Biofuels in Canada 2018

Tracking biofuel consumption, feedstocks and avoided greenhouse gas emissions

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About Navius Research

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

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Executive Summary

Policies aimed at reducing greenhouse gas (GHG) emissions from transportation will likely increase the consumption of renewable and low-carbon biofuels. 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 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. In this analysis, Navius has updated a series of studies on renewable fuel use in Canada, previously released in 2017 by Navius and in 2016 in partnership with Clean Energy Canada.

Objectives

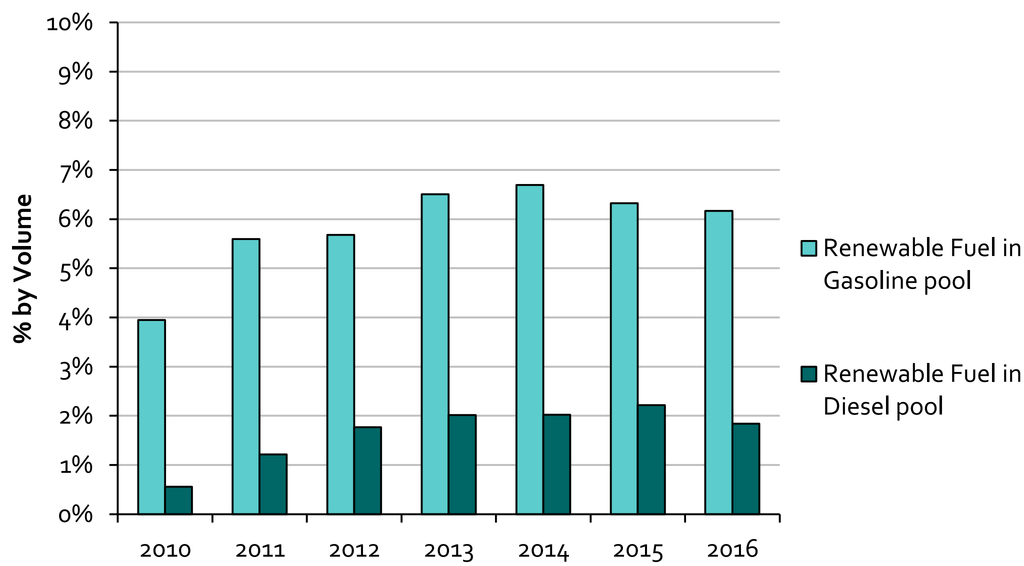
The objectives of this project are to evaluate and communicate the impact of renewable and low-carbon fuel policy in Canada by:

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

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 liters in 2010 to 2,800 million liters in 2016. Annual consumption of biodiesel has grown from roughly 123 million liters in 2010 to 240 million liters in 2016. HDRD is also believed to be blended into diesel in even larger volumes than biodiesel in recent years. HDRD content is estimated to have increased from 37 million liters in 2010 to 300 million liters in 2016. 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 24.9 Mt CO_2e between 2010 and 2016. Annual avoided GHG emissions have grown from 1.8 Mt in 2010 to 4.1 Mt in 2016. 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 2016 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 2016. The cost components are the wholesale cost, the marketing margin cost (i.e. distribution) and the fuel tax cost. The wholesale cost accounts for 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.

Biofuel consumption has yielded a small savings relative to a scenario where no biofuel was consumed, roughly $1.6 billion (2017 CAD) over seven years, or -0.26% 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: most fuel taxation (e.g. excise and carbon taxes) in Canada is charged per liter, regardless of how much energy is in that liter.

Figure 2: Cumulative Cost Impact by Source (2010-2016), total % change in data label

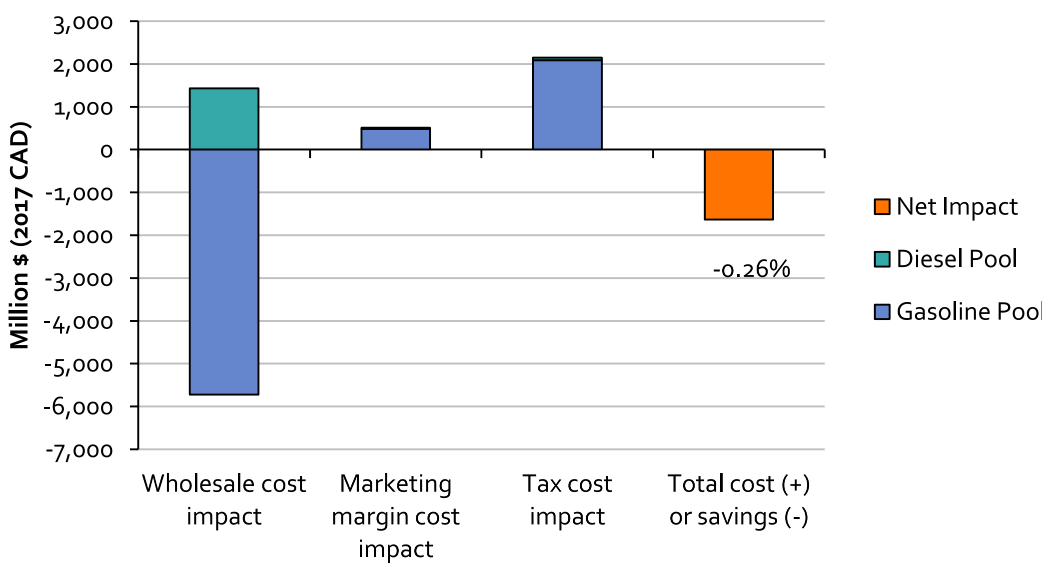
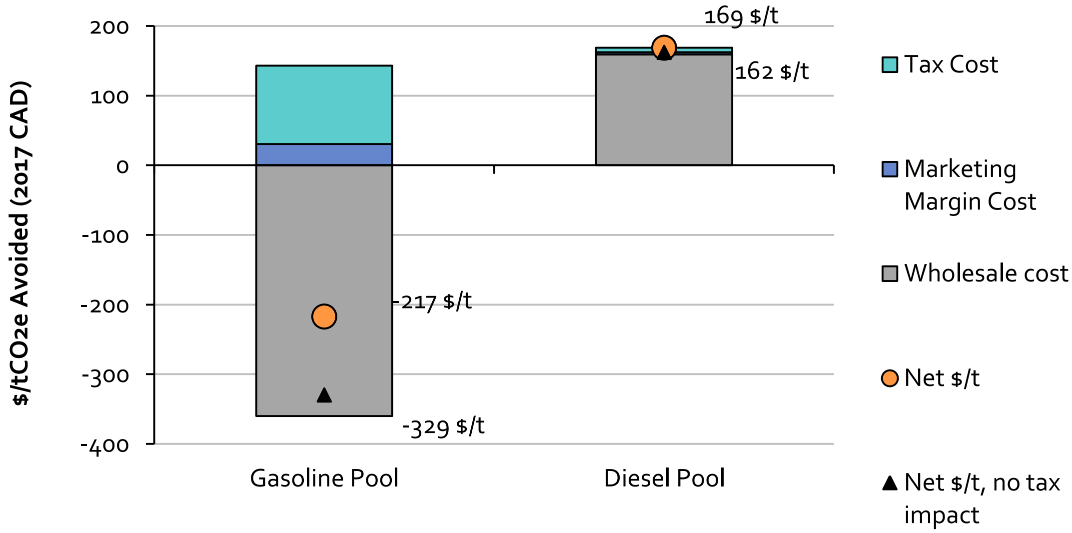


Figure 3 shows the cumulative consumer cost divided by the cumulative avoided GHG emissions from 2010-2016 for gasoline and diesel pools in Canada. Again, the costs do not account for any co-benefits or costs other than those shown in Figure 2 (i.e. no accounting for reduced air pollution and health impact related to biofuel consumption). The abatement cost in the gasoline pool is -$217/tCO2e versus $169/tCO2e 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 largely offset 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 $16.1/yr (-0.82%), whereas it has cost a typical diesel consumer (based on a long-distance trucker) an additional $224/yr (+0.61%).

