Biofuels in Canada 2020

Tracking biofuel consumption, feedstocks and avoided greenhouse gas emissions

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October 9th, 2020

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About Navius Research

Navius Research is a private consulting firm, specializing in the analysis of policies designed to meet environmental goals, with a focus on energy and greenhouse gas emission policy. We are Canada's leading experts in forecasting the environmental and economic impacts of energy and greenhouse gas emissions policies.

Funding

Navius Research thanks Advanced Biofuels Canada for funding this project. Navius Research maintained full control over the analysis and editorial content of this project.

Acknowledgments

Navius Research would like to thank individuals within the governments of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Canada for providing data and input to our analysis. We would also like to thank Don O’Connor of (S&T)^2 Consultants for his review of data sources, assumptions and the cost analysis.

Executive Summary

There are many policies designed to increase the consumption of renewable and low-carbon biofuels in Canada, and thus reduce transportation greenhouse gas (GHG) emissions. However, there is no detailed and comprehensive data source characterizing the impact of these policies. Environment and Climate Change Canada (ECCC) and the US Department of Agriculture both provide reporting and estimates of biofuel consumption in Canada, while several provincial governments publish data describing fuel consumption in their province, sometimes with estimates of fuel carbon intensity (CI) and GHG emission impacts. Still, there is no comprehensive data source in Canada that allocates renewable fuel consumption by province using data from provincial regulators and no single source that communicates the impact of renewable fuel consumption on GHG emissions and fuel costs. As such, Advanced Biofuels Canada has again engaged Navius Research to fill this information gap by updating the "Biofuels in Canada" report that has been released annually since 2016.

Objectives

The objectives of this project are to evaluate and communicate the impact of renewable and low-carbon fuel policies in Canada by:

1. Quantifying the volumes of renewable transportation fuels consumed in each Canadian province (i.e. biofuel), characterized by fuel type, feedstock, and CI. The biofuels include ethanol, biodiesel and hydrogenation derived renewable diesel (HDRD)
2. Estimating their impact on GHG emissions
3. Estimating how biofuel consumption may impact energy costs, including an analysis on the role of fuel taxation within this cost impact.

New Analysis and Updates to the Methodology

Biofuels in Canada now includes:

- Estimated results for 2019
- A comparison of carbon tax and compliance credit impacts on fuel prices experienced by consumers
- An assessment of abatement costs experienced by fuel suppliers

This current edition of the Biofuels in Canada analysis includes some methodological changes that affect the results for 2018 and prior years:

- The cost of transporting biofuels by rail has been updated. The new method produces a cost per kilometer that scales inversely with the transportation distance to account for the economies of scale when using rail-freight over longer distances.
- All inputs and results that are averaged for Canada are now consistently calculated using fuel-consumption weighted averages (where fuel consumption is what is reported in this analysis). Where possible, all results such as GHG and fuel cost impacts for Canada are reported as the sum of provincial components.
- All inputs for Atlantic Canada are produced using population weighted averages of data for the individual provinces in that region.
- We have made minor corrections to some provincial fuel tax values used in previous years.
- For users of the accompanying spreadsheet, it is now implemented using named tables and cells as well as formulas that use structured references. This does not change the methodology of the analysis, though it does change how values are calculated. The "Read Me" tab in the spreadsheet provides more detail on this and links to tutorials.

This year's analysis also includes estimated results for 2019. The estimates are based on total gasoline and diesel pool volumes by province, which are derived from:

- The change in national consumption as recorded by Statistics Canada between 2018 and 2019
- The percent of national consumption that occurred in each province in 2018.

As with results in all other years, CI values are taken from the GHGenius lifecycle emissions model (v4.03a), and extrapolated from provincial data sources where possible.

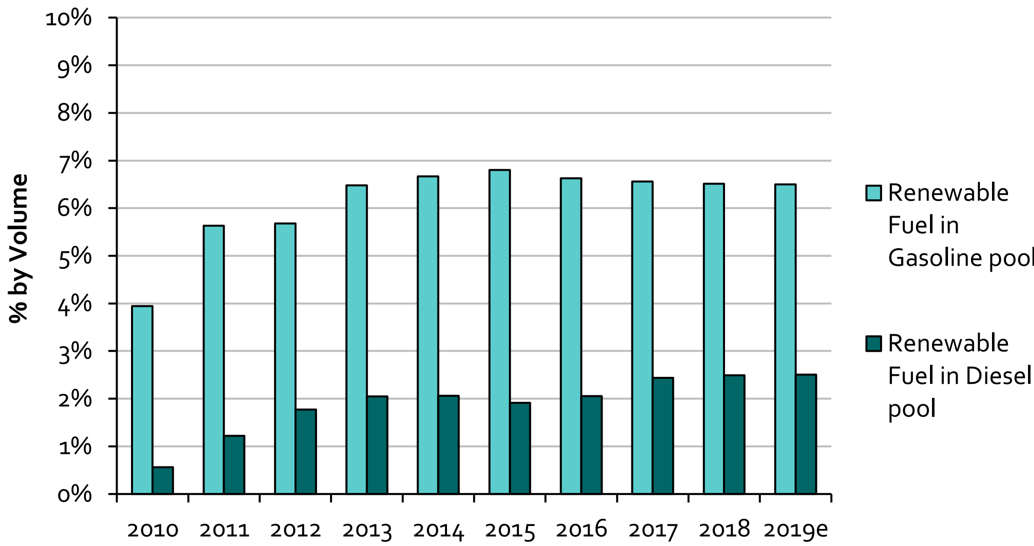
Fuel Consumption

Using data obtained from provincial and federal government sources and contacts, we estimate that annual ethanol consumption has increased from roughly 1,700 million litres in 2010 to 3,034 million litres in 2018 (0.5% lower than in 2017). The estimate for 2019 is only 2,817 million litres, where the reduction is a result of lower overall reported fuel consumption for that year.

The volume of biodiesel consumed annually has also increased substantially since 2010, rising from roughly 123 million litres in 2010 to 368 million litres in 2018. HDRD is now blended into diesel in similar volumes as biodiesel, with consumption calculated at 343 million L in 2018 (Table 9). The total quantity of biomass-based diesel consumption in Canada that we report for 2018 is 711 million litres, based on input from industry contacts (1.5% larger than in 2017).

Since 2013, ethanol has accounted for over 6% of the gasoline pool volume. Biodiesel and HDRD have been close to 2% of the diesel pool volume (Figure 1). The Blending rates were 6.5% and 2.5% in 2018 respectively (with the same blending rates assumed for 2019).

Figure 1: Renewable fuel content by fuel pool with estimate for 2019



Lifecycle GHG Emissions

Based on lifecycle carbon intensities reported by government contacts and obtained from GHGenius 4.03a, renewable fuel consumption has avoided 40 Mt CO_2e between 2010 and 2018. Annual avoided GHG emissions have grown from 2.1 Mt in 2010 to 5.6 Mt in 2018. The estimated annual reduction for 2019 is just 5.3 MtCO_2e, where the reduction in avoided emissions relates to the lower quantity of overall fuel consumption reported in the data.

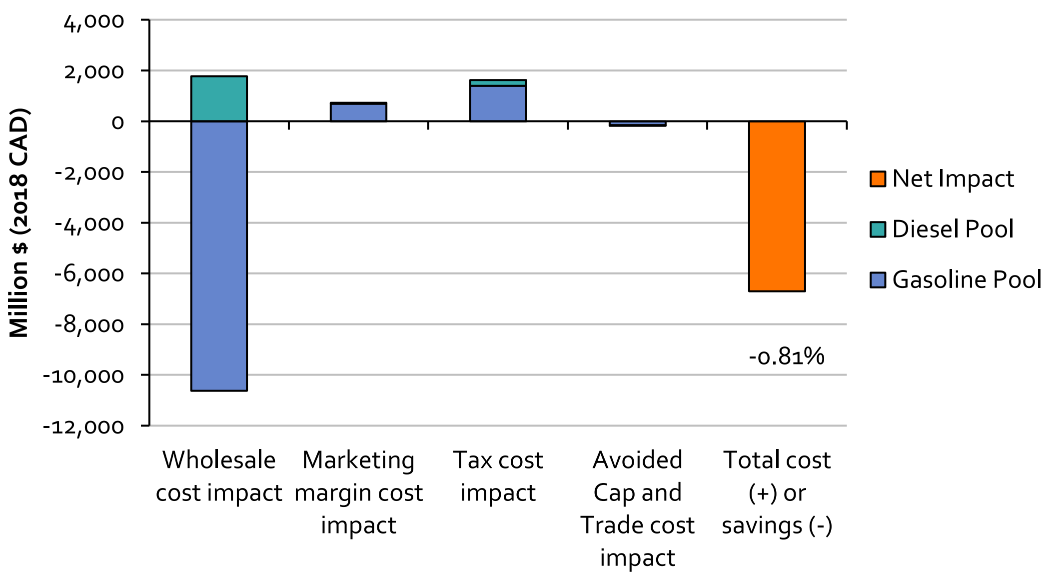
Trends in biofuel carbon intensities in British Columbia indicate that biofuel production is becoming less emissions intensive. Therefore, a fixed amount of biofuel consumption avoids more GHG emissions in 2018 than it would have in 2010.

Cost Analysis

Figure 2 shows the cumulative consumer cost impact, by component, resulting from biofuel consumption between 2010 and 2018. The cost components are the wholesale cost, the marketing margin cost (i.e. distribution), the fuel tax cost, and avoided costs under emissions cap and trade policies. The wholesale cost impact is based on observed market prices for fuels and accounts for biofuel transportation costs and the octane value of ethanol, which allows a lower-cost gasoline blendstock to be used. While Canadian refiners may not capture the octane value of ethanol in all cases, this analysis assumes they do; higher octane fuels have a higher market price and we assume that refiners would not provide extra octane with no additional charge.

Biofuel consumption has yielded a cost savings relative to a scenario where no biofuel was consumed, roughly $6.7 billion over nine years (2018 CAD), or -0.81% of total gasoline and diesel pool expenditures.

Figure 2: Cumulative cost impact resulting from ethanol blending in the gasoline pool and biomass-based diesel blending in the diesel pool (2010-2018), total % change in data label

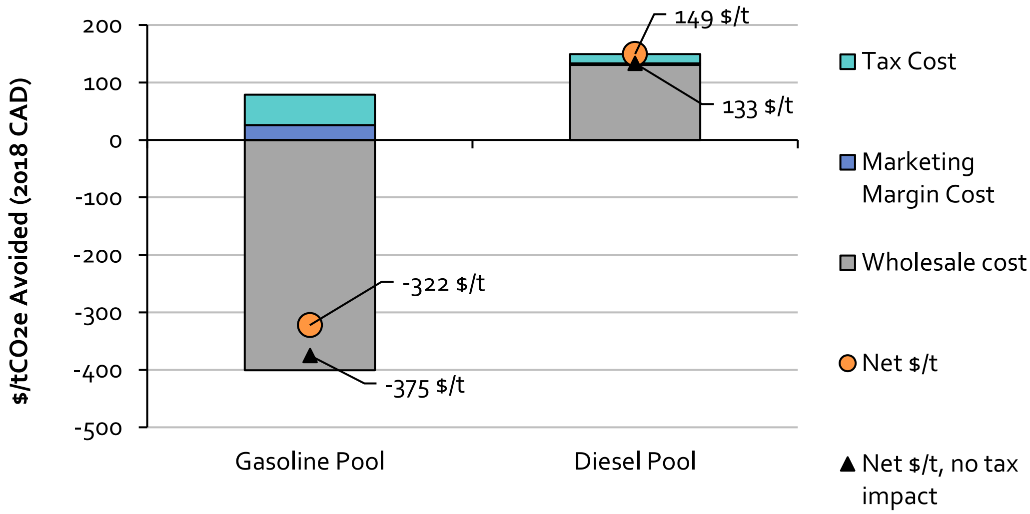


The total cost impact has a component related to wholesale fuel costs, where the octane value of ethanol reduces wholesale fuel costs. The total cost also has components related to tax costs and distribution costs that exist because of the differences in energy density between fossil fuels and renewable biofuels. Notably, because ethanol is roughly 33% less energy dense than gasoline, consumers must purchase more of it to obtain the same amount of energy. That exposes them to greater distribution costs based on our assumption that marketing margins in a $/L basis are not affected by biofuel blending rates. Lower energy density also increases the tax consumers paid on biofuels since most fuel taxation (e.g. excise and carbon taxes) in Canada is charged per litre, regardless of how much energy is in that litre.

Furthermore, percent sales taxes (e.g. PST, GST, HST) may be larger per litre on renewable fuels if these fuels cost more per litre, as often is the case with blends containing biomass-based diesels. Consequently, consumers generally pay more taxes per kilometer driven when using biofuel blends. In 2018, on average in Canada (fuel consumption-weighted), a driver of a light-duty vehicle using gasoline with 10% ethanol (i.e. E10) will have paid an additional 0.3% more taxes per kilometre than when using E0. Similarly, a heavy-duty vehicle driver will pay an additional 0.3% more taxes per kilometre when using diesel with 5% biodiesel (i.e. B5) than when using B0. Consequently, Canadians have paid an additional $1.6 billion in taxes from 2010 through 2018 as a result of renewable fuel blending (Figure 2).

Figure 3 shows the cumulative consumer cost divided by the cumulative avoided GHG emissions from 2010-2018 for the gasoline and diesel pools in Canada. The costs do not account for any co-benefits or costs other than those shown in Figure 2 (i.e. no accounting for reduced air pollution and health impact related to biofuel consumption). The abatement cost in the gasoline pool is -\$322/tCO_2e versus \$144/tCO_2e in the diesel pool. The negative abatement cost for ethanol is largely a consequence of its value in raising the octane of gasoline blends, though this value is offset partly by the additional distribution cost and tax burden associated with ethanol consumption. On net, renewable fuel consumption in Canada has saved a typical gasoline consumer (based on a typical light-duty vehicle) $27/yr (-1.3%), whereas it has cost a typical diesel consumer (based on a long-distance truck operator) an additional $206/yr (+0.6%).

Figure 3: GHG abatement cost, 2010-2018



Note that the wholesale cost impact in the diesel pool is relatively high given that HDRD, which is generally more costly than biodiesel, accounts for roughly half of the diesel renewable fuel blend. The diesel pool wholesale cost impact could have been lower if fuel suppliers used more biodiesel, which has been on average 60% cheaper than HDRD from 2010 through 2018. Adding more biodiesel was possible: the results show that in Canada, biodiesel has only accounted for just over 1% of the diesel pool volume, well below even the most conservative fraction of biodiesel commonly blended into diesel.

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1. Introduction

There are many policies designed to increase the consumption of renewable and low-carbon biofuels in Canada, and thus reduce transportation greenhouse gas (GHG) emissions. However, there is no detailed and comprehensive data source characterizing the impact of these policies. Environment and Climate Change Canada (ECCC) and the US Department of Agriculture both provide reporting and estimates of biofuel consumption in Canada, while several provincial governments publish data describing fuel consumption in their province, sometimes with estimates of fuel carbon intensity (CI) and GHG emission impacts. Still, there is no comprehensive data source in Canada that allocates renewable fuel consumption by province using data from provincial regulators and no single source that communicates the impact of renewable consumption on GHG emissions and fuel costs. As such, Advanced Biofuels Canada has again engaged Navius Research to fill this information gap by updating the "Biofuels in Canada" report that has been released annually since 2016.

The goals of this project are to evaluate and communicate the impact of renewable and low-carbon fuel policies in Canada. This is done by quantifying the annual volumes of transportation fuels consumed in individual provinces and nationally from 2010 to 2018, the most recent year for which data is available (with estimates for 2019). These fuels are further characterized by type (i.e. gasoline, ethanol, diesel, biodiesel, etc.), feedstock, and CI. Using these volumes and CIs, we then estimate the impact of biofuel consumption on GHG emissions and energy costs by province, with additional focus on how fuel taxation affects these costs.

A further goal of this study is to provide transparent results that are available to a wide range of stakeholders. As such, this report is a companion to a Microsoft Excel spreadsheet model that contains the analysis and a visual representation of key results for fuel volumes, cost impacts and avoided GHG emissions ("Biofuels in Canada Analysis, 2020-10-09"). Results are shown for Canada and each province.

The remainder of this report provides an overview of the existing renewable fuel policies in Canada and a discussion of carbon pricing policies and upcoming low-carbon fuel policies in Canada. This is followed by a description of the analysis methodology and then a discussion of the results. Appendices contain more information on the cost analysis methodology and on our renewable fuel volume and feedstock data and assumptions.

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2. Canadian Policy Background

This section of the report summarizes the existing renewable fuel policies in Canada as of August 2020 at both the federal and provincial levels to provide an understanding of the regulations driving renewable fuel consumption in the period. The existing and upcoming carbon pricing policies that affect the price of gasoline and diesel blends are also explained, as is the potential impact of the proposed Canadian Clean Fuel Standard (CFS). Throughout this report, fuel carbon intensity (CI) refers to the lifecycle GHG emissions associated with each fuel, from feedstock production (e.g. an oil well or a corn farm) through to final consumption.

2.1. Renewable Fuel Blending Requirements

National Summary

The Canadian federal government enacted the *Renewable Fuels Regulations* on August 23, 2010. This regulation mandates 5% renewable fuel by volume in the gasoline pool, and 2% renewable fuel by volume in diesel pool. The purpose of this policy is to reduce the amount of GHGs emitted from the combustion of these fuels.

