Biofuels in Canada 2019

Tracking biofuel consumption, feedstocks and avoided greenhouse gas emissions

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Errata

The consumer cost impact in the diesel pool on page 35 was corrected to +0.65% from 65%

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 emissions policy initiatives.

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Executive Summary

Policies aimed at reducing greenhouse gas (GHG) emissions from transportation have increased the consumption of renewable and low-carbon biofuels in Canada. Currently, there are several policies in Canada that target emissions from transportation fuels, including the federal Renewable Fuels Regulations, which mandate minimum renewable fuel blending, or British Columbia's Renewable and Low Carbon Fuel Requirements Regulation, which mandates minimum renewable fuel blending and requires the average lifecycle carbon intensity (CI) of fuel sold within the province to decline over time. Environment and Climate Change Canada (ECCC) and the US Department of Agriculture both provide reporting and estimates of biofuel consumption in Canada. However, 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 engaged Navius Research Inc. ("Navius") to fill this information gap. This analysis updates the "Biofuels in Canada" reports released in 2016, 2017 and 2018.

Objectives

The objectives of this project are to evaluate and communicate the impact of renewable and low-carbon fuel policy 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 their impact on energy costs, now with an additional focus on how fuel taxes affect these costs

Updates to the Methodology

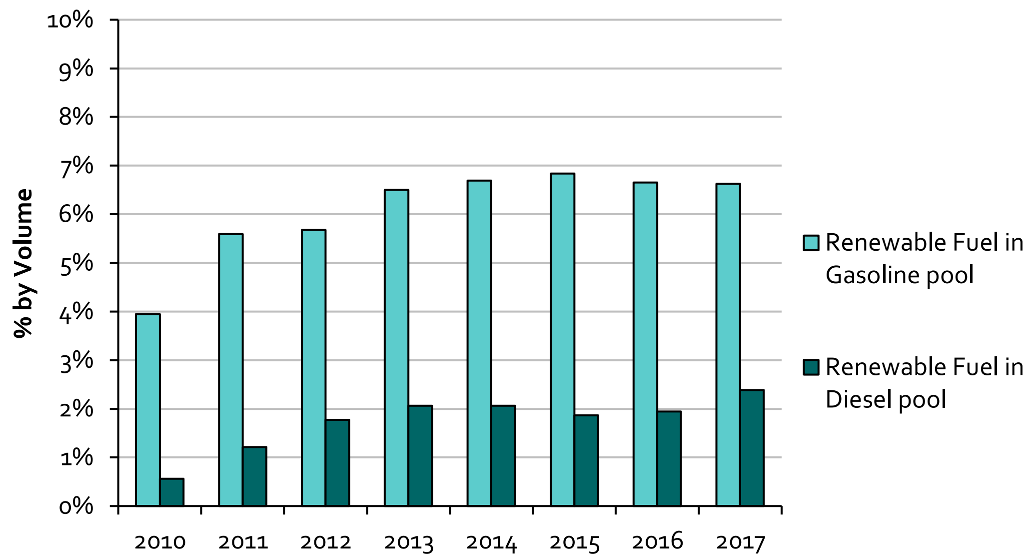
This current edition of the Biofuels in Canada analysis includes four methodological changes that affect the result for 2017 and prior years:

- First, ECCC has released new data from the federal Renewable Fuels Regulations. These data contain national totals for ethanol and biomass-based diesel consumption for all years covered by this analysis except 2010. We use these national totals in place of the values estimated by the US Department of Agriculture found in prior editions of this analysis.
- Second, we have increased the lifecycle carbon intensity of gasoline 7 gCO_2e/MJ (roughly 8% to 9%) for all regions and years covered by this analysis. Now the direct combustion GHG from gasoline in this analysis are consistent with the values used by ECCC; they now account for CO_2 produced when carbon monoxide and volatile organic compounds in gasoline exhaust oxidize in the atmosphere. This update increases the GHG reductions we attribute to ethanol consumption in all years covered by the analysis.
- Third, we have improved our calculation of how using renewable fuels changes the fuel taxes consumers pay. Sales taxes are calculated on observed fuel prices (i.e. on fuels with renewable content) and compared against what sales taxes would have been without renewable fuel consumption. This change reduces the total tax paid on gasoline/ethanol blends somewhat, while increasing the total tax paid on diesel blends. On net, the current tax structure still imposes an additional tax burden on consumers of renewable fuels.
- Finally, our assumption that renewable fuel consumption does not change vehicle energy efficiency (i.e. energy per km) is now supported by a literature review. The weight of evidence supports this assumption, but there is some uncertainty in that result. There is also evidence demonstrating that new engines optimized to use renewable fuel blends can achieve greater energy efficiency. Therefore, the literature review and assumption will be reviewed with each new iteration of this analysis.

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 3,047 million litres in 2017. Annual consumption of biodiesel has grown from roughly 123 million litres in 2010 to 376 million litres in 2017. Hydrogenation-derived renewable diesel (HDRD) is also believed to be blended into diesel in similar volumes to biodiesel in recent years. HDRD content is estimated to have increased from 37 million litres in 2010 to 326 million litres 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). Note that this result does not indicate whether the Canadian federal renewable fuel requirement for diesel has been missed: our analysis is on total gasoline and diesel consumption which includes volumes that are exempt from the policy.

Figure 1: Renewable Fuel Content by Fuel Pool



Lifecycle GHG Emissions

Based on lifecycle carbon intensities reported by government contacts and obtained from GHGenius 4.03a, renewable fuel consumption has avoided 34.3 Mt CO_2e between 2010 and 2017. Annual avoided GHG emissions have grown from 2.1 Mt in 2010 to 5.5 Mt in 2017.

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 2017 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 2017. The cost components are the wholesale cost, the marketing margin cost (i.e. distribution) and the fuel tax cost. 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 small savings relative to a scenario where no biofuel was consumed, roughly $4.3 billion (2017 CAD) over eight years, or -0.42% of total gasoline and diesel pool expenditures. Note that 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.

It also increases the tax they pay 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. GST, HST) are also 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 will pay more taxes per kilometer driven when using biofuel blends. On average in Canada (population weighed), a driver of a light-duty vehicle using gasoline with 10% ethanol (i.e. E10) will pay an additional 0.4% more taxes per kilometre than when using E0. Similarly, a heavy-duty vehicle driver will pay an additional 0.2% more taxes per kilometre when using diesel with 5% biodiesel (i.e. B5) than when using B0. Consequently, Canadians have paid an additional $1.5 billion in taxes from 2010 through 2017 as a result of renewable fuel blending (Figure 2).

Figure 2: Cumulative Cost Impact Resulting from Ethanol Blending in the Gasoline Pool and Biomass-Based Diesel Blending in the Diesel Pool (2010-2017), total % change in data label

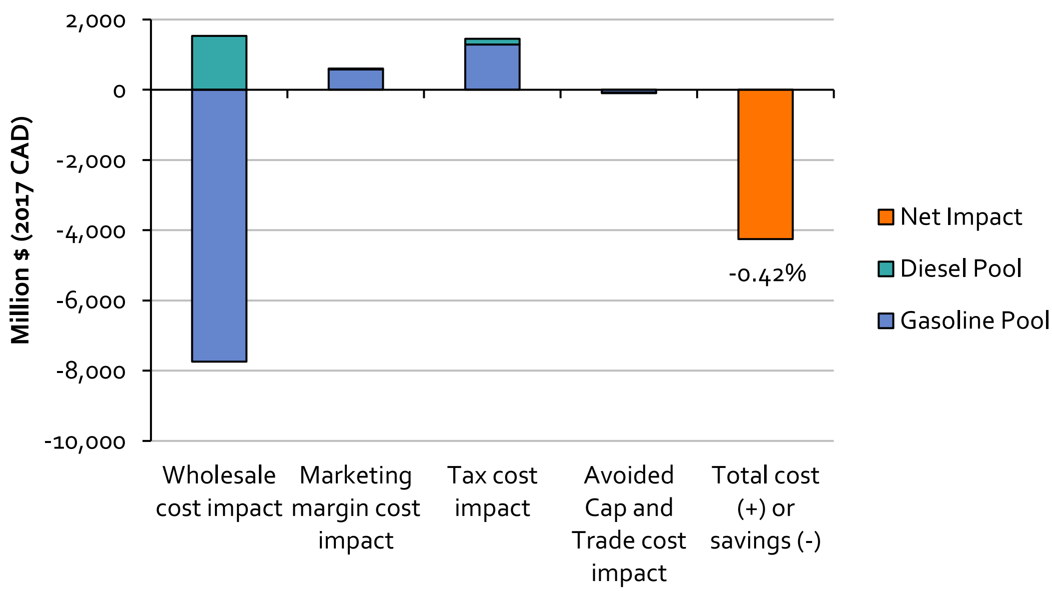
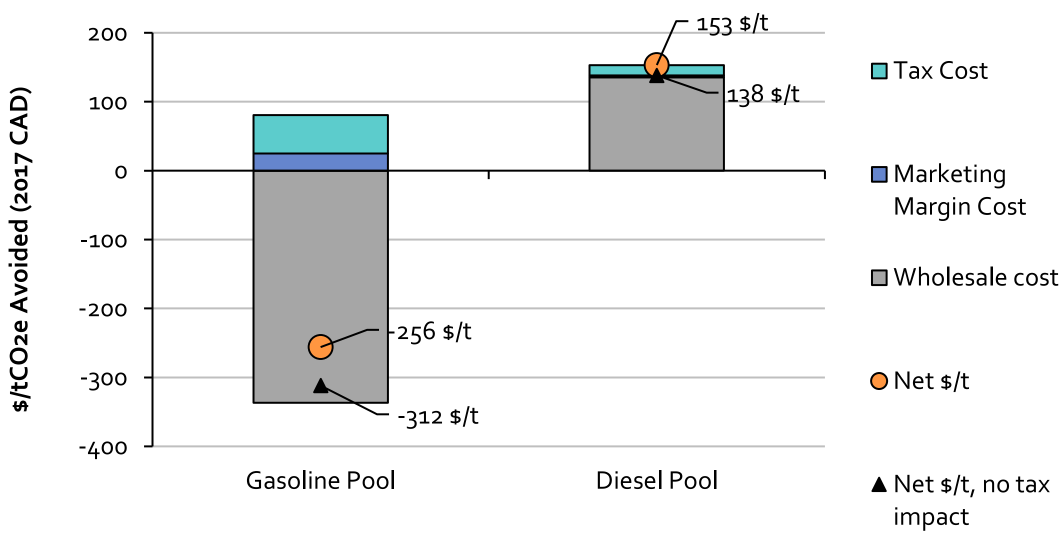


Figure 3 shows the cumulative consumer cost divided by the cumulative avoided GHG emissions from 2010-2017 for gasoline and diesel pools in Canada. The costs do not account for any co-benefits or costs other than those shown in Figure 2 (i.e. no accounting for reduced air pollution and health impact related to biofuel consumption). The abatement cost in the gasoline pool is -\$256/tCO_2e versus \$153/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) \$23/yr (-1.15%), whereas it has cost a typical diesel consumer (based on a long-distance trucker) an additional \$235/yr (+0.65%).

