# 4. Biodiesel

## 4.1. Biodiesel from Vegetable Oils

Diesel engines initially perform to much the same standard with pure vegetable oil as with diesel. In the past pure vegetable oils have been mainly used in tractors on farms. Pure vegetable oils create problems in turbocharged direct injection engines with charge air coolers, such as those used in trucks.

Table 4.1 compares some of the physical and chemical properties of diesel, canola oil and methyl esters. Vegetable oils have higher density than diesel, but lower energy content (gross calorific value). Vegetable oils have a lower carbon content than diesel, which means lower $CO_2$ emissions per litre of fuel burnt. $CO_2$ emissions per kilometre travelled may not be lower, however, due to the lower energy content of the vegetable oils and a higher proportion of multi bonded carbon compounds. The major difference in physical characteristics between canola and diesel is in the viscosity. Canola is more than 12 times as viscous as diesel at $20^{\circ}$C, and remains more than six times as viscous even after heating to $80^{\circ}$C.

**Table 4.1**
**Comparison of typical properties of diesel, canola oil, commercial US biodiesel, and various methyl esters.**

|  | Diesel | Canola | Biodiesel (FAMAE) | Palm oil methyl ester | Soy methyl ester | Sunflower methyl ester | Tallow methyl ester |
|---|---|---|---|---|---|---|---|
| Density (kg/L) at $15.5^{\circ}$C | 0.835 | 0.922 | 0.88 | 0.880 | 0.884 | 0.880 | 0.877 |
| Gross calorific value (MJ/L) | 38.3 | 36.9 | 33.3 | 37.8 | 39.8 | 38.1 | 39.9 |
| Viscosity (mm$^2$/s @ $37.8^{\circ}$C) | 3.86 | 37 | 4.7 | 5.7 | 4.08 | 4.6 | 4.1 |
| Cetane number | 51 to 58 |  | > 40 | 62 | 46 | 49 | 58 |

Source: Adapted from Table 6.1 of BTCE (1994), from www.afdc.doe.gov, and from Clements (1996).
FAMAE: Fatty Acid Mono Alkyl Ester

These high viscosity levels create problems for the use of canola, or other pure vegetable oils, as an unmodified fuel. The flow of the fuel from tank to engine is impeded, which can result in decreased engine power. Fuel filter blockages may also occur. The multi-bonded compounds pyrolyse more readily and engines can suffer coking of the combustion chamber and injector nozzles, and gumming, and hence sticking, of the piston rings. A progressive decline in power results. If left unchecked, dilution of the crankcase oil can lead to lubrication breakdown. Long-term tests have verified that there is a build-up of carbon deposits in the injection nozzles and cylinder heads.

The viscosity problem can be mitigated by preheating the oil and using larger fuel lines, by blending diesel and vegetable oils, or by chemical modification (i.e. producing biodiesel). Apart from the viscosity difficulties, vegetable oils may result in starting difficulties due to a high temperature being required before the oil will give off ignitable vapours. They also have a relatively slow burn rate as a result of the low cetane rating, which makes vegetable oils unsuitable for high speed engines.

## 4.2. Biodiesel

Biodiesel is a generic name for fuels obtained by transesterification of a vegetable oil. This produces a fuel with very similar combustion properties to pure diesel, but with lower viscosity. Often biodiesel refers to rapeseed oil methylester (RME), the main European

biodiesel. Esterified soybean oil is the main United States source of such fuel, called Soy diesel. Figure 4.1 depicts a flow chart of the esterification process.
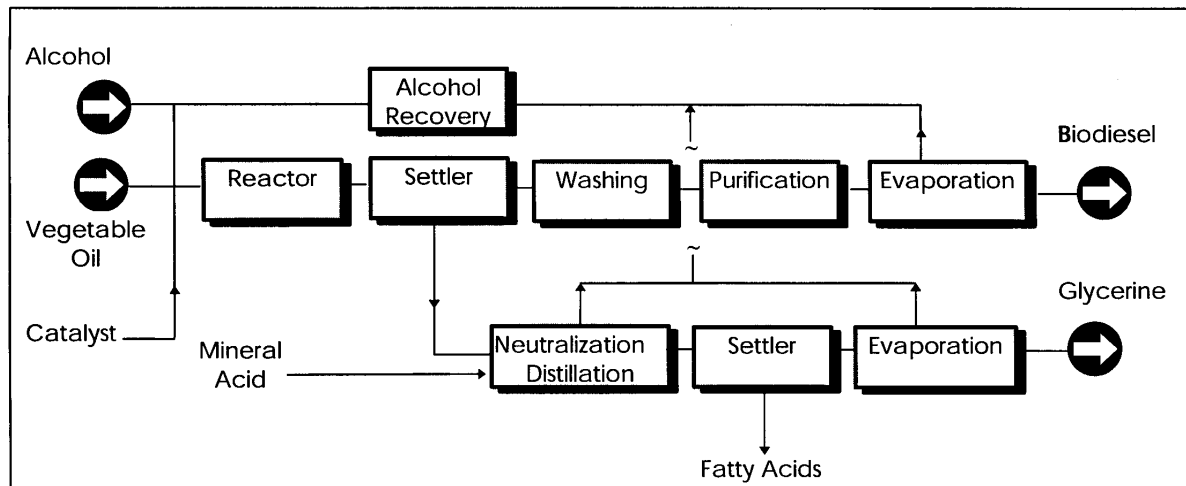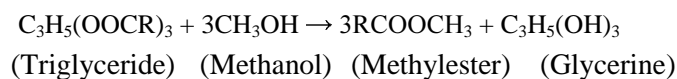


**Figure 4.1**
**Flowchart of the process of esterification to create biodiesel fuel**
**Source: National Biodiesel Board production factsheet**

Biodiesel can be used in a diesel engine without modification. Mittelbach (1998) quotes a cetane number of 48 for rapeseed methyl ester but notes that this can be increased to 59 if the biodiesel is made from the ethyl esters of tropical oilseeds. Mann (1998) claims a cetane number of 56 for soydiesel. The fuel consumption of biodiesel per kilometre travelled is similar to that for diesel when biodiesel is used as a diesel blend. Biodiesel has a lower energy content than diesel that leads to increased fuel consumption when pure biodiesel is used (Taberski et al., 1999).

The greenhouse gas emissions arising from the process depicted in Figure 4.1 depend on the amount of fossil fuel involved in the production of the alcohol. If methanol is used then this process is described by the equation.

$$C_3H_5(OOCR)_3 + 3CH_3OH \rightarrow 3RCOOCH_3 + C_3H_5(OH)_3$$
(Triglyceride) (Methanol) (Methylester) (Glycerine)

The term "triglyceride" in the equation may be either vegetable oil or tallow. From a chemical point of view, the differences between various plant and animal derived fats are due to the structural variations of fatty acids contained in fat molecules.

In most fats, the length of the fatty acid carbon chain ranges between C16 and C18. There are also differences in the degree of saturation (number and position of double bonds) in acid molecules. Saturation is the major factor determining physical properties of fats. Highly unsaturated vegetable oils are low viscosity liquids, while fully saturated animal fats are solid at ambient temperature.

From the point of view of the transesterification process itself, these differences in molecular structure are insignificant in terms of process parameters or energy demand. The greenhouse gas emissions arising from the process depicted in Figure 4.1 depend mostly on the amount of fossil fuel involved in the production of the alcohol as given by Sheehan et al. (1998: p. 147), who estimate that 5% (by mass) of the carbon emissions are fossil-fuel carbon.

For example, if methanol is used, overall emissions will be higher because current production of methanol involves solely fossil-fuel feedstocks such as natural gas or coal. By contrast, if

the use of ethanol produced from renewable resources (biomass) using bioprocesses is contemplated, greenhouse emissions will be lower. Methanol can be produced by the gasification of biomass but this is currently not done.

Another source of differences in life-cycle emissions of biodiesel arises at the stage of oil and tallow production. In the case of oil-seed crops, there needs to be accounting for energy and raw materials inputs into fertiliser production, land cultivation, materials transportation, harvesting and oil extraction. Similarly, when tallow is used as a feedstock, energy expended in farming activities needs to be accounted for. In both cases appropriate allocation procedures for multiple product streams need to be observed.

**Table 4.2**
**Comparison of different national standards for biodiesel**

|  |  | Austria | Czech Republic | France | Germany | Italy | Sweden | USA |
|---|---|---|---|---|---|---|---|---|
| Standard / Specification |  | ON C1191 | CSN 65 6507 | Journal Officiel | DIN V 51606 | UNI 10635 | SS 155436 | ASTM PS121-99 |
| Date |  | July 1997 | Sep 1998 | Sep 1997 | Sep 1997 | April 1997 | Nov 1996 | July 1999 |
| Application |  | FAME | RME | VOME | FAME | VOME | VOME | FAMAE |
| Density 15°C | g/cm³ | 0.85 - 0.89 | 0.87 - 0.89 | 0.87 - 0.90 | 0.875 - 0.90 | 0.86 -0.90 | 0.87 - 0.90 | - |
| Viscos. 40°C | mm²/s | 3.5-5.0 | 3.5 - 5.0 | 3.5-5.0 | 3.5-5.0 | 3.5-5.0 | 3.5-5.0 | 1.9-6.0 |
| Distillat. 95% | °C | - | - | ≤ 360 | - | ≤ 360 | - | - |
| Flashpoint | °C | ≥100 | ≥110 | ≥ 100 | ≥ 110 | ≥ 100 | ≥ 100 | ≥100 |
| CFPP | °C | 0/-15 | -5 | - | 0/-10/-20 | - | -5 | - |
| Pourpoint | °C | - | - | ≤ -10 | - | ≤ 0/≤-15 | - | - |
| Sulfur | % mass | ≤ 0.02 | ≤ 0.02 | - | ≤ 0.01 | ≤ 0.01 | ≤ 0.001 | ≤ 0.05 |
| CCR       100% | % mass | ≤ 0.05 | ≤ 0.05 |  | ≤ 0.05 |  |  | ≤ 0.05 |
|    10% dist. resid. | % mass |  |  | ≤ 0.3 |  | ≤ 0.5 | - |  |
| Sulfated ash | % mass | ≤ 0.02 | ≤ 0.02 | - | ≤ 0.03 | - | - | ≤ 0.02 |
| (Oxid) Ash | % mass | - | - | - | - | ≤ 0.01 | ≤ 0.01 | - |
| Water | mg/kg | - | ≤500 | ≤ 200 | ≤ 300 | ≤ 700 | ≤ 300 | ≤0.05% |
| Total contam. | mg/kg | - | ≤ 24 | - | ≤ 20 | - | ≤ 20 | - |
| Cu-Corros. 3h/50°C |  | - | 1 | - | 1 | - | - | ≤ No.3 |
| Cetane No. | - | - | ≥ 49 | ≥ 48 | ≥ 49 | ≥ 49 | - | ≥ 48 | ≥ 40 |
| Neutral. No. | mgKOH/g | ≤ 0.8 | ≤ 0.5 | ≤ 0.5 | ≤ 0.5 | ≤ 0.5 | ≤ 0.6 | ≤ 0.8 |
| Methanol | % mass | ≤ 0.20 | - | ≤ 0.1 | ≤ 0.3 | ≤ 0.2 | ≤ 0.2 | - |
| Ester content | % mass | - | - | ≥ 96.5 | - | ≥ 98 | ≥ 98 | - |
| Monoglycides | % mass | - | - | ≤ 0.8 | ≤ 0.8 | ≤ 0.8 | ≤ 0.8 | - |
| Diglyceride | % mass | - | - | ≤ 0.2 | ≤ 0.4 | ≤ 0.2 | ≤ 0.1 | - |
| Triglyceride | % mass | - | - | ≤ 0.2 | ≤ 0.4 | ≤ 0.1 | ≤ 0.1 | - |
| Free glycerol | % mass | ≤ 0.02 | ≤ 0.02 | ≤ 0.02 | ≤ 0.02 | ≤ 0.05 | ≤ 0.02 | ≤ 0.02 |
| Total glycerol | % mass | ≤ 0.24 | ≤ 0.24 | ≤ 0.25 | ≤ 0.25 | - | - | ≤ 0.24 |
| Iodine No. |  | ≤ 120 | - | ≤ 115 | ≤ 115 | - | ≤ 125 | - |
| C18:3 and high. unsat.acids | %mass | ≤ 15 | - | - | - | - | - | - |
| Phosphor | mg/kg | ≤ 20 | ≤ 20 | ≤ 10 | ≤ 10 | ≤ 10 | ≤ 10 | - |
| Alkalinity | mg/kg | - | ≤ 10 | ≤ 5 | ≤ 5 | - | ≤ 10 | - |

RME: Rapeseed oil methyl ester     FAME: Fatty acid methyl ester
VOME: Vegetable oil methyl ester    FAMAE: Fatty acid mono alkyl ester

## 4.3. *National Standardisation of Biodiesel*

The introduction of biodiesel as a fuel for diesel engines called for the development of standards in the respective countries. Thus, a working group in Austria in 1990 was instructed to prepare a standard for rape oil methyl ester. Currently, standards or specifications for biodiesel are available in Austria, the Czech Republic, France, Germany, Italy, Sweden, and

the United States. Table 4.2 shows a summary of currently valid national standards (Prankl and Woergetter, 1999). Environment Australia plans to develop standards for biodiesel under the *Fuel Quality Standards Act 2000.*

In Europe biodiesel is predominantly produced from rapeseed oil, and most information and data available deals with the practical experience gained in the use of rapeseed oil methyl ester (RME). In Austria and the Czech Republic standards for RME have been developed. In France, Italy and Sweden the specifications for biodiesel deal with plant oil used as a raw material. In Austria and Germany general standards for fatty acid methyl ester have been developed. The United States define biodiesel as "mono-alkyl esters of long chain fatty acids derived from vegetable oils and animal fats". However, the choice in raw material is limited considerably in the standards because of the selection of limiting values. By the year 2002 it is expected that there will be a European wide standard for biodiesel.

## 4.4.   Tailpipe Emissions

The extensive use of biodiesel fuels in the United States and Europe means that data is available on their emission characteristics during operational performance. Such data from the United States and from Europe was summarised by Beer et al. (2000). This section of the report reviews recent results, and some of the relevant older results. The next section compares the different studies.

Due to the absence of sulfur and the presence of oxygen in biodiesel, one would expect theoretically lower particle emissions. Recent results by Sharp et al. (2000a, b) indicate that modern American engines are now showing lowered particle emissions. Previous work by Motta, et al. (1996) using biodiesel in an earlier generation of engines installed in buses, indicated higher particle emissions. However, the high oxygen content means that the use of pure biodiesel generally results in a measurable loss of engine power and an increase in fuel consumption.

**Table 4.3**
**Engine dynamometer results (g/kWh) of emissions from a 20% blend of various biodiesel with diesel**

|          | CME20/Diesel | CME20/LSD | SME20/LSD |
|----------|--------------|-----------|-----------|
| Total PM | 0.32         | 0.34      | 0.36      |
| Total HC | 0.49         | 0.59      | 0.64      |
| NOx      | 7.87         | 7.44      | 6.31      |
| CO       | 1.40         | 1.61      | 1.50      |
| $CO_2$   | 875          | 877       | 924       |

Source: Spataru and Romig (1995) CME20 = 20% Canola methylester; SME20 = 20% Soy methylester

Spataru and Romig (1995) examined emissions from a DCC 6V92TA motor on an engine dynamometer, when both soy and canola methyl esters were used in blends with ordinary diesel and low sulfur diesel (California diesel). Their results are given in Table 4.3.

On the basis of the results in Table 4.3, it appears that biodiesel made from canola emits less greenhouse gases than biodiesel made from soy.

Most results and analyses that we have been able to find relate to methyl esters. Taberski et al. (1999) looked at the biodiesel emissions when using rapeseed ethyl ester (REE) blends in a 1995 Dodge 2500 four-wheel-drive pickup truck with a Cummins B 5.9 litre turbocharged direct injection diesel engine. They obtained results in 1995 and in 1998 with and without a catalytic converter. Table 4.4 and Table 4.5 present their results as the ratio of the observed emissions to the ratio obtained using D2 diesel, which is United States low sulfur diesel

containing 450 ppm sulfur. Both the ratios obtained in the 1995 tests and the ratios obtained in the 1998 test are given.

**Table 4.4**
**Range of ratios between emissions using diesel and ethyl ester biodiesel (no catalytic converter)**

|          | HC          | CO          | NOx         | CO$_2$       | PM          |
|----------|-------------|-------------|-------------|-------------|-------------|
| REE20%   | 0.782-0.834 | 0.723-0.824 | 0.925-0.972 | 0.966-1.006 | 1.007-1.059 |
| REE50%   | 0.565-0.642 | 0.648-0.652 | 0.926-0.971 | 1.007-1.026 | 1.352-1.338 |
| REE100%  | 0.369-0.380 | 0.553-0.652 | 0.876-0.918 | 0.978-1.006 | 1.348-1.420 |

**Table 4.5**
**Range of ratios between emissions using diesel and ethyl ester biodiesel (with catalytic converter)**

|          | HC          | CO          | NOx         | CO$_2$       | PM          |
|----------|-------------|-------------|-------------|-------------|-------------|
| REE20%   | 0.834-0.922 | 0.822-0.841 | 0.950-0.964 | 1.007-1.012 | 1.283-1.278 |
| REE50%   | 0.628-0.693 | 0.655-0.692 | 0.913-0.932 | 0.986-1.005 | 1.257-1.403 |
| REE100%  | 0.364-0.385 | 0.534-0.668 | 0.905-0.919 | 1.000-1.021 | 1.109-1.255 |

In 1998 the Southwest Research Institute, on behalf of the United States National Biodiesel Board, generated data for submission to the USEPA in order to comply with Tier 1 requirements under section 211(b) of the Clean Air Act. The data (Sharp, 1998) was based on regulated and unregulated emissions from a new 1997 Cummins N14 engine. The testing was carried out over the heavy-duty transient Federal Test Procedure. The biodiesel used was Soy methyl ester, with a cetane number of 51.2. The reference fuel was number 2 diesel with a cetane number of 43.3, and a sulfur content of 476 ppm. These results were used in the LCA to characterise biodiesel tailpipe emissions.

The results from the National Biodiesel Board/USEPA Tier 1 Health and Environmental Effects Testing for Biodiesel (Sharp, 1998; Sharp et al., 2000a) are summarised in section 4.13.

### 4.4.1    Air toxics

The United States National Biodiesels Board summarised studies on the air toxics emitted during biodiesel combustion, compared to diesel combustion. These results, given on the web site (http://www.biodiesel.org/fleets/summary.shtml#attributes) during 1999, are reproduced in Table 4.6.

