LIFECYCLE ANALYSIS CANOLA BIODIESEL

Prepared For:

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EXECUTIVE SUMMARY

As environmental awareness increases, governments, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. The environmental performance of products and processes has become a key operational issue. Many organizations have found it advantageous to explore ways to improve their environmental performance, while improving their efficiency, reducing costs and developing a "green marketing" advantage. One useful tool is called life cycle assessment (LCA). This concept considers the entire life cycle of a product.

This work has been undertaken for the Canola Council of Canada to document the unique life cycle attributes of Canadian canola production and conversion to biodiesel. These include:

1. Low N_2O emissions in the primary canola production areas due to the low annual precipitation.
2. The production on alkaline soils and thus avoiding the need for soil pH adjustment through the addition of lime.
3. The use of ammonium type fertilizers rather than nitrate fertilizers, with their lower GHG emissions profile.
4. The energy efficient production methods employed by Canadian producers, including high adoption rates of no till and conservation tillage practices.

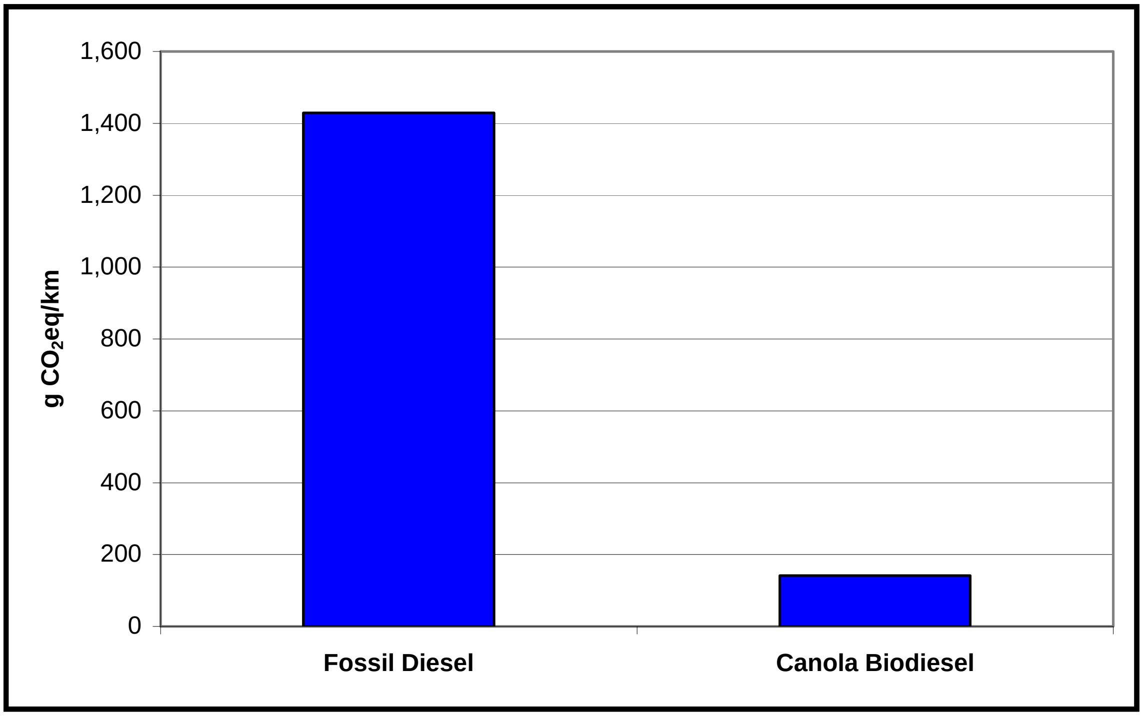
All of these production methods result in a crop with a good energy balance and a low GHG emissions profile. Biodiesel produced from Canadian canola has a very good GHG emissions profile and it is significantly different from European rapeseed biodiesel. This work documents the Canadian canola production methods and data and uses the information in GHGenius to determine the energy balance and the lifecycle GHG emissions for Canadian canola biodiesel. The work utilizes version 3.19 of GHGenius. The model is set to the year 2010 and the Canadian average values are used. The Global Warming Potentials are set to the 2007 IPCC values.

The GHG emissions for the production of the fuel can be informative but, in the case of biofuels, these emissions do not provide the complete picture because, by definition, the biogenic CO_2 emissions are not counted for the production of biomass or a biofuel and thus the fossil fuel will have significantly higher emissions when it is produced and burned compared to many biofuels.

Canola biodiesel, however, is one of the biofuels that have lower emissions for both the production and combustion stages compared to fossil fuels.

The full lifecycle emissions from the production and use of biodiesel include the benefit of the biogenic emissions. When the results for the canola biodiesel (B100) are compared to those for petroleum diesel (and it is assumed that the fuel is used in a large heavy-duty truck), the canola biodiesel reduces the GHG emissions by 92.5% without considering the emissions from the manufacture of the truck and by 90.1% if those emissions are included as shown in the following figure.

Figure ES- 1 Canola Biodiesel GHG Emissions (B100) vs. Fossil Diesel



The GHG emission reduction can also be presented on the basis of the biodiesel produced and consumed. On this basis, the GHG emission reduction per litre of canola biodiesel produced and consumed amounts to 2.97 kg CO_2eq/litre of biodiesel.

Canola biodiesel demonstrates very large GHG emission reductions. This is primarily a function of a number of unique characteristics of the Canadian canola production situation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

As environmental awareness increases, governments, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. The environmental performance of products and processes has become a key operational issue, which is why many organizations are investigating ways to minimize their effects on the environment. Many have found it advantageous to explore ways to improve their environmental performance, while improving their efficiency, reducing costs and developing a “green marketing” advantage. One useful tool is called life cycle assessment (LCA). This concept considers the entire life cycle of a product.

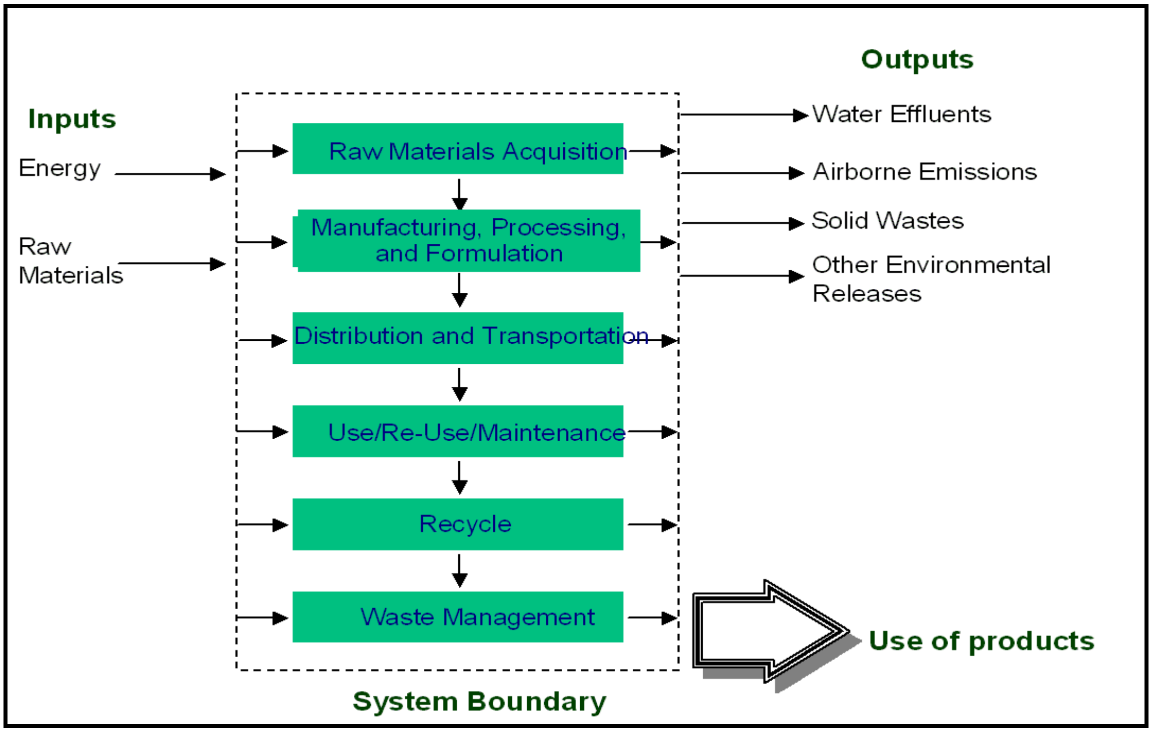
Life cycle assessment is a "cradle-to-grave" (or “well to wheels”) approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection.

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- **Compiling** an inventory of relevant energy and material inputs and environmental releases;
- **Evaluating** the potential environmental impacts associated with identified inputs and releases;
- **Interpreting** the results to help make more informed decisions.

The term "life cycle" refers to the major activities in the course of the product's life span from its manufacture, use, maintenance, and final disposal; including the raw material acquisition required to manufacture the product. The following figure illustrates the typical life cycle stages that can be considered in an LCA and the quantified inputs and outputs.

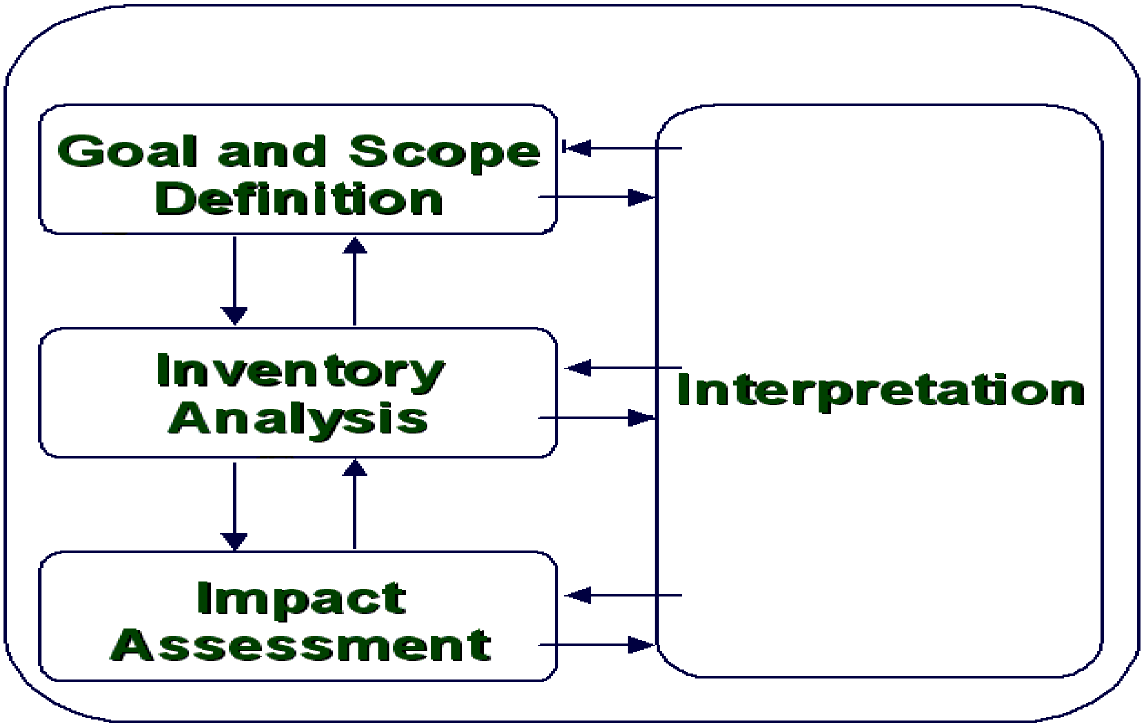
Figure 1-1 Life Cycle Stages



The LCA process is a systematic, iterative, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation as illustrated in the following figure:

1. *Goal Definition and Scoping* - Define and describe the product, process or activity. Establish the context in which the assessment is to be made, and identify the boundaries and environmental effects to be reviewed for the assessment.
2. *Inventory Analysis* - Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, wastewater discharge).
3. *Impact Assessment* - Assess the human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
4. *Interpretation* - Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

Figure 1-2 Phases of a LCA



1.1 GHGENIUS

LCA work involves the collection and utilization of large amounts of data and thus is ideally suited to the use of computer models to assist with the inventorying and analysis of the data. In North America, two models are widely used for the analysis of transportation fuels:

- GREET. A model developed by Argonne National Laboratory in the United States, and
- GHGenius. A model developed by Natural Resources Canada, which has data for both Canada and the United States. This model also has much greater flexibility for modelling different types of crude oil production and many more types of alternative fuels.