Figure 3: GHG Abatement Cost, 2010-2016



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 2017. Adding more biodiesel was possible: the results show that in Canada, biodiesel has only accounted for 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

Policies aimed at reducing greenhouse gas (GHG) emissions from transportation have increased the consumption of renewable and low-carbon biofuels in Canada. Currently, there are several policies in Canada that target emissions from transportation fuels, including the federal Renewable Fuels Regulations, which mandates minimum renewable fuel blending, or British Columbia's Renewable and Low Carbon Fuel Requirements Regulation, which mandates minimum renewable fuel blending and requires the average lifecycle carbon intensity (CI) of fuels sold within the province to decline over time. Environment and Climate Change Canada (ECCC) and the US Department of Agriculture both report biofuel consumption for Canada. However, there is no comprehensive data source in Canada that allocates provincial regulator data for renewable fuel consumption by province and communicates the impact of renewable fuel consumption on GHG emissions and fuel costs.

The objective of this report is to update the comprehensive study of renewable fuel use in Canada completed by Clean Energy Canada and Navius Research in early 2016, and in 2017 and 2018 by Navius Research. The rationale for this work has not changed and the goal is to continue to fill this information gap to help government and industry understand and further develop GHG reduction and renewable fuel policies.

The specific 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 2017, the most recent year for which data is available. These fuels are further characterized by type (i.e. gasoline, ethanol, diesel, biodiesel, etc.), feedstock, and CI. For further details on the sources and assumptions used to characterize fuels please see Appendix B: Biofuel Volume and Feedstock Assumptions and Data. This report includes an analysis of the impacts of renewable fuel consumption on GHG emissions as well as energy costs in each Canadian province and for Canada as a whole. Biofuels in Canada now also focuses on how fuel taxation affects these costs.

A final 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, 2019-04-25"). 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.

2. Policy Background

This section of the report summarizes the existing renewable fuel policies in Canada as of April 2019 at both the federal and provincial levels to provide an understanding of the regulations driving renewable fuel consumption in the period. 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 Federal 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. Existing Renewable Fuel Policies

National Summary

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

Gasoline blending became effective December 15, 2010, whereas diesel blending did not become effective until July 1, 2011. The federal regulation need only be met on average by producers and importers of gasoline and diesel in the Canadian market. This means that provinces will not necessarily have to meet the compliance target by the same proportion, to satisfy the federal regulation.

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 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 the present
British Columbia	5.0%	5.0%
Alberta	-	5.0%
Saskatchewan	7.5%	7.5%
Manitoba	8.5%	8.5%
Ontario	5.0%	5.0%
Canada	-	5.0%

Some regions in Canada are not 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: Quebec, New Brunswick, Nova Scotia, 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 the present
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: Quebec, New Brunswick, Nova Scotia, and Prince Edward Island. Furthermore, fuel oil used for heating has been exempt from the federal regulation since 2013.

Provincial Policy Design

As mentioned above, 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% less carbon intense 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 GHGenius, 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. The ethanol policy mandates 8.5% renewable content in gasoline since January 1, 2008.

Ontario has the *Ethanol in Gasoline* regulation mandating 5% ethanol content in gasoline. Suppliers must meet the compliance target at all their facilities combined. The required renewable content will rise to 10% starting in 2020,[1] and the regulation name will change to *Greener Gasoline – Bio-Based Content Requirements for Gasoline*. The blending requirement could be increased to 15% as early as 2025.[2]

Additionally, Ontario has the *Greener Diesel Regulation* which consists of three phases prescribing 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

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[1] O. Reg. 535/05: ETHANOL IN GASOLINE

[2] Ontario Ministry of Environment, Conservation and Parks, 2018, Ontario's Environment Plan

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 average 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 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. The second component of the policy regulates the average CI of the fuels. The CI component of the policy (called a low carbon fuel standard, or LCFS), came into effect July 1, 2013, and sets a schedule that requires a 10% reduction in fuel CI by 2020 relative to a 2010 baseline. The CI requirement likely requires blending renewable fuels at volumes greater than the minimum, but renewable fuel blending is not the only action that can satisfy the low carbon fuel requirement of the RLCFRR. In other words, while the LCFS policy is likely to encourage more renewable fuel consumption, it does not prescribe this consumption. If the minimum renewable fuel standard is met, the CI requirement of the LCFS can be met by switching to lower carbon energy sources such as natural gas, electricity, or hydrogen. The RLCFRR policy is being reviewed in the context of achieving BC's 2030 GHG reduction targets, and the government has announced that average CI reduction will be increased to 20% by that year.[3]

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

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[3] Government of British Columbia, 2018, CleanBC: Our nature, our power, our future

parties that do not comply will pay a rate of 200 \$/tCO_2e for a compliance shortfall. Additionally, a minority of credits each year can be generated through special projects that 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.

2.2. Carbon Pricing Policies in Canada

British Columbia Carbon Tax

The British Columbia carbon tax was \$30/tCO_2e from 2012 until 2018. In April 2018, the tax rate increased to \$35/tCO_2e, and to \$40/tCO_2e as of April 2019. The tax rate will increase by \$5/tCO_2e each year until it reaches \$50/tCO_2e in 2021. Each \$5/tCO_2e increment increased the tax on gasoline by 1.11 ¢/L and the tax on diesel by 1.28 ¢/L (Table 3).[4]

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 April 1st, 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	2020	2021
Tax rate, \$/tCO_2e	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/tCO_2e carbon levy, essentially a carbon tax, in 2017, which rose to \$30/tCO_2e in 2018.[5] Similar to BC, the application of the levy to gasoline and diesel uses fuel emissions factors that reduce the rate by the prescribed

[4] www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax

[5] www.alberta.ca/about-tax-levy-rates-prescribed-interest-rates.aspx#carbon-levy

biofuel blend level (i.e. 5% ethanol by volume in gasoline 2% by volume biodiesel in diesel[6]) (Table 4). However, unlike British Columbia, Alberta's carbon levy exempts 100% of the biofuel component of blends that exceed 10% in gasoline and 5% in diesel.

There is no schedule for increases to the carbon levy after 2019, but to comply with the federal backstop carbon price, it would have to rise to $50/tCO_2e in 2022. Assuming biofuel blends are below the exemption thresholds, the resulting tax on gasoline and diesel would be like the tax in British Columbia as of 2021. It is likely that Alberta's incoming government will repeal the carbon levy.[7] Under such scenario, Alberta would be 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 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

[6] https://finance.alberta.ca/publications/tax_rebates/faqs_carbon-levy.html#index-exemptions

[7] United Conservative Party, 2019, *United Conservatives Alberta Strong & Free: Getting Alberta Back to Work.* Available from: https://www.albertastrongandfree.ca/wp-content/uploads/2019/04/Alberta-Strong-and-Free-Platform-1.pdf

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

exchange rate. In practice, the average annual credit price has remained slightly above the price floor[9] (Table 5).

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
Credit price, $/tCO$_2$e	13.4	15.9	17.2	18.8	19.2
Gasoline, ¢/L	3.3	3.9	4.2	4.6	4.7
Diesel, ¢/L	3.6	4.3	4.7	5.1	5.2

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]

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 $18.2/tCO$_2$e, roughly 4.3 ¢/L on gasoline. The average credit price in 2018 was $18.6/tCO$_2$e up until the program was cancelled.[11]

Federal carbon pricing backstop

The carbon pricing backstop applies to provinces that will not comply with the federal government's request to implement a carbon pricing system of their own. These include Saskatchewan, Manitoba, Ontario and New Brunswick.[12] It will likely also

[9] www.environnement.gouv.qc.ca/changements/carbone/ventes-encheres/avis-resultats-en.htm

[10] https://www.ontario.ca/page/cap-and-trade

[11] Government of Ontario, 2018, *Past auction information and results.* Available from : www.ontario.ca/page/past-auction-information-and-results

[12] Government of Canada, 2019, *How we're putting a price on carbon pollution*. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/putting-price-on-carbon-pollution.html

include Alberta as its incoming government has promised to repeal its current carbon levy. Newfoundland, PEI and Nova Scotia are developing carbon pricing systems rather than using the federal system.

A carbon price applies to fossil fuels sold in those provinces starting April 1st, 2019. The price starts at $20/tonne price in 2019 rising 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. The Clean Fuel Standard

Policy Description

The Canadian federal government is developing a fuel carbon intensity (CI) based 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.[16] 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 2020, with the policy coming into force in 2022. The CFS regulatory design paper released in

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

[14] McKenna, C., Morneau, W.F., 2018, Explanatory Notes Relating to the Greenhouse Gas Pollution Pricing Act and Related Regulations. www.fin.gc.ca/drleg-apl/2018/ggpp-tpcges-n-eng.pdf

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

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

December 2018 indicates that the CI target for all liquid fuels in 2030 will be 10 gCO_2e/MJ lower than a 2016 benchmark for fuels, which includes gasoline, diesel, and biofuels used in the baseline year. This is approximately the same stringency that the British Columbian RLCFRR has for 2020 but pushed back by ten years. Final regulations for gaseous and solid fuels are expected to be published in 2021 and should come into force in 2023.[17]

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 suppliers that are required by the policy to supply these lower-carbon fuels. Alternatively, they can purchase compliance credits from GHG reductions achieved in upstream oil production, upgrading, and refining stages. For example, this could involve protocols that quantify additional GHG reductions occurring at petroleum refineries. There may be additional flexibility options that include compliance credit trading between fuel streams (e.g. selling gaseous compliance credits into the liquid stream and vice versa) and a compliance fund that allows obligated parties to purchase unlimited compliance credits at a maximum ceiling price (i.e. capping compliance costs at a given $/$tCO_2e$ value).