**Table 4.6**
**Gaseous PAH levels (µg/cycle) of diesel fuel and a 50% biodiesel diesel blend.**

|                      | Diesel   | 50% Biodiesel |
|----------------------|----------|---------------|
| Naphthalene          | 331,654  | 384           |
| Methyl-2 Naphthalene | 10,289   | 329           |
| Fluorene             | 1,864    | 368           |
| Anthracene           | 4,301    | 873           |

*Particulate matter and unburned hydrocarbon emissions*

Chang and van Gerpen (1998) studied a John Deere model 4276T, 4 cylinder, 4 stroke, turbocharged, D1 diesel engine under dynamometer testing with a double dilution tunnel system. As fuels they used D2 diesel and biodiesel.

They concluded that under steady state testing (100% of maximum torque at 1400 rpm; 20% of maximum torque at 1400 rpm) the experimental results confirmed that biodiesel produced a higher soluble organic fraction (SOF) in its total particulate matter than diesel fuel under virtually all engine operating conditions. The SOF decreased with increasing particle filter temperature at constant dilution ratio and with increasing dilution ratio at constant filter temperature. Adsorption of vapour phase biodiesel on the carbon particle surface is the primary source of the SOF in the total particulate matter. We suspect that discrepancies in reported particulate matter results, discussed below, may result from different methods of reporting these SOF fractions.

## 4.5. *Comparison of Tailpipe Emissions*

Beer et al. (2000) points out that there are discrepancies between biodiesel emission results emanating from Europe and from the United States. In addition, during liaison meetings with stakeholders, particular concern was expressed that the findings by Beer et al. (2000) indicated greater tailpipe emissions of particulate matter from biodiesel than from diesel.

In particular, our attention was drawn to the results from the first phase of emissions testing programs (Tier I testing) on biodiesel undertaken on behalf of the National Biodiesel Board under USEPA regulations governing the introduction of new fuels and fuel additives (Sharp, 1998), and we used these data to characterise combustion emissions in the quantitative life-cycle analysis. The exhaust emissions of particulate matter in this study were found to be 30% lower than overall particulate matter emissions from diesel. Exhaust emissions of the insoluble portions of the particulate matter emissions were reduced by 80% for biodiesel compared to diesel.

To further examine this issue, Table 4.7 summarises the results of recent studies that compare the tailpipe emissions of biodiesel (BD100) to low sulfur diesel, generally United States D2 diesel. The only consistent finding is that biodiesel does not produce more tailpipe emissions of hydrocarbons than diesel fuel. For all the other pollutants in the table, some studies report an increase, whereas other studies report a decrease.

**Table 4.7**
**Comparison between emissions from biodiesel (BD100) and low sulfur diesel**

| Vehicle | | CO | NOx | THC | PM | Source |
|---|---|---|---|---|---|---|
| Buses | US Fleet | + | + | 0 | + | Beer et al. Table 2.10 |
| Trucks | US Fleet | + | + | no data | + | Beer et al. Table 2.11 |
| Cummins N14 Engine | | - | + | = | - | Sharp 1998 Table 3 |
| Dodge LCV | with catalyst | - | - | = | + | Taberski et al. 1999 |
| Dodge LCV | with catalyst | - | 0 | = | - | Durbin et al. 2000 |
| Dodge LCV | without catalyst | - | - | = | + | Taberski et al. 1999 |
| Dodge LCV | without catalyst | + | + | - | + | Durbin et al. 2000 |
| Ford LCV | with catalyst | - | + | - | + | Durbin et al. 2000 |
| Ford LCV | without catalyst | - | 0 | = | + | Durbin et al. 2000 |
| Composite | European | - | + | - | - | IEA/AFIS 1999 |
| Composite | Swedish LDV | = | 0 | = | - | Arcoumanis 2000 Table 5.2 |
| Composite | Swedish HDV | - | 0 | = | 0 | Arcoumanis 2000 Table 5.3a |

Symbols: ++ biodiesel more than double diesel emissions, + more, 0 within 10%, - less, = biodiesel less than half diesel emissions.

### 4.5.1 Hydrocarbons and carbon monoxide

Hydrocarbon emissions are mostly the result of flame quenching in an internal combustion engine. There is a narrow quench zone near the cooled cylinder walls that makes the flame go out and the hydrocarbons are not burned. CO is partially combusted fuel. Because of this, HC and CO are typically very high on cold start due to colder engine parts quenching the flame and preventing complete combustion. Biodiesel will reduce both HC and CO compared to diesel in the same engine, under the same conditions (Taberski et al., 1999).

### 4.5.2 Oxides of nitrogen

The NOx emissions behaviour of biodiesel in unmodified diesel engines varies in the literature, as evidenced by Table 4.7. This variability may be due to individual variables in the engines themselves. Gonzalez-Gomez et al. (2000) examined the emissions from esterified waste cooking oil and found that NOx levels were higher (than those of diesel) at all vehicle speeds.

### 4.5.3 Particulate matter

Taberski et al. (1999) suggest that whether one observes reductions in particulate matter when biodiesel is used in a diesel engine depends on the trade-off between a reduction in carbon soot and an increase in the soluble organic fraction. An exhaust catalyst typically reduces the soluble organic fraction – yet despite this we still note that there are studies on vehicles with such catalysts that report higher particle emissions from biodiesel than from diesel.

## 4.6.    Upstream Emissions of Canola and Rapeseed

### 4.6.1 Background

Canola is a member of the *Brassica* Family, which includes broccoli, cabbage, cauliflower, mustard, radish, and turnip. It is a variant of the crop rapeseed, with less crucic acid and glucosinolates than rapeseed. Grown for its seed, the seed is crushed for the oil contained within. After the oil is extracted, the by-product is a protein rich meal used by the intensive livestock industry.

In the 1990s, canola production increased dramatically due to new disease resistant varieties (Black Leg Resistance) and strong oilseed prices compared to wheat and wool. Australia has a land base to significantly increase canola area seeded.

Canola is a tiny seed, which means sowing depth must be controlled to minimise patchy germination. The current sowing practice is to lightly cover the seed with soil, which ensures more protection from drying out post-germination.

Canola is generally sown in autumn (late April/early May), develops over winter, flowers in the spring and is harvested early summer (Late November/early December) with a growing period of around 180-200 days

Climatic effects such as sudden heat waves can reduce yields and hot dry conditions can limit oil content, however summer weather ensures low moisture at harvest (<6% moisture). Carry-in stocks of canola are minimal because of a lack of on-farm storage.

Canola is a good rotational crop, acting as a break crop for cereal root diseases. However for disease-related reasons, a rotation period of 3-5 years is required for canola crops. Moreover, if on-going research on combating fungal root disease in wheat by seed inoculation proves successful, canola area will be pressured when canola prices fall.

*4.6.2    Production*

Current canola oil production is about 10% of Australian diesel oil consumption. Canola seed production in 2000/2001 was 1.6 Mt across a total cropping area of 1.3 Mha giving a gross yield of 1.26 t/ha of canola seeds. Oil yield from the seed is around 40% giving a total crude canola oil production of approximately 640,000 tonnes. If all of this were processed into biodiesel, with losses through refining of approximately 2.5% the potential Australian biodiesel production from canola would be 624 kt. This compares with a 1998 on-road diesel consumption in Australia of 6,600 kt (NGGIC, 2000).

Australian Oilseed Crush Capacity in 1997 was approximately 1.3 Mt p.a. made up of 0.40 Mt canola, 0.36 Mt cottonseed, 0.16 Mt sunflower seed, 0.15 Mt soybeans, 15,000 t other oilseeds

Crushing plant locations as in 1997 are detailed in Table 4.8. It is likely that more capacity has been introduced in Western Australia, where canola production has increased dramatically over the last five years. Refining capacity for vegetable oils in 1997 was approximately 500,000 tonnes with both crushing and refining capacity being utilised at around 90%. (Adaptation and Grain Policy Directorate, 2001).

**Table 4.8**
**Crushing plant locations and capacity for vegetable oil extraction in Australia**

| Location – Company | Capacity ('000 t) |
|---|---|
| Brisbane - Cargill | 125 |
| Moree(NSW) - Cargill | 120 |
| Narrabri(NSW) – Cargill | 350 |
| Maitland(NSW) – WC Caines | 50 |
| Newcastle - Cargill | 230 |
| Sydney - Seedex | 25 |
| Canowindra (NSW) - Aust. Country Canola | 12 |
| Cootamundra – Cootamundra Oilseeds | 5 |
| Grong Grong (NSW) - Ausguang | 100 |
| Footscray - Cargill | 130 |
| Numurkah(Vic) – Riverland | 80 |
| Millicent(SA) – Seedex | 25 |
| Pinjarra(WA) – Davison Industries | 25 |

Source: (Adaptation and Grain Policy Directorate, 2001)

Australian production in 2000/2001 decreased by one third from 1999/2000 due to lower area seeded, and lower yields related to severe drought across Western Australia. Exports are expected to decrease by almost 40% to 1.2 Mt. The production outlook is forecast to remain stable at 1.6 Mt as expected decline in seeded area is offset by a return to normal yields. Aventis and Monsanto plan to introduce Liberty Link and Round Up Ready canola to Australia in 2002 with exports of GMO canola occurring by 2003. GMO varieties are expected to increase yields by 25%.

Figure 4.2 shows the distribution of oilseed production in Australia in average hectares planted per farm. It reveals intensive activity in the inland area of south Western Australia and also in the Mallee region of western New South Wales. This is supported by data on state by state canola production, which is shown in Figure 4.3. While Western Australia has the largest area under cultivation for canola, its lower production rates per hectare mean that it is only slightly higher than New South Wales in terms of canola production.

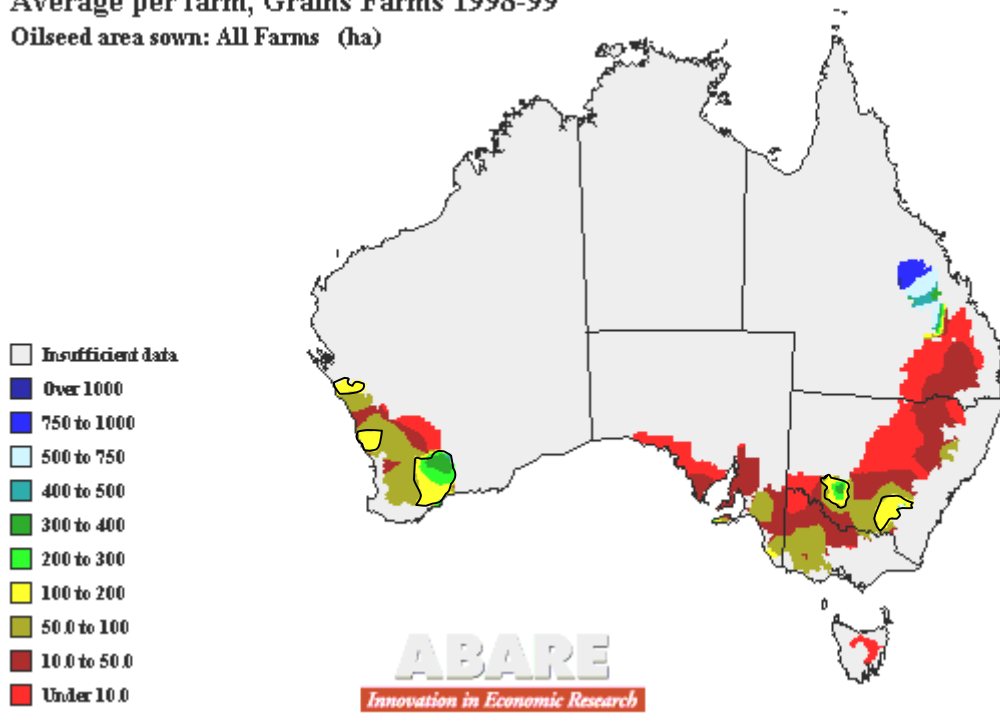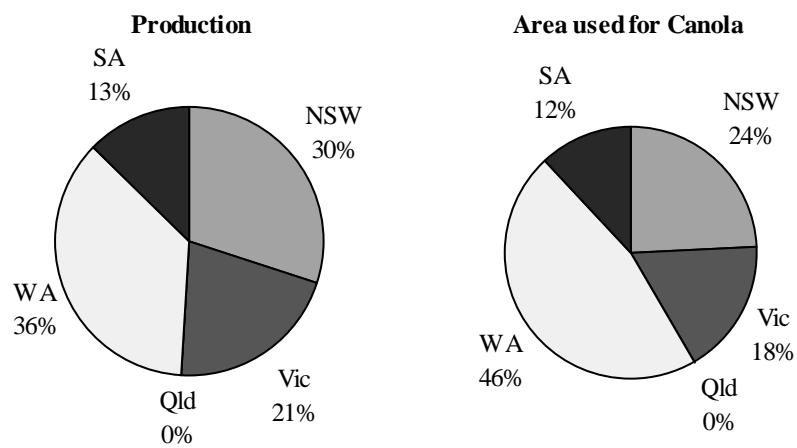Average per farm, Grains Farms 1998-99
Oilseed area sown: All Farms (ha)

| | |
|---|---|
| | Insufficient data |
| | Over 1000 |
| | 750 to 1000 |
| | 500 to 750 |
| | 400 to 500 |
| | 300 to 400 |
| | 200 to 300 |
| | 100 to 200 |
| | 50.0 to 100 |
| | 10.0 to 50.0 |
| | Under 10.0 |

**Figure 4.2**
**Location of Oil Seed production across Australia**



**Production**

SA 13%
NSW 30%
WA 36%
Qld 0%
Vic 21%

**Area used for Canola**

SA 12%
NSW 24%
Vic 18%
WA 46%
Qld 0%

Source: (Australian Bureau of Agricultural Research Economics, 2000)

**Figure 4.3**
**Canola production and land area used for farming by state for 2000-2001 Australia**

### 4.6.3 Fertiliser

Canola is a nutrient hungry crop compared to other winter crops, cereals, and grain legumes. The major nutrients required for Australian canola are nitrogen, sulfur, phosphorous, and zinc.

Available data regarding fertiliser input to canola farming has been collected from various sources, and is shown in Table 4.9. The second from the right column shows the nutrient removal per hectare of canola crop. Theoretically this is the amount needed to be replenished for canola agriculture to be sustainable. However, biomass from the canola plant is left behind in the field, which returns some of the nutrient to the soil. Recommendations for nutrient addition from the fertiliser producers is shown in the second column but varies widely according to soil conditions, and expected yield. The third column is recommendations from the Victorian Department of Natural Resources and Environment (NRE) in regards to the application rates of nitrogen for canola after cereal and pasture crops. The fourth column is estimated from figures on nitrogen and phosphorous usage data in oilseed growing areas from ABARE – Agaccess database (Australian Bureau of Agricultural Research Economics, 2000). (See Figure 4.4 and Figure 4.5, which overlay the oilseed growing area over the nitrogen and phosphorous usage maps.)

**Table 4.9**
**Information sources regarding fertilizer use when farming canola in kg/ha**

| Canola | Hi-Fert Recommendation[1] | Nitrogen application kg/ha[3] | Grain Access Data average fertilizer application in oilseed growing areas[2] | Nutrient removal kg per ha[1] | Data estimate used in this study |
|---|---|---|---|---|---|
| Nitrogen | 0-100 | A=100, B=60-80 | 20 to >30 | 82 | 20 |
| Phosphorous | 15-25 | | 10 to 20 | 14 | 10 |
| Sulfur | 0-30 | | | 20 | Supplied in other fertiliser |
| Zinc | 0-3 | | | 0.080 | 0 |

A=after cereal crop          B=after pasture crop

[1](WMC Fertilizers Pty Ltd, 2000)
[2](Australian Bureau of Agricultural Research Economics, 2000)
[3](Natural Resources and Environment, Victoria, Canola, www.nre.vic.gov.au, 2000) Des Whitfield Agronomist, NRE.

The only other data is from cost estimates for growing canola provided by NRE for 1995/96 (see Table 4.11), which has the cost of fertilisers at $65 per hectare for the Mallee in Victoria. Assuming nitrogen costs around $1.50 per kilogram (currently around $2 per kilogram elemental N after five years of inflation and GST) and phosphorous at around $6 per kilogram (currently around $8-10 per kilogram of elemental P after five years of inflation and GST), 20 kg of N and 10 kg of P would cost around $90. This discrepancy may be put down to higher fertility in the Victorian Mallee compared with other canola growing regions, particularly in Western Australia (which is supported by the nitrogen and phosphorous data in Figure 4.4 and Figure 4.5). Due to a lack of supporting data, sulfur and zinc were assumed to be supplied in existing fertiliser production.

The addition of fertiliser and cropping can lead to soil acidification. Data from the Land and Water Research Development Corporation (Australian Bureau of Statistics 1996) has liming costs for canola in South Australia at around $9 per ha per year in 1996 (averaged over a 15 year period). Using a price of 10c per kilogram from lime in 1996, a lime usage of 90 kg/ha/year was arrived at for use in the study.

# Part 2 Details of Fuels

The process of cultivation and application of fertiliser also has an impact on emissions of nitrous oxide ($N_2O$). The National Greenhouse Gas Inventory has emission listed for crop production of 0.45 kg $N_2O$ per hectare of crop per year. For fertiliser application it has an emission factor of 1.25% of Nitrogen applied ending up as $N_2O$ emission. This results in a total $N_2O$ emission per hectare of 0.85 kg as is shown in Table 4.10.