The gasoline blending requirement started December 15, 2010, whereas the diesel blending requirement began July 1, 2011. The federal regulation only requires compliance on average across Canada. This means that fuel sold across Canada may have very different biofuel blending rates, where over-compliance in one region is offset by undercompliance in another region.

Alongside the national policy there are a variety of provincial policies, which mandate specific volumes of renewable content in fuel pools. Table 1 summarizes the percentage of ethanol to be blended with gasoline as mandated by various regulations at different levels of government in Canada. It is important to note that some quantities of gasoline and diesel are exempt from blending policies in Canada. For example, gasoline and diesel pools in Newfoundland and Labrador, the Territories, as well as other regions north of 60 degrees latitude are not regulated under the federal policy.

Table 1: Gasoline biofuel blending policies

Region	2010	2011 to 2019	2020
British Columbia	5.0%	5.0%	5.0%
Alberta	-	5.0%	5.0%
Saskatchewan	7.5%	7.5%	7.5%
Manitoba	8.5%	8.5%	8.5%
Ontario	5.0%	5.0%	10%
Canada	-	5.0%	5.0%

Some regions in Canada are not yet subject to any provincial or territorial gasoline biofuel blending policies. However, they are still regulated under the federal policy. These regions have been excluded from Table 1: Québec, New Brunswick, Nova Scotia, Newfoundland and Labrador, and Prince Edward Island.

Similarly, Table 2 summarizes the prescribed percentage of biofuels to be blended in regulated diesel pools in Canada. The most common forms of biofuels blended into diesel include biodiesel and hydrogenation-derived renewable diesel (HDRD). As described in the following sub-section, the Ontario *Greener Diesel Regulation* prescribes the biofuel content based on the average CI of the biofuels relative to diesel, so the actual volume of biofuel may vary from what is reported in the table.

Table 2: Diesel biofuel blending policies

Region	2010	2011	2012	2013	2014	2015	2016	2017 to 2020
British Columbia	3.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Alberta	-	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Saskatchewan	-	-	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Manitoba	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Ontario	-	-	-	-	2.0%	2.0%	3.0%	4.0%
Canada	-	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%

As with ethanol, some regions in Canada are not subject to any provincial or territorial diesel biofuel blending policies, but they are still regulated under the federal policy. These regions have been excluded from Table 2: Québec, New Brunswick, Nova Scotia, Newfoundland and Labrador, and Prince Edward Island. Furthermore, fuel oil used for heating has been exempt from the federal regulation since 2013.

Provincial Policy Design

Canada has a variety of renewable fuel policies at the federal and provincial levels of government. However, besides prescribing different renewable fuel volumes (summarized in Table 1 and Table 2), these policies vary in design and application.

Alberta has the *Renewable Fuel Standard* which came into effect April 1, 2011. It mandates fuel producers to blend biofuels with gasoline and diesel. An average of 5% is required in gasoline pools, while an average of 2% is required in diesel pools. However, Alberta's policy also specifies that the CI of the renewable content must be 25% lower than the corresponding gasoline and diesel. In practice, most biofuels meet this criterion. For example, in 2011 the lifecycle CI of gasoline (as estimated by GHGenius 4.03a) was approximately 88.8 gCO_2e/MJ. In contrast, the default CI of ethanol was 59% to 65% lower, depending on the ethanol feedstock. The CI of diesel in Alberta in 2011 was 96 gCO_2e/MJ, while the CI of biodiesel in that province ranged from 8 to 20 gCO_2e/MJ, or 79% to 92% lower than diesel (also based on GHGenius 4.03a). Note that Alberta uses a different version of the GHGenius model, so actual lifecycle CI values used in the policy may differ slightly.

Manitoba has the *Ethanol General Regulation* and the *Biodiesel Mandate for Diesel Fuel Regulation*. These policies mandate the blending of biofuels with gasoline and diesel pools. The first compliance period for the diesel policy began in 2009 but was later revised to be effective on April 1, 2010. The policy requires 2% renewable content by volume. The ethanol policy mandates 8.5% renewable content by volume in gasoline since January 1, 2008.

Ontario previously had the *Ethanol in Gasoline* regulation mandating 5% ethanol content in gasoline, by volume. Suppliers must meet the compliance target at all their facilities combined. As of 2020, ethanol blending in Ontario will be regulated by the *Greener Gasoline – Bio-Based Content Requirements for Gasoline.* [1] This regulation will require an adjusted bio-based gasoline content of 10% by volume, where the actual volume content is a function of the carbon intensity of the biofuel. Compliance with the regulation will result in 10% bio-based fuel content if the weighted average CI of the biofuel is approximately 46 gCO_2e/MJ (45% below a benchmark CI for gasoline). If the CI of the biofuel is lower, then the blend rate may also be lower. For 2020 through 2022, gasoline sold for consumption in Northern Ontario is exempt from the blending requirement. Gasoline sold for marine, aviation and off-road use may also be

[1] Government of Ontario, O. Reg. 535/05: GREENER GASOLINE - BIO-BASED CONTENT REQUIREMENTS FOR GASOLINE

exempted. There is a proposed amendment that would increase the adjusted volume of the biomass content to 15% by 2025.[2]

Additionally, Ontario has the *Greener Diesel Regulation* which consists of three phases that prescribed a formula to determine a minimum renewable fuel blending requirement in diesel, based on the average CI of the biofuels. The first phase was effective from April 1, 2014 to the end of 2015 and mandated 2% biofuel content with an average CI reduction of 30% relative to diesel fuel. In other words, the actual volume of biofuel could vary depending on its CI (i.e. biofuels with CI levels below the CI average target require less volume). For context, the default CI of biodiesel sold in Ontario in 2014 is estimated to be roughly 14 gCO_2e/MJ by GHGenius 4.03a. This is 85% below the default CI of diesel, 93 gCO_2e/MJ. For 2016, the stringency of this policy increased to 3% renewable content with an average CI reduction of 50% relative to diesel fuel. In 2017 and thereafter, the blend increased to 4% biofuel content with an average CI reduction of 70% relative to diesel fuel. Again, the actual volumetric content of biofuel in the diesel pool may be less than indicated if the CI is below the prescribed threshold.

Saskatchewan has *The Ethanol Fuel Act* and *Ethanol Fuel (General) Regulations* that regulate the volume of ethanol to be blended with gasoline (7.5% by volume) and establishes quality standards for the ethanol to be blended. Saskatchewan also has *The Renewable Diesel Act* that started on July 1, 2012 mandating 2% renewable fuel by volume in diesel pools.

The **British Columbia** (BC) *Renewable and Low Carbon Fuel Requirements Regulation* (RLCFRR) has two components. The first component defines the minimum renewable fuel content of gasoline and diesel at 5% and 4% by volume respectively. This component came into effect January 1, 2010, with an initial 3% blending requirement for diesel which increased to 4% in 2011. The second component of the policy regulates the average CI of the fuels, as described in section 2.3.

Québec has no renewable fuel blending policy in force as of 2020, though the government has released a draft regulation for 2021 and beyond. As of July 1st 2021, the draft regulation would require 10% ethanol by volume and 2% biomass-based diesel by volume, with additional credit given for cellulosic ethanol. Those blending rates would rise to 15% ethanol and 4% biomass-based diesel by 2025.[3]

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[2] Environmental Registry of Ontario, 2020, Increasing Renewable Content in Fuels

[3] Government of Québec, 2019, Regulation respecting the minimum volume of renewable fuel in gasoline and diesel fuel

2.2. Carbon Pricing

British Columbia Carbon Tax

The British Columbia carbon tax was $30/t$CO_2$e from 2012 until 2018. In April 2018, the tax rate increased to $35/t$CO_2$e, and to $40/t$CO_2$e in April 2019. The tax rate will generally increase by $5/t$CO_2$e each year until it reaches $50/t$CO_2$e in 2021. However, the increase in 2020 was delayed in light of the COVID-19 pandemic and the tax rate is still $40/t$CO_2$e as of August 2020.[4] Each $5/t$CO_2$e increment increased the tax on gasoline by 1.11 ¢/L and the tax on diesel by 1.28 ¢/L (Table 3).[5]

The application of the tax to gasoline and diesel is based on emissions factors that account only for the minimum volumetric biofuel blending rate in the province: 4% for biodiesel and 5% for ethanol, resulting in a tax of 8.9¢/L on gasoline and 10.2¢/L on diesel as of August, 2019. The tax is applied equally to each litre of fuel, fossil and renewable, and is not adjusted for tailpipe or lifecycle GHG emissions of alternative fuels.

Table 3: British Columbia carbon tax rates (nominal CAD)

	2012-2017	2018	2019 and 2020 (actual)	2020 (planned, but delayed)	2021
Tax rate, $/t$CO_2$e	30	35	40	45	50
Gasoline, ¢/L	6.7	7.8	8.9	10.0	11.1
Diesel, ¢/L	7.7	9.0	10.2	11.5	12.7

Alberta Carbon Levy

Alberta implemented a $20/t$CO_2$e carbon levy, essentially a carbon tax, in 2017, which rose to $30/t$CO_2$e in 2018.[6] Similar to BC, the application of the levy to gasoline and diesel used fuel emissions factors that reduce the rate by the prescribed biofuel blend level (i.e. 5% ethanol by volume in gasoline 2% by volume biodiesel in diesel)

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4 Government of British Columbia, British Columbia's Carbon Tax

5 Ibid.

6 Government of Alberta, Carbon Levy Rates

(Table 4). However, unlike British Columbia, Alberta's carbon levy exempted 100% of the biofuel component of blends that exceeded 10% in gasoline and 5% in diesel.

The Alberta carbon levy was repealed by the newly elected provincial government in 2019.[7] Consequently, as of 2020, gasoline and diesel purchases are subject to the federal carbon pricing backstop discussed below.

Table 4: Alberta carbon levy rates on gasoline and diesel (nominal CAD)

	Rate in 2017	Rate in 2018 and early 2019
Gasoline, ¢/L	4.49	6.73
Diesel, ¢/L	5.35	8.03

Québec Cap and Trade

The Québec GHG emissions cap and trade system began in 2014 and suppliers of transportation fuels were included as of 2015. It applies to fuel suppliers who must hold credits for the emissions resulting from the fossil fuels they distribute; emissions from biofuels are exempt from the cap and trade system. The emissions credit price affects the wholesale price of fuels; however, wholesale gasoline and diesel pricing does not show a price differentiation between fossil-biofuel blends and fuels without biofuels.

The system has a price floor, which is a minimum price for credit trades. That price began in 2013 at $10.75/tCO_2e$ (nominal CAD) and rises by 5% plus inflation each year to 2020.[8] The Québec system is linked with the California cap and trade program, so the minimum credit price in the joint program must also account for the exchange rate. In practice, the average annual credit price has remained slightly above the price floor[9] (Table 5).

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[7] Government of Alberta, Carbon Tax Repeal

[8] www.environnement.gouv.qc.ca/changements/carbone/Systeme-plafonnement-droits-GES-en.htm

[9] Government of Québec, The Carbon Market, Cap-and-Trade Auction Notices and Results

And

California Air Resources Board, Summary of Transfers Registered in CITSS By California and Québec Entities in 2019, April 15 2020

Table 5: Québec cap and trade average annual credit price and estimated price impact on gasoline and diesel (nominal CAD)

	2014	2015	2016	2017	2018	2019
Credit price, \$/tCO_2e	13.4	22.71	22.59	22.31	22.67	22.71
Gasoline, ¢/L	3.3	5.5	5.6	5.5	5.5	5.6
Diesel, ¢/L	3.7	6.2	6.2	6.2	6.1	6.2

Ontario Cap and Trade

The Ontario cap and trade program came into force January 1st, 2017. The first credit auction was held in that year and the system linked with the cap and trade in California and Québec occurring in January 2018. However, the program was cancelled later that year by the newly elected provincial government, and all trading was stopped on July 3rd, 2018.[10] As of 2019, gasoline and diesel sales in Ontario are subject to the federal carbon pricing backstop described below.

Like the Québec cap and trade system, fuel suppliers must hold credits for the emissions resulting from the fuels they distribute. The credit price affects the wholesale gasoline and diesel price and these prices indicate that the carbon cost is spread evenly across all fuel blends, regardless of their renewable fuel content.

The average credit price in 2017 was \$18.2/tCO_2e, roughly 4.3 ¢/L on gasoline. The average credit price in 2018 was \$18.6/tCO_2e up until the program was cancelled.[11]

Federal Carbon Pricing Backstop

The carbon pricing backstop applies to provinces that chose to not to implement an acceptable carbon pricing system of their own. These include Saskatchewan, Manitoba, Ontario, New Brunswick[12] and Alberta following the repeal of the carbon levy. Newfoundland, PEI and Nova Scotia have developed their own provincial carbon pricing systems rather than using the federal system.

The federal carbon price backstop applied to fossil fuels sold in those provinces starting April 1st, 2019. The price began at \$20/tonne in 2019 and is scheduled to rise

[10] Government of Ontario, Archived – Cap and Trade

[11] Government of Ontario, 2018, *Past auction information and results*

[12] Government of Canada, 2019, *How we're putting a price on carbon pollution*

by $10 annually to $50/tonne by 2022.[13] The fuel charge rates shown in Table 6 account for the average volumetric renewable fuel content required in Canada: 5% in gasoline and 2% in diesel. Similar to Alberta's carbon levy, biofuel volumes used in blends greater than 10% in gasoline or 5% in diesel are exempt from the carbon price.[14]

Table 6: Federal backstop carbon levy rates on gasoline and diesel (nominal CAD)[15]

	2019	2020	2021	2022
Carbon price, $/tCO2e	$20	$30	$40	$50
Gasoline, ¢/L	4.42	6.63	8.84	11.05
Diesel, ¢/L	5.37	8.05	10.73	13.41

2.3. Low-Carbon Fuel Standards

British Columbia Low-Carbon Fuel Requirement

The CI component of the British Columbian *Renewable and Low-Carbon Fuel Requirements Regulation* (RLCFRR, often called a low-carbon fuel standard, or LCFS), came into effect July 1, 2013 with a schedule that required a 10% reduction in average fuel CI by 2020 relative to a 2010 baseline. The 2020 target was reduced to -9.1% in light of the COVID-19 pandemic and a new target of -20% was been legislated for 2030 and beyond.[16,17]

The CI component of the policy has required blending renewable fuels at volumes greater than the minimum 5% in gasoline and 4% in diesel. However, renewable fuel blending is not the only action that can satisfy the low-carbon fuel requirement of the RLCFRR. In other words, while this LCFS policy is likely to encourage more renewable fuel consumption, it does not prescribe this consumption. If the minimum renewable

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[13] Government of Canada, 2019, *Fuel Charge Rates*

[14] McKenna, C., Morneau, W.F., 2018, Explanatory Notes Relating to the Greenhouse Gas Pollution Pricing Act and Related Regulations

[15] Government of Canada, 2019, *Fuel Charge Rates*. www.canada.ca/en/revenue-agency/services/forms-publications/publications/fcrates/fuel-charge-rates.html

[16] Government of British Columbia, BC-LCFS Requirements

[17] Government of British Columbia, B.C. Reg. 394/2008, RENEWABLE AND LOW CARBON FUEL REQUIREMENTS REGULATION

fuel standard is met, the CI requirement of the LCFS can be met by switching to lower carbon transportation energy sources such as natural gas, electricity, or hydrogen.

The RLCFRR in BC need only be met on average by suppliers of gasoline and diesel in the provincial market. Compliance credits can be traded amongst suppliers, and parties that do not comply will pay a rate of 200 $/t$CO_2$e for a compliance shortfall. Additionally, a minority of credits each year can be generated through special projects called Part 3 Agreements. These projects may reduce the CI of the regulated fuels or permit greater availability of low-carbon fuels (e.g. installation of re-fuelling infrastructure capable of dispensing mid-to-high blend biofuels, such as diesel with 20% biodiesel in it). These credits may account for up to 25% of compliance in a given year.

The Clean Fuel Standard

The Canadian federal government is developing a LCFS-style regulation called the *Clean Fuel Standard* (CFS). Like the British Columbian RLCFRR and the similar California *Low Carbon Fuel Standard*, the CFS will require a reduction in the life-cycle CI of transportation fuels. Unlike these policies, the CFS extends to other liquid fuels outside of the transportation sector, though transportation represents approximately 77% of liquid fuel use in Canada.[18] The CFS will eventually also apply to gaseous and solid fuels produced and imported into Canada. The final CFS regulation for the liquid fuel stream is expected to be published in 2021, with the policy coming into force in 2022. Final regulations for gaseous and solid fuels are expected be published 12 months following the regulation for liquid fuels, sometime in 2022, and coming into force in 2023.[19]

The June 2019 proposed CFS regulatory approach was updated in June 2020 to now require that the CI target for all liquid fuels in 2030 will be 12 gCO_2e/MJ lower than a 2016 benchmark for fuels, which includes gasoline, diesel, and biofuels used in the baseline year.[20] The proposed June 2020 amendments also reduced the initial reduction requirement from 3.6 to 2.4 gCO_2e/MJ and increased the annual change in the carbon intensity target from +0.8 to +1.2 gCO_2e/MJ per year. The federal *Renewable Fuels Regulation* will end when the CFS comes into force for the liquids

[18] Statistics Canada, Supply and demand of primary and secondary energy in terajoules, Table 25-10-0029-01

[19] Environment and Climate Change Canada, Clean Fuel Standard – Revised Publication Timeline

[20] Environment and Climate Change Canada, 2019, Clean Fuel Standard Proposed Regulatory Approach

pool, though the CFS will maintain the same minimum renewable fuel blending rates for both the gasoline and diesel pool (5% and 2% by volume, respectively).

