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Life Cycle Assessment of Renewable Fuel Production from Canadian Biofuel Plants for 2008-2009

Final Report

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1. Summary of Results

The lifecycle greenhouse gas (GHG) changes due to the production of biofuels by the Canadian renewable fuel industry were analyzed based on data available from a recent survey by the Canadian Renewable Fuels Association (CRFA).[1]

1.1 Absolute Lifecycle GHG Reduction

As shown below, the reported production of 741 million litres of all biofuels during the period April 2008 to March 2009 results in a reduction of 1.1 million tonnes of lifecycle GHG emissions, compared to conventional fuels. Lifecycle GHG emissions include all stages of fuel production, fuel consumption, vehicle materials and assembly. The lifecycle emission reduction calculations were performed using the most recent version of the Natural Resources Canada GHGenius lifecycle assessment model for transportation fuels.

Table 1: GHG Reductions from Reported 2008-09 Biofuel Production

Biofuel/(Feedstock)	**No. of Plants Reporting**	**Reported Production Volume**	**Lifecycle GHG Intensity Change**	**Lifecycle GHG Emission Change**	**% of Total**
		(Litres)	(grams$_{CO2e}$/L)	(tonnes$_{CO2e}$)	
Ethanol (Corn, Wheat)	8	647,660,245	-1,252	-810,762	73%
Biodiesel (Tallow)	3	93,677,640	-3,273	-306,601	27%
Total All Biofuels	**13**	**741,337,885**	**-1,507**	**-1,117,363**	**100%**

Source: CRFA Survey, Apr 2008 - Mar 2009; Cheminfo analysis using GHGenius 3.16.xls

Ethanol production of 647 million litres was reported by eight plants in Canada; six from corn and two from wheat feedstocks. This is approximately 65% of total Canadian ethanol capacity active during the data reporting period.[2] Almost 70% of reported ethanol production came from five Ontario corn ethanol plants, with one Quebec corn ethanol plant and two Saskatchewan wheat ethanol plants accounting for the remainder.

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[1] Data provided to Cheminfo Services was blinded – i.e., facility names were not identified.

[2] Based on an analysis of 2008-2009 ethanol capacities published on CRFA website: www.greenfuels.org

Biodiesel production of 94 million litres was reported by three plants in Canada, all of which used tallow rendered from animal carcasses as feedstock. This is approximately 85% of total Canadian biodiesel capacity active during the data reporting period.[3] More than half of reported production came from the Ontario plant, with plants in Quebec and Alberta contributing the remainder.

1.2 Relative Fuelcycle GHG Reduction from Ethanol

On an energy basis, the results show that the reduction in fuelcycle GHG emissions from one megajoule (MJ) of ethanol (when used in an E10 fuel blend) is 62% of the fuelcycle GHG emissions for one megajoule (MJ) of gasoline (applied over the same road performance distance). This calculation is based on three factors and results are shown in the table below:

- Volumetric results from GHGenius that show that the reduction in fuelcycle GHG emissions from one litre of an E10 fuel blend is 125 grams CO2e per litre of E10, or 4.2% of the fuelcycle GHG emissions for one litre of gasoline. The calculation of this reduction is based on equivalent vehicle performance by distance).
- Adjustment of the volumetric fuelcycle GHG intensity from -125 g/L_{E10} (an E10 basis) to -1,253 g/L_{E100} (an E100 basis) by dividing by 10%, the ethanol content in E10; and
- Adjustment of the volumetric fuelcycle GHG intensities for RFG and E100 to an energy basis using the energy contents (expressed as Higher Heating Values) of the respective fuels (34.69 MJ/L for gasoline and 23.58 MJ/L for ethanol).