**Table 4.10**
**Nitrous Oxide Emissions from Fertiliser and Soil Disturbance**

| Nitrogen Source | Fertiliser Applied per year kg | Emission Factor % of N applied[1] | kg N ha$^{-1}$ year$^{-1}$ | Conversion Factor (N - N$_2$0)[1] | N$_2$O per Ha |
|---|---|---|---|---|---|
| Soil disturbance | | | 0.29[1] | 1.57 | 0.46 |
| Fertiliser application | 20 | 1.25% | 0.25 | 1.57 | 0.39 |
| Total | | | | | 0.85 |

Source:(NGGIC, 2000) Agricultural Soils 4D-1



Average per farm, Grains Farms 1998-99
Nitrogen used per area cropped: All Farms  (kg/ha)

Insufficient data
Over 30.0
20.0 to 30.0
15.0 to 20.0
12.0 to 15.0
10.0 to 12.0
8.00 to 10.0
6.00 to 8.00
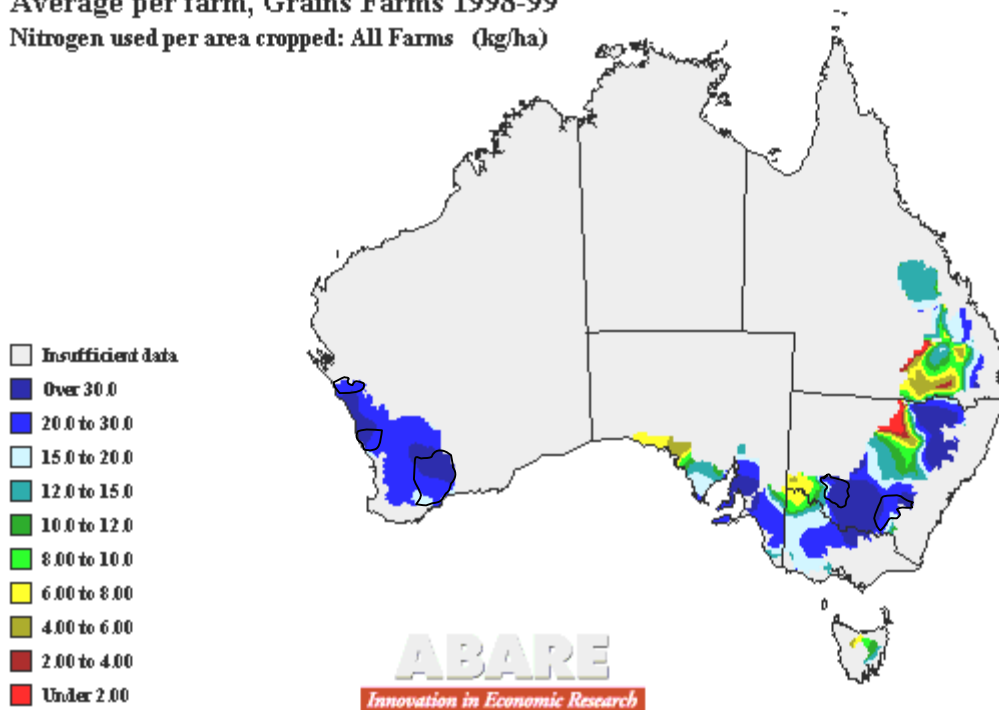4.00 to 6.00
2.00 to 4.00
Under 2.00

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**Figure 4.4**
**Elemental Nitrogen use per ha across Australian Farms with major oilseed production areas outlined.**

Average per farm, Grains Farms 1998-99
Phosphorus used per area cropped: All Farms (kg/ha)



Insufficient data
Over 30.0
20.0 to 30.0
15.0 to 20.0
12.0 to 15.0
10.0 to 12.0
8.00 to 10.0
6.00 to 8.00
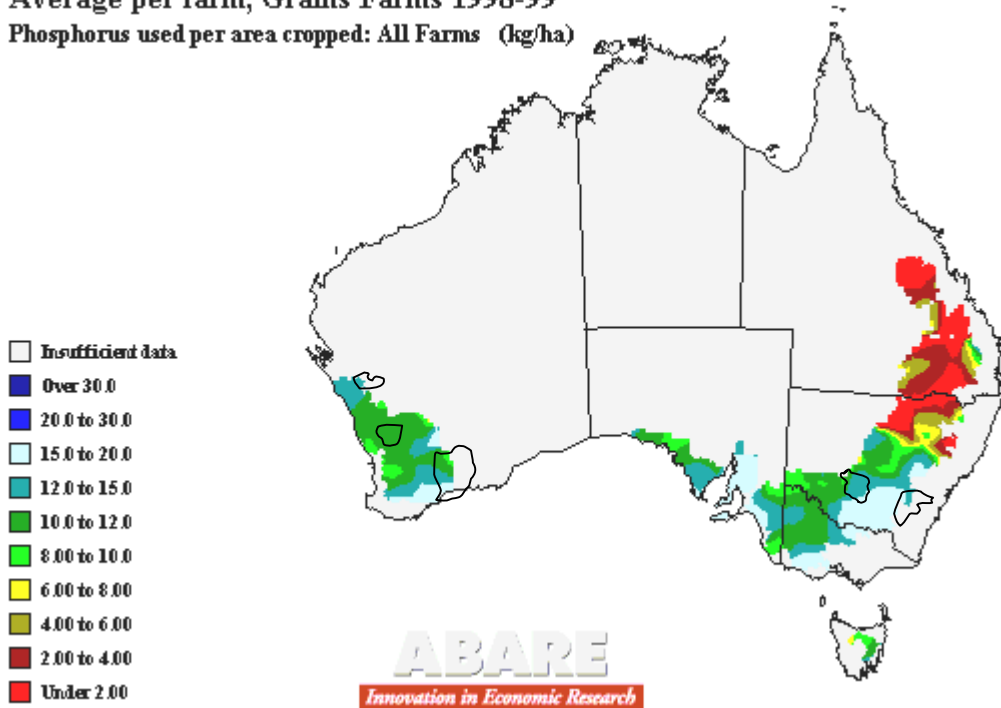4.00 to 6.00
2.00 to 4.00
Under 2.00

**Figure 4.5**
**Elemental Phosphorous use per ha across Australian Farms with major oilseed production areas outlined.**

**Table 4.11**
**Variable costs for canola grower in the Wimmera, 1995/96**

| Item | $/ha |
|---|---|
| seed | 13 |
| fertiliser | 65 |
| herbicides and insecticides | 36 |
| tractor costs | 20 |
| harvesting | 31 |
| other | 10 |
| total variable costs | 175 |

Source: [Natural Resources and Environment]

*4.6.4    Water requirements.*

The canola crop does not require excessive amounts of water. Although high temperatures and low water content limits oil yield, the cost of irrigating canola crops does not warrant such practices. Moreover industry experts believe that yield is affected more by disease, but at this stage are unsure about the exact nature of the disease and how it affects oil content. Data on irrigation practices within the field crop industry is lacking even for major crops such as wheat, consequently canola water use data does not exist presently (Gammie, 2001).

*4.6.5    Fuel Use*

Fuel use data on farms across Australia (Figure 4.6), shows that the oilseed growing areas in Western Australia have fuel use of around $15-20 per ha while in New South Wales the fuel cost is around $30 to more than $45 per ha. Overseas data from rapeseed production (Table 4.12) indicates a total diesel usage of 70 litres per ha. At a rate of 45c/litre for diesel (in 1998/99 with 80c pump price and 35c rebate for primary producers) the Australian data suggests a range from 33-44 litres per ha for Western Australia, and 66 to 100 litres per ha in New South Wales. With one third of the production being based in Western Australia at an average of 38 litres and two third in New South Wales, Victoria and South Australia at an average of 83 litres, a final estimate of 68 litres per hectare was used.

**Table 4.12**
**Fuel use data from rapeseed production in European RME LCA**

| Fuel | L/ha |
|------|------|
| Ploughing | 20.3 |
| Harrowing | 8.3 |
| Seed bed preparation | 12 |
| Sowing | 4.9 |
| Fertilizer application | 7.6 |
| Harvesting | 17 |
| Total | 70.1 |

Source: (Ceuterick and Spirinckx, 1997)



Average per farm, Grains Farms 1998-99
Fuel cost per hectare cropped: All Farms   ($/ha)

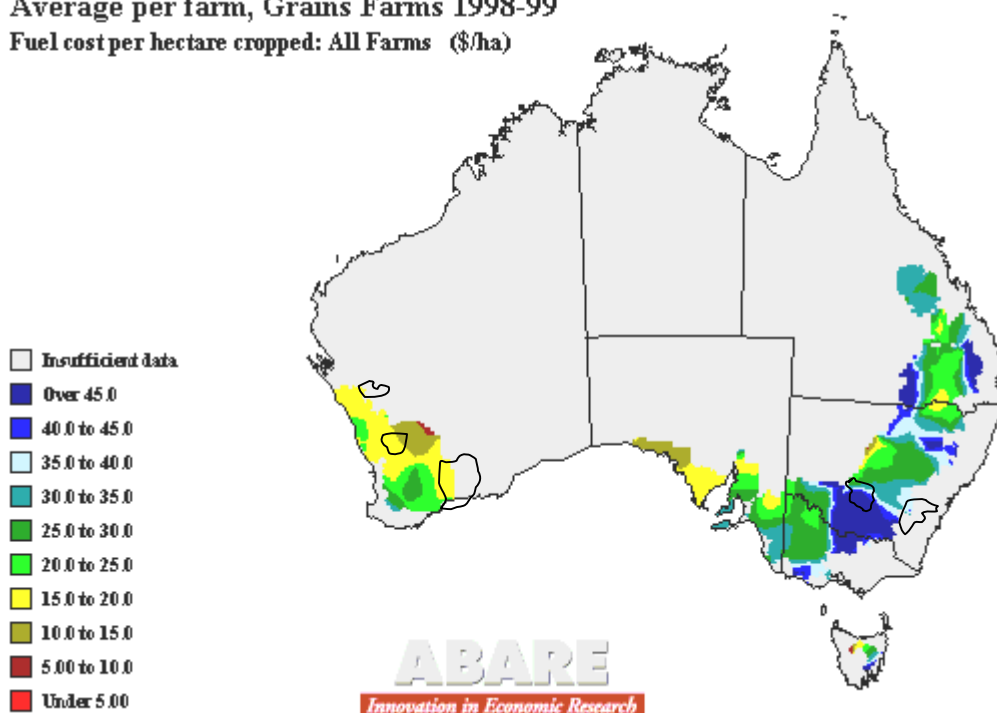Insufficient data
Over 45.0
40.0 to 45.0
35.0 to 40.0
30.0 to 35.0
25.0 to 30.0
20.0 to 25.0
15.0 to 20.0
10.0 to 15.0
5.00 to 10.0
Under 5.00

**Figure 4.6**
**Fuel cost per ha across Australian Farms with major oilseed production areas outlined.**

*4.6.6    Chemical crop protection*

Early weed control needs to be effective to ensure the canola crop establishes. Both broadleaves and grasses need to be controlled to ensure healthy crop development. One of the most common herbicides used in the agricultural industry is *Roundup*. As a dry formula the application rate is 265 g-660 g/ha and costs $120 per 11 kg container. In its liquid state the application rate is 400 ml-1.2 L/ha and costs $90 per 20 L container. (Prices based on bulk purchasing prices-E.E. Muir & Sons.)

Disease control is required to prevent fungal, bacterial, and viral pathogens. The impact of disease on canola crops is dependent upon region, climate, land management, as well as the previous crop harvested. Consequently application rates vary depending on the factors listed above.

High levels of insecticide are often unavoidable for insect pest control to ensure high yields of good quality canola seed. Pesticide application rates are influenced, like fungicides, by the factors listed above.

Figure 4.7 shows a map of spray usage per ha for Australian farms with the canola growing areas overlaid. It indicates that spraying costs in 1998-99 were around $40-$45 per ha in the oilseed growing areas.

The energy involved in the fertiliser and pesticide production and application, and the upstream emissions as a result of the production and application have been included in the calculation of upstream emissions.
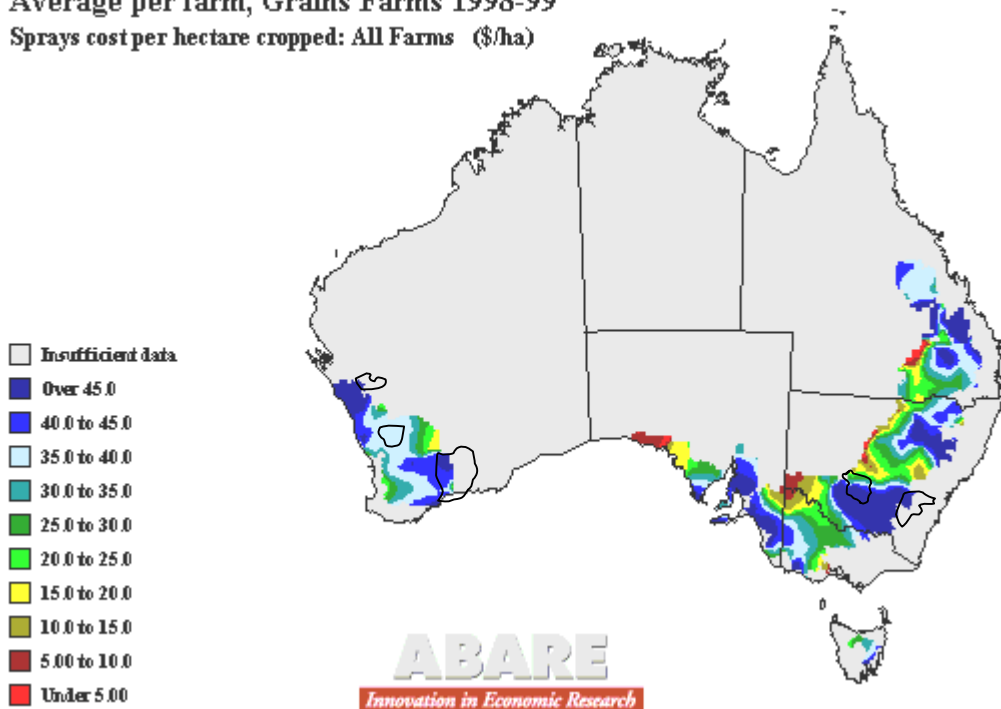


**Figure 4.7**
**Spray cost per ha farm across Australian Farms with major oilseed production areas outlined.**

**Table 4.13**
**Suggested crop protection application rates for canola (Coombs, 1994)**

| Herbicide kg/ha | Pesticide kg/ha | Fungicide kg/ha |
|:---:|:---:|:---:|
| 1.9 | 0.7 | 1.4 |

### 4.6.7    Co-products for canola seed production

Canola seed is produced as part of the canola crop and represents a small part of the total crop biomass. While the seed is clearly the primary product from canola, the other parts of the plant, the straw and stump and root material, also provide some economic benefits. The straw may be used for feed, or used as an energy source in the production of biodiesel. The straw and the root material may also be returned to the soil to replace nutrient material.

In the Flemish LCA of biodiesel (Ceuterick and Spirinckx, 1999) from rapeseed, the rape straw was assumed to be used for some economic purpose and was treated as product of equal value, per unit of dry mass. In a UK study (EcoTec Research and Consulting Ltd, 1999) straw was included as a fuel for biodiesel production, therefore eliminating the need to estimate the relative value of straw and the seed. In Australia the current practice is to leave the straw and stubble in the field as its quality does not warrant production into straw for feed, and the quantity is not sufficient for field burning (Gammie, 2001).

### 4.6.8    Drying, storage and handling

European data on rapeseed processing states that the seed requires drying treatment to reduce the moisture content from 15% to below 9% for storage purposes (Ceuterick and Spirinckx, 1999). In Australia, the canola seed contains approximately 6-10% moisture so no drying stage is required (Norton, 2000) and no drying was incorporated into the upstream activities. Transport of canola from the farm to oil processing is assumed to be relatively short given the locations of oil processing facilities detailed in Table 4.8. A value of 150 km by road is assumed in this study.

### 4.6.9    Oil extraction and refining

Data on canola oil extraction and refining is not available. However the canola refining process described by the Canadian Canola Council (Canola Council of Canada, 2001) is very similar to that used for rapeseed as described in the Flemish rapeseed biodiesel LCA (Ceuterick and Spirinckx, 1997), for which process data is available. The data and processes are described below.

Cleaning of the incoming seed is undertaken to remove plant material and other debris. The seeds are then dehulled, comminuted and heat-treated. The seeds are then pressed to produce oil (first press oil) and seed cake with an oil content of around 14 to 18%. This occurs at a temperature of between 72-84°C. The seed cake is then treated to a solvent extraction process (hexane), to decrease the oil content of the cake to between 3 and 5%. The hexane solvent is recycled through the process with a net loss of 1.5 kg per tonne of seeds handled. This is assumed to be lost as an emission to air. The seed cake is then toasted to remove the solvent before being sold as a protein source for feedstock. The oil hexane water mixture is then heated to remove water and recover the hexane, leaving the crude oil. Process data for these steps are shown in Table 4.14.

**Table 4.14**
**Process input and outputs for oil extraction of canola**

| Inputs | Unit | Value |
|---|---|---|
| Oils seeds | kg | 1000 |
| Electricity[1] | kWh | 45 |
| Steam (natural gas fired)[2] | kg | 310 |
| Hexane[1] | kg | 1.5 |
| **Outputs** | | |
| Crude Oil[3] | kg | 399 |
| Seed Cake[3] | kg | 598 |
| Solid Waste[1] | kg | 3 |
| Hexane to Air[1] | kg | 1.5 |

Notes
[1] Taken from rapeseed data (Ceuterick and Spirinckx, 1999)
[2] Taken from rapeseed data (Ceuterick and Spirinckx, 1999) based on energy input of 3.64 MJ/kg steam
[3] Based on expected canola oil yield of 40% less solid waste produced

The input and outputs of this process need to be allocated between the two valuable outputs – canola oil and meal. Canola oil is traded on the Western Canadian Exchange, which determines the price of canola. As with all commodities, the price fluctuates daily. The price is reported in the Australian Financial Review and on 29 March 2001 was C$281 per tonne. Canola meal is valued at US$162 per tonne (Canola Council of Canada, 2001). Due to the different value of the production a mass-based allocation would not be appropriate, so an economic allocation has been used and is shown in Table 4.15 with 63% of the burdens of the canola production and extraction process being allocated to the canola oil.

**Table 4.15**
**Allocation of environmental burdens between canola oil and meal**

| Product | Yield kg | Value per tonne $US | Value of Yield | Allocation % |
|---|---|---|---|---|
| Crude Oil | 399 | 411 | 164 | 63% |
| Seed Cake | 598 | 162 | 97 | 37% |

*Crude canola oil refining*

The crude canola oil from the extraction process contains phosphatides, gums and other colloidal compounds, which can cause problems through settling during storages. Therefore a refining process using steam removes them. During this process 2.5% of the oil is lost as a solid waste. Process data (shown in 4.16) is taken from the Flemish LCA for rapeseed oil, although their reported loss is 4%.

**Table 4.16**
**Process input and outputs for oil extraction of canola**

| Inputs | Unit | Value |
|---|---|---|
| Crude Oil | kg | 1000 |
| Electricity[1] | kWh | 10 |
| Steam (natural gas fired)[2] | kg | 80 |
| | | |
| **Outputs** | | |
| Refined Oil[3] | kg | 975 |
| Solid Waste[1] | kg | 25 |

Notes
[1] Taken from rapeseed data (Ceuterick and Spirinckx, 1999)
[2] Taken from rapeseed data (Ceuterick and Spirinckx, 1999) based on 2.5% of energy input as steam with an energy density of 3.64 MJ/kg

## 4.7. Soybean

Soybeans are a bushy, leguminous plant, *Glycine max*, native of South-East Asia that is grown for the beans, which are used widely in the food industry, for protein in cattle feed and for oil production.

