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Primary Energy and Greenhouse Gas Emissions from Biodiesel Made from Southland Rapeseed

1 Executive Summary

A life cycle assessment of primary energy and greenhouse gas (GHG) emissions (providing an indication of the global warming potential) was performed for the production of biodiesel from rapeseed oil grown in Southland, New Zealand, through to supply at the gate of the biodiesel production facility. This analysis followed a similar methodology to that used in analysis of tallow-based biodiesel carried out for EECA (CRL 2007). This life cycle assessment (LCA) considered energy and emissions from the cultivation of rapeseed, oil extraction and refining and processing to biodiesel. The transport of feedstocks was assessed to contribute a negligible amount as in the previous study (CRL 2007) found this transport to be a negligible contribution (about 1%) to the primary energy or greenhouse gas emissions associated with the production and supply of biodiesel and little difference was expected for biodiesel derived from rapeseed.

The base case LCA found the primary energy of the biodiesel to be 55% lower and the global warming potential to be 47% lower compared to the use of fossil diesel.

Whilst the base case LCA was considered appropriate for today's situation, new seed types appear to be providing higher cropping yields and hence the base case may soon (within the next five years) be found to be erring on the conservative side. This scenario was modelled and estimated that the reductions in primary energy and global warming potential of rapeseed-derived biodiesel would be to the order of 59% and 54% respectively. These are similar to those calculated in the earlier study (CRL 2007) for tallow-derived biodiesel in New Zealand.

The results from the base case and other scenarios considered are provided in Table 1.

Table 1. Summary Results from the Life Cycle Assessment.

Scenario	Primary Energy MJ/kg $_{biodiesel}$	Energy Input/ Output	Primary Energy reduction compared with fossil diesel use	GHG $kgCO_2eq$/ kg $_{biodiesel}$	Global Warming Potential Reduction Compared with fossil diesel use
1. Base Scenario (Yield 3.2 t/ha)	21.5	0.54	55%	2.03	47%
2. Higher Yield (Yield 3.9 t/ha)	19.5	0.49	59%	1.76	54%
3. Yield 3.2 t/ha plus glycerine credit	18.7	0.47	61%	1.77	54%

Primary Energy and Greenhouse Gas Emissions from Biodiesel Made from Southland Rapeseed

Contents

2 Introduction

This report has been prepared in response to a request from Solid Energy Ltd for a life cycle assessment (LCA) for the production of rapeseed methyl ester (RME) biodiesel from Southland-based rapeseed.

3 Background and Methodology

An LCA considers the inputs and outputs to a process for making a product from its raw materials through to some designated end point. There are different methods for carrying out an LCA and the "allocation" method has been used here as this is the most practical for assessing the biodiesel production process. Further detail has been provided in an LCA of biodiesel produced from New Zealand tallow and reported in the report *Primary Energy and Net Greenhouse Gas Emissions from Biodiesel made from New Zealand Biodiesel Tallow*, CRL Energy Report No. 06-11547b, February 2007 (CRL, 2007), a report on which the analysis and results reported here have been based.

The analysis reported here has been divided into sections considering: cultivation of rapeseed, oil extraction, transportation and biodiesel production. The section on the cultivation of rapeseed has been largely based upon a short report prepared by Andrew Barber of AgriLINK that was specifically developed for this analysis. The section on oil extraction was based upon findings of a literature review. The sections on transportation and biodiesel production were based on CRL Energy's LCA report (CRL, 2007). For the biodiesel production, only summary figures have been brought forward from the CRL 2007 report as the detail is available in that report. The overall process from cultivation through to the biodiesel is shown in Figure 1.