Like the British Columbian and Californian policies, the CI of liquid fuels can be reduced by blending lower CI biofuels into petroleum fuels, or by switching transportation energy consumption to natural gas, electricity and hydrogen. It is the fuel producers and importers (i.e. the fuel suppliers) that are required by the policy to supply these lower-carbon fuels. Alternatively, they can generate or purchase compliance credits from GHG reductions achieved in upstream oil production, upgrading, and refining stages with the use of lower-carbon fuels, integration of renewable energy, and the use of carbon capture and storage. Other options will be available to increase the flexibility of compliance: For example, there will be limited credit trading between the three fuel pools (e.g. selling gaseous compliance credits into the liquid stream), credit given for early action and surplus compliance with the Renewable Fuels Regulation, and a compliance fund that allows obligated parties to purchase a limited proportion of the required compliance credits at a maximum ceiling price (i.e. capping compliance costs at a given \$/tCO_2e value).

Impact of Low-Carbon Fuel Standards on Retail Fuel Prices

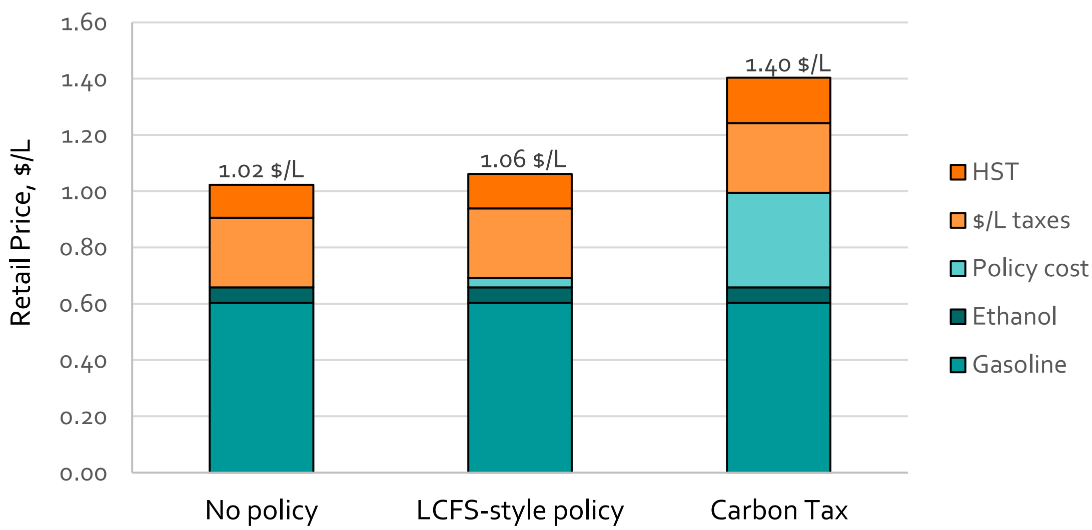
LCFS-style policies create a market-based incentive to supply low-carbon fuels because this action generates compliance credits which can be traded in their associated market. The price of credits will rise until it is high enough to incentivize fuel suppliers to comply with the policy. In a properly functioning market, the credit price will be same as the GHG abatement cost of the costliest action required for compliance, including ancillary costs like fuel distribution and blending or even foregone revenues from fuel refining and sales. All other actions taken to comply with the policy will be less costly. Therefore, the average cost of compliance and the average carbon abatement cost associated with the policy is less than the credit price.

LCFS credit prices and carbon tax rates are often improperly compared when assessing the impact on retail fuel prices. A LCFS credit price and a carbon price with the same \$/tCO_2e value have a very different impact on retail fuel prices. The difference exists for two reasons. First, a carbon tax applies to 100% of the GHG emissions associated with a fuel while on-net, a LCFS credit price only applies to the portion of the fossil fuels emissions above a given threshold (i.e. the required CI reduction in a given year). Second, the LCFS policies in Canada do not produce any financial transfer to the government like a carbon tax does (unless it has a ceiling price for credits that is reached, at which a subset of compliance credits might be purchased from the government).

Using the example of retail fuel prices that were typical in Ontario in 2017 and gasoline containing 10% ethanol by volume (E10), a LCFS policy with a credit price of 150 \$/tonne would result in an E10 price of 1.06 \$/L versus 1.02 \$/L without an LCFS. The net retail-price impact is just 4 ¢/L. In contrast, a carbon tax of 150 \$/tCO_2e tax would increase that price to 1.40 \$/L (Figure 4), with a net price impact of 38 ¢/L (34 ¢/L and 4 ¢/L in additional sales tax) However, carbon tax revenue recycling, which is not considered here, could mitigate the cost impact for consumers if, for example, that revenue were used to lower income tax or returned to households as a lump sum payment. Nonetheless, the price impact at the pump of a carbon tax would remain significantly higher than with a LCFS policy.

LCFS policies have a different impact on retail prices because they act like a “feebate” on fuels that have a CI above and below the average life-cycle CI target: the policy applies a “fee” to fuels with CI’s above the target, but all the revenue earned from the “fee” ultimately becomes a “rebate” to fuels with CI’s that are below the target.

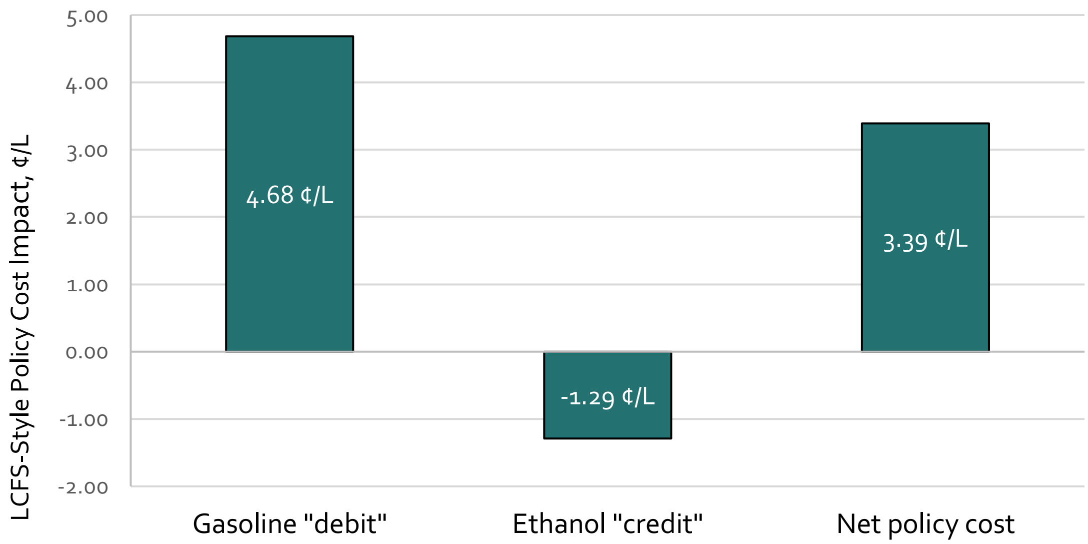
Figure 4: Impact of an LCFS-style policy and a carbon tax on E10 retail prices, where an LCFS credit price is equal to the carbon tax \$/tonne CO_2e value (\$150 t/CO_2e)



Note: wholesale fuel costs and fuel taxes are based on Ontario in 2017. LCFS credit price and carbon tax are 150 \$/tonne. The gasoline CI is 87 gCO_2e/MJ, the ethanol CI is 40 gCO_2e/MJ, and the CFS target CI is 77 gCO_2e/MJ

This “feebate” is illustrated with the example of E10 in Ontario again. If petroleum-derived gasoline has a life-cycle CI of 87 gCO_2e/MJ and the target for 2030 is 10 gCO_2e/MJ lower, the “fee” on the gasoline component in that year would be 4.7 ¢/L of E10 when the compliance credit price is 150 \$/tCO_2e. The ethanol component of the E10 would earn a “rebate” of 1.3 ¢/L of E10, when the CI of ethanol is 40 gCO_2e/MJ. Assuming a functioning and somewhat competitive fuel market where the LCFS costs and benefits are mostly passed to the consumer, that policy would increase the price of E10 by 3.8 ¢/L (Figure 5, 3.4 ¢/L from the LCFS policy, 0.4 ¢/L from increased sales tax.

Figure 5: Breakdown of an LCFS-style policy's cost impact on E10 retail price with a hypothetical \$150/tCO_2e credit price



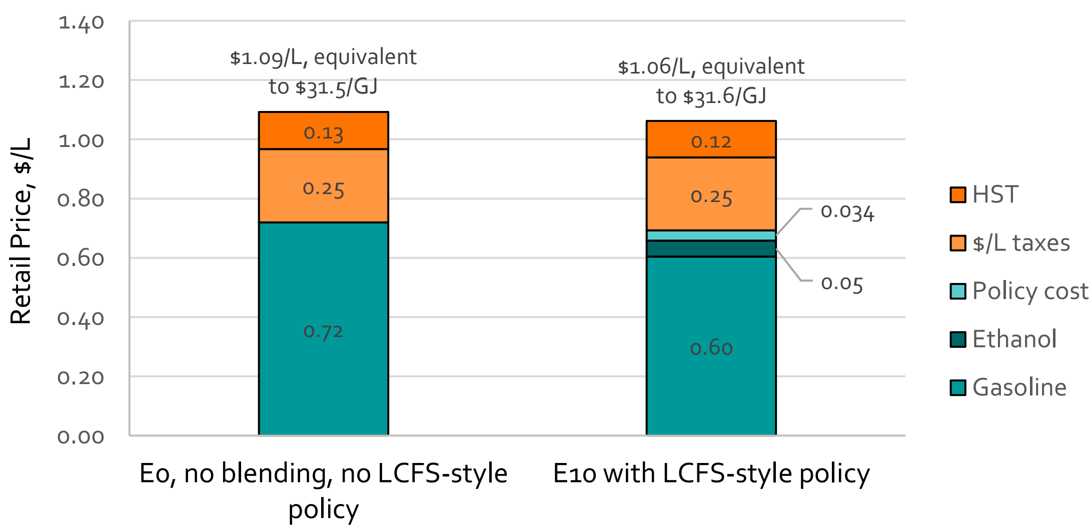
The GHG abatement cost broadly perceived by consumers under a LCFS-style policy is defined by the average abatement costs of the actions used to make that consumer's fuel compliant with the policy. This abatement cost is not solely defined by the policy credit price, which represents the abatement cost of the costliest action needed for overall policy compliance (i.e. the marginal cost). In reality, most compliance in response to LCFS-style policies is generated internally by fuel providers when blending low-carbon fuels. Only a small subset of compliance is purchased as credits at the marginal abatement price of the policy, so the credit price does not represent the average abatement cost. For example, since 2013, the start of British Columbia's low-carbon fuel requirement, to 2018 (most recent year with complete data), 11% of compliance credits were obtained by trading while the rest were generated by fuel providers when blending lower-carbon fuels.[21]

Using the example of E10 above, the average abatement cost perceived by a consumer is just \$10/tCO_2e even though the marginal compliance cost in this example came from the purchase of credits at \$150/tCO_2e. This average cost is based on a comparison with a counterfactual scenario where E0 is used without any policy requirement to blend biofuel or reduce the average fuel CI. The abatement cost comes

21 Government of British Columbia, RLCF-17: Low Carbon Fuel Credit Market Report

from energy costs of $31.5/GJ ($1.09/L) for E0 versus $31.6/GJ ($1.06/L) for E10 including the credits require to comply with the policy (Figure 6). Recall that ethanol is roughly 33% less energy dense than gasoline, thus, as in this example, a liter of E0 can be more expensive than E10 per liter, but can still cost less per GJ. Consistent with the cost-impact methodology used later in this analysis, the gasoline in the E0 fuel is more expensive than the gasoline used with E10 since it must be produced with a higher octane rating rather than having its octane raised with the addition of ethanol. This octane value brings down the abatement cost of using ethanol to comply with the LCFS-style policy. While there is some uncertainty in the magnitude of the octane value of ethanol, that uncertainty does not change the fact that the average abatement cost experienced by a consumer is not the same as the policy credit price.

Figure 6: Inputs to calculating the average GHG abatement cost when using E10 and compliance credits to comply with a hypothetical LCFS-style policy



Note: wholesale fuel costs and fuel taxes are based on Ontario in 2017. LCFS credit price is $150/tonne. The gasoline CI is 87 gCO_2e/MJ, the ethanol CI is 40 gCO_2e/MJ, and the LCFS target CI is 77 gCO_2e/MJ. Gasoline without ethanol must be produced with a higher octane and is more expensive than the gasoline blendstock used with ethanol (i.e. 0.72/L vs. $0.60/L÷90%=$0.67/L)

Abatement Costs with Foregone Refining Margins

The abatement actions that a fuel provider might use in response to a LCFS-style policy are significantly influenced by their costs. However, to understand which actions are used, it is important to include all costs, or perceived potential costs, that a fuel provider might experience when calculating abatement cost. In addition to the direct cost of an abatement action, a fuel provider might also consider the indirect cost of that action, by way of how it might change their revenues. For example, a refinery earns a margin on the product it refines (i.e. the refining margin) and refining and selling less product would reduce its revenues (i.e. there would be foregone refining margins on sales of a refined petroleum product).

Notably, when selling blended biofuels purchased from another producer, there is the potential that this action will reduce the quantity of gasoline or diesel that the refinery may sell. If this outcome is expected, the value of the foregone refining margin will be included in the abatement cost.

The following example illustrates that foregone refining margin could change the relative abatement costs of two actions available to a fuel provider. In this case, a fuel provider can reduce emissions by blending additional biodiesel into the diesel or adding carbon capture and storage (CCS) at their refinery hydrogen (H_2) unit. The calculations use the following assumptions:

- Abatement from CCS with H_2 costs $100/t$CO_2$e reduction.
- The fuel provider does not need additional investments in blending infrastructure.
- The fuel provider assumes the prices, CI values and fuel densities recorded for 2017[22] in the Biofuels in Canada analysis are representative of future conditions (using Canada fuel-weighted averages): biodiesel costs $0.75/L with a $0.05/L transportation cost, has a CI of 7.9 gCO_2e/MJ and a density of 35.4 MJ/L; wholesale diesel (B0) sells for $0.68/L with a CI of 93.8 gCO_2e/MJ, and a density of 38.7 MJ/L. The refining margin (net revenue) is $0.34/L,[23]
- The fuel provider cannot pass the additional costs on the consumers.
- Both actions would count towards compliance under a LCFS-style policy and would generate credits worth $150/t$CO_2$e.

Based on fuel costs and properties alone, the abatement cost of blending additional biodiesel is $61/t$CO_2$e. This is the abatement cost if the fuel provider can find an alternative market for all of its prior diesel production (e.g. in a region without an LCFS-style policy) and blending additional biodiesel has no impact on overall diesel sales. Therefore, the fuel provider would first choose to reduce emissions by blending

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[22] 2017 provides a convenient data year for this example because there was a positive abatement cost associated with using biodiesel. In 2018 and 2019, that abatement cost is negative, i.e. it theoretically saves money to use biodiesel. This does not change the fact that foregone revenues can change the abatement cost experienced by a fuel provider, but it complicates the example.

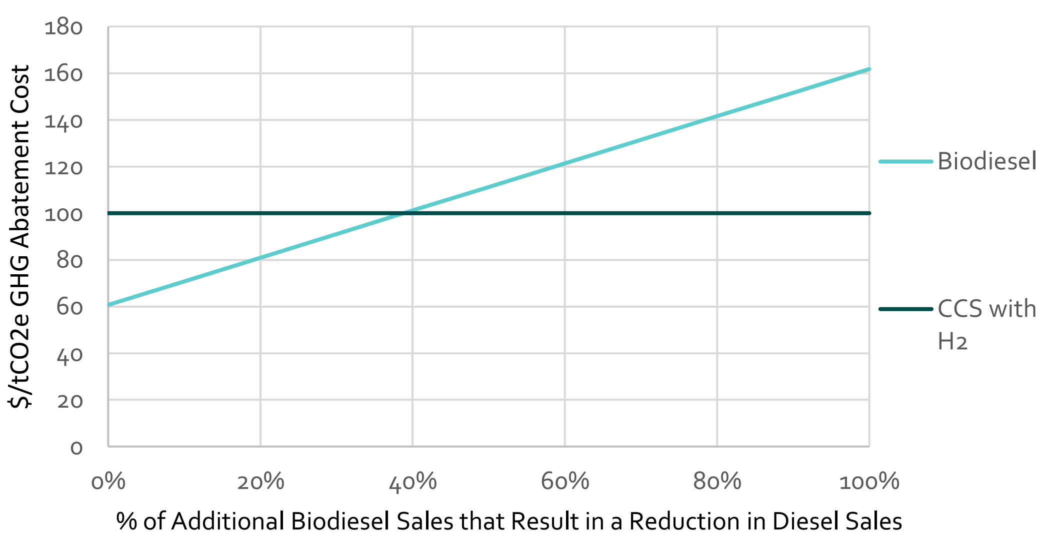
[23] Kent Marketing, http://kentreports.com/wpps.aspx

biodiesel and might also invest in CCS since both abatement actions are less than the credit price.

However, if selling more biodiesel does reduce diesel sales and result in a foregone refining margin, then the fuel provider loses $0.34 for each liter of diesel not sold. To reduce GHG emissions by one tonne, the fuel provider would have to sell 11.6 GJ of biodiesel, equivalent to 301 L of diesel. If the biodiesel sales completely displace an energetically equivalent amount of diesel, then there is $101 in foregone refining margin per tonne of GHG reduction and the net abatement cost is $162/tonne. In this case, the fuel provider would only choose to reduce emission with CCS and would not blend more biodiesel since its abatement cost is greater than the credit price.

