driven by biofuel policies depend on the extent to which biofuels produce fewer emissions than fossil fuels over their life cycle (from production to combustion). Multiple factors drive these potential reductions, which is why there is a wide range of life-cycle estimates—dependent on the type, feedstock, origin, and land-use impacts of biofuels. See Appendix A for a discussion of how life-cycle emissions of biofuels are estimated.

The evidence that biofuels reduce GHG emissions relative to petroleum fuels is mixed, for two main reasons. First, life-cycle estimates of biofuels have a natural variation due to the many factors that make up each emissions profile: different feedstocks, soil carbon content, co-products, energy inputs, farming emissions, and so forth. Each factor varies by region, facility, and type of biofuel. Ethanol produced from a plant in Ontario, for example, will have a different emissions profile from ethanol produced from a plant in Alberta. Second, estimates of emissions reductions vary according to the different methodologies across different life-cycle assessment (LCA) models (IEA, 2013; Mullins et al., 2011; National Research Council, 2011; Holland et al., 2015). Different methodological choices can lead to different outcomes.[6]

[5] Early forecasts by Environment Canada (2010) concluded that provincial and federal policies would result in average annual reductions of approximately 2.5 Mt of GHGs in 2010 and would climb to roughly 3 Mt by 2021. Provincially, the Ontario government estimated that its 5% ethanol mandate would reduce its provincial carbon emissions by 0.8 Mt per year (Government of Ontario, 2005). To help put these numbers in perspective, Canada's total emissions from the transport sector in 2014 were 203 Mt (ECCC, 2016b).

[6] Generally, LCA models are poor at integrating secondary and tertiary emissions impacts, such as indirect land-use changes (McKone et al., 2011). Predicting heterogeneous variables such as production methods, technologies, and practices used by farmers and production facilities, along with understanding the different feedstock inputs and co-products, further complicates LCA models (Webb & Coates, 2012). These limitations make LCAs an approximation at best.

Figure 3: Life-cycle CO_2 Emissions of Various Biofuels

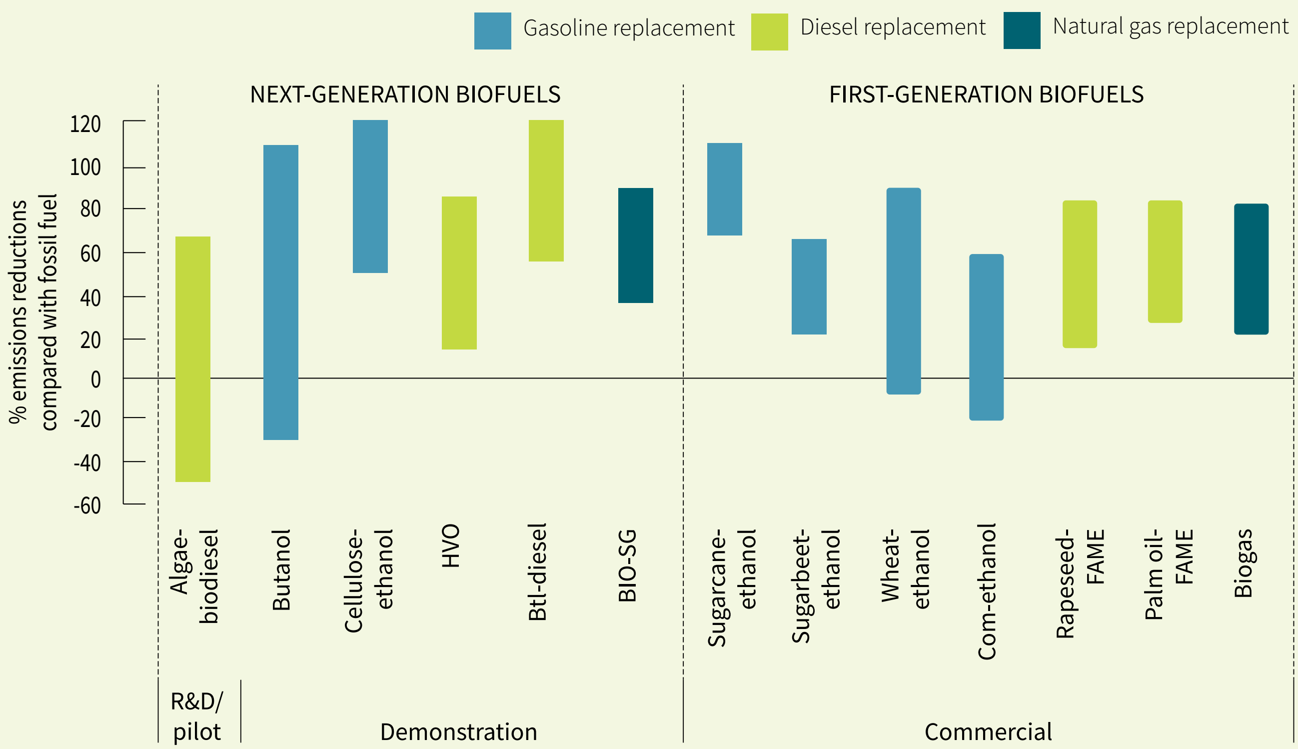


Figure 3 summarizes the GHG reduction potential of ethanol and biodiesels (and excludes indirect land-use emissions). The height of each bar indicates the range of the estimated emissions reduction; the colour of the bar indicates which fossil fuel is replaced. Note that next-generation biofuels can offer greater GHG reductions than first-generation biofuels. As some of these new technologies continue to mature, the ranges of GHG reductions are likely to change.

Source: Adapted from IEA, 2011.

Figure 3 shows the wide range of life-cycle estimates across different types of biofuels. Note that some first-generation biofuels can have carbon intensities greater than those of fossil fuels (so that estimated emissions reductions are actually negative).

In Canada, only one model currently exists to assess life-cycle emissions. GHGenius uses detailed Canadian-specific data to estimate emissions, stated in terms of carbon-intensity values. According to this model, most biofuels have life-cycle carbon intensities that are lower than those of gasoline and diesel, and recent estimates based on GHGenius find that biofuel policies have indeed reduced GHG emissions (ECCC, 2016a; Moorhouse & Wolinetz, 2016; (S&T)[2] Consultants, 2016). These studies typically find that emissions reductions from biofuel policies range between 3.4 and 4.2 Mt per year, and increased over the 2010–2014 period as federal and provincial fuel mandates increased in stringency.

3.1 ANALYTICAL APPROACH

Our core analysis builds upon these recent estimates, using GHGenius as our primary source for carbon-intensity values. Although we use a similar methodology to these previous studies, we conduct our own estimates of GHG emissions reductions to explore and challenge some of the core assumptions made in conventional estimates, and also take the analysis one step further by estimating the costs of government policies. We return to the uncertainty around the life-cycle estimates of biofuels at the end of this section to explore how changing these values significantly affects the overall effectiveness and cost-effectiveness of current Canadian policies.

Our analytical approach employs data from 2010 to 2015 to estimate historical emissions reductions and, more specifically, the GHG reductions that can be attributed to biofuel policies. We then estimate the average costs of these emissions reductions.

To test our approach, we convened a diverse group of biofuel experts and stakeholders in the spring of 2016. We presented our analysis—including the methodology and preliminary results—to this group as a way to solicit feedback on our approach and findings. Our final analysis draws on insights learned from this workshop. See Appendix B for the list of participants.

We estimate GHG emissions with and without policy

To estimate the emissions impacts from biofuel policies, we conceptualize two main cases: The first is a world *without* Canadian biofuel policies (the *counterfactual* scenario), and the second is a world *with* biofuel policies (the *policy* scenario). Establishing these two scenarios allows us to estimate the incremental impact of Canadian policies; the net emissions reduction attributed to policy is the difference between the two scenarios.[7]

Estimating GHG emissions in the policy scenario is relatively straightforward. We start with the actual historical volume of biofuels consumed.[8] We then estimate the GHG emissions for each type of biofuel based on life-cycle carbon intensities (which differ based on feedstock). These carbon intensities come from GHGenius, version 4.03.

Developing the counterfactual scenario, by contrast, requires us to make assumptions about what would have occurred in the absence of the biofuel policies in Canada. We estimate the incremental amount of *petroleum* fuels that would have been consumed in the absence of the policies, and then calculate the corresponding GHG emissions from these additional fuel volumes using the carbon intensities of gasoline and diesel. In other words, we assume that the ethanol or biodiesel that was *actually* consumed would have been replaced with gasoline or diesel fuels if government policies had not been implemented.[9]

The incremental volume of petroleum fuel in the counterfactual scenario is dependent on assumptions about "additionality"—that is, the extent to which biofuel production and consumption increase as a direct result of the policies. In the absence of biofuel policies, would ethanol and biodiesel still have been produced and consumed? If so, then fewer of the emissions reductions from biofuels can be attributed to government policies.

We assume that some ethanol would have been consumed in the absence of government policies. Ethanol improves fuel combustion and is a key additive in gasoline, and wholesale prices of ethanol have historically been competitive with other oxygenates (Irwin & Good, 2016).[10] Note, however, that results were quite insensitive to this assumption; by assuming that all observed ethanol use is because of Canadian biofuel policies, the estimated average yearly emissions reductions increase only slightly.[11]

We estimate both *global* and *Canadian* emissions reductions

Defining the scope, or boundary, of the analysis ultimately determines which GHG emissions are included in our estimates. We consider two different boundaries, and we estimate the GHG emissions impacts from biofuel policies under each case:

Global GHG emissions impacts take into account the total life-cycle emissions from producing biofuels and include the GHG impacts from both domestically produced and imported biofuels. In other words, our use of the term *global* means that we are not concerned with where the emissions impacts from Canadian policies occur—whether they occur in Canada or elsewhere is immaterial. This case is appropriate for identifying the global GHG implications of Canadian policies.

7 This method is commonly used in cost–benefit analysis and is described in the Treasury Board of Canada Secretariat's *Canadian Cost–Benefit Analysis Guide* (2007).

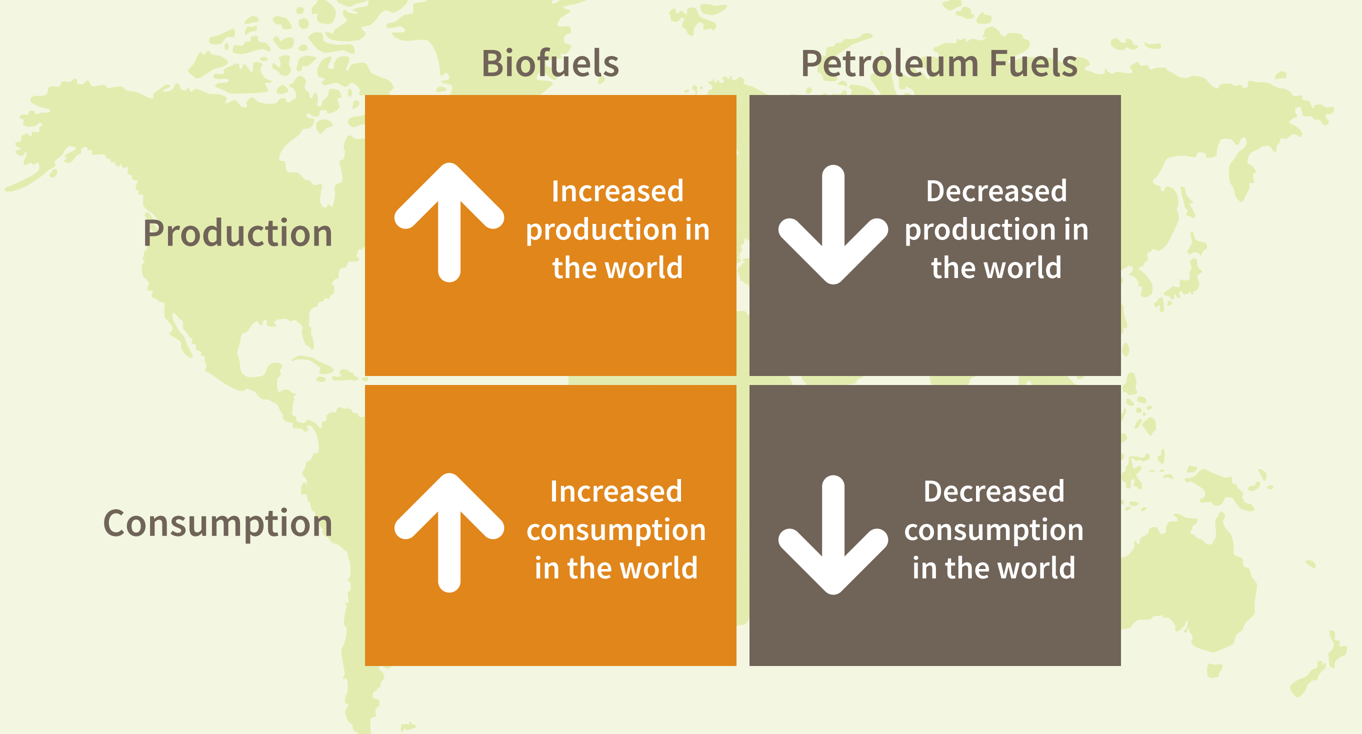
8 We use data from the USDA's annual GAIN report, which contains nation-specific data on biofuels, in addition to data from Statistics Canada on the level of gasoline and diesel consumption in Canada.

9 We convert ethanol and biodiesel volumes into equivalent gasoline and diesel volumes, respectively, by adjusting for the lower fuel efficiency of biofuels. Biofuels, and ethanol in particular, contain less energy than does petroleum, which results in lower fuel efficiency (or lower mileage); but biofuels can also improve fuel combustion, which can help offset their lower energy content. Even when adjusting for improved fuel combustion, research suggests that a greater volume of biofuels is required to drive the same distance than when using petroleum fuels. We assume that ethanol is 26% less fuel-efficient than gasoline, and biodiesel is 6% less fuel-efficient than diesel. These are mid-range estimates based on data from NRCan (2013) and the U.S. National Renewable Energy Laboratory (Knoll et al., 2009).

10 According to historical data (OECD-FAO, 2016), the average ethanol consumption over the 2000–2002 period was approximately 0.6% of Canada's total gasoline consumption, which was during a period before major government support policies were introduced. For the 2010–2015 period of analysis, we use this figure to estimate the volume of ethanol that would have been consumed in the absence of biofuel policies (i.e., the counterfactual scenario).

11 Canada did not produce or consume biodiesel prior to the introduction of government policies, which is why we only consider partial additional for ethanol. For biodiesel, we assume full additionality of government policies.

Figure 4: Global Emissions Reductions From Canadian Policies



Increases in the production and consumption of biofuels in Canada are assumed to represent global increases, and displace an equivalent amount of fossil fuels produced and consumed in Canada or elsewhere.

Canadian GHG emissions impacts examine the life-cycle emissions using the formal rules of national GHG accounting. When we refer to *Canadian* GHG emissions, we are only concerned with the GHG emissions associated with producing or using petroleum and biofuels inside Canada. This case allows us to explore the implications of government policies for federal and provincial emissions-reduction targets.

For both metrics, we assume that any biofuels produced in Canada perfectly displace the production of petroleum fuels globally (on an energy-adjusted basis). In other words, when one unit of biofuel is produced and consumed as a result of Canadian policy, we assume that one energy equivalent unit of petroleum is not produced and consumed in Canada or somewhere else in the world.

3.2 EMISSIONS REDUCTIONS FROM CANADIAN BIOFUEL POLICIES

We estimate both global and Canadian emissions reductions that result from Canadian biofuel policies, and use "tonnes of emissions reduced" as the guiding metric.

Global emissions reductions are relatively straightforward to estimate

We begin with the global framework of emissions reductions, which is the conventional method used in Canada (Moorhouse & Wolinetz, 2016; (S&T)[2] Consultants, 2016). Figure 4 provides a simple way to conceptualize the impact of policy in this framework. Biofuel policies in Canada increase the production and consumption of biofuels in Canada (and globally), with a corresponding decrease in the global levels of petroleum fuel produced and consumed. And because petroleum fuels typically have higher carbon intensities than do

Table 4: Estimated Global Emissions Reductions (Mt CO_2e)

	2010	2011	2012	2013	2014	2015	Annual Average
Ethanol	1.1	1.9	2.3	2.7	2.6	2.4	**2.2**
Biodiesel	0.3	0.7	1.0	1.0	1.0	1.1	**0.8**
Total*	1.4	2.6	3.3	3.7	3.6	3.6	**3.0**

*Totals may not sum due to rounding.

biofuels, their replacement by the latter results in a decrease in overall GHG emissions.