Figure 3: GHG Abatement Cost, 2010-2016



Note that the wholesale cost in the diesel pool is now higher than previously reported because this analysis has improved HDRD price data relative to previous releases of this study. The current cost estimate is roughly double what it would have been using the HDRD price assumption from the previous iteration of this analysis. However, the diesel pool wholesale cost impact could have been much lower if fuel suppliers used more low-cost biodiesel. This action was indeed 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 volume that can be easily blended into diesel.

Future Work

The GHG and cost results assume that using ethanol blends does not change the energy efficiency of vehicles or the GHG intensity of petroleum refining. However some research indicates that using ethanol blends at 5-10% by volume can increase vehicle energy efficiency by 1%.[1] Likewise, ethanol blends allow petroleum refineries to produce a lower octane gasoline blendstock which may reduce the GHG intensity of refining.[2] The magnitude of these impacts are uncertain, but if they were included in

[1] 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

[2] 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

this analysis, the avoided GHG emissions in 2016 would have been 1.5-2.0 MtCO_2e/yr larger (+35-49%) and the fuel cost savings over the seven-year study period would have been $3 billion (2017 CAD) larger. Similarly, biofuel blends in the diesel pool may also affect energy efficiency; data regarding this dynamic will also be monitored.

Further, given emerging federal and provincial carbon pricing systems and their application to transportation and industrial fuels, the impact of volumetric vs. energetic taxation may change in the future (2017 onward). For example, where carbon pricing policy is currently in place, biofuels use can be subject to the full carbon price (British Columbia), partially exempt (Alberta), or fully exempt (Ontario and Quebec). The shifting carbon pricing policy framework for Ontario and the final framework and application of the federal carbon pricing system will affect the tax cost component of our cost analysis in future periods.

Future work will incorporate research regarding energy efficiency of biofuel blends and impacts of carbon taxation policy and include them in the analysis, where warranted.

Table of Contents

1. Introduction

Policies aimed at reducing greenhouse gas (GHG) emissions from transportation will likely increase the consumption of renewable and low-carbon biofuels. 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 and the US Department of Agriculture both report biofuel consumption for Canada. However, there is no comprehensive data source in Canada that allocates renewable fuel consumption by province using data from provincial regulators 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 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 policy in Canada. This is done by quantifying the annual volumes of transportation fuels consumed in individual provinces and nationally from 2010 to 2016, 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 also 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. For this edition, we sought to estimate results for 2017 but the data was insufficient. We also attempted to report data about fuel policy compliance credits, but this data was only available for British Columbia.

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, 2018-07-05 840"). Results are shown for Canada and each province.

The remainder of this report provides a brief overview of the incumbent renewable fuel policies in Canada, with some comparison to US policies for context. 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 incumbent (2016) renewable fuel policies in Canada at both the federal and provincial levels to provide an understanding of the regulations driving renewable fuel consumption in the period. For greater context, the Canadian policies are briefly compared with the key biofuel policies in the United States. For the following policy discussion and the remainder of the 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. Canadian Policy

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	2012	2013	2014	2015	2016
British Columbia	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Alberta	-	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Saskatchewan	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
Manitoba	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
Ontario	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Canada	-	5.0%	5.0%	5.0%	5.0%	5.0%	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, and include: 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 below, 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
British Columbia	3.0%	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%
Saskatchewan	-	-	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%
Ontario	-	-	-	-	2.0%	2.0%	4.0%
Canada	-	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, and include: Quebec, New Brunswick, Nova Scotia, and Prince Edward Island. Furthermore, fuel oil used for heating has been exempt from the federal regulation since 2013.

Upcoming federal policies that will affect biofuel blending post-2018 may include a carbon price and the Clean Fuel Standard. The proposed carbon price will apply to provinces in Canada that do not have a provincial carbon price. The proposed Clean Fuel Standard will prescribe an average CI reduction schedule for liquid, gaseous and solid fuels. This report will provide more detail on these policies as they are finalized and come into force.

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. 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 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.[3]

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 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 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*

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

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) defines minimum renewable fuel content as well as a schedule of reductions to the average lifecycle CI of fuel sold in BC. This policy came into effect January 1, 2010, and BC was the first Canadian province to regulate the CI of biofuel. The RLCFRR requires 5% renewable fuels by volume in the gasoline pool and 4% renewable fuel by volume in the diesel pool (initially 3% in 2010). Additionally, the carbon intensity policy (called a low carbon fuel standard, or LCFS), which came into effect July 1, 2013, requires a 10% reduction in fuel CI in 2020 relative to a 2010 baseline. Consequently, renewable fuel blending is not the only approach able to 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 be reviewed in the context achieving BC's 2030 GHG reduction targets, and the average CI reduction may be increased.

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, with a maximum credit price of 200 $/tCO_2e$. 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. US Renewable Fuel Policies

This section compares Canadian renewable fuel policies with the key American policies. Although the United States has many state level blending requirements, this section focuses on the federal renewable fuel standard (RFS) initiative, as well as the low carbon fuel standard (LCFS) in California. The California LCFS is like the LCFS component of the British Columbia policy, though it was implemented first and covers a much larger market. The federal RFS in the United States has a higher blending mandate than the Canadian policy and specifies minimum volumes for advanced biofuels (e.g. cellulosic ethanol).

The US Federal Renewable Fuel Standard

The *US Renewable Fuel Standard* (RFS) requires a minimum quantity of renewable fuel consumption. However, unlike the Canadian federal policy which only mandates blending a certain percentage of renewable fuel by volume, the US policy characterizes required renewable fuels within four categories. Each category has a defined feedstock and CI reduction relative to the petroleum fuels, inclusive of indirect land-use GHG emissions:[4]

- Conventional biofuel must have a lifecycle CI reduction of at least 20% relative to petroleum fuels
- Advanced biofuel must have a CI reduction of at least 50%
- Renewable diesel/biodiesel must have a CI reduction of at least 50%
- Cellulosic biofuel must have a CI reduction of at least 60%

The US RFS requires significantly more renewable fuel content by volume than the Canadian federal policy. The US policy has mandated 8%-11% renewable fuel content between 2010 and 2018. In contrast, the Canadian regulation has only mandated 5% in gasoline and 2% in diesel.

Furthermore, the US Environmental Protection Agency (EPA) is required to set biofuel blending requirements each year, which are meant to escalate, based on goals defined in the Energy Independence and Security Act of 2007 (EISA). Under the EISA, total biofuel volumes were to increase at roughly 9% annually to 2022. However, in practice, the renewable fuel volume obligations set by the EPA have not met the maximum targets set in EISA.

Table 3 summarizes the implied fuel blends by volume mandated by the policy. Under the US RFS, ethanol (conventional biofuel) blending in regular grade gasoline is 10%. Note that the biomass-based diesel content applies to the entire distillate fuel pool, which includes light-fuel oil used for heating. Actual biofuel blending levels in on-road transport diesel fuel is closer to 5% (biodiesel and HDRD).