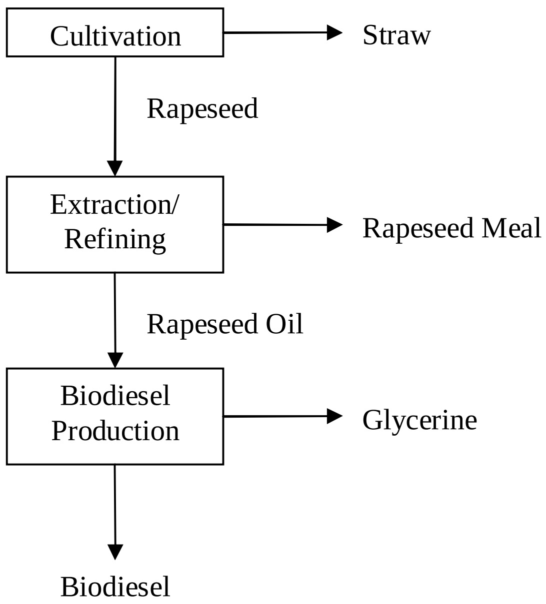

Figure 1. Flow Diagram for the Production of Biodiesel from Rapeseed.

The LCA methodology followed was to determine the mass balance for the entire process and then from this calculate the energy requirements and greenhouse gas emissions for each process on the basis of 1kg of biodiesel output. For the base scenario it was assumed that some of the energy and emissions for the cultivation and extraction processes can be apportioned to the rapeseed meal by-product.

It is important that LCA studies specify whether they are conducted on a net or gross basis for comparing energy requirements. This study follows the convention used in New Zealand to use higher heating values (HHV, or gross calorific values). This has the advantage that GHG emission factors in New Zealand are related to HHV (CRL, 2007).

4 Results

4.1 Mass Balance

The mass balance shown in Table 2 was determined by calculating backwards from 1 kg of biodiesel. A refined rapeseed oil to biodiesel conversion rate of 96.5% (from Beer et al, 2001) was used, 1 kg of biodiesel requiring 1.04 kg of refined rapeseed oil. There is also 0.1 kg of glycerine produced for every 1kg of biodiesel. A crude rapeseed to refined rapeseed conversion rate of 97.5% (from Beer et al, 2001) was used, 1.04 kg of refined rapeseed oil requiring 1.06 kg of crude rapeseed oil. A rapeseed to rapeseed oil conversion rate of 39.9%[1] (also from Beer et al, 2001) was used, 1.06 kg of rapeseed oil requiring 2.66 kg of rapeseed. The extraction process also produces 0.601 kg of rapeseed meal for every kg of rapeseed processed and so 1.6 kg of rapeseed meal is produced for every kg of biodiesel. The quantity of straw produced during cultivation is approximately the same as the quantity of rapeseed produced by weight, but this product is not further considered in this evaluation as it is assumed to have negligible value (and therefore does not attract a primary energy or GHG emission allocation).

Table 2. Mass Balance for the Production of 1kg of Biodiesel from Rapeseed.

Product	Quantity
Rapeseed	2.66 kg
Rapeseed Meal	1.6 kg
Crude Rapeseed Oil	1.06 kg
Refined Rapeseed Oil	1.04 kg
Glycerine	0.1 kg
Biodiesel	1 kg

4.2 Cultivation of Rape

Table 3 provides a summary breakdown of the estimated primary energy and GHG emissions (in carbon dioxide equivalents (CO_2eq)) for un-irrigated rapeseed cropping in Southland, for delivery to the farm gate. This data was specifically prepared for this LCA by Andrew Barber of AGRIlink. The fertiliser application for this estimate was 160 kg N/ha/yr.[2]

Note that these emissions for rapeseed cropping have been based on typical arable tillage techniques (3-4 passes) and that the cultivation of rapeseed in Southland may utilise low tillage (2 pass) techniques. If this is the case, lower GHG emissions would be expected than for the base case offered here. The estimation of field emissions is an area that requires further investigation. The calculated emissions may be lower (or higher) than the actual emissions that occur in practice.