Many other LCA models have been developed by governments, universities and the private sector. While all of these models have some small differences in the scope and system boundaries, they may have different emission factors for different regions of the world and thus using a model that is tailored for the production region of interest is an important parameter in deciding which model to use for a lifecycle analysis. GHGenius is therefore the ideal model for use in studying canola biodiesel as Canadian canola production has some unique attributes.

The GHGenius model has been developed for Natural Resources Canada over the past eleven years. It is based on the 1998 version of Dr. Mark Delucchi's Lifecycle Emissions Model (LEM). GHGenius is capable of analyzing the energy balance and emissions of many contaminants associated with the production and use of traditional and alternative transportation fuels.

GHGenius is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion and process sources. The specific gases that are included in the model include:

- Carbon dioxide (CO_2),
- Methane (CH_4),
- Nitrous oxide (N_2O),
- Chlorofluorocarbons (CFC-12),
- Hydro fluorocarbons (HFC-134a),
- The CO_2-equivalent of all of the contaminants above.
- Carbon monoxide (CO),
- Nitrogen oxides (NOx),
- Non-methane organic compounds (NMOCs), weighted by their ozone forming potential,
- Sulphur dioxide (SO_2),
- Total particulate matter.

The model is capable of analyzing the emissions from conventional and alternative fuelled internal combustion engines or fuel cells for light duty vehicles, for class 3-7 medium-duty trucks, for class 8 heavy-duty trucks, for urban buses and for a combination of buses and trucks, for light duty battery powered electric vehicles, and for marine vessels. There are over 200 vehicle and fuel combinations possible with the model.

GHGenius can predict emissions for past, present and future years through to 2050 using historical data or correlations for changes in energy and process parameters with time that are stored in the model. The fuel cycle segments considered in the model are as follows:

- Vehicle Operation
  Emissions associated with the use of the fuel in the vehicle. Includes all greenhouse gases.
- Fuel Dispensing at the Retail Level
  Emissions associated with the transfer of the fuel at a service station from storage into the vehicles. Includes electricity for pumping, fugitive emissions and spills.
- Fuel Storage and Distribution at all Stages
  Emissions associated with storage and handling of fuel products at terminals, bulk plants and service stations. Includes storage emissions, electricity for pumping, space heating and lighting.
- Fuel Production (as in production from raw materials)
  Direct and indirect emissions associated with conversion of the feedstock into a saleable fuel product. Includes process emissions, combustion emissions for process heat/steam, electricity generation, fugitive emissions and emissions from the life cycle of chemicals used for fuel production cycles.
- Feedstock Transport
  Direct and indirect emissions from transport of feedstock, including pumping, compression, leaks, fugitive emissions, and transportation from point of origin to the fuel refining plant. Import/export, transport distances and the modes of transport are considered. Includes energy and emissions associated with the transportation infrastructure construction and maintenance (trucks, trains, ships, pipelines, etc.)
- Feedstock Production and Recovery

Direct and indirect emissions from recovery and processing of the raw feedstock, including fugitive emissions from storage, handling, upstream processing prior to transmission, and mining.

- Fertilizer Manufacture

  Direct and indirect life cycle emissions from fertilizers, and pesticides used for feedstock production, including raw material recovery, transport and manufacturing of chemicals. This is not included if there is no fertilizer associated with the fuel pathway.

- Land use changes and cultivation associated with biomass derived fuels

  Emissions associated with the change in the land use in cultivation of crops, including N_2O from application of fertilizer, changes in soil carbon and biomass, methane emissions from soil and energy used for land cultivation.

- Carbon in Fuel from Air

  Carbon dioxide emissions credit arising from use of a renewable carbon source that obtains carbon from the air.

- Leaks and flaring of greenhouse gases associated with production of oil and gas

  Fugitive hydrocarbon emissions and flaring emissions associated with oil and gas production.

- Emissions displaced by co-products of alternative fuels

  Emissions displaced by co-products of various pathways. System expansion is used to determine displacement ratios for co-products from biomass pathways.

- Vehicle assembly and transport

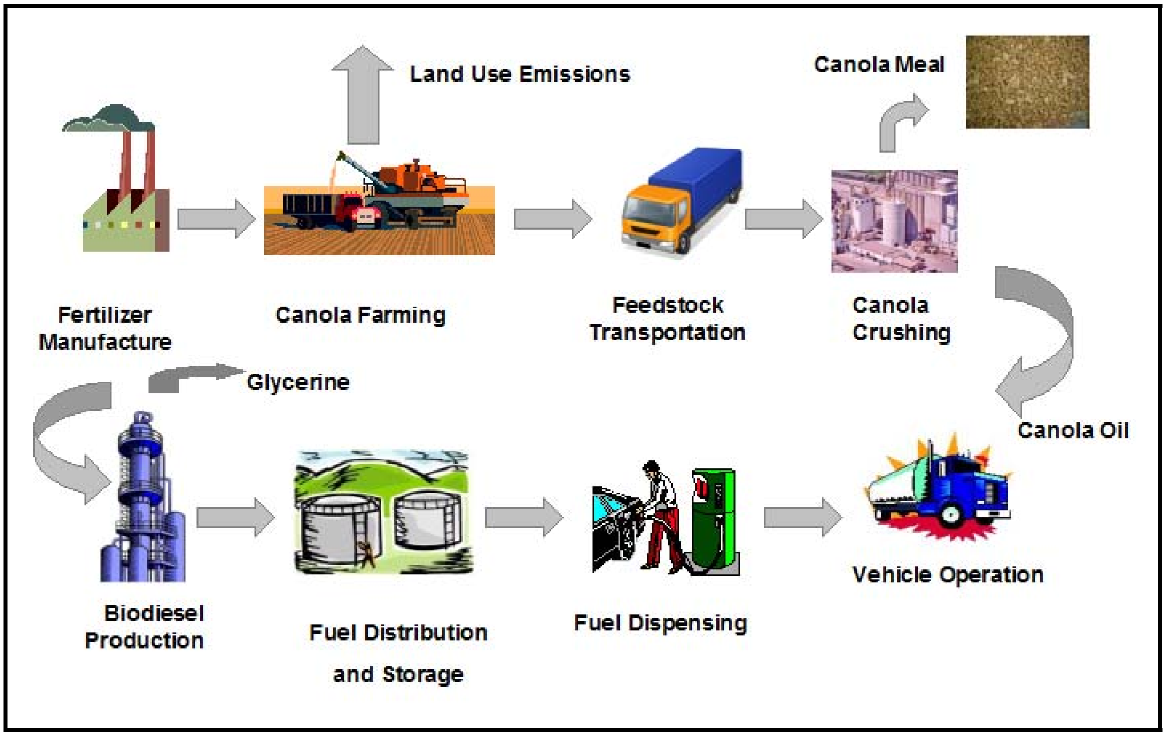
  Emissions associated with the manufacture and transport of the vehicle to the point of sale, amortized over the life of the vehicle.

- Materials used in the vehicles

  Emissions from the manufacture of the materials used to manufacture the vehicle, amortized over the life of the vehicle. Includes lube oil production and losses from air conditioning systems.

The main lifecycle stages for canola biodiesel are shown in the following figure.

Figure 1-3 Lifecycle Stages – Canola Biodiesel



1.2 SCOPE OF WORK

This work has been undertaken for the Canola Council of Canada to document the unique life cycle attributes of Canadian canola production and conversion to biodiesel. These include:

1. Low N_2O emissions in the primary canola production areas due to the low annual precipitation.
2. The production on alkaline soils and thus avoiding the need for soil pH adjustment through the addition of lime.
3. The use of ammonium type fertilizers rather than nitrate fertilizers, with their lower GHG emissions profile.
4. The energy efficient production methods employed by Canadian producers, including high adoption rates of no till and conservation tillage practices.

All of these production methods are expected to result in a crop with a good energy balance and a low GHG emissions profile. Biodiesel produced from Canadian canola is expected to have a very good GHG emissions profile and be significantly different from European rapeseed biodiesel. This work documents the Canadian canola production methods and data and uses the information in GHGenius to determine the energy balance and the lifecycle GHG emissions for Canadian canola biodiesel.

The work utilizes version 3.19 of GHGenius. The model is set to the year 2010 and the Canadian average values are used. The Global Warming Potentials are set to the 2007 IPCC values.

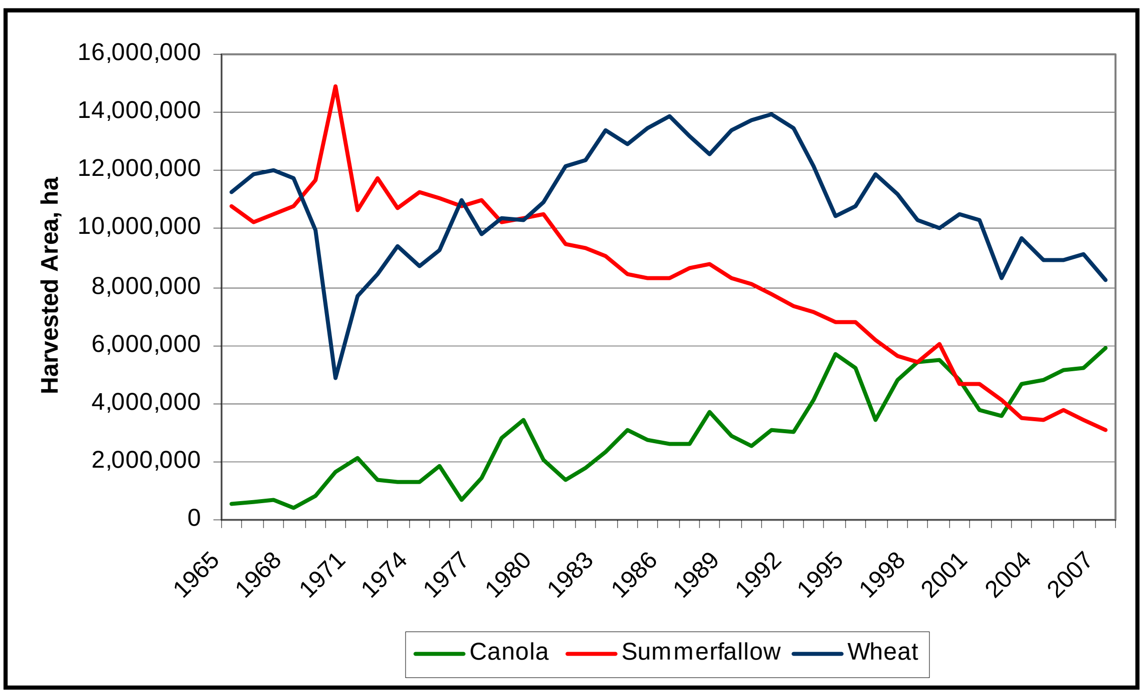
2. CANOLA PRODUCTION

The canola we know today was developed in the early 1970s using traditional plant breeding techniques; as a result of the efforts by Canadian plant breeders to remove the anti-nutritional components erucic acid and glucosinolates from rapeseed so that it would be absolutely safe for human and animal consumption. The plant also produced seeds with a very low level of saturated fat, 7% or below.

This new oilseed was christened “canola” and there is a strict internationally regulated definition of canola that differentiates it from rapeseed, based upon canola oil having less than 2% erucic acid and the non-oil portion of the seed having less than 30 µmoles glucosinolates. Therefore, oilseed products that do not meet this standard cannot use the trademarked term, canola and are called rapeseed. High erucic acid rapeseed acreage, although still present in Canada, is now confined to production under contract for specific industrial uses.

Canola production in Canada has grown significantly since the 1970s. The availability of an economically viable, non-cereal crop in western Canada has also facilitated the reduction of summerfallow area and the increase in no till agriculture. Increased canola production has therefore not been a result of increased agricultural land, but rather the better and more sustainable use of the existing land base. The following figure demonstrates this change in summerfallow, wheat and canola area in western Canada over the past 40 years.