Life-cycle analysis works well for estimating emissions reductions in our global framework. Because the boundary of our analysis is the global energy system, and because we assume that biofuels fully displace the energy equivalent of petroleum fuels, the net impact is simply the difference between the life-cycle emissions from the displaced petroleum and those from the biofuels. For example, if the life-cycle emissions from 1 GJ of gasoline are 90 kg (CO_2e) and those from an equivalent amount of ethanol are 50 kg, the net GHG reduction from using 1 GJ of ethanol (instead of gasoline) is 40 kg CO_2e.

Based on this framework, Table 4 shows the estimated global emissions reductions from Canadian biofuel policies.

For both ethanol and biodiesel, global emissions reductions grow over time. This increase reflects the rising volumes of biofuels produced and consumed in Canada over the six-year period. On average, ethanol policies reduced global GHG emissions by 2.2 Mt per year, while biodiesel policies reduced global emissions by 0.8 Mt per year.

Despite using different data sources and slightly different methodologies, our estimated emissions reductions are only slightly lower than those of Clean Energy Canada (Moorhouse & Wolinetz, 2016), (S&T)² Consultants (2016), and Environment and Climate Change Canada (ECCC, 2016a). On average, Clean Energy Canada estimates that biofuel policies reduced GHG emissions by 2.3 Mt in 2010 and by 4.3 Mt in 2014. Similarly, (S&T)² Consultants estimates a total reduction of 3.8 Mt in 2012 and roughly 4.2 Mt per year from 2013 to 2015.[12] The evaluation by ECCC, which estimates the emissions reductions from the federal renewable fuel mandates for the 2011-12 period, finds a reduction of 7 Mt over the two years.

Much of the convergence of our estimates and those of others can be attributed to using carbon-intensity values from GHGenius for petroleum fuels and biofuels. Building on this alignment, however, we can also consider the implications of alternative assumptions not considered in other studies, as we discuss below.

Domestic emissions reductions are more complicated to estimate

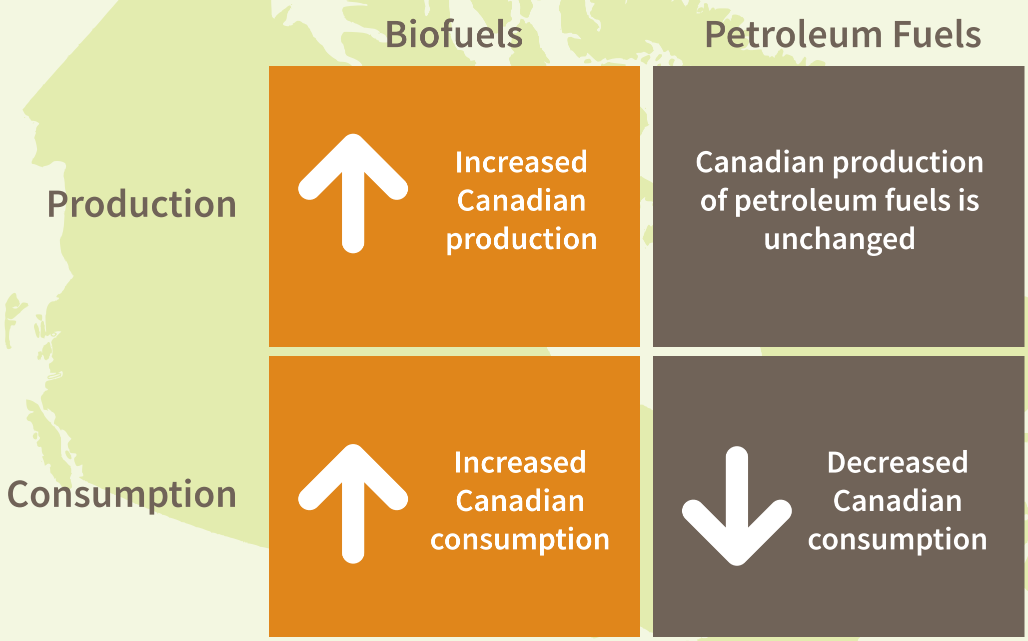
We now narrow the scope of our analysis to include only the emissions reductions that occur within Canada. Figure 5 highlights key assumptions for this case.

Two differences emerge between global and Canadian emissions reductions; both are rooted in international trade. Because the system boundary is Canada rather than the world, trade in biofuels and petroleum products in and out of the system affects the emissions reductions that can be attributed to Canadian policies.

First, the domestic framework assumes that *Canadian* fossil fuel production is unaffected by domestic biofuel policies. Because Canada is a price-taker in both biofuels and petroleum markets, changes in the demand and supply of Canadian fuels caused by domestic biofuel policies are unlikely to affect global fuel prices. And

[12] Discrepancies between our results and those from other organizations are due partly to differences in biofuel consumption data, but mostly to differences in assumptions regarding *additionality*. Unlike the other analyses, ours assumes that some ethanol would have been consumed in Canada even in the absence of Canadian biofuel policies.

Figure 5: Domestic Emissions Reductions From Canadian Policies



When we estimate Canadian emissions reductions resulting from Canadian biofuel policies, it is assumed that the upstream production of petroleum fuels in Canada is unchanged, but that Canadian consumption is displaced.

with unchanged world prices, Canadian producers are assumed to leave their petroleum output unchanged.

To operationalize this assumption, we consider more than just the changes in life-cycle carbon emissions between biofuels and petroleum fuels. The use of biofuels clearly displaces the *consumption* of gasoline and diesel and the associated GHG emissions, but it does not displace the emissions associated with the *production* of petroleum fuels in Canada.[13] By assuming that Canadian levels of upstream petroleum production are unaffected by Canadian biofuel policies, the total emissions in the counterfactual scenario becomes smaller, which reduces the overall emissions reductions attributed to biofuel policies.[14] In other words, considering only Canadian emissions reductions leads to estimates showing government policies to be less effective.

Second, the GHG emissions associated with the growing, production, and transportation of *imported* biofuels are not included in our estimate of Canadian emissions reductions. In practical terms, the life-cycle emissions from a unit of biofuels cross the geographic boundary of our analysis: a fuel might be manufactured in the United States but consumed in Canada. International rules for GHG accounting attribute life-cycle emissions associated with biofuels to the country in which the biofuels were produced (IPCC, 2006). In other words, the emissions associated with imported biofuels, which increase over the 2010–2015 period, do not count toward Canada's total GHG emissions.

13 Combustion emissions of petroleum fuels represent approximately two-thirds of the total life-cycle emissions from gasoline and diesel. The remainder are emissions from mining, processing, upgrading, and transporting petroleum fuels.

14 Just as we are only measuring GHG emissions associated with biofuels produced in Canada, we are also only concerned with the portion of petroleum fuels that are produced in Canada and refined into gasoline and diesel.

Table 5: Estimated Canadian Emissions Reductions (Mt CO_2e)

	2010	2011	2012	2013	2014	2015	Annual Average
Ethanol	0.5	1.5	2.3	2.8	2.8	2.5	**2.1**
Biodiesel	0.3	0.7	1.2	1.5	1.4	1.3	**1.1**
Total*	0.9	2.2	3.5	4.3	4.1	3.8	**3.1**

*Totals may not sum due to rounding.

In this domestic framework, these two effects—no displacement of upstream petroleum emissions and the exclusion of import emissions—pull in opposite directions. Importing biofuels has the effect of lowering the emissions in the policy case, which works to *increase* Canadian emissions reductions relative to the global reductions framework. But we also assume that upstream production of petroleum in Canada is unaffected (i.e., no upstream displacement), which *dampens* domestic emissions reductions. Which effect dominates depends on the importance of imported biofuels relative to total Canadian consumption.

Table 5 shows our estimates of Canadian emissions reductions. Comparing domestic and global emissions reductions for ethanol and biodiesel highlights these two effects. Canadian emissions reductions were, on average, 2.1 Mt per year—roughly 0.1 Mt *lower* than the average global emissions reductions. In contrast, domestic emissions reductions for biodiesel were 1.1 Mt per year—roughly 0.3 Mt *higher* than the average global emissions reductions. This difference reflects trade flows: from 2010 to 2015, 96% of biodiesel used in Canada was imported, but only 30% of ethanol used in Canada was imported (see Appendix C for details).

The results in Table 5 also illustrate how the two new assumptions interact. In 2010, for example, Canadian imports were relatively small. This allows the displacement assumption, which has the effect of increasing emissions, to dominate any of the benefits from imported biofuels. As a result, the estimated emissions reductions in 2010 are considerably smaller for the domestic case than for the global one. As imports increase over time, however, so do the associated benefits, thus making the estimated domestic emissions reductions closer to (and in some cases larger than) the global ones.

Summary: Canadian biofuel policies reduced emissions by about 3 Mt per year

We have estimated global and domestic GHG emissions reductions caused by Canadian biofuel policies. In both cases, government policies resulted in emissions reductions; however, the results are dependent on the assumed emissions boundary. Table 6 summarizes the results.

The historical differences between global and Canadian emissions reductions from biofuel policies are relatively small. However, as we discuss later in this report, the difference could become more significant moving forward.

Table 6: Average Annual Emissions Reductions, 2010–2015 (Mt CO_2e)

	Global Emissions Reductions	Domestic Emissions Reductions
Ethanol	2.2	2.1
Biodiesel	0.8	1.1
Total*	**3.0**	**3.1**

*Totals may not sum due to rounding.

Emissions reductions from biodiesel are roughly half those from ethanol, yet biodiesel consumption volumes are only 20% of those for ethanol. Most biodiesels used in Canada have lower emission intensities than ethanol, so if biodiesels were blended in equivalent ratios to ethanol, emissions reductions for biodiesel would be larger. The implication is that the GHG reduction potential of biodiesel is proportionally greater than for ethanol.

To help put our estimates in perspective, Canada's total transportation and agricultural emissions in 2014 were 203 Mt and 59 Mt, respectively (ECCC, 2016b). Emissions reductions from biofuel policies therefore represent, at most, 1.5% of Canada's total transportation emissions and 5.1% of agricultural emissions. Emissions reductions from biofuel policies represent only about 0.4% of Canada's total GHG emissions of 732 Mt.

We may overestimate emissions reductions by excluding indirect land-use impacts

Growing biofuel feedstocks can cause a range of land-use emissions, some of which are not included in our analysis. Land-use impacts are commonly categorized as either direct or indirect (National Research Council, 2011; Hertel et al., 2010). *Direct land-use emissions* occur when land is repurposed for biofuel feedstock production or when biofuel crops replace other crops (De La Torre & English, 2015). This may include, for example, the change in emissions from converting grassland into farmland, which releases the previously stored carbon from the grassland into the atmosphere. These direct land-use emissions are integrated in the GHGenius model and are therefore included in our analysis.

Indirect land-use emissions, however, which include the wider impacts that occur beyond the specific piece of land devoted to biofuel feedstock production, are not included in our estimates. In other words, if more farmers grow and sell biofuel feedstocks instead of food and animal feed, this shift indirectly increases the need for farmland elsewhere—increasing the likelihood of converting forests, wetlands, or grasslands into farmland (European Commission, 2012; Plevin et al., 2010).[15] Based on emerging evidence that indirect land-use emissions are positive, the implication is that our estimates could overstate emissions reductions from biofuels.[16] While some research suggests that indirect land-use emissions from Canadian biofuels may be minimal at present, they may become more important in the future should Canada produce more biofuels or increase its biofuel imports (Laan et al, 2011). Some jurisdictions, such as the United States and California, have already integrated indirect land-use estimations into their overall analysis of GHG implications from biofuels production and use (Khanna et al., 2016). We explore these U.S. estimates in greater detail later in this section.

3.3 COST-EFFECTIVENESS OF CANADIAN BIOFUEL POLICIES

The estimates in the previous section reveal the effectiveness of current biofuel policies in reducing GHG emissions. But how costly are these emissions reductions? And how do these costs compare with those for emissions reductions available through alternative policies? This is a critical component to understanding the economic and environmental case for using biofuels to replace fossil fuels, and whether it makes economic sense to expand, reform, or remove our current biofuel policies.

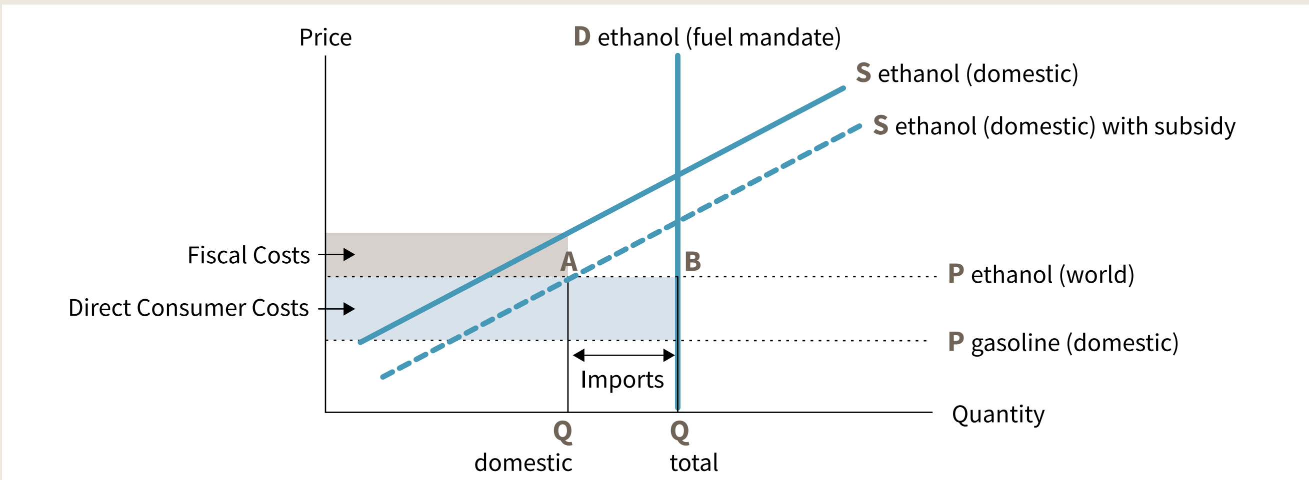
We begin by estimating the costs of biofuel policies, separated into the costs for consumers and those for governments, both of which are illustrated in Box 4. We also consider alternative approaches to defining these costs. Whichever approach we use, however, biofuel policies appear to have a high cost per tonne of emissions reductions relative to alternative policies.

15 GHG emissions from converting virgin land into cropland in Canada were roughly 3 Mt in 2014 (ECCC, 2016b). The extent to which biofuels contributed to these indirect land-use emissions is unknown.

16 Research on indirect land-use emissions has evolved significantly over the past decade, and a growing body of research indicates that indirect land-use emissions can represent a significant proportion of total life-cycle emissions, particularly as the land required for biofuel crops increases over time (Creutzig et al., 2012; Croezen et al., 2010; European Environment Agency Scientific Committee, 2011; Fargione et al., 2008; Hertel et al., 2010; Warner et al., 2013). Published indirect land-use emissions values range between 200% below and up to 1,700% above the carbon-intensity values of fossil fuels (Finkbeiner, 2014).

Box 4: Illustrating the Costs of Biofuel Policies

A simple economic model can illustrate the various costs of biofuel policies. The figure shows the effects of both production subsidies and fuel mandates for ethanol, and illustrates the fiscal costs for governments as well as the costs for consumers. The same basic logic applies to the costs of biodiesel policies.



Demand for ethanol in Canada ($D_{ethanol}$) is fixed by the fuel mandate, and is therefore "price inelastic"—distributors must sell fuel blended with a minimum level of ethanol, and thus demand Q_{Total} from biofuel producers, irrespective of price. Biofuel producers provide ethanol according to their supply curve ($S_{ethanol}$). The production subsidy increases the profitability for Canadian producers, shifting the supply curve to the right.