It is likely that the impact of additional biodiesel blending on diesel sales is somewhere between the maximum and minimum cases explained above. Still, the abatement cost of biodiesel in this example is sensitive to its impact on diesel sales. If just 40% of the additional biodiesel sales offset an energetically equivalent amount of diesel sales, CCS is the lower cost abatement action (Figure 7). In reality, this would be further complicated by changes in corporate income tax, lost retail revenues for integrated refiners, potential changes in wholesale or retail prices and economies of scale (i.e. it costs less per liter to refine greater volumes). Nonetheless, this example indicates why a fuel provider might prefer to reduce the emissions intensity of their fuels rather than sell biofuels, even when that latter action appears to have a lower abatement cost.

Figure 7: Relative abatement cost of blending biodiesel versus capturing and storage CO_2e as a function of how biodiesel sales affect diesel sales.



3. Methodology

3.1. Process

Table 7 outlines the tasks we undertook in this study as well as our approach for each of these tasks.

Table 7: Study method by task

Task	Approach
1. Tabulate renewable fuel use and requirements	Provincial and federal renewable fuel regulation and Renewable and Low Carbon Fuel Regulation compliance data (published, direct communication) were collected. An updated summary of regulations in each jurisdiction was also collected. The data in this report includes January 1, 2010 to December 31, 2018, the most recent data period available for most jurisdictions.
2. Characterize biofuel product use	Biofuel products were defined as: ethanol, biodiesel, or hydrogenation-derived renewable diesel (HDRD). These products were further disaggregated by biomass feedstocks as identified and estimated from personal correspondences with government contacts and biofuel market experts, publications, or based on region of origin.
3. Characterize biofuel CI and impact on energy efficiency to estimate GHG reductions	Carbon intensities (CI) were defined with GHGenius (v.4.03a), data from 1 & 2 above and with a review by government contacts and industry experts. Energy efficiency (i.e. change in energy per km) impacts (or lack thereof) are defined by literature review. These assumptions were used to estimate the GHG impact of biofuel. Furthermore, this report illustrates how average CI of fuel types (e.g. ethanol, biodiesel) can change through time using the fuels registered under the BC fuels policy. BC is used as a case study because it is one of the few jurisdictions where CI is documented by fuel.
4. Estimate the impact of biofuel on energy costs	Wholesale ethanol and biodiesel prices from the Chicago Board of Trade were used to estimate the landed price (based on typical rail shipping rates) of these fuels in major Canadian cities. Regular gasoline and diesel prices were used in these cities (NRCAN data) to estimate the unblended wholesale price of the petroleum fuels. HDRD prices were estimated using Neste Oyj's financial materials for investors. These prices, along with marketing margins and taxes were then used to quantify how biofuels may have affected the fuel costs for consumers, accounting for the volumetric energy content of biofuels and the impact of ethanol on the octane rating of gasoline/ethanol fuel blends.

Task	Approach
5. Produce estimated results for 2019	All results (volumes, GHG and cost impacts) were estimated for 2019, assuming constant biofuel blending rates from 2018 and using Statistics Canada data to define the size of the gasoline and diesel pools. Carbon intensities for 2019 are taken from GHGenius or assumed based on provincial data for 2018

3.2. Summary of Inputs and Updates to the Methodology

Table 8 summarizes the data and assumptions used in this analysis to complete tasks 1 through 4. The data used in the analysis was either obtained through direct communication with government contacts or from published data (represented in green). Some data required assumptions (represented in yellow). For example, several months of fuel sales data have been suppressed by Statistics Canada. This redacted data was estimated from the average volume reported in other months of the same year, or pro-rated to match energy demand trajectories as published by Statistics Canada.

Table 8 also flags the greatest uncertainties in orange, representing data gaps. For example, neither Québec nor the Atlantic provinces have reporting mandates for biofuels blended into transportation fuels. To infer the volume of ethanol, biodiesel, and HDRD consumed in these provinces, we used the difference between national consumption totals, reported by Environment and Climate Change Canada (ECCC) for 2011-2018[24,25] and the data we collected. Because ECCC does not report renewable fuel consumption in 2010, consumption in that year is based on the US Department of Agriculture Global Agricultural Information Network (USDA GAIN). Note that for 2018, we increased the national total consumption of biomass-based diesel relative to what was reported by ECCC, from 684 to 711 million L/yr. This decision is based on information from industry contacts indicating that some renewable fuel was imported pre-blended with diesel and was not picked up by ECCC's accounting.

[24]Environment and Climate Change Canada, 2016, Renewable Fuels Regulation Report: December 15, 2010 to December 31, 2012.

[25] Environment and Climate Change Canada, 2020, Open Data: Renewable Fuels Regulations 2013, 2014, 2015, 2016, 2017 and 2018

Biomass-based diesel consumption in Ontario was previously a substantial uncertainty, but this year's analysis now has data for this value in 2018. Furthermore, the 2018 data supports the estimates made for 2016 and 2017. Volumes in these years are based on the assumption that fuel providers complied with the *Greener Diesel Regulation* using a mix of biodiesel and HDRD with a relatively low CI (less than 12 gCO_2e/MJ). Specific CI assumptions and the breakdown between biodiesel and HDRD are listed in "Appendix B: Biofuel Type and Feedstock Assumptions and Data".

CI values are mostly still taken from GHGenius 4.03a. However, the CI for gasoline in all years and regions has been increased by 7 gCO_2e/MJ to approximately 70 gCO_2e/MJ based on input from $(S\&T)^2$ Consultants. The updated gasoline CI's closely align with what is in the latest GHGenius version 5.0 and the gasoline combustion GHG coefficient used by ECCC in the National Inventory Report. These sources account for emissions of carbon monoxide and volatile organic compounds that oxidize to CO_2 in the atmosphere. For example, ECCC uses a combustion GHG coefficient of 67 to 71 gCO_2e/MJ for light-duty vehicles operating under tier 1 and tier 2 emissions standards,[26] whereas GHGenius 4.03a uses 63 gCO_2e/MJ. The Canada fuel-consumption weighted average CI for gasoline (upstream and downstream) is approximately 92 gCO_2e/MJ.

This current edition of the Biofuels in Canada analysis includes some methodological changes that affect the results for 2018 and prior years:

- The cost of transporting biofuels by rail has been updated. The new method produces a cost per kilometer that scales inversely with the transportation distance to account for the economies of scale when using rail-freight over longer distances.
- All inputs and results that are averaged for Canada are now consistently calculated using fuel-consumption weighted averages rather than simple averages or population weighted averages. Where possible, all results such as GHG and fuel cost impacts for Canada are reported as the sum of provincial components.
- All inputs for Atlantic Canada are produced using population weighted averages of data for the individual provinces in that region (fuel-consumption weighted is not possible with the data available for these provinces).
- We have made minor corrections to some provincial fuel tax values used in previous years.

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[26] Environment and Climate Change Canada, 2019, National Inventory Report 2019, Emissions Factors Table A6-12

- For users of the accompanying spreadsheet, it is now implemented using named tables and cells as well as formulas that use structured references. This does not change the methodology of the analysis, though it does change how values are calculated. The "Read Me" tab in the spreadsheet provides more detail on this and links to tutorials.

As noted in Table 7, results for 2019 are preliminary estimates that are based on several inputs and assumptions. First, we assume that biofuel blending rates by province (i.e. % by volume) remained constant between 2018 and 2019. Because blending rates have been relatively stable for the past several years, this is a reasonable assumption for all provinces in the analysis.

Second, we derive the size of the gasoline and diesel pools in each province using Statistics Canada data (Table: 25-10-0076-01, Petroleum products supply and disposition, monthly, domestic consumption of diesel fuel oil and motor gasoline). Because there is a difference between the fuel consumption reported by Statistics Canada and what is reported in the Biofuels in Canada analysis, we only used the percent change from 2018 to 2019 to calculate national consumption, not the absolute values. For 2019, gasoline and diesel consumption data are available from Statistic Canada only at a Canada-wide level, rather than disaggregated by province, as it was in 2018 and earlier. Therefore, consumption by province for 2019 in the analysis is a function of national consumption in that year, pro-rated to each province proportional to provincial consumption in 2018.

Furthermore, there is some concern that there may have been a change in Statistics Canada's data collection method for 2019-onward versus 2018 and earlier. For example, some industry experts are unsure if biofuels that that are blended downstream of a refinery are still included in the gasoline and diesel consumption data. Notably, the 2019 data shows an 8% reduction in gasoline and a 9% reduction in diesel consumption since 2018, which is an unusually large change when compared to the data available prior to 2019. The lack of provincial data disaggregation and changes in data collection methodology will add additional uncertainty to future Biofuels in Canada analyses.

Finally, the 2019 results also require CI assumptions. For most provinces, CI values come from GHGenius 4.03a. For Ontario, we assume a constant average CI for biomass-based diesel across 2018 and 2019. For British Columbia, we assume a constant HDRD CI and biodiesel CI for 2018/2019. Because CI for ethanol consumed in British Columbia has been declining steadily, the value for 2019 is an extrapolation of the 2017/2018 trend.

Table 8: Summary of Inputs (data in green, assumptions in yellow, major uncertainties in orange)

<table>
<tr><th></th><th>BC</th><th>Alberta</th><th>Saskatchewan</th><th>Manitoba</th><th>Ontario</th><th>Québec</th><th>Atlantic</th></tr>
<tr><td>Gasoline volume</td><td rowspan="4">RLCFRR Summary: 2010-2018. Gasoline and diesel volumes are the total, not the non-exempt volume</td><td>For 2010 Statistics Canada Table: 25-10-0044-01, domestic sales
2011-2018: From govt. contact</td><td>Statistics Canada Table: 25-10-0044-01, domestic sales</td><td rowspan="4">Data from govt. contact</td><td rowspan="2">Data from govt. contact</td><td>Statistics Canada Table: 25-10-0044-01, domestic sales</td><td>Statistics Canada Table: 25-10-0029-01, motor gasoline</td></tr>
<tr><td>Ethanol fuel volume</td><td>Data from govt. contact</td><td>Average % blending rate provided by govt. contact</td><td>Difference between national total reported under the RFS by ECCC[1] and sum from other provinces, pro-rated to QC and AT</td><td>Difference between national total reported under the RFS by ECCC[1] and sum from other provinces, pro-rated to QC and AT</td></tr>
<tr><td>Diesel volume</td><td>2010: Statistics Canada Table: 25-10-0044-01, domestic sales
2011-2016: from govt. contact</td><td>Data from govt. contact</td><td>2010 to 2017 Statistics Canada Table: 25-10-0044-01, domestic sales. 2018: data from govt. contact</td><td>Statistics Canada Table: 25-10-0044-01, domestic sales, with estimates of redacted data</td><td>Statistics Canada Table: 25-10-0029-01, diesel fuel oil</td></tr>
<tr><td>Biodiesel and HDRD volume</td><td>Data from govt. contact</td><td>Data from govt. contact</td><td>Provisional data from govt. contact for 2015. Estimates for 2016 and 2017. Data for 2018.</td><td>Same method as for ethanol</td><td>Same method as for ethanol</td></tr>
<tr><td>Biofuel feedstock</td><td>RLCFRR Summary: 2010-2018</td><td colspan="6">Assumptions reviewed by govt. contact and (S&T)[2] Consultants</td></tr>
</table>

	BC	Alberta	Saskatchewan	Manitoba	Ontario	Québec	Atlantic
Fuel Carbon Intensity	RLCFRR Summary: 2010-2018	GHGenius 4.03a by year for Alberta	GHGenius 4.03a by year for Saskatchewan	GHGenius 4.03a by year for Manitoba	Ethanol: GHGenius 4.03a by year for Ontario. Biodiesel/HDRD: avg. from govt. contact for 2015 and 2018, estimated for 2016 and 2017	GHGenius 4.03a by year for Québec	GHGenius 4.03a by year for Canada East
Wholesale gasoline and diesel price	NRCAN,[2] for Vancouver	NRCAN,[2] for Calgary	NRCAN,[2] for Regina	NRCAN,[2] for Winnipeg	NRCAN,[2] for Toronto	NRCAN,[2] for Montreal	NRCAN,[2] for Halifax
Wholesale ethanol price	Chicago Mercantile Exchange futures price						
Wholesale biodiesel price	Chicago Mercantile Exchange spot price						
Wholesale HDRD price	Neste Investor Financials[6]						
Marketing margin	Kent marketing,[3] for Vancouver	Kent marketing,[3] for Calgary	Kent marketing,[3] for Regina	Kent marketing,[3] for Winnipeg	Kent marketing,[3] for Toronto	Kent marketing,[3] for Montreal	Kent marketing,[3] for Halifax
Fuel Taxes	NRCAN, Fuel Consumption Taxes in Canada[7]						
Carbon costs	Government of BC, British Columbia's Carbon Tax[8]	Government of Alberta, Alberta's Carbon Levy[9]	NA	NA	Government of Ontario, Past auction information and results[10]	Government of Québec, The Carbon Market[11]	NA
Biofuel transportation cost	5-13 $/bbl (2019), applied to biofuels based on distance between Chicago and representative city[4]						
Ethanol octane	Used a value of 113, corresponding to ethanol used in low concentration blends						
Value of octane	Value in $/octane point/L based on difference in wholesale price between regular and premium gasoline in the United States[5]						
Energy efficiency	Assume vehicle energy efficiency (e.g. km/GJ fuel consumed) is constant regardless of the blend.[12]						
Refinery GHG intensity	Assume that petroleum refining GHG intensity is independent of the biofuel blend.						
Impact of biofuels on refining and marketing margins	Assume the refining margins for petroleum fuels would be same in a counterfactual scenario without biofuel blending. The refining margin is the $/L net revenue of refiners, embedded in gasoline and diesel wholesale prices from NRCAN. Also assume the marketing margin would be the same if there were no biofuel. The marketing margin is the $/L net revenue of the fuel retailers.						

1) ECCC, Open Data reported under the Renewable Fuels Regulations, 2010-2012, 2013-2014, 2015, 2016, 2017 and 2018. National total for biomass-based diesel in 2018 was increased slightly based on information from industry contacts.

2) Natural Resources Canada, 2020, Daily Average Wholesale (Rack) Prices. http://www2.nrcan.gc.ca/eneene/sources/pripri/wholesale_bycity_e.cfm

3) http://charting.kentgroupltd.com/

4) Gallagher, Paul and Denicoff, Marina. 2015. Ethanol Distribution, Trade Flows, and Shipping Costs, Iowa State University Economics Technical Reports and White Papers Accessed from https://lib.dr.iastate.edu/econ_reportspapers/45

5) EIA, 2020. Petroleum & Other Liquids: Weekly Retail Gasoline and Diesel Prices. Accessed from: https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm

6) Neste. 2020. Annual Report 2019, Accessed from: https://www.neste.com/corporate-info/investors/materials-0

7) Natural Resources Canada. Fuel Consumption Taxes in Canada. Accessed from: https://www.nrcan.gc.ca/energy/fuel-prices/18885. Note that when tax rates change mid-year, this analysis uses the value that applied during the majority of that year.

8) Government of British Columbia. British Columbia Carbon Tax. Accessed from: https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax. Note that when carbon tax rates change mid-year, this analysis uses the value that applied during the majority of that year.

9) Government of Alberta. 2020. About tax and levy rates and prescribed interest rates. Accessed from: https://www.alberta.ca/about-tax-levy-rates-prescribed-interest-rates.aspx#carbon-levy. Note that when carbon levy rates change mid-year, this analysis uses the value that applied during the majority of that year.

10) Government of Ontario. Past auction information and results. Accessed from: https://www.ontario.ca/page/past-auction-information-and-results

11) Government of Québec. The Carbon Market: Cap-and-Trade Auction Notices and Results. Accessed from: http://www.environnement.gouv.qc.ca/changements/carbone/ventes-encheres/avis-resultats-en.htm

12) Weight of evidence indicates that there is no change in energy efficiency (see literature review in 2019 Biofuels in Canada report):

Niven, R.K., 2005, Ethanol in gasoline: environmental impacts and sustainability review article. Renewable and Sustainable Energy Reviews 9, 535-555. doi.org/10.1016/j.rser.2004.06.003

Yan, X. et al., 2013, Effects of Ethanol on Vehicle Energy Efficiency and Implications on Ethanol Life-Cycle Greenhouse Gas Analysis. Environmental Science & Technology 47, 5535-5544. DOI: 10.1021/es305209a

US Environmental Protection Agency, 2016, Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025.

Coordinating Research Council, 2018, Renewable Hydrocarbon Diesel Fuel Properties and Performance Review (CRC Report No. DP-08-18).

4. Results and Discussion

The results section summarizes data on the biofuel content of transportation fuels sold in Canada. Also included in the results is an analysis of the avoided GHG emissions, and cost impacts of blending biofuels with gasoline and diesel. The analysis reported in this section focuses on biofuels at the national level. However, the same analysis was done for each Canadian province. The analysis and corresponding data on individual provinces are in the associated excel spreadsheet, named "Biofuels in Canada Analysis, 2020-10-09".

4.1. Fuel Consumption

Figure 8 summarizes collected and estimated data for transportation fuel consumption in Canada. This includes volumes exempt from biofuel blending policy. The data shows that, compared to other biofuels, substantially more ethanol has been consumed in Canada between 2010 and 2018.