Figure 2-1 Western Canada Area



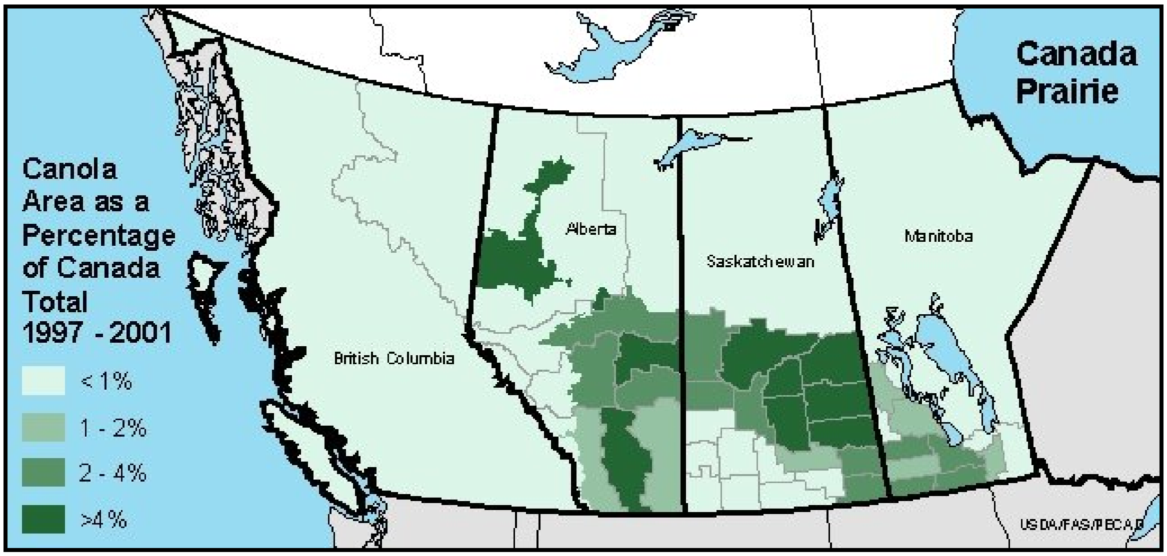
Canola is a significant oilseed crop in Canada with about 6.47 million hectares grown in Canada in 2009. Most of the canola is grown in the three prairie provinces of Manitoba, Saskatchewan, and Alberta as shown in the following table (Statistics Canada, 2010). The production in 2009 was 11.8 million tonnes.

Table 2-1 Canadian Canola Production

	2005	2006	2007	2008
	tonnes			
Manitoba	1,261,000	1,825,700	1,950,400	2,576,400
Saskatchewan	4,456,500	3,696,800	4,082,300	5,629,100
Alberta	3,651,400	3,424,600	3,401,900	4,322,700
Other provinces	114,400	53,200	93,900	114,700
Total	9,483,300	9,000,300	9,528,500	12,642,900

The major canola growing regions in Canada are shown in the following table. The legend is the % of the total Canadian canola crop grown in each of the crop regions.

Figure 2-2 Canola Growing Regions in Canada



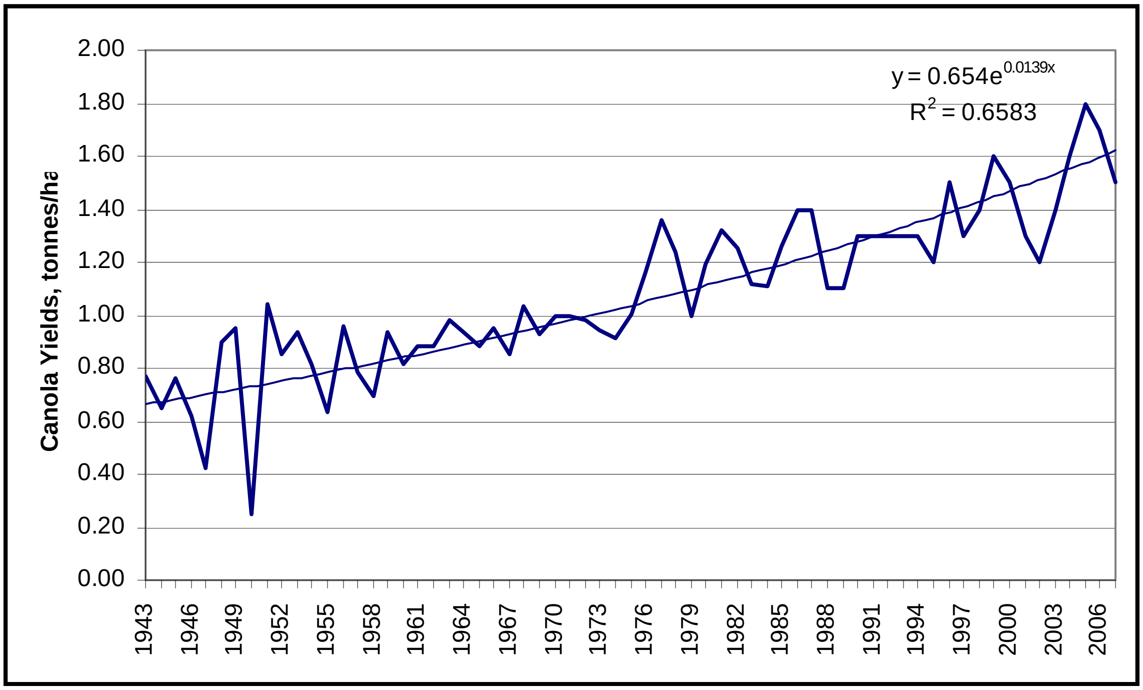
Canola seeds produced in Canada are both crushed domestically and exported. Historically about two thirds of the crop has been exported and one third has been crushed domestically.

2.1 Crop Yield

An important parameter in biofuels lifecycle assessment work is the yield of the crop. The yield can influence the inputs required, and the need for expanded acres.

Information on canola yield in Canada has been collected by Statistics Canada. The yield performance in Canada is shown in the following figure. The Statistics Canada yield data is included in GHGenius, and is used to continually update the yield for the year that is modelled. The yield in the model year 2010 is 1.55 tonnes/ha. Yields in recent years have been above the trend line. GHGenius minimizes the impact of yield on the calculations by using a tonne of production as the functional unit for most of the inputs rather than a unit of area.

Figure 2-3 Canola Yield Canada



2.2 FERTILIZER

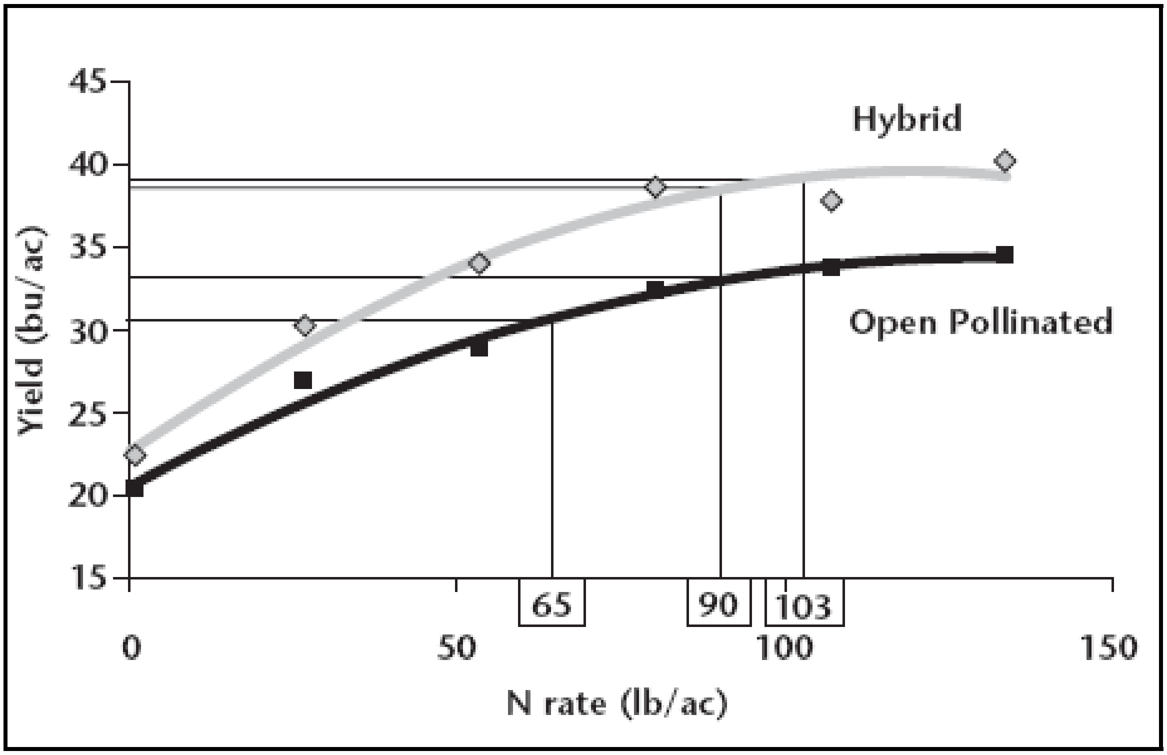
In Canada, a major survey of 650 western Canadian canola growers was undertaken in October/November 2000 (Canola Council, 2001). The study was designed to compare transgenic canola to conventional canola. About 90% of the canola produced in Canada is now genetically modified. The survey collected data on yield, fertilizer application and other production practices. The fertilizer results are summarized in the following table.

Table 2-2 Fertilizer Survey Data - 2000

		Transgenic	Conventional	Used for modelling
Yield	Tonnes/acre	0.663	0.602	
Seeds	kg/tonne	4.0	4.6	4.0
N	kg/tonne	48.7	53.5	49.0
P_2O_5	kg/tonne	17.1	19.0	17.1
K_2O	kg/tonne	4.0	3.7	4.0
S	kg/tonne	8.4	8.9	8.4

The higher nitrogen utilization efficiency of hybrid seeds shown above has been documented in other research trials (Canola Council, 2006). This is shown in the following figure.

Figure 2-4 Yield Response to Nitrogen



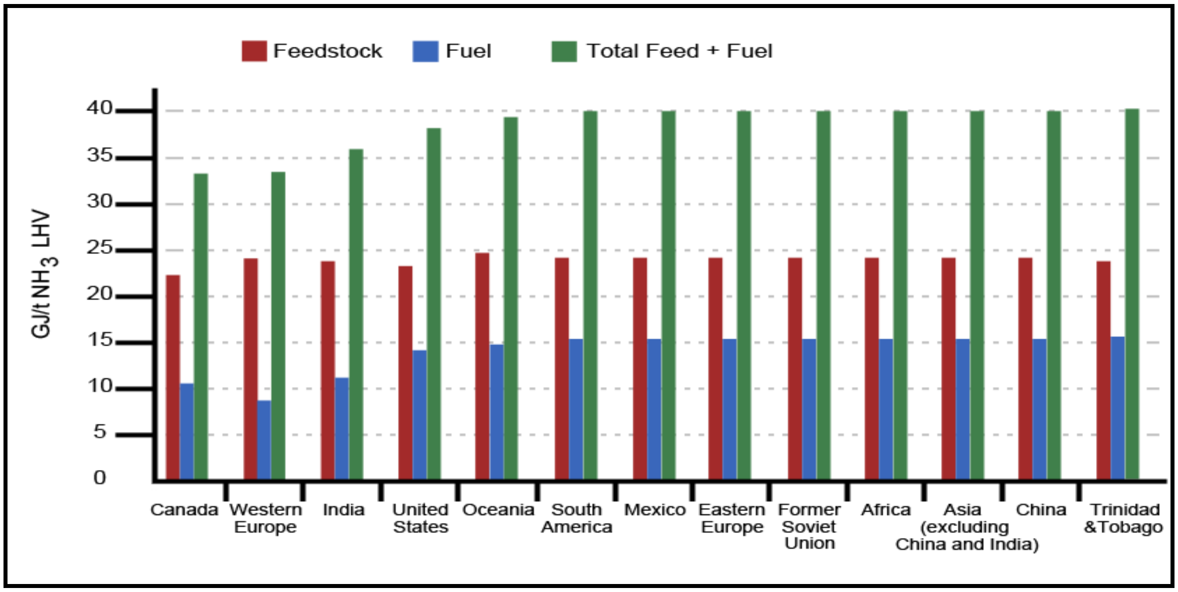
The types of nitrogen fertilizer used in the three prairie provinces in the period July 2007 to June 2008 is summarized in the following table (CFI, 2009). This data is important because the energy requirements and emissions intensity of each type of nitrogen fertilizer are quite different. For example, in Europe, ammonium nitrate (AN) and calcium ammonium nitrate are the dominant types of nitrogen fertilizer and their production GHG emission intensity is about double that of urea (Brentrup, 2008). The low rate of use AN and UAN fertilizer in western Canada reduces the GHG emissions of canola production compared to rapeseed production in Europe.

Table 2-3 Nitrogen Fertilizer Use

	Nitrogen Content	1,000 tonnes	Nitrogen in fertilizer	% by Nitrogen
Ammonia	0.82	479	393	27.9%
Urea	0.46	1,664	765	54.3%
Ammonium Nitrate	0.34	0	0	0.0%
Ammonium Sulphate	0.20	507	101	7.2%
UAN	0.28	532	149	10.6%
Total		3,182	1,409	100.0%

The Canadian nitrogen fertilizer industry is the most efficient in the world as shown in the following figure from an NRCan report (2007) that benchmarked the performance of the Canadian ammonia industry.