From the Table 3 data and the requirement of 2.66 kg of rapeseed for 1 kg of biodiesel, the energy requirement for cultivation is 15.2 MJ/$kg_{biodiesel}$[3] and the greenhouse gas emissions are 2.06 $kgCO_2eq/kg_{biodiesel}$.[4]

[1] Noting that there are rounding errors if working out this figure from the data in Table 3.
[2] Fertiliser application in quantified in terms of kg and nitrogen per hectare per year – kg N/ha/yr.
[3] 2.66 kg x 5.7 MJ/kg

Table 3. Greenhouse Gas Emissions from the Cultivation of Rapeseed on a Per-tonne of Rapeseed Basis.

	Energy, MJ/t	CO_2(kg/t)	CO_2eq(kg/t)	Percentage
Fuel	1240	74	77	10%
Fertiliser and Agri-chemical	4000	257	279	36%
Capital	460	40	41	5%
Field Emissions (Nitrous Oxide)*		-	376	49%
TOTAL	**5700**	**371**	**772**	
Production				
Total yield		3.3	tonnes[†]	
Net yield[Δ]		3.2	tonnes	
Net yield		3.0	tDM[⌂]	

* Estimated using IPCC methodology and researched nitrogen inputs (rapeseed is not a crop that is included in the New Zealand GHG Inventory).
[†] Per hectare
[Δ] Includes consideration of seeds sown, i.e., less the rapeseed seed, etc.
[⌂] DM: dry matter basis

4.3 Drying, Oil Extraction and Refining

It is assumed that drying of rapeseed is required.

The estimation of GHG emissions from the extraction and refining of the oil from the rapeseed has been based on data from Ceuterick and Spirinckx, 1999 referenced by Beer et al (2001, pages 154 and 155). Ceuterick and Spirinckx, estimate the energy requirements of the oil extraction process at 45 kWh of electricity and 310 kg of steam based on a energy input of 3.64 MJ/kg (which at this value, is assumed to be the gross energy supplied to the boiler[5]) per tonne of rapeseed processed. The estimate of the energy requirements of the oil refining process is 10 kWh of electricity and 80 kg of steam per tonne of rapeseed oil processed.

Electricity has been converted into primary energy and GHG emission using the same method as the CRL Energy report[6]. Similarly steam energy has been converted into primary energy and

[4] 2.66 kg x 0.772 kg/t
[5] This is based on an energy input of 3.64 MJ/kg steam. This takes boiler efficiency into consideration as the energy for steam production alone is generally around 2.7 MJ/kg
[6] CRL 2007, i.e., for average electricity use, using a factor of 2.11 kWh of primary energy to supply 1 kWh to the consumer (from 2005 MED data) and using a total GHG emission factor of 54.8 $gCO_2eq/MJ_{consumer}$

GHG emission assuming coal firing[7] using the method as given in the CRL Energy report (CRL 2007)[8].

The result is a primary energy of 3.38 $MJ/kg_{biodiesel}$[9] and a GHG emission of 0.35 $kgCO_2eq/kg_{biodiesel}$ for the oil extraction process and a primary energy of 0.34 $MJ/kg_{biodiesel}$ and a GHG emission of 0.04 $kgCO_2eq/kg_{biodiesel}$ for the oil refining process

4.4 Rapeseed Meal Credit

For New Zealand, there is a large market for rapeseed. Hence under the base scenario the rapeseed oil and rapeseed meal by-product both have economic value and an economic allocation is used to allocate primary energy and GHG emissions between the two products. Data reported by the Canadian Canola Council indicates that the value of canola meal[10] was approximately 25% that of canola oil[11], on a weight basis, for the period of 1996 to 2005 and this weight-based factor has been used for this study. Note that this ratio likely errs on the conservative side as stock feeds in New Zealand normally retail for twice the price used for bulk rapeseed meal in this analysis.