Table 2: Relative Fuelcycle GHG Reduction from Ethanol

(Based on ethanol used in an E10 fuel blend at equivalent vehicle performance distance)

	Calc.	**Reformulated Gasoline (RFG)***	**Difference E10 Basis****		**Difference E100 Basis*****	
Volume Basis:		(g_{CO2e}/L_{RFG})	(g_{CO2e}/L_{E10})	(% of RFG)	(g_{CO2e}/L_{E100})	(% of RFG)
Fuelcycle GHG Intensity (g/L)	A	2,967	-125	-4.2%	-1,253	n/a
Energy Content (MJ/L)	B	34.69			23.58	68%
Energy Basis:		(g_{CO2e}/MJ_{RFG})			(g_{CO2e}/MJ_{E100})	(% of RFG)
Fuelcycle GHG Intensity (g/MJ)	A/B	85.5			-53.1	-62%

* RFG is Reformulated Gasoline (at 30 ppm sulphur), the reference gasoline fuel in GHGenius
** E10 is an ethanol fuel blend with 90% gasoline and 10% ethanol
*** E100 is 100% ethanol blendstock produced from either corn or wheat feedstocks

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[3] Based on an analysis of 2008-2009 biodiesel capacities published on CRFA website: www.greenfuels.org

It is important to note that the -1,253 g/L_{E100} reduction in GHG intensity (on a volumetric E100 basis) cannot be directly compared to the 2,967 g/L_{RFG} volumetric baseline GHG intensity because they are expressed on a different basis. The 4.2% reduction in volumetric GHG intensity from the use of one litre of E10 vs. one litre of gasoline does not directly convert by 10 times to a 42% reduction in volumetric GHG intensity from the use of one litre of E100 vs. one litre of gasoline because the energy content of one litre of E100 is only 68% of that of gasoline.

Details of the calculation of the difference in GHG intensity are provided in Table 4, later in the report.

1.3 Relative Fuelcycle GHG Reduction from Biodiesel

On an energy basis, the results show that the reduction in fuelcycle GHG emissions from one megajoule (MJ) of tallow biodiesel (when used in a D95/TD5 fuel blend) is 99% of the fuelcycle GHG emissions of one megajoule (MJ) of petroleum diesel (applied over the same road performance distance). This calculation is based on three factors and results are shown in the table below:

- Volumetric results from GHGenius that show that the reduction in fuelcycle GHG emissions from one litre of a D95/TD5 fuel blend is 164 grams CO2e per litre of TD5, or 4.7% of the fuelcycle GHG emissions for one litre of petroleum diesel. The calculation of this reduction is based on equivalent vehicle performance by distance).
- Adjustment of the volumetric fuelcycle GHG intensity from -164 g/L_{TD5} (a TD5 basis) to -3,273 g/L_{TD100} (a TD100 basis) by dividing by 5%, the tallow diesel content in TD5; and
- Adjustment of the volumetric fuelcycle GHG intensities for petroleum diesel and TD100 to an energy basis using the energy contents of the respective fuels (38.65 MJ/L for petroleum diesel and 36.94 MJ/L for tallow diesel).

Table 3: Relative Fuelcycle GHG Reduction from Biodiesel

(Based on Tallow Diesel used in a TD5 blend at equivalent vehicle performance distance)

	Calc.	**Petroleum Diesel (PD)***	**Difference TD5 Basis****		**Difference TD100 Basis*****	
Volume Basis:		(g_{CO2e}/L_{PD})	(g_{CO2e}/L_{TD5})	(% of PD)	(g_{CO2e}/L_{TD100})	(% of PD)
Fuelcycle GHG Intensity (g/L)	A	3,463	-164	-4.7%	-3,273	n/a
Energy Content (MJ/L)	B	38.65			36.94	96%
Energy Basis:		(g_{CO2e}/MJ_{PD})			(g_{CO2e}/MJ_{TD100})	(% of PD)
Fuelcycle GHG Intensity (g/MJ)	A/B	89.6			-88.6	-99%

* PD is On-Road Petroleum Diesel (at 15 ppm sulphur), the reference diesel fuel in GHGenius
** TD5 is a biodiesel fuel blend with 95% Petroleum Diesel and 5% Tallow Diesel
*** TD100 is 100% Tallow Diesel blendstock produced from tallow rendered from animal carcasses

It is important to note that the -3,273 g/L_{E100} reduction in GHG intensity (on a volumetric TD100 basis) cannot be directly compared to the 3,463 g/L_{PD} volumetric baseline GHG intensity because they are expressed on a different basis. The 4.7% reduction in volumetric GHG intensity from the use of one litre of TD5 (vs. one litre of petroleum diesel) does not directly convert by 20 times to a 94% reduction in volumetric GHG intensity from the use of one litre of TD100 (vs. one litre of petroleum diesel) because the energy content of one litre of TD100 is slightly lower than that of petroleum diesel.