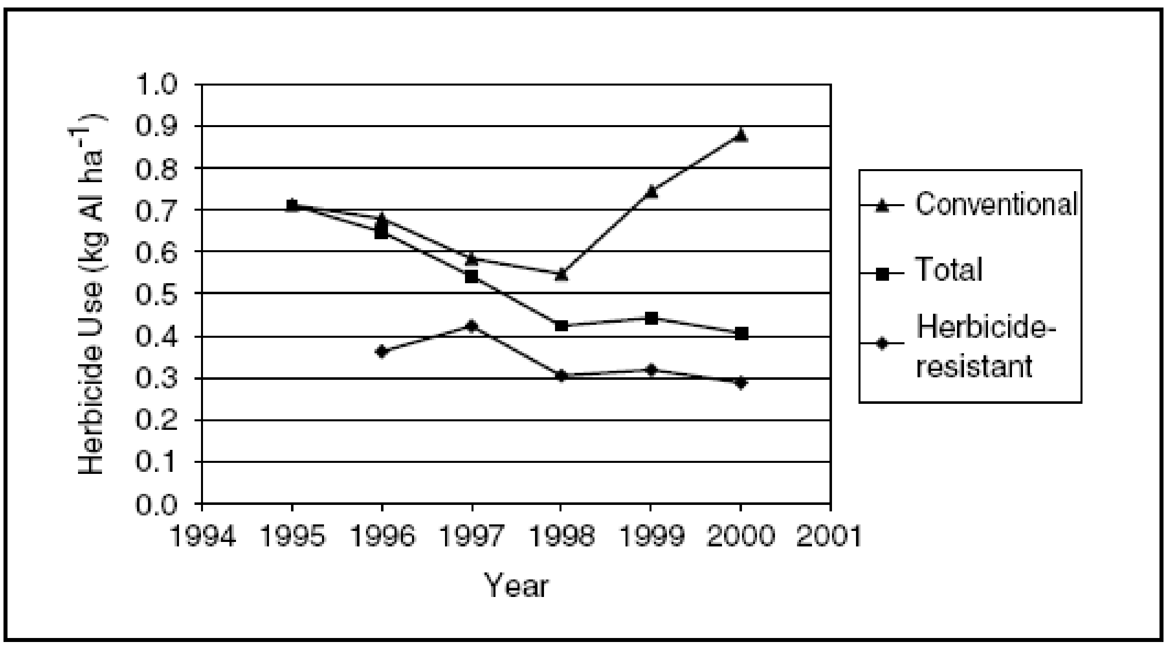
Figure 2-5 Regional Ammonia Plant Energy Efficiency



2.3 Agricultural Chemicals

Herbicide use for canola in Canada was analyzed by Brimmer et al (2005). It was found that the active ingredient application rate was declining and it varied between conventional and genetically modified seeds. A summary figure from that publication is shown in the following figure. The application rate was 0.3 litres a.i./hectare for the genetically modified crop and 0.9 l a.i./ha for the conventional seed. The default value in GHGenius is a conservative 0.8 kg a.i./tonne of canola produced.

Figure 2-6 Herbicide Use Canola 1995-2000



Lime is rarely used in western Canada due to the alkaline nature of most of the soils. No data is available for lime use for canola production but the total area that is limed in each province is available in the 2006 Census of Agriculture (Statistics Canada). A comparison of area prepared for seed to area limed is shown in the following table. No lime is assumed for canola production.

Table 2-4 Lime Area in Western Canada

	Seeded Area	Limed Area	% Limed Area
	hectares		
Manitoba	3,890,618	17,883	0.46
Saskatchewan	13,348,192	54,265	0.41
Alberta	7,578,201	12,117	0.16
Total	24,817,011	84,265	0.34

2.4 DIRECT ENERGY

The energy consumption value for canola in GHGenius has always been conservative.

Agriculture and Agri-Food Canada (2000) did a significant amount of analysis on the opportunities to reduce energy use in agriculture throughout the 1990s. Crop inputs, field operations (use of farm machinery) and yield data from field experiments conducted by AAFC Research Centres and the University of Manitoba were used for the micro-level analysis (Agriculture and Agri-Food Canada 1999). Several sites and four soil zones were used in the micro-level analysis:

- Swift Current, SK for the Brown soil zone
- Lethbridge, AB and Scott, SK for the Dark Brown soil zone
- Melfort, SK, Indian Head, SK and Glenlea, MB for the Black soil zone
- Tisdale, SK and Rycroft, AB for the Gray soil zone.

The micro-level data were scaled to the farm level using representative farms typical of the soil zones within each province. This scaled data was obtained for canola from the original researchers (Nagy, 2010). The field energy data was extracted from the information and the summary is presented in the following table. All of the data was collected before the development of transgenic canola. The benefits of no till practices are much lower in this data set than in most other descriptions of the benefits of no-till.

Table 2-5 Field Energy Requirements Canola

	Percentage of Canola Production	Full Tillage	No Tillage
		L diesel fuel equivalent/ha	
Manitoba	20%	43.0	37.1
Saskatchewan	45%	39.8	34.8
Alberta	25%	40.4	35.1
Weighted Average		36.6	31.9

The GHGenius fuel is input on the basis of fuel/tonne produced and not per hectare. Using 1994 as the base year, and 35 l/ha as an average of the fuel consumed the default input value is 28.2 l/tonne.

2.5 AGRONOMIC PRACTICES

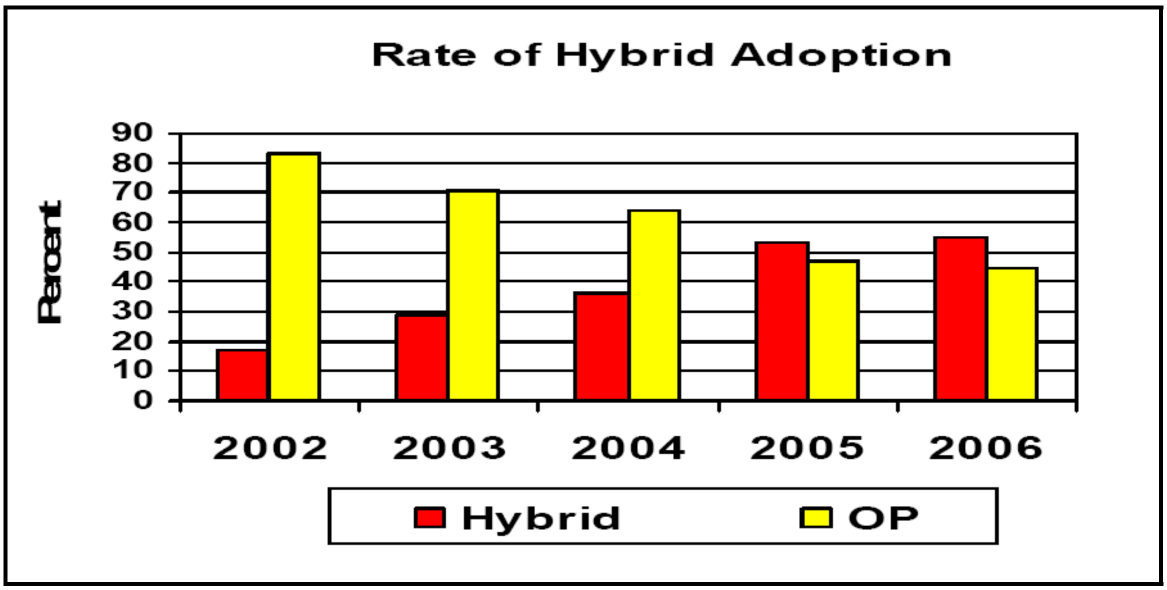
The specific agronomic practices employed by feedstock producers can have a significant impact on the GHG emissions resulting from the growing of feedstock. Some of the primary practices are discussed below.

2.5.1 Varieties

The varieties of seed planted can have a significant impact on crop yield, energy requirements and other practices. One of the primary drivers of increased canola production in the past decade has been the introduction of hybrid varieties. The rate of hybrid adoption in 2009 was estimated at 85%.

Hybrids have higher yields than open pollinated varieties and the adoption of hybrids is one of the reasons for the rapid increase in yields in the past decade. Hybrids are not necessarily transgenic varieties.

Figure 2-7 Canadian Hybrid Varieties Adoption



In Canada, more than 90% of the canola crop is now transgenic including varieties with herbicide resistance and hybrids.

2.5.2 N_2O Emissions

A significant portion of the GHG emissions associated with agriculture is related to the release of N_2O resulting from the breakdown of nitrogen fertilizers and crop residues.

Environment Canada and Agriculture Canada have developed a Tier 2 country-specific methodology to estimate N_2O emissions from nitrogen fertilizer application on agricultural soils, which takes into account local climate regimes and topographic conditions. Rochette et al (2008, 2008b) have presented this methodology and have scaled up the results to provide provincial or regional as well as national averages.

The direct N_2O factors developed by Rochette and the weighted average for the three regions of Canada in GHGenius are summarized in the following table. These factors were calculated for every year between 1990 and 2005 and the minimum, maximum and mean values are presented. The emissions can change from year to year, based on precipitation and other factors.

Table 2-6 Tier 2 N_2O Emission Factors for Canada

	Minimum	Maximum	Average
	Kg N_2O-N/kgN applied		
Atlantic	0.0128	0.0168	0.0161
Quebec	0.0147	0.0167	0.0160
Ontario	0.0098	0.0166	0.0139
Manitoba	0.0065	0.0142	0.0105
Saskatchewan	0.0021	0.0101	0.0067
Alberta	0.0045	0.0099	0.0075
BC	0.0047	0.0113	0.0081
Canada	0.0076	0.0120	0.0100
Canada East	0.0128	0.0168	0.0161
Canada Central	0.0117	0.0166	0.0147
Canada West	0.0037	0.0106	0.0076

Note that the average value for Canada is 0.010, the same value as the Tier 1 IPCC emission factor. However there is a wide variation between regions. One of the implications of this is that some crops, such as canola, tend to be grown in just certain parts of the country so having regional emission factors also leads to different emission factors for different feedstocks. The appropriate N_2O emission factor to use for Canadian canola is therefore 0.76% of nitrogen applied and nitrogen in the crop residue rather than the IPCC Tier 1 value of 1.0%.

2.5.3 Tillage Practices

Western Canada is a leading adopter of conservation and zero tillage practices. The data from the 2006 Census of Agriculture is shown in the following table. Conservation and no tillage rates are likely now higher than they were in 2005.

Table 2-7 Tillage Practices in Western Canada

	Seeded Area	Full Tillage	Conservation Tillage	No Tillage
	hectares			
Manitoba	3,890,618	1,689,335	1,371,380	829,903
Saskatchewan	13,348,192	2,443,085	2,876,161	8,028,946
Alberta	7,578,201	1,877,391	2,098,535	3,622,274
Total	24,817,011	6,009,811	6,346,076	12,481,123
% of seeded acres		24.2	25.6	50.3

In western Canada, the higher percentage of conservation and no till will have a positive impact on fuel consumption, soil carbon, and on N_2O emissions. It will be assumed in the model that 75% of the canola is produced by either no till or conservation tillage.

Environment Canada, in the National Inventory Report, has complied a list of generalized values for estimating the rate of change of soil organic carbon in the different regions of the country and assuming different changes in practices. These are summarized in the following table.

Table 2-8 Rate of Change of Soil Carbon

	Atlantic	Central	Parkland	Semi-arid Prairies	West
	kg C/ha/year				
Intensive till to no-till	60	100	140	100	50
Intensive till to reduced till	50	40	50	40	0
Reduced till to no till	0	60	70	50	40
Decrease fallow	300	300	300	300	300
Increase perennial	770	740	550	560	460

In Table 2-7, the assumptions regarding the adoption of no-till or reduced till agriculture for canola in GHGenius were identified. With these values and those from Table 2-8 the default values for the rate of change of soil organic carbon (SOC) for canola has been estimated as a soil carbon increase of 48.5 kg C/ha/year. This is conservative, as it does not factor in any reduced summerfallow in the estimate.

2.5.4 Irrigation

Very little land in western Canada is irrigated. The Canola survey undertaken in 2000 found that only seven of the more than 600 participants in the survey practiced irrigation. This is generally consistent with the data in the 2006 Census of Agriculture which reports that 2.5% of western Canadian land is irrigated, with the majority of that being in southern Alberta and outside of the normal growing area for canola.

Irrigation has a negative impact on the energy consumption and N_2O emissions but a positive impact on the crop yield. Since so little canola is grown under irrigation no real data is available on the impacts. It is assumed that no irrigation is used in the model.

