Biofuels in Canada 2017

Tracking biofuel consumption, feedstocks and avoided greenhouse gas emissions

Michael Wolinetz,
Mikela Hein
Navius Research Inc.
1199 West Hastings Street
PO Box 48300 Bentall,
Vancouver BC V7X 1A1

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Phone: 778-970-0355
Email: Michael@NaviusResearch.com

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 mandates minimum renewable fuel blending, or British Columbia's Low Carbon Fuel Standard, which requires the average lifecycle carbon intensity (CI) of fuel sold within the province to decline over time. However, there is no comprehensive data source monitoring the state of renewable fuel consumption in Canada, and no single source that communicates the impact of renewable fuel policies on fuel consumption, 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 the comprehensive study of renewable fuel use in Canada, first completed by Clean Energy Canada and Navius Research in early 2016.

Objectives

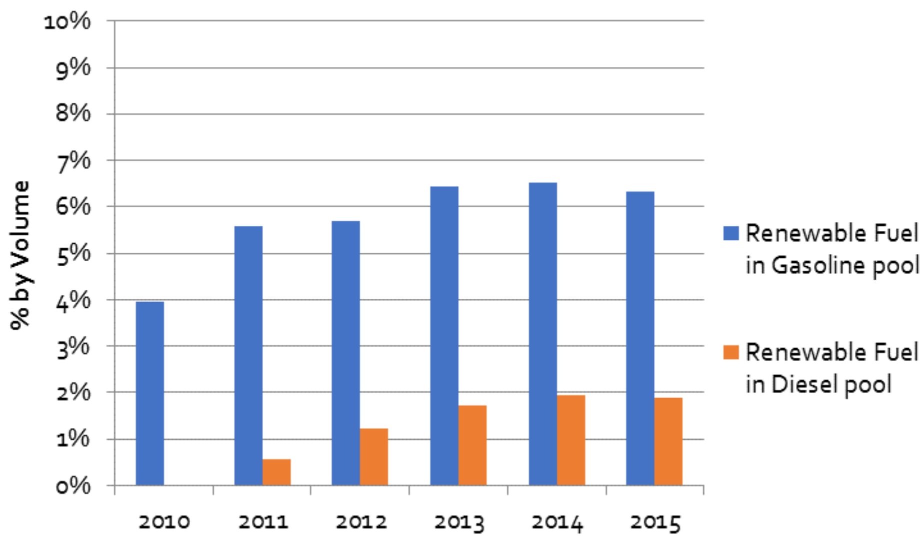
The objectives of this project are to evaluate and communicate the impact of renewable and low-carbon fuel policy in Canada by:

1. Quantifying the volumes of renewable transportation fuels consumed in Canada (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 prices

Fuel Consumption

Using data obtained from provincial and federal government contacts, we estimate that annual ethanol consumption has increased from roughly 1,700 million liters in 2010 to 2,800 million liters in 2015. Annual consumption of biodiesel has grown from roughly 110 million liters in 2010 to 470 million liters in 2015. HDRD is also believed to be blended into diesel — albeit in smaller volumes. HDRD content is estimated to have increased from 50 million liters in 2010 to 150 million liters in 2015. Since 2013, ethanol has accounted for over 6% of the gasoline pool volume. Biodiesel and HDRD has been close to 2% of the diesel pool volume (Figure 1). Note that this result does not necessarily mean the Canadian federal renewable fuel requirement has not been met for diesel: our analysis is on total diesel consumption which includes volumes that are exempted by that 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 21 $MtCO2_e$ between 2010 and 2015. Annual avoided GHG emissions have grown from 1.8 Mt in 2010 to 4.4 Mt in 2015. Trends in biofuel carbon intensities in British Columbia indicate the biofuel production is becoming less emissions intensive. Therefore, a fixed amount of biofuel consumption avoids more GHG emissions in 2015 than it would it 2010

Cost Analysis

Figure 2 shows the cumulative consumer cost impact, by component, resulting from biofuel consumption between 2010 and 2015. 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. 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. Finally, this analysis accounts for no other potential co-benefits of using biofuel, for example a reduction in air pollution and the associated health impacts.

Net biofuel consumption has yielded a small savings relative to a scenario where no biofuel was consumed, roughly $750 million (2017 CAD) over five years, or -0.14% 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 tax in Canada is charged per liter, regardless of how much energy is in that liter.

Figure 2: Cumulative Cost Impact by Source (2010-2015), total % change in data label

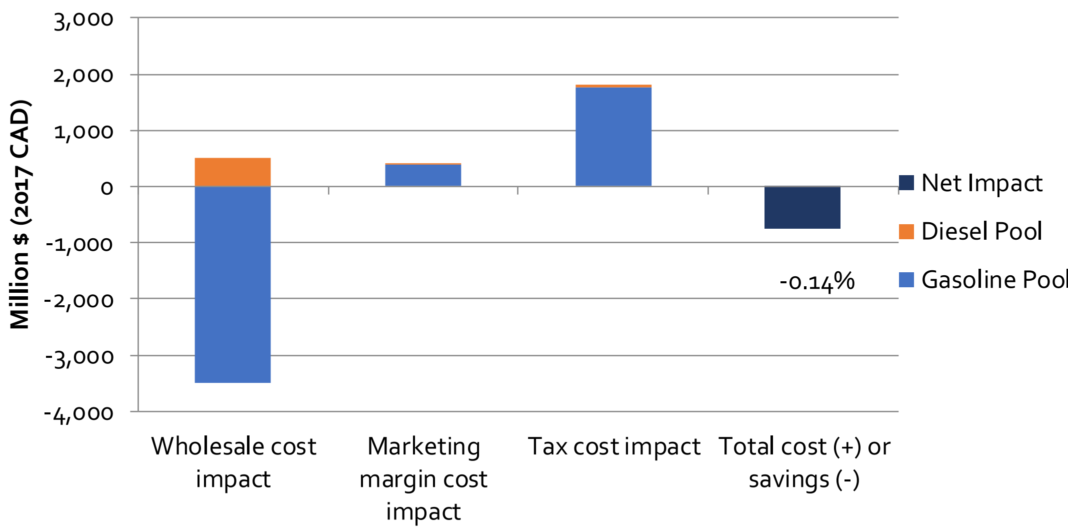
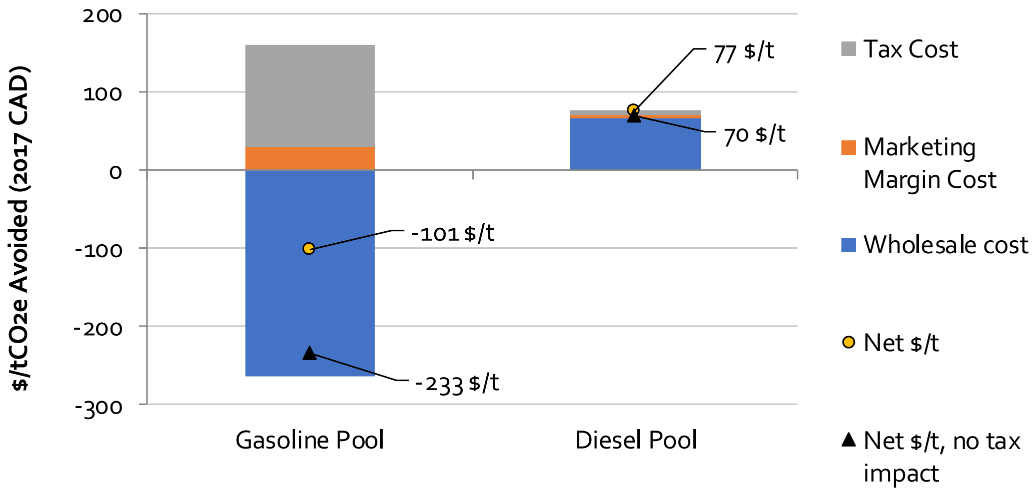