Figure 8: Fuel consumption, 2010 to 2018 with an estimate for 2019

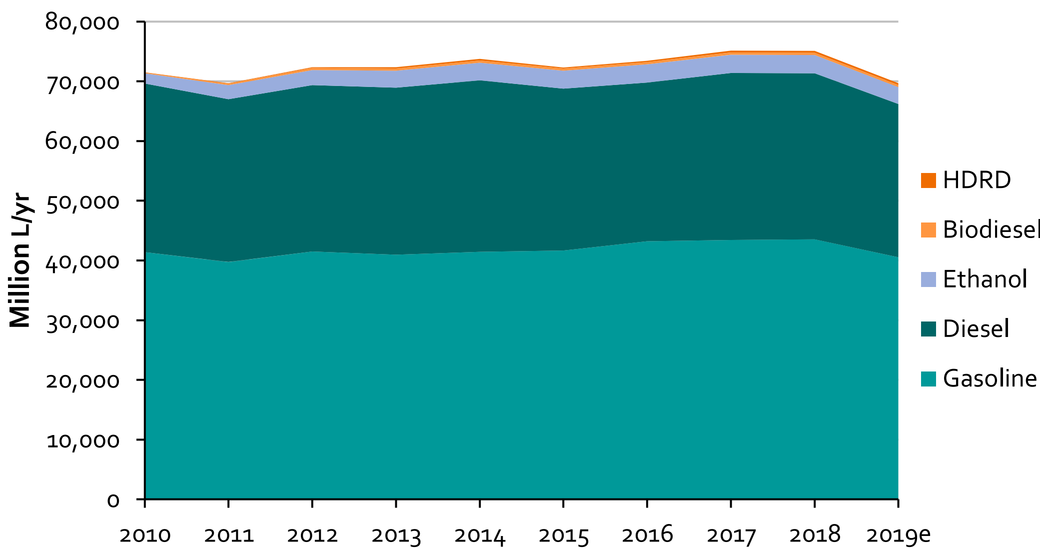


Table 9 summarizes the data in Figure 8. Our analysis shows that the volume of ethanol consumed annually has increased from roughly 1,700 million litres in 2010 to 3,034 million litres in 2018 (0.5% lower than in 2017). The estimate for 2019 is only 2,817 million litres. While we have assumed the ethanol blending rate has remained constant, data from Statistics Canada indicates that the total size of fuel pool into which ethanol is blended declined by 7% from 2018 to 2019. As noted earlier, we have some concerns about the comparability of this data across those years.

Table 9: Canadian fuel consumption in million litres per year (2010 and 2015 to 2018, with an estimate for 2019)

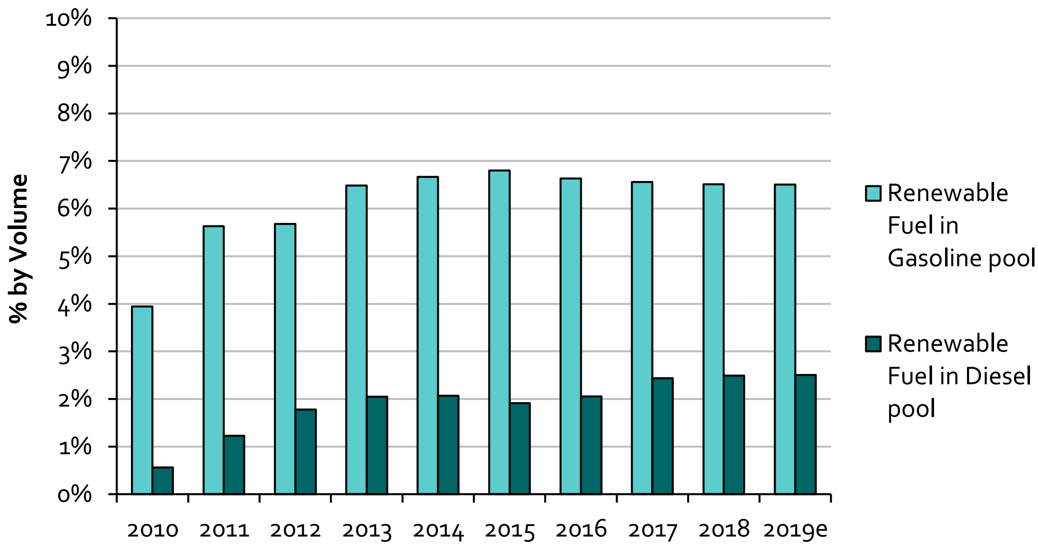
Fuel type	2010	2015	2016	2017	2018	2019 (est.)
HDRD	37	193	217	324	343	316
Biodiesel	124	334	340	376	368	345
Ethanol	1,701	3,041	3,069	3,047	3,034	2,817
Diesel	28,224	27,087	26,566	27,987	27,833	25,697
Gasoline	41,415	41,669	43,231	43,409	43,542	40,515

The volume of biodiesel consumed annually has also increased substantially since 2010, rising from roughly 123 million litres in 2010 to 368 million litres in 2018. HDRD is now blended into diesel in similar volumes as biodiesel, with consumption calculated at 343 million L in 2018 (Table 9). The total quantity of biomass-based diesel consumption that we have assumed across Canada in 2018 is 711 million litres per year, based on input from industry contacts (1.5% larger than in 2017). Note that this is 4% higher than what ECCC reports within the *Renewable Fuels Regulation* data. The discrepancy largely comes from HDRD, where this fuel may be imported (either blended or unblended) but recorded as a fossil diesel import. Note that, in general, the volume of HDRD in the Canadian fuel pool is more uncertain compared to other biofuels. Only British Columbia and Alberta report HDRD consumption in those respective provinces and the allocation of HDRD consumption to other provinces is confounded by the uncertainty in the total quantity that is imported.

Our estimate for total biomass-based diesel consumption in 2019 is 661 million litres. As with ethanol, we have assumed that the blend rate was constant between 2018 and 2019. Because Statistics Canada data shows a reduction in total diesel consumption across those years, the quantity of biomass-based diesel is also smaller.

Figure 9, shows the percentage of renewable fuel in the gasoline pool (ethanol) and in the diesel pool (biodiesel plus HDRD). Because of the uncertainty in the volume of HDRD consumed in Canada, biodiesel and HDRD are grouped together to avoid giving false precision. The percentages are based on total fuel consumption, including gasoline and diesel volumes exempted from biofuel blending policies. As well, the content does not include any policy-based adjustments to the renewable fuel share (e.g. a volume-equivalency bonus awarded for using for low-CI feedstocks or fuels, as is the case in Ontario's *Greener Diesel* regulation).

Figure 9: Renewable fuel content by fuel pool, 2010 to 2018 with an estimate for 2019



The ethanol content in Canadian gasoline was 6.5% by volume in 2018, down slightly from 6.6% in 2017 (Figure 9). The biomass-based diesel content in 2018 was 2.5%, up from 2.4% in 2017. As noted earlier, we have used the 2018 blending rates for the 2019 estimate.

The national average blend rates are above what is required by the federal *Renewable Fuels Regulation*, partly a result of provincial policies as well as the economies of scale for renewable fuel blending once blending infrastructure is acquired (e.g. supplying a fuel market with 10% ethanol, rather than the specific required percent, once blending infrastructure is built). Consequently, the data shows that blending rates differ substantially by province. While there is no sub-provincial data, blending rates likely vary within provinces as well.

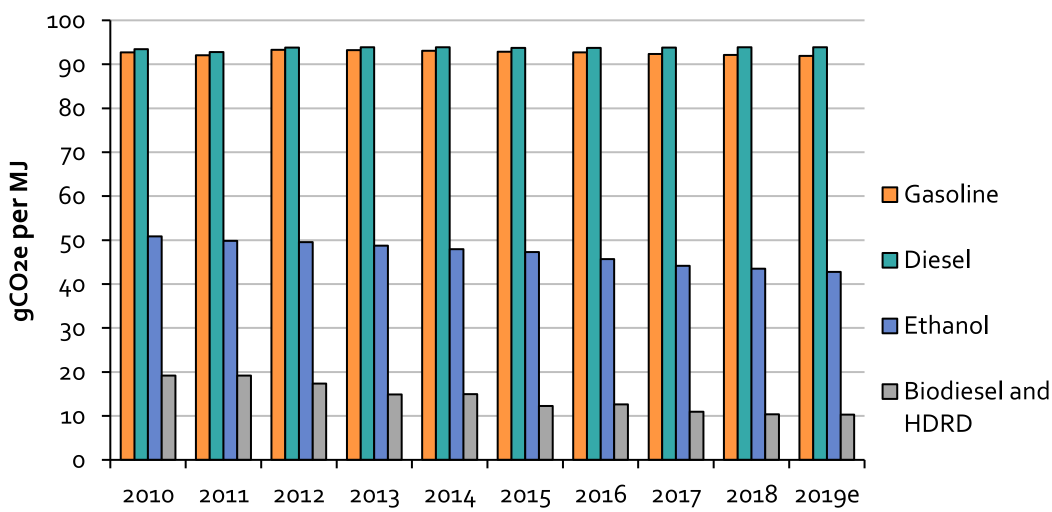
4.2. Lifecycle GHG Emissions

Figure 10 shows the estimated lifecycle CI (i.e. well to wheels or farm to wheels) of transportation fuels in Canada between 2010 and 2018, with an estimate for 2019. Because of the uncertainty in volume, feedstock, and CI, biodiesel and HDRD are grouped together to avoid giving false precision.

For most provinces, these CI estimates were based on average fuel CI from GHGenius 4.03a. However, for British Columbia, the CI's were obtained from provincial compliance reports which publish carbon intensities for ethanol, biodiesel, and HDRD, where CI values prior to December 31st, 2014, come from GHGenius 4.01b and the province does not retroactively revise these values. For Ontario, provisional data for the average biodiesel and HDRD CI was obtained from a government contact for 2015 and 2018, while we estimated the CI for 2016 and 2017. CI's for Ontario are assumed to be constant from 2018 to 2019, while CI's in British Columbia are assumed to be consistent with changes over previous years (further reduction in the ethanol CI, no additional reduction for biodiesel, no change for HDRD). For the rest of Canada, CI's in 2019 are taken from GHGenius 4.03a.

The CI for ethanol in 2018 is 42.7 gCO_2e/MJ, 15% below the value used for 2010. The weighted average for the biomass-based diesel CI in 2018 is 10.4 gCO_2e/MJ, 46% below the value used for 2010 (Figure 10). As discussed below, the causes of this change are the reported decline in fuel CI from the British Columbia RLCFRR and the Ontario Greener Diesel Regulation, as well as the estimated year over year CI reduction estimated with the GHGenius model.

Figure 10: Lifecycle CI by fuel type, for Canada, with estimate for 2019



GHG emissions resulting from direct land use changes are included in the lifecycle CI of biofuels. For example, this includes the GHG emissions resulting from the conversion of pasture or forest to crop land. These intensities are based only on direct land use changes, and do not include any potential indirect changes from increased biofuel demand. Some fuel regulations, such as the California Low-Carbon Fuel Standard include "indirect land-use change" (ILUC) emissions in the carbon intensities of biofuels. ILUC emissions are one type of "indirect effect" emissions that are applied to biofuels under the assumption that biofuel production increases agricultural commodity prices which indirectly result in more pasture and forest being converted to crop production. The data systems and lifecycle modelling to support accurate measurement of indirect-effect emissions for all fuels (fossil and renewable) are the subject of on-going research and policy debate. Regulators in Canada are stating that they will not include a quantitative factor for these emissions in current policy but will monitor the science and may include them in the future.[27] Currently the *Clean Fuel Standard* proposes developing criteria that would not allow fuels that have a high risk of producing indirect-land use emissions to generate credits.[28]

The results in Figure 10 suggest that the biofuels consumed in Canada offer significant lifecycle CI reductions relative to gasoline and diesel. The data implies that, on average in 2018, ethanol sold in Canada was 53% less carbon intensive than gasoline, while biodiesel and HDRD, are estimated to be 89% less carbon intensive than diesel.

Figure 10 also suggests that the CI of ethanol, biodiesel, and HDRD are decreasing over time. However, the regional carbon intensities used to produce Figure 10 are mostly based on default data from GHGenius 4.03a. This data assumes that the GHG intensity of inputs to biofuel production declines over time, hence the fuel CI declines as well (e.g. reduced GHG emissions associated with electricity consumption for biofuel refining, process improvements, increased agricultural yields and reduced fertilizer inputs per area farmed etc.).

In contrast, CI's for biofuels consumed in British Columbia are based on collected data, reported by fuel and feedstock to the government. The data suggest that from 2010 to 2018, the CI of ethanol decreased by 45%, the CI of biodiesel decreased by 84%, and the CI of HDRD decreased by 58% (Figure 11). This trend may indicate that the CI of renewable fuel production is decreasing, consistent with the year-over year improvements assumed in the GHGenius model. However, without broader monitoring of fuel CIs across North America, it is difficult to know if there is a general reduction in CIs or if the British Columbian data is an indicator of "fuel shuffling", where renewable fuels with low lifecycle CI's are sold in regulated jurisdictions, while fuels with higher intensities are sold in jurisdictions without policies that regulate CI.

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[27] Meyer, C., *Canada's Math May Overlook Carbon Pollution from Biofuels,* Canada's National Observer, April 18th, 2018

[28] Environment and Climate Change Canada, 2019, Clean Fuel Standard Proposed Regulatory Approach

Figure 11: Lifecycle CI by fuel type for British Columbia

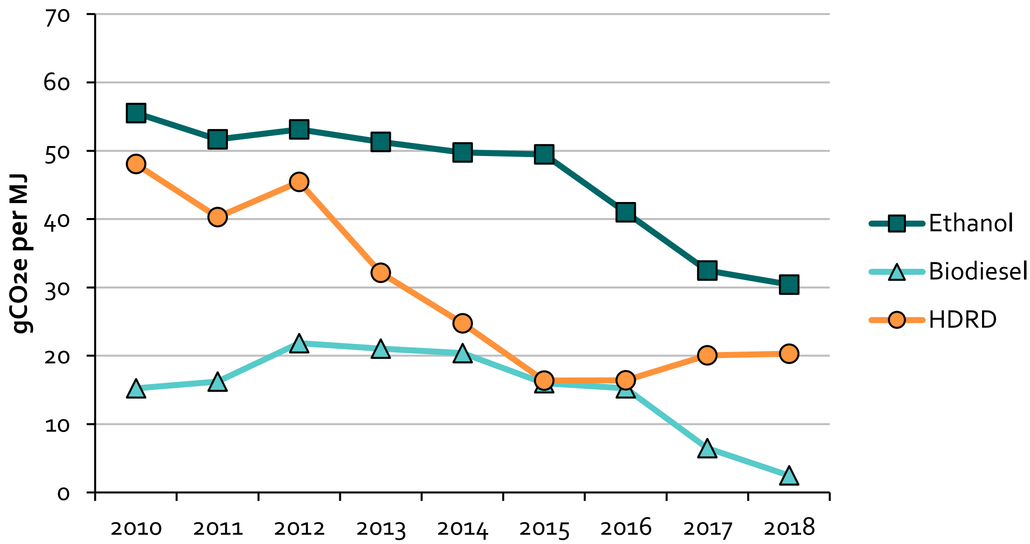


Figure 12 shows the avoided lifecycle GHG emissions in Canada resulting from biofuel consumption. Again, the avoided emissions are based on the volumes and CI's of biofuels described above, assuming biofuels displace an equal amount of fuel energy from their fuel pool (i.e. ethanol displaces gasoline, biodiesel and HDRD displace diesel). This analysis shows that the avoided GHG emissions in Canada resulting from biofuel consumption have increased from 2.1 $MtCO_2e$/yr in 2010 to 5.6 $MtCO_2e$/yr in 2018. Cumulative national avoided GHG emissions from 2010 to 2018 are estimated to be 40.0 $MtCO_2e$. The estimated annual reduction for 2019 is just 5.3 $MtCO_2e$/yr, where the reduction in avoided emission relates to the lower quantity of overall fuel consumption showing up in the data.