Soybeans are grown predominantly in the wheat belts of Queensland and New South Wales and to a lesser extent in Victoria, as is shown in Figure 4.8. A total of 53 000 ha produced 105,000 tonne of soybeans in 2000 (Australian Bureau of Agricultural Research Economics, 2001), giving a yield of 2t/ha of soybeans.
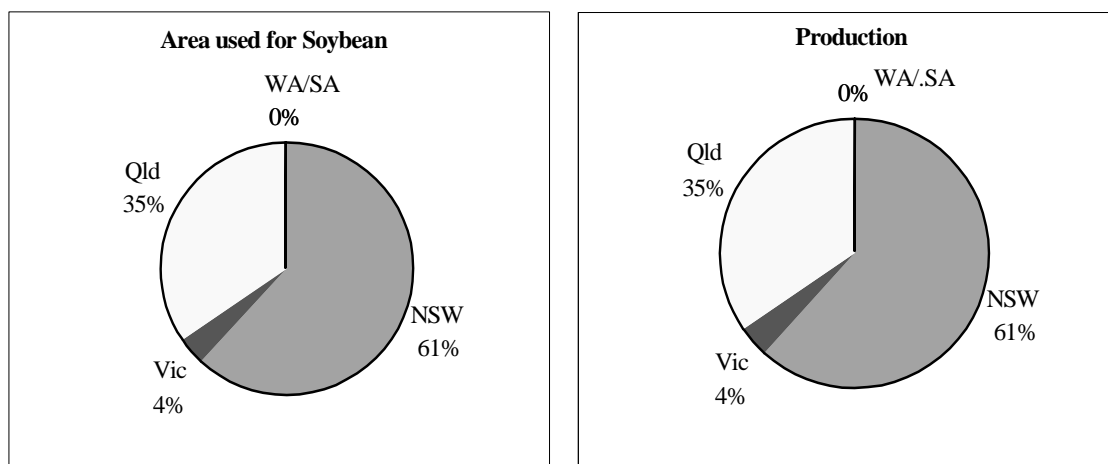


**Figure 4.8**
**Soybean area and production by state 2000 Australia**

Available overseas information regarding fertiliser input to soybean farming is shown in Table 4.17. This is contrasted with data on nitrogen and phosphorous usage in the wheat growing areas from ABARE – Agaccess database (Australian Bureau of Agricultural Research Economics, 2000). The final values chosen in the study are also given. These were the values applicable to soybeans, except for phosphorous where it was felt that the Australian data indicated that the overseas growers were over-applying phosphorous.

**Table 4.17**
**Information sources regarding fertiliser use when farming soybeans and wheat**

| Soybean | NREL Data[1] | Grain Access Data average fertiliser application in pulse growing areas[2] | Data used in Study |
|---|---|---|---|
| | kg/ha | kg/ha | kg/ha |
| Nitrogen | 15 | 20 to >30 | 15 |
| phosphorous | 25 | 6 to 12 | 12 |
| potash | 20 | | 20 |

[1](Sheehan et al., 1998)
[2](Australian Bureau of Agricultural Research Economics, 2000)

Fuel use data on farms across Australia from ABARE, show that in the wheat belt of Queensland fuel costs are around $15 to $25 per hectare. In New South Wales costs vary from $25 to $35, or more. This equates to fuel usage of between 33L and 77L using a fuel price of 45c/L for diesel (in 1998/99 with 80c pump price and 35c rebate for primary producers). The NREL study in the United States has fuel usage for soybean growing at 84L comprising of different fuels as shown in Table 4.18. It appears from the range of fuels in Table 4.18 that some other vehicle transport is included in the data (gasoline and LPG) which we may account for separately in product transport to oil processing. Ignoring the non-diesel fuels, the NREL data of 57.5 L is almost the same as the midpoint of the range given by the ABARE data of 55 L. Therefore the 55 L figure has been used in the study for soybean production in Australia.

**Table 4.18**
**Soybean Agriculture System Inputs from NREL study for USA**

| Energy: | Gal./acre[1] | L/ha | Density | kg per ha |
|---|---|---|---|---|
| Gasoline | 3.11 | 29.1 | 0.74 | 39.6 |
| Diesel | 5.29 | 49.5 | 0.86 | 57.4 |
| LP | 0.38 | 3.6 | 0.51 | 7.0 |

[1] Source:(Sheehan et al., 1998: Table 49)

### 4.7.1 Crop protection

The NREL study has a value of 4 lb per acre or 4.5 kg/ha for chemical application, which is listed predominantly as herbicides. The chemical directory in the Australian grains reference book (Coombs, 1994) suggests herbicide applications of around 1-2 litres per ha, and insecticides at around 0.5 to 2.5 L/ha. Assuming density close to this gives 1.5 to 4.5 kg of pesticide per ha of soybean crops. A figure of 3 kg/ha has been chosen for use in the study.

The only data available on pesticide manufacture is from a Danish study (Weidema, 1995) in which 60 MJ of ethane is used as feedstock and 164 MJ of process heat is required for manufacture. This data has been used for generic pesticide inputs in the absence of other information.

### 4.7.2 Drying, storage and handling (through to oil extraction and refining)

Due to the low volume of soybeans processed in Australia, very little data is available locally on oil extraction and processing. Data from the United States on soybean handling and processing (Sheehan et al., 1998) has been used for this study. Details of the process are provided by Sheehan et al. (1998), and it is similar to other seed crops. For transport of

soybean to oil processes a value of 150 km by road is assumed in this study, which is the same default value used for canola

The soybean are dried, dehulled, preconditioned with heat, crushed to extract the initial first press oil, before the remaining oil is extracted using a solvent (hexane) which is largely recovered in the process. The oil is then degummed before being ready for conversion to biodiesel. Energy and material inputs and outputs from the NREL study are given in Table 4.19 and Table 4.20.

**Table 4.19**
**Process inputs for 1 tonne for soybeans**

| Inputs | Value | Unit |
|---|---|---|
| Receiving and Storage | | |
| Australian Electricity | 21.3 | kWh |
| | | |
| Soybean Drying | | |
| Natural Gas Energy | 1.1 | GJ |
| | | |
| Dehulling | | |
| Natural Gas Energy | 0.173 | GJ |
| Australian Electricity | 21.59 | kWh |
| | | |
| Oil extraction | | |
| Natural Gas Energy | 0.087 | GJ |
| Australian Electricity | 0.38 | kWh |
| | | |
| Solvent Recovery, degumming oil and water treatment | | |
| Natural Gas Energy | 0.173 | GJ |
| Australian Electricity | 2.78 | kWh |
| | | |
| Meal processing | | |
| Hexane input | 2.02 | kg |
| Natural Gas Energy | 0.557 | GJ |
| Australian Electricity | 19.9 | kWh |

Source: (based on Sheehan et al., 1998)

**Table 4.20**
**Process Outputs for 1 tonne for soybeans**

| | | |
|---|---|---|
| Crude soybean oil | 170 | kg |
| Soymeal | 760 | kg |
| Hexane to Air | 1.72 | kg |
| Solid Waste [1] | 70 | kg |

Source: (Sheehan et al., 1998)
[1] This is based on a mass balance of input of soybeans – some of this material may be lost in waste water.

### 4.7.3    Allocation procedure for meal and oil from soybeans

The input and outputs of this process need to be allocated between the two valuable outputs – soybean oil and meal. Soybean oil is currently valued at around US$491 per tonne while the meal is valued at US$205 per tonne[1]. Due to the different value of the production a mass based allocation would not be appropriate, so an economic allocation has been used and is shown in Table 4.15 with 33.9% of the burdens of the soybean production and extraction process being allocated to the oil.

**Table 4.21**
**Allocation of environmental burdens between soybean oil and meal**

| Product | Yield kg | Value per tonne $US | Value of Yield | Allocation % |
|---|---|---|---|---|
| Crude Oil | 170 | 491 | 83 | 33.9% |
| Soybean Cake | 760 | 214 | 163 | 66.1% |

## 4.8.    Tallow

### 4.8.1    Background

Meat rendering is the processing of carcass waste from the meat industry. The process involves crushing the raw material, followed by the indirect application of heat. This evaporates the moisture and enables the fat, known as 'tallow', to be separated from the high-protein solids, known as 'greaves'. Pure tallow is a creamy-white substance. The greaves are pressed, centrifuged or subjected to a process of solvent extraction to remove more tallow, before being ground into meat and bone meal (MBM) (Matravers et al., 2000).

According to the UK report (Matravers et al., 2000), most rendering plants were 'dry rendering' (atmospheric) batch processors up until the 1960's. From the 1970s onwards, a variety of continuous rendering systems became available. They all use heating, separation and cooling on a continuous flow basis - essentially, raw material was fed in one end of the cooker and the finished product ejected out the other (Matravers et al., 2000). Solvent extraction appears to have fallen out of favour in most countries due to the cost and hazards.

### 4.8.2    Allocation issues for biodiesel from tallow

The main bioproducts from the meat industry are hides, offal, meat and bone meal and tallow. "The beef industry alone contributes $400 million worth of co-products annually, which are estimated to supply around one-fifth of the total value of an animal."(Meat and Livestock Australia, 2001).

There are two possible approaches to determining the impacts from increasing the use of tallow for biodiesel. One is to assume that increased demand for tallow will marginally increase the demand and consequent production of beef products in general.  This is not very likely as beef demand is the main determining factor in beef cattle production (assuming this increase is linked to the economic value of the by products, then this is referred to as an economic allocation of co-products). The second approach is to assume that tallow will be taken from other current users of tallow to meet the demand for tallow in bio-diesel. These other uses include soap and cosmetic applications and use in animal feedstocks. Many vegetable oils can be used in place of tallow for the soap and for cosmetic purposes, and are

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[1] The Australian Financial Review of 1 June 2001 quotes soybean futures as US$4.36 per bushel, soymeal as US$160 per ton, and soyoil as US$14.80 per lb.

assumed to be the most likely replacement for displaced tallow. While canola is not a good oil for soap production, it is cheap to produce and could therefore be expected to increase in production to meet increased demands for oils (needed for soap and other uses) created by the diversion of tallow into bio-diesel.[2] The impact of diverting tallow to bio-diesel is therefore modelled as the production of canola to replaced tallow displaced into biodiesel as shown in Figure 4.9. The LCA Standards (International Standards Organisation, 1997) refer to this type of modelling as system boundary expansion, which avoids allocation between the different beef by-products.
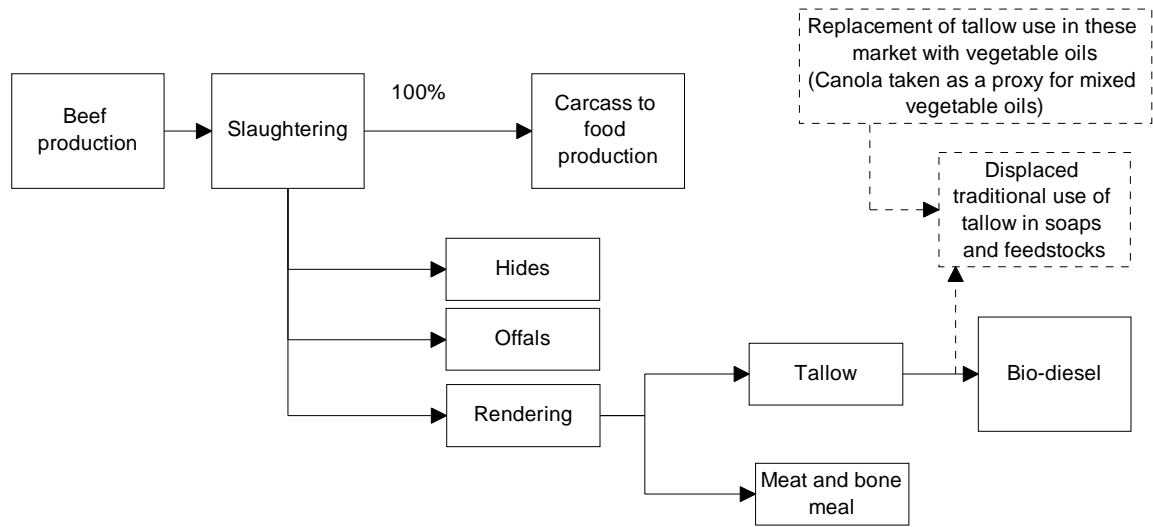


**Figure 4.9**
**Allocation of beef impact with system boundary expansion to include implications of using tallow in biodiesel production**

The alternative approach, mentioned above, is the economic allocation of emissions between the different by-products. Table 4.22 outlines estimates of the prices per head of beef for different products and co-products with the yield of production and the allocation percentage used in the study. Rendering products represent approximately 3.6% of the value of beef cattle.

Table 4.23 details the value and allocation percentage for rendering products showing that tallow represents 45% of the economic value of rendering products, which equates to 1.6% of total beef value. This leads to an allocation of beef production impacts to tallow as shown in Figure 4.10.

The modelling of beef production has been simplified in the study. From a greenhouse perspective the beef industry is responsible for a significant proportion of the greenhouse emissions due to methane from enteric fermentation in the intestines of cattle, and $N_2O$ from faecal matter and urine. Due to its importance, these emissions are included in the beef (and therefore in part in the tallow) production inventory.

While numerous animal products other than beef contribute to total tallow production, for reasons of simplicity this study will assume all tallow is derived primarily from beef products (the beef industry is estimated to provide 60% of the input to meat rendering).

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[2] Note that due to BSE and other cattle borne diseases the dynamics of tallow use are likely to change over the next few years, however no clear indication has been found as to how this might affect the use of allocation procedure for tallow in bio-diesel.

**Table 4.22**
**Allocation of beef products and co-products**

| | Average yield per kg of beef cattle | Average value of product per head of cattle (A$) | Allocation % |
|---|---|---|---|
| Beef Product | 0.55[3] | 800[1] | 80.2% |
| Hides | 0.060 | 90[2] | 9.1% |
| Render Products | 0.292[2] | 36[2] | 3.6% |
| Offals | 0.098[2] | 71[2] | 7.1% |

[1] At estimated US$400 per head
[2] Averaged across for Australian beef types (Prime Steer, US Cows, Japan Grass Fed Steer, Japan Grain Fed Steer) from (Meat and Livestock Australia, 2000)
[3] Estimated meat yield of 55%

**Table 4.23**
**Allocation of rendering products based on economic value**

| | Average yield kg per kg render feedstock | Average price per head of cattle (A$) | Allocation % |
|---|---|---|---|
| Tallow | 0.54 | 16.23[1] | 0.45 |
| Meat and Bone Meal | 0.46 | 19.76[1] | 0.55 |

[2] Averaged across for Australian beef types (Prime Steer, US Cows, Japan Grass Fed Steer, Japan Grain Fed Steer)
Source: Adapted from (Meat and Livestock Australia, 2000)
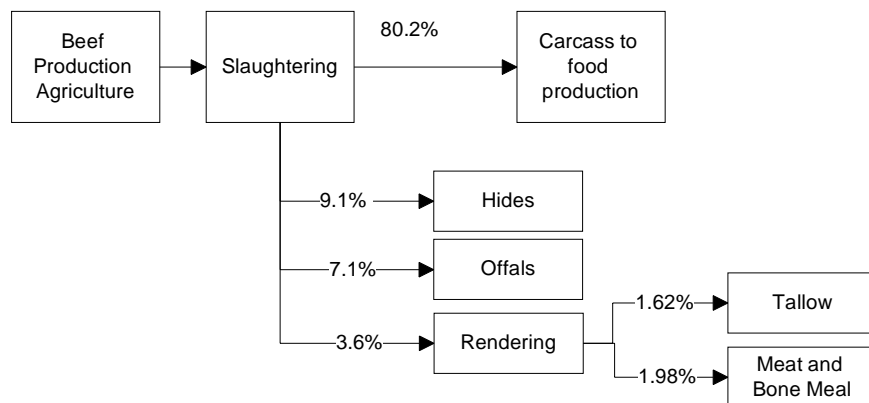


**Figure 4.10**
**Summary of tallow production allocation from beef cattle agriculture**

# 4.9.  Recycled Waste Cooking Oil

## 4.9.1  Background

Cooking oils, used for frying food have a limited life in food production due to contamination of the oil by food material. The disposal of waste cooking oil into landfill is generally prohibited in Australia[3], so that at the present time cooking oil needs to be collected from the

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3 For Victoria - Environment Protection (Prescribed Waste) Regulations 1998 S.R. No. 95/1998, Part B Prescribed Industrial Wastes Waste cooking oils unfit for their original intended use.

food industry for recycling or treatment for use in stockfeed. Current possibilities for the processing of waste cooking oils appear to be:

- Treatment and use in stockfeed in Australia (EcoRecycle Victoria, undated)
- Export to Asia for soap or stockfeed production (Anthony & Cornish, 2001)
- Use for production of biodiesel (Anthony & Cornish, 2001)

It is also clear that some waste cooking oil is not collected and is disposed of in landfill or other locations (Anthony and Corish, 2001). Biodiesel made from waste cooking oil has come to be known as McDiesel, because the largest source of waste cooking oil is McDonald's restaurants.

A sensitivity analysis has been included in the study to show the impact of assuming that the waste oil is of significant resale value, as has been suggested by some stakeholders. Under this alternate scenario 10% of the original value of the oil is assumed to be retained, and therefore 10% of the oil production impacts (assumed to be canola) are attributed to the waste oil.

### 4.9.2  Alternative technology association biodiesel project

The Alternative Technology Association (ATA) has undertaken some research into waste cooking oil generation and disposal by restaurants in the City of Moreland. They found the average restaurant (of those which responded), produced around 3000 litres of oil a year. Five per cent of the oil volume was reported as going to landfill (it is expected that this would be higher for the non respondents (Anthony, 2001).

In 1999, ATA received a small grant from the City of Moreland to establish a mini processing plant that could be used as a model for other small processing plants. Biodiesel production began in June 2000 and has been sold to various individuals and organisations, at a price between $1.50 and $2.00 per litre(Anthony and Cornish, 2001).

### 4.9.3  Allocation Issues for biodiesel from waste cooking oil

Current information on waste cooking oil collection indicates that large providers of oil are paid for their oil while small producers may have to pay to have their oil collected (Anthony, 2001). This suggests that in some situations the waste cooking oils collection is being driven by waste management imperatives and not by the recognised value in the oil. Following allocation guidelines developed by Weidema (1999), waste cooking oil can be seen as a "near to waste" co-product of the food production industry, that is not fully utilised (i.e. not all oil is currently recycled and there is little competition for waste cooking oil). Under this assumption only the impacts of recycling processes are allocated to the biodiesel with credits for avoided waste treatment processes being given to the biodiesel product. The difficult task for waste vegetable oil is determining the current waste treatment processes. Given poor quality of the information relating to waste cooking oil destinations, and the complexity of modelling upstream process for soap production in Asia, and the landfill impact of waste cooking oil being disposed of illegally, these systems have not been included at this stage. In effect waste cooking oil is modelled as a raw material with no upstream burdens that is input to the esterification process.