Details of the calculation of the difference in GHG intensity are provided in Table 5, later in the report.

2. Lifecycle Analysis Using GHGenius

2.1 Input Factors

The CRFA survey data provided the key input factors applied in the lifecycle analysis using the GHGenius model. The key input data included:

- fuel production in litres;
- feed charged in tonnes;
- electric power consumption in kilowatt-hours (kWh);
- natural gas consumption in gigajoules (GJ); and
- other fuel energy inputs (e.g. heavy fuel oil or biofuels, in GJ).

Provincial averages of the input energy factors were calculated on a fuel output basis (e.g., GJ per litre fuel, kWh per litre of fuel) for use in the model. The feed/product ratio (in kg/L) was also calculated for input.

For the most part, facility input factors were close to default values calculated for 2009 in GHGenius. However, in some cases, there were high variations between reported values and expected values, based on facility-specific factors such as: integration with other processing operations (e.g., tallow rendering), fuels used, power production, and by-product finishing.

For corn ethanol, the reported input factors were very close to those expected by GHGenius. The average reported power usage rate was approximately 10% lower than the default levels calculated for 2009 corn ethanol production in GHGenius. The average reported natural gas usage rate was approximately 2% higher than the 2009 GHGenius default levels for corn ethanol. The average reported corn feed/ethanol ratio was almost identical to the default 2009 feed/product ratio.

For wheat ethanol, the reported data was higher than expected. The average reported power usage rate was significantly higher than the GHGenius default levels calculated for 2009 wheat production. Average reported natural gas usage for wheat production was also higher than the GHGenius 2009 defaults. The average reported wheat feed/ethanol ratio was higher than the 2009 default feed/product ratio.[4]

For tallow biodiesel, the average results were slightly higher than default values in GHGenius. The average reported power usage was approximately 10% lower than 2009 default power levels. The average reported energy usage was approximately 20% higher

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[4] Quantitative results for wheat ethanol withheld for confidentiality reasons.

than the 2009 default level but one plant used a mixture of fuels. The average reported tallow feed/biodiesel ratio was 10% lower than the 2009 default value.

2.2 GHGenius Lifecycle Comparison

2.2.1 Ethanol

This lifecycle analysis assumes that ethanol is blended into an E10 fuel (90% reformulated gasoline and 10% ethanol), which is distributed to retail outlets, since this is the most common use for ethanol as fuel. GHGenius calculates the change in GHG intensity due to ethanol (in grams CO_2e per litre of ethanol) from the comparison between the lifecycle GHG intensity of E10 and the lifecycle GHG intensity of reformulated gasoline (RFG). The results of these adjustments and changes of reporting basis are shown in Table 4. However, in order to isolate the impact of pure ethanol (E100) on GHG intensity, GHGenius makes two adjustments:

1. GHGenius first adjusts the "raw" calculated GHG intensity of RFG to an equivalent performance basis as E10 based on the relative fuel efficiency performance in light-duty vehicles (LDV). Since RFG has a slightly better average LDV fuel efficiency default value in GHGenius (9.56 L/100km) than E10 (9.78 L/100km), the GHG intensity of RFG is adjusted downwards slightly to standardize its performance basis with that of E10. The results of this adjustment are shown in the second column of Table 4.

2. The changes in GHG intensity on an E10 basis are shown in the fourth column of Table 4. GHGenius calculates the GHG intensity change on an E100 basis by dividing the results by 10%, the share of E100 in the E10 blend. The GHG intensity changes due to ethanol are shown in the fifth column. This shows the overall GHG intensity change to be used in the calculation of total lifecycle GHG emission reductions.