[4] US Environmental Protection Agency, 2018, Final Renewable Fuel Standards for 2018 and Biomass-Based Diesel Volume for 2019

Table 3: Implied fuel blends by volumes in the US renewable fuel standard

Fuel type	2014	2015	2016	2017	2018
Cellulosic biofuel (min.)	0.0%	0.1%	0.1%	0.2%	0.2%
Biomass-based diesel (min.)	1.4%	1.5%	1.6%	1.7%	1.7%
Other Advanced biofuel (min.)	0.1%	0.1%	0.3%	1.1%	2.4%
Conventional biofuel (remainder)	7.7%	7.9%	8.1%	7.7%	6.4%
Total biofuel	**9.2%**	**9.5%**	**10.1%**	**10.7%**	**10.7%**

The Californian Low-Carbon Fuel Standard

The *Californian Low-Carbon Fuel Standard*, like British Columbia's standard, requires a 10% reduction in the lifecycle CI of transportation fuels by 2020, relative to a 2010 baseline. Like the BC policy, the Californian policy uses tradable credits with a ceiling price.

3. Methodology

Table 4 outlines the tasks we undertook in this study as well as our approach for each of these tasks.

Table 4: Study method by task

Task	Approach
1. Tabulate renewable fuel use and requirements	Provincial and federal Renewable Fuel Standard (RFS) and Low Carbon Fuel Standard (LCFS) 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, 2016, 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 estimate GHG reductions	Carbon intensities (CI) were defined and used to estimate greenhouse gas (GHG) reductions using the latest version of GHGenius (v.4.03a) and data from 1 & 2 above. New data was used to verify past data and assumptions. We also reviewed any assumptions made in the previous years' analyses for tasks 1 through 3. 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 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.

Table 5 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 5 also flags the greatest uncertainties in orange, representing data gaps. For example, neither Quebec nor the Atlantic provinces have reporting mandates for biofuels blended into transportation fuels. To infer volumes of ethanol, biodiesel, and HDRD in these provinces, we used the difference between national totals and the data we collected.

The US Department of Agriculture Global Agricultural Information Network (GAIN) provides national renewable fuel consumption totals from 2010-2016.[5] However, the totals from GAIN are estimates based on trade data, whereas Environment and Climate Change Canada (ECCC) has published national totals for 2011-2014 based on volumes reported to the Canadian government under the federal renewable fuels regulations.[6] The national totals from ECCC were assumed to be correct and replaced the GAIN totals for 2011 to 2014.

Other assumptions in this report have been modified from the previous year. For example, we did not have HDRD price data for the 2015 report. This year we have HDRD prices from Neste financial reports. These are substantially higher than assumed in the previous analysis. Therefore, our resulting diesel pool abatement cost for Canada is 120% higher than suggested by last year's report and higher still in regions with HDRD consumption that is higher than the national average.

The estimated feedstock proportions have also changed since last year. These have been modified for two reasons. First, we have received more information about the types of feedstocks used from a review by Don O'Connor of (S&T)[2] Consultants and from national data to 2014 from ECCC. Second, we have updated estimated volumes of HDRD to better align with total annual sales as reported by ECCC for 2013 and

[5]Global Agricultural Information Network, 2016, Canada Biofuels Annual Report

[6]Environment and Climate Change Canada, 2016, Renewable Fuels Regulation Report: December 15, 2010 to December 31,2012 and data shared for 2013 and 2014

2014. Although we have not modified the total volume of biofuels in the diesel pool, the proportion of HDRD to biodiesel has been updated from our 2015 report. All these changes affect our estimates for yearly GHG intensity by fuel and yearly avoided lifecyle GHG emissions from last year’s report.

Table 5: Summary of Inputs (data in green, assumptions in yellow, major uncertainties in orange)

	BC	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Atlantic
Gasoline volume	RLCFRR Summary: 2010-2016. Gasoline and diesel volumes are the total, not the non-exempt volume	2010: domestic sales, CANSIM 134-0004 2011-2016: From govt. contact	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 in USDA GAIN[1] report and sum from other provinces, pro-rated to QC and AT	Difference between national total in USDA GAIN[1] report and sum from other provinces, pro-rated to QC and AT
Diesel volume		2010: domestic sales, CANSIM 134-0004 2011-2016: From govt. contact	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	Same method as for ethanol	Same method as for ethanol
Biofuel feedstock	RLCFRR Summary: 2010-2016	Based on typical noted in USDA GAIN[1] report	Assumption reviewed by govt. contact	Assumption reviewed by govt. contact	Assumption reviewed by govt. contact.	Assuming corn ethanol and yellow grease biodiesel	Assuming corn ethanol and unknown biodiesel feedstock
Fuel Carbon Intensity	RLCFRR Summary: 2010-2016	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 in Ontario Biodiesel/HDRD: avg. from govt. contact	GHGenius 4.03a by year for Quebec	GHGenius 4.03a by year for Canada East

	BC	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Atlantic
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
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 midgrade gasoline in the United States[5]						
Energy efficiency	Assume vehicle energy efficiency (e.g. km/GJ fuel consumed) is constant regardless of the blend.						
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) US Department of Agriculture, Global Agriculture Information Network, Canada Biofuels Annual 2016

2) Natural Resources Canada, 2018, 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, 2018. Investors: Materials. Accessed from: https://www.neste.com/corporate-info/investors/materials-0

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 is in the associated excel spreadsheet, named "Biofuels in Canada Analysis, 2018-07-05 840".

4.1. Fuel Consumption

Figure 4 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 2016.

Figure 4: Fuel Consumption

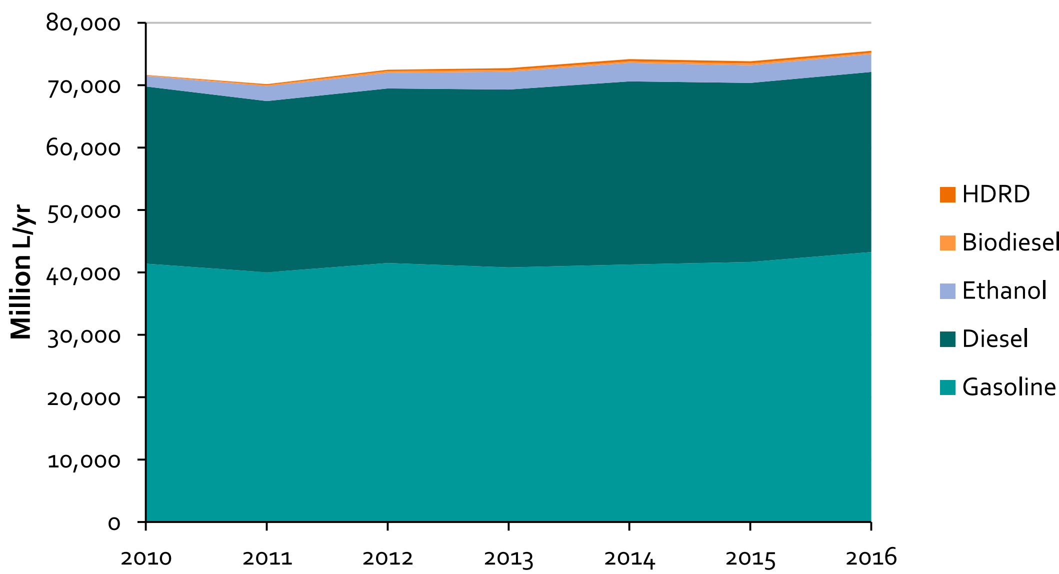


Table 6 summarizes the data in Figure 4. Our analysis shows that the volume of ethanol consumed annually has increased from roughly 1,700 million liters in 2010 to 2,800 million liters in 2016. The volume of biodiesel consumed annually also increased over that period from roughly 123 million liters in 2010 to 240 million liters in 2016.