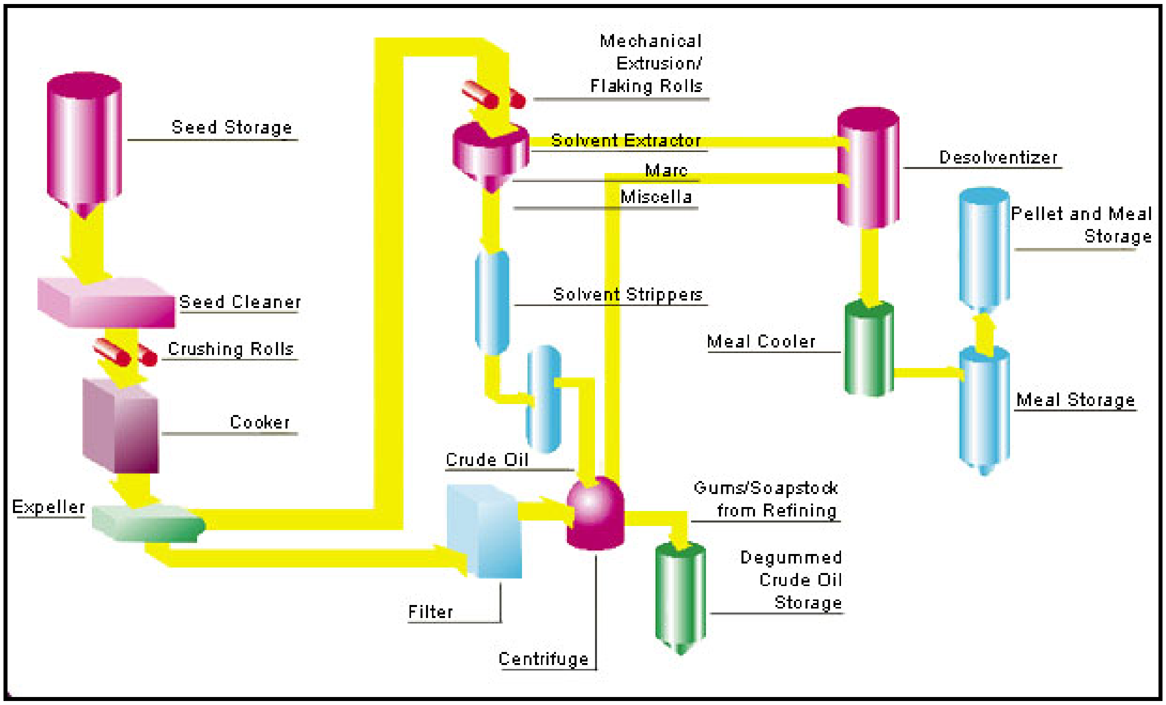
2.6 TRANSPORTATION

The canola seeds are moved from the farm to the crushing facilities by truck. Each facility will have slightly different trucking distances depending on the facility size and the density of canola fields in the region. An average trucking distance of 100 km is used for this modelling work.

3. CANOLA CRUSHING

Canola seed is traditionally crushed and solvent extracted in order to separate the oil from the meal. The process usually includes seed cleaning, seed pre-conditioning and flaking, seed cooking, pressing the flake to mechanically remove a portion of the oil, solvent extraction of the press-cake to remove the remainder of the oil, and desolventizing and toasting of the meal. Meal quality is influenced by several variables during the process, especially temperature. The basic process is shown in the following figure.

Figure 3-1 Canola Crushing Process



The process has been described as follows (Canola Council):

> *Canola seed is graded according to strict grading standards established by the Canadian Grain Commission. These include specifications for maximum moisture content, seed damage and chlorophyll level. The seed delivered to the crushing plant contains dockage materials, which are removed by cleaning operations prior to processing.*
>
> *Many crushing plants in colder climates preheat the seed to approximately 35°C through grain dryers in order to prevent shattering which may occur when cold seed from storage enters the flaking unit. The cleaned seed is first flaked by roller mills set for a narrow clearance to physically rupture the seed coat. The objective here is to rupture as many cell walls as possible without damaging the quality of the oil. The thickness of the flake is important, with an optimum of between 0.3 to 0.38 mm. Flakes thinner than 0.2 mm are very fragile while flakes thicker than 0.4 mm result in lower oil yield.*
>
> *Flakes are cooked/conditioned by passing them through a series of steam-heated drum or stack-type cookers. Cooking serves to thermally rupture oil cells, which have*

survived flaking, reduce oil viscosity and thereby promote coalescing of oil droplets, increase the diffusion rate of prepared oil cake, and denature hydrolytic enzymes. Cooking also adjusts the moisture of the flakes, which is important in the success of subsequent prepressing operations. At the start of cooking, the temperature is rapidly increased to 80-90°C. The rapid heating serves to inactivate the myrosinase enzyme present in canola. This enzyme can hydrolyze the small amounts of glucosinolates present in canola and will produce undesirable breakdown products which affect both oil and meal quality.

The cooking cycle usually lasts 15 to 20 minutes and the temperatures usually range between 80 and 105°C, with an optimum of about 88°C. In some countries, especially China, cooking temperatures of up to 120°C have been traditionally used when processing high glucosinolate rapeseed to volatize some of the sulphur compounds which can cause odours in the oil. However, these high temperatures can negatively affect meal protein quality.

The cooked canola seed flakes are then pressed in a series of low pressure continuous screw presses or expellers. These units consist of a rotating screw shaft within a cylindrical barrel, which consists of flat steel bars set edgewise around the periphery and spaced to allow the oil to flow between the bars while the cake is contained within the barrel. The rotating shaft presses the cake against an adjustable choke, which partially constricts the discharge of the cake from the end of the barrel. This action removes most of the oil while avoiding excessive pressure and temperature. The objective of pressing is to remove as much oil as possible, usually between 60 and 70% of the seed oil content, while maximizing the output of the expellers and solvent extractor, with the production of acceptable quality presscake.

Since the pressing is not able to remove all of the oil from the canola seed, the presscake is solvent extracted to remove the remaining oil. The cake from the expellers, containing between 14 and 20% oil, is sometimes broken into uniform pieces prior to solvent extraction. In solvent extraction, they use a hexane specially refined for use in the vegetable oil industry. Various mechanical designs of solvent extractors have been developed for moving the cake and the miscella (solvent plus oil) in opposite directions to effect a continuous counter current extraction. Basket and continuous loop type extractors are commonly used for canola. The principles are the same - the cake is deposited in the extractor, which is then flooded with solvent or miscella. A series of pumps spray the miscella over the presscake with each stage using a successively "leaner" miscella, thereby containing a higher ratio of solvent in proportion to the oil. The solvent percolates by gravity through the cake bed, diffusing into and saturating the cake fragments. The marc (hexane saturated meal) that leaves the solvent extractor, after a fresh solvent wash, contains less than 1% oil.

The solvent is removed from the marc in a desolventizer-toaster. In a series of compartments or kettles within the desolventizer, the majority of the solvent is flashed from the meal by injection of live steam. The final stripping and drying of the meal is accomplished in the subsequent compartments heated to between 103 and 107°C. The total time spent in the desolventizer-toaster is approximately 20 minutes. The meal emerges free of solvent. It contains about 1% residual oil and 15 to 18% moisture. After drying to 8 to 10% moisture and cooling, the meal is often granulated to a uniform consistency and then is either pelleted or sent directly as a mash to storage.

3.1 OIL EXTRACTION

A survey of the canola crushing plants in North America was recently undertaken by Canadian Oilseed Processors Association for the Canola Council in support of the data supplied to the EPA for their RFS2 process. A total of 10 plants in Canada and the United States participated in the survey. All of the plants used natural gas as their source of thermal energy. To the extent possible, the plants normalized their energy requirements to produce the quality of canola oil required for biodiesel production as opposed to the quality used for human food applications. The results from the survey are summarized in the following table.

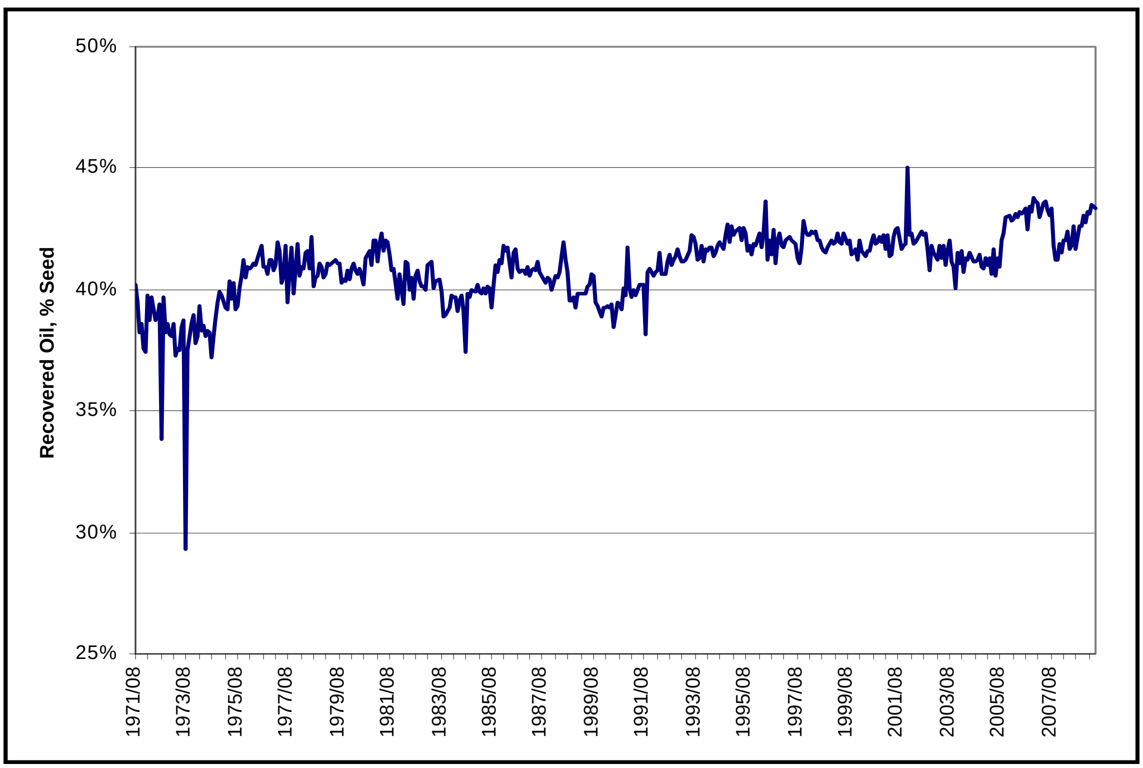
Table 3-1 Canola Crushing Energy Requirements

	Per tonne of Canola crushed	Per tonne of Oil produced
Electricity Purchased, kWh	49	114.5
Natural Gas Purchased, GJ	1.0	2.34
Total Energy, GJ	1.18	2.75

3.1.1 Crushing Yields

The oil content in the seed is important, but ultimately for a biodiesel LCA, it is the oil that is extracted from the seed that is needed for the analysis. This information is reported monthly by Statistics Canada and is shown in the following figure. This figure has generally increased over time and has averaged 42.8% over the past three years. This oil extraction rate is 2.25 times that of soybeans.

Figure 3-2 Oil Extraction Rates – Canadian Canola Crushers



The specific gravity of the canola oil is 0.914 - 0.917 g/litre. The kg of seed required to produce a litre of canola oil is therefore 2.15 kg.

3.2 Co-Products

One of the important factors in performing life cycle assessments is the proper treatment of co-products. There are several approaches that have been used. These include a mass or volume allocation, an energy consumed allocation, a financial or economic allocation, or the displacement method.

The displacement method is now generally preferred and most studies attempt to use the displacement method to calculate the co-product credits. Using this method, the greenhouse gas or energy credit for a co-product is equivalent to the greenhouse gas or energy that was produced or used to manufacture the displaced product. To properly implement this approach, it is necessary to know:

- What products are being displaced by the new co-product,
- The displacement ratios for the co-product, and
- The emissions and energy use associated with the displaced product.

These are not always simple tasks.

It is now generally accepted that the preferable method of determining co-product credits where some allocation is needed is to perform a system expansion. This process is recommended by Weidema (1999) and by Kim and Dale (2002). Weidema used the method for determining the value of value of rapeseed meal in the biodiesel production process and Kim and Dale suggest a similar approach for the calculation of DDG credits. GHGenius was modified in 2002 to utilize this systems expansion approach to quantifying the displacement credits.

The method of system expansion has been explained by Weidema and is described below.