Canadian biofuel production represents less than 2% of the global total and 4% of North America's total (USEIA, 2016c). As such a small producer, Canada is a price-taker in the North American and global ethanol markets. The relevant price is therefore $P_{ethanol}$ (world), which is determined in the global market but is assumed to be unaffected by Canadian production subsidies.*

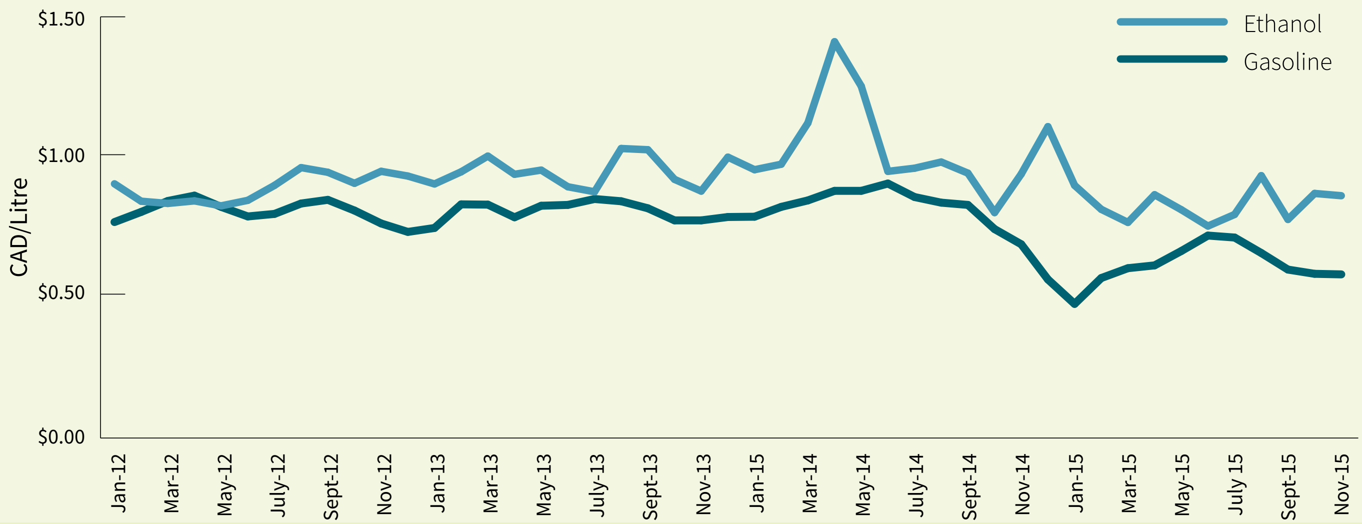
As a result, Canadian producers supply $Q_{domestic}$ of ethanol at point A. Even in the presence of the production subsidies, the domestic supply of ethanol is insufficient to meet the quantity demanded under the fuel mandate at point B. This shortfall is satisfied by imports from other countries.

As the (energy adjusted) price of ethanol is higher than the price of gasoline (as shown in the figure), the consumer costs are equal to the area of the blue rectangle. The height of the rectangle represents the per-litre price differential between gasoline and ethanol, and the length represents the number of litres of ethanol consumed. The fiscal costs for government are shown by the grey rectangle. The height of the rectangle represents the per-litre subsidy given to producers, and the length represents the number of litres of ethanol produced.

The most straightforward estimate of the total cost of Canadian biofuel policies is to add together the consumer costs and the fiscal costs, the areas of the two rectangles in the figure. This is the primary measure used in this report; Appendix D examines a more complex alternative measure.

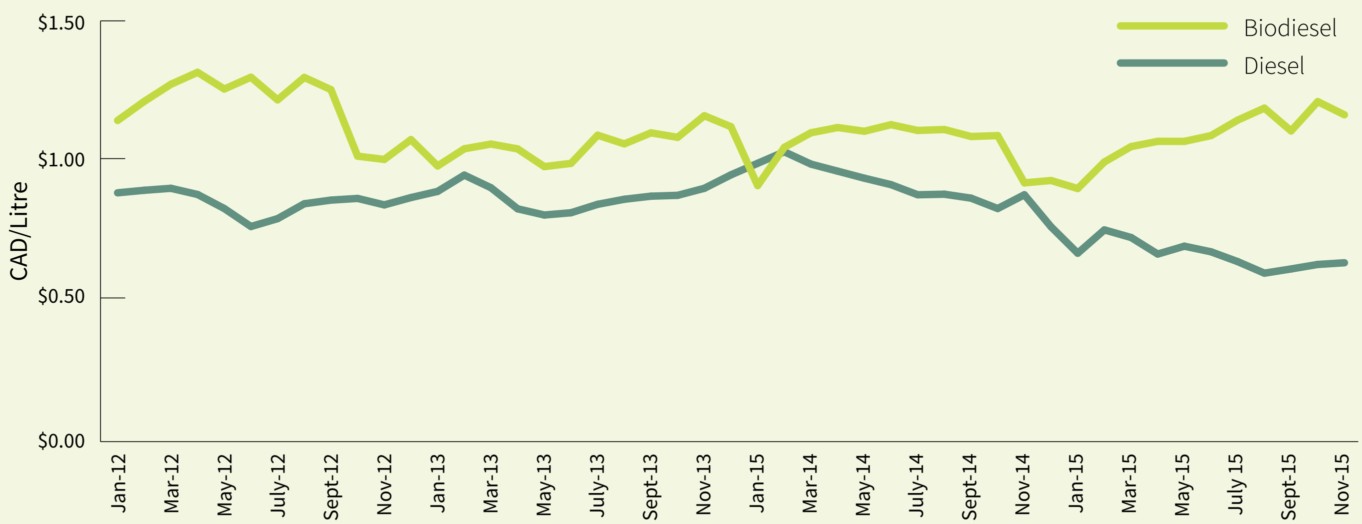
* Even in bigger markets such as the United States, research suggests that consumers do not benefit from supply-side biofuel subsidies. Bielen et al. (2016), for example, identify who benefits from the U.S. Ethanol Tax Credit. They conclude that benefits from the subsidy are captured mostly by ethanol producers, and find no evidence that ethanol subsidies reduce the price of fuel paid by consumers.

Figure 6: Wholesale Prices of Ethanol and Gasoline, 2012–2015



Ethanol prices are adjusted to reflect its lower energy efficiency relative to gasoline. We use an average fuel efficiency value, 74% of gasoline, meaning that we multiply wholesale ethanol prices by 1.35 (= 1/0.74). Wholesale (unadjusted) prices were provided by Renewable Industries Canada, based on data from Statistics Canada (2016a).

Figure 7: Wholesale Prices of Biodiesel and Diesel, 2012–2015



Biodiesel prices are adjusted to reflect its lower energy efficiency relative to diesel. We use an average fuel efficiency value, 96% of diesel, meaning that we multiplied wholesale biodiesel prices by 1.04 (= 1/0.96). Wholesale (unadjusted) prices were provided by Renewable Industries Canada, based on data from Statistics Canada (2016a).

Table 7: Estimated Consumer Costs of Biofuel Policies ($ Millions)

	2012	2013	2014	2015
Ethanol	$146	$277	$449	$399
Biodiesel	$148	$97	$71	$208

Biofuel policies generate costs for consumers

The first cost we estimate is associated with the higher prices paid by consumers at the pump. In the absence of data on retail prices, we use wholesale prices of ethanol and biodiesel, which have historically been higher than the wholesale prices of gasoline and diesel (adjusted for fuel efficiency). Renewable fuel mandates, which require consumers to purchase blended ethanol and biodiesel—regardless of its price—can therefore result in net costs for consumers.[17] Figures 6 and 7 illustrate the average price differentials between fuel types over the 2012–2015 period.[18]

To estimate consumer costs, we again compare the policy and no-policy (counterfactual) scenarios; the difference between the two cases provides an estimate of the net impact of the policy. For our policy scenario, we estimate what consumers actually paid for fuel, based on the historical consumption of petroleum and biofuels, multiplied by the wholesale price of each fuel. The counterfactual scenario, by contrast, estimates what consumers would have paid in the absence of government policy. As with our emissions-reduction estimates, we assume that gasoline and diesel would have been consumed instead of ethanol and biodiesel in the absence of the biofuel policies.[19] Estimated consumer costs for 2012–2015 are shown in Table 7.

Total consumer costs from ethanol policies over the 2012–2015 period were approximately $1.3 billion and increased over time. This cost is due to the difference in the wholesale prices of gasoline and ethanol: average wholesale gasoline prices remained roughly stable, while average ethanol prices increased slightly, including two significant price spikes in 2014. This change in relative prices resulted in increased costs for consumers.[20]

The total consumer costs from biodiesel policies were more than $500 million over the 2012–2015 period. The drop in consumer costs during 2013 to 2014 is attributed to a decrease in biodiesel prices, while the substantial decline in wholesale diesel prices largely explains the large jump in costs in 2015.

Biofuel policies also have fiscal costs for governments

The second cost we estimate is the fiscal cost associated with the federal and provincial policies supporting the biofuels industry. For these estimates, we only consider production subsidies—the explicit payments made to companies based on their production levels. While governments have used other fiscal instruments to support the biofuels industry, production subsidies represent the bulk of the fiscal outlays over the 2012–2015 period (as many of the other support programs ended before 2012). Indeed, the fiscal costs for biofuel policies were much higher prior to the time period of our analysis. See Box 5 for cost estimates during this earlier period.

To calculate fiscal costs, we use annual government expenditure estimates at the federal and provincial levels. In some cases, where government estimates are not publicly available, we estimate annual fiscal costs by using a combination of payments schedules, lists of participant facilities, and production levels. Provinces without production subsidies are not included, such as British Columbia and Atlantic Canada.

17 We make the assumption that higher wholesale prices for biofuels (relative to fossil fuels, energy adjusted) lead to higher retail prices paid by consumers. Although the degree of "pass-through" may not be complete in the short run, research suggests that higher costs for petroleum refiners/distributors are eventually passed onto consumers (Chacra, 2002; Competition Bureau of Canada, 2005; ECCC, 2011). Increased retail prices may create only a small cost for the average consumer, but across millions of consumers they can amount to significant aggregate costs. Any costs not passed on to higher retail prices would be borne by fuel distributors.

18 Price data for biofuels is only available from 2012 onward. As a result, although our GHG emissions estimates are for the 2010–2015 period, our cost and cost-effectiveness estimates are limited to the 2012–2015 period.

19 Again, we assume that some ethanol would have been consumed even in the absence of the policy, given ethanol can assist combustion. For biodiesel, which lacks such advantages, we assume that none would have been consumed in the absence of the policies. As with the emissions-reduction analysis, these assumptions do not materially affect our cost estimates.

20 Due to limitations in data, some secondary costs and benefits are not included in the analysis. For example, evidence from the National Renewable Energy Laboratory (2008) suggests that blending ethanol with gasoline could increase the overall yield of finished gasoline, putting downward pressure on pump prices (assuming these cost-savings are passed onto consumers). The analysis also excludes costs that may not be reflected in wholesale prices, such as higher operating and maintenance costs, and higher transportation costs to industry from the renewable fuel mandates (Environment Canada, 2010). The interaction between these competing effects and their impact on pump prices requires further study.

Box 5: Historical Estimates of the Fiscal Costs of Biofuel Policies

Considering the wide scope of government support, estimating the total fiscal cost of Canadian biofuel policies is challenging.

Different policies are administered by different departments, and across federal and provincial governments. Despite these challenges, the International Institute for Sustainable Development conducted one of the most comprehensive analyses of biofuel subsidies in Canada (Laan et al., 2011). The institute's estimates of fiscal costs are summarized in the table below; the ranges shown reflect varying assumptions used in its analyses. Costs for the 2006–2008 period are historical estimates, while the costs for the 2009–2012 period are projections.

Estimated fiscal costs of provincial and federal biofuel policies ($ millions)

		2006	2007	2008	2009	2010	2011	2012
Ethanol	Low	$167	$241	$305	$163	$154	$134	$93
	High	$179	$272	$366	$462	$458	$460	$379
Biodiesel	Low	$31	$46	$73	$57	$97	$94	$ 64
	High	$31	$72	$100	$104	$153	$174	$137

The fiscal costs for ethanol subsidies peaked in 2009, at $163 million to $462 million, and the costs of biodiesel policies peaked in 2011, at $94 million to $174 million. The extent of government support then decreased over the subsequent years.

Table 8: Estimated Fiscal Costs of Canadian Production Subsidies ($ Millions)[22]				
	2012	2013	2014	2015
Ethanol	$200	$171	$155	$81
Biodiesel	$46	$41	$39	$32

As Table 8 shows, the total fiscal costs of federal and provincial ethanol subsidies are approximately $607 million over the 2012–2015 period, while the costs of biodiesel subsidies are $158 million. Annual fiscal costs for both fuels decrease over time, due primarily to the declining payment schedules of the federal government's EcoEnergy program for ethanol and biodiesel.[21] Of note, payments to the majority of recipients of the EcoEnergy program ended in March of 2015, which explains the substantial drop in fiscal costs from 2014 to 2015 (NRCan, 2016a).

Emissions reductions from biofuel policies are costly relative to other policies

One way of considering total costs is to add the fiscal and consumer costs, as suggested in Box 4. Table 9 provides this sum over the 2012–2015 period. As we discuss below, and also in Appendix D, there are alternative ways to consider total costs. The total costs shown in Table 9, however, are most comparable to the estimated costs of abatement under alternative policies.

We can consider the cost-effectiveness of biofuel policies by comparing the costs per tonne of GHG reduced against other policies. Table 10 shows the per-tonne cost of emissions reductions from biofuel policies for both global and domestic emissions reductions. These figures are simply the ratio of the costs from Table 9 to the emissions reductions from Table 6 (figures are rounded).

Table 9: Estimated Total Costs of Biofuel Policies ($ Millions)				
	2012	2013	2014	2015
Ethanol	$346	$448	$604	$479
Biodiesel	$194	$138	$110	$240

Table 10: Per-Tonne Cost of Emissions Reductions From Biofuel Policies						
	Fuel Type	2012	2013	2014	2015	Annual Average
Global Emissions Reductions	Ethanol	$147	$168	$230	$196	**$185**
	Biodiesel	$201	$132	$112	$214	**$165**
Domestic Emissions Reductions	Ethanol	$153	$159	$218	$191	**$180**
	Biodiesel	$160	$93	$80	$178	**$128**

[21] With the exception of those in Manitoba, provincial programs provide fixed rates for biofuels production.
[22] Note that fiscal costs are expressed in terms of fiscal years, while consumer costs and GHG emissions are expressed in calendar years.

A higher per-tonne cost of reducing GHG emissions reflects a less cost-effective policy. But how costly is too costly? There are different ways to view these numbers, but all of them suggest that biofuel policies are a relatively high-cost way to reduce GHG emissions.

One benchmark of the cost-effectiveness of biofuel policies is to use the *social cost of carbon* (SCC). The SCC is an estimate of the social damages caused by an additional tonne of GHG emissions. Emissions reductions that cost less than the SCC are economically sensible, as they improve overall social well-being.

According to Environment and Climate Change Canada (2016c), the central estimated value of the SCC in 2016 is $41/tonne—which is roughly one-third (or less) of the cost of reducing emissions through biofuel policies. Only if we use the high-risk, low-probability estimates of the SCC, at $167 per tonne (ECCC, 2016c), do biofuel policies begin to look cost-effective. But this still only tells part of the story.

We can also compare the costs of emissions reductions from biofuel policies with those from alternative policies. Economy-wide carbon pricing policies create financial incentives to implement all reductions costing less than the carbon price. Carbon pricing is cost-effective precisely because this incentive is consistent across all emissions. The carbon tax in British Columbia, for example, has reduced emissions by an estimated 5% to 15%, with a carbon price of $30/tonne (Murray & Rivers, 2015). The average cost of these emissions reductions is therefore less than $30, far less than our estimated per-tonne cost from biofuel policies.

The costs of biofuel policies are high even when we consider that carbon prices must eventually increase to drive deeper emissions reductions. Modelling by Jaccard (2016), for example, finds that for Canada to meet its 2030 emissions-reduction target, it would require a carbon price starting at $30/tonne in 2017 and increasing to $160/tonne by 2030. Similarly, the IEA (2014) finds that OECD countries would need to adopt a carbon price of $140/tonne by 2040 to avoid a two-degree Celsius increase in average global temperature. Even these ambitious policy scenarios would drive emissions reductions that are less costly than those resulting from current Canadian biofuel policies.

Canada's biofuel policies are costly even if we use a broader concept of cost

Alternatively, we can consider overall costs to the economy through the lens of economic efficiency. This approach considers costs to the economy as a whole. As a result, transfers within the economy can be ignored; production subsidies represent fiscal costs to government, but provide equal financial benefits to the biofuel producers that receive them. These transfers certainly have distributional implications—they transfer money from all taxpayers to a small group of biofuel producers—but total value stays within the economy. With this approach, the net economic cost of biofuel production subsidies is restricted to the costs of raising government funds to finance the subsidies—what economists often call the "excess burden" of taxation. Note that such distortions were excluded from the cost estimates shown above in Table 9.[23]

To estimate these broader economic costs, we use the concept of the *marginal cost of public funds* (MCF), which measures the economic loss associated with raising one additional dollar of tax revenue from a particular source (Dahlby, 2008). (See Appendix D for more details on our method.)

Use of this broader concept of economic cost does not change our central analytical result. The per-tonne economic costs of emissions reductions from biofuel policies are still nearly five times the costs of emissions reductions from a broad-based carbon price, such as British Columbia's carbon tax.

In summary, no matter how costs are calculated, emissions reductions from Canadian biofuel policies appear to be very costly relative to those available from alternative approaches.