Impact on Retail Fuel Prices

The CFS creates a market-based incentive to supply low-carbon fuels because it establishes a market for compliance credits. 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. 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.

As well, the CFS does 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 point regulated parties can buy credits from the government). Consequently, it's impact on retail fuel prices is very different than a carbon tax. Using typical Ontario retail fuel prices in 2017, the CFS with a credit price of 150 $/tonne would result in an E10 price of 1.06 $/L versus 1.02 $/L without the CFS. A 150 $/$tCO_2e$ carbon tax would

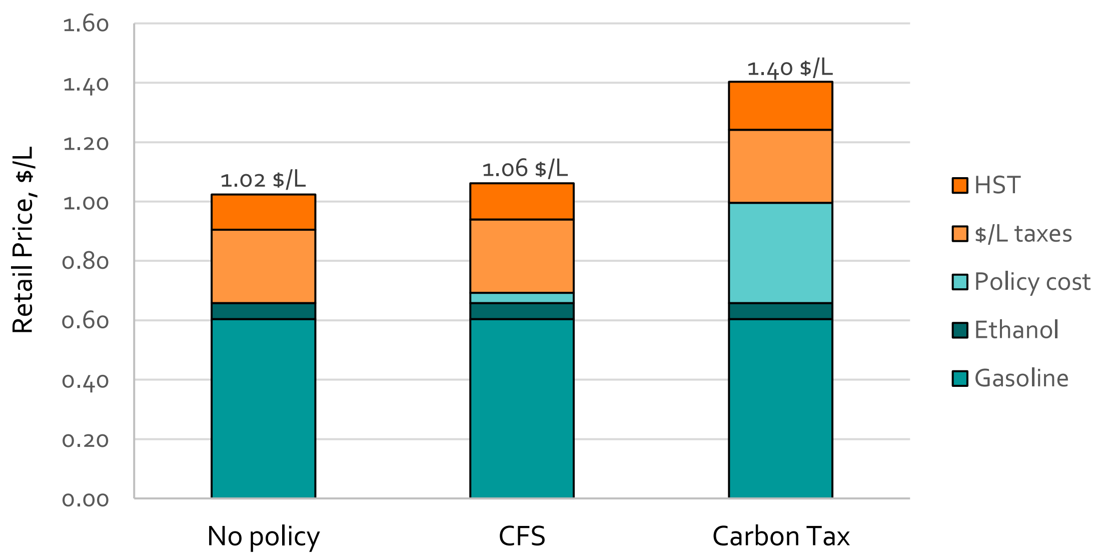
[17] Environment and Climate Change Canada (2018). Clean Fuel Standard Regulatory Design Paper.

increase that price to 1.40 $/L (Figure 4). If that credit price were instead a carbon tax, the price of E10 would be 34 ¢/L higher due to the policy, with another 4 ¢/L in additional sales tax. However, carbon tax revenue recycling, for example used to lower income tax, could mitigate the cost impact for consumers – this is not considered here.

The CFS has a different impact on retail prices because it acts 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.

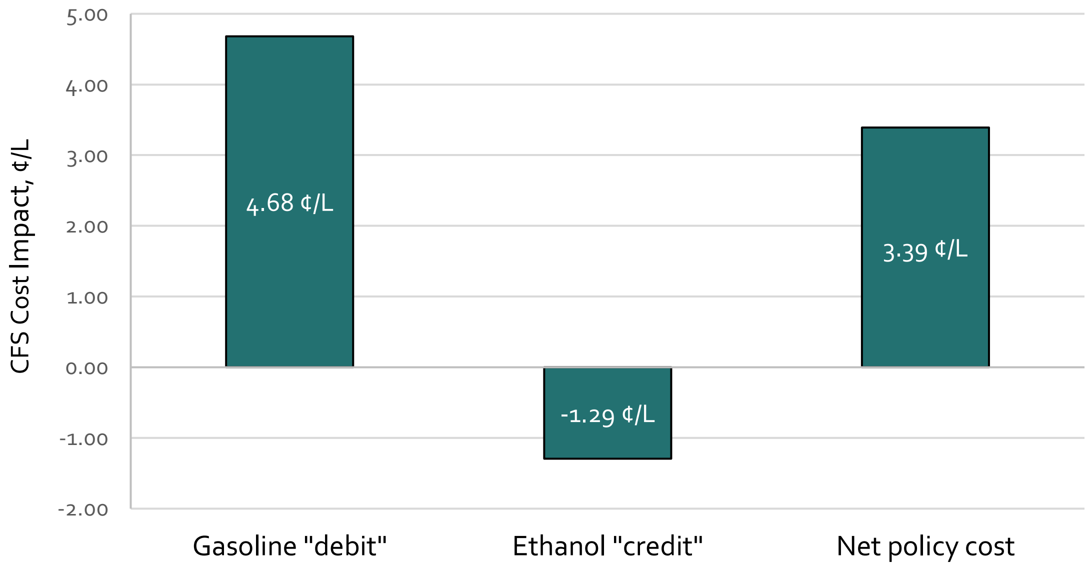
This "feebate" is illustrated with the example of E10 in Ontario. If petroleum-derived gasoline has a life-cycle CI of 87 gCO_2e/MJ and the target for 2030 is 10 gCO_2e/MJ lower, the "fee" on the gasoline component in that year would be 4.7 ¢/L of E10 when the compliance credit price is 150 $/tCO_2e$. 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 fuel market where the CFS costs and benefits are passed to the consumer, that policy would increase the price of E10 by 3.8 ¢/L (3.4 ¢/L from the CFS, 0.4 ¢/L from increased sales tax, Figure 5).

Figure 4: Impact of the CFS and a carbon tax on E10 retail prices, where the CFS credit price is equal to the carbon tax $/tonne CO_2e value



Note: Wholesale fuel costs and fuel taxes are based on Ontario in 2017. CFS 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

Figure 5: Breakdown of the CFS impact on E10 retail price



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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, 2017, the most recent data period available, by jurisdiction.
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 market experts. A literature review was used to support the assumption that biofuel does not affect energy efficiency (i.e. energy per km). 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 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.

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 2011-2017[18,19] 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). In the previous version of this analysis, the national totals for 2015 and 2016 were from the USDA GAIN. Updating to the values reported by ECCC results in some changes to fuel consumption in these years.

A further uncertainty is the volume of biomass-based diesel (i.e. HDRD and biodiesel) consumed in Ontario in both 2016 and 2017. We have assumed that fuel providers complied with the Greener Diesel Regulation, where the fuel volume required for compliance depends on the CI of those fuels. Specific CI assumptions and the breakdown between biodiesel and HDRD are listed in "Appendix B: Biofuel Volume and Feedstock Assumptions and Data". Regardless of what assumptions are used, assuming compliance with the Greener Diesel Regulation in 2017 results in significant growth in the consumption of biomass-based diesel in Ontario in that year, to a

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

[19] Environment and Climate Change Canada, 2019, Open Data: Renewable Fuels Regulations 2013, 2014, 2015, 2016 and 2017

quantity that is roughly double what ECCC reports in its regional breakdown. Since our national total biomass-based diesel consumption is still what ECCC reports, the fuel consumption we allocated to Québec and the Atlantic Provinces is lower than what ECCC reports in its regional breakdown.

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 based on input from Don O'Connor of (S&T)[2] Consultants. The updated gasoline CI's are now more closely aligned 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,[20] whereas GHGenius 4.03a uses 63 gCO_2e/MJ. This update to the gasoline CI increases the GHG emissions avoided from ethanol consumption.

A final improvement to the methodology, relative to previous versions of this analysis, involves the calculation of sales tax in the cost analysis. In previous versions of this analysis, sales taxes were applied to the retail price of gasoline and diesel blends, composed of the observed wholesale prices, marketing margin, and federal and provincial fuel taxes. There was no differentiation between the actual sales taxes paid and the sales taxes that would have been paid in a counterfactual scenario without biofuel blending. The updated methodology now accounts for how differences in retail prices between these scenarios affects the total value of sales taxes. This change tends to reduce the additional tax burden associated with ethanol consumption because ethanol is generally cheaper per volume than gasoline. Conversely, this change increases the additional tax burden associated with consuming biomass-based diesel fuels since they are generally more expensive than diesel per volume. On net, there is a slight reduction in the total additional tax burden associated with biofuel consumption.

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

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

	BC	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Atlantic
Gasoline volume	RLCFRR Summary: 2010-2017. Gasoline and diesel volumes are the total, not the non-exempt volume	2010: domestic sales, CANSIM 134-0004	Domestic sales, CANSIM 134-0004, with estimates of redacted data	Data from govt. contact	Data from govt. contact	Domestic sales, CANSIM 134-0004	Domestic sales, CANSIM, 134-0004, with estimates of redacted data
Ethanol fuel volume		Data from govt. contact	Estimate from govt. contact			Difference between national total reported under the RFS by ECCC[1] report and sum from other provinces, pro-rated to QC and AT	Difference between national total reported under the RFS by ECCC[1] report and sum from other provinces, pro-rated to QC and AT
Diesel volume		2010: domestic sales, CANSIM 134-0004	Domestic sales, CANSIM 134-0004, with estimates of redacted data		Domestic sales, CANSIM 134-0004, with estimates of redacted data	Domestic sales, CANSIM 134-0004, with estimates of redacted data	Domestic sales, CANSIM 134-0004, with estimates of redacted data
Biodiesel and HDRD volume		Data from govt. contact	Estimate from govt. contact 2012-2016		Provisional data from govt. contact for 2015. Assuming compliance thereafter.	Same method as for ethanol	Same method as for ethanol
Biofuel feedstock	RLCFRR Summary: 2010-2017	Assumption reviewed by govt. contact and (S&T)[2] Consultants	Assumption reviewed by govt. contact and (S&T)[2] Consultants	Assumption reviewed by govt. contact and (S&T)[2] Consultants	Assumption reviewed by govt. contact and (S&T)[2] Consultants	Assuming corn ethanol and yellow grease biodiesel	Assuming corn ethanol and unknown biodiesel feedstock

	BC	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Atlantic
Fuel Carbon Intensity	RLCFRR Summary: 2010-2017	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, estimated for 2016 and 2017	GHGenius 4.03a by year for Quebec	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]						
Fuel taxes and 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
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 Quebec, The Carbon Market[11]	NA
Fuel Taxes	NRCAN, Fuel Consumption Taxes in Canada[7]						
Transport margin	5-21 $/bbl, applied to biofuels based on distance between Chicago and representative city, $/bbl/km based on US EIA[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	Literature review indicates that vehicle energy efficiency (i.e. energy) should be constant regardless of the blend.						