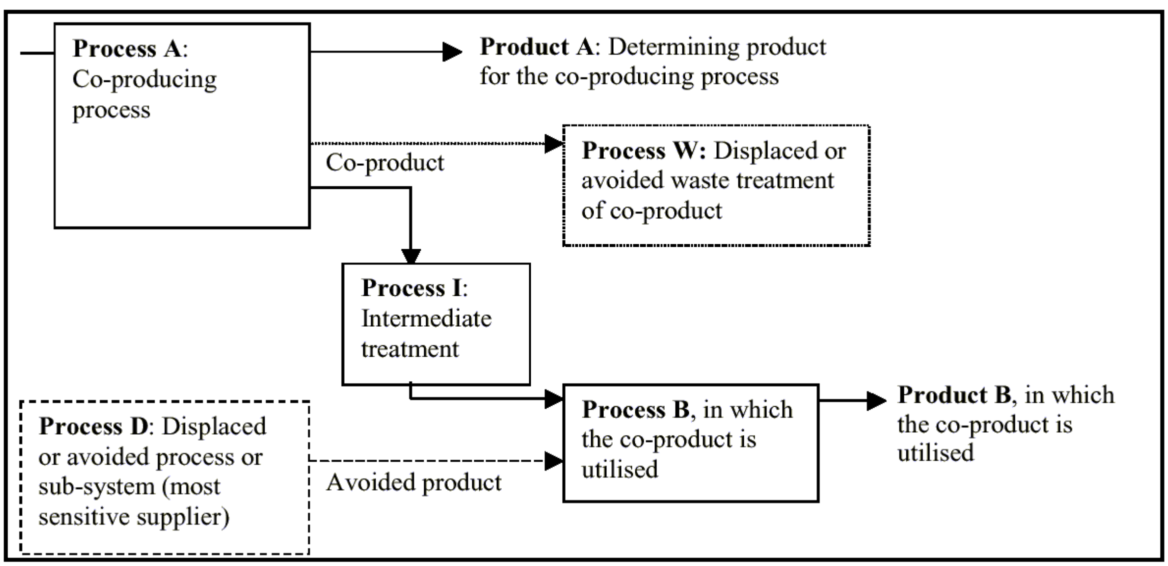
> *The production of most renewable materials involves co-products. Traditionally, the environmental impacts have been allocated between the different co-products according to a more or less arbitrary allocation ratio.*
>
> *The idea that co-product allocation can be avoided by system expansion has been put forward by Tillman et al. (1991) in respect to waste incineration, and more generally by Heintz & Baisnee (1992). It was given a prominent place in the procedure of ISO 14041, where it reads: "Step 1: Wherever possible, allocation should be avoided by: 1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes; 2) expanding the product system to include the additional functions related to the co-products…"*
>
> *Although avoiding allocation is seen as the preferable option, it has been the general belief that avoiding allocation through system expansion was not always possible for co-products from renewable material production, since the substitutions involved were believed to be too complex, difficult to determine, and sometimes involving endless regressions.*
>
> *However, these perceived problems can be solved by adapting a stringent procedure for identifying the affected processes, earlier presented in Weidema et al. (1999), leading to the conclusion that allocation can (and shall) always be avoided in prospective life cycle assessments.*

The following figure shows how the co-producing process has one determining product (product A), i.e. the product that determines the production volume of that process. This is not necessarily the product used in the specific life cycle study. In the figure, also just one co-product is shown, but in practice there may be any number of co-products, while at any given moment there can be only one determining product.

That a product is determining the production volume of a process, is the same as saying that this process will be affected by a change in demand for this product. How to identify the processes affected by a change in demand (which is also the processes to be included in a prospective life cycle study) has been shown in Weidema et al. (1999a).

To say that there can be only one determining product at any given moment, is not the same as saying that the other co-products are not of importance. That the co-products can obtain a certain price on the market may well be a precondition for the process to expand its production volume. But when this precondition is fulfilled, it is still only a change in demand for the determining product that will be able to affect the production volume of the process. For example, out of the total income of growing sunflowers, 63% comes from selling the oil and 37% from selling the protein-containing pressing cake as animal fodder. Thus, it is unlikely that more sunflowers would be grown if it were not possible to sell additional sunflower pressing cakes. Yet, it is not the demand for fodder cakes that determines the production of sunflowers, since an increased demand for protein can be met at a lower cost by producing soybeans. Thus, the determining product for sunflowers is the sunflower oil, which is in demand for its particular composition of fatty acids.

Figure 3-3 Model for Describing System Expansion



Performing a system expansion in relation to co-products is exactly to identify how the production volume of the processes in the above figure, will be affected by a change in demand for the product that is used by the life cycle study in question (both when this is the determining product for the co-producing process (A) and when it is the product in which the co-product is utilized (B)).

Weidema has recently (2001) determined that three simple rules can be applied to assist with the process and the new rules are shown below.

> *1) The co-producing process (and its exchanges) shall be ascribed fully (100%) to the determining co-product for this process (product A),*
>
> *2) Under the conditions that the dependent co-products are fully utilized in other processes, product A shall be credited for the processes that are displaced by the dependent co-products. The intermediate treatment shall be ascribed to product A. If there are differences between a dependent co-product and the product it displaces, and if these differences cause any changes in the further life cycles in which the co-product is used, these changes shall likewise be ascribed to product* A.
>
> *3) When a dependent co-product is not utilized fully (i.e., when part of it must be regarded as a waste), the intermediate treatment shall be ascribed to product B, while product B is credited for the avoided waste treatment of the co-product.*

3.2.1 Protein Meals

Protein meals make an important contribution to livestock diets. In most cases, protein meals are co-produced along with an oil product. In the following table, the world production of protein meals is shown (USDA, 2010).

Table 3-2 World Protein Meal Production

Production	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010
				Prelim	Forecast
	Million tonnes				
Soybean	145.8	153.9	158.4	151.7	161.9
Rapeseed	26.5	25.9	27.6	30.8	33.6
Cottonseed	14.6	15.3	15.7	14.4	14.0
Sunflowerseed	11.5	11.5	10.6	12.8	12.3
Palm Kernel	5.3	5.3	5.9	6.2	6.5
Peanut	6.0	5.5	5.9	6.1	5.6
Fish	5.0	5.1	5.2	5.1	4.8
Copra	1.8	1.7	1.9	1.9	1.9
Total	216.4	224.2	231.2	228.9	240.6

Soybean meal dominates the protein meal sector with about 67% of the total production and the next largest component is rapeseed or canola meal with 14%.

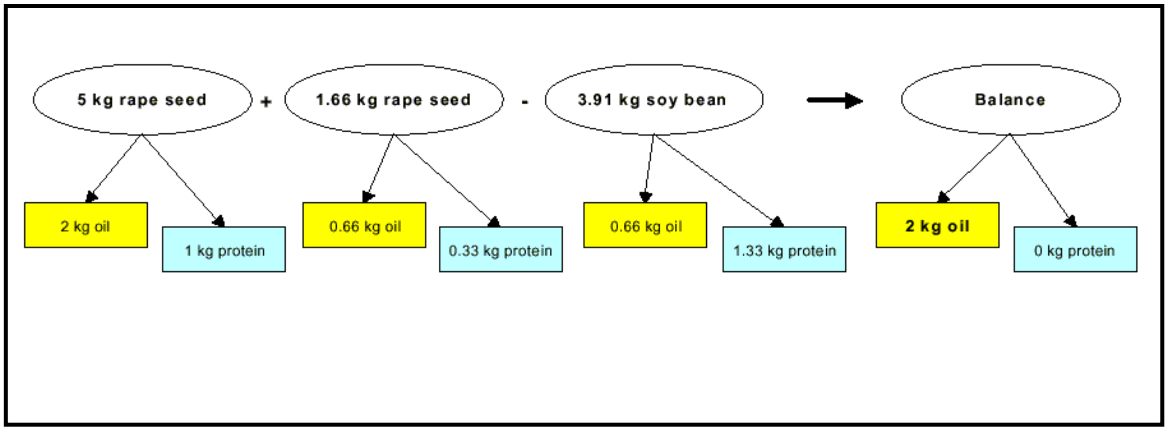
In order to determine how much of the energy and emissions associated with the production and crushing of the oilseeds should be attributed to the oil and how much such be attributed to the protein a systems expansion can be performed. The objective of this is to identify a combination of production systems that only has a net production of one of the products, either oil or protein. Weidema performs this system expansion between rapeseed (Canola) and soybeans based on the following assumptions:

- Soybean meal is the marginal protein and rapeseed oil is the marginal oil on the market.
- Rapeseed contains 40% oil and 20% protein in the dry matter and soybeans contains 17% oil and 34% protein.

- The protein and oil from both products are substitutable in the marginal applications.

These assumptions are reasonable considering the supply and demand of protein and oils in the world. The system expansion is shown in the following figure.

Figure 3-4 Protein Meal System Expansion



In this case, 2kg of rape oil is the net production from the production of 6.66 kg of rapeseed less 3.91 kg of soybeans. An alternative expansion that could be undertaken would find that the production of 5 kg of soybeans less 2.15 kg of rapeseed would yield a net 1.27 kg of protein. Both approaches will produce equivalent results for the oil and the meal. The only problem with this method is that the energy requirements for crushing of the beans are not included.

Kim and Dale assume that product systems with an equivalent function have the same environmental burdens. Where Kim and Dale take the system expansion through corn wet milling and urea production the system could also be expanded to canola production and milling. This is a slight variation on the method used by Weidema so that the energy used for the milling process is also accounted for.

Soybean meal is a co-product of the soybean milling process. The environmental burdens associated with the soybean milling process, E soybean milling, becomes

E soybean milling = a soyoil * E soyoil + a soybean meal * E soybean meal (eq 1)

Where

E soybean milling = Environmental burdens associated with milling soybeans, includes growing and crushing beans. This is calculated by GHGenius.

E soybean oil = Environmental burdens associated with producing one kg of soybean oil.

a soybean oil = Amount of soybean oil produced in the soybean milling process (0.18)

E soybean meal= Environmental burdens associated with producing one kg of soybean meal.

a soybean meal = Amount of soybean meal produced in the soybean milling process (0.82).

Considering the canola system, the similar Canola equation becomes

E Canola milling = a Canola oil * E Canola oil + a Canola meal * E Canola meal (eq 2)

Where

E Canola milling = Environmental burdens associated with milling canola, includes growing and crushing beans.

E Canola oil = Environmental burdens associated with producing one kg of Canola oil, includes growing and crushing beans. This is calculated by GHGenius.

a Canola oil = Amount of Canola oil produced in the Canola milling process (0.40)

E Canola meal= Environmental burdens associated with producing one kg of canola meal.

a Canola meal = Amount of Canola meal produced in the Canola milling process (0.60).

Canola oil and soy oil are substitutable for each other in almost all applications so the displacement ratio between these two products is;

E Canola oil = E soybean oil. (eq 3)

Canola meal and soybean meal are both used in animal feed rations as a source of protein but since soybean meal has a protein content of 48% and canola meal has a protein content of 36% more canola meal must be used to deliver the same amount of protein. The displacement ration between these two products is therefore;

1.33 E Canola meal = E soybean meal. (eq 4)

There are now four simultaneous equations and four unknowns so the system can be solved. The equations are:

1. E soybean milling = 0.18 *E soyoil + 0.82 *E soybean meal.
2. E Canola milling = 0.40 *E Canola oil + 0.60 *E Canola meal
3. E soybean oil = E Canola oil
4. E soybean meal = 1.33*E Canola meal

3.2.1.1 Canola Meal

The credits for Canola meal can be obtained from the above set of equations. Since the Canola meal displacement ratio is 1.33 times that for soybean meal, the following equation can be derived from the soybean meal equation.

E Canola meal = 1.21 E soybean milling – 0.55 E Canola milling.

This equation has been programmed into the model.

The system could just have easily been solved for canola oil and since soybean oil and canola oil are direct replacements, that would have resulted in the following equation.

E canola oil = 3.33 E Canola milling –1.85 E soybean milling.

Since the proportion of oil and meal for soybeans and canola is continually changing, GHGenius uses the actual oil contents that the user inputs into the model in the above set of equations, in this way the system expansion is continually updated with the latest information.

3.3 TRANSPORTATION SCENARIO

Biodiesel plants could be co-located at the oilseed crusher or they could be stand-alone facilities at a different location. There are examples of both business models in North America.

For this work, it will be assumed that the biodiesel facility is located 50 km from the crushing facility and that the oil is transported by truck between the two facilities.