3.4 COST-EFFECTIVENESS OF THE FUEL MANDATES SHOULD PRODUCTION SUBSIDIES END

Our analysis so far has looked backwards, considering both production subsidies and renewable fuel mandates. As of 2017-18, however, half of this policy mix is scheduled to end—renewable fuel mandates will be the last major policies in place, and have no planned expiration dates. We now use our analytical approach to consider the implications of phasing out the production subsidies.

Based on forecasts by the IEA (2016) and the USDA (2015), we assume that no new production capacity for either ethanol or biodiesel will be added in the absence of production subsidies. Biofuel blenders, however, will still be required to meet federal and provincial mandates for renewable fuels—meaning that fuel mandates will be met either by existing domestic capacity or imported biofuels.

Once production subsidies have ended, the extent to which existing Canadian biofuels production will be economically viable is uncertain. We consider the full range of this uncertainty with two

[23] The two different methods of exploring the costs of biofuel policies have advantages and disadvantages. The economic cost is inherently more complex and difficult to estimate, but provides a better description of net costs and benefits for society. By comparison, the simpler measure—which sums the consumer and fiscal costs—allows us to benchmark our results against the social cost of carbon. This latter approach also highlights important distributional impacts from government policy.

extreme possibilities: (1) Canadian producers maintain levels of biofuel production and their existing market share, and (2) biofuel mandates are met exclusively with imported biofuels.[24]

Domestic production could remain stable in the absence of production subsidies

At one extreme, we estimate the GHG and cost implications if Canadian producers remained economically viable without supply-side policies and continued to produce at their existing levels. Assuming that domestic production and imports remained unchanged, GHG emissions reductions would be similar to the results from the most recent year in our historical analysis (2015). Total global emissions reductions (from both ethanol and biodiesel policies) would be roughly 3.6 Mt per year; domestic emissions reductions would be roughly 3.8 Mt annually.

In the absence of production subsidies, the policy costs in this scenario would now be exclusively those paid by consumers in the form of higher prices. Future consumer costs would be entirely dependent on the spread between petroleum fuels and biofuels, but if we use the range from our historical analysis over the 2012–2015 period, the costs of global emissions reductions would range between $62 and $171 per tonne for ethanol, and between $72 and $185 per tonne for biodiesel. The costs of domestic emissions reductions would range between $65 and $162 per tonne for ethanol, and between $51 and $155 per tonne for biodiesel.

Alternatively, ending production subsidies might lead to less domestic production

At the other extreme, consider the implications if Canadian biofuel producers could no longer remain competitive with imported biofuels in the absence of Canadian subsidies. In a worst-case scenario, all Canadian production would be replaced with imports. This scenario is perhaps unlikely, but demonstrates the potential impact of sharply decreased domestic output (Campbell et al., 2016). To approximate GHG reductions in this scenario, we again extrapolate from our model by replacing all domestically produced biofuels with imported biofuels.

Using the 2015 levels of production, global emissions reductions would be smaller in this scenario compared with the one in which domestic production is unchanged, because the imported biofuels tend to have higher GHG intensities relative to domestically produced biofuels. Overall, the expected global emissions reductions would be roughly 3.3 Mt per year, which represents fewer total emissions reductions from the previous scenario (3.6 Mt).

Domestic emissions reductions, however, would be higher in this scenario. Under international accounting conventions, consuming imported biofuels contributes zero GHG emissions for Canada. Average emissions reductions would be approximately 5.7 Mt per year, compared with 3.8 Mt per year when Canadian biofuel producers maintain their market share.

Similar to the first scenario, the cost-effectiveness of policy depends on the future spread between petroleum and biofuel prices, and also whether we refer to global or domestic emissions reductions. The costs of global emissions reductions in this scenario would be between $70 and $189 per tonne for ethanol, and between $75 and $194 per tonne for biodiesel. If we consider only domestic reductions, however, the cost-effectiveness of policy improves: between $35 and $95 per tonne for ethanol, and between $53 and $159 per tonne for biodiesel.

Governments may be pressured to renew production subsidies

If Canadian governments do not introduce new biofuel policies, the impact to the Canadian biofuels industry will likely fall somewhere between our two extreme scenarios—some domestic production may be lost to imports, but some Canadian producers will likely remain competitive. This middle-ground outlook is supported by forecasts by the IEA, which predicts that as supply-side support to the industry ends, Canadian ethanol production will decrease by 38% between 2015 and 2021, while biodiesel output is expected to remain stable (IEA, 2016).[25]

Production subsidies were specifically designed to ease producers' ability to satisfy the renewable fuel mandates, raising questions of the extent to which Canadian producers will remain competitive without these support policies (Campbell et al., 2016). This could, at the very least, mean renewed pressures for additional supply-side policies to prevent a decline in domestic production. As we discuss below, any calls for additional policy—especially more targeted biofuel policies—require careful consideration and an awareness of other policy alternatives.

[24] In both the global and domestic frameworks, we assume in our computations that the total demand for transportation fuels remains at 2015 levels. Because the blend mandates are based on total demand for petroleum fuels, more biofuels would be required as total demand for transport fuels increases. But by assuming that demand remains stable at 2015 levels, we can more accurately assess the differences between global and domestic emissions reductions.

[25] Indeed, federal production subsidies ended for the majority of recipient facilities in March of 2015, meaning that many firms are now operating with diminished public support (NRCan, 2016a). Whether Canadian firms can remain competitive in the longer term without production subsidies is currently unclear.

These additional scenarios also highlight a tension between policy objectives. Phasing out the production subsidies improves the cost-effectiveness of the policy in both scenarios, because fiscal costs fall to zero. Even if a policy change leads to increased imports, the costs of emissions reductions decrease. From an emissions-reduction perspective, there is no problem in relying on lower-cost imports rather than domestic production. Eliminating production subsidies may, however, undermine other policy objectives, including supporting rural development, reducing air pollution, and supporting an advanced biofuels industry. We address these other policy objectives shortly.

3.5 SENSITIVITY ANALYSIS

Our main estimates of emissions reductions are based on carbon-intensity values for fuels from the GHGenius model. Despite the robustness of this model, there are good reasons to explore the sensitivity of the estimates to changes in these values. As discussed earlier in this report, carbon-intensity values are highly variable and sensitive to methodological assumptions (Cruetzig et al., 2012; IEA, 2013; Lemoine, 2013; Mullins et al., 2011).

Based on this uncertainty, we explore how using different estimates of each fuel's life-cycle emissions might change our overall conclusions about the effectiveness and cost-effectiveness of Canadian biofuel policies. For this we build on the existing literature that has taken a similar approach. Auld and McKitrick (2014), for example, canvass a number of different estimates of carbon intensities for biofuels (Mullins et al., 2011; National Research Council, 2011; USEPA, 2009; Wang et al., 2007), all of which are higher than the carbon-intensity values from GHGenius for first-generation biofuels—some are even higher than for petroleum fuels. Overall, their work highlights the wide range of GHG estimates of biofuels.

The International Institute for Sustainable Development also reviewed the carbon-intensity values of biofuels from a variety of sources (Laan et al., 2011). It found that, when compared with international estimates, carbon-intensity values used by the GHGenius model often represent a lower bound, thus possibly exaggerating the estimated benefits of biofuels. This conclusion is also supported by Unnasch et al. (2011), who compare the carbon-intensity values of select biofuels across eight different life-cycle assessment models. They find that the GHGenius model indeed produces carbon-intensity values that are lower bounds for soybean biodiesel and wheat and/or corn ethanol.

There are valid reasons why life-cycle emissions estimates for biofuels in Canada may be lower than estimates for biofuels in other countries. One of the primary reasons is that many Canadian biofuel facilities are powered from low-carbon sources, such as hydroelectricity, nuclear, or natural gas. Other important factors include the higher use of manure over nitrogen fertilizers (which are more GHG intensive), the relatively young age (and thus greater efficiency) of Canadian production facilities, and a cooler climate (Laan et al., 2011).

Notwithstanding the possibility that biofuels in Canada may be less carbon intensive than those in other countries, conducting sensitivity analysis on this parameter is important. As GHGenius is the only Canadian model for this kind of analysis, there is a danger of relying too much on a single approach, especially if it embeds unrealistic assumptions.

Another reason to conduct sensitivity analysis of carbon-intensity values is to recognize the significance of indirect land-use emissions. GHGenius currently does not include indirect land-use emissions within its calculations and therefore may underestimate total emissions impacts (Laan et al., 2011). Even if indirect land-use emissions are currently a relatively small factor in Canada (due to the modest size of the biofuels industry), they may become more important over time if biofuel production increases.

We therefore conduct sensitivity analysis on the carbon-intensity values used in the core analysis, above. We draw on carbon-intensity estimates by the California Air Resources Board, some of which are for Canadian biofuel facilities. (See Appendix C for a description of our methods and parameters.)

Table 11 shows how using upper-bound carbon-intensity values drastically changes the estimated effectiveness and cost-effectiveness of Canadian biofuel policies.[26] The clear implication is that biofuel policies are much less effective at reducing GHG emissions and emissions reductions are much more costly on a per-tonne basis if life-cycle carbon intensities are higher than those used in the GHGenius model.

[26] While these new carbon-intensity values are all higher than those used in our main estimates, the increase in carbon intensities is not uniform across ethanol and biodiesel. Generally, the increase in carbon intensities for biodiesels is much greater than the increase in carbon intensities for ethanol. This explains why the costs of biodiesel policies increase by a much wider margin than the costs of ethanol policies.

Table 11: Estimated Effects of Biofuel Policies (With Higher Carbon Intensities)

Emissions Reductions (Mt CO_2e)

	Fuel Type	2010	2011	2012	2013	2014	2015	Average Annual
Global Emissions Reductions	Ethanol	0.8	1.4	1.8	2.0	2.0	1.9	**1.7**
	Biodiesel	0.1	0.2	0.3	0.2	0.2	0.3	**0.2**
Domestic Emissions Reductions	Ethanol	-0.2	0.5	1.3	1.8	1.8	1.6	**1.1**
	Biodiesel	0.1	0.5	1.0	1.2	0.8	0.8	**0.7**

Per-Tonne Cost of Emissions Reductions

	Fuel Type	2012	2013	2014	2015	Average Annual
Global Emissions Reductions	Ethanol	$191	$216	$295	$252	**$238**
	Biodiesel	$630	$554	$450	$749	**$596**
Domestic Emissions Reductions	Ethanol	$263	$243	$330	$300	**$284**
	Biodiesel	$194	$116	$143	$302	**$189**

3.6 SUMMARY

Our main estimates suggest that Canadian biofuel policies have led to average annual emissions reductions of around 3.0 Mt, which represents roughly 1.5% of Canada's total transportation emissions. Our estimates also suggest that these emissions reductions have come at a high cost, with averages of $180 to $185 per tonne for ethanol and $128 to $165 per tonne for biodiesel.

Compared against the social cost of carbon, or the cost of emissions reductions under carbon pricing policies, biofuel policies are a very costly way to reduce GHG emissions. While biodiesel policies may provide more cost-effective emissions reductions compared with ethanol policies, both sets of policies appear costly when set against alternative policy approaches. (Note that our estimates do not cover the 2008–2011 period, when the fiscal costs of government programs were larger than in recent years and GHG emissions reductions were smaller.)

In addition, our main estimates may be a lower bound, as they are based on assumed carbon intensities for biofuels that are much lower than competing estimates. When we use carbon-intensity values from different models, the estimated emissions reductions from biofuel policies drop significantly, while the per-tonne cost of emissions reductions rises sharply. In this case, ethanol policies have an estimated cost of $238 to $284 per tonne, and biodiesel policies have an estimated cost of $189 to $596 per tonne. According to these new estimates, biodiesel policies are not necessarily more cost-effective compared with ethanol policies; in fact, biodiesel policies can be more than twice as expensive.

Moving forward, the planned phase-out of Canadian production subsidies may raise tensions between achieving cost-effective GHG reductions, promoting rural economic development, and encouraging the development of advanced biofuel technologies. Our analysis suggests that governments may face pressure to renew these subsidies to support these other objectives, even though this would result in expensive GHG emissions reductions. We consider the implications of the changing policy landscape for Canadian GHG policy in Section 5.

4 ASSESSING OTHER OBJECTIVES OF BIOFUEL POLICIES

Biofuel policies are clearly expensive as a means of reducing GHG emissions, but they were introduced to achieve other objectives as well. In this section, we focus on three remaining policy objectives: improving economic opportunities for rural communities, reducing air pollution, and accelerating the development of advanced biofuel technologies. We find little compelling evidence that biofuel policies have helped to achieve these other objectives.

4.1 IMPROVING RURAL ECONOMIC OPPORTUNITIES

Improving economic opportunities for rural communities has been an important objective of biofuel policies for provincial and federal governments alike (Le Roy & Klein, 2012). This objective has typically been expressed as supporting farmers and biofuel producers, but also rural communities more generally through the expected benefits of increased economic activity. In addition, distillers and refiners of biofuels, though located primarily in cities, also stand to benefit from policies supporting the production and use of biofuels.

In Canada, nearly all ethanol, and most biodiesel, is made from agricultural crops, thus making a solid link between farmers and the biofuels industry. The federal government implemented the Renewable Fuel Strategy in part to increase revenues and diversify risk for agricultural producers (NRCan, 2016b; USDA, 2015). Some government programs were specifically designed to help integrate the farming and processing components of biofuel production by helping farmers own and operate biofuel refineries (e.g., the federal EcoAgriculture program).

Unlike the GHG reduction objective described in the previous section, which includes specific and clear targets from government, the goal of increasing economic opportunities for rural communities is defined in vague terms. Evaluating whether policy has achieved the stated objective is therefore challenging.

Rural economic benefits from Canadian biofuel policies have been small

Evidence suggests that *global* biofuel policies have been effective in stimulating rural economic development in many countries. Biofuel policies have provided economic benefits to farmers through production subsidies and guaranteed minimum levels of feedstock demand. In addition, fuel mandates, by driving up global demand, have increased world commodity prices for staple grains such as maize and wheat (FAO et al., 2011; USDA, 2014), thus benefiting farmers who grow these crops. These price increases have largely resulted from biofuel policies in jurisdictions large enough to affect global markets, such as the United States, Brazil, and the European Union.[27] There are also important downsides to these global policies; see Box 6 for a discussion of the global impacts of biofuel subsidies, including how these policies create challenging distortions in agricultural markets.

At the same time, evidence suggests that *Canadian* biofuel policies have had limited impacts on Canadian farmers' income (Laan et al., 2011). This is primarily because Canada is a small producer in global agricultural markets, and so domestic biofuel policies are unlikely to affect the world price of agricultural commodities (AAFC, 2011; Le Roy & Klein, 2012). Early forecasts made by Agriculture and Agri-Food Canada suggested that federal biofuel mandates would increase income for the crop sector by only 0.7% (Environment Canada, 2010).

Canadian biofuel policies may help some farmers and biofuel producers, but have other adverse economic impacts

Small impacts on total farm income may also be explained by the fact that increases in the output of biofuel feedstocks may be offset by output declines for other agricultural crops or from other sectors (AAFC, 2011). In particular, the biofuel policies were expected to lead to losses in the livestock sector, owing to increased feed prices (Environment Canada, 2010). Overall, net benefits to the agricultural sector are very small; however, it is important to note that these estimates do not include the benefits of greater certainty that farmers receive through a guaranteed market for some of their crops.

Even if it is accepted that Canadian biofuel policies result in small benefits to biofuel feedstock farmers, analysis by Environment Canada (2010) suggests that the costs of one of the biggest government policies—renewable fuel mandates—exceed their benefits.

Box 6: The Distortionary Impacts From Global Biofuel Policies

Aside from the narrowly defined benefits to farmers who grow biofuel feedstocks, the overall economic impacts from biofuel policies are unclear. Globally, higher commodity prices resulting from biofuel policies mean higher food prices for consumers—with particularly damaging effects in poorer regions of the world (Wright, 2014). The inherent trade-off between using land for food production and fuel production has provoked a global "food versus fuel" debate, highlighting important ethical and moral challenges.

Over 80% of the global food supply is derived from grains (Adusumilli et al., 2016), making any competition between food and fuel calories an important issue. A report by the Food and Agriculture Organization of the United Nations (FAO) et al. (2011) finds that biofuel mandates reduce the amount of total calories available for human consumption, particularly in low-income countries. Similarly, the USDA (2014) argues that, although higher commodity prices are expected to have only a modest impact on food prices in the United States, the incidence of increased prices will likely be higher in low-income countries where some biofuel feedstocks are staple goods.

Any economic gains for farmers from higher crop prices are also partially offset by price impacts on other parts of the supply chain. For example, increased demand for biofuel feedstocks can increase the demand (and price) for other agricultural inputs, such as fertilizers, pesticides, and land (Le Roy & Klein, 2012).