	BC	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Atlantic
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, 2015 and 2017.

2) Natural Resources Canada, 2019, Daily Average Wholesale (Rack) Prices. http://www2.nrcan.gc.ca/eneene/sources/pripri/wholesale_bycity_e.cfm

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

4) www.eia.gov/todayinenergy/detail.php?id=7270

5) EIA, 2018. 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, 2019. Investors: Materials. 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

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

9) Government of Alberta. 2019. 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

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

11) Government of Quebec. 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

3.3. Review of the Impact of Biofuel Blends on Energy Efficiency

The analyses of how biofuel consumption has affected GHG emissions and fuel costs described in this report assume that gasoline/ethanol blends and diesel/biomass-based diesel blends (i.e. biodiesel and renewable diesel) do not change the energy efficiency of the vehicles using these fuels, relative to using fuels without these renewable additives. This assumption is supported by academic literature and the research behind California's Low-Carbon Fuel Standard (LCFS).

However, this assumption will require ongoing review: The evidence for no change in energy efficiency is not unanimous and the cost and GHG results are very sensitive to this assumption. Some studies indicate that biofuel blends may increase energy efficiency, and this outcome will become increasingly likely as new vehicles, designed to use biofuel blends to achieve regulated GHG and efficiency targets, enter the market. As an example, if E10 consumption increased the energy efficiency of gasoline-fuelled vehicles by 1.8%, as found in one peer reviewed study discussed below, avoided GHG emissions resulting from biofuel consumption between 2010 and 2017 would increase by 17% (5.8 $MtCO_2e$) and consumer cost savings would double (another $4.6 billion (2017 CAD) from 2010 to 2017).

Ethanol

Vehicles that are optimized to use gasoline/ethanol blends in the range of E15 to E25 can achieve a higher energy efficiency than when using gasoline with no ethanol (i.e. E0).[21,22,23] For example, one of these vehicles may have the same volumetric fuel consumption when using E15 and E0, even though the E15 has 5% less energy per volume, indicating a 5% increase in energy efficiency. Even existing vehicles that have

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[21] Thomas, J.F., West, B.H., Huff, S.P., 2018, Effects of High-Octane Ethanol Blends on Four Legacy Flex-Fuel Vehicles, and a Turbocharged GDI Vehicle. Oak Ridge National Laboratory. DOI: 10.2172/1185964

[22] Phuanwongtrakul, S. et al., 2016, Experimental study on sparking ignition engine performance for optimal mixing ratio of ethanol–gasoline blended fuels. Applied Thermal Engineering 100, 869-879. doi.org/10.1016/j.applthermaleng.2016.02.084

[23] Leone, T., G., et al., 2015, The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency, Environmental Science and Technology 49, 10778-10789 DOI: 10.1021/acs.est.5b01420

been re-calibrated to run on high octane E10 (e.g. premium grade octane), may see their energy efficiency increase by 2-4% when using these fuels.[24]

However, most sources indicate that the existing fleet of vehicle on average sees no consistent improvement in energy efficiency when using gasoline/ethanol blends. A review by Niven (2005) found that E10 offers no advantage in terms of energy efficiency.[25] More recently, the review done by Yan et al. (2013) found that the impact on energy efficiency is very sensitive to the vehicle being tested. Using E10 increased the median energy efficiency of vehicles by 1%, but with a standard deviation of 3%.[26] Furthermore, vehicles with indirect fuel injection showed a median increase in energy efficiency, while vehicles with direct injection, which has become increasingly common over the last decade, showed a median reduction in energy efficiency.[27]

More recent studies confirm the general finding that the ethanol blends used with current vehicles do not result in greater energy efficiency. Barakat et al. (2016) found that ethanol blends up to 20% by volume did not affect energy efficiency.[28] Dongyoung et al. (2017) found no noticeable impact when using E10.[29] Consistent with this literature, The California Air Resource Board (CARB) uses an "Energy Effectiveness Ratio" (EER) of 1 for E5 to E10 in the California LCFS.[30] The EER describes the extent to which energy from one fuel substitutes for the energy of another fuel, where a value of 1 indicates no change in energy efficiency. This value has remained constant through several reviews of the policy since 2009.

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[24] Ibid.

[25] 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

[26] 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

[27] 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.

[28] Barakat, Y., Eziz, N.A., Ibrahim, V., 2016, Fuel consumption of gasoline ethanol blends at different engine rotational speeds. Egyptian Journal of Petroleum 25 (3), 309-315. doi.org/10.1016/j.ejpe.2015.07.019

[29] Dongyoung, J. et al., 2017, The impact of various ethanol-gasoline blends on particulates and unregulated gaseous emissions characteristics from a spark ignition direct injection (SIDI) passenger vehicle. Fuel 209 (1). 702-712. doi.org/10.1016/j.fuel.2017.08.063

[30] California Environmental Protection Agency Air Resources Board, 2009, Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume 1, Staff Report Initial Statement of Reasons.

Nonetheless, the literature does not unanimously conclude that ethanol blends do not affect vehicle energy efficiency. Another meta-analysis of how ethanol affects vehicle energy efficiency found that a 5-10% by volume ethanol blend on average increases the energy efficiency of vehicles by 1.8%.[31] Furthermore, as new vehicles with modern combustion technologies enter the market, high octane gasoline/ethanol blends will likely be used to achieve regulated engine efficiency and vehicle GHG regulations.[32]

Biomass-based diesel

CARB also uses an EER of 1 for biomass-based diesel. Like the EER for ethanol, this value dates from 2009 and has remained unchanged through several reviews of the LCFS.[33] Similarly, the Coordinating Research Council states that fuel economy scales linearly to the change in diesel energy density caused by the addition of biomass-based diesel, also indicating no change in energy efficiency.[34]

But this conclusion is not definite in the diesel pool either: A comparison of truck fleets using diesel and a 20% biodiesel blend found no statistical difference in fuel economy, indicating that biodiesel blends, which are less energy dense than straight diesel, improve vehicle energy efficiency.[35] In this case, a B20 blend that has about 1.7% less energy per litre resulted in the same volumetric fuel economy, indicating a 1.7% increase in energy efficiency.

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[31] 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

[32] Leone, T., G., et al., 2015, The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency, Environmental Science and Technology 49, 10778-10789 DOI: 10.1021/acs.est.5b01420

[33] Ibid.

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

[35] McKinley, C.R., Lumkes Jr., J.H., 2009, *Quantitative Evaluation of an On-Highway Trucking Fleet to Compare #2USLD and B20 Fuels and their Impact on Overall Fleet Performance*, Applied Engineering in Agriculture, 25(3), 335-346

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, 2019-04-25".

4.1. Fuel Consumption

Figure 6 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 2017.

Figure 6: Fuel Consumption

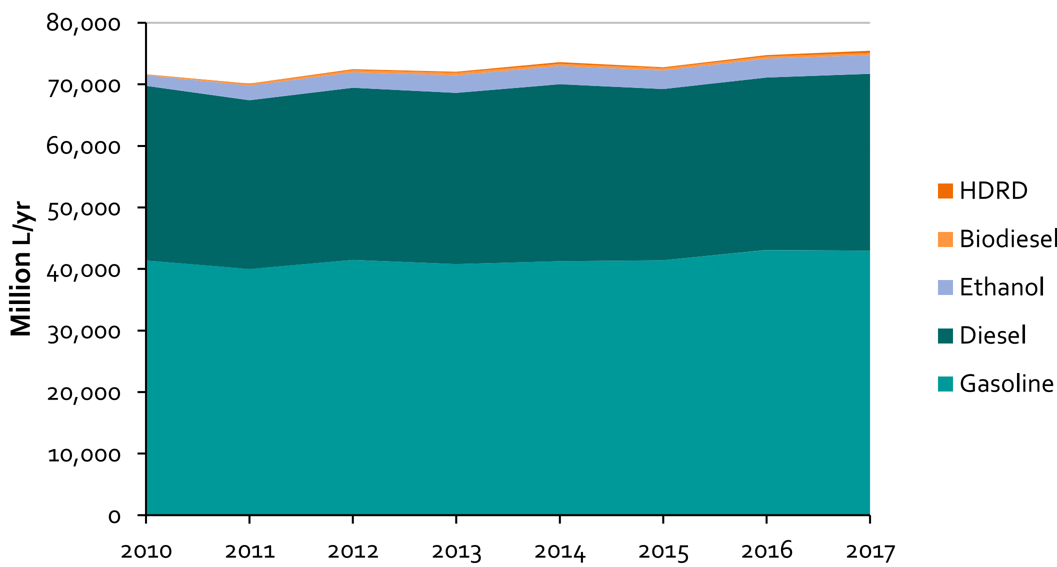


Table 9 summarizes the data in Figure 6. Our analysis shows that the volume of ethanol consumed annually has increased from roughly 1,700 million litres in 2010 to 3,050 million litres in 2017. The volume of biodiesel consumed annually also increased over that period from roughly 123 million litres in 2010 to 376 million litres in 2017.