Figure 3 shows the cumulative consumer cost divided by the cumulative avoided GHG emissions from 2010-2015 for gasoline and diesel pools in Canada. Again, the costs do not account for any co-benefits or costs other than those shown in Figure 2 (i.e. no accounting for reduced air pollution and health impact related to biofuel consumption). The abatement cost in the gasoline pool is -$101/tCO2e versus $77/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 tax burden associated with ethanol consumption. On net, renewable fuel consumption in Canada has saved a typical gasoline consumer $8.2/yr (-0.40%), whereas it has cost a typical long-distance trucker an additional $106/yr (+0.28%).

Figure 3: GHG Abatement Cost, 2010-2015



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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 Low Carbon Fuel Standard, which requires the average lifecycle carbon intensity (CI) of fuel sold within the province to decline over time. However, there is no comprehensive data source monitoring the state of renewable fuel consumption in Canada, and no single source that communicates the impact of renewable fuel policies on fuel consumption, 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. The rational 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 volumes of transportation fuels consumed in individual provinces and the country as a whole from 2010 to 2015, the most recent year for which data is available. These fuels are further characterized by type (i.e. gasoline, ethanol, biodiesel, etc), feedstock, and CI. For further details on the sources and assumptions used to characterize fuels please see Appendix B: Biofuel Feedstocks. This report also includes an analysis of the impacts of renewable fuel consumption on GHG emissions as well as energy costs in Canada.

Lastly, this study aims 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 avoided ("Biofuels in Canada Analysis, June 6 2017").

The remainder of this report provides an overview of the current 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 feedstock data and assumptions.

2. Policy Background

This section of the report provides a summary of the renewable fuel policies in Canada at both the federal and provincial levels to provide an understanding of the regulations driving renewable fuel consumption. For greater context within the North American fuel market, 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 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

At the federal level the Canadian government enacted a *Renewable Fuels Regulation* 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 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 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
British Columbia	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Alberta	-	5.0%	5.0%	5.0%	5.0%	5.0%
Saskatchewan	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%
Ontario	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Canada	-	5.0%	5.0%	5.0%	5.0%	5.0%

Some provinces in Canada are not subject to any provincial gasoline biofuel blending policies. However, they are regulated under the federal policy. These provinces have been excluded from Table 1, and include: Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland, Yukon, and Northwest Territories.

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 CI of the biofuel 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
British Columbia	3.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Alberta	-	2.0%	2.0%	2.0%	2.0%	2.0%
Saskatchewan	-	-	2.0%	2.0%	2.0%	2.0%
Manitoba	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Ontario	-	-	-	-	2.0%	2.0%
Canada	-	2.0%	2.0%	2.0%	2.0%	2.0%

As with ethanol, some regions in Canada are not subject to any provincial diesel biofuel blending policies but they are still regulated under the federal policy. These provinces have been excluded from Table 2, and include: Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland, Yukon, and Northwest Territories. Furthermore, fuel oil used for heating has been exempt from any policy since the federal regulation removed it from the Renewable Fuels Regulation in 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 in 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 gCO2e/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, and began January 1, 2008.

Ontario has an *Ethanol General Regulation* mandating 5% ethanol content in gasoline. Suppliers must meet the compliance target at all their facilities combined. Additionally, Ontario has the *Greener Diesel Regulation* which consists of three phases prescribing both the CI and volume of renewable content to be blended with diesel.

The first phase was effective from April 1, 2014 to the end of 2015 and mandated 2% biofuel content assuming the CI of the biofuel is 30% less than the diesel fuel in the regulated diesel pool. In other words, the actual volume of biofuel could vary depending on its CI. For context, the default CI of biodiesel sold in Ontario in 2014 is estimated to be roughly 14 gCO2e/MJ by GHGenius 4.03a. This is far below the average CI of diesel, 93 gCO2e/MJ. The stringency of this policy has since increased to prescribe 4% renewable content, assuming a CI that is at 70% below the CI of standard diesel (roughly 28 gCO2e/MJ). Again, actual volumetric content of biofuel in the diesel may vary depending on the CI of the biofuel.

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.

Currently, British Columbia is the only region in Canada with an active low carbon fuel standard (LCFS) in addition to a renewable fuel standard; however, the federal government started consulting on the potential implementation of a national Clean Fuel Standard that may borrow elements of the British Columbian policy in spring 2017.

The British Columbian (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 British Columbia was the first province to regulate the CI of biofuel. The

RLCFRR requires 5% renewable fuels by volume in gasoline pool and 4% renewable fuel by volume in diesel pool (only 3% in 2010). Additionally, the carbon intensity policy, which came into effect in July 2013, requires a 10% reduction in fuel CI in 2020 and a 15% reduction by 2030 relative to a 2010 baseline. Consequently, renewable fuel blending is not the only approach able to satisfy the LCFS. In other words, while the policy is likely to encourage more renewable fuel consumption, it does not prescribe this consumption. As long as the minimum renewable fuel standard is met, the CI can be furthered decreased by switching to energy sources such as natural gas, electricity, or hydrogen.