Given that collection of the oil is required for both the current waste treatment method, and for biodiesel production, there is no need to include collection as it can be assumed to be the same in each case.

## 4.10.  European Work

The European life-cycle studies of the IEA Automotive Fuels Information Services were summarised by Beer et al. (2000). Since that time the British Association for Bio Fuels and

Oils (BABFO) produced a report (EcoTec Research and Consulting Ltd., 1999) that summarised the life cycle emissions of gaseous pollutants from diesel and biodiesel for the UK. Their results are summarised in Table 4.24.

**Table 4.24**
**UK life cycle emissions for diesel and biodiesel used in a 2.5L Ford Transit van**

|  |  | GHG (g/km) | SOx (mg/km) | NOx (mg/km) | PM (mg/km) | VOC (mg/km) | CO (mg/km) |
|---|---|---|---|---|---|---|---|
| Diesel | Upstream | 33 | 207 | 145 | 4 | 416 | 19 |
| Diesel | Tailpipe | 245 | 80 | 1050 | 200 | 135 | 900 |
| Diesel | Total | 278 | 287 | 1195 | 204 | 551 | 919 |
| Biodiesel (from straw) | Upstream | 59 | 62 | 561 | 128 | 182 | 394 |
| Biodiesel (from straw) | Tailpipe | 0 | 20 | 1100 | 220 | 60 | 950 |
| Biodiesel (from straw) | Total | 59 | 82 | 1661 | 348 | 242 | 1344 |
| Biodiesel (from gas) | Upstream | 75 | 36 | 485 | 99 | 249 | 232 |
| Biodiesel (from gas) | Tailpipe | 0 | 20 | 1100 | 220 | 60 | 950 |
| Biodiesel (from gas) | Total | 75 | 56 | 1585 | 319 | 309 | 1182 |

Given the difference in vehicle types it is not possible to directly compare the results in Table 4.24 with those in Beer et al. (2000). Nevertheless the relative differences between diesel and biodiesel confirm some of the earlier findings – in particular the larger full fuel-cycle emissions of particulate matter from biodiesel when compared to diesel.

## 4.11. By-Products

During the production of biodiesel, by-products are formed. Straw, for instance, is a by-product of the production of rapeseed and the esterification of rapeseed oil produces glycerine. These by-products have a certain energetic value, the magnitude of which depends very much on the method used to determine energy-content. One way to express energy content is the calorific value of the by-product; another way is in terms of substitute energy - that is the energy saved when a certain fuel is replaced by use of the by-product. Thus the energy stored in the by-products cannot be compared directly with the energy value of biodiesel. The energy contents of, for instance, straw cannot serve directly as a diesel combustion fuel. For this reason, when calculating upstream emissions, the energy stored in by-products is considered of lower quality than the energy stored in biodiesel or diesel oil.

## 4.12. Full Fuel-Cycle Analysis of Emissions

The analysis given in this section deals with biodiesel as a fuel in its own right. In most cases biodiesel is used as a blend, or an additive, comprising about 20% of the diesel fuel (BD20). The exbodied emissions from such a blend can be calculated for the upstream emissions by using 80% of the diesel fuel exbodied emissions, and 20% of the corresponding biodiesel emissions given below. Tailpipe emissions do not appear to follow such a linear procedure. Tailpipe emissions for BD20 for buses and BD35 for trucks may be found in Beer et al. (2000).

In the tables below we consider two possible allocations for both tallow and waste cooking oil. The standard assumption is that both are waste products, and an expanded systems boundary approach was used to quantify their emissions. In both cases, an alternative allocation considers them to be marketable products.

# Part 2 Details of Fuels

## 4.12.1 *Emissions on a mass per unit energy basis*

The results obtained by using the SimaPro life-cycle model, along with the upstream and tailpipe emissions data specified in this chapter of this report, are given in Table 4.25 for the full life cycle for greenhouse gases and criteria pollutants. The upstream emissions and the tailpipe emissions that comprise these totals are given in Table 4.26 and Table 4.27 respectively. The greenhouse gas emissions and the economic weighted air pollutant emissions are graphed in Figure 4.11.

**Table 4.25**
**Urban and total life cycle emissions (per MJ) calculated for diesel and biodiesel**

| Full Lifecycle | Units | LS Diesel | Canola biodiesel | Soybean biodiesel | Rape biodiesel | Tallow biodiesel | Tallow alternative allocation | Waste cooking oil biodiesel | Waste cooking oil alternative allocation |
|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 0.0858 | 0.0433 | 0.0326 | 0.0443 | 0.0420 | 0.0498 | 0.0062 | 0.0065 |
| NMHC total | g HC | 0.140 | 0.145 | 0.172 | 0.146 | 0.142 | 0.060 | 0.053 | 0.054 |
| NMHC urban | g HC | 0.111 | 0.134 | 0.163 | 0.134 | 0.131 | 0.059 | 0.052 | 0.053 |
| NOx total | g NOx | 1.044 | 1.296 | 1.283 | 1.314 | 1.292 | 1.184 | 1.179 | 1.184 |
| NOx urban | g NOx | 0.987 | 1.219 | 1.235 | 1.221 | 1.217 | 1.184 | 1.179 | 1.183 |
| CO total | g CO | 0.253 | 0.171 | 0.219 | 0.172 | 0.170 | 0.141 | 0.140 | 0.145 |
| CO urban | g CO | 0.242 | 0.155 | 0.210 | 0.156 | 0.155 | 0.141 | 0.140 | 0.144 |
| PM10 total | mg PM10 | 40.7 | 29.9 | 29.4 | 30.5 | 29.8 | 27.6 | 27.5 | 27.5 |
| PM10 urban | mg PM10 | 39.3 | 28.4 | 28.5 | 28.4 | 28.4 | 27.6 | 27.5 | 27.5 |
| Energy Embodied | MJ LHV | 1.18 | 0.42 | 0.45 | 0.43 | 0.41 | 0.17 | 0.14 | 0.15 |
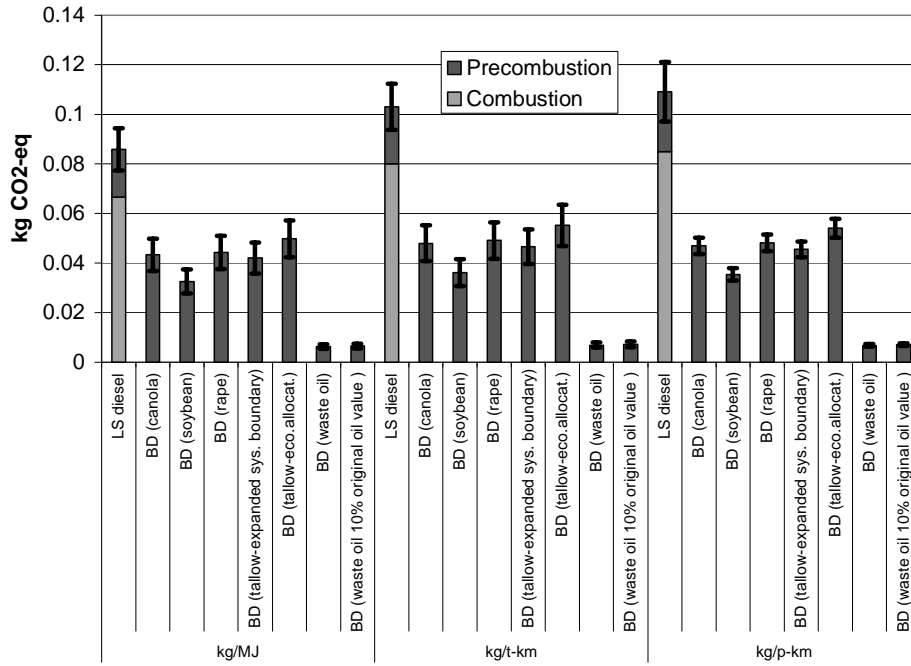
**Figure 4.11**
**Life cycle emissions of fossil fuel greenhouse gases from biodiesel compared to low sulfur diesel**

The results separate urban and rural emissions. Rural emissions may be evaluated as the difference between the total and the urban emissions. Emissions were assumed to occur in urban areas unless they were produced by a known rural or maritime activity.

Many of the values reported in the literature are in terms of g/MJ measured as useable energy from the engine driveshaft (normally represented as g/kWh), whereas the life-cycle calculations are consistent in setting all the calculations in terms of g/MJ based on the inherent chemical energy of the fuel. On average, this reduces quoted engine dynamometer values by a factor of three.

# Part 2 Details of Fuels

**Table 4.26**
**Urban and total upstream emissions per MJ for diesel and biodiesel**

| Precombustion | Units | LS Diesel (Aus) | Biodiesel (canola) | Biodiesel (soybean) | Biodiesel (rape) | Tallow biodiesel | Tallow alternative allocation | Waste cooking oil biodiesel | Waste cooking oil alternative allocation |
|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | kg CO$_2$ | 0.0191 | 0.0433 | 0.0326 | 0.0443 | 0.0420 | 0.0498 | 0.0062 | 0.0065 |
| NMHC total | g HC | 0.0565 | 0.141 | 0.168 | 0.142 | 0.138 | 0.0564 | 0.0494 | 0.0503 |
| NMHC urban | g HC | 0.027 | 0.130 | 0.159 | 0.130 | 0.127 | 0.055 | 0.049 | 0.049 |
| NOx total | g NOx | 0.100 | 0.140 | 0.127 | 0.158 | 0.136 | 0.028 | 0.023 | 0.027 |
| NOx urban | g NOx | 0.043 | 0.062 | 0.079 | 0.064 | 0.061 | 0.027 | 0.022 | 0.027 |
| CO total | g CO | 0.023 | 0.035 | 0.083 | 0.035 | 0.033 | 0.005 | 0.004 | 0.008 |
| CO urban | g CO | 0.012 | 0.019 | 0.074 | 0.019 | 0.019 | 0.005 | 0.004 | 0.008 |
| PM10 total | mg PM10 | 5.42 | 2.51 | 2 | 3.13 | 2.43 | 0.219 | 0.166 | 0.166 |
| PM10 urban | mg PM10 | 4 | 1.01 | 1.07 | 1.05 | 0.982 | 0.206 | 0.156 | 0.156 |
| Energy Embodied | MJ LHV | 1.18 | 0.42 | 0.45 | 0.43 | 0.41 | 0.17 | 0.14 | 0.15 |

**Table 4.27**
**Urban and total tailpipe emissions per MJ from diesel and biodiesel**

| Combustion | Units | LS Diesel (Aus) | Biodiesel (canola) | Biodiesel (soybean) | Biodiesel (rape) | Biodiesel (tallow) | Biodiesel (waste cooking oil) |
|---|---|---|---|---|---|---|---|
| Greenhouse | kg CO$_2$ | 0.0667 | - | - | - | - | - |
| NMHC total | g HC | 0.0835 | 0.0039 | 0.004 | 0.004 | 0.0038 | 0.0038 |
| NMHC urban | g HC | 0.0835 | 0.0039 | 0.0040 | 0.0040 | 0.0038 | 0.0038 |
| NOx total | g NOx | 0.944 | 1.156 | 1.156 | 1.156 | 1.156 | 1.156 |
| NOx urban | g NOx | 0.944 | 1.156 | 1.156 | 1.156 | 1.156 | 1.156 |
| CO total | g CO | 0.230 | 0.136 | 0.136 | 0.136 | 0.136 | 0.136 |
| CO urban | g CO | 0.230 | 0.136 | 0.136 | 0.136 | 0.136 | 0.136 |
| PM10 total | mg PM10 | 35.3 | 27.4 | 27.4 | 27.4 | 27.4 | 27.4 |
| PM10 urban | mg PM10 | 35.3 | 27.4 | 27.4 | 27.4 | 27.4 | 27.4 |
| Energy Embodied | MJ LHV | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |

*4.12.2   Vehicle emissions - trucks (g/km)*

This section gives the calculated values for the emissions from trucks, on a per-kilometre basis.

**Table 4.28**
**Urban and total life cycle emissions per km for trucks calculated for diesel and biodiesel**

| Full LC | | LS Diesel engine | Canola biodiesel | Soybean biodiesel | Rape biodiesel | Tallow biodiesel | Tallow alternative allocation | Waste cooking oil biodiesel | Waste cooking oil alternative allocation |
|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 0.9250 | 0.4310 | 0.3250 | 0.4410 | 0.4180 | 0.4960 | 0.0705 | 0.0736 |
| NMHC total | g HC | 1.509 | 1.439 | 1.709 | 1.449 | 1.409 | 0.600 | 0.597 | 0.607 |
| NMHC urban | g HC | 1.192 | 1.329 | 1.619 | 1.329 | 1.299 | 0.588 | 0.587 | 0.597 |
| NOx total | g NOx | 11.250 | 12.895 | 12.775 | 13.075 | 12.855 | 11.784 | 11.764 | 11.814 |
| NOx urban | g NOx | 10.638 | 12.125 | 12.292 | 12.144 | 12.112 | 11.775 | 11.757 | 11.807 |
| CO total | g CO | 2.723 | 1.699 | 2.184 | 1.707 | 1.689 | 1.407 | 1.403 | 1.450 |
| CO urban | g CO | 2.612 | 1.545 | 2.088 | 1.548 | 1.540 | 1.404 | 1.400 | 1.447 |
| PM10 total | mg PM10 | 438.4 | 297.5 | 292.4 | 303.6 | 296.7 | 274.6 | 274.3 | 274.3 |
| PM10 urban | mg PM10 | 423.1 | 282.6 | 283.1 | 282.9 | 282.2 | 274.5 | 274.2 | 274.2 |
| Energy Embodied | MJ LHV | 12.7 | 4.14 | 4.5 | 4.25 | 4.05 | 1.69 | 1.61 | 1.65 |

# Part 2 Details of Fuels

**Table 4.29**
**Urban and total precombustion emissions per km for trucks calculated for diesel and biodiesel**

| Precombustion | | LS Diesel (Aus) | Canola biodiesel | Soybean biodiesel | Rape biodiesel | Tallow biodiesel | Tallow alternative allocation | Waste cooking oil biodiesel | Waste cooking oil alternative allocation |
|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 0.2060 | 0.4310 | 0.3250 | 0.4410 | 0.4180 | 0.4960 | 0.0705 | 0.0736 |
| NMHC total | g HC | 0.609 | 1.4 | 1.67 | 1.41 | 1.37 | 0.561 | 0.558 | 0.568 |
| NMHC urban | g HC | 0.292 | 1.290 | 1.580 | 1.290 | 1.260 | 0.549 | 0.548 | 0.558 |
| NOx total | g NOx | 1.080 | 1.390 | 1.270 | 1.570 | 1.350 | 0.279 | 0.259 | 0.309 |
| NOx urban | g NOx | 0.468 | 0.620 | 0.787 | 0.639 | 0.607 | 0.270 | 0.252 | 0.302 |
| CO total | g CO | 0.243 | 0.343 | 0.828 | 0.351 | 0.333 | 0.051 | 0.047 | 0.094 |
| CO urban | g CO | 0.132 | 0.189 | 0.732 | 0.192 | 0.184 | 0.048 | 0.044 | 0.092 |
| PM10 total | mg PM10 | 58.4 | 25 | 19.9 | 31.1 | 24.2 | 2.17 | 1.87 | 1.87 |
| PM10 urban | mg PM10 | 43.1 | 10.1 | 10.6 | 10.4 | 9.77 | 2.05 | 1.76 | 1.76 |
| Energy Embodied | MJ LHV | 12.7 | 4.14 | 4.5 | 4.25 | 4.05 | 1.69 | 1.61 | 1.65 |

**Table 4.30**
**Urban and total tailpipe emissions per km for trucks calculated for diesel and biodiesel**

| Combustion | | LS Diesel (Aus) | Biodiesel (canola) | Biodiesel (soybean) | Biodiesel (rape) | Biodiesel (tallow) | Biodiesel (waste cooking oil) |
|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 0.719 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| NMHC total | g HC | 0.900 | 0.039 | 0.040 | 0.040 | 0.038 | 0.038 |
| NMHC urban | g HC | 0.900 | 0.039 | 0.040 | 0.040 | 0.038 | 0.038 |
| NOx total | g NOx | 10.18 | 11.51 | 11.51 | 11.51 | 11.51 | 11.51 |
| NOx urban | g NOx | 10.18 | 11.51 | 11.51 | 11.51 | 11.51 | 11.51 |
| CO total | g CO | 2.48 | 1.36 | 1.36 | 1.36 | 1.36 | 1.36 |
| CO urban | g CO | 2.48 | 1.36 | 1.36 | 1.36 | 1.36 | 1.36 |
| PM10 total | mg PM10 | 380 | 272 | 272 | 272 | 272 | 272 |
| PM10 urban | mg PM10 | 380 | 272 | 272 | 272 | 272 | 272 |
| Energy Embodied | MJ LHV | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

## 4.12.3   Vehicle emissions - buses (g/km)

This section gives the calculated values for the emissions from buses, on a per-kilometre basis. The greenhouse gas emissions are graphed in Figure 4.10.