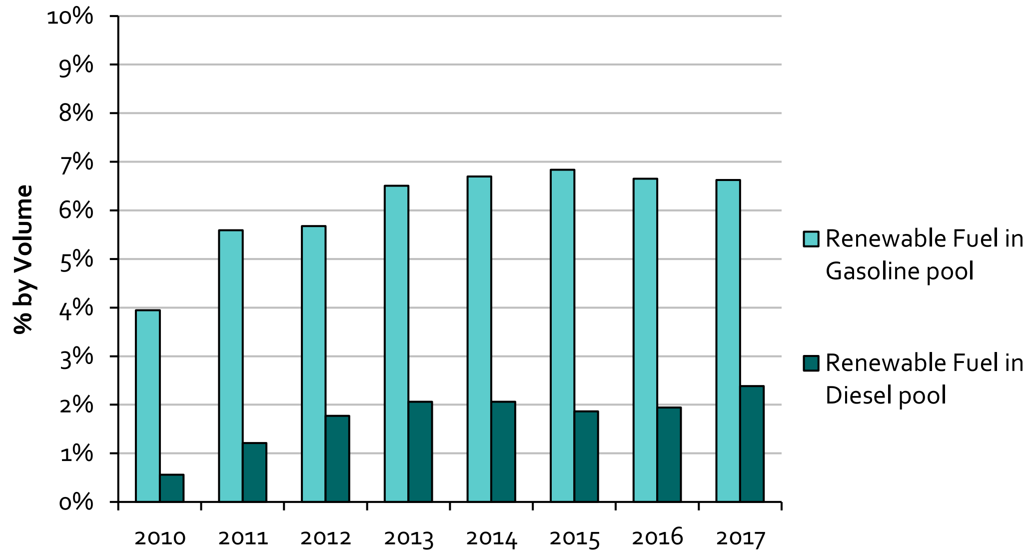
Table 9: Canadian Fuel Consumption in million litres per year

Fuel type	2010	2011	2012	2013	2014	2015	2016	2017
HDRD	37	82	142	180	227	193	212	326
Biodiesel	123	255	362	405	379	335	345	376
Ethanol	1,701	2,371	2,497	2,838	2,961	3,041	3,069	3,047
Diesel	28,374	27,429	27,960	27,823	28,767	27,778	28,057	28,754
Gasoline	41,394	40,006	41,496	40,797	41,262	41,439	43,067	42,955

HDRD is also blended into diesel in similar volumes as biodiesel. HDRD content is estimated to have increased from 37 million litres in 2010 to 326 million litres in 2017 (Table 9). The volume of HDRD in the Canadian fuel pool is more uncertain compared to other biofuels. This estimate is based on assumptions and feedback from government contacts and market experts. Some data is available on HDRD consumption from the government of British Columbia, which publishes the volumes reported by fuel suppliers for 2010 through 2017, and from the Government of Alberta, which reports HDRD consumption separately from biodiesel for 2017 only. Total national consumption can be inferred from trade data (e.g. what is reported by ECCC with their RFR data) by assuming that all imported HDRD is consumed. This is confounded by the fact that biodiesel and HDRD imports are recorded as aggregate values and Canada imports both fuels from the United States, making it difficult to be accurate about the relative quantity of each fuel consumed in Canada. Consequently, our estimate of HDRD consumption in Canada is generally somewhat lower than the amount reported as imports by ECCC, even when assuming that 80% of biomass-based diesel consumed in Ontario and Quebec is HDRD. In fact, our estimate of national HDRD consumption in 2017 could not match what ECCC reports for HDRD imports without changing HDRD consumption volumes reported by British Columbia and Alberta.

Figure 7, 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 7: Renewable Fuel Content by Fuel Pool



The ethanol content in Canadian gasoline complies with the federal Renewable Fuels Regulations, which requires at least 5% ethanol content by volume, since December 15th, 2010 (Figure 7). That same policy requires 2% renewable content in diesel since July 1st, 2011. Although the renewable content in the diesel pool was below 2% from 2011 to 2012 and again in 2015, this does not necessarily mean the mandate was not met. First, Figure 7 includes diesel exempt from policy, so the diesel pool used in this analysis is larger than would be used to measure the 2% biofuel mandate. Second, specifically for 2011, the results show the biofuel content for the entire year, yet the regulation did not take effect until July of 2011. It is possible that compliance was met in 2011 for the second half of the year, but we cannot infer this from the yearly data we received.

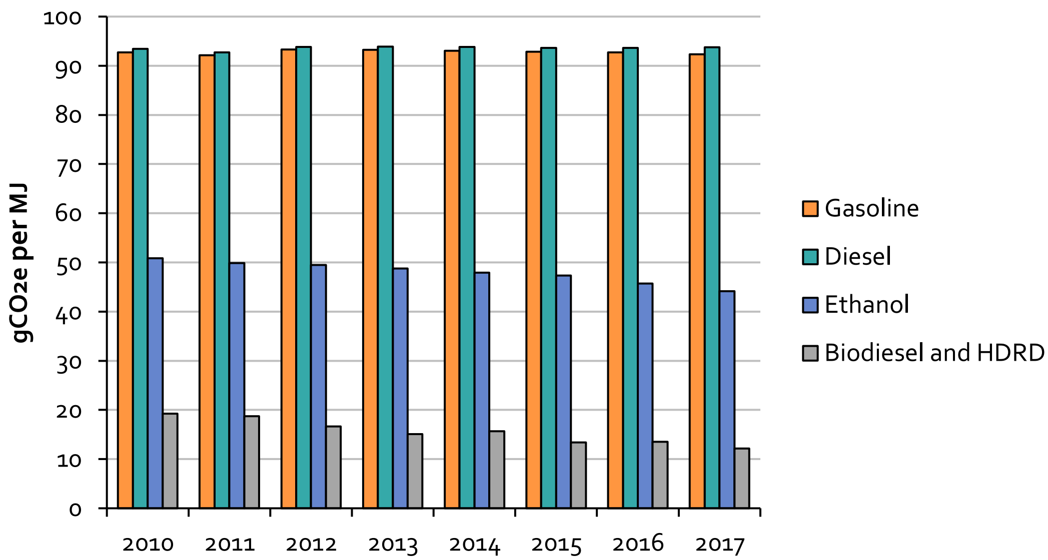
To comply with the federal Renewable Fuels Regulations, fuel suppliers only need to achieve the regulated national averages. Therefore, provincial blending will not necessarily reflect the national average. Consequently, Figure 7 does not depict the percentage of renewable content in the gasoline and diesel pools supplied to individual provinces.

4.2. Lifecycle GHG Emissions

Figure 8 shows the estimated lifecycle CI (i.e. well to wheels or farm to wheels) of transportation fuels in Canada between 2010 and 2017. 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 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, while we estimated the CI for 2016 and 2017.

Figure 8: Lifecycle CI by Fuel Type, for Canada



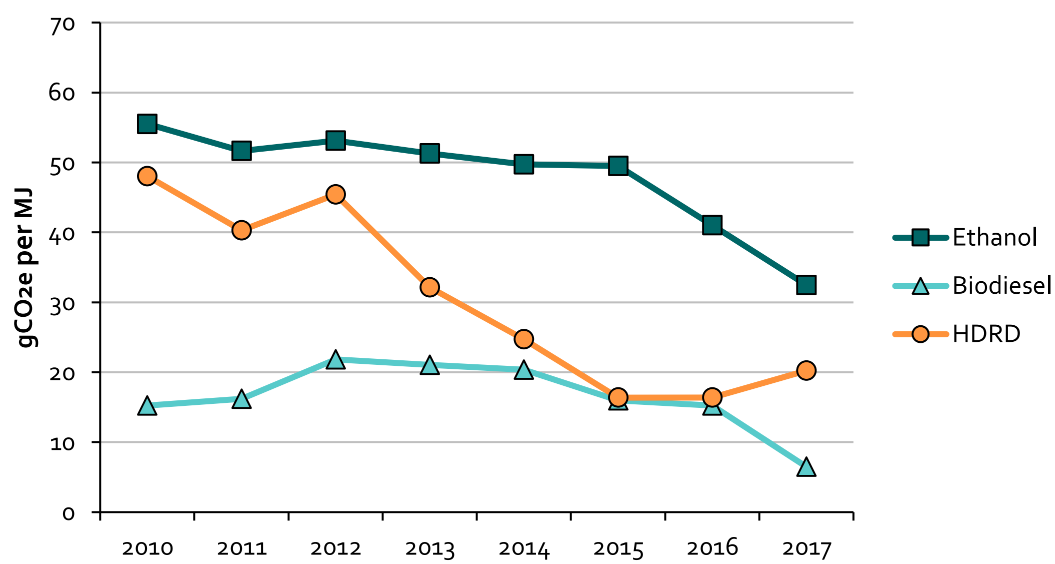
GHG emissions resulting from direct land use changes are included in the lifecycle CI of biofuels. For example, this includes the GHG emissions resulting from the conversion of pasture or forest to crop land. These intensities are based only on direct land use changes, and do not include any potential 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.[36]

The results in Figure 8 suggest that the biofuels consumed in Canada offer significant lifecycle CI reductions relative to gasoline and diesel. The data implies that, on average in 2017, ethanol sold in Canada was 52% less carbon intensive than gasoline, while biodiesel and HDRD, are estimated to be 87% less carbon intensive than diesel.

Figure 8 also suggests that the CI of ethanol, biodiesel, and HDRD are decreasing over time. However, the regional carbon intensities used to produce Figure 8 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 etc.).

In contrast, CI's for biofuels consumed in British Columbia are based on collected data, reported by fuel and feedstock to the government. These can be seen in Figure 9. The data suggest that from 2010 to 2017, the CI of ethanol decreased by 41%, the CI of biodiesel decreased by 57%, and the CI of HDRD decreased by 58%. This trend indicates that the CI of renewable fuel production is decreasing. However, it could reflect "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.

Figure 9: Lifecycle CI by Fuel Type, for British Columbia



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

Figure 10 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 displaces 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 5.5 $MtCO_2e$/yr in 2017. Cumulative national avoided GHG emissions from 2010 to 2017 are estimated to be 34.3 $MtCO_2e$. Note that values for GHG impacts since 2010 have been updated in this version compared to previous versions of the analysis as a result of the updated gasoline CI assumption.