The RLCFRR in British Columbia need only be met on average by suppliers of gasoline and diesel in the provincial market. Compliance credits can be traded amongst supplier, with a maximum credit price of 200 $/t$CO_2$e. 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 initiative, as well as the low carbon fuel standard in California. The California LCFS is like the British Columbian policy, albeit covering a much larger market. The federal Renewable Fuel Standard 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* 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:[1]

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

The US Renewable Fuel Standard requires significantly more renewable fuel content by volume than the Canadian federal policy. The US policy has mandated 8%-11% fuel content between 2010 and 2017, in contrast the Canadian regulation has only mandated 5% in gasoline and 2% in diesel.

Furthermore, the US Environmental Protection Agency expects to increase the biofuel requirements each year, based on goals defined in the Energy Independence and Security Act of 2007, which had the total biofuel volumes increasing at roughly 9% annually to 2022. Table 3 summarizes the implied fuel blends by volume mandated by the policy. Note that the biomass based diesel content applies to the entire distillate fuel pool, which includes light-fuel oil used for heating. Therefore, the specific requirement for biomass-based diesel is also likely higher than the 2% in Canada.

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

Fuel type	2014	2015	2016	2017
Cellulosic biofuel (min.)	0.0%	0.1%	0.1%	0.2%
Biomass-based diesel (min.)	1.4%	1.5%	1.6%	1.7%
Other Advanced biofuel (min.)	0.1%	0.1%	0.3%	1.1%
Conventional biofuel (remainder)	7.7%	7.9%	8.1%	7.7%
Total biofuel	**9.2%**	**9.5%**	**10.1%**	**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. Similar to the BC policy, the Californian policy uses tradable credits with a ceiling price.

[1] US Environmental Protection Agency, 2016, Final Renewable Fuel Standards for 2017 and Biomass-Based Diesel Volume for 2018. www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2017-and-biomass-based-diesel-volume

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 2015, 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, 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 year's analysis 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 prices	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. These prices were then used to quantify how biofuels may have affected the price of fuels 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 task 1-4, as outlined in the methodology. Table 2 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 Global Agricultural Information Network (GAIN) provided national totals from 2010-2015[2]. However, the totals from GAIN are only estimates, whereas Environment and Climate Change Canada (ECCC) has published national totals for 2011 and 2012 based on volumes reported by the provinces to the Canadian government[3]. The national totals from the ECCC were assumed to be correct and replaced the GAIN totals for 2011 and 2012.

Another major uncertainty was the wholesale price of HDRD which is not publicly available. Since HDRD is costly to produce, we assumed that HDRD matches the higher of biodiesel or diesel price for any given month included in the analysis.

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 on our part (represented in yellow). In particular, several months of fuel sales data have been suppressed by Statistic 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.

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

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

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

<table>
<tr><th></th><th>BC</th><th>Alberta</th><th>Saskatchewan</th><th>Manitoba</th><th>Ontario</th><th>Quebec</th><th>Atlantic</th></tr>
<tr><td>Gasoline volume</td><td rowspan="4">RLCFRR Summary: 2010-2015. Gasoline and diesel volumes are the total, not the non-exempt volume</td><td>2010: domestic sales, CANSIM 134-0004
2011-2015: From govt. contact</td><td>Domestic sales, CANSIM 134-0004, with estimates of redacted data</td><td rowspan="4">Data from govt. contact</td><td rowspan="2">Data from govt. contact</td><td>Domestic sales, CANSIM 134-0004</td><td>Domestic sales, CANSIM, 134-0004, with estimates of redacted data</td></tr>
<tr><td>Ethanol fuel volume</td><td>Data from govt. contact</td><td>Estimate from govt. contact</td><td>Difference between national total in USDA GAIN[1] report and sum from other provinces, pro-rated to QC and AT</td><td>Difference between national total in USDA GAIN[1] report and sum from other provinces, pro-rated to QC and AT</td></tr>
<tr><td>Diesel volume</td><td>2010: domestic sales, CANSIM 134-0004
2011-2015: From govt. contact</td><td>Domestic sales, CANSIM 134-0004, with estimates of redacted data</td><td>Domestic sales, CANSIM 134-0004, with estimates of redacted data</td><td>Domestic sales, CANSIM 134-0004, with estimates of redacted data</td><td>Domestic sales, CANSIM 134-0004, with estimates of redacted data</td></tr>
<tr><td>Biodiesel and HDRD volume</td><td>Data from govt. contact</td><td>Estimate from govt. contact 2012-2015</td><td>Provisional data from govt. contact</td><td>Same method as for ethanol</td><td>Same method as for ethanol</td></tr>
<tr><td>Biofuel feedstock</td><td>RLCFRR Summary: 2010-2015</td><td>Based on typical noted in USDA GAIN[1] report</td><td>Assumption reviewed by govt. contact</td><td>Assumption reviewed by govt. contact</td><td>Assumption reviewed by govt. contact.</td><td>Assuming corn ethanol and yellow grease biodiesel</td><td>Assuming corn ethanol and unknown biodiesel feedstock</td></tr>
<tr><td rowspan="2">Fuel CI</td><td rowspan="2">RLCFRR Summary: 2010-2015</td><td rowspan="2">GHGenius 4.03a by year for Alberta</td><td rowspan="2">GHGenius 4.03a by year for Saskatchewan</td><td rowspan="2">GHGenius 4.03a by year for Manitoba</td><td>Ethanol: GHGenius 4.03a by year in Ontario</td><td rowspan="2">GHGenius 4.03a by year for Quebec</td><td rowspan="2">GHGenius 4.03a by year for Canada East</td></tr>
<tr><td>Biodiesel/HDRD: avg. from govt. contact</td></tr>
</table>

	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	Assumed the higher of biodiesel or diesel price						
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[2]						
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) Miller, Gord. 2016. Staying the Course: The case for policy support for biofuel development and a renewable fuels mandate

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

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

5)www.eia.gov/todayinenergy/detail.php?id=11131

4. Results and Discussion

The results section summarizes data on biofuel content of transportation fuels sold in Canada. Also included in the results is an analysis of the avoided greenhouse gas 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 of the Canadian provinces. The analysis and corresponding data on individual provinces can be accessed in the associated excel spreadsheet, named "Biofuels in Canada Analysis, June 6 2017".

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 2015.