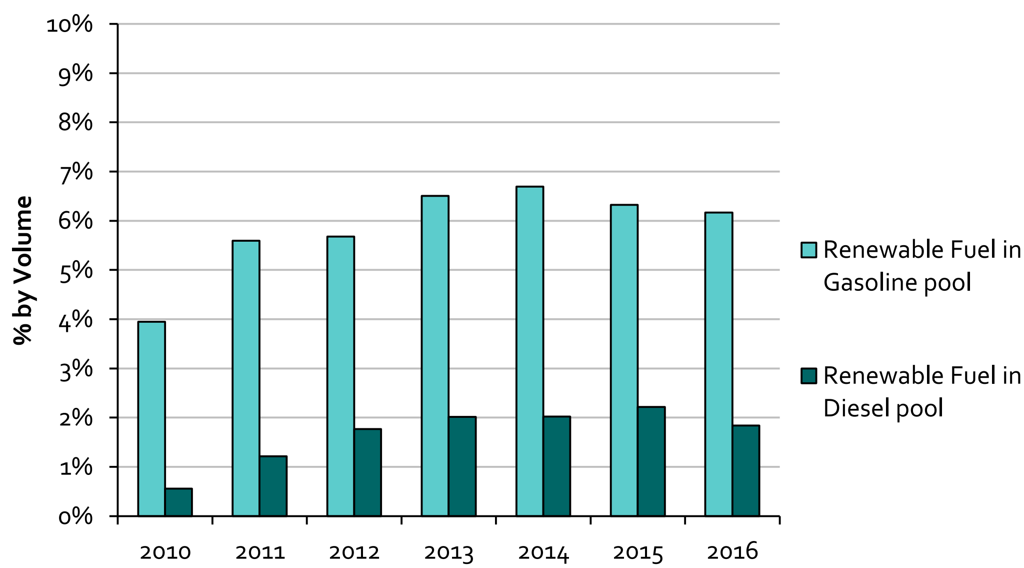
Table 6: Canadian Fuel Consumption in million liters per year

Fuel type	2010	2011	2012	2013	2014	2015	2016
HDRD	37	139	206	289	347	333	300
Biodiesel	123	198	298	296	259	317	240
Ethanol	1,701	2,371	2,497	2,838	2,961	2,813	2,843
Diesel	28,374	27,429	27,960	28,486	29,327	28,680	28,844
Gasoline	41,394	40,006	41,496	40,797	41,262	41,667	43,256

HDRD is also blended into diesel — now likely in larger volumes than biodiesel. HDRD content is estimated to have increased from 37 million liters in 2010 to 300 million liters in 2016 (Table 6). It should be noted that volume of HDRD in the Canadian fuel pool is more uncertain compared to other biofuels. Estimates were based on assumptions and feedback from government contacts and market experts. However, the only data available on HDRD is from the government of British Columbia which publishes the volumes reported by suppliers. National totals based on trade data (e.g. from US Department of Agriculture (GAIN) are confounded by the fact that biodiesel and HDRD imports from the US are recorded as aggregate values.

Figure 5, 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).

Figure 5: 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 5). 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, this does not necessarily mean the mandate was not met. First, Figure 5 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. Finally, there is uncertainty surrounding the national estimate. Only some provinces record data on renewable fuel volumes, and currently the federal government has only released data for 2011 to 2014. For the remaining years, the national total is aligned with data estimated by the US Department of Agriculture GAIN[7] which may underestimate total biodiesel and HDRD consumption.

It should be noted that to meet compliance, national biofuel content need only be met on average across the country. In other words, provincial blending will not necessarily reflect the national average. Therefore, Figure 5 does not depict the percentage of renewable content in the gasoline and diesel pools supplied to individual provinces.

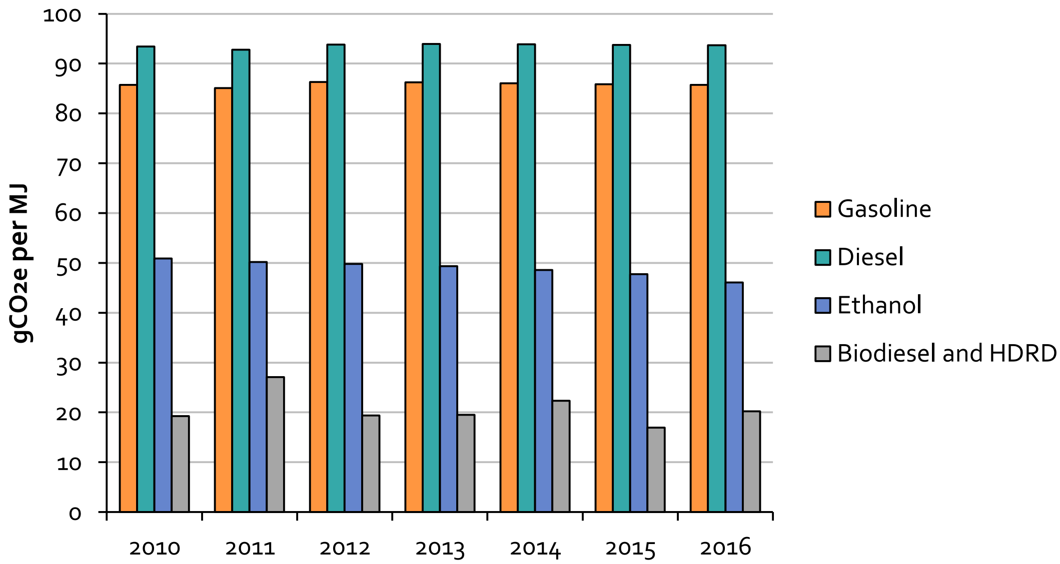
4.2. Lifecycle GHG Emissions

Figure 6 shows the estimated lifecycle CI (i.e. well to wheels or farm to wheels) of transportation fuels in Canada between 2010 and 2016. 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.

[7] Global Agricultural Information Network, 2016, Canada Biofuels Annual Report

Figure 6: 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. However, these intensities are based on direct land use changes, and do not include any potential indirect changes from increased biofuel demand. Some fuel regulations, such as the US RFS and California LCFS include "indirect land-use change" (ILUC) emissions in the carbon intensities of biofuels. ILUC emissions are one type of "indirect effect" (IE) 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 IE 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 these emissions in current policy, but will monitor the science and may include them in the future.[8]

The results in Figure 6 suggest that the biofuels consumed in Canada offer significant lifecycle CI reductions relative to gasoline and diesel. The data implies that, on average, ethanol sold in Canada was 43% less carbon intensive than gasoline, while biodiesel and HDRD, on average, are estimated to be 78% less carbon intensive than diesel.

Figure 6 also suggests that the CI of ethanol, biodiesel, and HDRD are decreasing over time. However, the regional carbon intensities used to produce Figure 6 are mostly

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

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).

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 7. The data suggest that from 2010 to 2016, the CI of ethanol decreased by 26%, and the CI of biodiesel and HDRD decreased by 40%. 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 regulating CI.