Increases in global commodity prices have been particularly damaging to livestock producers, even in the world's richest countries. Fridfinnson and Rude (2009), for example, find that biofuel policies worldwide resulted in Canadian livestock producers paying an average of 28% more for coarse grain, wheat, and oilseed meal over the 2005–2015 period. While

[27] Higher global prices from international biofuel policies may have also had the effect of decreasing Canadian government support payments to farmers. During the period of aggressive biofuel policies, from 2007 to 2014, net direct transfer payments to Canada's agricultural sector decreased by 67% (Statistics Canada, 2016b).

Box 6 continued

some of these price increases are partially offset by co-products produced at biofuel facilities, research suggests that the overall availability of feed for livestock production is reduced even when co-product gains are taken into account (USDA, 2014). These economic losses to the livestock industry can be significant, albeit difficult to quantify (Grier et al., 2012).

Increases in crop yield over the longer run will undoubtedly play a role in mitigating some of these effects, but productivity gains can only do so much. Some agricultural resources and local ecosystems are already stressed from population growth, increasing demand for protein, and rising rates of urbanization (FAO et al., 2011). Any future increases in the use of first-generation biofuels will likely add to these pressures.

For all these reasons, a study by the OECD (2008) concludes that while biofuel policies generate some isolated benefits to specific groups, they are an inefficient means of supporting rural communities.

Prior to the implementation of the federal fuel mandate for gasoline in 2010, Environment Canada (2010) conducted a cost–benefit analysis of the regulation, estimating the impacts over the 2010–2034 period. It found that the net benefits—exclusively from GHG emissions reductions—would be $560 million, assuming a social cost of carbon of $25 per tonne. The costs of the regulation, however, were nearly four times larger: an estimated $1.9 billion. More than one-third of these costs would be borne by petroleum producers (from making necessary upgrades and modifications for distributing and blending biofuels), while consumers would bear the remaining costs. Environment Canada (2011) conducted a similar analysis for the renewable fuel mandate for diesel fuels, which also concluded that the regulation would have a net cost ($2.4 billion over 25 years on a net present-value basis).

Methodological problems have hampered a full understanding of the direct and indirect economic impacts from biofuel policies. In many cases, Canadian studies use analytical approaches that overestimate the benefits of government policy and understate (or ignore) the wide range of costs (Swenson, 2006; Tombe, 2016).

4.2 Reducing air pollution

The transport sector is one of the largest sources of air pollution in Canada (ECCC, 2016d). Much of this air pollution comes from extracting, refining, and combusting fossil fuels, and poses significant health risks—including respiratory problems, cardiovascular issues, cancer, and premature death (Health Canada, 2010). Exposure to these pollutants, to varying degrees, results in added health-care costs, lower productivity, and reduced well-being.[28]

Some governments have introduced biofuel policies as a means of reducing air pollution. In particular, reducing air pollution has been one of the long-standing objectives of Ontario's ethanol and biodiesel policies (Government of Ontario, 2006, 2016a). Improving air quality is also one of the many objectives of the B.C. Bioenergy Strategy (Government of British Columbia, 2008).

It is not clear that biofuels reduce air pollution

The health impacts from blending petroleum with ethanol and biodiesel depend largely on whether the full life cycle of biofuel production is being considered. If considering only combustion, ethanol and biodiesel typically emit lower rates of criteria air contaminants than do gasoline and diesel, and so reduce the risks to human health (Health Canada, 2012; Knoll et al., 2009). However, when evaluated on a full life-cycle basis, which includes consideration of the air pollutants associated with growing, harvesting, processing, and transporting the ethanol and biodiesel, biofuel policies may actually work to *increase* the emissions of a number of different air pollutants.

Table 12 provides a brief summary of the emissions profile of each biofuel. For some specific air pollutants, the research is still unclear about the overall impact on emissions.

[28] Pollutants include nitrogen dioxide, sulphur dioxide, carbon monoxide, particulate matter, volatile organic compounds, ozone, 1,3-butadiene, benzene, and aldehydes.

Table 12: Air Pollution Impacts From the Production and Combustion of Biofuels

	Air Pollution Impacts
Ethanol	• Health Canada (2010) concludes that a 10% ethanol-gasoline blend, when combusted, results in lower emissions intensities for carbon monoxide, volatile organic compounds, benzene, 1,3-butadiene, and particulate matter than occurs when burning conventional gasoline. However, the study also concludes that ethanol blended with gasoline increases acetaldehyde emissions by 118% to 137%, which is listed as a probable carcinogen by the U.S. EPA (2015). • When the full life-cycle emissions are considered, evidence suggests that conventional biofuels (particularly ethanol derived from corn) may actually increase many air pollutants compared with gasoline (Delucchi, 2006). • Hill et al. (2009) conducted an emissions analysis of corn ethanol in the United States and concludes that corn ethanol, when produced with natural gas or coal-fired electricity, emits several times the amount of nitrogen oxides, particulate matter, sulphur dioxide, and ammonia as gasoline. Even in a favourable scenario where corn ethanol is made with cleaner and more energy-efficient inputs (e.g., reducing fertilizer, increasing crop yield, or improved conversion), the study finds that ethanol still only breaks even with the air pollution emissions of gasoline.
Biodiesel	• Health Canada (2012) conducted an impact analysis for using biodiesel-diesel blends that included a full life-cycle analysis. The study compared 5% and 20% blends of biodiesel-diesel with an ultra-low sulphur diesel. At the point of combustion, the study concludes that B5 and B20 blends reduce levels of carbon monoxide and volatile organic compounds, and increase levels of nitrogen dioxide. • Other studies indicate similar reductions in carbon monoxide, sulphur dioxide, particulate matter, and aromatic and poly-aromatic compounds (McCormick, 2007; Speight & Singh, 2014). However, the upstream production of biodiesel may emit higher levels of air pollutants. The Health Canada (2012) study finds that growing and refining the biodiesel feedstock might emit higher levels of particulate matter, nitrogen dioxide, and volatile organic compounds on a g/GJ and g/km basis compared with conventional diesel.

Low blending levels of biofuels are unlikely to generate significant health benefits

Blending levels of biofuels in petroleum fuels are, on average, between 2% and 7%. As a result, even if using ethanol and biodiesel can offer improvements in air quality, blending levels are currently too small to make a discernible impact (Health Canada, 2010, 2012). More research is ultimately needed in the Canadian context, especially in considering the full life-cycle emissions of biofuels and the associated health impact.

4.3 ACCELERATING THE DEVELOPMENT OF NEW BIOFUEL TECHNOLOGIES

A longer-term objective of Canadian biofuel policies has been to make the transition from first- to next-generation biofuels. Despite their higher production costs, next-generation biofuels generally have a better environmental profile than first-generation biofuels, and are also made from non-food feedstocks, thus avoiding the important trade-off between food and fuel that exists for first-generation biofuels (see Box 6). The federal government made this an explicit priority of the EcoEnergy Program, which aims to "accelerate the commercialization of new biofuel technologies" (NRCan, 2014). Although the current market share of next-generation biofuels is negligible, government policies have played a key role in funding the research and development of new technologies.

Policies were intended to reduce risk and help industry overcome market barriers

Many of the supply-side policies in Canada have been targeted specifically at next-generation biofuels, primarily for research and development (see Table 2). Government programs such as the NextGen Biofuels Fund provide financial and in-kind assistance to help reduce the challenges associated with funding high-risk and capital-intensive technologies.

The hope in providing these support programs is that, eventually, new technologies will be commercialized and compete in the market without government support. If successful, society can benefit from the technological advancements, especially as they spread to other sectors through what economists call "spillovers" (Jaffe et al., 2005). In terms of biofuels and emissions reductions, scaling up new technologies can result in more competitive fuels with lower emissions abatement costs. Such an "infant industry" argument is often used to justify government innovation policies in many sectors of the economy.

The extent to which next-generation biofuels will become available and adopted in the future is unclear. Technical progress has so far been slow, both globally and in Canada; but governments and researchers are optimistic that next-generation biofuels will eventually displace first-generation biofuels. Current forecasts suggest that the lion's share of future growth in the demand for biofuels will come from next-generation biofuels, with first-generation fuels becoming obsolete by about 2040 (IEA, 2011). Like all forecasts, however, this one is sensitive to the development of policies and other factors that affect world energy markets.

Current policies may have slowed the development of next-generation biofuels

Despite significant investments, the development of next-generation biofuels has been very slow.[29] This slow progress is not unique to Canada—worldwide, efforts to expand next-generation biofuels have been inhibited by similar economic and technological barriers (Campbell et al., 2016). Select technologies have been demonstrated on a small scale, such as using wood waste to make ethanol, but next-generation biofuels are still too costly to compete with first-generation biofuels and petroleum fuels. Processing the required feedstocks into biofuels, whether algae or wood waste, is both energy intensive and capital intensive, and involves high technological risk. Moreover, establishing reliable feedstocks for large-scale operation has been a constant challenge (Le Roy & Klein, 2012; Stephen et al., 2011). A recent study estimates that cellulosic ethanol is unlikely to be cost competitive with corn ethanol in Canada until at least 2020 (Stephen et al., 2013).

Although some provincial and federal subsidies specifically target the development of next-generation biofuels, some programs have been slow to distribute funds. The NextGen Biofuels Fund (administered by Sustainable Development Technology Canada) is the biggest targeted support program in Canada for next-generation biofuels. The federal government earmarked $500 million to the fund over the 2007–2027 period; however, the government's actual contribution to the fund has been only $66 million so far (NRCan, 2016c). This low level of funding may reflect a lack of commercially viable opportunities for next-generation biofuels.

Existing renewable fuel mandates may have played an interesting role in the slow development of next-generation biofuels. Almost all fuel mandates in Canada set specific volumes of renewable fuels that must be used, regardless of their carbon intensity. Notable exceptions include the Low Carbon Fuel Standard in British Columbia and Ontario's Greener Diesel Regulation, both of which are based on the emissions content of fuels (Laan et al., 2011). As a result, most renewable fuel mandates inadvertently provide an advantage to the cheaper incumbent fuel types that have a higher carbon footprint—first-generation biofuels. In other words, existing renewable fuel mandates may be "crowding out" the development of next-generation biofuels.

Research on this phenomenon is limited in Canada, but it is beginning to garner attention in the United States. De La Torre Ugarte and English (2015), for example, conclude that current U.S. policies—which are similar to Canadian policies—have provided a dominating incentive to produce crop-based biofuels, which has redirected investment away from next-generation biofuels. A study by the Environmental Working Group similarly argues that U.S. policies have favoured first-generation biofuels at the expense of low-carbon alternative fuels (Cassidy, 2015).

Tensions exist between objectives of rural economic development and driving next-generation biofuels

The objective of accelerating the development of next-generation biofuels may conflict with the objective of supporting rural economic development. If the primary objective is to reduce GHG emissions, then commercializing and deploying next-generation biofuels from wood or waste products is clearly the more effective way to reach this goal (see Appendix A). But if producing more next-generation biofuels means producing less first-generation biofuels, this may undermine whatever benefits might exist for farmers. This potential conflict in objectives has not been acknowledged or addressed by Canadian governments.

[29] One of Canada's first commercial-scale advanced biofuel facilities is located in Edmonton, owned and operated by Enerkem. The facility is designed to turn municipal solid waste into ethanol and has received over $29 million from the Alberta government and the City of Edmonton (City of Edmonton, 2014). Although the facility has a rated capacity of 38 million litres, it has yet to start producing ethanol. Instead, Enerkem has chosen to produce more profitable chemicals, such as methanol and carbon dioxide, owing to the comparatively low price of ethanol (USDA, 2015).

5 A NEW POLICY CONTEXT FOR BIOFUELS IN CANADA

When biofuel policies were accelerated in the mid-2000s, they appeared to provide a practical opportunity to generate benefits for farmers, biofuel producers, and the environment. But today's policy context is markedly different.

First, our information is better today than it was a decade ago. Current evidence suggests that biofuel policies have not performed well against their stated objectives. Section 3 illustrates that biofuel policies do reduce GHG emissions, but do so at a considerably higher cost than what can be achieved with other available policies. Section 4 suggests that none of the other three policy objectives have been clearly met.

The context around biofuel policies is also different, owing to advancements in other policies. Notably, the federal and provincial governments have made progress in implementing various climate policies to reduce GHG emissions. Carbon pricing, for example, is gaining traction across the country. Considering the significant challenges associated with transitioning to a low-carbon economy—and avoiding costly effects of climate change—policies today are focusing on how to generate significant emissions reductions in the most cost-effective manner.

Given this new and emerging policy context, the remainder of this report focuses on the future of biofuel policies as climate policy—the only objective that has seen measurable (albeit costly) success. To what extent are emerging carbon pricing policies a more cost-effective approach to achieving emissions reductions? Or, to what extent might biofuel policies be complementary to a carbon price? This section examines these broader policy questions.

5.1 CARBON PRICING IN CANADA

Canadian governments have taken significant steps to address climate change since biofuel policies were first introduced more than a decade ago. The federal government has committed to reducing economy-wide GHG emissions by 30% below 2005 levels by 2030, and provinces have made similar targets.

Canadian governments are moving forward with carbon pricing

To achieve these targets, Canadian governments have implemented a wide range of policies. Most notably, carbon pricing systems have been adopted in four provinces; taken together, roughly 60% of Canadian GHG emissions will face an explicit carbon price by 2017. Other provinces are also making progress with developing carbon pricing systems. And the federal government has a stated objective of pan-Canadian carbon pricing.

Carbon pricing is a cost-effective approach to emissions reductions

Pricing carbon creates incentives for all emissions-reducing technologies across many sectors of the economy. Because of its breadth and flexibility, carbon pricing is generally the most cost-effective approach to reducing emissions. In terms of achieving

Canada's GHG targets and contributing to global emissions reductions, the source of emissions reductions is immaterial. The overarching objective is to reduce emissions at least-cost—and not just from the transportation sector. Depending on the stringency of different carbon pricing policies, cost-effective emissions reductions may first come from other sectors of the economy. In the presence of a carbon price, biofuels will be used for transportation should they become cost-effective.

In the absence of carbon pricing, alternative policies for emissions reductions might be justified as "second best" alternatives. They might be more costly, but they may be more attractive because of political constraints or because they address a specific market barrier. Yet as Canada begins to transition toward more cost-effective policy, to what extent are these highly targeted biofuel policies still necessary?

5.2 THE ROLE OF COMPLEMENTARY POLICIES

Other policies can complement carbon pricing policies. It is often argued that the transportation sector may be particularly well suited to such policies, though this argument is not necessarily clear-cut (Lade & Lawell, 2015a; Flachsland et al., 2011; Rubin & Leiby, 2013).

The transportation sector may be slow to respond to carbon pricing

Despite the advantages of carbon pricing, this approach does present some challenges. In particular, carbon pricing may drive few short-term emissions reductions in the transportation sector (Rubin & Leiby, 2013). This is due primarily to the paucity of low-carbon alternatives.

Unlike in other areas of the economy where renewable and low-carbon energy have seen significant market penetration, fossil fuels are still the dominant fuel source for transportation, representing 93% of total transport energy (IEA, 2014). Indeed, few low-carbon fuels currently offer the same advantages of petroleum-based fuels—relatively cheap, energy-dense, and highly reliable. These advantages of petroleum fuels make it particularly difficult to adopt low-carbon technologies for heavy-duty transport, such as freight and aviation. Put another way, emissions reductions in transportation appear to be more expensive than in other sectors of the economy (Lutsey & Sperling, 2009; Kopp et al., 2012; Yeh & Sperling, 2010).

The lack of alternatives in transportation may simply reflect the fact that emissions reductions in transportation are difficult and expensive in the short term. Yet, the expectation of a high carbon price in the *future* should provide incentives for innovators to develop and commercialize these kinds of alternatives, whether they are electric vehicles, next-generation biofuels, compressed natural gas engines, or hydrogen fuel cells. Over time, the transportation sector is expected to respond to prices as new technologies emerge and as vehicle stocks turn over.

This slower response might justify complementary policies

If the response in the transportation sector to the carbon price is inadequate to achieve timely emissions reductions, the carbon price may be simply too low. Alternatively, the slow response could be due to other problems or barriers in the market (Brunner et al., 2012; Holland et al., 2009; Twomey, 2012). If so, overcoming these problems through complementary policies can be cost-effective (Gerlagh & van der Zwaan, 2006; Jaffe et al., 2005; Fischer, 2009; Fischer & Newell, 2008). Two specific examples of barriers are worth noting in the context of transportation.