Figure 4: Fuel Consumption

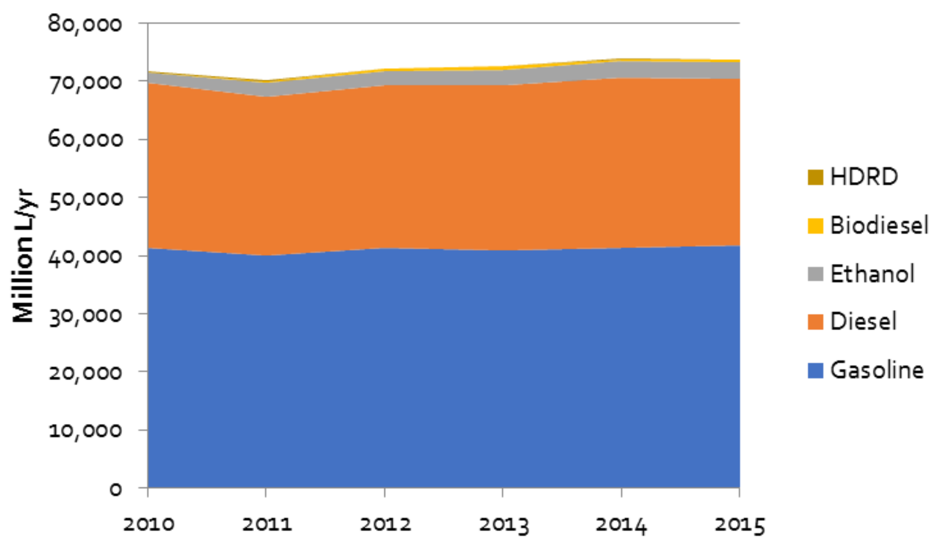


Table 6 summarizes the data in Figure 4. Our analysis shows that the volume of ethanol consumed annually has increased from roughly 1,700 million liters in 2010 to 2,800 million liters in 2015. The volume of biodiesel consumed annually also increased over that period from roughly 110 million liters in 2010 to 470 million liters in 2015.

Table 6: Canadian Fuel Consumption in million liters per year

Fuel type	2010	2011	2012	2013	2014	2015
HDRD	53	85	85	117	144	148
Biodiesel	107	252	404	449	418	474
Ethanol	1,701	2,371	2,495	2,808	2,873	2,819
Diesel	28,380	27,435	27,882	28,444	29,320	28,695
Gasoline	41,398	40,006	41,385	40,820	41,223	41,682

HDRD is also believed to be blended into diesel — albeit in smaller volumes. HDRD content is estimated to have increased from 50 million liters in 2010 to 150 million liters in 2015 (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; however, the only data available on HDRD is from the government of British Columbia which publishes the volumes reported by suppliers.

Figure 5, shows the percentage renewable fuel in the gasoline pool (ethanol) and in the diesel pool (biodiesel and HDRD). Biodiesel and HDRD are grouped together, to not give false precision, given the uncertainty in the volume of HDRD consumed. 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

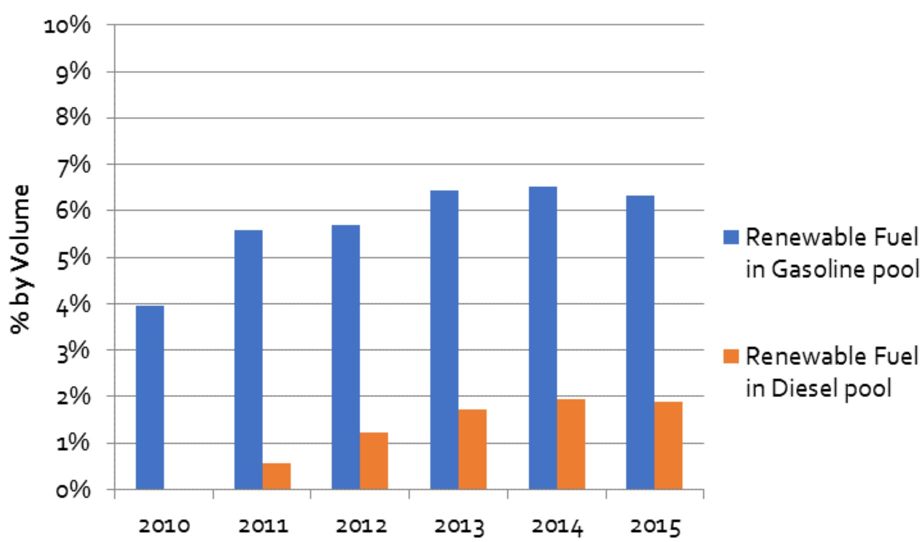


Figure 5 shows the ethanol content in Canadian gasoline complies with the federal Renewable Fuels Regulation, which requires at least 5% ethanol content by volume, since December 15th, 2010. That same policy required 2% renewable content in biodiesel since July 1st, 2011. Although Figure 5 shows the renewable content in the diesel pool was below 2% from 2011 to 2015, this does not necessarily mean the mandate was not met. First, Figure 5 includes diesel exempt from policy, and therefore, 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; however, 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 and 2012. For the remaining years, the national total is aligned with data estimated by GAIN[4] 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 amongst the provinces. In other words, not all provinces will necessarily have to increase biofuel content by the same amount. Therefore, Figure 5 does not depict the percentage of renewable content in the gasoline and diesel pools supplied to individual provinces.

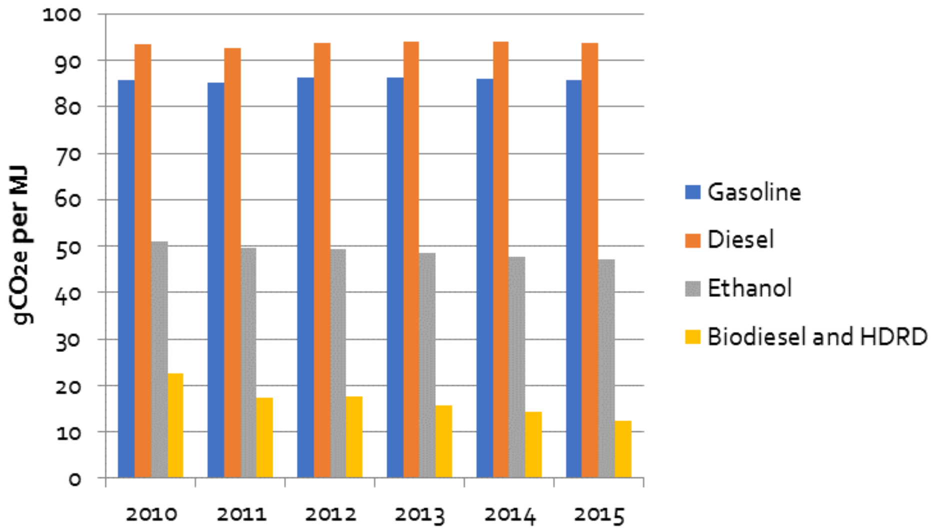
4.2. Lifecycle GHG Emissions

Figure 6 shows the estimated lifecycle CI (i.e. well to wheels or farm to wheels) of transportation fuels in Canada between 2010 and 2015. Biodiesel and HDRD are grouped together, to avoid giving false precision, given the uncertainty in volume, feedstock, and CI.