Figure 7: Lifecycle CI by Fuel Type, for British Columbia

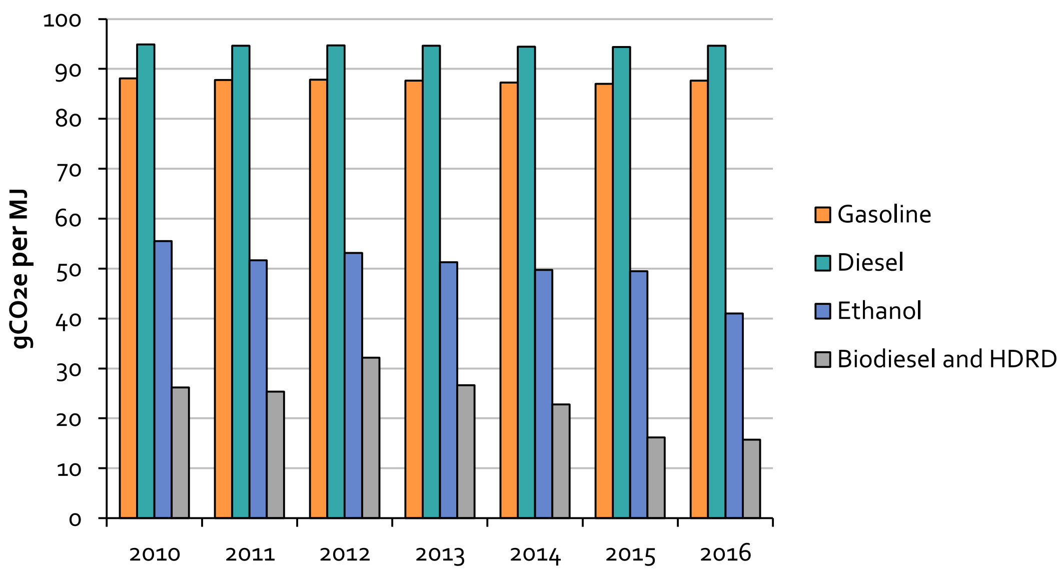


Figure 8 shows the avoided lifecycle GHG emissions in Canada resulting from the biofuel consumption. Again, the avoided emissions are based on the volumes and CI's of biofuels described above, assuming biofuels displace an equal amount of fuel energy from their fuel pool (i.e. ethanol displaces gasoline, biodiesel and HDRD displaces diesel). This analysis shows that the avoided GHG emissions in Canada resulting from biofuel consumption have increased from 1.8 $MtCO_2e$/yr in 2010 to 4.1 $MtCO_2e$/yr in 2016. Cumulative national avoided GHG emissions from 2010 to 2016 are estimated to be 24.9 $MtCO_2e$.

Figure 8: Avoided Lifecycle GHG Emissions

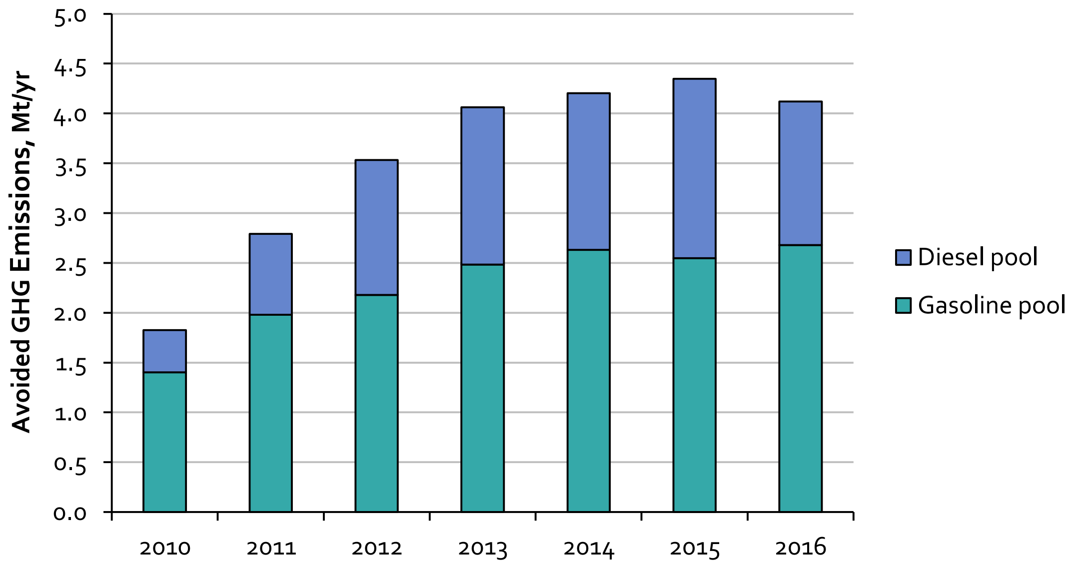
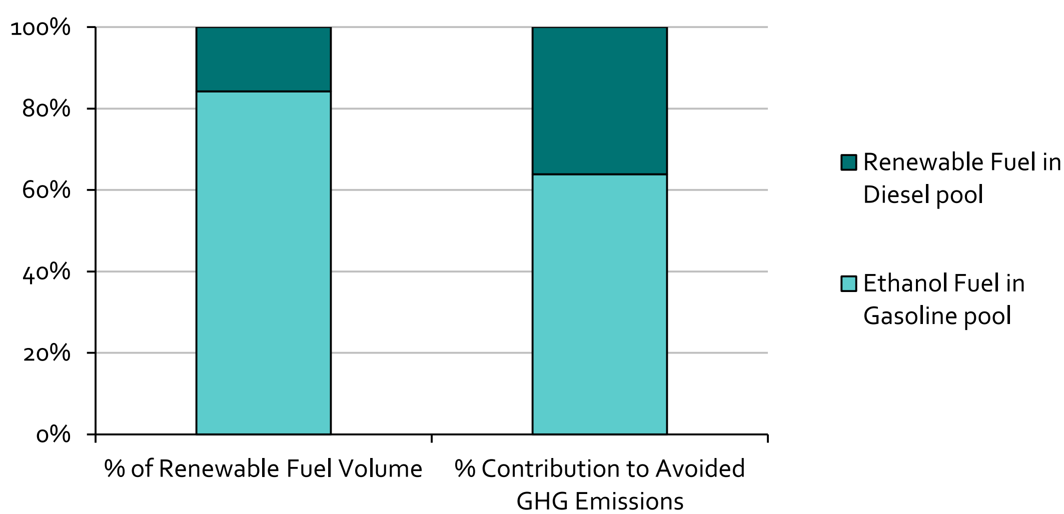


Figure 9 shows the percentage of renewable fuel volume in the gasoline and diesel pool compared with the percentage of avoided GHG emissions resulting from renewable fuel consumption in those fuel pools. Ethanol accounted for 84% of the renewable fuel volume consumed during the 2010-2016 period, but only produced 64% 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 36% of the avoided GHG emissions.

Figure 9: % of total Renewable Fuel Volume vs. % Contribution to Avoided GHG Emissions



The avoided GHG emissions are calculated assuming that renewable fuel consumption does not change the energy efficiency of vehicles (i.e. km/GJ of fuel consumed is not affected by the fuel blend). However, a 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%.[9] In other words, without ethanol, gasoline energy consumption in Canada and the resulting GHG emissions would have been 1% higher. In 2016, this impact equates to an additional 1.3 Mt/CO_2e avoided that this analysis does not account for (+32%).

As well, this analysis assumes 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%.[10] Prorating this impact for $6\%_{vol}$ ethanol blend versus using no ethanol indicates that current levels of blending in Canada may reduce petroleum refining GHG intensity by 1-4%. Assuming the Canadian refining sector's GHG emissions in 2016 were 17.5 MtCO_2e (based on 2015 emissions[11]), a 1-4% decline in refining GHG intensity means that without ethanol blending, GHG emissions would have been 0.2 to 0.7 MtCO_2e/yr higher. This impact is also not included in this analysis.

In 2016, the combined impact of increased energy efficiency and reduced petroleum refining GHG intensity would increase the GHG emissions avoided by ethanol consumption by 1.5-2.0 MtCO_2e/yr (+35-49%). We may include this impact in future analyses if it can be further supported by ongoing research and published literature. Similarly, biofuel blends in the diesel pool may also affect energy efficiency. A comparison of truck fleets using diesel and a 20% diesel blend found no difference in fuel economy, indicating that biodiesel blends, which are less energy dense than

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[9] 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

[10] 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

[11] Natural Resources Canada, Comprehensive Energy Use Database

straight diesel, improve vehicle energy efficiency.[12] Data regarding this dynamic will also be monitored for future analyses.