2.2.2 Biodiesel

This analysis assumes that biodiesel produced from tallow is blended into a D95/TD5 fuel (95% petroleum diesel and 5% tallow diesel), which is distributed to retail outlets, since this is the most common use for biodiesel as fuel. This is also abbreviated as TD5 in the table above. GHGenius calculates the change in GHG intensity due to tallow diesel (in grams CO_2e per litre of tallow diesel) from the comparison between the lifecycle GHG intensity of D95/TD5 and the lifecycle GHG intensity of petroleum diesel (PDies). The results of these adjustments and changes of reporting basis are shown in Table 5.

As with ethanol, GHGenius adjusts the “raw” petroleum diesel lifecycle GHG intensity based on a ratio of fuel efficiencies. There is only a slight difference in fuel efficiencies contained as defaults in GHGenius (i.e., 40.94 L/100km for petroleum diesel and 41.03 L/100km for TD5), so the GHG intensity adjustment for petroleum diesel is only a small reduction. The calculated results are converted to a pure TD100 basis by dividing by 5%, the share of TD100 in a TD5 blend.

2.3 Provincial Differences

The GHGenius lifecycle assessment model has the capability of modeling emissions on a regional or provincial basis taking into consideration differences in transportation distances and energy supply. Since there are biofuel plants operating in four provinces (Alberta, Saskatchewan, Ontario, and Quebec), four provincial model runs were conducted. Some of the key assumptions and differences between the provinces include:[5]

Alberta - Electric power generation (EPG) is mostly coal-based and therefore has a high carbon intensity. Crude oil supply is the default Canada West average, which has a relatively high carbon intensity due to the contribution of synthetic crude from the Oil Sands. Tallow is sourced locally. Fuel distribution to blending then retail uses moderate distances.

Saskatchewan - Like Alberta, EPG is mostly coal-based, so power has a high carbon intensity. Crude oil uses the same Canada West average as Alberta, which has a high carbon intensity. Wheat feed is sourced locally. E10 distribution assumes longer distances than provinces in eastern Canada.

Ontario - EPG is dominated by nuclear and hydro and coal power is a small share, so power is less carbon-intensive than in Alberta and Saskatchewan. Crude oil supply and petroleum refining stages use a Canada Central average, made up of both western Canadian crude and imported crude. Since imported crude has a lower carbon intensity than western Canadian crude, the carbon intensity of petroleum fuels is slightly lower than in western provinces. Petroleum fuel distribution is mostly by low-intensity pipeline and short distance trucking. A share of Ontario corn is imported so corn feed transport distances are longer than other provinces. Ethanol distribution distances are longer than those assumed for Quebec, while biodiesel distribution distances are relatively short and comparable to those assumed for Quebec.

Quebec - EPG is dominated by hydro power, so the GHG-intensity of input power is very low. Crude oil supply uses an Eastern Canada average, which is dominated by lower-intensity imported oil. Petroleum refining uses a Central Canada average, which is comparable to Ontario. All fuels have short average distribution distances because of the concentrated population.

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[5] Natural Resources Canada, The Development of Provincial Inputs for GHGenius, Mar. 2009, [by (S&T)^2 Consultants Inc.]

3. Lifecycle GHG Intensity by Stage

This section examines the GHG intensity contributions made all lifecycle stages for each fuel. The tables show the Canadian weighted average GHG intensities for both fuels.

3.1 GHG Reduction from Ethanol

The reduction in lifecycle GHG intensity due to ethanol production was calculated using 3 provincial runs of the GHGenius model: Saskatchewan, Ontario, and Quebec. The results of each provincial run could not be presented due to the small number of plants in some provinces to maintain confidentiality. However, a lifecycle profile of total Canadian bioethanol is shown in the table below, calculated as a weighted average of the provincial results. The table shows how GHGenius calculates the reduction in GHG intensity associated with one litre of ethanol.