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. Some of these CI values came from earlier versions of GHGenius. For Ontario, provisional data for the average biodiesel and HDRD CI was obtained from a government contact.

[4] 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 into 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 California low-carbon fuel standard (LCFS) include indirect land-use change (iLUC) emissions in the carbon intensities of fuels. These emissions 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 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. On the other hand, biodiesel and HDRD on average are estimated to be 82% 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 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 short, the average national CI is not based on data collected from fuel suppliers.

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 2015 the CI of ethanol decreased by 10%, and the CI of biodiesel and HDRD decreased by 47%. This trend indicates that the CI of renewable fuel production is decreasing. However, it could be a result of "fuel shuffling", where renewable fuels with low lifecycle CI's are sold in regulated jurisdictions, while fuels with higher intensities are sold in jurisdictions without policy regulating CI.

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

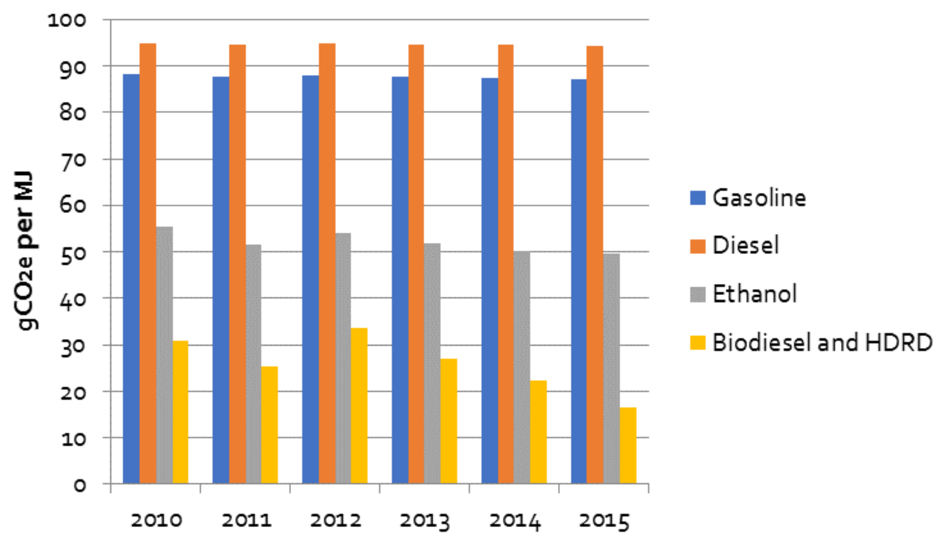


Figure 8 shows the avoided lifecycle GHG emissions in Canada resulting from the biofuel consumption. Again, the avoided emissions are based on the volumes and CIs of biofuels described above, assuming biofuels displace an equal amount of fuel from their fuel pool (i.e. ethanol displaces gasoline, biodiesel and HDRD displaced diesel). This analysis shows that avoided GHG emissions in Canada to biofuel blending practices have increased from 1.8 $MtCO_2e$/yr in 2010 to 4.4 $MtCO_2e$/yr in 2015. Cumulative avoided GHG emissions from 2010 to 2015 are estimated to be 21 $MtCO_2e$ in total.

Figure 8: Avoided Lifecycle GHG Emissions

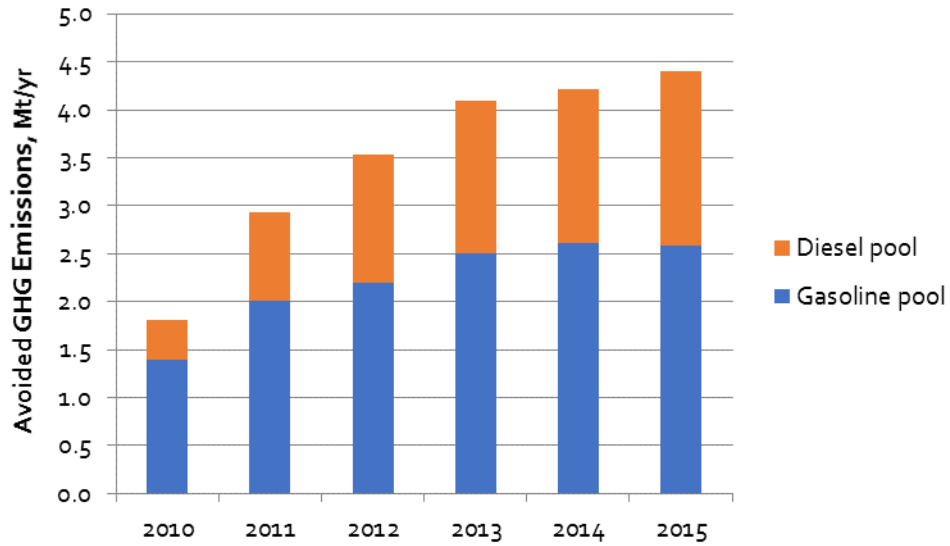
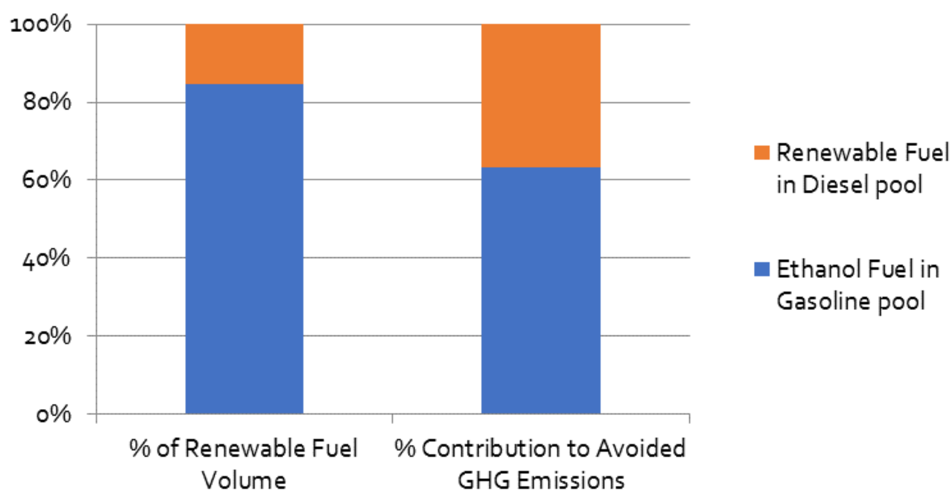