4.3. Cost Analysis

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 liter of ethanol is approximately 32% lower than it is for gasoline and energy per liter 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 liters of fuel to drive the same distance. Although, there is research indicating that using biofuel blends may be more energy efficient than we calculate, these findings are still uncertain given that current vehicles are optimized to run on gasoline and diesel.
- Finally, cost reductions may arise due to different biofuel properties, such as: changes in fuel octane value (i.e. the anti-knock index of a gasoline blend); combustibility (i.e. the extent to which more complete combustion occurs with biofuel use, minimizing air pollution and associated health impacts); and, lubricity (i.e. the extent to which biodiesel fuel reduces friction and wear in the engine). Of these biofuel properties, this cost analysis only accounts for the octane value of ethanol.

Gasoline in North America must meet a standard octane value before it can be sold to the consumer. Refiners have various methods to raise the octane value of gasoline blendstock, one of which is the addition of ethanol to gasoline. The U.S. Energy Information Administration (EIA) estimates that American refiners produce gasoline blendstock with octane 84, which is raised to 87 (regular gasoline) with the addition of

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[12] 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

ethanol[13]. When used in a gasoline blend, ethanol has an octane rating of 113.[14] 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.

Also note that 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 10 shows the cumulative change in consumer fuel costs resulting from renewable fuel blending in Canada from the start of 2010 to the end of 2016. We estimate that the net-costs have diverged less than 1% relative to what they would have been without biofuel consumption. Assuming that all costs and savings are passed onto consumers, their fuel expenditures were 0.26% lower, equivalent to a savings of $1.6 billion over seven years. Note that all costs in the analysis are expressed in 2017 CAD.

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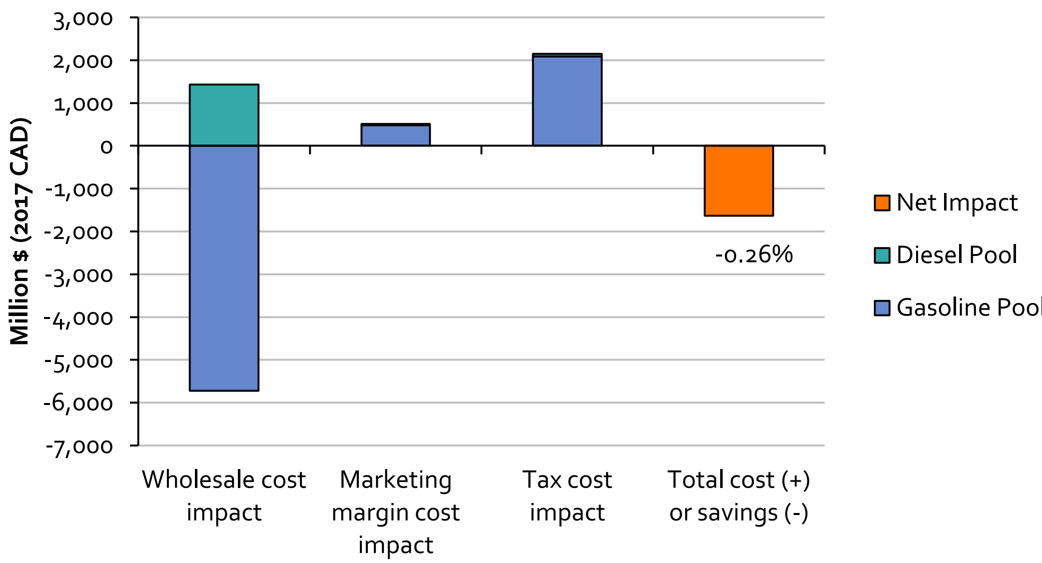
[13] U.S. Energy Information Administration, 2013, Price spread between regular and premium gasoline has changed over time. https://www.eia.gov/todayinenergy/detail.php?id=11131

[14] 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 10: Cumulative Cost Impact by Source (2010-2016), 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** includes 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 $5.7 billion from 2010-2016. 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 $1.4 billion. Note that this wholesale cost is almost double than it would have been using the HDRD price assumption from the previous iteration of this analysis. However, the diesel pool wholesale cost impact could have been much lower if fuel suppliers used more low-cost biodiesel. This action was indeed 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 volume 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

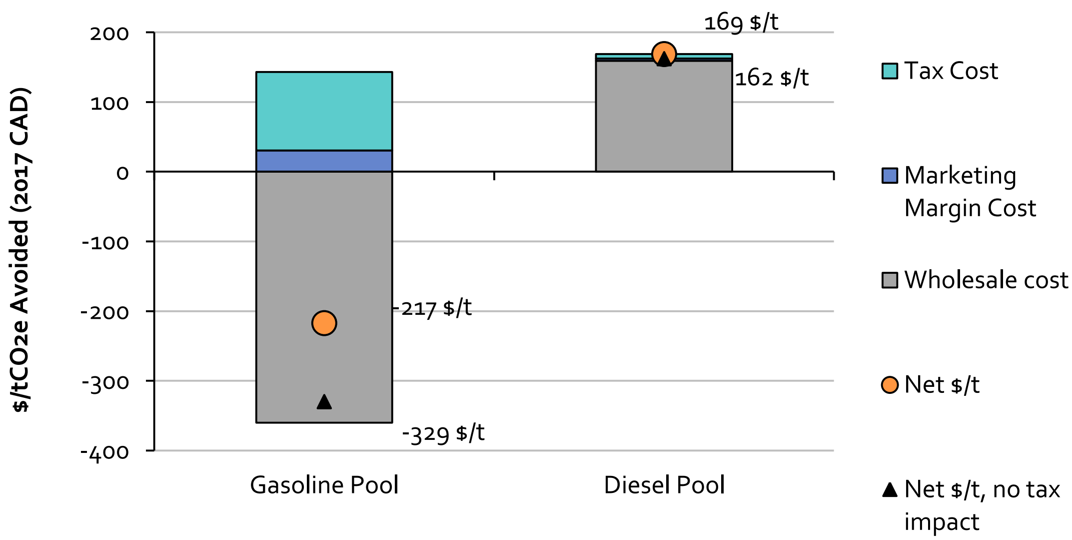
renewable fuel had been used. Margins generally range from 6 to 12 cent/L depending on the region and fuel in question. Because biofuels are less energy dense than petroleum fuels, using biofuels involves consuming a greater volume of fuel. Therefore, the marketing cost is higher (e.g. more fuel delivery 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 $484 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 $27 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 where biofuels are subject to the full carbon tax). 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 low energy density, the tax cost resulting from ethanol blending is large, roughly an additional $2.1 billion over seven years relative to a scenario with no biofuel consumption. At only $59 million, the cost is much smaller in the diesel pool. Note that any impact of the emissions cap-and-trade policy in Quebec and Ontario. Biofuels are exempt from this policy, but this exemption may not translate into reduced prices at the pump. For 2017, the analysis will need to account for carbon taxes on fuels in Alberta and Ontario, where biofuels are partially exempt (ethanol greater than 10% and biodiesel greater than 5%). If the federal carbon pricing backstop is implemented, then this partially exempted methodology will need to be applied to other provinces.