# Part 2 Details of Fuels

**Table 4.31**
**Urban and total life cycle emissions per km for buses calculated for diesel and biodiesel**

| Full LC | | LS Diesel | Canola biodiesel | Soybean biodiesel | Rape biodiesel | Tallow biodiesel | Tallow alternative allocation | Waste cooking oil biodiesel | Waste cooking oil alternative allocation |
|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 1.66 | 0.77 | 0.58 | 0.79 | 0.75 | 0.89 | 0.13 | 0.13 |
| NMHC total | g HC | 2.71 | 2.58 | 3.07 | 2.60 | 2.53 | 1.08 | 1.07 | 1.09 |
| NMHC urban | g HC | 2.14 | 2.39 | 2.91 | 2.39 | 2.33 | 1.06 | 1.05 | 1.07 |
| NOx total | g NOx | 20.20 | 23.15 | 22.94 | 23.48 | 23.08 | 21.16 | 21.12 | 21.21 |
| NOx urban | g NOx | 19.10 | 21.77 | 22.07 | 21.81 | 21.75 | 21.14 | 21.11 | 21.20 |
| CO total | g CO | 4.89 | 3.05 | 3.92 | 3.06 | 3.03 | 2.53 | 2.52 | 2.60 |
| CO urban | g CO | 4.69 | 2.77 | 3.75 | 2.78 | 2.76 | 2.52 | 2.51 | 2.60 |
| PM10 total | mg PM10 | 787 | 534 | 525 | 545 | 533 | 493 | 493 | 493 |
| PM10 urban | mg PM10 | 760 | 507 | 508 | 508 | 507 | 493 | 492 | 492 |
| Energy Embodied | MJ LHV | 22.8 | 7.4 | 8.1 | 7.6 | 7.3 | 3.0 | 2.9 | 3.0 |

**Table 4.32**
**Urban and total precombustion emissions per km for buses calculated for diesel and biodiesel**

| Precombustion | | LS Diesel (Aus) | Canola biodiesel | Soybean biodiesel | Rape biodiesel | Tallow biodiesel | Tallow alternative allocation | Waste cooking oil biodiesel | Waste cooking oil alternative allocation |
|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 0.37 | 0.77 | 0.58 | 0.79 | 0.75 | 0.89 | 0.13 | 0.13 |
| NMHC total | g HC | 1.09 | 2.51 | 3.00 | 2.53 | 2.46 | 1.01 | 1.00 | 1.02 |
| NMHC urban | g HC | 0.52 | 2.32 | 2.84 | 2.32 | 2.26 | 0.99 | 0.98 | 1.00 |
| NOx total | g NOx | 1.94 | 2.50 | 2.28 | 2.82 | 2.42 | 0.50 | 0.47 | 0.55 |
| NOx urban | g NOx | 0.84 | 1.11 | 1.41 | 1.15 | 1.09 | 0.48 | 0.45 | 0.54 |
| CO total | g CO | 0.44 | 0.62 | 1.49 | 0.63 | 0.60 | 0.09 | 0.08 | 0.17 |
| CO urban | g CO | 0.24 | 0.34 | 1.31 | 0.34 | 0.33 | 0.09 | 0.08 | 0.16 |
| PM10 total | mg PM10 | 104.9 | 44.9 | 35.7 | 55.8 | 43.5 | 3.9 | 3.4 | 3.4 |
| PM10 urban | mg PM10 | 77.4 | 18.1 | 19.0 | 18.7 | 17.5 | 3.7 | 3.2 | 3.2 |
| Energy Embodied | MJ LHV | 22.8 | 7.4 | 8.1 | 7.6 | 7.3 | 3.0 | 2.9 | 3.0 |

**Table 4.33**
**Urban and total tailpipe emissions per km for buses calculated for diesel and biodiesel**

| Combustion | | LS Diesel (Aus) | Biodiesel (canola) | Biodiesel (soybean) | Biodiesel (rape) | Biodiesel (tallow) | Biodiesel (waste cooking oil) |
|---|---|---|---|---|---|---|---|
| Greenhouse | kg $CO_2$ | 1.2910 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| NMHC total | g HC | 1.616 | 0.070 | 0.071 | 0.071 | 0.068 | 0.068 |
| NMHC urban | g HC | 1.616 | 0.070 | 0.071 | 0.071 | 0.068 | 0.068 |
| NOx total | g NOx | 18.270 | 20.658 | 20.658 | 20.658 | 20.658 | 20.658 |
| NOx urban | g NOx | 18.270 | 20.658 | 20.658 | 20.658 | 20.658 | 20.658 |
| CO total | g CO | 4.453 | 2.434 | 2.434 | 2.434 | 2.434 | 2.434 |
| CO urban | g CO | 4.453 | 2.434 | 2.434 | 2.434 | 2.434 | 2.434 |
| PM10 total | mg PM10 | 682.3 | 489.2 | 489.2 | 489.2 | 489.2 | 489.2 |
| PM10 urban | mg PM10 | 682.3 | 489.2 | 489.2 | 489.2 | 489.2 | 489.2 |
| Energy Embodied | MJ LHV | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### 4.12.4  Uncertainties

We use the uncertainty estimates given by Beer et al. (2000) on the basis of the tailpipe emissions to estimate the uncertainties associated with the above results to be as given in Table 4.34.

**Table 4.34**
**Estimated one standard deviation uncertainties for biodiesel emissions**

| | g/MJ | g/t-km | g/p-km |
|---|---|---|---|
| CO2 | 15 | 15 | 7 |
| NMHC | 43 | 71 | 15 |
| NOx | 30 | 23 | 38 |
| CO | 72 | 106 | 37 |
| PM10 | 71 | 81 | 61 |

| | |
|---|---|
| 1 km. Canola biodiesel per km. Value: 0.428 | |

```
1 km.
Canola biodiesel
per km.

Value: 0.428
        ↑
9.95 MJ
Canola biodiesel
engine

Value: 0.428
        ↑
0.263 kg
Biodiesel (canola)

Value: 0.428
     ↑         ↑
```

| 0.285 kg Canola (refined) Value: 0.359 | 0.275 kg Transesterification of biodiesel Value: 0.0696 |
|---|---|

| 0.292 kg Canola crude oil Value: 0.356 | 0.0234 kg Steam from natural gas 3.64MJ/kg Value: 0 | 0.0105 MJ Australian Electricity HV Value: 0.00275 |
|---|---|---|

| 0.462 kg Canola seed Value: 0.336 | 0.000692 kg Hexane (Aus) Value: 0.00047 | 0.143 kg Steam from natural gas 3.64MJ/kg Value: 0 | 0.0748 MJ Australian Electricity HV Value: 0.0195 |
|---|---|---|---|

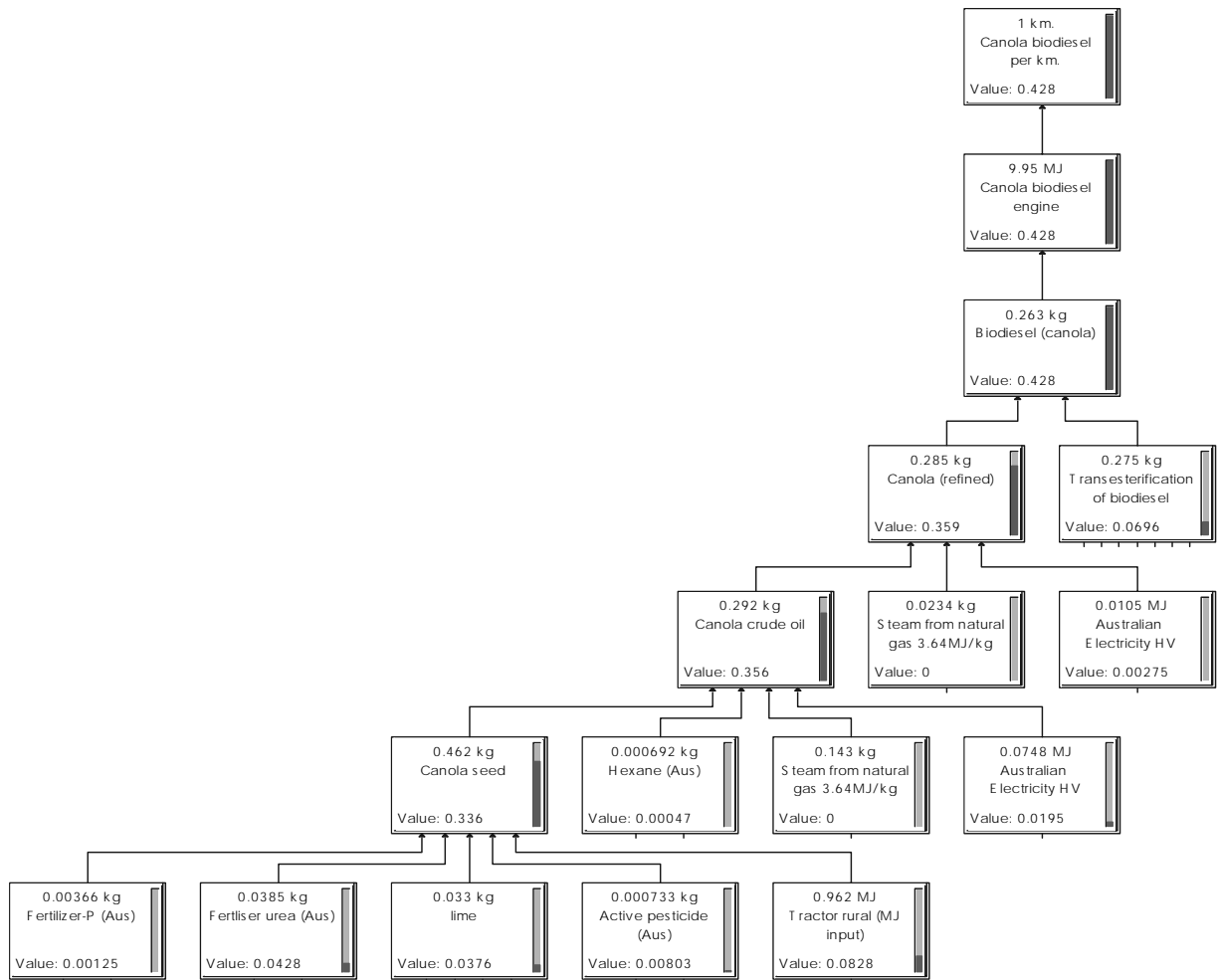| 0.00366 kg Fertilizer-P (Aus) Value: 0.00125 | 0.0385 kg Fertiliser urea (Aus) Value: 0.0428 | 0.033 kg lime Value: 0.0376 | 0.000733 kg Active pesticide (Aus) Value: 0.00803 | 0.962 MJ Tractor rural (MJ input) Value: 0.0828 |
|---|---|---|---|---|

**Figure 4.12**
**Exbodied greenhouse gas emissions (kg CO$_2$ eq) from canola biodiesel production and processing and use in vehicle (canola production expanded)**
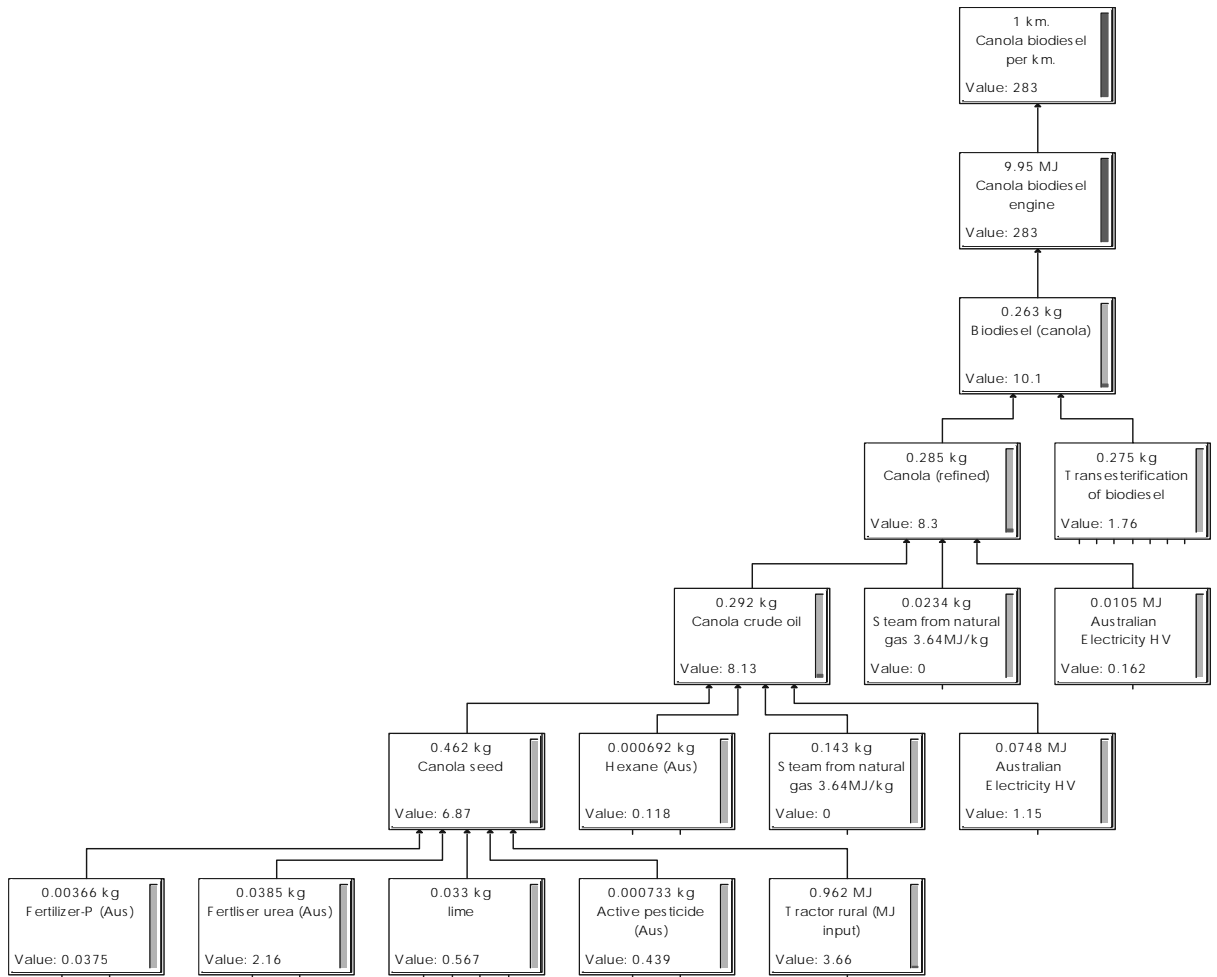
# Part 2 Details of Fuels



**Figure 4.13**
**Exbodied particulate matter (mg - urban) from canola biodiesel production and processing and use in vehicle**
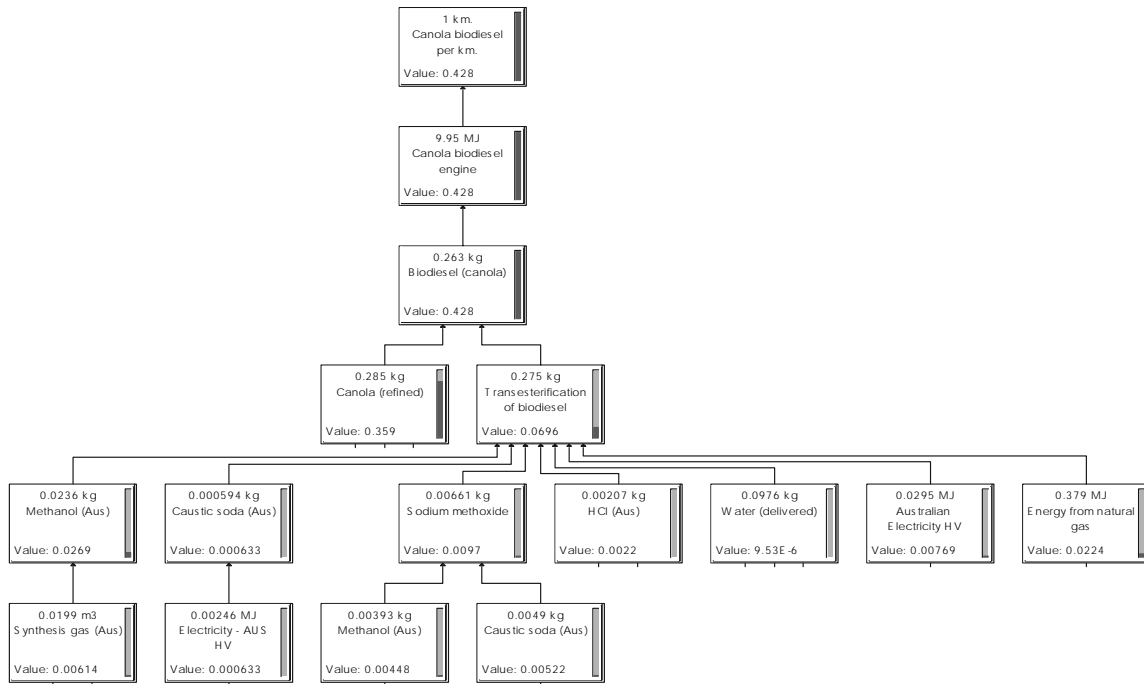
# Part 2 Details of Fuels



**Figure 4.14**
**Exbodied greenhouse gas emissions (kg CO$_2$ eq) from canola biodiesel production and processing and use in vehicle (transesterification process expanded)**
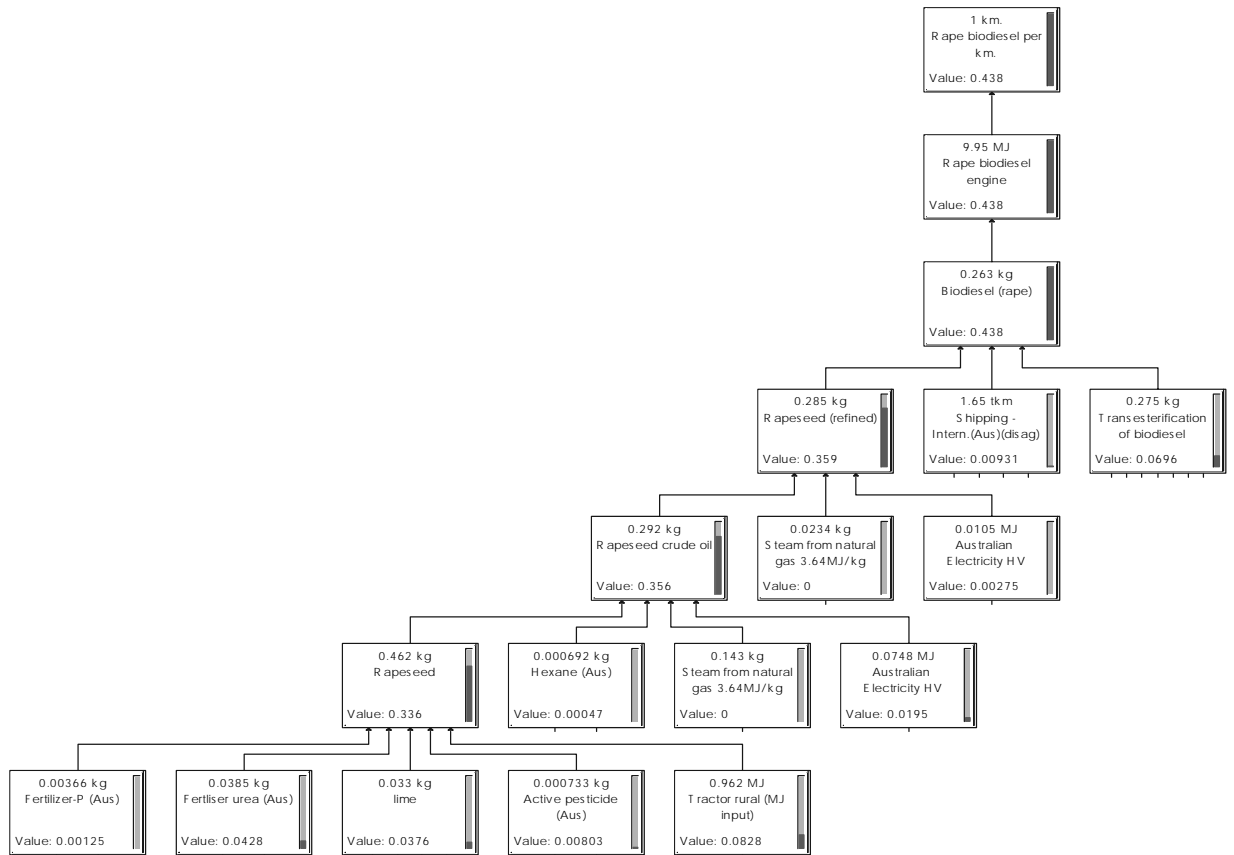
```
                                    ┌─────────────────┐
                                    │     1 km.       │
                                    │ Rape biodiesel per│
                                    │      km.        │
                                    │                 │
                                    │  Value: 0.438   │
                                    └─────────────────┘
                                            ▲
                                    ┌─────────────────┐
                                    │    9.95 MJ      │
                                    │ Rape biodiesel  │
                                    │     engine      │
                                    │                 │
                                    │  Value: 0.438   │
                                    └─────────────────┘
                                            ▲
                                    ┌─────────────────┐
                                    │    0.263 kg     │
                                    │ Biodiesel (rape)│
                                    │                 │
                                    │  Value: 0.438   │
                                    └─────────────────┘
                        ┌───────────────┬───┴───────────┬───────────────┐
              ┌─────────────────┐ ┌─────────────────┐ ┌─────────────────┐
              │    0.285 kg     │ │    1.65 tkm     │ │    0.275 kg     │
              │ Rapeseed (refined)│ │  Shipping -    │ │ Transesterification│
              │                 │ │ Intern.(Aus)(disag)│ │  of biodiesel  │
              │  Value: 0.359   │ │  Value: 0.00931 │ │  Value: 0.0696  │
              └─────────────────┘ └─────────────────┘ └─────────────────┘
```