Figure 10: Avoided Lifecycle GHG Emissions

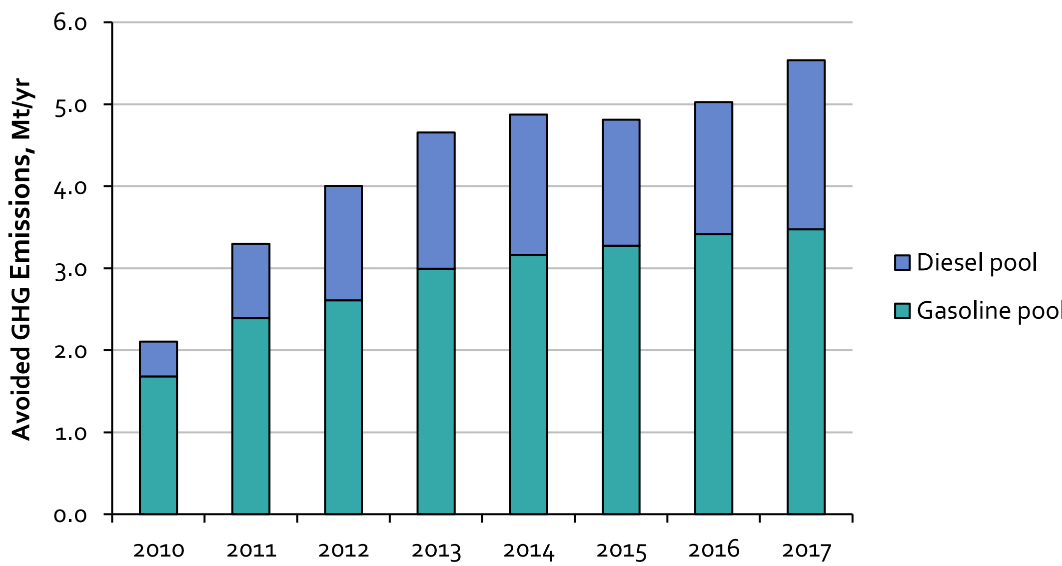
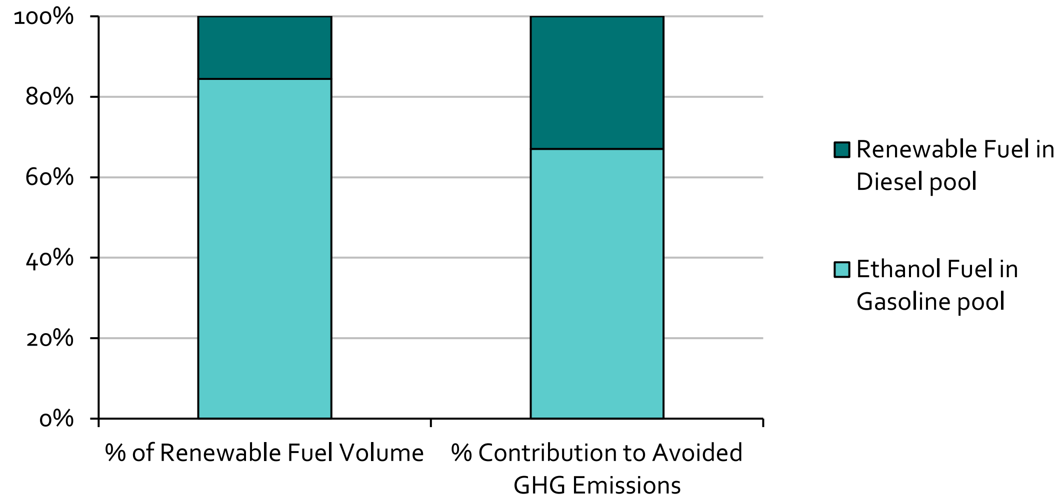


Figure 11 shows the percentage of renewable fuel volume in the gasoline and diesel pool compared with the percentage of avoided GHG emissions resulting from renewable fuel consumption in those fuel pools. Ethanol accounted for 84% of the renewable fuel volume consumed during the 2010-2017 period, but only produced 67% 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 33% of the avoided GHG emissions.

Figure 11: % of total Renewable Fuel Volume vs. % Contribution to Avoided GHG Emissions



Again, while the weight of evidence supports our assumption that biofuel blending does not affect the energy efficiency of vehicles (i.e. energy per km), there is a probability that biofuel blends have increased energy efficiency. The GHG impact is sensitive to this assumption: even a 1.8% increase in energy efficiency resulting from using E10, as found by Geringer and Spreitzer (2014)[37], would increase the cumulative GHG impact by 17%, or 5.8 $MtCO_2e$ from 2010 through 2017.

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%.[38] 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

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[37] 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

[38] 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

refining sector's GHG emissions in 2016 were 15.6 $MtCO_2e$[39]. 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 GHG emissions avoided by ethanol consumption by another 6-17% of the 2017 GHG reduction.

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:

- 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 per litre of ethanol is approximately 33% lower than it is for gasoline and energy per litre of biodiesel is approximately 9% lower than 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 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.

[39] Natural Resources Canada, Comprehensive Energy Use Database

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[40]. When used in a gasoline blend, ethanol has an octane rating of 113.[41] 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.

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 12 shows the cumulative change in consumer fuel costs resulting from renewable fuel blending in Canada from the start of 2010 to the end of 2017. 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 0.42% lower, equivalent to a savings of $4.3 billion over eight years. Note that all costs in the analysis are expressed in 2017 CAD.

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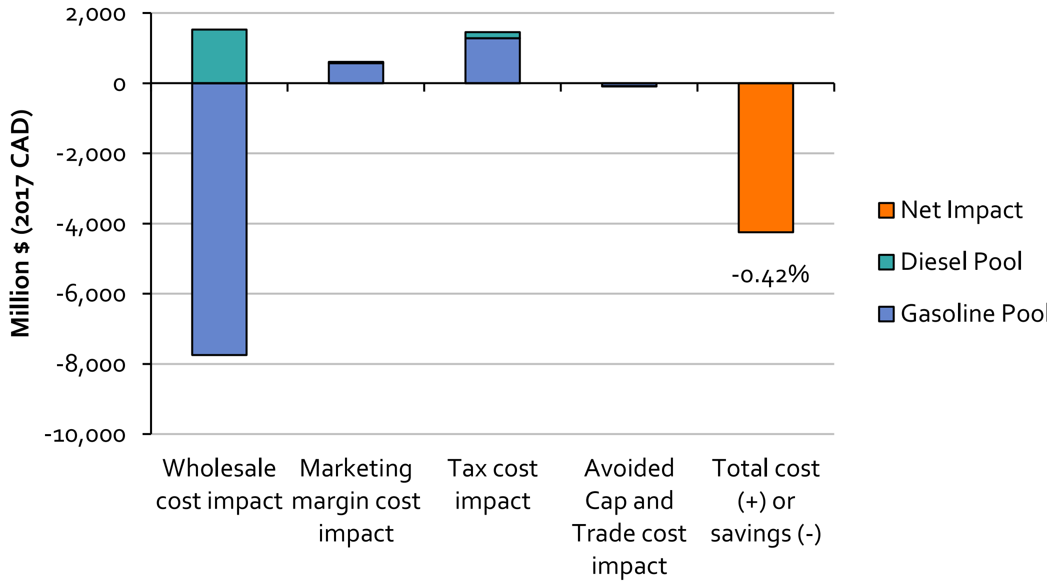
[40] U.S. Energy Information Administration, 2013, Price spread between regular and premium gasoline has changed over time. https://www.eia.gov/todayinenergy/detail.php?id=11131

[41] 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.

Figure 12: Resulting from Ethanol Blending in the Gasoline Pool and Biomass-Based Diesel Blending in the Diesel Pool (2010-2017), 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. 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 to octane value of ethanol which reduces the cost of the gasoline blendstock. Without ethanol, the cost of the gasoline would have otherwise been higher. This savings more than offsets any increase in the unit energy cost of the fuel blend, with a wholesale savings of $7.7 billion from 2010-2017. 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 $1.5 billion. 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 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, 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 $573 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 and carbon levy in Alberta 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 6% ethanol is roughly 2.94 $/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 $1.3 billion over eight years relative to a scenario with no biofuel consumption. At only $170 million, the cost 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

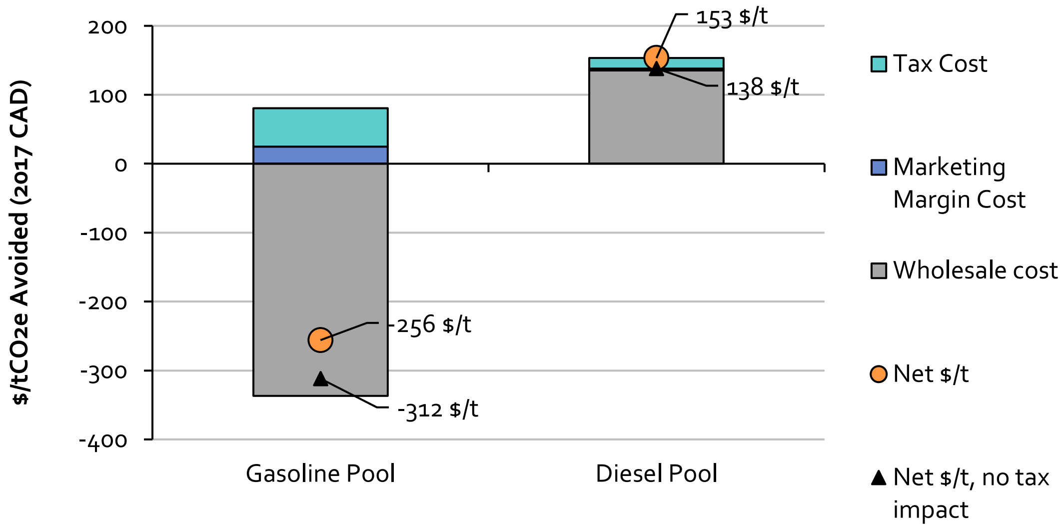
the cap and trade cost is being spread evenly across all fuels. The avoided cap and trade costs represent the additional carbon costs that would have been incurred without biofuel consumption.

All costs are calculated assuming biofuel blending does not affect the energy efficiency of vehicles (i.e. energy per km). The literature review supports this assumption, but it will require frequent review because of the uncertainty in the literature, the changing vehicle fleet, and the sensitivity of these cost impact results to this input. Again, using the example based on the analysis of Geringer and Spreitzer (2014), if E10 yielded a 1.8% improvement in energy efficiency, consumers would have saved another $4.6 billion from 2010 through 2017, equivalent to +108% of the total cost impact in the gasoline and diesel pools.

4.4. GHG Abatement Cost

Figure 13 shows the 'maximum' GHG abatement cost of biofuel blending in Canada. 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 2010-2017 for the gasoline and diesel pool. Avoided policy costs are not included in this calculation, nor are any additional costs savings and GHG reductions associated with the use of biofuels (e.g. the impact of ethanol blending on vehicle energy efficiency and refinery GHG intensity). For interest, net abatement costs without the tax cost impact are shown. In other words, Figure 13 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.