As noted earlier, the cost impacts assume that renewable fuel blending does not change the energy efficiency of vehicles. Even this small change would have a large impact on fuel expenditures. If ethanol blending did increase the average energy efficiency of vehicles by 1%, then it would have reduced the wholesale fuel cost between 2010 and 2016 by an additional $2.9 billion (+177% of the total cost impact in the gasoline and diesel fuel pools). It would also significantly mitigate the marketing margin cost and the tax cost resulting from ethanol consumption. Any improvement in energy efficiency resulting from blending in the diesel pool would also reduce the cost in that pool.

Figure 11 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 2010-2016 for the gasoline and diesel pool. Again, costs in this case relate only to those costs included in this analysis and do not account for 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 11 shows the net abatement cost if excise and carbon taxes on fuels had the same $/energy value for gasoline and ethanol, and for diesel, biodiesel and HDRD.

Figure 11: GHG Abatement Cost, 2010-2016

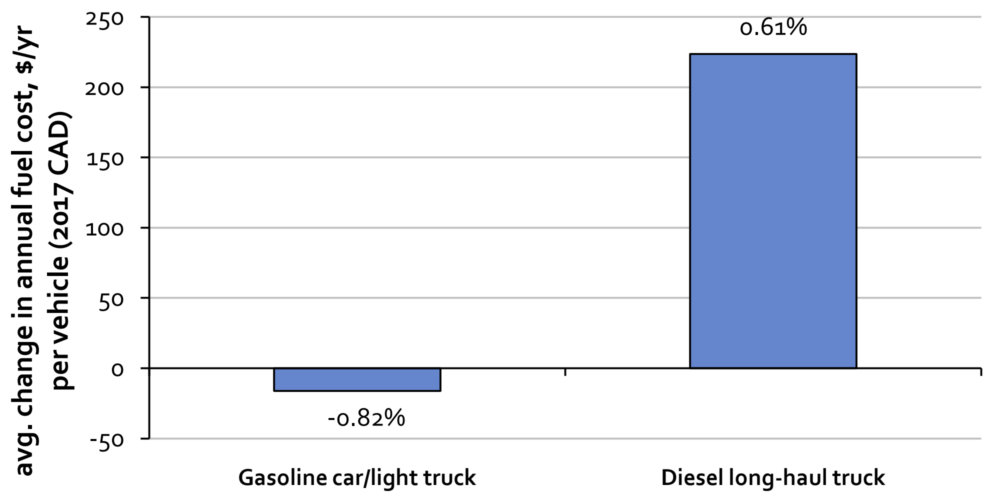


The cost of abatement from ethanol blending is -$217/t$CO_2$e (Figure 11). Furthermore, the results suggest that excise and carbon taxes on fuels have a significant impact on the net dollar value per tonne CO_2e abated, which would be -$329/t$CO_2$e if the excise taxes on ethanol and gasoline were equivalent on an energy basis. The abatement cost in the diesel pool is $169/t$CO_2$e, or $162/t$CO_2$e if fuel taxes were based on energy rather than volume. Again, because the HDRD price used in this year's analysis is higher than in previous years, the diesel pool abatement cost estimate is roughly double what was in the 2017 version of this analysis.

Figure 12 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 16,041 km per year with an average fuel economy of 10 liters per 100 km travelled. For the diesel pool, the archetypal consumer is a trucker who uses a tractor-trailer combination to travel approximately 90,581 km per year with a fuel economy of 33 liters 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 $16/yr (-0.82%) because of ethanol blending in Canada. A typical diesel consumer spent an additional $224/yr (+0.61%) because of biodiesel and HDRD blending (Figure 12). 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 seven-year study period.

Figure 12: Archetypal fuel consumer cost impact, annual average 2010-2015



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.

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 2016. 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 2,800 million L/yr in 2016. Annual biodiesel consumption has increased from roughly 122.8 million L/yr in 2010 to 240 million L/yr in 2016. HDRD consumption increased from roughly 36.7 million L/yr to 300 million L/yr in that same period.
2. Annual avoided GHG emissions resulting from biofuel blending in Canada have increased from 1.8 $MtCO_2e$/yr in 2010 to 4.1 $MtCO_2e$/yr in 2016. The cumulative GHG emission avoided between 2010 and 2016 are 24.9 $MtCO_2e$.
3. Between 2010 and 2016, blending ethanol, diesel, and HDRD with conventional transportation fuels reduced consumer fuel costs in Canada by 0.26%, relative to what they would have been without renewable fuels. If all costs and savings were passed on to consumers, they saved $1.6 billion (2017 CAD) over the seven-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, -$217/$tCO_2e$, whereas the abatement cost from biofuel blending with diesel is positive at $169/$tCO_2e$. Ethanol blending reduced the annual fuel costs of a typical driver by $16/yr (-0.82%), relative to a scenario without ethanol consumption. Biodiesel and HDRD blending increased the annual fuel costs of an archetypal long-haul trucker by $224/yr (+0.61%).
4. Because of updated HDRD price data, the cost of renewable fuel consumption in the diesel pool is higher than previously estimated. However, the diesel pool wholesale cost impact could have been lower if fuel suppliers used more low-cost biodiesel. This action was indeed 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.
5. 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 liter: excise taxes as well as carbon taxes that do not distinguish between biofuel and petroleum fuel (e.g. in British Columbia). 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 levied per liter. This impact is most noticeable with ethanol because it is roughly 33% less energy dense than gasoline. Consequently, volumetric fuel taxation of ethanol cost consumers $1.8 billion (2017 CAD) during the seven-year study period (included within the net savings of noted above).

6. Future work should include a more detailed treatment of the impact of ethanol blending on vehicle energy efficiency and petroleum refinery GHG intensity based on existing literature and ongoing research. The GHG and fuel cost impact of renewable fuel consumption could be larger than estimated in this analysis because it excludes these potential impacts. While their magnitude is uncertain, they could have increased the avoided emissions in 2016 by another 1.5-2.0 $MtCO_2e$/yr (+35-49%) and reduced wholesale fuel costs by another $3 billion (2017 CAD) over the seven-year study period. An improvement in energy efficiency would also mitigate the marketing margin and tax cost associated with ethanol consumption. A similar impact may exist in the diesel pool if biofuel blending changes energy efficiency in diesel consuming vehicles. Other upcoming work includes accounting for new carbon pricing regimes in Canada where biofuels are either subject to the full carbon price (British Columbia), partially exempt (Alberta), or fully exempt (Ontario and Quebec).

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 2010-2016.
  - 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 2016.
- 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.[15]
  - USD was converted to CAD based on Bank of Canada historic data.[16]
- 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.[17]
- All values were converted to 2017 dollars.[18]

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[15] 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.

[16]Bank of Canada, 2017, Exchange Rates. http://www.bankofcanada.ca/rates/exchange/monthly-average-lookup/

[17]Natural Resources Canada, 2016, Daily Average Wholesale (Rack) Prices. http://www2.nrcan.gc.ca/eneene/sources/pripri/wholesale_bycity_e.cfm

[18] CANSIM, 2017, Table 326-0020 Consumer Price Index

- 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.[19]
  - The implied cost per octane point was estimated for each year based on the difference between regular and premium gasoline in the US market[20] where that price spread better reflects the cost of octane than in the Canadian market.
  - Our estimated price of pure sub-octane gasoline was decreased based on the implied cost per octane point and the estimated octane of the gasoline blendstock:

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

Where:

[19] 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.