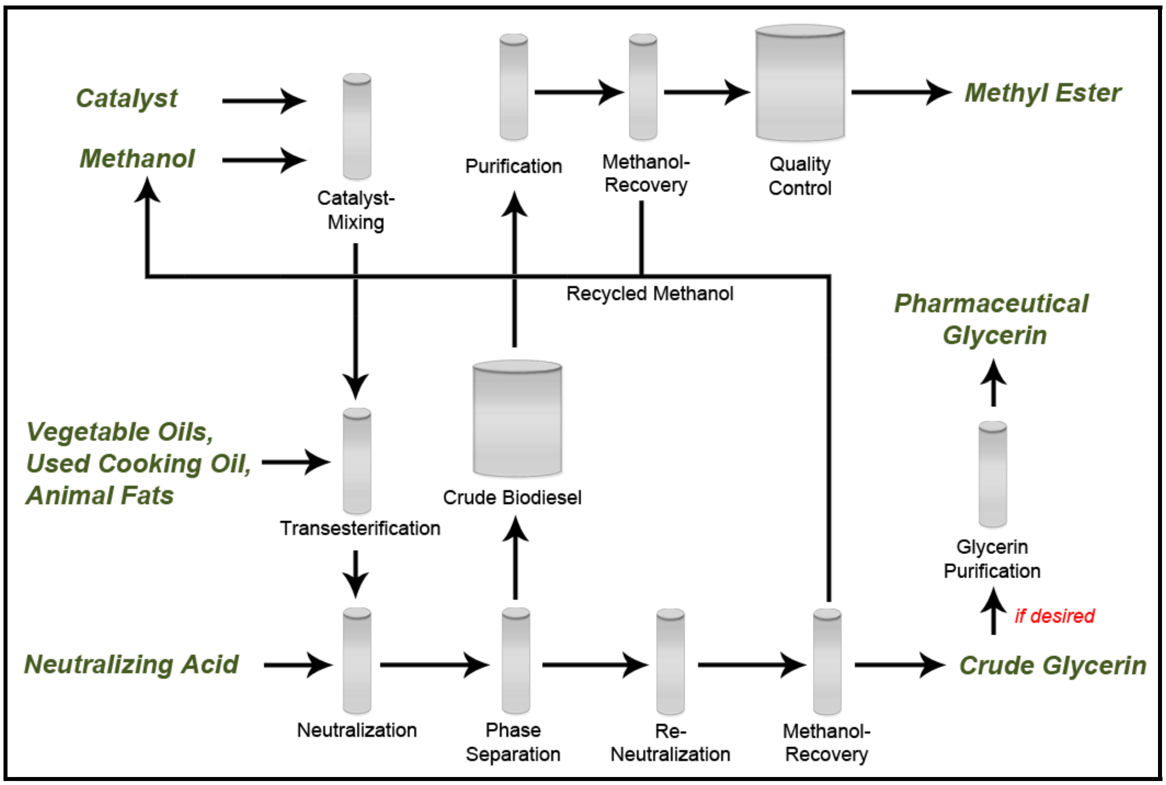
4. BIODIESEL MANUFACTURING

The production of biodiesel, or methyl esters, is a well-known process. A fat or oil is reacted with methanol in the presence of a catalyst to produce esters or biodiesel. The methanol is charged in excess to assist in quick conversion and recovered for reuse. The catalyst is usually sodium or potassium hydroxide, which has already been mixed with the methanol.

The theoretical mass balance is such that 100 kilograms of oil or fat produces 100 kilograms of methyl ester. The density of the methyl ester is 0.888 kg/litre. Thus, 100 kilograms of oil produces 51 litres of methyl ester.

The general biodiesel production process, as described by the National Biodiesel Board (2002) shown in the following figure, consists of the following steps:

Figure 4-1 Biodiesel Production Process



Mixing of methanol and catalyst. The catalyst is typically sodium hydroxide (caustic soda). Dry caustic is dissolved in methanol by simple mixing. Care must be exercised to ensure the dry caustic (typically pellets or flakes) does not take on too much water in storage. This could cause the formation of large clumps, which are hard to dissolve. Water also has an adverse impact on downstream processing.

Reaction. The methanol/catalyst mix is then charged into a reactor, either continuously or batch, and the oil is added. The reaction mix is kept at approximately 65 °C for between 1 and 8 hours under vigorous agitation. Excess methanol is normally utilized to ensure total conversion of the fat/oil to esters. The catalyst will first react with any free fatty acids in the oil to form soap. There must be enough additional catalyst to catalyze the reaction, as well as to react with the free fatty acids. If the free fatty acid level is too high (above 0.5% to 1%), or if any water is present, the soap formed will begin to form emulsions with the methanol and oil, preventing the reaction from occurring. In some cases, the emulsion can be so strong it becomes unbreakable and forms a cottage cheese looking product. In this case, the product must be physically removed from the system and most likely scrapped. For these reasons, the incoming oil is treated to remove fatty acids and all feed streams are kept free of water.

Methanol removal. In some systems, the excess methanol is removed at this stage via a simple flash process or distillation. In other systems, the methanol is removed after the glycerine and esters have been separated. In either case, the methanol is recovered and reused using conventional equipment. Care must be taken to ensure no water accumulates in the recovered methanol stream.

Separation. Once the reaction is complete and the methanol has been removed, two major products exist: glycerine and methyl esters. Due to the density difference between glycerine (1.0 kg/l) and methyl esters (0.88 kg/l) the two are allowed to gravity separate and glycerine is simply drawn off the bottom. In some cases, a centrifuge is used to separate the two. Any rag layer is either recycled or sent to sewage treatment.

Glycerine neutralization. The resulting glycerine contains unused catalyst and soaps, which are neutralized with an acid (usually hydrochloric or phosphoric) to form salts and sent to storage as crude glycerine. In some cases (for example, if potassium hydroxide is used as the catalyst rather than sodium hydroxide and phosphoric acid is used as the quench acid), the salt is recovered for fertilizer. In most cases, however, a caustic soda catalyst and hydrochloric acid are used, creating sodium chloride, which is simply left in the glycerine. The glycerine is typically 80-88% pure and ready to be sold as crude glycerine.

Methyl Ester Wash. Once separated from the glycerine, the methyl esters are washed gently with warm water to remove residual catalyst or soaps, dried, and sent to storage. Some processes can eliminate this washing step through the use of clean feedstock. It is typically 98% ester and ready to be sold as fuel. In some cases, the esters are distilled under vacuum to achieve even higher purity. The washing step can be greatly affected by the free fatty acid level of the feed, since all the free fatty acids form soaps in the reaction. If the soap content in the washing step is too high, a water wash will entrain the esters and yields will be diminished, sometimes severely.

There are a number of variations of the basic process for the production of biodiesel becoming available. Some feedstocks, such as those with a high free fatty acid content, require pretreatment to deal with the free fatty acids otherwise soaps are formed in the traditional esterification process.

4.1 BIODIESEL YIELD

In 2009, the National Biodiesel Board (NBB) conducted the most comprehensive survey of the actual energy used by commercial biodiesel production plants in the world and released the data for public use.

This survey found that for biodiesel produced from virgin vegetable oils 0.88 kg of oil was used to produce one litre of biodiesel.

4.2 ENERGY CONSUMPTION

The energy consumption data for virgin vegetable oils from the NBB survey is summarized in the following table.

Table 4-1 Biodiesel Energy Use

	Units	NBB
Electricity	kWh/litre	0.032
Natural Gas	L NG/litre biodiesel	20.2

4.3 Other Inputs

There are a number of chemicals that are used in the production in addition to the methanol that has been identified above. The NBB survey results for chemical usage are shown in the following table.

Table 4-2 NBB Chemical Inputs

	Units	Value
Methanol	litres/litre biodiesel	0.102
Sodium Methylate	kg/litre biodiesel	0.021
Sodium Hydroxide	kg/litre biodiesel	0.001
Hydrochloric Acid	kg/litre biodiesel	0.039
Phosphoric Acid	kg/litre biodiesel	0.001
Citric Acid	kg/litre biodiesel	0.001

Not all of these chemicals are included in GHGenius. The methylate is proportioned between methanol and sodium hydroxide, sulphuric acid is substituted for citric and hydrochloric acid and phosphate nutrients are substituted for phosphoric acid. The revised inputs are summarized in the following table.

Table 4-3 GHGenius Chemical Inputs

	Units	Value
Methanol	litres/litre biodiesel	0.122
Sodium Hydroxide	kg/litre biodiesel	0.005
Sulphuric Acid	kg/litre biodiesel	0.040
Phosphate nutrients	kg/litre biodiesel	0.001

4.4 Co-Products

The biodiesel production process produces crude glycerine and small amounts of fatty acids. The information from the NBB survey is shown in the following table. The fatty acids are treated as a waste in GHGenius.

Table 4-4 NBB Co-product Data

	Value
Glycerine, kg/litre	0.106
Fatty acids, kg/litre	0.002

4.5 TRANSPORTATION SCENARIO

The biodiesel must be transported from the biodiesel plant to the point that it is blended with petroleum fuels. In GHGenius, this distance depends on the region that is being modelled. Since we have set the model to use the Canada average values, and canola biodiesel is produced mostly in western Canada, the transportation distances are relatively high. The transportation assumptions are shown in the following table.

Table 4-5 Biodiesel Transportation

	Distance	Fraction by Mode
	km	
By Rail	1,970	0.63
Domestic water	0	0.00
International water	0	0.00
Pipeline, tram, conveyor	0	0.00
Truck	145	1.00

5. LIFECYCLE RESULTS

The primary drive for the production of biofuels in North America is their ability to displace petroleum and to reduce the GHG emissions associated with the transportation sector. The lifecycle results for these parameters are discussed below.

Lifecycle results should always be presented relative to a baseline system, in this case petroleum diesel fuel. The results that are presented here consider the Canadian average diesel fuel results.

5.1 ENERGY BALANCE

There are two different energy balance measures that are important for biofuels, the total energy balance and the fossil energy balance. Both of these are calculated in GHGenius. The energy balance is defined as the energy consumed per unit of energy delivered. It includes the full lifecycle energy consumption, e.g. the energy consumed in producing electricity or natural gas is considered.

In the following table, the total energy balance is presented for canola biodiesel and for petroleum diesel fuel. The energy balance for biodiesel is slightly better than it is for petroleum diesel.

Table 5-1 Total Energy Balance – Canola Biodiesel

Fuel	Hwy diesel	Biodiesel
Feedstock	Crude oil	Canola
	Joules consumed/Joule Delivered	
Fuel dispensing	0.0024	0.0027
Fuel distribution, storage	0.0069	0.0153
Fuel production	0.1168	0.1363
Feedstock transmission	0.0117	0.0126
Feedstock recovery	0.1182	0.0722
Ag. chemical manufacture	0.0000	0.1643
Co-product credits	-0.0011	-0.1779
Total	**0.2549**	**0.2255**
Net Energy Ratio (J delivered/J consumed)	**3.9231**	**4.4345**

Some biofuel systems can use a large amount of bioenergy in the production of the case so the fossil energy balance is sometimes used as a more appropriate measure of the energy balance. In this metric, only the fossil energy that is consumed in the production process is counted. The biodiesel production system is not one of the biofuels that uses a large amount of biofuels so the results shown in the following table are quite close to the total energy balance. The bio-diesel co-product glycerine has a significant amount of electricity that is displaced and when the fossil energy only is included, this co-product credit is lower.

Table 5-2 Fossil Energy Balance – Canola Biodiesel

Fuel	Hwy diesel	Biodiesel
Feedstock	Crude oil	Canola
	Joules consumed/Joule Delivered	
Fuel dispensing	0.0005	0.0006
Fuel distribution, storage	0.0056	0.0147
Fuel production	0.1097	0.1196
Feedstock transmission	0.0088	0.0124
Feedstock recovery	0.1057	0.0712
Ag. chemical manufacture	0.0000	0.1554
Co-product credits	-0.0009	-0.1196
Total	**0.2294**	**0.2543**
Net Energy Ratio (J delivered/J consumed)	**4.3595**	**3.9326**

5.2 Upstream Emissions

The GHG emissions for the production of the fuel can be informative, but in the case of biofuels these emissions do not provide the complete picture because by definition the biogenic CO_2 emissions are not counted for the production of biomass or a biofuel and thus the fossil fuel will have significantly higher emissions when the fuel is produced and burned compared to many biofuels.

Canola biodiesel, however, is one of the biofuels that have lower emissions for both the production and combustion stages compared to fossil fuels. The upstream emissions for canola biodiesel are compared to petroleum diesel in the following table.

Table 5-3 Upstream GHG Emissions Canola Biodiesel

Fuel	Hwy diesel	Biodiesel
Feedstock	Oil	Canola
	g CO_2eq/GJ (HHV)	
Fuel dispensing	114	131
Fuel distribution and storage	476	1,187
Fuel production	8,432	7,231
Feedstock transmission	905	976
Feedstock recovery	8,626	6,276
Land-use changes, cultivation	266	6,321
Fertilizer manufacture	0	10,116
Gas leaks and flares	1,855	0
CO_2, H_2S removed from NG	0	0
Emissions displaced	-230	-27,172
Total	20,444	5,065

5.3 Lifecycle Emissions

The full lifecycle emissions from the production and use of biodiesel include the benefit of the biogenic emissions. The results for the canola biodiesel (B100) are compared to those for petroleum diesel fuel in the following table. In both cases, it is assumed that the fuel is used in a large heavy-duty truck. The canola biodiesel reduces the GHG emissions by 92.5% without considering the emissions from the manufacture of the truck and by 90.1% if those emissions are included.