First, road and fuelling infrastructure play a key role in the uncertainty of developing new transportation technologies and their expected payoff. Infrastructure can "lock in" specific technologies for decades, and provides important network benefits and scale economies for specific technologies. Petroleum-based infrastructure is deeply embedded in local, regional, and global transportation networks, which makes it challenging for new technologies to penetrate existing vehicle or fuel markets.[30]

Second, government failures may play a role. If vehicle manufacturers do not have clear expectations as to future carbon prices, they may have a reduced incentive to develop innovative low-carbon vehicles (Brunner et al., 2012). This challenge matters, of course, for all sectors and all sources of emissions. It could, however, prove particularly costly for transportation, given the lack of alternatives and the high carbon prices required to decarbonize the sector. If deep reductions are required in the long term, significant emissions reductions in transportation cannot be avoided.

R&D is critical for deploying low-carbon transportation technologies

In addition to the market barriers specific to the transportation sector, "knowledge spillovers" represent another type of market barrier that can apply to all areas of technological innovation. Knowledge is a public good that can be imitated, or used as an input in developing new technologies by competing firms. These spillovers benefit society as a whole through the dispersion of

[30] This is partly why biofuels are an attractive low-carbon fuel compared with electricity, natural gas, or hydrogen: most of the infrastructure is already compatible.

information and technical advancements, but their presence can also prevent firms from fully investing in the new research that creates the knowledge in the first place (Jaffe et al., 2005; Popp, 2016).

Decisions to invest in research and development hinge on the prospect of innovation and expected returns (Clancy & Moschini, 2015). Developing new technologies can require significant amounts of R&D in order to climb steep learning curves. And while the costs of successful technologies typically decline over time, the benefits of climbing the learning curve are hard for individual firms to capture. If firms cannot capture the full return on their investment, or if the payoff is highly uncertain, too little research is undertaken. The lower level of R&D harms society as a whole.

Given these challenges, public funding that augments private sector investment is often justified to achieve a greater level of research and development (Acemoglu et al., 2016; Gerlagh & van der Zwaan, 2006; Popp, 2016). For the transportation sector in particular, public funding for R&D can help accelerate the discovery, development, and deployment of new, low-carbon technologies (Egenhofer et al., 2016; Moorhouse & Wolinetz, 2016). This support can complement other climate policies (such as carbon pricing or flexible performance standards) by providing lower-cost emissions reductions in the long term.

5.3 FLEXIBLE PERFORMANCE STANDARDS AS COMPLEMENTARY POLICY

Even if additional emissions-reduction policies for transportation can be justified, our analysis in Section 3 suggests that existing biofuel policies in Canada are very costly. Some alternative policies—often called "flexible performance standards"—may be lower-cost approaches to encouraging the development and use of low-carbon fuels and vehicles.

Performance-based regulations can reduce GHG emissions and drive innovation

Flexible performance standards have been implemented in several jurisdictions and can provide direct and continuous incentives to develop and use low-carbon technologies, such as zero-emission vehicles or next-generation biofuels. In general, a flexible performance standard sets an average benchmark for emissions performance that regulated firms (e.g., vehicle manufacturers or fuel suppliers) must meet. The standard increases in stringency over time to ensure deeper emissions reductions and to help drive ongoing technological innovation (Lade & Lawell, 2015a). To ensure flexibility, the regulation also establishes a market: firms that exceed the standard can generate credits and sell them to firms that do not meet the standard.

Two specific types of flexible performance standards could be viable replacements for existing biofuel policies in Canada: vehicle emission standards and low-carbon fuel standards. We assess the advantages and limitations of each policy separately, but they can also be considered together. In either case, the production and uptake of biofuels will depend on how cost-effectively these fuels reduce emissions compared with alternative fuels.

Flexible *vehicle emission standards* can be designed to support emerging technologies, while avoiding being technologically prescriptive. They are similar to existing vehicle efficiency standards, but instead of regulating mileage improvements—which can be met with existing fossil fuel technologies—they directly target vehicle GHG emissions.[31] California's Zero Emission Vehicle (ZEV) and Partial Zero Emission Vehicle (PZEV) standards require an increasing share of manufacturers' fleets to include vehicles that meet two distinct emissions-intensity thresholds.[32] Yet the policy is flexible in terms of the specific technologies (e.g., electric, hybrid-electric, biofuel, hydrogen fuel-cell, compressed natural gas vehicles) that automobile manufacturers produce to comply with the policy. It also includes trading mechanisms to minimize overall costs: some manufacturers can produce more low-carbon vehicles and others can produce fewer.

To drive improvements in transportation fuels, *low-carbon fuel standards* (LCFS) require fuel suppliers to reduce the average carbon intensity of fuels. In British Columbia, for example, the performance standard applies to all transportation fuels—including petroleum, biofuels, hydrogen, electricity, natural gas—and is based on the life-cycle emissions associated with each fuel type. The value of compliance credits is higher for fuels with lower life-cycle emissions intensities, which can be traded among suppliers. This rewards producers that can innovate and deploy low-cost and low-carbon alternatives (Yeh & Sperling, 2010). The LCFS in British Columbia and California each require a 10% reduction in the average carbon intensity of fuels by 2020 (relative to 2010 levels).

[31] Another option is to increase the stringency of existing vehicle efficiency standards for light and heavy-duty vehicles, which require manufacturers' fleets—on average—to meet a given standard for fuel efficiency. Efficiency standards, however, were designed to improve efficiency of vehicles; the mileage thresholds have done little to encourage new and innovative technologies that could replace the internal combustion engine and petroleum fuels.

[32] The California regulations apply to vehicle operating emissions, not life-cycle vehicle emissions. Electric vehicles may therefore be classified as "zero-emission vehicles," even though the electricity required to power the vehicle may come from fossil fuels.

Flexible performance standards can have lower costs than renewable fuel mandates

A comparison between low-carbon fuel standards and renewable fuel mandates is illustrative. Renewable fuel mandates—as they currently exist in Canada—prescribe that producers must blend specific volumes of ethanol and biodiesel to comply with the regulation. Importantly, renewable fuel mandates do not distinguish between high- and low-carbon biofuels. By contrast, low-carbon fuel standards allow producers to choose the fuel type that minimizes their costs while complying with the standard.

Research by Chen et al. (2014) finds that LCFS lead to a higher penetration of low-carbon biofuels and achieves greater emissions reductions than do renewable fuel mandates. In addition, because LCFS encourage all types of low-carbon fuels, and not just crop-based biofuels, they also create fewer distortions in agricultural markets. Similar analysis by Rajagopal et al. (2011) compares the effectiveness of LCFS with other transportation policies—including renewable fuel mandates—and finds that LCFS rank highly for their ability to reduce emissions, minimize consumer costs, and support the development of a low-carbon fuel industry.

Analysis by Holland et al. (2011) provides additional support that LCFS can be less costly than a renewable fuel mandate. Specifically, they model the relative cost-effectiveness of a national renewable fuel mandate, a low-carbon fuel standard, and a cap-and-trade system in the United States. By holding the level of emissions reductions constant across each policy, they find that carbon pricing (through cap-and-trade) is the cheapest emissions-reduction policy (an average cost of $20 per tonne), followed by a low-carbon fuel standard ($49 per tonne). The renewable fuel mandate had the highest average cost of the three policies ($58 per tonne). These findings are supported by Lade and Lawell (2015b), who find that renewable fuel mandates are more costly compared with LCFS because they are unable to differentiate fuels based on their relative carbon intensities.

Compliance data from California's LCFS reinforces the finding that the cost of emissions reductions are lower than what is available from renewable fuel mandates. Credits within the LCFS program started at a price of roughly $17 per tonne in 2012 and increased to $62 per tonne by 2015—reflecting the increasing stringency of the fuel standard over time (CARB, 2016a). These credit prices represent an approximation to the per-tonne costs of emissions reductions.

Performance standards must balance stringency with the potential of future technologies

A key challenge with designing flexible performance standards is determining the appropriate stringency of the benchmark. This requires regulators to forecast the potential and capacity of technology.

On the one hand, regulators run a risk of setting a standard that is not stringent enough if they underestimate how quickly technologies advance. On the other hand, the standard could be unachievable if they overestimate the future capacity of technology, resulting in unacceptably high compliance costs (Bedsworth & Taylor, 2007). While regulations can be amended and flexibility provisions added to ensure the right balance, this can weaken market signals to innovate and deploy new technologies. This is particularly true if flexibility requirements are repeatedly added to help producers comply with a standard that is viewed as too stringent. For more discussion on the design of flexible performance standards, see Lade and Lawell (2015a, 2015b), Lemoine (2013), and Rubin and Leiby (2012).

In California, for example, manufacturers were unable to meet the ZEV standard in the 1990s and required additional flexibility (Bedsworth & Taylor, 2007). As a result, the California Air Resources Board introduced a new vehicle category, called the partial-zero emissions vehicle, and was forced to make subsequent flexibility amendments after a court case in 2003. Similar flexibility amendments were added to California's LCFS in 2015 to help producers comply with the regulation (CARB, 2016b).

In addition to the challenges with setting the right stringency, regulators must also grapple with the relative uncertainty with assigning carbon-intensity values to different technologies. These values ultimately determine the market value of different fuel or vehicle technologies, and can change over time as new information emerges. Having a robust yet flexible approach to this uncertainty is therefore an important component of any performance-based standard (Lemoine, 2013).[33]

[33] Most of the research presented in this report on flexible performance standards comes from empirical evidence from the United States. Undertaking research in the Canadian context is therefore important before moving ahead with implementing flexible performance standards for fuels or vehicles.

5.4 CHALLENGES OF POLICY INTERACTIONS

The extent to which flexible performance standards could complement carbon pricing depends on how different policies interact. Interactions with different carbon pricing policies—as well as other transportation policies—lead to different implications for emissions reductions and the associated costs.

Depending on how a cap-and-trade system is designed, additional policies do not necessarily contribute additional emissions reductions. The LCFS in California, for example, is expected to reduce emissions in the transportation sector by an estimated 35 Mt over the 2016–2020 period. But if transportation emissions were originally included within the California emissions cap, the LCFS would simply drive down the price of emissions permits and lead to increased emissions elsewhere in the economy. In this case, total emissions in California would remain unchanged.

Under a carbon tax, on the other hand, complementary performance standards would lead to additional emissions reductions beyond those generated by the carbon tax (IPCC, 2011). Because a carbon tax does not fix the quantity of emissions reductions, layering additional policies on top of a carbon tax can create greater incentives to reduce emissions. A low-carbon fuel standard or zero-emission vehicle standard, for example, adds an additional (implicit) carbon price to low-carbon technologies, therefore providing a greater incentive for research, development, and deployment of low-carbon technologies (Yeh & Sperling, 2010). But in both cases, as discussed above, vehicle and fuel technologies must be based on their relative carbon content to maximize incentives for new low-carbon innovation.

The lowest-cost carbon policy seeks to create consistent incentives across all emissions, as occurs with an economy-wide carbon price, yet complementary policies can make economic sense if the benefits of learning and innovation are particularly important.

6 SUMMARY AND RECOMMENDATIONS

This report has assessed the economic and environmental case for biofuel policies in Canada. It has examined the extent to which biofuel policies have achieved their multiple stated objectives. In particular, it has taken a closer look at whether biofuels have reduced GHG emissions in a cost-effective way. This report has also compared biofuel policies with other alternatives to reduce GHG emissions, such as carbon pricing and flexible performance standards within the transportation sector.

6.1 SUMMARY

This report has reached four overarching policy conclusions:

Biofuel policies are an expensive way to reduce GHG emissions

Based on our estimates, biofuel policies have indeed reduced GHG emissions. Overall, our analysis suggests that average annual emissions reductions over the 2010–2015 period was roughly 3 Mt. To help put this estimate in perspective, emissions reductions from biofuel policies represent approximately 5.1% of Canada's agricultural emissions, 1.5% of Canada's transportation emissions, or 0.4% of total Canadian GHG emissions.[34]

These emissions reductions have been very costly. Using our estimates of both fiscal and consumer costs, we estimate that the cost of reducing emissions with ethanol policies is approximately $180 to $185 per tonne, and $128 to $165 per tonne with biodiesel policies. Further, these estimates represent a lower bound: if we use less optimistic estimates for the life-cycle carbon-intensity of biofuels, the cost of emissions reductions with ethanol policies increases to $238 to $284 per tonne, while emissions reductions with biodiesel costs $189 to $596 per tonne.

The costs of emissions reductions from these policies are high relative to the social cost of carbon (estimated at $41 per tonne), but also high relative to the costs of emissions reductions expected under carbon pricing (at either today's carbon prices or future higher carbon prices). In terms of the costs to the overall economy, emissions reductions from current Canadian biofuel policies are more than five times larger than those driven by the carbon tax in British Columbia.

Biofuel policies have not achieved other policy objectives

Other potential benefits associated with biofuel policies appear unlikely to justify these high costs. Biofuel policies were initially intended to achieve several objectives in addition to reducing GHG emissions, including creating economic opportunities for rural communities, reducing air pollution, and accelerating the development of next-generation biofuels.

[34] Based on Canada's 2014 emissions inventory (ECCC, 2016b).

Evidence suggests these objectives have not been achieved:

- Biofuel policies may provide small benefits to some Canadian farmers and biofuel producers, but these benefits are offset by adverse impacts on other sectors of the economy, such as the livestock sector. According to the federal government's own cost–benefit analysis, the economic costs of renewable fuel mandates exceed the benefits.
- Increased use of ethanol and biodiesel has had a negligible impact on reducing air pollution. This is due, in part, to the small blending levels of biofuels, but also because some biofuels can actually increase emissions of certain air pollutants.
- Biofuel policies have had little impact on the development of next-generation biofuels. Projections by the IEA (2016) and USDA (2015) suggest that biofuel production and consumption in Canada will remain flat in the short to medium term in the absence of new government policies.

Competing objectives undermine the performance of biofuel policies

Some policy objectives cannot be achieved without undermining others. Emerging next-generation biofuels, for example, are based on non-crop feedstocks and can have the potential for greater environmental benefits; but they may also have smaller benefits for farmers and rural areas. And existing policies may actually create disincentives for developing and deploying these next-generation biofuel technologies. Importing biofuels might drive more emissions reductions at lower cost, but provides smaller economic gains for Canadian biofuel producers. Canadian governments should recognize that the multiple stated objectives of current biofuel policies are in conflict.

An emerging Canadian policy context offers a window for smarter climate policy

Biofuel policies were developed at a time when policymakers believed these policies could deliver on their multiple objectives. A new understanding and new policy context, however, suggest a need—and provide an opportunity—for changing our policy course. Consider four points.

First, as this report shows, we now have a better idea about the modest benefits and relatively large costs of biofuel policies. We conclude that biofuel policies have not performed well against their stated objectives. New policies should take account of what has been learned from this experience.

Second, many of the provincial and federal production subsidies are scheduled to expire in 2017-18, marking an opportunity to adjust policy.

Third, governments are implementing or beginning to implement carbon pricing policies. This policy framework is still emerging across the country, but the prospect of a pan-Canadian carbon price changes the context in a crucial way, especially regarding which complementary policies are best suited to achieve Canada's emissions-reduction targets.

Fourth, flexible and lower-cost alternative policies to support biofuels are emerging. The low-carbon fuel standard in British Columbia and the zero-emission vehicle standard in California are two examples of flexible policies that take advantage of market mechanisms to deliver a lower-cost approach than do existing policies. These policies specifically target reductions in the carbon intensity of vehicles and fuels—providing incentives for low-carbon technologies and disincentives for high-carbon technologies.

6.2 RECOMMENDATIONS

This report makes four recommendations to provincial and federal governments, all with the goal of using climate policies that drive GHG emissions reductions at the lowest cost to consumers, industry, and government. If followed, these recommendations will change incentives and market outcomes. While the recommended adjustment will reduce costs of policy overall, it may increase costs for specific firms and sectors. As a result, throughout the following recommendations, we stress the importance of easing the transition to alternative policies by considering these distributional impacts.

RECOMMENDATION #1: Provincial and federal production subsidies should be terminated, as initially planned.

Canadian biofuel policies were integral to building domestic capacity to meet federal and provincial fuel mandates, but they were an expensive way to achieve emissions reductions. When compared with other policies, especially carbon pricing, biofuels are clearly not the most cost-effective approach to reducing GHG emissions.

Beyond the relatively high costs of production subsidies, basic principles of subsidy design suggest that support be transitional rather than permanent; subsidies should provide support for emerging technologies to help them become competitive without creating a need for ongoing public funding. First-generation biofuels have now received more than two decades of substantial public support. If producing biofuels in Canada still proves uneconomic, there is a clear indication that additional support for the industry is not a good use of public funds.

The transition away from production subsidies will be assisted by the fact that firms benefiting from these subsidies knew from the outset that they would end in 2017-18, and could thus plan accordingly. In fact, the majority of recipients through the federal production subsidy program stopped receiving payments in 2015, so the transition is already well underway.