[20] EIA. 2018. U.S. Premium Conventional Retail Gasoline Prices. Accessed on April 4, 2018 from: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMM_EPMPU_PTE_NUS_DPG&f=M

- $P_{gasoline,sub\text{-}octane}$ 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[21]
- $O_{blend,prem}$ 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 liter 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 liter cost/savings of blending biodiesel and HDRD with pure diesel was estimated.
- The average $/GJ cost or savings that results from blending biofuel was estimated, assuming biofuel consumption does not change energy consumption. The following energy densities from GHGenius 4.03a were used to convert $/L price to $/MJ prices:
  - Ethanol= 23.6 MJ/L
  - Gasoline= 34.7 MJ/L

[21] ibid

- 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 and taxes were obtained from Kent Marketing.[22] Taxes include federal and provincial fuel excise taxes, sales taxes and in British Columbia, the carbon tax which is applied equally to each liter sold, regardless of the renewable fuel blend. Any potential "tax" impact of the cap-and-trade system in Ontario and Quebec is not included. Biofuels are exempted from this policy, but that exemption may not affect prices at the pump.
  - 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

[22] Kent Marketing, 2017, Petroleum Price Data. http://charting.kentgroupltd.com/

consumer, these values are 10 L/100 km and 16,300 km/yr. For the archetypal diesel consumer, these values are 33 L/100 km and 91,600 km/yr.[23,24]

23 Natural Resources Canada, 2017, Passenger Transportation Explanatory Variables.

24 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.

Feedstock data 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 summarizes the assumptions and sources we used to define fuel feedstocks by region in Canada.

British Columbia

Feedstock data was obtained from the government of British Columbia.[25] However, the data appeared to have some minor summation errors. Therefore, we made the following adjustments:

1. We reduced volumes for biodiesel Canola by 1.8 and 2.3 million litres in 2015 and 2016 respectively. This was done so that the sum of all feedstocks would not be greater than the total reported volume for biodiesel.

2. Some feedstock volumes were added to an "unknown" category to make the total feedstock volume equal to the total reported volumes. These values were calculated to fill summation errors. They are not numbers reported by British Columbia.

3. British Columbia reporting does not distinguish between feedstocks used for biodiesel or HDRD and we assume that all tallow and palm derivatives are used for HDRD.

Alberta

1. Ethanol feedstock volumes are estimated based on the types of feedstocks processed in Alberta's facilities as reported by GAIN.[26] This includes a substantial amount of corn ethanol based on a review by Don O'Connor of $(S\&T)^2$ Consultants.

[25]Ministry of Energy and Mines, 2017, Renewable and Low Carbon Fuel Requirements Regulation Summary: 2010-2015

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

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.[27]

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, as well as correspondence with Don O'Connor of $(S\&T)^2$ Consultants.[28]

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.[29]

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 that there is no HDRD based on correspondence with Don O'Connor of $(S\&T)^2$ Consultants.

Ontario

1. For 2016, gasoline pool sales are from CANSIM 134-0004 and the ethanol blend is assumed to be constant from 2015 (an estimate, pending data). For 2015 and

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[26]Global Agricultural Information Network, 2014, Canada Biofuels Annual. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_11-24-2014.pdf

[27] This was confirmed through correspondence with a government contact.

[28] Global Agricultural Information Network, 2014, Canada Biofuels Annual. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_11-24-2014.pdf

[29] Ibid

earlier, gasoline and ethanol volumes were received from personal correspondence with the government of Ontario.

2. We assume that ethanol is made primarily from corn.
3. We assume biodiesel is 50/50 soy and yellow grease, and HDRD is made from tallow. These assumptions are based on correspondence with a government contact.
4. Bio-based diesel (biodiesel and HDDRD) consumption volumes in 2016 are estimated assuming compliance with the Greener Diesel Regulation, 80% of volume is HDRD with CI based on Diamond Green Diesel in 2016, 20% is biodiesel with net-0 CI, 10% of diesel pool is distributed in Northern Ontario (based on 2015 data).
5. 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 biodiesel volumes are estimated based on the difference between federal data in GAIN and ECCC reports and total biofuel content collected for the other provinces. Negative values are set to zero.

2. We assume most biodiesel and HDRD is produced using used cooking oil and waste.

3. We assume ethanol feedstocks are primarily corn since there is a facility in Quebec that processes corn ethanol. We also assume some wheat and unknown feedstocks to align with ECCC national feedstock values.

Atlantic

1. Ethanol and biodiesel volumes are estimated based on the difference between federal data in GAIN and ECCC reports and total biofuel content collected for the other provinces. Negative values are set to zero.

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

Based on the assumptions outlined above, the feedstocks used to produce biofuels sold in Canada were estimated and summarized in Figure 13 and Figure 14. Figure 13 shows the renewable fuel content in the diesel pool in Canada from 2010 to 2016, by fuel type and feedstock: most biodiesel is from canola, most HDRD is from palm and tallow. Figure 14 shows the renewable fuel content in gasoline pool in Canada from 2010 to 2016, by fuel type and feedstock: most ethanol consumed in Canada is produced from corn.

Figure 13: National Results for Renewable Fuel Consumption of Diesel Pool by Fuel Type, and Feedstock

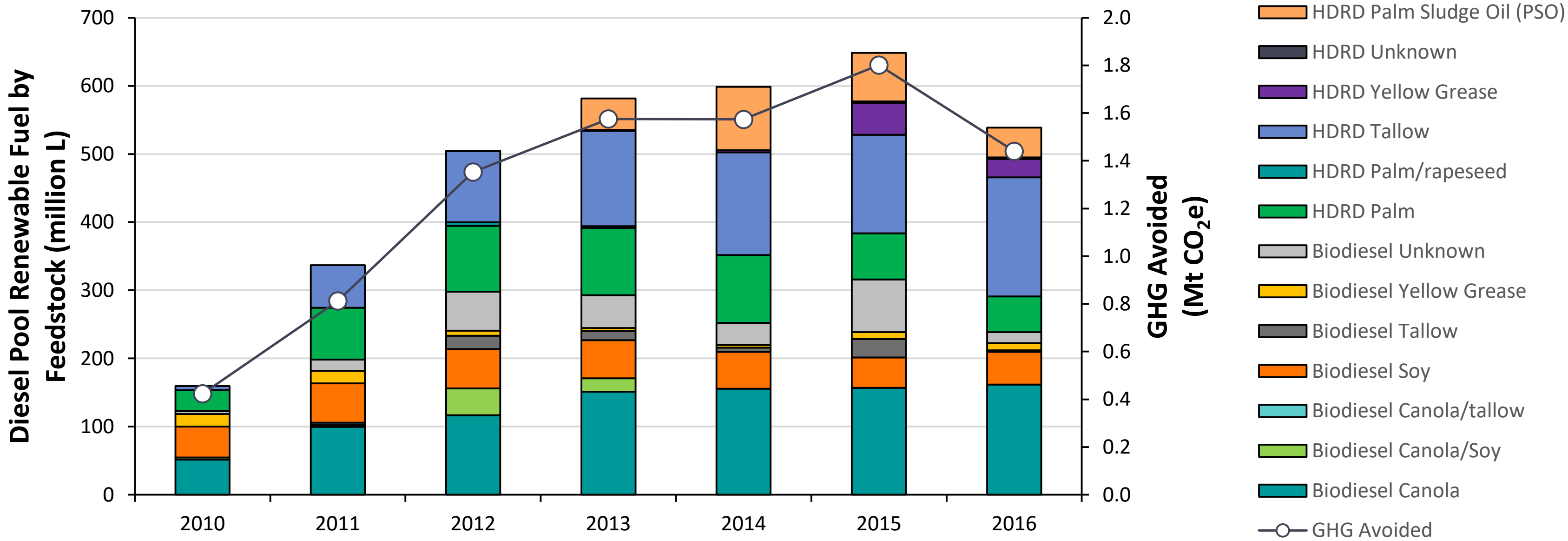

Figure 14: National Results for Renewable Fuel Consumption for Gasoline Pool by Fuel Type, and Feedstock