Figure 12: Avoided lifecycle GHG emissions, with estimate for 2019

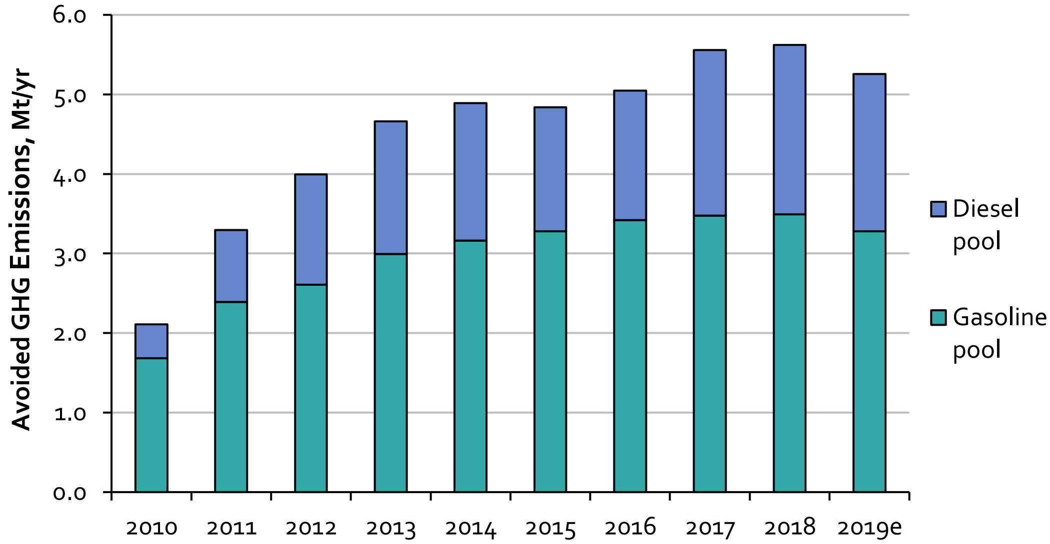
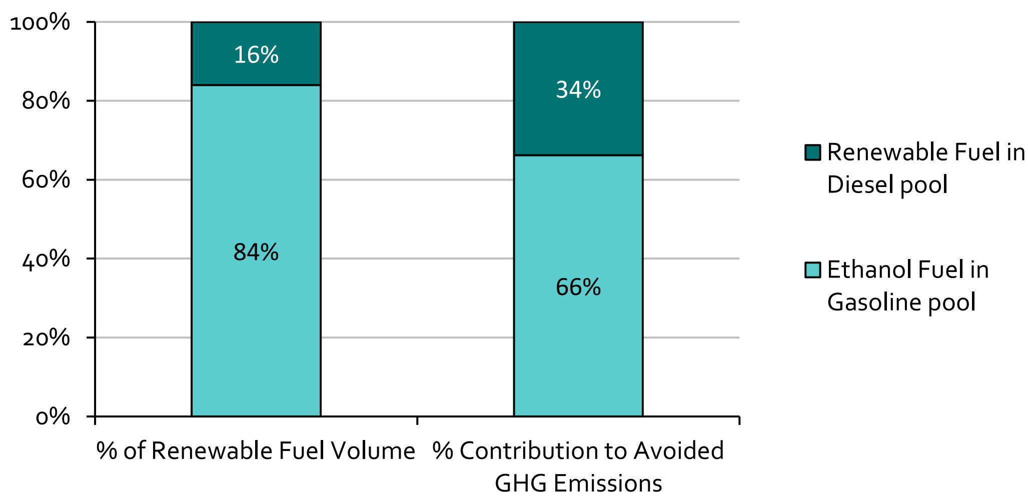


Figure 13 shows the percentage of renewable fuel volume in the gasoline and diesel pool compared with the percentage of avoided GHG emissions resulting from renewable fuel consumption in those fuel pools. Ethanol accounted for 84% of the renewable fuel volume consumed during the 2010-2018 period, but only produced 66% of the avoided GHG emissions. Biodiesel and HDRD, which generally have lower CI's than ethanol, yielded a proportionally larger GHG impact; these fuels accounted for 16% of renewable fuel consumption, but 34% of the avoided GHG emissions.

Figure 13: % of total renewable fuel volume vs. % contribution to avoided GHG Emissions from 2010 to 2018



The weight of evidence supports our assumption that biofuel blending does not affect the energy efficiency of vehicles (i.e. energy per km), but there is a non-zero probability that biofuel blends have increased energy efficiency and the GHG impact is very sensitive to this assumption. A meta-analysis by Geringer et al. (2014) found that at the 50th percentile, E10 increased engine energy efficiency by 1.8%.[29] Even scaling this impact to the ethanol blend rates in our analysis, this increase in efficiency would increase the cumulative GHG impact by 35%, or 5 $MtCO_2e$ from 2010 through 2018.

The avoided GHG emissions are calculated assuming that the CI of gasoline blendstock is independent of the ethanol blend. However, ethanol raises the octane rating of the fuel blend meaning the gasoline blendstock can have a lower octane rating than if no ethanol were used. Producing lower-octane gasoline blendstock requires less severe petroleum refining which in turn reduces the GHG emissions intensity of refining. A study exploring the impact of $30\%_{vol}$ ethanol vs. $10\%_{vol}$ ethanol blends found that the refining GHG intensity fell by 4-15%.[30] Prorating this impact for a $6\%_{vol}$ ethanol blend versus using no ethanol indicates that current levels of blending in Canada may reduce petroleum refining GHG intensity by 1-4%. The Canadian refining sector's GHG emissions in 2016 were 15.6 $MtCO_2e$[31]. A 1-4% decline in refining GHG intensity means that without ethanol blending, GHG emissions would have been 0.2 to 0.6 $MtCO_2e$/yr higher. This impact is not included in this analysis, but if it were, it would increase the cumulative GHG avoided between 2010 and 2018 by 2 to 6 $MtCO_2e$, or 5-15%.

4.3. Cumulative Costs

Below, we report our cost impact analysis resulting from the renewable fuel consumption described above, focusing on the impact of renewable fuel blending on consumer fuel expenditures. Refer to Appendix A: "Cost Analysis Methodology" for a detailed explanation of the methodology used for this cost analysis.

Renewable fuel consumption may change overall fuel costs for three reasons:

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[29] Geringer, B., Spreitzer, J., Mayer, M., Martin, C, 2014, *Meta-analysis for an E20/25 technical development study - Task 2: Meta-analysis of E20/25 trial reports and associated data*, Institute for Powertrains and Automotive Technology, Vienna University of Technology

[30] Vincent Kwasniewski, John Blieszner, Richard Nelson, 2016, *Petroleum refinery greenhouse gas emission variations related to higher ethanol blends at different gasoline octane rating and pool volume levels*, Biofuels, Bioproducts and Biorefining, 10, 36–46

[31] Natural Resources Canada, Comprehensive Energy Use Database

- First, the commodity price per volume of renewable fuels may be different from the price of the petroleum fuels they replace.
- Second, the energy content per volume of fuel may differ; for example, the energy contained in one litre of ethanol is approximately 33% lower than it is for gasoline. The energy content of biodiesel is approximately 9% lower than it is for diesel fuel. We have assumed no change in energy efficiency (i.e. distance per unit of energy) resulting from renewable fuel use. In other words, if a renewable fuel has less energy content per volume, we assume the volume of fuel consumed rises proportionally, so a consumer is buying more litres of fuel to drive the same distance. Although some of the sources we reviewed indicate that using biofuel blends, especially gasoline/ethanol blends, can allow vehicles to operate with greater energy efficiency, the weight of evidence in our literature review indicates that this benefit is likely not realized by the current fleet of vehicles that is not optimized for biofuel blends.
- Finally, cost reductions may arise due to different biofuel properties, such as: changes in fuel octane value (i.e. the anti-knock index of a gasoline blend); combustibility (i.e. the extent to which more complete combustion occurs with biofuel use, minimizing air pollution and associated health impacts); and, lubricity (i.e. the extent to which biodiesel fuel reduces friction and wear in the engine). Of these biofuel properties, this cost analysis only accounts for the octane value of ethanol.

Gasoline in North America must meet a standard octane value before it can be sold to the consumer. Refiners have various methods to raise the octane value of gasoline blendstock, one of which is the addition of ethanol to gasoline. The U.S. Energy Information Administration (EIA) estimates that American refiners produce gasoline blendstock with octane 84, which is raised to 87 (regular gasoline) with the addition of ethanol.[32] When used in a gasoline blend, ethanol has an octane rating of 113.[33] Consequently, the ethanol can be blended with a lower-octane gasoline blendstock. Based on the price spread between regular gasoline (octane 87) and premium gasoline (octane 91 or more), one can infer that raising octane imposes a cost. Therefore, using lower-octane gasoline blendstock with ethanol is a potential cost-saving opportunity that may offset any additional cost related to using ethanol.

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[32] U.S. Energy Information Administration, 2013, Price spread between regular and premium gasoline has changed over time. https://www.eia.gov/todayinenergy/detail.php?id=11131

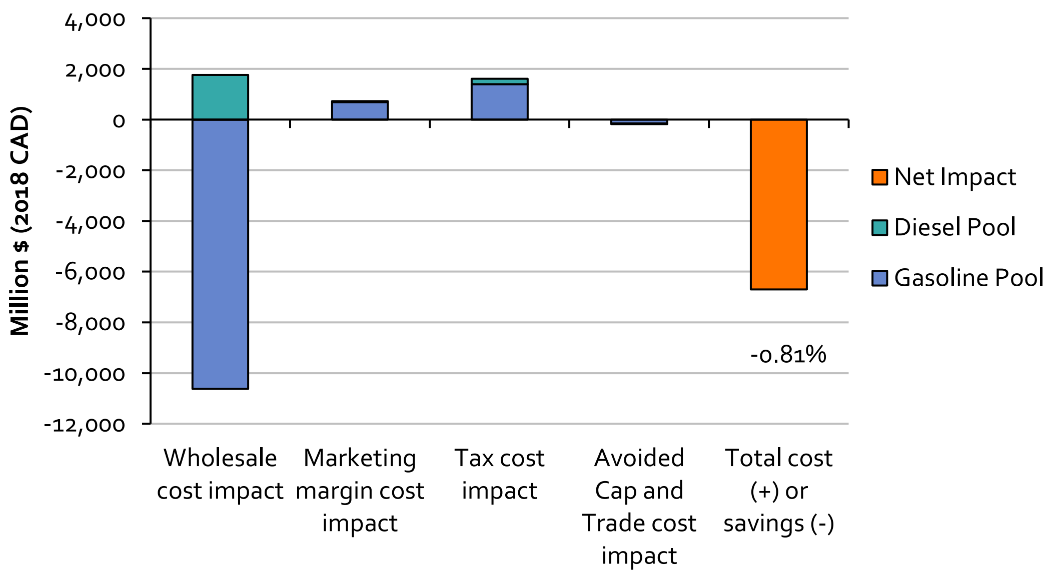
[33] 113 to 115 is a typical value for blends cited by EIA https://www.eia.gov/todayinenergy/detail.php?id=11131. This value corresponds to ethanol used in low concentration blends. The octane rating of pure ethanol is 100.

Note that we do not know if Canadian refiners are capturing the octane value of ethanol. In this analysis, we assume they do. Therefore, the cost analysis presents a reasonable scenario of what the cost of using renewable fuel could be, though the octane costs savings may not be realized in all cases.

This value of octane is only included insofar as it reduces the cost of gasoline blendstock used with ethanol; any energy or GHG reduction that may occur at the refinery due to producing a lower octane blendstock is not included.

Figure 14 shows the cumulative change in consumer fuel costs resulting from renewable fuel blending in Canada from the start of 2010 to the end of 2018. We estimate that the net-costs have diverged by less than 1% relative to what they would have been without biofuel consumption. If all costs and savings are passed onto consumers, their fuel expenditures were 0.81% lower, equivalent to a savings of $6.7 billion over nine years. Note that all costs in the analysis are expressed in 2018 CAD.

Figure 14: Cumulative cost impact resulting from ethanol blending in the gasoline pool and biomass-based diesel blending in the diesel pool (2010-2018), total % change in data label



The net impact on consumer cost comes from both the gasoline and diesel pool, and is composed of:

- **The wholesale cost** including the commodity cost and the refining margin, which is the net cost and revenue for fuel refining, where we assume that differences in wholesale prices are reflected in retail prices. This cost component includes the octane value of ethanol but does not include other cost benefits like reduced air pollution and health impacts. The wholesale cost of using ethanol in the gasoline pool is negative due, in part, to the octane value of ethanol which reduces the cost of the gasoline blendstock. Without ethanol, the cost of the gasoline would have otherwise been higher, ranging between ¢1 and ¢5/L over the course of this analysis depending on the value of octane in a given year. This savings more than offsets any increase in the unit energy cost of the fuel blend due to the lower energy density of ethanol, with a wholesale savings from ethanol use of $10.63 billion from 2010-2018. In the diesel pool, the wholesale cost is positive because biodiesel and HDRD are on average more expensive than diesel, resulting in a wholesale cost of $1.77 billion from 2010 to 2018. However, the diesel pool wholesale cost impact could have been much lower if fuel suppliers used more low-cost biodiesel. This action was possible: the results show that on average in Canada, biodiesel has only accounted for roughly 1% of the diesel pool volume, well below even the most conservative estimate of the fraction that can be easily blended into diesel.

- **The marketing margin**, which is the net cost and revenue for fuel marketers (e.g. transport and distribution from fueling stations). Marketing margins are based on historic data and we have assumed they would have been the same even if no renewable fuel had been used. Margins generally range from 6 to 12 cent/L depending on the region and fuel in question. Because biofuels are less energy dense than petroleum fuels, using biofuels involves consuming a greater volume of fuel. Therefore, we have assumed the marketing cost is higher (e.g. more fuel delivery trucks are needed to carry the same amount of energy to fuelling stations). This is most noticeable with ethanol because it is roughly 33% less energy dense than gasoline. Therefore, ethanol consumption increased the marketing cost paid by consumers by $690 million. Because diesel and HDRD are only slightly less energy dense than petroleum diesel, the cumulative marketing cost change in the diesel pool is only $32 million.

- **The tax cost**, which results from the application of taxes based on the volume of fuel sold (i.e. excise taxes and the carbon tax in BC (full period) and carbon levy in Alberta (2018 and part of 2019) where biofuels are subject to the full carbon tax) and sales taxes (e.g. GST and HST). The federal excise tax is $0.10/L for gasoline and $0.04/L for diesel. Provincial excise taxes range from $0.13 to $0.33/L. As mentioned earlier, because biofuels are less energy dense than petroleum fuels, a consumer must purchase a greater volume of fuel to obtain the same amount of energy. Consequently, consumers pay additional excise taxes. For example, the federal excise tax on gasoline with 10% ethanol is roughly 2.98 $/GJ, but only 2.88 $/GJ for gasoline with no ethanol. Due to ethanol's lower energy density, the tax cost resulting from ethanol blending is large, roughly an additional $1.40 billion over eight years relative to a scenario with no biofuel consumption. At only $219 million, the tax cost related to lower energy densities is much smaller in the diesel pool. Because biofuel blending can change the retail price of fuel, sales taxes that are charged as a percent of the retail price also result in different taxation on biofuel blends versus gasoline and diesel with no biofuel. For example, ethanol is typically cheaper per volume than gasoline. Combined with the assumption that the octane boost from ethanol further reduces the cost of gasoline blendstock, ethanol blends have a lower per litre retail price than the counterfactual gasoline without ethanol. Consequently, the sales tax per litre would be higher in the counterfactual scenario. Where sales tax rates are high, such as with the 13% HST in Ontario, this difference in sales taxes can substantially offset the tax cost impact from the federal excise tax and provincial fuel taxes. On the other hand, the volumetric retail prices of biomass-based diesels are generally higher than petroleum diesel so sales taxes per litre are also higher, increasing the overall tax cost impact.

- **The avoided cap and trade costs**, which result from the GHG emissions cap and trade systems operating in Québec, since 2015, and in Ontario, for 2017 to mid-2018. The cap and trade systems add a carbon cost to gasoline and diesel that will affect the wholesale price of these fuels. Biofuels are exempt from the cap and trade systems, but there is generally no price distinction between biofuel blends and fuels without biofuels at the wholesale 'rack' for fuel distribution, indicating that the cap and trade cost is being spread evenly across all fuels. The avoided cap and trade costs represent the additional carbon costs that would have been incurred without biofuel consumption. The cost impact calculated here is a savings of $153 million in the gasoline pool and $28 million in the diesel pool.

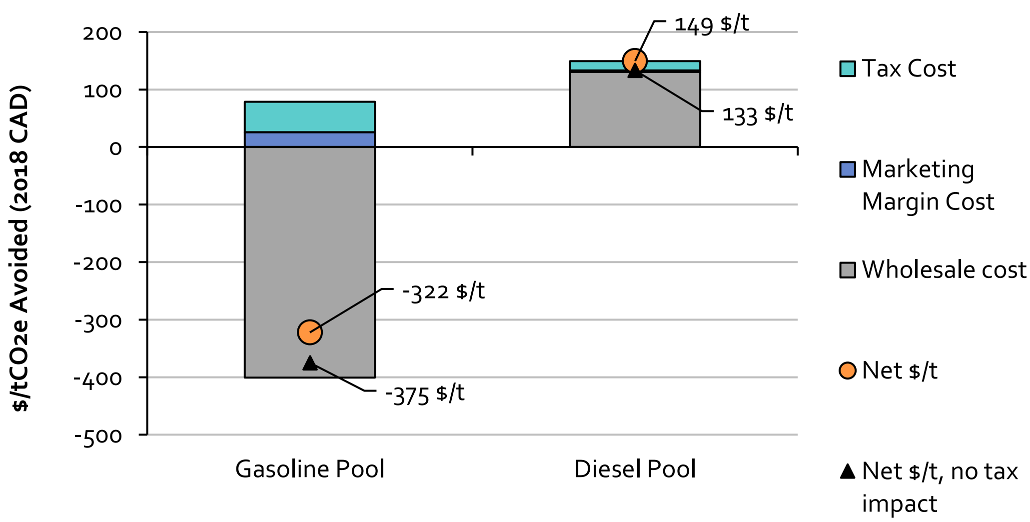
There are several important caveats with regards to the cost analysis. First, the wholesale prices of the fuels are a major driver of the overall cost impact. As noted above, we assume that differences in wholesale prices are reflected in retails prices, but given the dynamics of price setting, this may not be the case in all fuel markets in Canada. Furthermore, the marketing margin will be affected by this price setting and that margin, on a per litre basis, may not be independent of the renewable fuel content as we have assumed. As well, the wholesale prices are based on commodity prices listed on the Chicago mercantile exchange. While these are indicative of the prices paid for fuels, actual contracts will be settled relative to this price and wholesale costs could be different than calculated in this analysis.

A further uncertainty in the cost analysis is the impact of renewable fuel blends on energy efficiency (i.e. energy per km). The weight of evidence suggests that energy efficiency has not been affected by current blending rates and there is no efficiency change included in the cost analysis. However, the results of the cost analysis are very sensitive to this assumption. Again, using the example based on the analysis of Geringer et al. (2014), if E10 yielded a 1.8% improvement in energy efficiency (scaled to other blend rates), consumers would have saved another $5.6 billion from 2010 through 2018, equivalent to +83% of the total cost impact in the gasoline and diesel pools.