Figure 9 shows the percentage of renewable fuel volume in the gasoline and diesel pool compared with the percentage of avoided GHG emissions resulting from renewable fuel consumption in those fuel pools. Biodiesel and HDRD are estimated to account for 15% of renewable fuel consumption from 2010-2015. Ethanol accounted for 85% of the renewable fuel volume consumed during that period, but only produced 63% 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 15% of renewable fuel consumption, but 37% of the avoided GHG emissions.

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



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. For a detailed explanation on the methodology used for this cost analysis, please refer to Appendix A: Cost Analysis Methodology.

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 one third less than it is for gasoline. Given that current vehicles are optimized to run on gasoline and diesel, 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. Finally, cost reductions may arise due to different fuel properties resulting in changes in fuel octane value (i.e. the anti-knock index of a gasoline blend), combustibility (i.e. the extent to which complete combustion occurs while minimizing air pollution and associated health impacts) and lubricity (i.e. the extent to which diesel fuel reduces friction and wear in the engine). Of these fuel properties, this cost analysis only accounts for the octane value of ethanol.

Gasoline in North America must meet a standard octane value before it can be sold to the consumer. Refiners have various methods to raise the octane value of gasoline blendstock, one of which is the addition of ethanol to gasoline. The U.S. Energy Information Administration (EIA) estimates that American refiners produce gasoline blendstock with octane 84, which is raised to 87 (regular gasoline) with the addition of ethanol[5]. 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.

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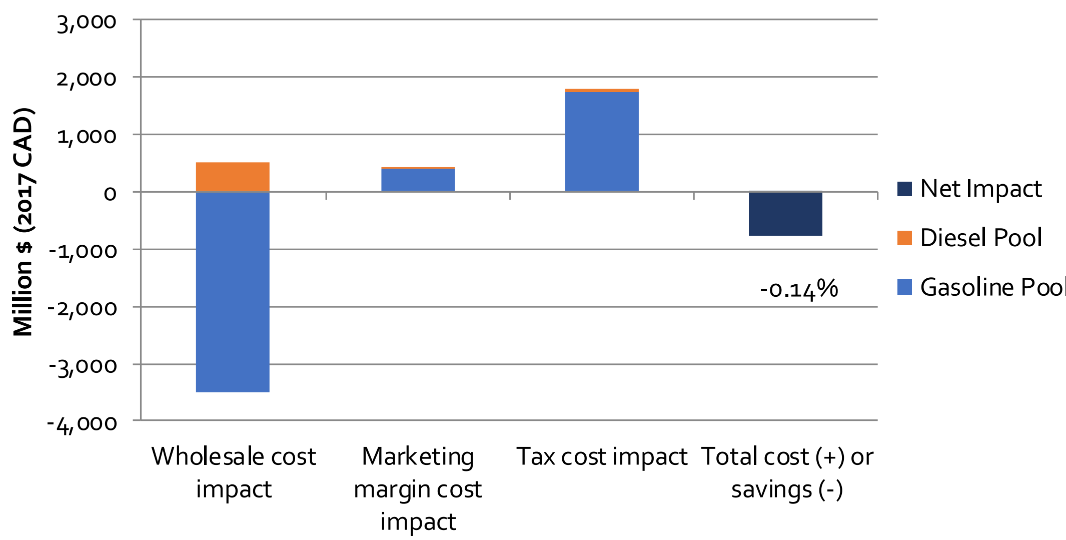
[5] U.S. Energy Information Administration, 2013, Price spread between regular and premium gasoline has changed over time. https://www.eia.gov/todayinenergy/detail.php?id=11131

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 2015. We estimate that the net-cost have diverged less than 1% relative to what they would have been without biofuel consumption: A reduction in fuel expenditures of 0.14%, equivalent to a savings of $760 million over five years. Note that all costs in the analysis are expressed in 2017 CAD and have been corrected for inflation.

Figure 10: Cumulative Cost Impact by Source (2010-2015), total % change in data label



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

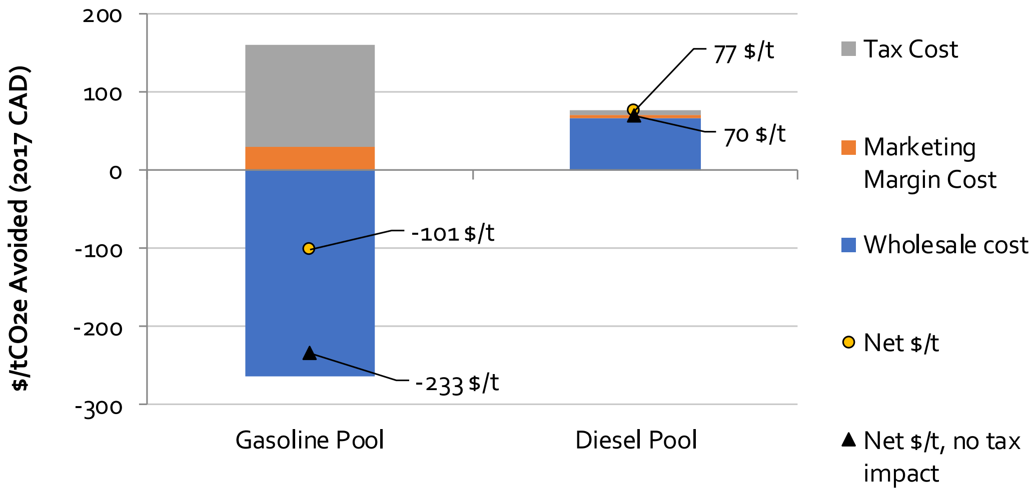
- **The wholesale cost**, which includes the commodity cost and the refining margin, which is the net cost and revenue for fuel refining. The wholesale cost of using ethanol in the gasoline pool is negative due to octane value of ethanol. Without ethanol, the cost of the gasoline would have otherwise been higher. This savings more than offsets any increase in the unit energy cost of the fuel blend, with a wholesale savings of $3.5 billion from 2010-2015. In the diesel pool, the wholesale cost is positive because biodiesel and HDRD, on average, are more expensive than diesel, resulting in a wholesale cost of $516 million. Again, other cost benefits like reducing air pollution and health impacts are not included in this analysis.
- **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 $396 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 $24 million.