Also taking the relative weight of product into consideration[12], the allocation factor to the crude rapeseed oil is 0.72[13], and to the rapeseed meal is 0.28. This is applied to the primary energy and GHG emissions of processes up to and including oil extraction (i.e., for cultivation and oil extraction, but does not include oil refining as the rapeseed meal has already been divided from the rapeseed oil by this stage). Hence the rapeseed meal credit for the base case is a primary energy of 5.08 $MJ/kg_{biodiesel}$[14] and a GHG emission of 0.66 $kgCO_2eq/kg_{biodiesel}$[15]. The credits for the extraction process are 0.92 $MJ/kg_{biodiesel}$ and 0.09 $kgCO_2eq/kg_{biodiesel}$ respectively.

4.5 Transport

CRL Energy (CRL 2007) found that the emissions from transporting tallow to the processing plant in a LCA of tallow methyl ester biodiesel production was insignificant (at about 1% of the total emissions). It is assumed in this analysis that the emissions from transportation are also insignificant and are taken as zero.

4.6 Biodiesel Production

The GHG emissions from the production of biodiesel from rapeseed oil are assumed to be the same as that for biodiesel production from tallow.[16] CRL Energy (CRL, 2007) found that the

[7] Noting that Ceuterick and Spirinckx based their calculations on the use of natural gas fired boilers, but for this current study the use of coal fired boiler has been assumed due to the availability of this energy resource in Southland. For this, it has been assumed that the primary energy requirement for producing the steam is the same but the GHG emissions are different for the use of coal compared to the use of natural gas.

[8] i.e. for average coal use, using a factor of 1.04 MJ of primary energy to supply 1.00 MJ to the consumer and using a total GHG emission factor of 96.81 $gCO_2eq/MJ_{consumer}$

[9] Electricity = 45 kW/t x 2.66 kg/kg x 2.11 kWh/kWh x 3.6 MJ/kWh /1000 kg/t. Steam = 310 kg/t x 3.64 MJ/kg x 2.66 kg/kg / 1000 kg/t.

[10] Noting that the reference used referred to "canola" which is a variety of rapeseed.

[11] http://www.canola-council.org/canolaprices.html also see appendix 1 for more detail.

[12] 1.6 kg of rapeseed meal and 1.06 kg of crude rapeseed oil produced during the process of producing 1 kg of biodiesel.

[13] That is, (100% x 1.06 kg)/ (25% x 1.6 kg + 100% x 1.06 kg) = 0.72

[14] 0.28 × (3.38+15.2)

[15] 0.28 × (0.35+2.06)

[16] Noting that the energy required to prepare the different feedstocks is expected to be similar, as is the energy required for processing and product finishing.

primary energy for biodiesel production was 7.7 $MJ/kg_{biodiesel}$ and that the GHG emissions from biodiesel production were 0.25 $kgCO_2eq/kg_{biodiesel}$.

4.7 Total Primary Energy

The total primary energy for the base scenario is summarised in Table 4.

Table 4. Gross Primary Energy for Biodiesel Production from Rapeseed

Process	**Gross Primary Energy, $MJ/kg_{biodiesel}$**		**Percentage of Total with credit**
	no credit	**with credit**	
Cultivation	15.2	11.0	50%
Oil Extraction	3.4	2.5	13%
Oil refining	0.3	0.3	2%
Transportation	0	0	0%
Biodiesel Production	7.7	7.7	35%
Total	**26.6**	**21.5**	**100%**

As shown in Table 4, the gross primary energy of biodiesel at the production plant gate, with credit for the rapeseed meal, is 21.5 $MJ/kg_{biodiesel}$. Based on a higher heating value of RME of 40.07 MJ/kg (Mittelbach and Ramschmidt, 2004), the energy input/output ratio for rapeseed-derived biodiesel is 0.54 $MJ_{primary}/MJ_{consumer}$ [17]. This compares with a higher heating value of New Zealand diesel of 45.6 MJ/kg (CRL, 2007) and an input/output ratio of 1.19 (CRL, 2007). An engine will provide the same work provided with 1 MJ of biodiesel as it would with 1 MJ of diesel and hence the percentage reduction in primary energy consumed is 55%[18] for the use of rapeseed-derived biodiesel compared with the use of fossil diesel.