Table 4: Lifecycle GHG Intensity Reduction from Ethanol

(Canada Weighted Average from 3 Provincial Analyses: SK, ON, QC)

Lifecycle Stage	**Raw RFG GHG Intensity**	**Adjusted RFG GHG Intensity***	**E10 GHG Intensity**	**Difference E10 Basis**	**Difference E100 Basis**	**% of Total Difference**
	(g_{CO2e}/L_{RFG})	(g_{CO2e}/L_{E10eq})	(g_{CO2e}/L_{E10})	(g_{CO2e}/L_{E10})	(g_{CO2e}/L_{E100})	(%)
	A	B=A x ratio*	C	D=C-B	E=D/10%	
Vehicle operation			2,141			
C in end-use fuel from CO2 in air			-143			
Net Vehicle Operation	2,213	2,164	1,997	-167	-1,666	133%
Fuel dispensing	3	3	3	0	1	0%
Fuel storage and distribution	15	15	17	2	19	-2%
Fuel production	437	427	456	29	285	-23%
Feedstock transport	40	39	43	4	36	-3%
Feedstock and fertilizer production	274	268	269	1	8	-1%
Land use changes and cultivation	0	0	51	51	514	-41%
CH4 and CO2 leaks and flares	56	55	50	-4	-43	3%
Emissions displaced by co-products	-4	-4	-45	-41	-407	33%
Sub total (fuelcycle)	**3,035**	**2,967**	**2,842**	**-125**	**-1,253**	**100%**
Vehicle assembly and transport	48	47	47	0	0	0%
Materials in vehicles	291	285	285	0	1	0%
Grand total	**3,374**	**3,298**	**3,173**	**-125**	**-1,252**	**100%**

Source: CRFA survey, Apr 2008 - Mar 2009; Cheminfo analysis using GHGenius 3.16.xls

* RFG LCA results adjusted to same performance basis as E10 blend based on ratio of fuel efficiencies.

Legend: RFG - Reformulated Gasoline (30 ppm S); E10 - Gasoline/Ethanol fuel blend with 10% ethanol; E100 - Ethanol fuel as produced

Four key observations are made about the weighted average Canadian ethanol results.

1. The key factor responsible for the GHG reduction is the credit that GHGenius gives to the carbon in the E10 that comes from plant origins. For biofuels, GHGenius calculates the total GHG released from their combustion, then deducts the CO_2 that is generated from biomass carbon.
2. GHGenius gives a co-product credit for the Distillers Dried Grains with Solubles (DDGS) produced in ethanol production. The production of this co-product reduces the demand for shelled corn/wheat and soybean meal as animal feed and the associated GHG emissions.
3. The above benefits are offset by a higher GHG intensity of ethanol production relative to petroleum refining and the estimated impacts of land use changes for the production of corn feed.
4. Several lifecycle stages have a negligible impact because they have similar GHG intensities for both RFG and E10. These include: feedstock & fertilizer production, feedstock transport, fugitive emissions, fuel distribution, and vehicle manufacturing.

Beyond the differences in individual plant energy and production yield performance, the lifecycle GHG results are also influenced by the province in which the plant is located. However, the variation for ethanol is not large. The range (maximum minus minimum) of GHG intensity changes due to ethanol from each province was only 11% of the Canadian weighted average. This range is due to both input factor variations for ethanol production and provincial differences.

3.2 GHG Reduction from Biodiesel

The reduction in lifecycle GHG intensity due to biodiesel production was calculated using 3 provincial runs of the GHGenius model: Alberta, Ontario, and Quebec. The results of each provincial run could not be presented due to the fact that there was one plant in each province. However, a lifecycle profile of total Canadian biodiesel is shown in the table below, calculated as a weighted average of the provincial results. Similar to ethanol, the table shows how GHGenius calculates the reduction in GHG intensity associated with one litre of biodiesel.

Table 5: Lifecycle GHG Intensity Reduction from Biodiesel

(Canada Weighted Average from 3 Provincial Analyses: AB, ON, QC)