Table 5-4 Lifecycle GHG Emissions Canola Biodiesel

General fuel	Petrol diesel	Biodiesel
Fuel specification	0.0015% S	Canola B100
Feedstock	Crude oil	Canola
	g CO_2eq/km	
Vehicle operation	1,078.3	1,108.3
C in end-use fuel from CO_2 in air	0.0	-1,081.7
Net Vehicle Operation	1,078.3	26.7
Fuel dispensing	1.8	2.0
Fuel storage and distribution	7.3	18.2
Fuel production	129.4	111.0
Feedstock transport	13.9	15.0
Feedstock recovery	132.4	96.4
Land-use changes, cultivation	4.1	97.1
Fertilizer manufacture	0.0	155.3
Gas leaks and flares	28.5	0.0
CO_2, H_2S removed from NG	0.0	0.0
Emissions displaced by co-products	-3.5	-417.2
Sub total (fuel cycle)	1,392.0	104.4
% changes (fuel cycle)	--	-92.5
Vehicle assembly and transport	*5.5*	*5.5*
Materials in vehicles	*31.3*	*31.3*
Grand total	1,428.7	141.2
% changes (grand total)	--	-90.1

The GHG emission reduction can also be presented on the basis of the biodiesel produced and consumed. On this basis, the GHG emission reduction per litre of canola biodiesel produced and consumed amounts to 2.97 kg CO_2eq/litre of biodiesel.

In GHGenius, it is assumed that a unit of energy supplied by biodiesel displaces the same unit of energy of petroleum fuel. That is there is no energy efficiency improvement from the blend of biodiesel and petroleum diesel. Some fleet operators have claimed that there has been no impact on fleet fuel consumption for low-level biodiesel blends. For this to be true there would have to be some engine efficiency improvement from the use of low-level biodiesel blends. There is a lack of well controlled fleet or dynamometer fuel consumption data to include an improvement in engine efficiency in GHGenius at this time. If there were an improvement in engine efficiency, then the GHG emission reduction would be even greater than shown here.

6. Discussion and Conclusions

Canola biodiesel demonstrates very large GHG emission reductions in GHGenius. This is a function of a number of unique characteristics of the Canadian canola production situation and the modelling framework. The characteristics that lead to low GHG emissions for Canadian canola production include:

1. An efficient nitrogen fertilizer production industry in Canada with a low percentage of nitrate fertilizers produced and sold. This leads to a low GHG emission intensity for the nitrogen fertilizer used for canola production.
2. Dryland production of canola, which results in low N_2O emissions from the application of fertilizer and crop residues.
3. Alkaline soils, which do not require soil pH adjustment with lime.
4. Energy efficient production systems with a low diesel fuel requirement.
5. High adoption of low or no till agriculture resulting in an increase in soil carbon from the new modern management practices.

The impact of each of these issues is investigated in the following sections to show the sensitivity of the LCA results to the issues that are unique to western Canada.

6.1 Nitrogen Fertilizer

The Canadian nitrogen fertilizer industry is the most efficient in the world and produces mostly ammonia based fertilizers rather than nitrate fertilizers. Ammonia based fertilizers have lower GHG emissions.

GHGenius does not provide a credit for CO_2 consumed in urea production since almost all of this CO_2 is released during field application. The average carbon intensity of nitrogen fertilizer in GHGenius is 2.8 kg CO_2 eq/kg of N. In the European Union Life Cycle Assessment (LCA) models, the nitrogen fertilizer emission intensity that is used is 5.88 kg CO_2 eq/kg of N, 110% increase. A significant part of the higher emission rate is due to the high proportion of nitrate-based fertilizers used in Europe. Since no Canola is produced in Canada with ammonium nitrate fertilizer, the GHG emissions related to fertilizer production are much lower in Canada than they are in Europe.

The impact of increasing the emissions intensity of nitrogen fertilizer in GHGenius is shown in the following table. The emissions for canola biodiesel triple, with this higher emission factor.

Table 6-1 Impact of Canada vs. Europe N Fertilizer Emission Intensity on Canola Biodiesel Emissions

Fuel	Hwy diesel	Biodiesel	Biodiesel
Feedstock	Oil	Canola	Canola
Fertilizer emission intensity		Canada	Europe
	g CO_2eq/GJ (HHV)		
Fuel dispensing	114	131	131
Fuel distribution and storage	476	1,187	1,187
Fuel production	8,432	7,231	7,231
Feedstock transmission	905	976	976
Feedstock recovery	8,626	6,276	6,276
Land-use changes, cultivation	266	6,321	6,321
Fertilizer manufacture	0	10,116	18,626
Gas leaks and flares	1,855	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-230	-27,172	-24,706
Total	20,444	5,065	16,041

6.2 N_2O EMISSIONS

One of the other advantages of crop production in western Canada is the low N_2O emission factor. Most models use a factor of 1 or 1.25% for the N_2O emissions as a function of the nitrogen applied. As discussed previously the average value for western Canada is 0.76%. The cumulative impact of this change and the nitrogen fertilizer change is shown in the following table, the emissions are now four times higher than they are in the base GHGenius case.

Table 6-2 Impact of N_2O Emission Factor on Canola Biodiesel Emissions – Canada vs. Europe

Fuel	Hwy diesel	Biodiesel	Biodiesel
Feedstock	Oil	Canola	Canola
Location		Canada	Europe
			N_2O +Fert
	g CO_2eq/GJ (HHV)		
Fuel dispensing	114	131	131
Fuel distribution and storage	476	1,187	1,187
Fuel production	8,432	7,231	7,231
Feedstock transmission	905	976	976
Feedstock recovery	8,626	6,276	6,276
Land-use changes, cultivation	266	6,321	9,876
Fertilizer manufacture	0	10,116	18,626
Gas leaks and flares	1,855	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-230	-27,172	-23,582
Total	20,444	5,065	20,720

6.3 ALKALINE SOILS

The typical practice in Europe is to add lime to the soil to increase the soil pH and improve the yield. The EU default value for lime for rapeseed is 6.1 kg/tonne of rapeseed.

Table 6-3 Impact of Lime Use on Canola Biodiesel Emissions – Canada vs. Europe

Fuel	Hwy diesel	Biodiesel	Biodiesel
Feedstock	Oil	Canola	Canola
Location		Canada	Europe
			N_2O + Fert + Lime
	g CO_2eq/GJ (HHV)		
Fuel dispensing	114	131	131
Fuel distribution and storage	476	1,187	1,187
Fuel production	8,432	7,231	7,231
Feedstock transmission	905	976	976
Feedstock recovery	8,626	6,276	6,276
Land-use changes, cultivation	266	6,321	10,121
Fertilizer manufacture	0	10,116	18,795
Gas leaks and flares	1,855	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-230	-27,172	-23,451
Total	20,444	5,065	21,266

6.4 FIELD ENERGY

The European default value for diesel fuel consumption is 82.6 litres/ha. When this is presented on a per tonne produced basis, the value is 26.5 litres/tonne, essentially the same value used in GHGenius. Fuel consumption is much better correlated to field area rather than crop production, it is primarily a function of the number of passes that a tractor has to make over the field and not how much is produced. The cumulative impact of tripling fuel consumption is shown in the following table. This has a significant impact and it has also significantly reduced the value of the co-product credit due to the system expansion determination.

Table 6-4 Impact of Field Energy Intensity on Canola Biodiesel Emissions – Canada vs. Europe

Fuel	Hwy diesel	Biodiesel	Biodiesel
Feedstock	Oil	Canola	Canola
Location		Canada	Europe
			N_2O + Fert + Lime + Fuel
		g CO_2eq/GJ (HHV)	
Fuel dispensing	114	131	131
Fuel distribution and storage	476	1,187	1,187
Fuel production	8,432	7,231	7,231
Feedstock transmission	905	976	976
Feedstock recovery	8,626	6,276	18,827
Land-use changes, cultivation	266	6,321	10,121
Fertilizer manufacture	0	10,116	18,795
Gas leaks and flares	1,855	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-230	-27,172	-19,482
Total	20,444	5,065	37,785

6.5 Soil Carbon

Western Canada is building soil carbon in the agricultural area due to the reduction of summerfallow and the increased adoption of no tillage management practices. The impact of removing this soil carbon increase from the LCA is shown in the following table. This change accounts for 8,679 g CO_2eq/GJ of biodiesel.

Table 6-5 Impact of Soil Carbon on Canola Biodiesel Emissions – Canada vs. Europe

Fuel	Hwy diesel	Biodiesel	Biodiesel
Feedstock	Oil	Canola	Canola
Location		Canada	Europe
			N_2O + Fert + Lime + Fuel + no SOC
		g CO_2eq/GJ (HHV)	
Fuel dispensing	114	131	131
Fuel distribution and storage	476	1,187	1,187
Fuel production	8,432	7,231	7,231
Feedstock transmission	905	976	976
Feedstock recovery	8,626	6,276	18,827
Land-use changes, cultivation	266	6,321	17,266
Fertilizer manufacture	0	10,116	18,795
Gas leaks and flares	1,855	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced	-230	-27,172	-17,223
Total	20,444	5,065	47,189

6.6 Model Structure

The one difference in the GHGenius modelling structure from some of the other biofuel LCA models is that GHGenius uses the ISO preferred system expansion process for allocating emissions to co-products, whereas other models use mass or energy allocation approaches. Neither mass nor energy allocation is ideal for biofuel systems, and particularly biodiesel systems, because they don't recognize the nutritional differences between canola meal, soybean meal or any of the oilseed meals. Since all of these meals are used almost exclusively for animal feed, valuing them on the basis of their mass or thermal energy contents is not the best approach.

In the following table, the impact of different approaches to the value of canola meal is shown. Energy allocation, as called for in the European Union Renewable Energy Directive (RED) produces similar results for canola meal, as does GHGenius. This is a coincidence and would not necessarily hold true if the emissions differ or for other oilseed feedstocks. Mass allocation provides a greater emission credit and thus would reduce the GHG emissions for canola biodiesel even further.

Table 6-6 Canola Meal Credits

	GHGenius System Expansion	Mass Allocation	Energy Allocation
	G CO_2eq/GJ of Canola Oil		
Fuel production	3,978	3,978	3,978
Feedstock transmission	808	808	808
Feedstock recovery	6,255	6,255	6,255
Land-use changes, cultivation	6,301	6,301	6,301
Fertilizer manufacture	10,083	10,083	10,083
Co-product Credit	-10,673	-15,906	-10,284
Total	16,752	11,519	17,141

The biodiesel production process produces glycerine as well as methyl esters. GHGenius uses displacement as the method of determining the co-product credit for glycerine, assuming that the glycerine displaces the emissions embedded in the materials that are used to produce synthetic glycerine (but not the total lifecycle emissions for the production of synthetic glycerine as energy must still be expended to upgrade the crude glycerine to synthetic glycerine. Other models have provided an energy credit based on displacing another fuel or by allocating the emissions between biodiesel and the glycerine. The alternative systems are compared in the following table. It can be seen that there is much more variation in the overall results depending on how the glycerine co-product treatment is done.

Table 6-7 Glycerine Credits

	GHGenius System Expansion	Energy Displacement Heating Oil	Energy Allocation
	g CO_2eq/GJ Biodiesel		
Fuel dispensing	131	131	131
Fuel distribution and storage	1,187	1,187	1,187
Fuel production	7,231	7,231	7,231
Feedstock transmission	976	976	976
Feedstock recovery	6,276	6,276	6,276
Land-use changes, cultivation	6,321	6,321	6,321
Fertilizer manufacture	10,116	10,116	10,116
Gas leaks and flares	0	0	0
CO_2, H_2S removed from NG	0	0	0
Emissions displaced-Canola meal	-10,708	-10,708	-10,708
Emissions displaced-Glycerine	-16,464	-4,580	-1,546
Total	5,065	16,950	19,984

6.7 Summary

This work has been undertaken for the Canola Council of Canada to document the unique life cycle attributes of Canadian canola production and conversion to biodiesel. These include:

1. Low N_2O emissions in the primary canola production areas due to the low annual precipitation.
2. The production on alkaline soils and thus avoiding the need for soil pH adjustment through the addition of lime.
3. The use of ammonium type fertilizers rather than nitrate fertilizers, with their lower GHG emissions profile.
4. The energy efficient production methods employed by Canadian producers, including high adoption rates of no till and conservation tillage practices.

All of these production methods result in a crop with a good energy balance and a low GHG emissions profile. Biodiesel produced from Canadian canola has a very good GHG emissions profile and it is significantly different from European rapeseed biodiesel.

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