4.8 Total GHG Emissions

The total GHG emissions for the base scenario are summarised in Table 5.

Table 5. Life Cycle Greenhouse Gas Emissions for the Base Scenario with a Breakdown by Process

Process	GHG from Process $kgCO_2eq/kg_{biodiesel}$		Percentage of Total with credit
	no credit	with credit	
Cultivation	2.06	1.49	73%
Oil Extraction	0.35	0.25	12%
Oil refining	0.04	0.04	2%
Transportation	0	0	0%
Biodiesel Production	0.25	0.25	12%
Total	2.69	2.03	100%

As shown in Table 5, the total GHG emissions associated with biodiesel at the production plant gate, with credit for the rapeseed meal, is 2.06 $kgCO_2eq/kg_{diesel}$. Comparing the results to fossil diesel (GHG emissions of 3.8 $kgCO_2eq/kg_{diesel}$, as given in CRL, 2007) and accounting for the

[17] 21.5/40.07
[18] 1-0.55/1.19

differences in heating value[19], the use of rapeseed-derived biodiesel provides a 42% reduction in global warming potential compared with the use of fossil diesel[20].

4.9 Glycerine Credits

The second commercially valuable by-product from the process is glycerine. At the time of reporting, CRL Energy (CRL 2007) found the glycerine credit to be worth an equivalent of 13% of the total GHG and energy requirements of the biodiesel product. For the analysis considered in this report, this is equivalent to a primary energy credit of 2.8 $MJ/kg_{biodiesel}$[21] and a GHG emission credit of 0.26 $kgCO_2eq/kg_{biodiesel}$[22].

Note that the glycerine credit has not been taken into account for the base case as a significant increase in biodiesel production, worldwide, is expected to cause a decrease in the value of glycerine (and hence at least partial loss of this credit). This potential credit is instead considered in the sensitivity analysis.

4.10 Sensitivity Analysis

Solid Energy has indicated that the typical yields of rapeseed in Southland may be closer to 4 t/ha (3.9 t/ha net) rather than the 3.3 t/ha (3.2 t/ha net) used for the base case, using the same inputs of fertiliser and seed. This would reduce the primary energy and GHG emissions associated with cultivation by a ratio of 82% (3.2/3.9). The change in yield also has an effect on the amount of GHG and primary energy that can be allocated to the rapeseed meal and glycerine by-products, although the relative allocation proportions do stay the same.

Table 6 provides the base scenario results plus results when higher cultivation yields and a glycerine credit are included, showing the sensitivity to these parameters. The case where no by-product credits are applied is also included to illustrate the sensitivity to credits – a case where no credit is provided would be highly unlikely in practice.

Table 6. Scenarios for Sensitivity Analysis.

Scenario	Primary Energy $MJ/kg_{biodiesel}$	Energy Input/ Output	Primary Energy reduction from fossil diesel	GHG $kgCO_2eq/kg_{biodiesel}$	GHG Reduction from fossil diesel
1. Base Scenario Yield 3.2 t/ha	21.5	0.54	55%	2.03	47%
2. Yield 3.9 t/ha	19.5	0.49	59%	1.76	54%
3. Yield 3.2 t/ha Glycerine credit	18.7	0.47	61%	1.77	54%
4. Yield 3.9 t/ha Glycerine credit	17.0	0.42	64%	1.53	60%
5. Yield 3.2 t/ha No credits	26.6	0.66	44%	2.69	29%
6. Yield 3.9 t/ha No credits	23.9	0.60	50%	2.32	39%

[19] 1.08 kg of biodiesel has the same energy content as 1.00 kg of fossil diesel – 43.28/40.07
[20] 1.08 kg/kg x 2.06/3.8 kg/kg
[21] 0.13 x 21.5 $MJ/ kg_{biodiesel}$
[22] 0.13 x 2.03 $kgCO_2eq/kg_{biodiesel}$