4.4. GHG Abatement Cost

Figure 15 shows the GHG abatement cost of biofuel blending in Canada from the perspective of consumers. The abatement cost is the cumulative cost impact by source (i.e. wholesale cost, marketing cost, tax cost), divided by the cumulative avoided GHG emissions from 2010-2018 for the gasoline and diesel pool. Avoided cap and trade costs are not included in this calculation, nor are any additional costs savings, co-benefits, or GHG reductions associated with the use of biofuels (e.g. the impact of ethanol blending on vehicle energy efficiency and refinery GHG intensity, reduced health costs related to reductions in air pollution). For interest, net abatement costs without the tax cost impact are shown. In other words, Figure 15 shows the net abatement cost if excise taxes, sales taxes, and carbon taxes on fuels had the same $/energy value for gasoline and ethanol, and for diesel, biodiesel and HDRD (i.e. taxes were applied on an energetic basis rather than volumetric).

Figure 15: GHG abatement cost, 2010-2018

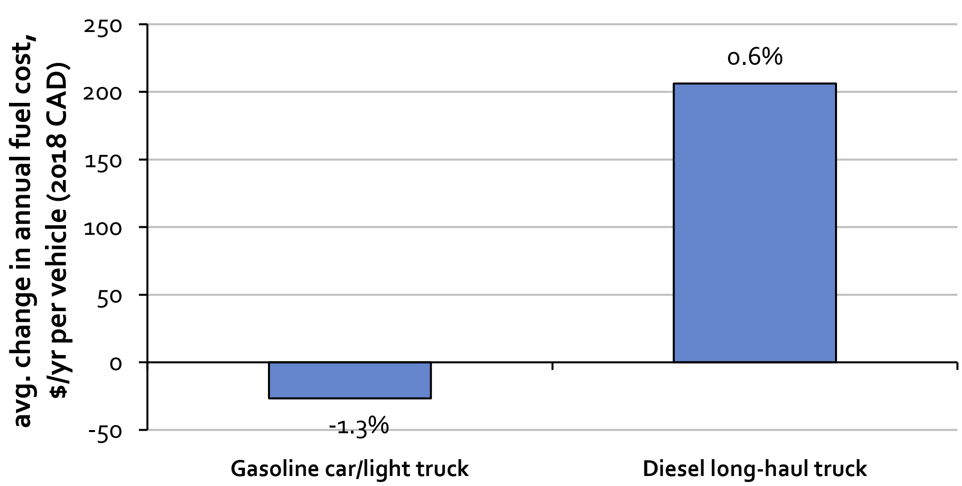


The cost of abatement from ethanol blending is -$322/t$CO_2$e (Figure 15). Furthermore, the results suggest that excise and carbon taxes on fuels have a significant impact on the net dollar value per tonne CO_2e abated, which would be -$375/t$CO_2$e if the excise taxes on ethanol and gasoline were equivalent on an energy basis. The abatement cost in the diesel pool is \$149/tCO_2e, or \$133/tCO_2e if fuel taxes were based on energy rather than volume.

4.5. Consumer Cost Impact

Figure 16 shows the cost impact expressed as a change in average annual fuel expenditures for archetypal consumers. For the gasoline pool, the archetypal consumer uses a light-duty vehicle to travel approximately 15,832 km per year with an average fuel economy of 9.8 litres per 100 km travelled. For the diesel pool, the archetypal consumer is a truck operator who uses a tractor-trailer combination to travel approximately 87,622 km per year with a fuel economy of 32.2 litres per 100 km travelled. These archetypes reflect the average statistics of Canadian consumers from 2010-2017 as reported by Natural Resource Canada in the Comprehensive Energy Use Database. The average consumer of gasoline saved \$27/yr (-1.3%) because of ethanol blending in Canada. A typical heavy-duty diesel consumer spent an additional \$206/yr (+0.6%) because of biodiesel and HDRD blending (Figure 16). The high cost for the diesel archetype could have been mitigated if more biodiesel and less HDRD had been used. This outcome was technically feasible given that on average in Canada, biodiesel has only accounted for just over 1% of the diesel pool volume during the eight-year study period, while a 2% average annual blend is considered feasible by even the most conservative fuel supplier. The expectation of ongoing biodiesel and HDRD price spreads could result in increased use of biodiesel (putting upward pressure on biodiesel prices) or increased investment in HDRD supply (putting downward pressure on its price).

Figure 16: Archetypal fuel consumer cost impact, annual average 2010-2018



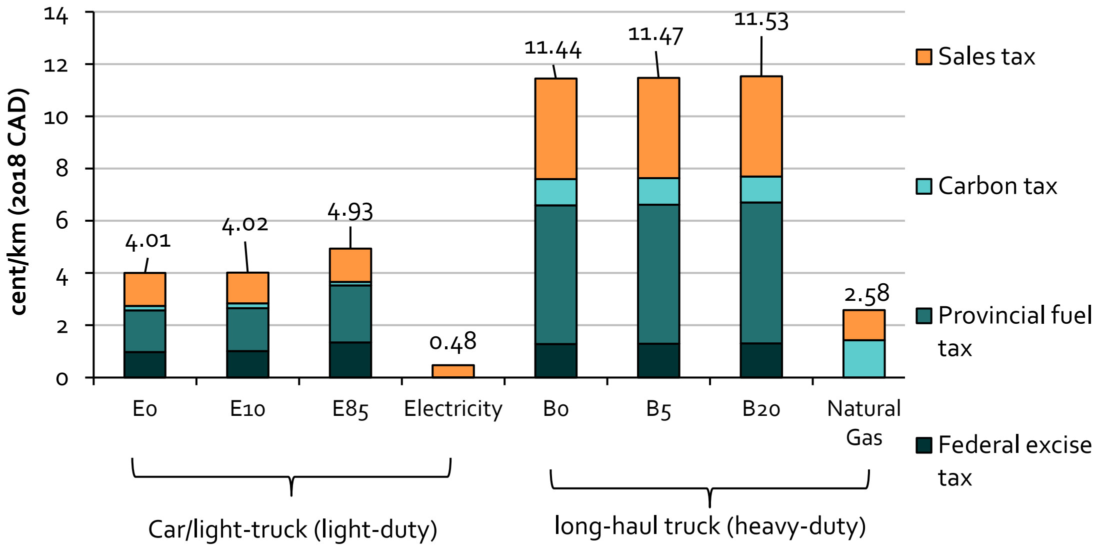
Finally, since the impact of ethanol blending results in savings to consumers, it implies that the ethanol blending mandates in Canada might not be causing substantial changes to fuel use. In other words, since ethanol can be used to boost gasoline's octane value, refiners may be incentivized to blend ethanol regardless of whether the blending mandate is present or not. However, some policies in Canada, notably the British Columbia *Renewable and Low Carbon Fuel Requirements Regulation*, constrain the CI of ethanol, which has potentially increased the avoided GHG emissions. Furthermore, while these results indicate that ethanol use may be 'voluntary', it is possible that the mandates are forcing refiners to use ethanol to boost octane rather than some other method that might result in greater GHG emissions.

4.6. Detailed Tax Costs

A breakdown of fuel taxes per-km-travelled by tax type for different biofuel blends illustrates why there is a tax cost impact associated with biofuel consumption. Taxes per km are calculated using the same archetypal consumers of gasoline and diesel as in Figure 16 (a light-duty gasoline vehicle and a long-haul diesel tractor-trailer). On average in Canada in 2018, the archetypal gasoline user paid 0.2% more tax per km when using E10 rather than E0. Likewise, in 2018 the archetypal diesel user also paid 0.3% more tax per km when using B5 rather than B0 (Figure 17 17). Again, this "additional" taxation relates to the lower energy density of biofuels and the fact that most fuel taxes are applied per litre. The tax impact would be exacerbated when using fuels with more biofuel content like E85 or B20. In contrast, other alternative fuel vehicles that run on electricity, hydrogen, or renewable natural gas are exempt from provincial fuel taxes and federal excise tax and pay a much lower overall tax per km.

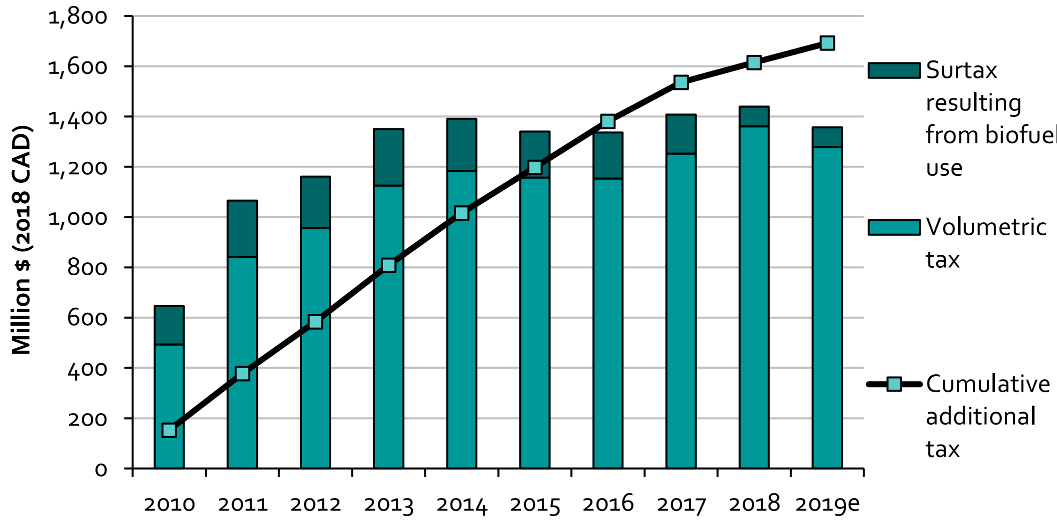
The tax impacts in Figure 17 are fuel-consumption-weighted averages for Canada and are not specific to any province. However, there are important regional differences hidden within that average. For example, biofuel users will pay less sales tax per km (charged as a % of the fuel price) when there is a sufficiently large volumetric price discount between the biofuel blend and the unblended fossil fuel (i.e. the $/L price of the biofuel is lower). In 2018, the volumetric price of ethanol was discounted heavily relative to gasoline and the octane value of the ethanol was higher than average resulting in less sales tax on E10 compared to E0. In provinces with HST (i.e. a higher sales tax rate, as in Ontario), the reduction in sales tax per km on E10 versus E0 was larger than the increase in other taxes, meaning there was a negative tax cost impact (i.e. using E10 resulted in less tax paid per km). In contrast, ethanol consumption resulted in more tax per km in 2018 in regions with lower sales tax rates (i.e. GST rather than HST), especially those with carbon prices that do not distinguish between unblended fossil fuels and typical biofuel blends (e.g. E5 to E10, B2 to B5).

Figure 17: Fuel Taxes and carbon costs for archetypal fuels and consumers, illustrative fuel consumption weighted average for Canada in 2018 (total shown in data label)



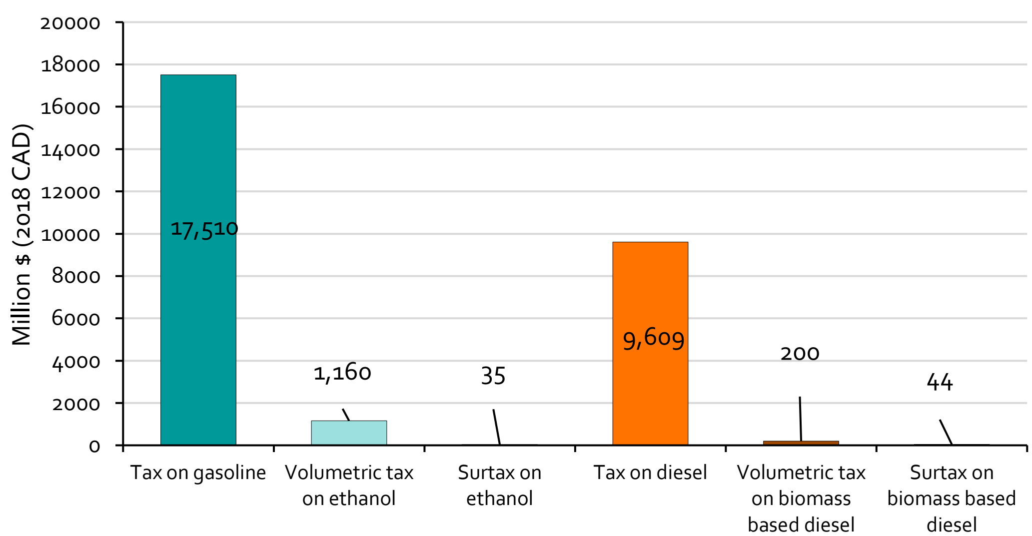
In 2018, these "surtaxes" taxes paid on biofuels amounted to an extra 5%/yr, or roughly $79 million (2018 CAD), relative to the "volumetric" tax that would have been paid if taxes per unit of energy were the same across all fuels used in a given fuel type (i.e. with gasoline or diesel) (Figure 18). Because ethanol was relatively cheap in 2018 and its octane value was relatively high, the "surtax" impact was smaller in 2018 than in previous years. From 2010 to 2017, this surtax was equivalent to an additional 12%-30% tax paid on biofuels, or roughly $150 to $225 million/yr (2018 CAD), where the annual variation comes from variations in fuel prices, marketing margins and the value of octane from ethanol. The cumulative tax cost impact since 2010 rose to just over $1.6 billion (2018 CAD) in 2018 (note, this is the same as the total tax cost impact shown in Figure 14). Our estimate for 2019 shows that the tax cost impact will again be relatively small, again roughly $70 million, with the cumulative surtaxes paid on biofuels rising to just under $1.7 billion (2018 CAD).

Figure 18: Breakdown of fuel taxes paid on biofuels in Canada, with cumulative "Surtax" paid



Taxes paid on ethanol in Canada in 2018 account for 6.4% of the total taxes paid on fuel from the gasoline pool, where the "additional" tax on ethanol is 0.2% percentage points of that total. Taxes paid on biomass-based diesel represent 2.5% of the total taxes paid on the diesel pool in Canada in 2018. The "additional" tax on biomass-based diesel is 0.5% percentage points of that total (Figure 19).

Figure 19: Breakdown of taxes paid on the gasoline and diesel fuel pools in 2018



5. Conclusions

The aim of this study is to provide a comprehensive analysis of the volumes of renewable transportation fuels being consumed in Canada as well as the impact of this fuel consumption on GHG emissions and consumer fuel expenditures. Key conclusions from this study are summarized below.

Renewable fuel consumption

The renewable content in gasoline and diesel pools has increased from 2010 to 2018, though volumes are largely unchanged since 2017. The data compiled for this study indicates that the volume of ethanol consumed in Canada each year has increased from roughly 1,700 million L/yr in 2010 to 3,030 million L/yr in 2018 (down by 0.5% since 2017). Annual biodiesel consumption has increased from roughly 123 million L/yr in 2010 to 368 million L/yr in 2018. HDRD consumption increased from roughly 37 million L/yr to 343 million L/yr in that same period (overall biomass-based diesel is up by 1.5% since 2017). Our estimate for 2019 shows a reduction in renewable fuel consumption due to an overall reduction in gasoline and diesel consumption within Statistic Canada data. Note that this estimate is based on the assumption of constant biofuel blending rates that will be updated when data become available. As well there are some concerns about the comparability of gasoline and diesel consumption in 2019 versus 2018 in the Statistics Canada data. These will be addressed during future iterations of this project.

Avoided GHG emissions

Annual avoided GHG emissions resulting from biofuel blending in Canada have increased from 2.1 MtCO_2e/yr in 2010 to 5.6 MtCO_2e/yr in 2018. Because of declining biofuel CIs, avoided emissions are slightly higher than in 2017, even though the total volume of renewable fuel was slightly lower in 2018. The cumulative GHG emissions avoided between 2010 and 2018 are 40 MtCO_2e.

Cost Impacts

Between 2010 and 2018, blending ethanol, diesel, and HDRD with conventional transportation fuels reduced consumer fuel costs in Canada by 0.81%, relative to what they would have been without renewable fuels. If all costs and savings were passed on to consumers, they saved $6.7 billion (2018 CAD) over the nine-year study period. The octane value of ethanol creates a substantial savings that offsets other costs associated with renewable fuel consumption. Assuming no other co-benefits related to biofuels other than the octane value of ethanol, the GHG abatement cost resulting from ethanol blending is negative, -\$322/tCO_2e, whereas the abatement cost from biofuel blending with diesel is positive at \$149/tCO_2e. Ethanol blending reduced the annual fuel costs of a typical driver by \$27/yr (-1.3%) over the study period, relative to a scenario without ethanol consumption. Biodiesel and HDRD blending increased the annual fuel costs of an archetypal long-haul trucker by \$206/yr (+0.6%). Costs are higher for diesel consumers since roughly half of the renewable fuel blended into the diesel pool is the more costly HDRD. The cost could have been lower if more biodiesel had been used. The results show that on average in Canada, biodiesel accounted for just over 1% of the diesel pool volume, well below even the most conservative estimate of the volume that can be easily blended into diesel.