- **The tax cost**, which results from the application of taxes based on a % of the fuel price (i.e. GST or HST) and taxes based on the volume of fuel sold (i.e. excise taxes). The federal excise tax is 0.10 $/L for gasoline and 0.04 $/L for diesel. Provincial excise taxes range from 0.13 to 0.33 $/L. As mentioned earlier, because biofuels are less energy dense than petroleum fuels, a consumer must purchase a greater volume of fuel to obtain the same amount of energy. Consequently, consumers pay additional excise taxes. For example, the federal excise tax on gasoline with 10% ethanol is roughly 2.97 $/GJ, but only 2.85 $/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 $1.75 billion over five years relative to a scenario with no biofuel consumption. At only $50 million, the cost is much smaller in the diesel pool.

Figure 11 shows the 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 2010-2015 for the gasoline and diesel pool. Again, costs in this case relate only to those costs included in this analysis. For interest, net abatement costs without the tax cost impact are shown. In other words, the figure shows the net abatement cost if excise taxes had the same $/energy value for gasoline and ethanol, and for diesel, biodiesel and HDRD.

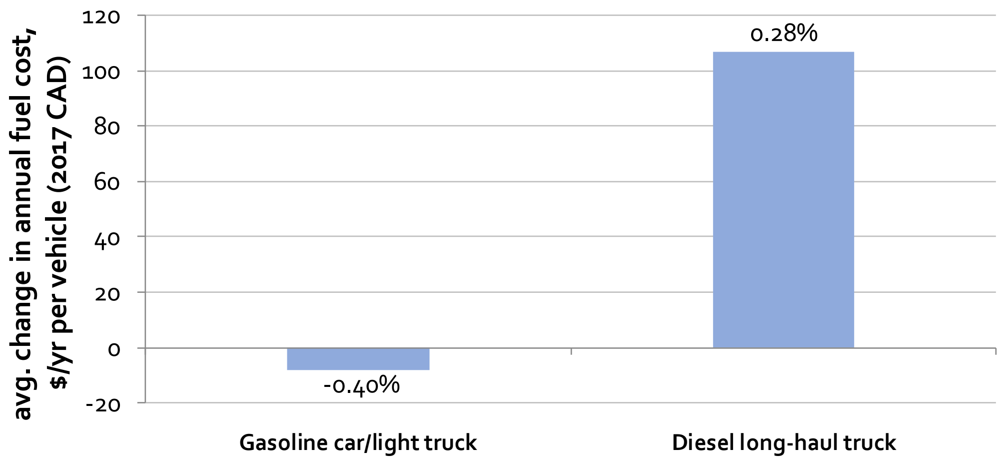
Figure 11: GHG Abatement Cost, 2010-2015



The results (Figure 11) estimate that the cost of abatement from ethanol blending is -$101/tCO2e. Furthermore, the results suggest that excise taxes on fuels have a significant impact on the net dollar value per tonne CO2e abated, which would be -$233/tCO2e if the excise taxes on ethanol and gasoline were equivalent on an energy basis. The abatement cost in the diesel pool is $77/tCO2e, or somewhat lower at $70/tCO2e if fuel taxes were set based on energy rather than volume.

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 16,300 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 91,600 km per year with a fuel economy of 33 liters per 100 km travelled. These archetypes reflect the average statistics of Canadian consumers from 2010-2014 as reported by Natural Resource Canada in the Comprehensive Energy Use Database. These estimates (Figure 12) show that the average consumer of gasoline saved $8.2/yr (-0.40%) as a result of ethanol blending in Canada. A typical diesel consumer spent an additional $106/yr (+0.28%) because of biodiesel and HDRD blending.

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 Columbian Renewable and Low Carbon Fuel Regulation constrains the CI of ethanol, which has potentially increased the avoided GHG emissions. Furthermore, while these results indicate that the ethanol mandates are not binding, 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. From these volumes, this study estimated the resulting quantity of avoided lifecycle GHG emissions and the cost of renewable fuel consumption on consumers. Key conclusions from this study are that:

1. The renewable content in gasoline and diesel pools has increased from 2010 to 2015. The data compiled for this study estimates 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 2015. Annual biodiesel consumption has increased from roughly 110 million L/yr in 2010 to 470 million L/yr in 2015. HDRD consumption increased from roughly 50 million L/yr to 150 million L/yr in that same period.
2. Annual avoided GHG emissions resulting from biofuel blending in Canada have increased from 1.8 Mt/yr in 2010 to 4.4 Mt/yr in 2015
3. The cumulative GHG emission avoided between 2010 and 2015 are 21 Mt.
4. Between 2010 and 2015, blending ethanol, diesel, and HDRD with conventional transportation fuels reduced consumer fuel costs in Canada by 0.14%, relative to what they would have been without renewable fuels. 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, -$101/tCO2e, whereas the abatement cost from biofuel blending with diesel is positive at $77/tCO2e. Ethanol blending reduced the annual fuel costs of a typical driver by $8.2/yr (-0.40%), relative to a scenario without ethanol consumption. Biodiesel and HDRD blending increased the annual fuel costs of an archetypal long-haul trucker by $106/yr (+0.28%).
5. Finally, biofuel consumption, especially ethanol, has increased the fuel tax burden on consumers while creating additional tax revenue for governments in Canada. 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.

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 2010-2015.
  - These were based on monthly averages from Chicago Board of Trade (CBOT) spot prices (biodiesel) and futures prices (ethanol) from 2010 to the end of 2015.
  - No HDRD wholesale prices were available. Instead the price was assumed to be the higher of biodiesel or diesel price for each month from 2010 to 2015.
- 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[6]
  - USD was converted to CAD based on Bank of Canada historic data[7].
- 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[8].
- All values were converted to 2017 dollars[9] .
- 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:

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[6] 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.

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

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

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

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

- 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. In other words, 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[10].
  - The implied cost per octane point was estimated for each year based on the difference between regular and premium gasoline in the US market[11] where that price spread better reflects the cost of octane than in the Canadian market.
  - Our estimated price of pure sub-octane gasoline was decreased based on the implied cost per octane point and the estimated octane of the gasoline blendstock:

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

Where:

- $P_{gasoline,sub-octane}$ 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[12]

[10] 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 100.