Information from Solid Energy suggests that cropping yields of at least 4.0 t/ha (3.9 t/ha, net) could be typical for rapeseed grown in Southland with using similar fertiliser application. There are other reports of achieving yet higher yields. Hence this current study's base case, whilst considered appropriate for today, may soon (within the next five years) be found to be erring on the conservative side. Scenario 2 of Table 6 estimates the benefit of higher cropping yield, modelling estimating a 59% reduction in primary energy and a 54% reduction in global warming potential for the use of rapeseed-derived biodiesel over the use of fossil diesel. This benefit was found to be similar to keeping the base case yield but allowing for a glycerine credit at 2007 market value for glycerine (Scenario 3, Table 6). As shown in Table 6, the reductions are increased further where increased yield and glycerine credits are lined up together, resulting in an estimated reduction of primary energy of 64% and an estimated reduction in global warming potential of 60% for the use of rapeseed-derived biodiesel over the use of fossil diesel.

5 Further Discussion

The calculated reductions in primary energy and global warming potential for tallow-derived biodiesel, from CRL 2007, were 58% and 49% respectively without a glycerine credit. These are greater than those for the rapeseed-derived biodiesel base scenario, but very similar to those for the higher yield scenario.

Note that the makeup of the primary energy for the two derivations of biodiesel differ significantly: tallow is a by-product and is only allocated a relatively small fraction of the farming-related primary energy and GHG emissions, whereas rapeseed it allocated the majority of the farming primary energy and GHG emissions. On the other hand the extraction and refining process is far more energy intensive for tallow compared with that for rapeseed.

The calculated GHG emissions from the cultivation of rapeseed of 2.06 $kgCO_2eq/kg_{biodiesel}$ is similar to the emissions determined in the often referred to "well-to-wheels" study instigated by General Motors and others (GM 2002). In the GM study, four scenarios for cultivation were considered with GHG emissions from cultivation of 1.10 $kgCO_2eq/kg$ (for 146 kg N/ha/yr[23]), 1.890 $kgCO_2eq/kg$ (for a fertiliser application of 101 kg N/ha/yr), 2.22 $kgCO_2eq/kg$ (for 101 kg N/ha/yr) and 2.37 $kgCO_2eq/kg$ biodiesel (for 146 kg N/ha/yr). The latter three used the IPCC (revised 1996 guidelines) methodology to determine the N_2O emissions so should be comparable to this current study and the calculated N_2O emissions of this current study do fall within the range of the GM results. The result from the first of the GM scenarios used an alternative methodology and so is not directly comparable to this current study.

Note that a UK study by Audsley et al (2006) showed the GHG emissions for cultivation of rapeseed to be 1400 $kgCO_2eq/t$ which is almost twice that of this current study. The difference is attributed to the high fertiliser use of 204 kg N/ha/yr used in the analysis.

6 Conclusions

The base case scenario for the supply of rapeseed-derived biodiesel at the production plant gate and including rapeseed cultivation in Southland, oil extraction, refining and biodiesel production has found the primary energy of the biodiesel to be 53% lower than for the use of fossil diesel and the global warming potential to be 43% lower compared to the use of fossil diesel.

Whilst the base case LCA was considered appropriate for today's situation, new seed types appear to be providing higher cropping yields and hence the base case may soon (within the next five years) be found to be erring on the conservative side. A scenario modelling a higher cropping yield estimated that the reductions in primary energy and global warming potential of

[23] Referring to the amount of nitrogen in the fertilizer (kg) that is applied the rapeseed crop per unit area (ha) in a year.

rapeseed-derived biodiesel could be to the order of 60% and 50% respectively. These were found to be similar to those calculated for tallow-derived biodiesel in New Zealand.