Nevertheless, as production subsidies come to an end, governments may experience pressure to renew them to ensure the fuel mandates are met with domestic rather than imported biofuels. They should resist this pressure, given the high costs of these subsidies and potential cost advantages in biofuel production in other jurisdictions. If governments seek to support rural economic development, they could explore alternative policies that create fewer undesirable distortions in agricultural markets.

RECOMMENDATION #2:
Provincial and federal governments should phase out renewable fuel mandates.

Renewable fuel mandates will represent the biggest form of government support for biofuel policies once production subsidies end in 2017–18. These policies have been costly for consumers, who pay a premium when filling their tanks at fuelling stations.

Fuel mandates have also inhibited the development of emerging low-carbon technologies, and this has implications for achieving cost-effective emissions reductions. Decarbonizing the transportation sector will surely involve many different and competing technologies; the technologies that prove the most effective and economically viable should win the day. Only through this competition of ideas will the most cost-effective technologies emerge.

Instead of providing equal incentives to any and all emerging technologies, existing renewable fuel mandates only benefit the biofuels sector—a subset of available and potential technologies. In addition, most fuel mandates in Canada do not create incentives for biofuels based on their carbon content. Because higher-carbon biofuels (first-generation) are typically cheaper and more readily available than lower-carbon biofuels, renewable fuel mandates send a weak incentive for next-generation biofuels and no incentive whatsoever for other vehicular or fuel technologies.

Lastly, similar to the reasons for not renewing production subsidies, no targeted support for industry should last forever. Renewable fuel mandates were implemented with no defined cut-off dates, which runs counter to basic principles of prudent government support.

Yet, there is value in having a smooth policy transition. Renewable fuel mandates have provided stable demand for the biofuels industry, a relatively small group of producers and farmers. Some biofuel companies may have been established with the expectation that renewable fuel mandates would continue indefinitely. Policies should therefore be gradually phased out over the span of several years to ensure that industry has sufficient time to adjust. Most importantly, the final two recommendations will help ensure that clear incentives still exist for low-carbon transportation technologies, including biofuels.

RECOMMENDATION #3:
Provincial and federal governments should continue to work toward an increasing pan-Canadian carbon price.

The development of carbon pricing in Canada is changing the landscape for climate policy. Federal and provincial governments continue to work toward achieving a pan-Canadian carbon price, which we argue is the most effective and cost-effective way to achieve Canada's climate targets. Achieving a broad-based carbon price in Canada will shift the incentives for developing and deploying low-carbon technologies. In particular, it will increase the value of technologies—including some biofuels—that can deliver more GHG emissions reductions at a lower cost. The Ecofiscal Commission therefore continues to support Canadian governments in their pursuit of establishing carbon pricing as the best overall policy tool to achieve Canada's climate targets.

RECOMMENDATION #4:
As part of the policy transition, governments should complement carbon pricing with flexible performance standards and broad funding for research and development.

By itself, a pan-Canadian price on carbon may not be enough to meet Canada's emissions-reduction targets. One key factor is market failures that inhibit the development of low-carbon technologies. Such barriers may be particularly relevant for decarbonizing transportation, where few alternatives to fossil fuels exist and where infrastructure can create barriers to the deployment of new technologies.

To make the shift to low-carbon transportation, complementary policies may be required in the short term. Provincial and federal governments should replace renewable fuel mandates with flexible performance standards. Low-carbon fuel standards, for example, can offer a cost-effective approach to transitioning to new technologies—extending incentives beyond biofuels to other low-carbon fuels. Other flexible performance standards, such as zero-emission vehicle standards, should also be considered as valuable complementary policies.

As governments implement broad carbon prices that increase in stringency over time, the flexible performance standards should be gradually phased out. Once a carbon price high enough to generate significant reductions in GHGs is established, the need for these complementary transportation regulations will diminish. The low-carbon fuel standards in both British Columbia and California were implemented over a 10-year period, which may be a satisfactory transition period while the carbon price increases in stringency.

Finally, governments should understand the potential interactions between flexible performance standards and a carbon price. For jurisdictions with a carbon tax, the implications are clear: complementary policies will drive additional emissions reductions. However, jurisdictions with cap-and-trade systems should understand that additional policies will not necessarily lead to additional emissions reductions. These interactions can be complex, but are nevertheless extremely important for designing and implementing performance standards.

In addition to introducing flexible performance standards, provincial and federal governments should continue to fund research and development of low-carbon transportation technologies. This will help complement a pan-Canadian carbon price and flexible performance standards by bridging the gaps between discovering, testing, and scaling up new technologies that are currently too costly for private firms to pursue or deploy.

Considering the smaller environmental footprint of next-generation biofuels, and their potential for bigger GHG emissions reductions, next-generation biofuels may be a worthwhile candidate for continued R&D support. Yet the transition to a low-carbon transportation sector will likely involve many different emerging technologies. Government support for R&D should therefore be aimed across the spectrum of emerging transportation technologies, rather than just at next-generation biofuels.

7 NEXT STEPS

Our discussion of Canadian biofuel policies has underscored a more general issue: What policies best complement a broad, stringent carbon pricing policy? As we have argued previously, a carbon price is only one piece (though the most important one) of a comprehensive policy strategy to reduce GHG emissions. Yet the case of Canada's biofuel policies shows that some policies truly complement carbon pricing, while others only increase costs overall. What differentiates good complementary policies from poor ones? The Ecofiscal Commission will address this question in a future report.

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Appendix A: Emissions Reductions From Biofuels Relative to Fossil Fuels

Liquid biofuels are made from renewable biomass that can be grown domestically from many sources. The carbon dioxide *absorbed* during the growth of the feedstock crop (e.g., corn or soybeans) approximately offsets the carbon dioxide released back into the atmosphere upon combustion (this does not include land-use changes, discussed below). Despite this "carbon neutrality" between absorption and combustion, farming and producing biofuels can be energy intensive with multiple sources of GHG emissions. In particular, crop-based biofuels require vast amounts of agricultural land and fossil fuel-based inputs, such as fertilizers, pesticides, and diesel fuel.

To properly account for the energy and GHG impact of each stage of production, life-cycle analysis (LCA) is commonly used to estimate the total emissions associated with producing and using different fuels. LCA includes the emissions associated with farming, processing, and combusting biofuels, and also any land-use changes to the physical environment (DeCicco, 2013).

Notwithstanding the methodological limitations of LCAs (described in the report), emissions-intensity values can be estimated for both biofuels and petroleum, which represent the carbon emissions associated with producing one unit of fuel (by volume, distance, or energy). If we assume that an energy equivalent amount of biofuel displaces its petroleum substitute, the net GHG impact is simply the difference between the emissions intensities of the biofuel and the petroleum fuel.

Estimating the life-cycle emissions of biofuels involves both sources and sinks. The net effect is highly dependent on site-specific characteristics of growing, harvesting, and processing biofuels. As illustrated in Table A1, the total production process for biofuels must account for many factors, including the feedstock, management conditions, production pathways, end uses, co-products, and interactions between energy and land markets.[35] These variables are also impacted by regional climates and ecological cycles.

Table A1: Life-Cycle Components of Biofuels Production and Use

Production Stage	Energy Use	Energy Creation	GHG Releases	GHG Absorption	Other Environmental Impacts
Direct and Indirect Land-Use Changes	Clearing land and tilling soil		Vegetation removal and soil disturbance		Erosion, loss of biodiversity, water pollution
Growing and Harvesting Feedstock	Fertilizer and pesticide production, farm equipment		Farm equipment emissions, nitrogen release from fertilizer	Feedstocks during growth through photosynthesis	Pesticides and herbicide runoff, soil erosion, water consumption
Processing Feedstock	Equipment fuels		Fuels used in production process	Emissions offsets from co-products	
Transportation to Biofuel Facility	Haulage by truck or rail		Vehicle emissions		
Refining Process	Refinery energy, heat, electricity, production inputs	Co-generation of heat energy	Fuels used in refining process		Liquid waste disposal
Transportation to Blending Process	Haulage by truck or rail		Vehicle emissions		
Fuel Combustion			Vehicle emissions		

Sources: Adapted from Auld (2008) and Laan et al. (2011).

[35] In addition to producing biofuels, facilities also produce many co-products (i.e., products that have their own market value), such as animal feed for corn ethanol and glycerine for biodiesel. These co-products displace other products on the market, which counts as an emissions-reduction credit in LCA accounting.

The potential for biofuels to reduce GHGs has been studied for decades, typically by using the LCA methodology discussed above. The production of biofuels has evolved significantly over time, with gradual reductions in life-cycle emissions for most biofuels.

Overall, the GHG reduction potential of biofuels is highly variable within and across different feedstocks, as shown in Figure 3 in the report. Sugarcane offers the highest GHG reduction potential for first-generation ethanol, and also the smallest range. The GHG reduction potential for corn- and wheat-based ethanol is smaller, but with larger ranges of variability. Net emissions can even be negative for corn and wheat, meaning a net *increase* in GHG emissions. First-generation biodiesels made from waste products (such as recycled grease or animal fats) offer the greatest GHG emissions reductions; however, the availability of these feedstocks can be quite limited (IEA–ETASAP & IRENA, 2013).

Next-generation biofuels can offer greater GHG reductions than can first-generation biofuels. At best, first-generation biofuels reduce GHGs by 60% to 80% when they displace an energy equivalent amount of petroleum fuel, while next-generation biofuels can potentially reduce GHGs by more than 100% (because of the offsets associated with the co-products).

While all these figures sound promising, note that these estimates assume that one unit of biofuel fully displaces one unit of petroleum fuel. In actuality, this rarely occurs, owing to the practical limitations of using biofuels. Most biofuels can only be blended with petroleum fuels at low levels: most vehicles can use ethanol blends of up to 10% to 15% and biodiesel blends of 5% to 20% without modifications (U.S. Department of Energy, 2015). These characteristics therefore constrain the potential GHG reduction estimates shown in Figure 3 in the report.

Appendix B: Attendance for Stakeholder Engagement Session

The following organizations participated in our stakeholder engagement session, held at the University of Ottawa (March 2016). The content, conclusions, and recommendations advanced in this report are those of Canada's Ecofiscal Commission and do not necessarily reflect the views of the organizations. We thank each organization for participating.

Advanced Biofuels Canada
Agriculture and Agri-Food Canada
Canadian Centre for Policy Alternatives
Canadian Renewable Fuels Association
Clean Energy Canada
Conference Board of Canada
Enerkem Inc.
Environment and Climate Change Canada
International Institute for Sustainable Development
Natural Resources Canada
Pembina Institute
Queen's University
Transport Canada
Trottier Energy Futures Project

Appendix C: GHG Emissions Estimation Methodology

Table C1 includes the main dataset used in our estimates of emissions reductions. It includes data on the production (1), imports (2), and consumption (3) of biofuels in Canada (USDA, 2015), along with the sales of petroleum fuels (4) (Statistics Canada, 2016c). This table also includes the estimated amount of biofuels used in our counterfactual case. The amount of ethanol consumed in the absence of government policy (5) is calculated by taking 0.6% of gasoline sales in each year (4). The amount of ethanol that would have been displaced by gasoline in the absence of biofuel policies (6) is calculated by subtracting (5) from (3).

Table C1: Fuel Data Used for Analysis (Million Litres)

	2010	2011	2012	2013	2014	2015
1. Canadian Biofuel Production						
Ethanol	1,445	1,700	1,695	1,730	1,708	1,650
Biodiesel	115	120	100	140	340	305
2. Canadian Biofuel Imports						
Ethanol	11	450	893	1,214	1,200	1,050
Biodiesel	130	235	419	549	508	480
3. Canadian Biofuel Exports[36]						
Ethanol	46	35	0	0	0	0
Biodiesel	110	80	85	123	327	295
4. Canadian Biofuel Consumption (~ Production + Imports - Exports)[37]						
Ethanol	1,390	2,116	2,585	2,943	2,909	2,705
Biodiesel	126	275	449	550	511	500
5. Canadian Fuel Sales						
Ethanol	44,186	44,555	43,065	44,009	45,501	44,698
Biodiesel	28,516	30,030	28,179	29,464	30,464	29,415
6. Volume of Biofuels Produced in Absence of Policies (Counterfactual Case)						
Ethanol	257	260	251	256	265	260
Biodiesel	0	0	0	0	0	0
7. Volume of Biofuels Displaced by Petroleum in Absence of Policies (Counterfactual Case)						
Ethanol	1,133	1,856	2,334	2,687	2,644	2,445
Biodiesel	126	275	449	550	511	500
Sources: USDA (2015); Statistics Canada (2016c).						

[36] Biodiesel trade between Canada and the United States is affected by the U.S. Biodiesel Blenders Credit. This provides blenders with a credit of US $1 per gallon, and is available to Canadian exporters as well. A significant share of Canadian biodiesel is exported to the United States to capture the tax credit, which means Canadian fuel producers must import biodiesel (sometimes in significant volumes) to fulfill the provincial and federal renewable fuel mandates. A portion of these imports into Canada may have been previously exported to the United States but, because of data limitations, the actual amount is unknown.

[37] Estimated biofuel consumption (line 4) is not exactly equal to production plus imports minus exports because of changes in biofuel inventories.

To estimate the breakdown of biofuels by feedstock, we use a combination of data from Moorhouse and Wolinetz (2016) and USDA (2015). The share of feedstock is presented in Table C2, which is held constant across the 2010–2015 period of analysis. Because of limitations in data, the share of feedstocks for biodiesel is based on weight rather than volume.

Table C2: Share of Canadian Biofuel Production, by Feedstock

Biofuel Type and Feedstock	% Used as Feedstock	Source
Ethanol		
Corn	80%	Moorhouse and Wolinetz (2016)
Wheat	20%	
Total	**100%**	
Biodiesel		
Canola	55%	USDA (2015)
Tallow	14%	
Yellow Grease	31%	
Total	**100%**	

Defining the scope, or boundary, of our analysis ultimately determines which GHG emissions are included. As such, whether we use a national or global frame affects the estimated emissions reductions from government policies.

We consider two different boundaries, and we estimate the GHG emissions impacts from biofuel policies under each frame:

- *Global* GHG emissions take into account the total life-cycle emissions from producing biofuels and include the GHG impacts from domestically produced biofuels as well as imports. In other words, our use of the term *global* means that we are not concerned with where the emissions impacts from Canadian policies occur.
- *Canadian* GHG emissions analyze GHG impacts through the formal rules of national GHG accounting. When we refer to Canadian GHG emissions impacts, we are only concerned with the GHG emissions associated with producing or using petroleum and biofuels *inside* Canada.

Table C3 shows the key parameters used to estimate emissions reductions, including the energy content and carbon intensity of each fuel. The key parameters used to estimate Canadian (as opposed to global) reductions require two changes. We no longer include the emissions associated with imported biofuels, and we replace the full life-cycle GHG estimate of gasoline and diesel with only the combustion portion, thus only a fraction of their total life-cycle carbon-intensity values.

Table C3: Energy and Carbon-Intensity Values[38]		
Fuel Type	**For Global Reductions**	**For Domestic Reductions**
Energy (GJ)		
1m³ gasoline	34.7	34.7
1m³ ethanol	23.6	23.6
1m³ diesel	38.7	38.7
1m³ biodiesel	35.6	35.6
GHG Emissions (kgCO_2e)		
1GJ gasoline (CAN)	86.1	64.5 (combustion only)
1GJ ethanol (wheat, CAN)	41.6	41.6
1GJ ethanol (corn, CAN)	49.8	49.8
1GJ ethanol (corn, US)	55.9	–
1GJ diesel (CAN)	95.1	70.0 (combustion only)
1GJ biodiesel (canola, CAN)	3.6	3.6
1GJ biodiesel (soybean, US)	17.4	–
1GJ biodiesel (tallow, CAN)	-20.2	-20.2
1GJ biodiesel (yellow grease, CAN)	4.2	4.2
1GJ renewable diesel (palm, US)	75.3	75.3
Sources: GHGenius (version 4.03); Moorhouse and Wolinetz (2016).		

Our main estimates use carbon-intensity values from GHGenius, which is a comprehensive life-cycle assessment (LCA) model model calibrated for Canadian-specific fuel production. Despite the robustness of the GHGenius model, there are good reasons to explore the sensitivity of the estimates to reasonable changes in the assumed carbon-intensity values. These values ultimately determine the extent to which biofuels can reduce GHG emissions, yet they are highly variable and sensitive to methodological assumptions (IEA, 2013; Mullins et al., 2011; Holland et al., 2011).

To account for this uncertainty, we conduct sensitivity analysis on the carbon-intensity values from Table C3, using estimates by the California Air Resources Board (CARB).