**Figure 4.15**
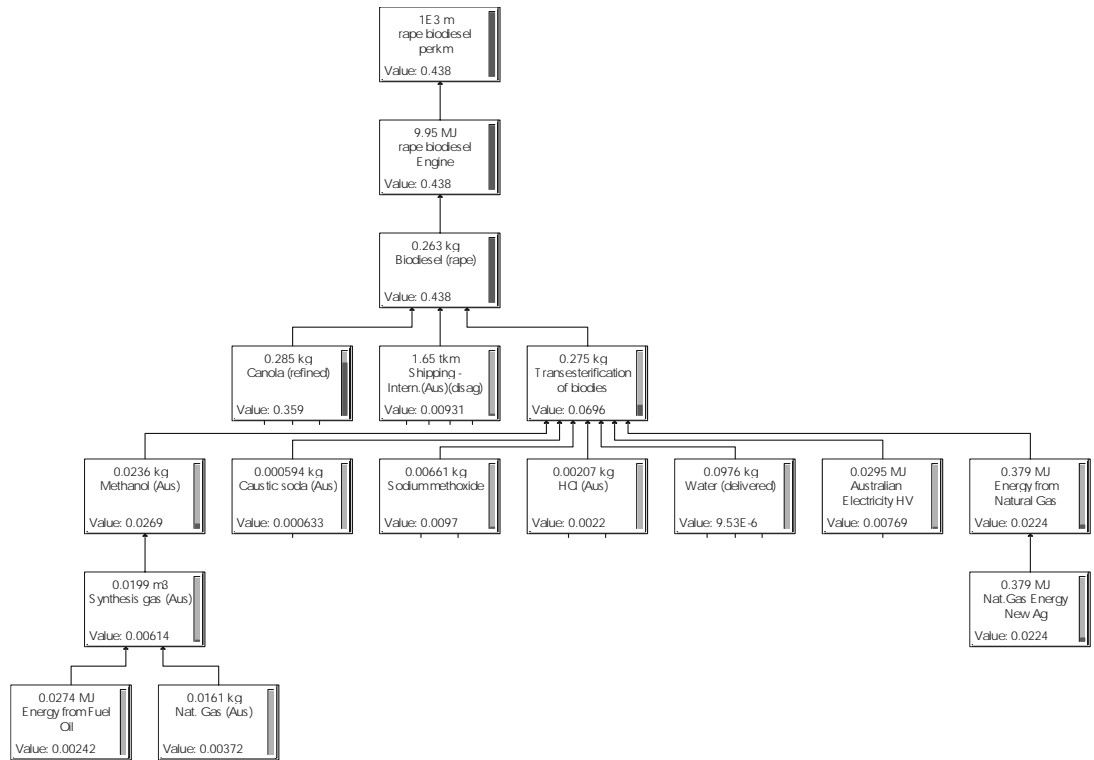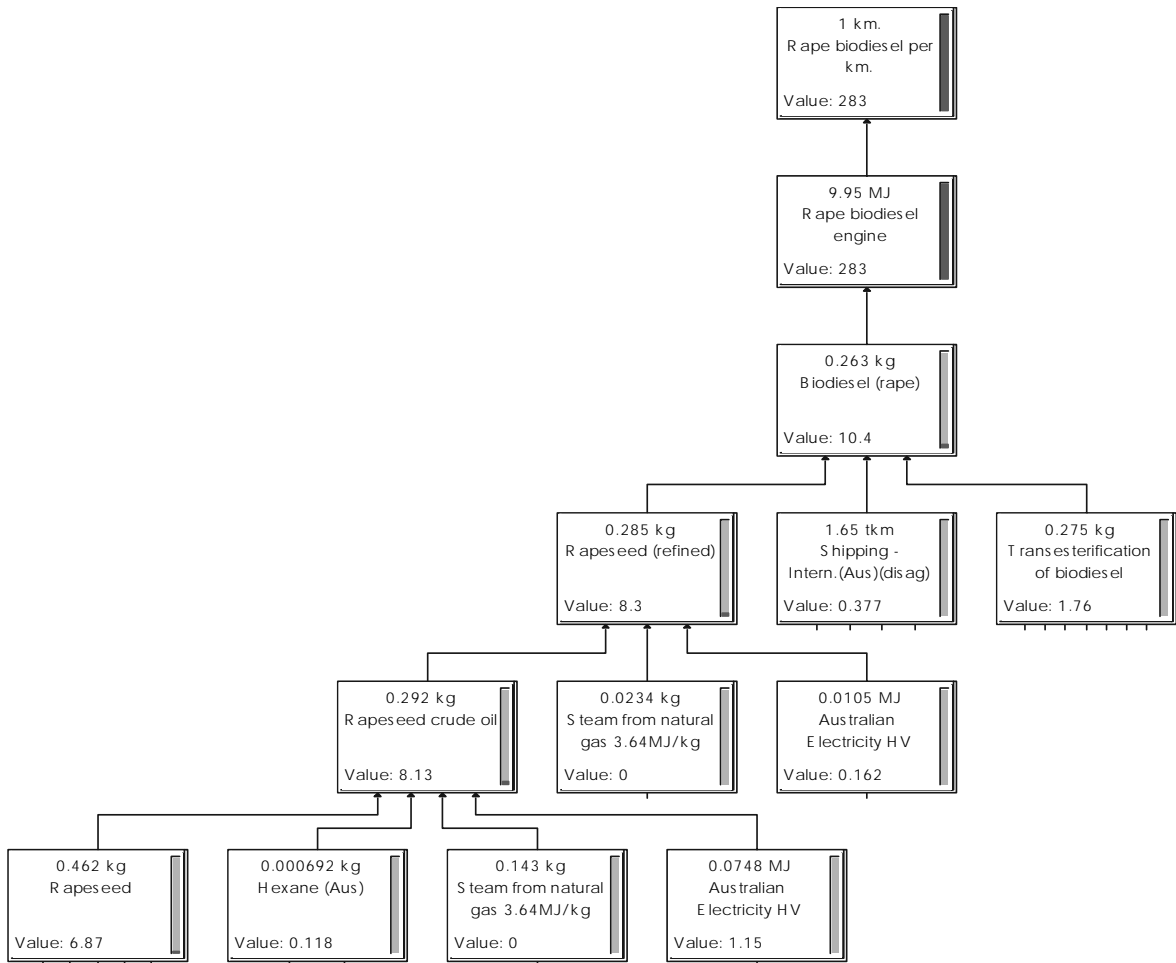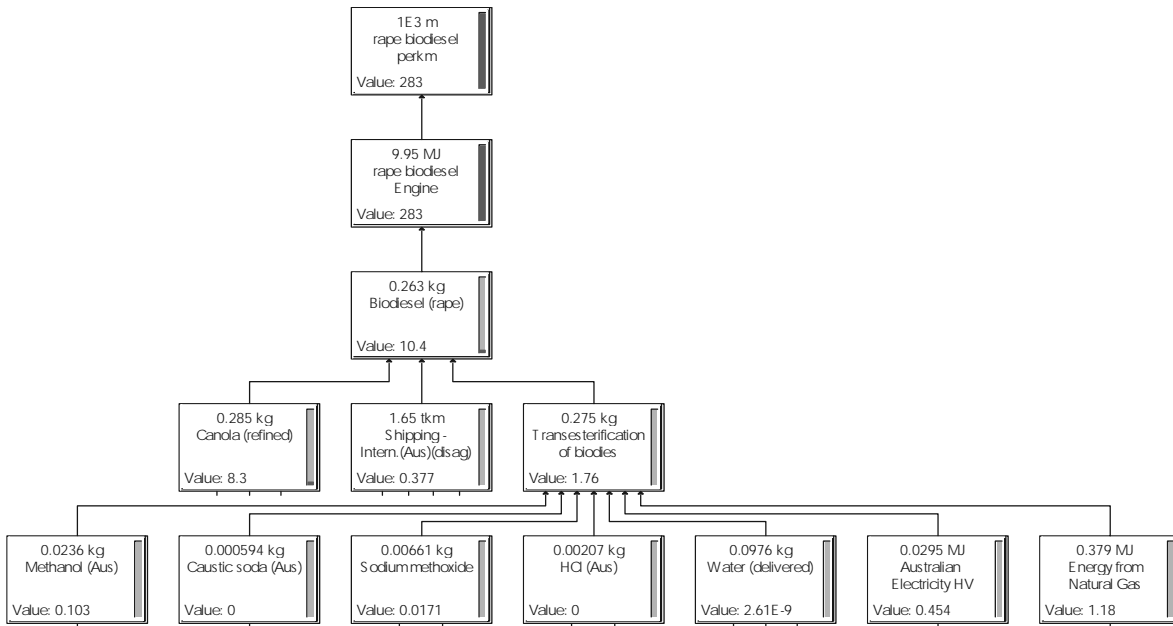**Exbodied greenhouse gas emissions (kg $CO_2$ eq) from rapeseed biodiesel production and processing and use in vehicle**

**Figure 4.16**
**Exbodied greenhouse gas emissions (kg CO$_2$ eq) from rapeseed biodiesel transesterification**

# Part 2 Details of Fuels

```
                          ┌─────────────────────┐
                          │      1 km.          │ │
                          │  Rape biodiesel per │ │
                          │       km.           │ │
                          │                     │ │
                          │  Value: 283         │ │
                          └─────────────────────┘
                                    ▲
                          ┌─────────────────────┐
                          │     9.95 MJ         │ │
                          │  Rape biodiesel     │ │
                          │      engine         │ │
                          │                     │ │
                          │  Value: 283         │ │
                          └─────────────────────┘
                                    ▲
                          ┌─────────────────────┐
                          │    0.263 kg         │ │
                          │  Biodiesel (rape)   │ │
                          │                     │ │
                          │  Value: 10.4        │ │
                          └─────────────────────┘
```

| 0.285 kg Rapeseed (refined) Value: 8.3 | 1.65 tkm Shipping - Intern.(Aus)(disag) Value: 0.377 | 0.275 kg Transesterification of biodiesel Value: 1.76 |

| 0.292 kg Rapeseed crude oil Value: 8.13 | 0.0234 kg Steam from natural gas 3.64MJ/kg Value: 0 | 0.0105 MJ Australian Electricity HV Value: 0.162 |

| 0.462 kg Rapeseed Value: 6.87 | 0.000692 kg Hexane (Aus) Value: 0.118 | 0.143 kg Steam from natural gas 3.64MJ/kg Value: 0 | 0.0748 MJ Australian Electricity HV Value: 1.15 |

**Figure 4.17**
**Exbodied particulate matter (mg - urban) from rapeseed biodiesel production, processing and use in vehicle**

**Figure 4.18**
**Exbodied particulate matter from rapeseed biodiesel transesterification**

# Part 2 Details of Fuels

| 1 km. Soybean biodiesel per km. | Value: 0.323 |

| 9.95 MJ Soybean biodiesel engine | Value: 0.323 |

| 0.263 kg Biodiesel (soybean) | Value: 0.323 |

| 0.0412 tkm Artic.Truck 22t load eff 75% | Value: 0.00567 |
| 0.275 kg Soybean crude oil | Value: 0.248 |
| 0.275 kg Transesterification of biodiesel | Value: 0.0696 |

| 0.548 kg Meal processing | Value: 0.0282 |
| 0.548 kg Oil Extraction and Solvent Rec | Value: 0.0086 |
| 0.548 kg Soybeans (crushed) | Value: 0.211 |

| 0.548 kg Soybean (Aus) | Value: 0.134 |
| 0.0106 kg Water (delivered) | Value: 1.04E-6 |
| 0.548 kg Dehulling Soybeans | Value: 0.0167 |
| 0.548 kg Soybean Drying | Value: 0.0357 |
| 0.137 tkm Artic.Truck 28t load -rural | Value: 0.0139 |
| 0.042 MJ Australian Electricity HV | Value: 0.011 |

| 0.00329 kg Fertilizer-P (Aus) | Value: 0.00112 |
| 0.00863 kg Fertliser urea (Aus) | Value: 0.0096 |
| 0.000822 kg Active pesticide (Aus) | Value: 0.00901 |
| 0.582 MJ Tractor rural (MJ input) | Value: 0.0501 |

**Figure 4.19**
**Exbodied greenhouse gas emissions (kg CO$_2$ eq) from soydiesel production, processing and use in vehicle**

# Part 2 Details of Fuels



**Figure 4.20**
**Exbodied greenhouse gas emissions (kg CO$_2$ eq) from soydiesel transesterification**
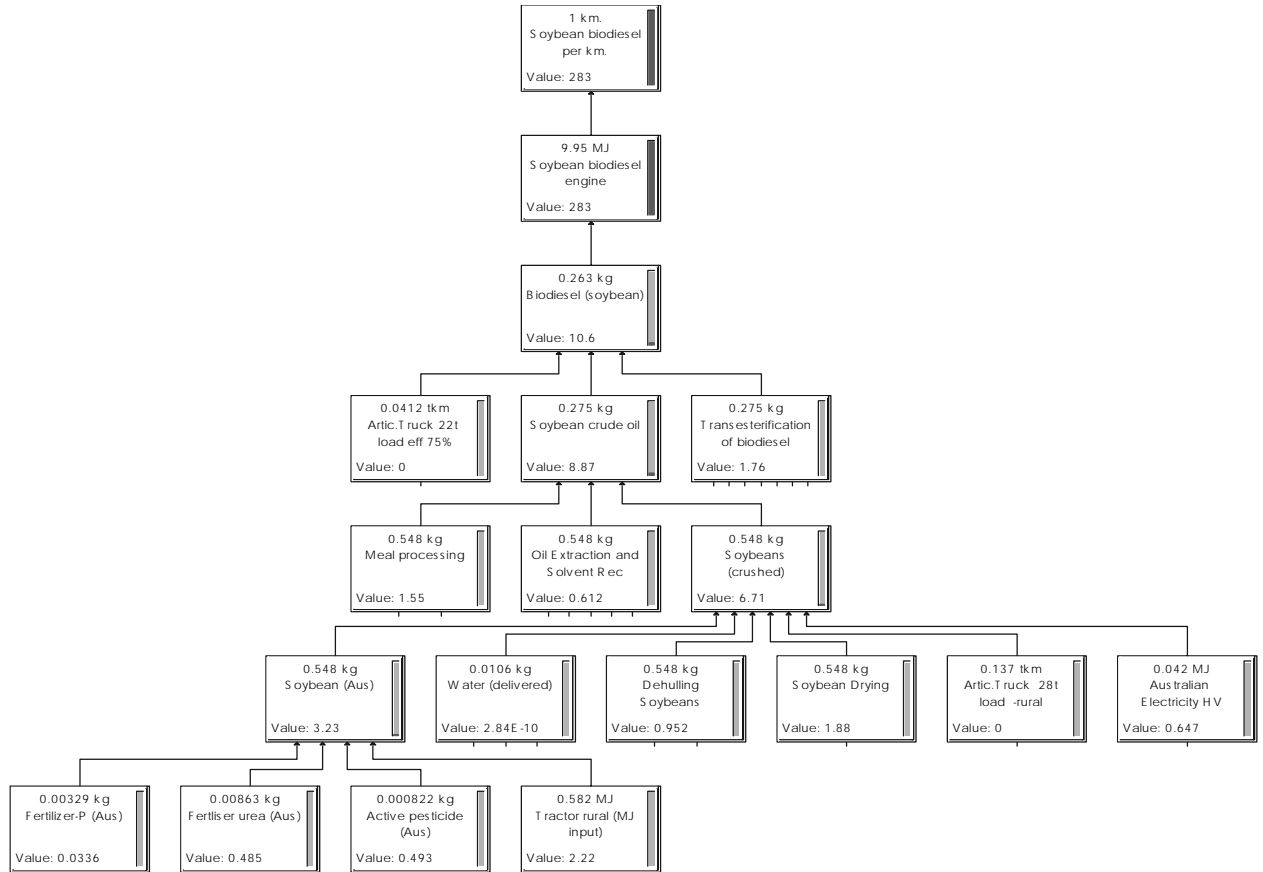
**Figure 4.21**
**Exbodied particulate matter (mg - urban) from soydiesel production, processing and use in vehicle**