7 References

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Appendix A – Calculations

A.1 Value of Rapeseed Meal

The data for determining the value of rapeseed meal relative to that for rapeseed oil was taken from the Canola Council of Canada website (http://www.canola-council.org/canolaprices.html).

Canola is a variety of rapeseed. This website provides the price for oil and the price for meal on a monthly basis and as an annual average. The relative value was determined by dividing the oil price by the meal price. The relative value for the ten years from 1997 to 2006 in Canada are shown in Figure 2. The average value for the ten year period is 3.75 with the average for the last four years being 4. This shows that since 1997 the value of the meal was subject to significant fluctuations. The value of 4 has assumed for this assessment meaning that the rapeseed meal has a quarter (0.25) of the value of the rapeseed oil.

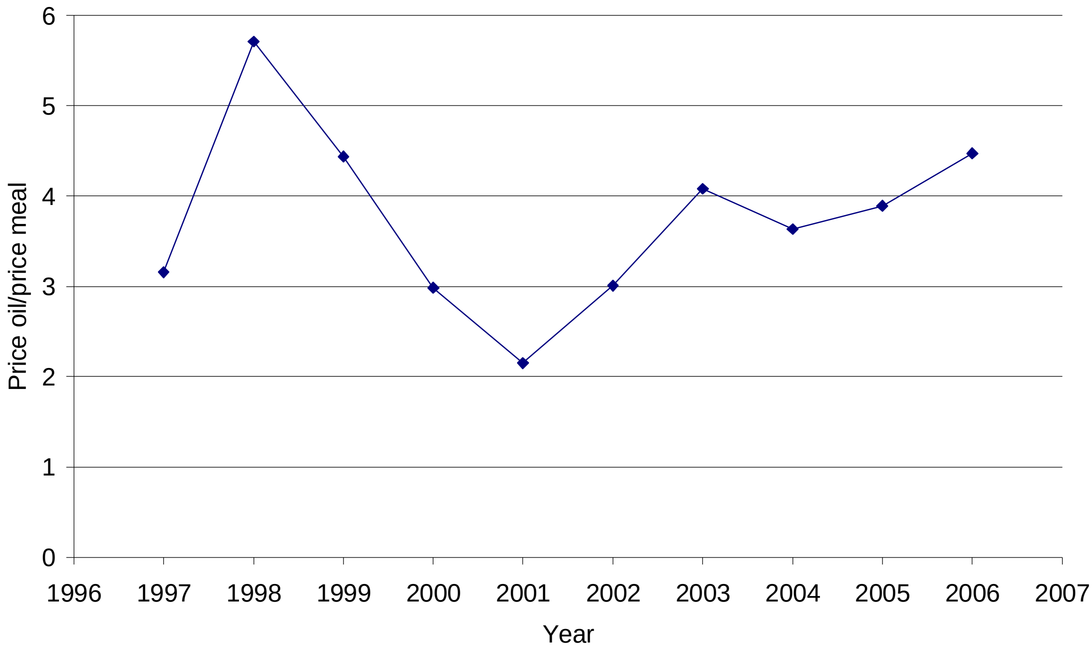

Figure 2. Value of Canola Oil compared to Canola Meal in Canada from 1997 to 2006.

Appendix B – Tallow Biodiesel Results

Table B-1: Primary Energy and Greenhouse Gas Emissions for Tallow-Derived Biodiesel

Stage in Process	Primary Energy MJ/kg biodiesel	As a Percentage of Total	Greenhouse Gas Emissions kgCO_2eq/kg of biodiesel	As a Percentage of Total
Farming and meat processing	1.0	5%	0.77	39%
Rendering	13.9	60%	0.92	46%
Transport to plant	0.3	1%	0.02	1%
Biodiesel production	7.7	34%	0.25	13%
Glycerine credit	-3.0	-	-0.26	-
Total with glycerine credit of 13%	**20.0**	**100%**	**1.75**	**100%**

Note: totals provided may be slightly different to the sum of the components due to rounding.