[11] Miller, Gord. 2016. Staying the Course: The case for policy support for biofuel development and a renewable fuels mandate

- $O_{blend,prem}$ 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
  - Diesel= 38.7 MJ/L
  - Biodiesel= 35.4 MJ/L
  - HDRD= 36.5 MJ/L

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12 ibid

- 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.[13]
  - 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 2010-2014 as reported by Natural Resource Canada, for the average L/100 km and annual km travelled. For the archetypal gasoline consumer, these values are 10 L/100 and 16,300 km/yr. For the archetypal diesel consumer, these values are 33 L/100 km and 91,600 km/yr.[14,15]

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

[14] National Resources Canada, 2017, Passenger Transportation Explanatory Variables.

[15] National Resources Canada, 2017, Freight Transportation Explanatory Variables.

Appendix B: Biofuel Feedstocks

In this analysis, data was 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 in order 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[16]. However, the data appeared to have some summation errors. Therefore, we made the following adjustments:

1. Barley and wheat volumes for 2014 were adjusted downward compared to what was published by the BC government. This was done because the total volume from each feedstock was greater than reported total volume. This appears to be due to summation errors in the BC government report.

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. Canola based biodiesel for 2015 was decreased 4 million liters below reported levels because otherwise total biodiesel would be larger than the reported total.

4. Tallow was divided evenly between biodiesel and HDRD, since the BC report does not distinguish what fuel the feedstock was used to produce.

Alberta

1. We assumed that ethanol feedstocks are split evenly between wheat and corn. This assumption is based on a GAIN Report[17].

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

2. We assumed that biodiesel feedstocks are split evenly between canola and soy. This assumption is based on personal correspondence with government contacts while collecting data for the 2016 report by Clean Energy Canada and Navius titled *Biofuels in Canada: Tracking progress in tackling greenhouse gas emissions from transportation fuels*.

Saskatchewan

1. We assumed that the primary feedstock for ethanol is wheat. We base this assumption on contact with the government of Saskatchewan[18].

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

Manitoba

1. We assumed that ethanol feedstocks are 100% wheat. We base this assumption from personal correspondence with a government contact.

2. We assumed that biodiesel feedstocks are split evenly between canola and soy. We base this assumption on personal correspondence with a government contact.

3. We don't have data on HDRD feedstock so it has been set to unknown.

Ontario

1. We assumed that ethanol is made from corn following the assumptions made in the 2016 Clean Energy Canada report.

2. We assumed that biodiesel was evenly split between soy and yellow grease, and that HDRD was 100% tallow. Both assumptions were based on correspondence with a government contact.

Quebec

1. We assumed all biodiesel is produced from yellow grease. This assumption was based on what was in the 2016 Clean Energy Canada Report.

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

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

2. We assumed all ethanol was from corn. This assumption was based on what was done in the 2016 Clean Energy Canada Report.

Atlantic

1. We assumed all ethanol was from corn. This assumption was based on what was done in the 2016 Clean Energy Canada Report.

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 represents the renewable fuel content of diesel pools on average in Canada from 2010 to 2015, by fuel type and feedstock. As can be seen, we estimate that most of biodiesel is produced from canola, and most of HDRD is produced from palm. Figure 14 represents the renewable fuel content of gasoline pools on average in Canada from 2010 to 2015, by fuel type and feedstock. The results imply that the majority of ethanol in Canada is produced from corn.

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

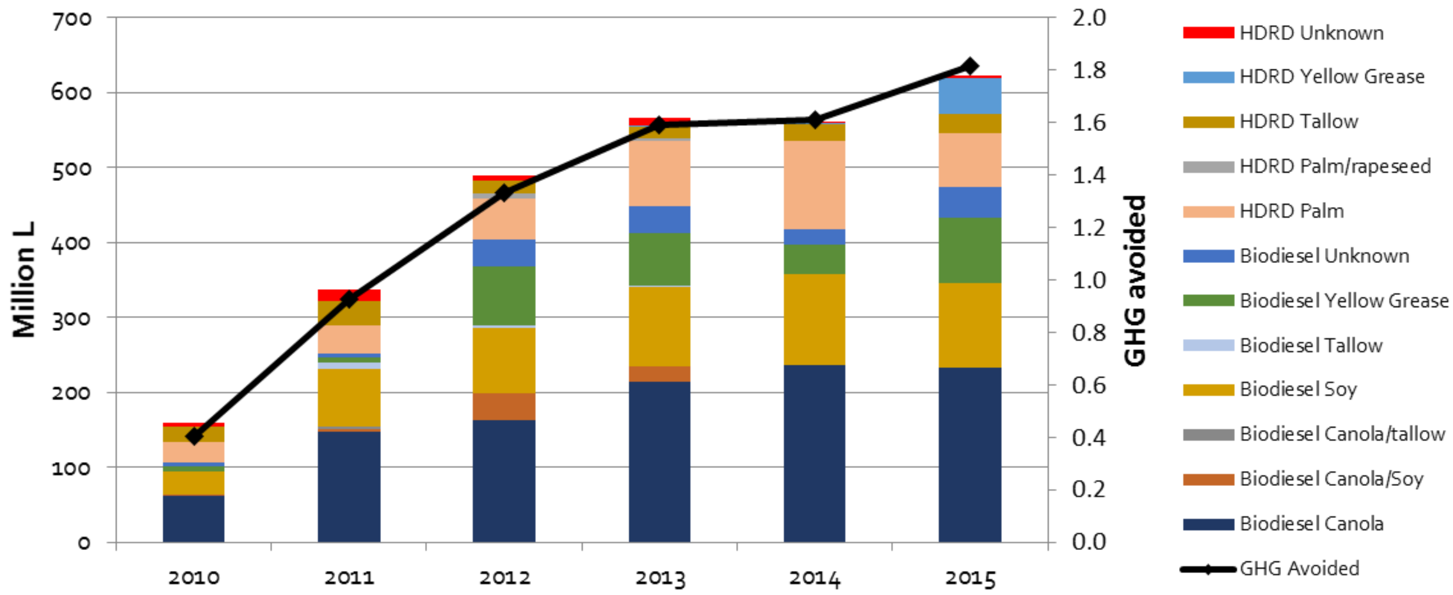

Figure 14: National Results for Renewable Fuel Consumption for Gasoline Pool by Fuel Type, and Feedstock