Figure 13: GHG Abatement Cost, 2010-2017

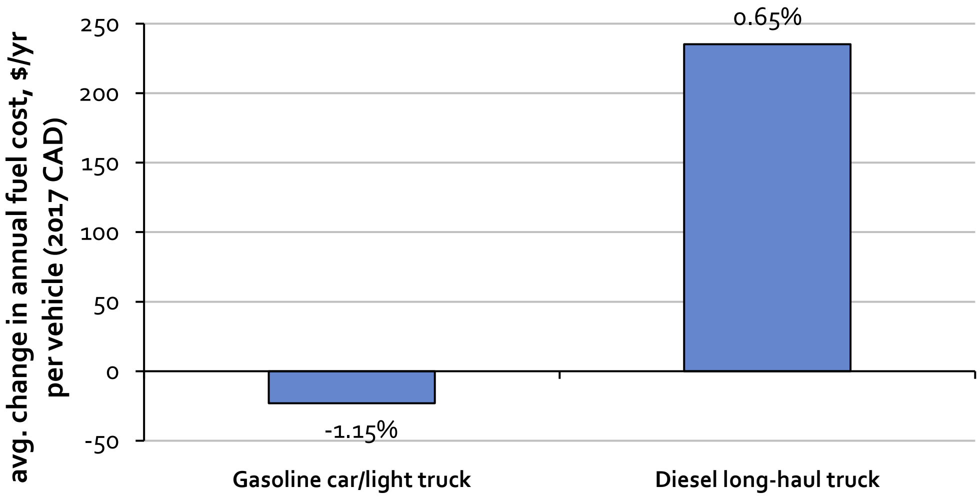


The cost of abatement from ethanol blending is -\$256/tCO_2e (Figure 13). Furthermore, the results suggest that excise and carbon taxes on fuels have a significant impact on the net dollar value per tonne CO_2e abated, which would be -\$312/tCO_2e if the excise taxes on ethanol and gasoline were equivalent on an energy basis. The abatement cost in the diesel pool is \$153/tCO_2e, or \$138/tCO_2e if fuel taxes were based on energy rather than volume.

4.5. Consumer Cost Impact

Figure 14 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 15,905 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 trucker who uses a tractor-trailer combination to travel approximately 88,753 km per year with a fuel economy of 32.4 litres per 100 km travelled. These archetypes reflect the average statistics of Canadian consumers from 2010-2016 as reported by Natural Resource Canada in the Comprehensive Energy Use Database. The average consumer of gasoline saved \$23/yr (-1.15%) because of ethanol blending in Canada. A typical diesel consumer spent an additional \$235/yr (+0.65%) because of biodiesel and HDRD blending (Figure 14). 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 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 drive investments in biodiesel blending and storage capacity, reducing the rate of HDRD blending while increasing biodiesel blending.

Figure 14: Archetypal fuel consumer cost impact, annual average 2010-2017



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 constrains 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.

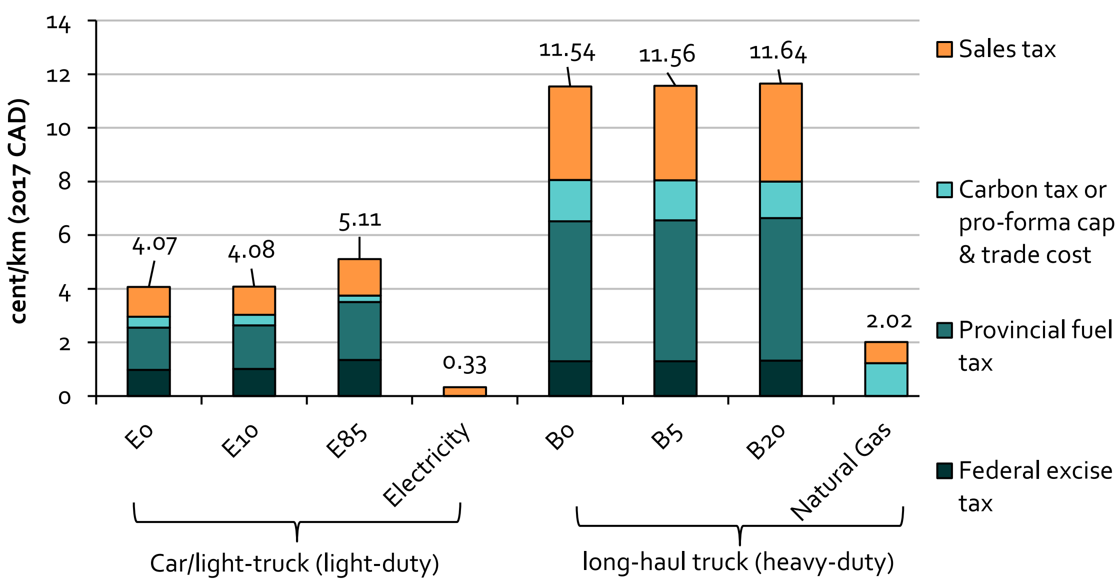
4.6. Detailed Tax Costs

A breakdown of fuel taxes per km for different fuel blends illustrates why there is a tax cost impact associated with biofuel consumption: On average in Canada, a typical gasoline user pays 0.4% more tax per km when using E10 rather than E0. A typical diesel user pays 0.2% more tax per km when using B5 rather than B0 (Figure 15). Because this result is a population weighted average for Canada, it is not specific to any province, but illustrates fuel taxation in general across Canada. There are important regional differences: For example, the percent tax cost impact is highest in regions without lower sales tax rates and carbon taxes/levies such as Alberta and British Columbia.

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 or natural gas, pay substantially less tax per km.

Figure 15 shows total fuels taxes broken down into sales tax (e.g. GST, HST), federal and provincial fuel taxes, and carbon taxes/levies. Although cap and trade costs are not taxes, pro-forma estimates of these costs, with biofuels exempted, have been included with carbon taxes. The light-duty and heavy-duty vehicle archetypes are the same as those used in the calculation of consumers costs in Figure 14. For context, taxes applied to the energy used by a plug-in electric car and a natural gas heavy-duty truck are included, assuming the electric car is 3.4 times more efficient than a gasoline car and the natural gas truck is 10% less efficient than a diesel truck.[42]

Figure 15: Fuel Taxes and Carbon Costs for Archetypal Fuels and Consumers, Illustrative Population Weighted average for Canada in 2017 (total in data label)

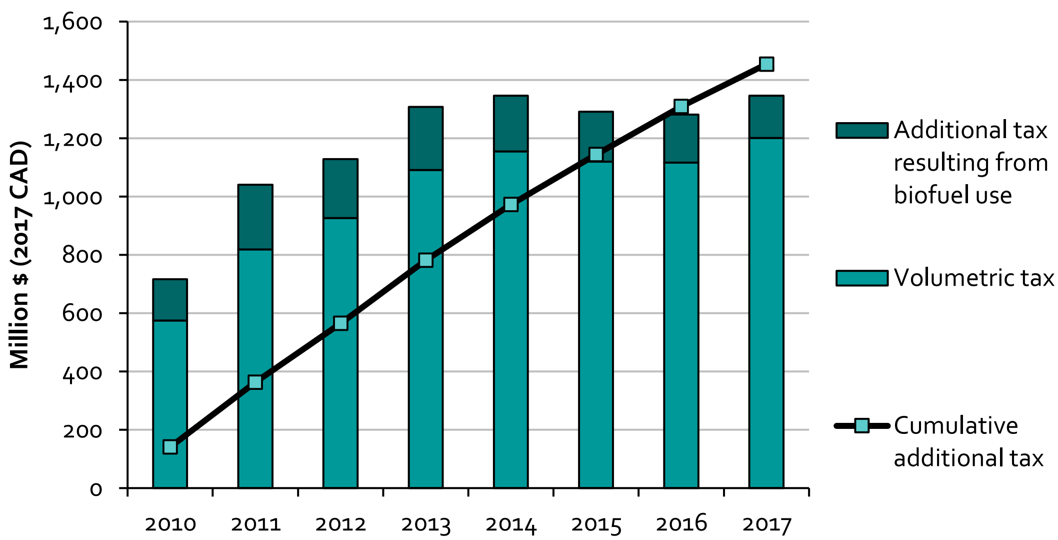


These “additional” fuel taxes paid on biofuels have amounted to an extra 12-27%/yr relative to the “volumetric” tax that would have been paid if taxes per kilometer were

[42] Based on the values used in the California and British Columbian Low-carbon fuel standards, e.g. see California Environmental Protection Agency Air Resources Board, 2009, Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume 1, Staff Report Initial Statement of Reasons.

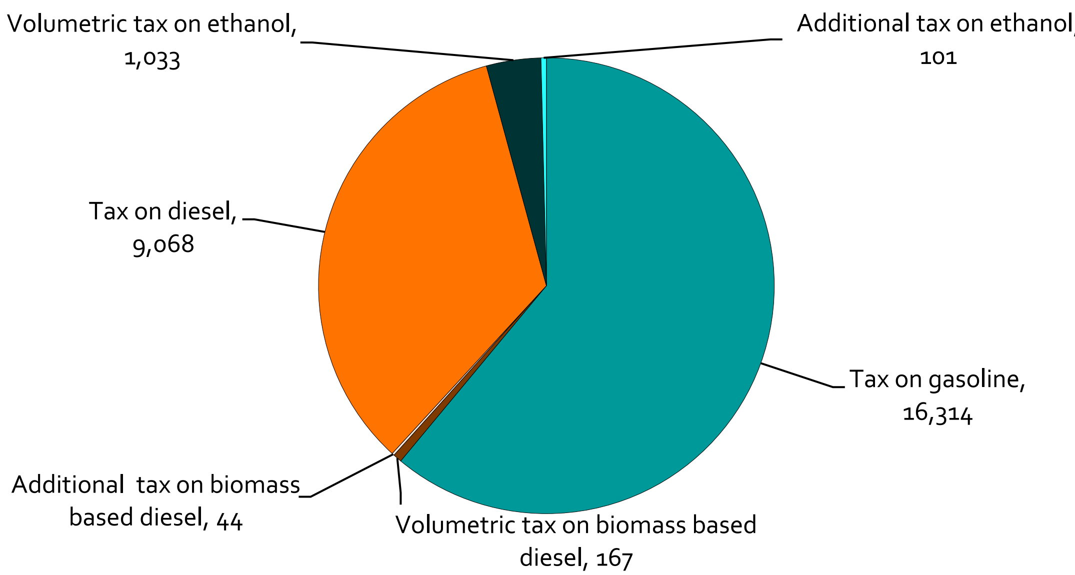
the same across all fuels used in the gasoline and diesel fuel pools (Figure 16). The cumulative tax cost impact rose to $1.5 billion (2017 CAD) in 2017 (This is the same as the tax cost impact shown in Figure 12). Variation in the relative size of the "additional" tax and "volumetric" tax are a function of annual variations the biofuel and petroleum fuel wholesale prices, marketing margins, and the additional value of octane provided by ethanol.