As part of its low-carbon fuel regulation, CARB uses a different LCA model (called GREET)[39] to generate a list of approved pathways for compliance with the fuel standard, with detailed carbon-intensity estimates that are specific to each facility. Unlike GHGenius, the GREET model includes indirect land-use emissions, which helps explain why the CARB carbon-intensity values for biofuels are typically higher than those from GHGenius. For consistency, the

38 The carbon-intensity values for gasoline and diesel are Canadian-specific. These data come from Moorhouse and Wolinetz (2016).

39 The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model is a life-cycle analysis tool used by the Argonne National Laboratory, of the U.S. Department of Energy.

Table C4: Energy and Carbon-Intensity Values for Sensitivity Analysis		
Fuel Type	**For Global Reductions**	**For Domestic Reductions**
Energy (GJ)		
1m³ gasoline	34.7	34.7
1m³ ethanol	23.6	23.6
1m³ diesel	38.7	38.7
1m³ biodiesel	35.6	35.6
GHG Emissions (kgCO_2e)		
1GJ gasoline (CAN)	100.6	64.5 (combustion only)
1GJ ethanol (wheat, CAN)	61.0	61.0
1GJ ethanol (corn, CAN)	78.5	78.5
1GJ ethanol (corn, US)	78.5	78.5
1GJ diesel (CAN)	102.8	70.0 (combustion only)
1GJ biodiesel (canola, CAN)	61.0	61.0
1GJ biodiesel (soybean, US)	88.6	88.6
1GJ biodiesel (tallow, CAN)	46.4	46.4
1GJ biodiesel (yellow grease, CAN)	21.4	21.4
1GJ renewable diesel (palm, US)	90.8	90.8

sensitivity analysis also uses carbon intensities for fossil fuels from the GREET model.

The carbon-intensity values from CARB work well for estimating Canadian biodiesel emissions. Several Canadian biodiesel producers export their fuels to California, and are therefore included in its approved pathways with site-specific carbon-intensity values. So for this, we simply take the average carbon-intensity value for each type of Canadian biodiesel (by feedstock).

Choosing the carbon-intensity values for Canadian ethanol is more challenging. Canadian ethanol producers do not export to California, meaning they are not included in its list of approved pathways. Instead, we use the average carbon intensity of corn ethanol across all U.S. producers and apply this value to Canadian ethanol produced from corn.

We are still, however, left without an estimate for wheat ethanol. The U.S. GREET model does not estimate emissions for wheat ethanol, so instead we use a carbon-intensity estimate of wheat ethanol from a European model (JEC) (Laan et al., 2011). Table C4 provides the carbon-intensity values for ethanol and biodiesel used in our sensitivity analysis, with the modified values shown in bold face.

Appendix D: Calculating the Economic Cost of Emissions Reductions From Biofuel Policies and Carbon Taxes

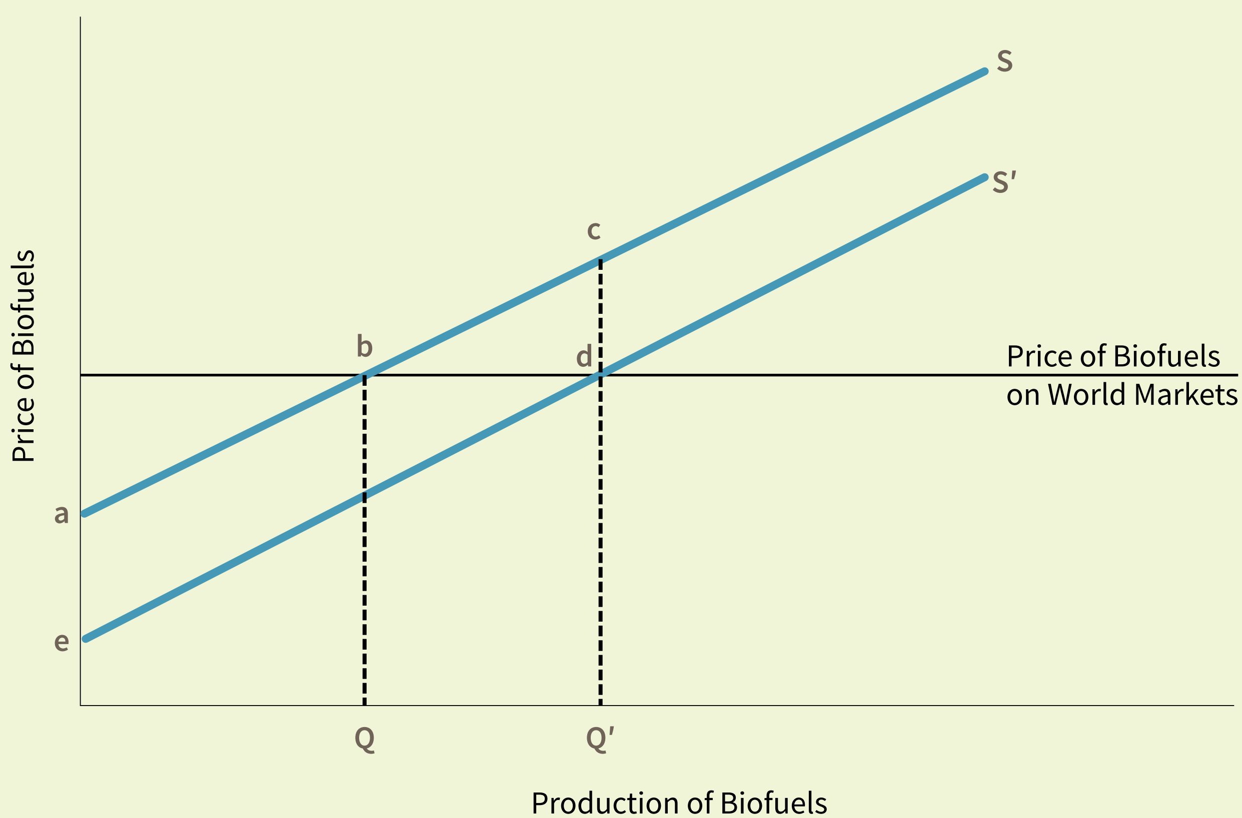
Here we describe our calculations of the overall economic costs of emissions reductions from biofuel policies and carbon taxes. Our measure of cost is the loss of economic welfare (or "economic surplus") per tonne of CO_2 emissions reduced. Thus we are measuring the broader economic cost from these policies, as opposed to their narrower financial impact on governments and consumers. Note also that we are not including the environmental benefits from reductions in CO_2 emissions, because these environmental benefits are common to both policy instruments. Policies with lower economic costs per tonne of emissions reduced are more cost-effective.

Cost of Emissions Reductions From Biofuel Policies

The main components of the biofuel policies are the mandates for adding biofuels to gasoline and diesel and the subsidies for biofuel producers in Canada. The mandates force refiners to increase the amount of biofuels included in gasoline and diesel, which raises the prices of these fuels compared with what they would be in the absence of these policies. In the 2012–2015 period, these mandates increased consumer expenditures on fuels by an average of $449 million per year. Canada is a small producer and consumer of biofuels, relative to the world market, and therefore these policies did not affect the prices of biofuels, which are set on world markets. The mandates, therefore, did not produce an offsetting benefit to Canadian producers of biofuels. The only effect of the mandates was to increase the volume of biofuels imported from abroad.

The second component of the biofuel policies is the subsidy to Canadian biofuel producers. In the 2012–2015 period, the average fiscal cost to the federal and provincial governments of these subsidies was $191 million. Figure D1 shows that the effect of the subsidy policy was to shift the supply curve of Canadian producers of biofuels from S to S′ and to increase domestic production from Q to Q′. The total fiscal cost of the subsidy is the area *acde*. These subsidies benefited some domestic biofuel producers because they received a higher net return for the units that they ended up producing. A measure of this gain to producers is the increase in

Figure D1: The Welfare Effect of Biofuel Subsidies for Canadian Producers



their producer surplus, shown in Figure D1 as the area *abde*. Thus the gain to producers, *abde*, is less than the fiscal cost of the subsidy, *acde*.

The entire amount of the subsidy must be financed through higher taxes levied by the federal and provincial governments. The marginal cost of public funds (MCF) is a measure of the reduction in economic welfare caused by raising an addition dollar of tax revenue. In general, the MCF is greater than one, because higher tax rates cause changes in work, savings, and investment behaviour that result in a less efficient allocation of resources. The economic cost of the biofuel subsidy is then estimated as the MCF multiplied by the total amount of the subsidy.

The overall economic cost per tonne of CO_2 emissions reductions for the biofuel policies can be calculated by the equation:

$$\text{Economic cost of emissions reductions from biofuel policies} = \frac{\text{Additional cost to consumers from fuel mandate} + \text{Economic cost of higher taxes} - \text{Additional producer surplus to biofuel producers}}{\text{Reduction of emissions in } CO_2}$$

The first term in the numerator is the cost to consumers from the biofuel mandates—this averaged $449 million per year.

The second term in the numerator is equal to the MCF times the total amount of the subsidy. The subsidy to biofuel producers averaged $191 million annually over the 2012–2015 period. We have used a relatively low estimate of the MCF, equal to 1.20; if the provincial governments raise personal and corporate income taxes to finance the subsidies, the MCF would be even greater.[40]

As for the third term in the numerator, we do not have the information necessary to calculate precisely the increase in producer surplus generated by the biofuel policy (because we cannot easily estimate the area of the triangle bcd in Figure D1). But the gain to producers must be no greater than the total amount of the subsidy itself. We use $191 million as this upper-bound estimate.

Finally, we use this report's high-end estimate of the annual average reduction in GHG emissions from biofuel policies, 3.1 Mt.

$$\text{Economic cost of emissions reductions from biofuel policies} = \frac{449 + (1.20)(191) - 191}{3.1} = \$157.2 \text{ per tonne}$$

[40] See Ferede and Dahlby (2016) for estimates of the marginal cost of public funds in Canada.

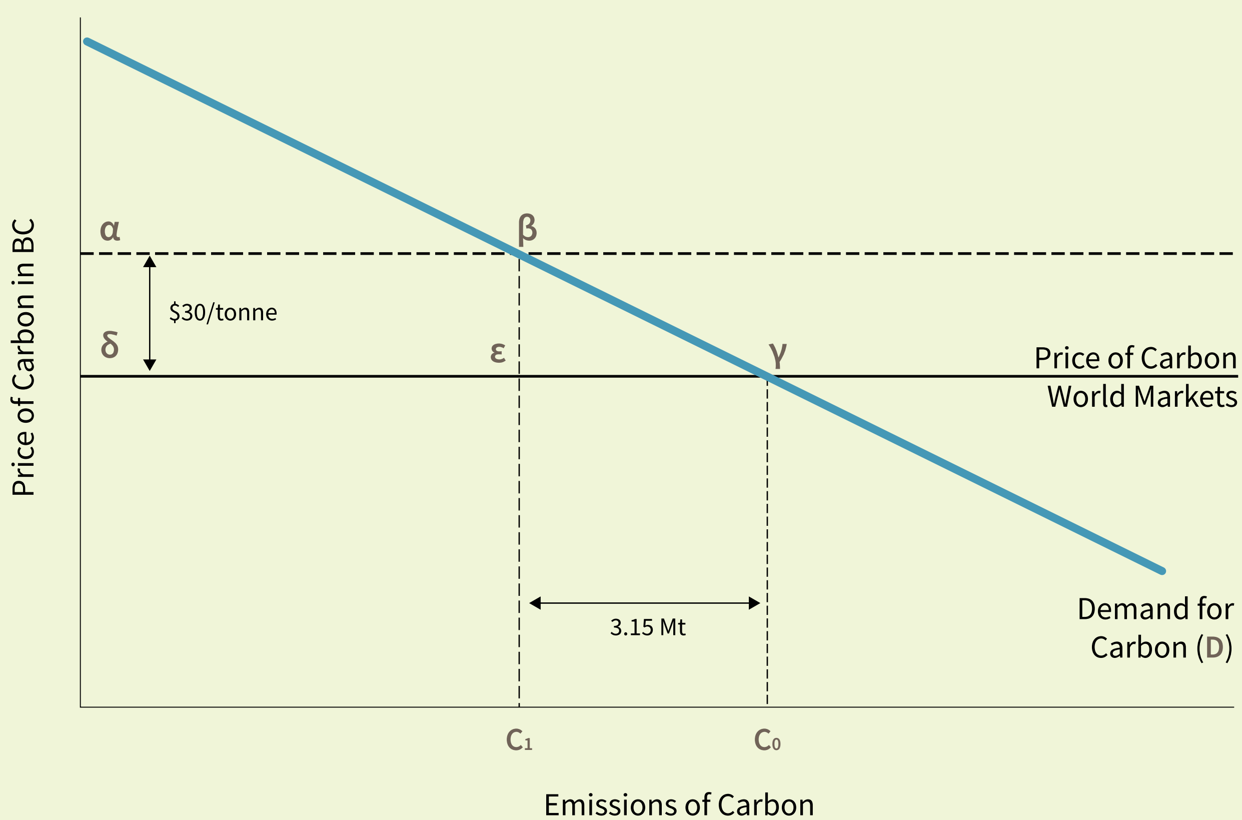
The biofuel policies thus reduced Canadian economic welfare by $157 for every tonne of CO_2 emissions that were displaced by the policies. (This number is slightly lower than the fiscal and consumer costs estimated in the main report, because it considers the net cost to the economy as a whole). We view this as a lower bound for the cost-effectiveness of the policy, because we have overestimated the gain to biofuel producers from the subsidy, used an upper bound for the reduction in CO_2 emissions, and used a relatively low value for the marginal cost of public funds. If we use the lower bound of the average annual emissions reductions from our sensitivity analysis (1 Mt), the cost of emissions reductions from biofuel policies increases to $487 per tonne.

Cost of Emissions Reductions From the B.C. Carbon Tax

We can also estimate the overall economic costs of emissions reductions from British Columbia's carbon tax. We use the revenue generated in 2012-13 of $1,120 million (Government of British Columbia, 2014); an estimate of the reduction in CO_2 emissions from the carbon tax of 3.15 Mt (Murray & Rivers, 2015); and an (unpublished) estimate of the MCF of the carbon tax by Hidemichi Yonezawa and Nicholas Rivers of 1.08.[41]

The basis for calculating the economic cost of the carbon tax is illustrated in Figure D2. Let D represent the demand for carbon, in the form of carbon-based fuels. In the absence of the carbon tax, the price of carbon is determined on world markets and C_0 is the associated level of emissions. With a $30/tonne carbon tax, the price of carbon increases and emissions are reduced to C_1. As a result of the higher carbon price, consumers have to make adjustments and are worse off; the resulting loss of consumer surplus is the area αβγδ. The MCF is the ratio of the loss of consumer surplus to the additional revenue raised by the tax, which is equal to the area αβεδ. Therefore, the loss of consumer surplus can be approximated as the MCF times the revenue generated by the carbon tax. For simplicity, we assume that this revenue is returned to consumers through a lump-sum tax cut.

Figure D2: The Welfare Effect of a Carbon Tax



[41] This estimate was generated using the EC-PRO computable general equilibrium model. See Böhringer et al. (2015) for model specifications. It is consistent with research by Barrios et al. (2013) that finds that the MCF for environmental taxes in the European Union are generally lower than the MCF for taxes on labour income.

$$\text{Economic cost of emissions reductions from the carbon tax} = \frac{\text{Loss of consumer surplus} - \text{Revenue generated by the carbon tax}}{\text{Reduction of emissions in } CO_2}$$

$$\text{Economic cost of emissions reductions from the carbon tax} = \frac{(1.08)(1{,}120) - 1{,}120}{3.15} = \$28.4 \text{ per tonne}$$

This is a high estimate of the costs of the carbon tax, because it is assumed that the revenue from the carbon tax is returned to the consumers as a lump-sum tax rather than through a reduction in personal and corporate income taxes, as is actually the case in British Columbia. That would generate an even larger benefit, because it would reduce the distortions in resource allocations caused by these taxes.

Note that the estimated cost of emissions reductions with the carbon tax, $28.4 per tonne, is lower than the tax rate, $30 per tonne. Despite the fact that the carbon tax has an MCF greater than 1, the economic cost is lower than the tax rate because our estimate represents average (as opposed to marginal) costs; some emissions are reduced at a cost of less than $30 per tonne. Again, this estimate does not count the environmental benefits that are common to both policies.

Comparative Costs of Emissions Reductions

Even when we use a concept of cost that is broader than the one we use in the main report, our results suggest that biofuel policies, though effective at reducing GHG emissions, do so at a considerably higher cost than what could be achieved by alternative policies. The economic cost of emissions reductions achieved by the biofuel policies is almost $160 per tonne. A similar estimation approach for the B.C. carbon tax suggests that emissions can be reduced with that policy at roughly one-fifth of that amount. By this standard, Canada's biofuel policies are certainly not a cost-effective means for reducing GHG emissions.

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