Lifecycle Stage	Raw PDies GHG Intensity	Adjusted PDies GHG Intensity*	D95/TD5 GHG Intensity	Difference TD5 Basis	Difference TD100 Basis	% of Total Difference
	(g_{CO2e}/L_{PD})	(g_{CO2e}/L_{TD5eq})	(g_{CO2e}/L_{TD5})	(g_{CO2e}/L_{TD5})	(g_{CO2e}/L_{TD100})	(%)
	A	B=A x ratio*	C	D=C-B	E=D/5%	
Vehicle operation			2,709			
C in end-use fuel from CO2 in air			-125			
Net Vehicle Operation	2,716	2,710	2,584	-127	-2,530	77%
Fuel dispensing	3	3	3	0	0	0%
Fuel storage and distribution	16	16	16	0	2	0%
Fuel production	333	332	383	51	1,011	-31%
Feedstock transport	45	45	49	4	81	-2%
Feedstock and fertilizer production	302	301	281	-21	-417	13%
Land use changes and cultivation	0	0	6	6	128	-4%
CH4 and CO2 leaks and flares	60	60	57	-3	-57	2%
Emissions displaced by co-products	-4	-4	-79	-75	-1,492	46%
Sub total (fuelcycle)	**3,471**	**3,463**	**3,299**	**-164**	**-3,273**	**100%**
Vehicle assembly and transport	21	21	21	0	0	0%
Materials in vehicles	74	74	74	0	0	0%
Grand total	**3,566**	**3,558**	**3,395**	**-164**	**-3,273**	**100%**

Source: CRFA survey, Apr 2008 - Mar 2009; Cheminfo analysis using GHGenius 3.16.xls

* Petroleum Diesel LCA results adjusted to same performance basis as D95/TD5 blend based on ratio of fuel efficiencies. Legend: PDies - Petroleum Diesel (15 ppm S); D95/TD5 - Petroleum Diesel/Biodiesel blend with 5% Tallow Diesel; TD100 - Tallow Diesel fuel as produced

The following observations were made about the weighted average Canadian biodiesel results.

1. The key factor responsible for the GHG reduction is the credit that GHGenius gives to the carbon in the TD5 that comes from plant origins.
2. The co-product credit granted by GHGenius for glycerine and protein co-products from tallow biodiesel production provides a greater contribution to GHG reduction than DDGS does for ethanol.
3. Biodiesel has a lower impact of feedstock and fertilizer production than the equivalent stages for petroleum diesel (crude oil production) and contributes positively to GHG reduction.
4. The above benefits are offset by a higher GHG intensity of biodiesel production relative to petroleum refining.
5. The impact of land use changes is much lower for tallow biodiesel than for corn ethanol, and almost negligible, since the feedstock comes from animal carcasses. In

future, the contribution of land use changes will increase as more biodiesel is produced from agricultural feedstocks.

Beyond the differences in individual plant energy and production yield performance, the lifecycle GHG results are also influenced by the province in which the plant is located. The range (maximum minus minimum) of GHG intensity changes due to biodiesel from each province was 20% of the Canadian weighted average. This range is due to both input factor variations for biodiesel production and provincial differences.

3.3 Lifecycle Stages for Ethanol and Biodiesel

The figure on the following page shows the fuelcycle stages for conventional gasoline, diesel, E10 fuel blend, and D95/TD5 biodiesel fuel blend as a reference for the preceding analysis. The term “fuelcycle” refers to the sequence of lifecycle stages of the fuel. A full lifecycle analysis also includes the vehicle materials and vehicle assembly stages, which are equivalent for both conventional petroleum fuels and fuel blends with low ethanol and biodiesel components because no vehicle changes are required for these fuels.

In GHGenius, GHG emissions are estimated for each stage in a fuelcycle based on the various forms of input energy and their GHG intensities, process GHGs, and feed/product yields. The GHG emissions for all fuelcycle stages are normalized into GHG intensities expressed as grams CO2e per gigajoule of fuel output. Subsequent calculations convert these GHG intensities into a volumetric basis (grams CO2e per litre of fuel) or a distance basis (grams CO2e per kilometre traveled).

The diagram also shows the co-products from ethanol and biodiesel production. These co-products attract a GHG credit because they displace the production of various products (animal feeds, glycerine, etc.) from other production routes.

Land use changes are also estimated for the production of crops used in biofuel feedstocks. In the current analysis, the production of corn and wheat as ethanol feedstocks incurs a land use changes in GHGs. The production of biodiesel has no land use changes in the current analysis because all biodiesel in the reporting period of April 2008 to March 2009 was produced from tallow rendered from animal carcasses, not agricultural feedstocks. In future reporting periods, as more biodiesel is produced from canola oil or soybean oil, the land use change contribution to the fuelcycle of biodiesel will increase.

Figure 1: Fuelcycle Stages for Petroleum Fuels, Ethanol, and Biodiesel