Taxation impacts

Biofuel consumption, especially ethanol, has increased the fuel tax burden on consumers while generating additional tax revenue for governments in Canada. This impact comes from taxes that are applied per litre, such as excise taxes as well as carbon taxes and levies. Because biofuels are generally less energy dense than petroleum fuels, using biofuels involves consuming a greater volume of fuel and paying more tax than when the tax is charged per litre. Consequently, consumers pay more tax per kilometer when using biofuel blends, all else being equal. This impact is most noticeable with ethanol because it is roughly 33% less energy dense than gasoline, though the impact varies from year to year as a function of the variation in spread between ethanol and gasoline prices and the value of octane from ethanol. The tax structure cost gasoline consumers an additional \$1.4 billion during the nine-year study period (2010 to 2018) and is included within the net savings noted above. The corresponding tax cost on diesel consumers during that period was roughly \$0.2 billion (2010 to 2018 CAD).

Appendix A: Cost Analysis Methodology

This appendix provides more detail on the methodology used for the cost analysis:

- The wholesale price of ethanol and biodiesel were obtained for 2010-2019.
  - Ethanol and biodiesel prices were based on monthly averages from Chicago Board of Trade (CBOT) spot prices (biodiesel) and futures prices (ethanol) from 2010 to the end of 2019. Biodiesel prices are used net of biodiesel blenders tax credit.
- HDRD wholesale prices were estimated using Neste financial materials for investors. Prices were calculated quarterly as follows:

$$P_{HDRD} = \frac{Revenue}{Volume}$$

- Landed prices of ethanol and biodiesel were estimated for each province in Canadian dollars. These prices were based on a representative major terminal city in each province, with costs relative to the CBOT price based on typical fuel transport costs by rail. Distances between Chicago and each representative city are based on results from Google maps (road distances used to approximate rail distance). Transportation costs ranged from $5/bbl to $13/bbl, with a variable cost per kilometer that inversely scales with distance to account for economies of scale when shipping longer distances with rail, based on Gallagher and Denicoff (2015).[34]
- The wholesale price for blended gasoline and diesel for each year was obtained for each of the provinces in the analysis.
  - These prices were based on monthly average wholesale price data for regular gasoline and diesel in representative cities in each province from collected by Kent Marketing.[35]

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[34] Gallagher, Paul and Denicoff, Marina. 2015. Ethanol Distribution, Trade Flows, and Shipping Costs, Iowa State University Economics Technical Reports and White Papers Accessed from https://lib.dr.iastate.edu/econ_reportspapers/45

[35] Kent Marketing, http://kentreports.com/wpps.aspx

- All values were converted to 2018 dollars[36] and Canadian currency from US dollars[37] and Euros.[38]

- Inputs for Atlantic Canada are constructed from provincial values averaged using population weights from Statistics Canada.[39]

- Inputs and results for Canada as whole are calculated using fuel-consumption weighted averages, based on the fuel consumption reported in the analysis.

- The price of gasoline blendstock and diesel were estimated based on average reported blends in each year and the price of biofuel and blended fuel. For example, the price of gasoline blendstock ($P_{BOB,}$ Where BOB=blendstock of oxygenate blending) was calculated as:

$$P_{BOB} = \frac{P_{blend,reg} - P_{eth} * \%vol_{eth}}{\%vol_{BOB}}$$

  - Where $P_{blend,reg}$ is the price of the blended regular gasoline and P_{eth} is the price of ethanol in each region.

  - $\%vol_{eth}$ and $\%vol_{BOB}$ are the volume fraction of ethanol and gasoline blendstock in the regular gasoline, respectively.

- The price of pure gasoline was estimated assuming the octane of that fuel would have had to be higher if no ethanol were added. In other words, we estimated the price of pure gasoline assuming the blendstock used with ethanol is sub-octane, and ethanol was used to boost its octane to 87. Without the addition of ethanol, pure gasoline would have had to be refined to a higher octane and its price would be higher than the price of the sub-octane blendstock. To estimate this price, we used the following method:

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[36] CANSIM, 2018, Table 326-0020 Consumer Price Index

[37] Bank of Canada, 2020, Exchange Rates. http://www.bankofcanada.ca/rates/exchange/monthly-average-lookup/

[38] www.investing.com/currencies/eur-cad-historical-data

[39] Statistics Canada: Table 17-10-0009-01. Population estimates, quarterly.

- The blended fuel was assumed to have an octane value of 87 (regular) and the ethanol was assumed to have an octane value of 113 when used in a gasoline blend.[40]

- The implied cost per octane point was estimated for each year based on the difference between regular and premium gasoline in the US market[41] where that price spread better reflects the cost of octane than in the Canadian market.

- Our estimated price of pure sub-octane gasoline was decreased based on the implied cost per octane point and the estimated octane of the gasoline blendstock:

$$P_{gasoline,sub-octane} = P_{BOB} - \left(\frac{P_{blend,prem} - P_{blend,reg}}{O_{blend,prem} - O_{blend,reg}}\right) * \left(O_{gasoline,87} - O_{BOB}\right)$$

Where:

- $P_{gasoline,sub\text{-}octane}$ is the estimate price of pure gasoline if the gasoline blendstock is sub-octane.

- $P_{blend,prem}$ and $P_{blend,reg}$ are the price of premium and regular gasoline blends, respectively, based on US data[42]

- $O_{blend,prem}$ and $O_{blend,reg}$ are the octane values of premium and regular gasoline blends, 91 and 87 respectively

- $O_{gasoline,87}$ is the octane of regular gasoline blend (87)

- O_{BOB} is the octane of the gasoline blendstock. If it is refined sub-octane 87, with the intention of adding ethanol to increase the octane rating, then:

$$O_{BOB} = \frac{O_{blend,reg} - O_{eth} * \%vol_{eth}}{\%vol_{BOB}}$$

Where:

- $O_{blend,reg}$ is the octane value of regular gasoline blend (87)

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[40] 113 to 115 is a typical value for blends cited by EIA https://www.eia.gov/todayinenergy/detail.php?id=11131. This value corresponds to ethanol used in low concentration blends. The octane rating of pure ethanol is 100.

[41] EIA. 2019. Petroleum & Other Liquids: Weekly Retail Gasoline and Diesel Prices. Accessed from: https://www.eia.gov/dnav/pet/PET_PRI_GND_DCUS_NUS_M.htm

[42] ibid

- $\%vol_{ethl}$ and $\%vol_{BOB}$ are the volume fraction of ethanol and gasoline blendstock in the regular gasoline, respectively
- O_{eth} is the octane value of ethanol (113)

- The average price per litre cost/savings of blending ethanol and gasoline was estimated for each province in each year of the analysis based on the estimated price of pure gasoline and ethanol. For example, this price differential (P_{Δ}) in $/L for gasoline was calculated as:

$$P_{\Delta\$/L} = P_{blend,reg} - P_{gasoline,87}$$

- Similarly, the price per litre cost/savings of blending biodiesel and HDRD with pure diesel was estimated.

- The average $/GJ cost or savings that results from blending biofuel was estimated, assuming biofuel consumption does not change energy consumption. The following energy densities from GHGenius 4.03a were used to convert $/L price to $/MJ prices:
  - Ethanol= 23.6 MJ/L
  - Gasoline= 34.7 MJ/L
  - Diesel= 38.7 MJ/L
  - Biodiesel= 35.4 MJ/L
  - HDRD= 36.5 MJ/L

- The equation is:

$$P_{\Delta\$/MJ} = \frac{P_{blend,reg}}{MJ/L_{gasoline} * \%vol_{BOB} + MJ/L_{eth} * \%vol_{eth}} - \frac{P_{gasoline,87}}{MJ/L_{gasoline}}$$

- We then estimated the total fuel expenditures in each region and year with biofuels blended and for a counterfactual without biofuels blended:
  - A counterfactual volume of gasoline and diesel was estimated that would have been consumed if no biofuels were blended into the fuel. This was calculated as the actual volume of fuel consumed multiplied by the ratio of the energy density (i.e. MJ/L) of gasoline to the energy density of the blend.

- Taxes and marketing margins were added to each price to get retail prices. Margins on $/L basis were obtained from Kent Marketing[43] and are assumed to be independent of biofuel blending rates. Taxes are from NRCAN.[44] Taxes include federal and provincial fuel excise taxes, and sales taxes. Sales taxes were applied as a percent of the actual retail price and the calculated retail price for the counterfactual scenario without biofuels.
- In British Columbia, the carbon tax was applied equally to each litre sold, regardless of the renewable fuel blend. The same is true for the carbon levy in Alberta for 2017 and 2018, though if there were blends with more than 10% renewable content in gasoline, or 5% in diesel, those biofuels would be exempt.
- The credit price impact of the cap-and-trade system in Ontario and Québec was assumed to already exist in reported wholesale gasoline and diesel blend prices. While biofuels are exempt from the cap and trade systems, the credit cost resulting from supplying gasoline and diesel was assumed to be spread evenly across all fuels, regardless of their biofuel content. For the counterfactual scenario with no biofuels, the additional cap and trade cost resulting from the gasoline and diesel that would have been consumed was based on average annual credit prices and added to the observed wholesale fuel price.[45,46]
- Retail prices were multiplied by volumes. For example: retail price of gasoline blend by volume consumed, or counterfactual retail price of gasoline by counterfactual volume. The same was done for diesel.
- The difference in cost in each year was calculated for each province for gasoline and diesel pools.

- The change in fuel expenditures was shown for an archetypal consumer, broken down by component (i.e. change in wholesale fuel cost, additional margin cost, taxes). The consumer archetype was defined to reflect the average statistics of Canadian consumers from 2010-2017 as reported by Natural Resource Canada, for the average L/100 km and annual km travelled. For the archetypal gasoline

[43]Kent Marketing, 2019, Petroleum Price Data. http://charting.kentgroupltd.com/

[44] NRACN, 2019, Fuel Consumption Taxes in Canada, https://www.nrcan.gc.ca/energy/fuel-prices/18885

[45] Government of Ontario. Past auction information and results. Accessed from: https://www.ontario.ca/page/past-auction-information-and-results

[46] California Air Resources Board, 2020, Summary of market transfers complete in 2019 Government of Quebec. Accessed from: https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program

consumer, these values are 9.8 L/100 km and 15,905 km/yr. For the archetypal diesel consumer, these values are 32.4 L/100 km and 88,753 km/yr.[47,48]

[47] Natural Resources Canada, 2020, Energy Use Data Handbook Tables, Passenger Transportation Explanatory Variables.

[48] Natural Resources Canada, 2020, Energy Use Data Handbook Tables, Freight Transportation Explanatory Variables.

Appendix B: Biofuel Type and Feedstock Assumptions and Data

In this analysis, data were collected on the volume of renewable fuels blended into gasoline and diesel — characterized as ethanol, biodiesel, or HDRD. However, to calculate the lifecycle CI of the various biofuels sold in Canada, it was necessary to further disaggregate these data by feedstock, and in some cases separate aggregate biomass-based diesel volumes into biodiesel and HDRD.

Feedstock data and guidance on the split between HDRD and biodiesel was obtained from personal correspondences with government contacts or obtained from various publications. However, data for every region and every fuel was not available. For this reason, various assumptions were made to fill these gaps. The following lists summarize the assumptions and sources we used to define fuel types and feedstocks and volumes by region in Canada.

Assumptions for British Columbia

Feedstock data was obtained from the government of British Columbia.[49] The data is essentially used "as-is" with little need for assumptions or interpretation:

1. In some years, there are minor summation errors in the data published by the BC government. We used an "Unknown" feedstock category to make the total fuel volume from individual feedstocks equal to the total reported volumes. These values were calculated to fill the gap and are not numbers reported by the BC government.

2. BC reporting does not distinguish between feedstocks used for biodiesel or HDRD. We assume that tallow, yellow grease and palm oil by-products are used for HDRD.

Assumptions for Alberta

1. Ethanol feedstock volumes are estimated based on the types of feedstocks processed in Alberta's facilities. We estimate a substantial amount of corn based on review with Don O'Connor of (S&T)[2] Consultants.

2. We assume that biodiesel feedstocks are canola and soy, as indicated through personal correspondence with Alberta Government. We assume a greater

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[49]Ministry of Energy and Mines, 20209, Renewable and Low Carbon Fuel Requirements Regulation Summary: 2010-2018

proportion of soy than canola based on review with Don O'Connor of (S&T)^2 Consultants.

3. The relative percent of biomass-based diesel that is biodiesel vs. HDRD from 2010 to 2016 is based on the proportion in the data reported for 2017 (9.9% of biomass-based diesel is HDRD). Data is used for 2018.

4. We assume the feedstocks used for HDRD in Alberta are proportionally the same as what is used in British Columbia, given that they are likely sourced from the same imports

Assumptions for Saskatchewan

1. We assume that the proportion of biofuel in diesel is 0% HRDR and 100% biodiesel.

2. We assume that the feedstocks for ethanol are wheat and corn. We base this on correspondence with Don O'Connor of (S&T)^2 Consultants.

3. We assumed that the primary feedstock for biodiesel is canola. This assumption is based on correspondence with a government contact.

Assumptions for Manitoba

1. We assume that ethanol feedstocks are wheat and corn, transitioning primarily to corn based on the feedstocks processed in Manitoba facilities as reported by Husky Energy and from discussion with industry contacts.

2. We assume that biodiesel feedstocks are 50/50 canola and soy based personal correspondence with a government contact.

3. We assume there is no HDRD consumption based on correspondence with Don O'Connor of (S&T)^2 Consultants.

Assumptions for Ontario

1. We assume that ethanol consumed in Ontario is made from corn.
2. We assume biodiesel is 50% soy-based, while the remaining 50% is sourced equally from tallow and yellow grease, whereas we assume HDRD is made from tallow and yellow grease. These assumptions are based on a qualitative discussion with a government contact.

Assumptions for Québec

1. We assumed most biodiesel and HDRD is produced from tallow and that 80% of the biomass-based diesel volume is HDRD from 2014 onward (same as Ontario assumption).

2. We assume ethanol feedstock is corn since there is a facility in Québec that processes corn ethanol and imports are assumed to be corn ethanol.

Assumptions for the Atlantic region

1. We assume ethanol is from corn and biodiesel is from unknown feedstock to better align with ECCC national feedstock values.

Detailed Feedstock Results

Based on the assumptions outlined above, the feedstocks used to produce biofuels sold in Canada were estimated and summarized in Figure 20 and Figure 21. Figure 20 shows the renewable fuel content in the diesel pool in Canada from 2010 to 2018, with an estimate for 2019. The volume of fuel is shown by fuel type and feedstock: most biodiesel is from canola and soy, most HDRD is from palm oil by-products and tallow. Figure 21 shows the renewable fuel content in gasoline pool in Canada from 2010 to 2018, by fuel type and feedstock: most ethanol consumed in Canada is produced from corn, with 10-15% produced from wheat

Figure 20: National Results for Renewable Fuel Consumption of Diesel Pool by Fuel Type, and Feedstock

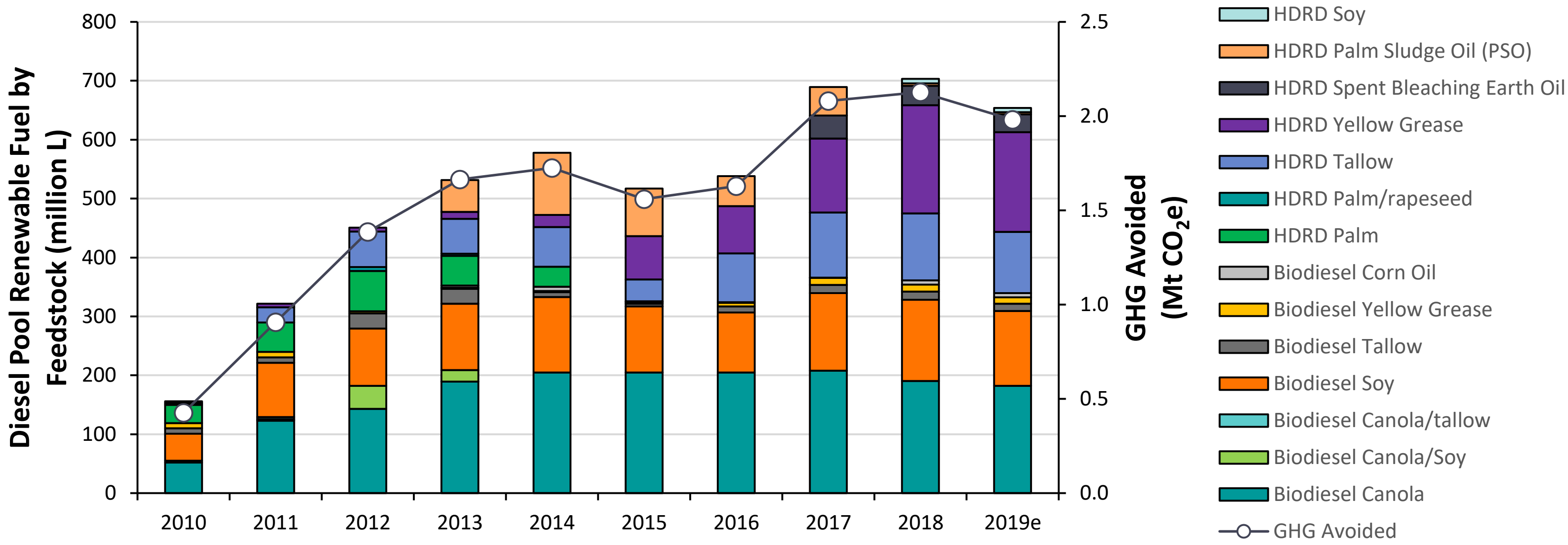

Figure 21: National Results for Renewable Fuel Consumption for Gasoline Pool by Fuel Type, and Feedstock