Figure 16: Breakdown of Fuel Taxes Paid on Biofuels in Canada, with Cumulative "Additional" Tax Paid



Taxes paid on ethanol in Canada in 2017 account for 6.5% of the total taxes paid on fuel from the gasoline pool, where the "additional" tax on ethanol is 0.6% of that total. Taxes paid on biomass-based diesel represent 2.3% of the total taxes paid on the diesel pool in Canada in 2017. The "additional" tax on biomass-based diesel is 0.5% of that total (Figure 17).

Figure 17: Breakdown of Taxes Paid on the Gasoline and Diesel fuel pools in 2017, million 2017 CAD



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:

1. The renewable content in gasoline and diesel pools has increased from 2010 to 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 3,050 million L/yr in 2017. Annual biodiesel consumption has increased from roughly 123 million L/yr in 2010 to 376 million L/yr in 2017. HDRD consumption increased from roughly 37 million L/yr to 326 million L/yr in that same period.
2. Annual avoided GHG emissions resulting from biofuel blending in Canada have increased from 2.1 $MtCO_2e$/yr in 2010 to 5.5 $MtCO_2e$/yr in 2017. The cumulative GHG emission avoided between 2010 and 2017 are 34.3 $MtCO_2e$. Because we have updated the CI of gasoline to a higher value, GHG impact for all years has increased since the last edition of this analysis.
3. Between 2010 and 2017, blending ethanol, diesel, and HDRD with conventional transportation fuels reduced consumer fuel costs in Canada by 0.42%, relative to what they would have been without renewable fuels. If all costs and savings were passed on to consumers, they saved $4.3 billion (2017 CAD) over the eight-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, -\$256/tCO_2e, whereas the abatement cost from biofuel blending with diesel is positive at \$153/tCO_2e. Ethanol blending reduced the annual fuel costs of a typical driver by $23/yr (-1.15%), relative to a scenario without ethanol consumption. Biodiesel and HDRD blending increased the annual fuel costs of an archetypal long-haul trucker by $235yr (+0.65%). 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. This action was possible: The results show that on average in Canada, biodiesel only accounted for 1% of the diesel pool volume, well below even the most conservative estimate of the volume that can be easily blended into diesel.

4. Biofuel consumption, especially ethanol, has increased the fuel tax burden on consumers while creating 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 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. The current tax structure cost gasoline consumers an additional $1.3 billion (2017 CAD) during the eight-year study period (included within the net savings noted above). The corresponding tax cost on diesel consumers during that period was $170 million (2017 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 2010-2017.
  - 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 2017.
- 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 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 were based on results from Google maps (road distances used to approximate rail distance). We assumed a transportation cost of $0.006/km/barrel based on EIA.[43]
  - USD was converted to CAD based on Bank of Canada historic data.[44]
- 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 NRCAN.[45]

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[43] Energy Information Administration, 2012, "Rail deliveries of oil and petroleum products up 38% in first half of 2012", available from www.eia.gov., accessed May 2017.

[44]Bank of Canada, 2018, Exchange Rates. http://www.bankofcanada.ca/rates/exchange/monthly-average-lookup/

[45]Natural Resources Canada, 2019, Daily Average Wholesale (Rack) Prices. http://www2.nrcan.gc.ca/eneene/sources/pripri/wholesale_bycity_e.cfm

- All values were converted to 2017 dollars.[46]

- 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 would have had to be higher if no ethanol were added. In other words, we estimated the price of pure gasoline assuming the blendstock 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 at 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:

  - 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.[47]

  - The implied cost per octane point was estimated for each year based on the difference between regular and premium gasoline in the US market[48] 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:

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

[47] 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.

[48] 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

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

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[49]
- $O_{blend,prem}$ 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)
- $\%vol_{ethl}$ 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

[49] ibid

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 were obtained from Kent Marketing.[50] Taxes are from NRCAN.[51] 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 from 2017 onwards, 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 Quebec 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

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

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

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.[52,53]

  - 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 2010-2016 as reported by Natural Resource Canada, for the average L/100 km and annual km travelled. For the archetypal gasoline 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.[54,55]

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

[53] Government of Quebec. 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

[54]Natural Resources Canada, 2017, Passenger Transportation Explanatory Variables.

[55] Natural Resources Canada, 2017, Freight Transportation Explanatory Variables.

Appendix B: Biofuel Volume 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 this 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 feedstocks and volumes by region in Canada.

British Columbia

Feedstock data was obtained from the government of British Columbia.[56] However, the data appeared to have some minor summation errors. Therefore, we made the following adjustments:

1. There appear to be 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 and palm oil by-products are used for HDRD.

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

[56]Ministry of Energy and Mines, 2019, Renewable and Low Carbon Fuel Requirements Regulation Summary: 2010-2017

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

3. Alberta's provincial regulation and the federal diesel regulation did not become effective until 2011. Since we do not have data for 2010, we are assuming that there was no renewable content in 2010.

4. The proportion of biodiesel vs. HDRD in all years is based on data reported for 2017 (9.9% of biomass-based diesel is HDRD),

Saskatchewan

1. We assume that the proportion of biofuel in diesel is 0% HRDR and 100% biodiesel. Volumes are based on correspondence with a government contact.

2. We assume that the feedstocks for ethanol are wheat and corn. We base this assumption on the feedstocks being processed in Saskatchewan as reported by GAIN,[57] as well as 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.

Manitoba

1. We assume that ethanol feedstocks are primarily corn with some wheat, based on the feedstocks processed in Manitoba facilities as reported by GAIN[58] as well as correspondence with Don O'Connor of (S&T)[2] Consultants.

2. We assume that biodiesel feedstocks are split evenly between canola and soy. We base this assumption on 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.

Ontario

1. We assume that ethanol consumed in Ontario is made from corn.

[57] Global Agricultural Information Network, 2016, Canada Biofuels Annual.

[58] Ibid

2. We assume that an equal amount of biodiesel is produced from soy and yellow grease, and HDRD is made from tallow. These assumptions are based on correspondence with a government contact.
3. Bio-based diesel (biodiesel and HDDRD) consumption volumes in 2016 and 2017 are estimated assuming compliance with the Greener Diesel Regulation, 80% of volume is HDRD with CI based on Diamond Green Diesel in 2016 and 2017 (20.5 and 15.2 g/MJ, respectively), 20% is biodiesel with net-0 CI, 10% of diesel pool is distributed in Northern Ontario (based on 2015 data).
4. Bio-based diesel in 2015 is based on Greener Diesel Regulation compliance data, prior years are based on fuel tax exemption data.

Quebec

1. Ethanol and biomass-based diesel volumes are estimated based on the difference between federal data reported by ECCC and total biofuel content collected for the other provinces. That difference is allocated to Québec and the Atlantic Provinces, pro-rating by population. Newfoundland and Labrador is excluded from the calculation since we have good confidence that very little biofuel is consumed there.

2. 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).

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

Atlantic

1. Ethanol and biomass-based diesel volumes are estimated based on the difference between federal data reported by ECCC and total biofuel content collected for the other provinces. That difference is allocated to Québec and the Atlantic Provinces, pro-rating by population. Newfoundland and Labrador is excluded from the calculation since we have good confidence that very little biofuel is consumed there.

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

Feedstocks

Based on the assumptions outlined above, the feedstocks used to produce biofuels sold in Canada were estimated and summarized in Figure 18 and Figure 19. Figure 18 shows the renewable fuel content in the diesel pool in Canada from 2010 to 2017, by fuel type and feedstock: most biodiesel is from canola, most HDRD is from palm oil by-products and tallow. Figure 19 shows the renewable fuel content in gasoline pool in Canada from 2010 to 2017, by fuel type and feedstock: most ethanol consumed in Canada is produced from corn, with 10-15% produced from wheat

Figure 18: National Results for Renewable Fuel Consumption of Diesel Pool by Fuel Type, and Feedstock

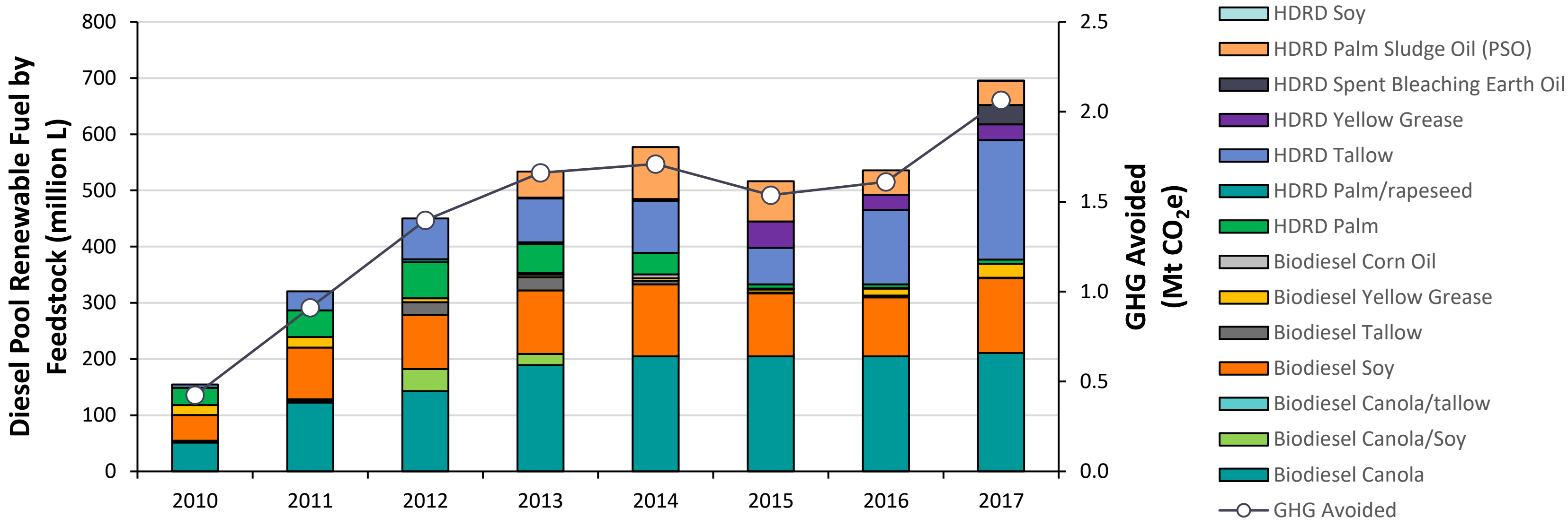

Figure 19: National Results for Renewable Fuel Consumption for Gasoline Pool by Fuel Type, and Feedstock