**Part 2 Details of Fuels**
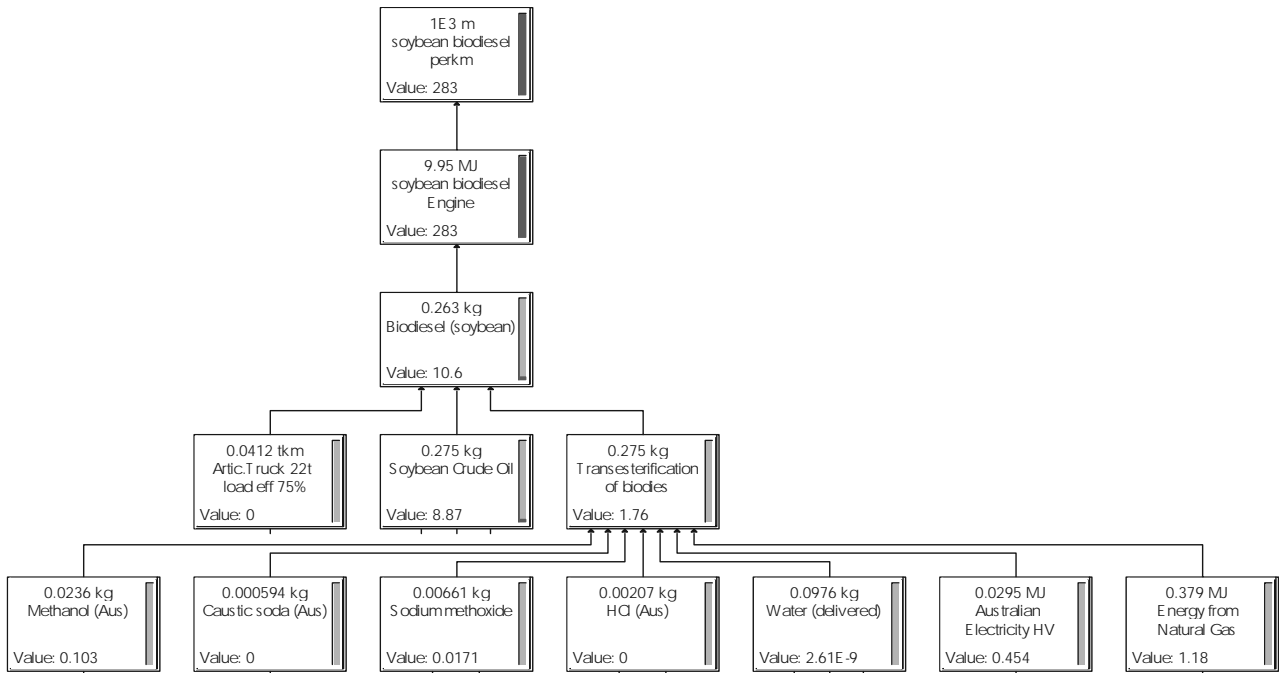


**Figure 4.22**
**Exbodied particulate matter from soydiesel transesterification**

**Part 2 Details of Fuels**
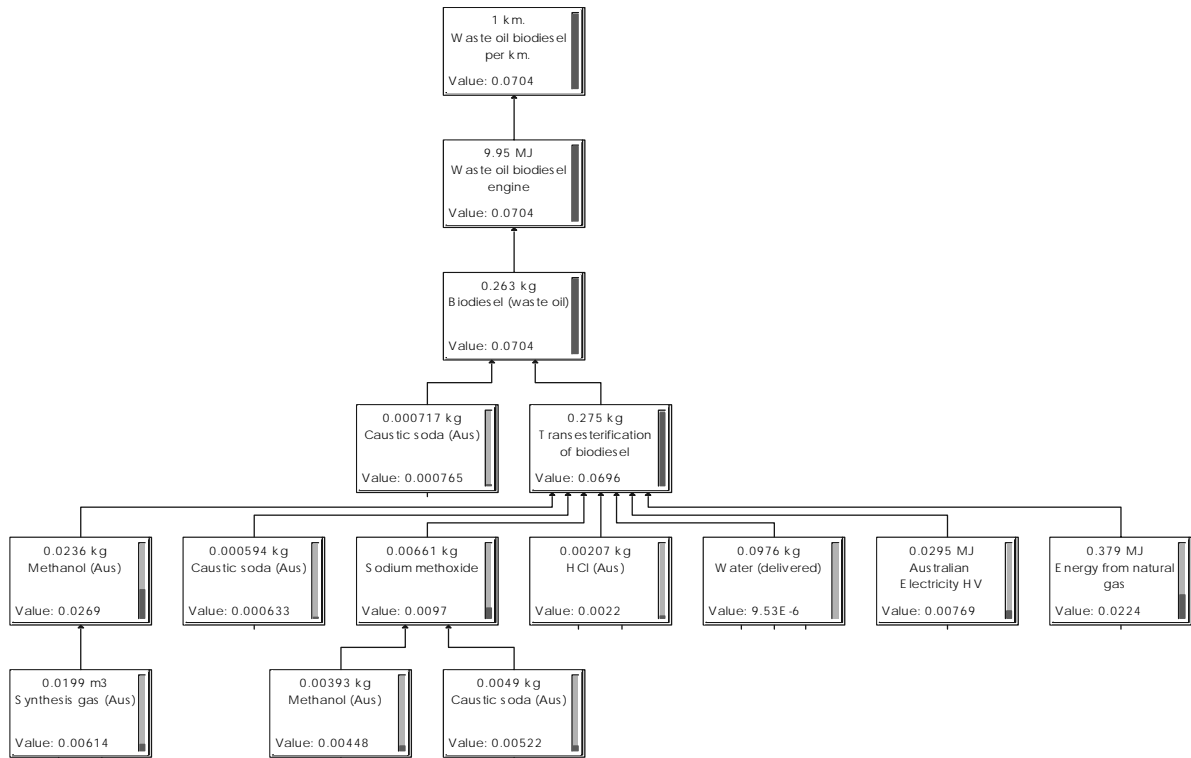


**Figure 4.23**
**Exbodied greenhouse gas emissions (kg $CO_2$ eq) from McDiesel production, processing and use in vehicle**
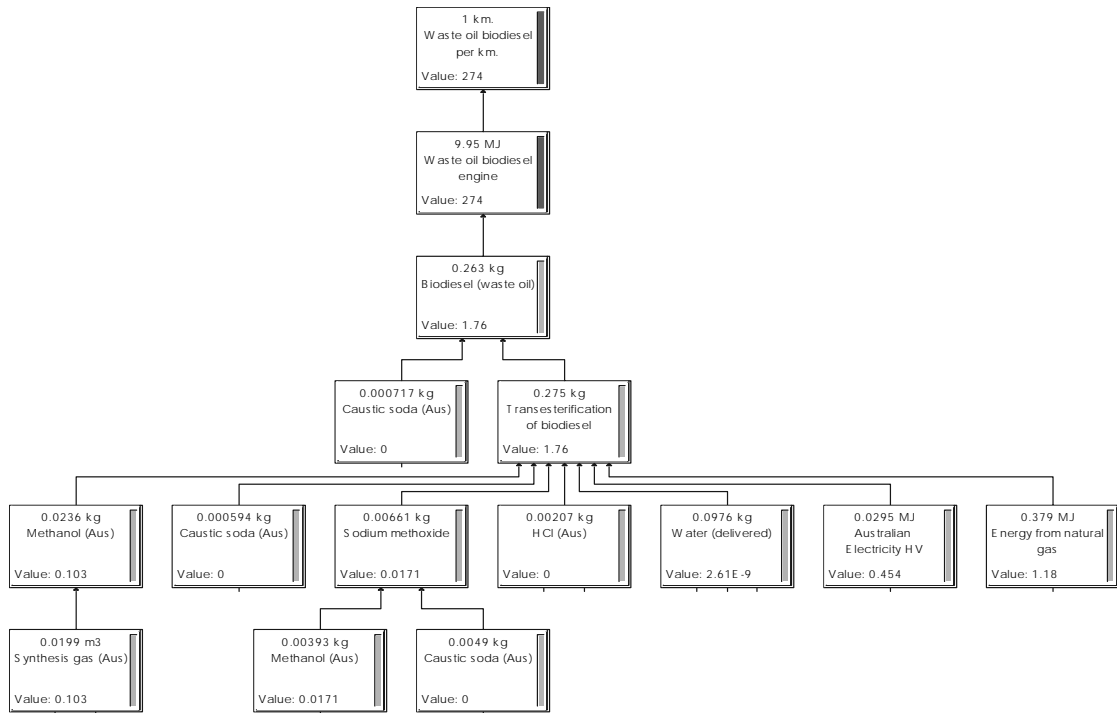
**Figure 4.24**
**Exbodied particulate matter (mg - urban) from McDiesel production, processing and use in vehicle**

# Part 2 Details of Fuels
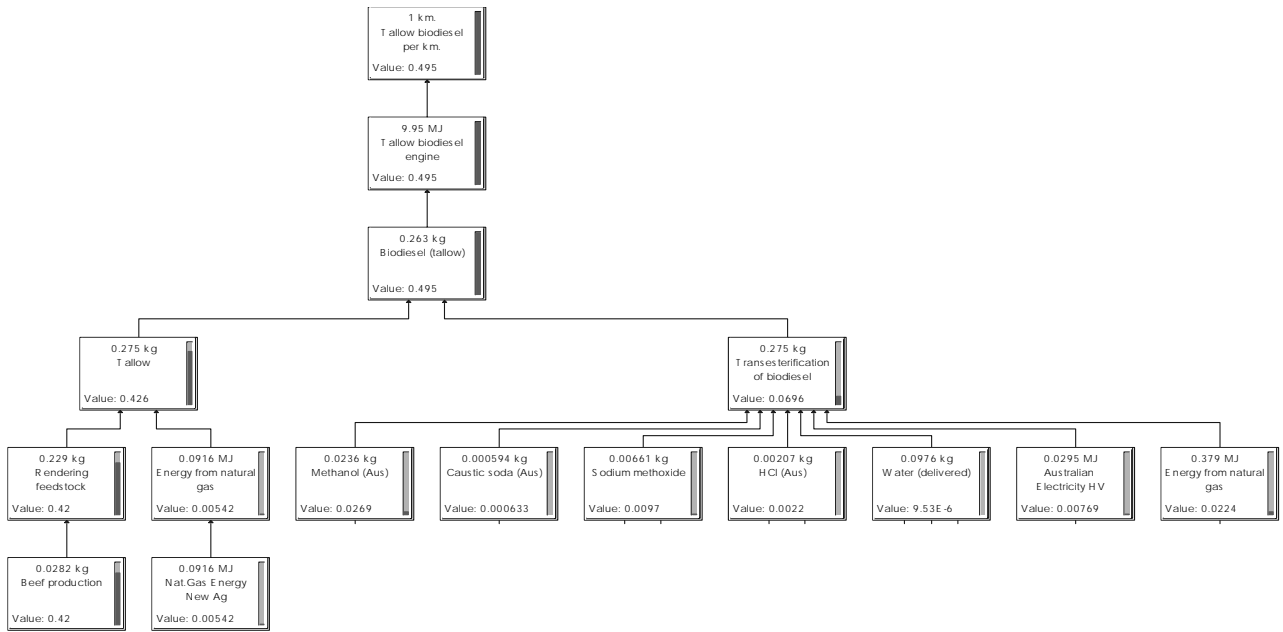


**Figure 4.25**
**Exbodied greenhouse gas emissions (kg CO$_2$ eq) from Tallow-diesel production, processing and use in vehicle**
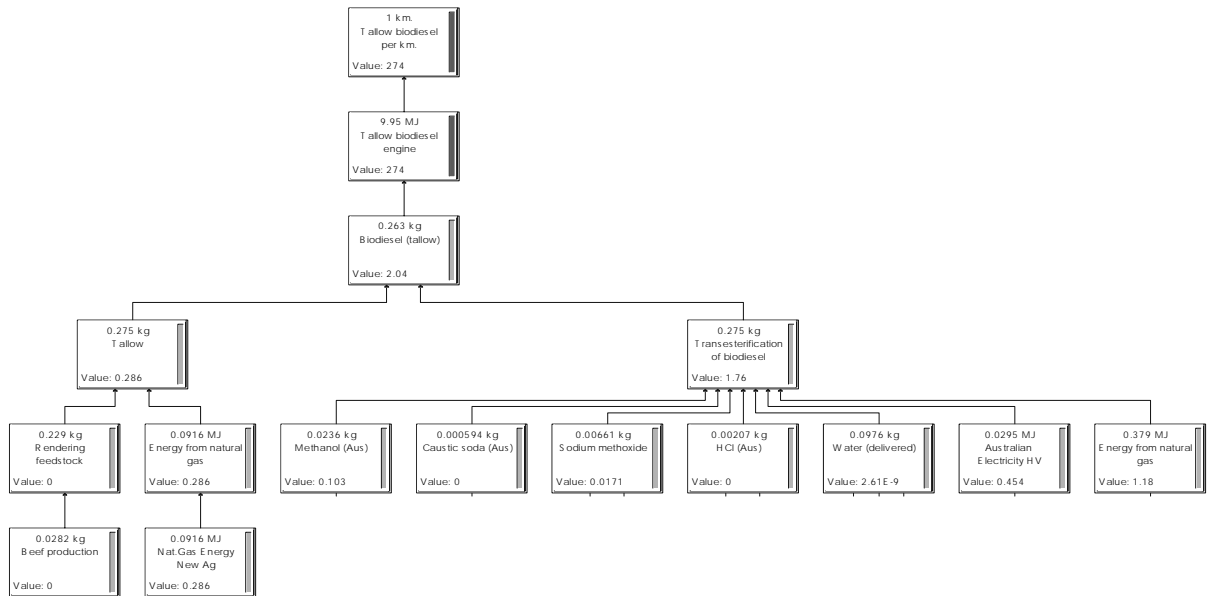


**Figure 4.26**
**Exbodied particulate matter (mg - urban) from Tallow-diesel production, processing and use in vehicle**

## 4.13. *Viability, Functionality and Health Issues*

European data (Arcoumanis, 2000) suggest biodiesel gives a reduction in HC compared with low sulfur diesel. CO tends to be lower for biodiesel. NOx tends to be slightly higher. PM may be lower (Buckmann & van Malsen, 1997) or it may be higher (Arcoumanis, 2000; Ceuterick & Spirinckx, 2000) but that is not clear. Within the variability and uncertainties associated with the fuels one should consider the particulate matter emissions of the two fuels to be much the same. The sulfur content of biodiesel is much lower than all grades of diesel.

United States LCA emissions estimates of BD100 compared to 500 ppm low sulfur diesel cited in Beer et al. (2000) found reductions for PM, CO and SOx by 32%, 35% and 8% respectively. BD100 increased LCA NOx emissions by 13% due mainly to increased tailpipe emissions. LCA HC emissions for BD100 are 35% higher with most of this increase due to soybean farming and production (soybean was the feedstock assessed), while tailpipe HC are 37% lower than diesel. Tailpipe emissions of PM10 and CO were substantially reduced by 68% and 46% respectively on a g/km basis.

The British Association for Bio Fuels and Oils (BABFO) summarised the life cycle emissions of gaseous pollutants from diesel and biodiesel for the UK (EcoTec Research and Consulting Ltd, 1999). Their results are summarised in Table 4.24. The relative differences between diesel and biodiesel confirm some of the earlier findings – in particular the larger full fuel-cycle emissions of particulate matter from biodiesel when compared to diesel although this may be different when compared with LSD which generally has lower PM emissions.

There are discrepancies between biodiesel emissions results emanating from Europe and the United States. Discrepancies in the PM emissions between studies may be related to whether the engine was optimised to run on biodiesel or diesel.

The influence of biodiesel fuels including rapeseed oil fuels on the formation of photochemical smog, whose main component is ozone, may be inferred from the fact that ozone in Australian cities is mainly NOx limited. The addition of extra NOx (from biodiesel compared to the NOx emissions from diesel) would thus slightly increase the smog production propensity.

The LCA biodiesel results from the earlier Stage 1 report are given in Table 8.9 of Beer et al. (2000).

### 4.13.1 *Production and transport*

Production of the canola, rapeseed and soybean feedstock crops would result in a range of particles and VOC from various sources including farm and transport vehicle emissions, plant respiration, agricultural chemicals and fertilisers. Feedstock transport to the vegetable oil processing facilities and vegetable oil transport to the esterification processing facility would also result in a range of particle and VOC emissions.

*Particulate matter*

The results summarised in Table 4.29 indicate that the upstream PM emissions from biodiesel are less than for LSD. This differs from the earlier analysis of Beer et al. (2000) as a result of using updated emission factors for agricultural machinery.

*Air toxics*

An accompanying disk to this report provides details of air toxics emissions from upstream activities.

*4.13.2   Use*

Taberski et al. (1999) looked at the biodiesel emissions when using rapeseed ethyl ester (REE) blends in a 1995 Dodge 2500 four-wheel-drive pickup truck with a Cummins B 5.9 litre turbocharged direct injection diesel engine with and without a catalytic converter. They found that REE100%:

- Reduced CO emissions by 40% (the catalytic converter had little effect).
- Reduced NOx emissions by 10% (the catalytic converter had little effect).
- Reduced HC emissions by 60% (the catalytic converter had little effect).
- Increased PM emissions by 15% and 40% with and without a catalytic converter respectively.

Engine dynamometer tests by Sharp et al. (2000a) found:

- With neat biodiesel, measurable HC emissions were generally eliminated, while CO was reduced roughly 40% from levels found in low sulfur diesel (2D diesel).
- Particle emissions were reduced between 25 and 50%, depending on the engine. In addition, the composition of engine-out particulate matter was shifted toward more volatile organic compounds and less carbon soot, creating a more favourable environment for treatment by a diesel oxidation catalyst.
- Neat biodiesel generally tended to increase NOx emissions by roughly 12%, although the Cummins B5.9 engine demonstrated almost no change in NOx emissions.

*Particulate matter*

We have noted that the particulate matter emission from biodiesel combustion is variable, with some studies indicating higher emissions than from diesel and some studies indicating lower emissions than from diesel. Consultation with stakeholders indicated that the Tier 1 test results (Sharp, 1998) – conducted on an engine dynamometer - have widespread credibility and thus these were used in the analysis. The particulate matter emissions during combustion of biodiesel are thus approximately 20% below those emitted during combustion of low sulfur diesel.

*Air toxics*

Sharp (1998) also conducted a detailed characterisation of the exhaust components. Unregulated emissions were characterised with neat biodiesel and conventional diesel fuel. This characterisation included several forms of hydrocarbon speciation, as well as measurement of aldehydes, ketones, and alcohols. In addition, both particle-phase and semi-volatile-phase PAH and nitro-PAH compounds were measured. Chemical characterisation revealed lower levels of most toxic and reactive hydrocarbon species when biodiesel fuels were used. Increases were observed only in heptane, acrolein, propionaldehyde, and hexanaldehyde, but the increases (except for heptane, which is not considered to be an air toxic) were small.

In addition, emissions of PAH and nitro-PAH compounds were substantially lower (30% with a catalytic converter, 12% without a catalytic converter) with biodiesel, as compared to conventional diesel fuel.

There are reduced emissions of speciated vapour phase hydrocarbons in the C1 to C12 range. The relative reactivity of speciated hydrocarbons with biodiesel was similar to that observed with diesel exhaust hydrocarbons, although the lower mass of speciated hydrocarbons present with biodiesel resulted in a lower overall ozone potential than for speciated diesel hydrocarbons.

Biodiesel reduced emissions of aldehydes and ketones substantially.

Biodiesel caused large reductions in PAH and NPAH emissions as already noted, and virtually eliminated some of the heavier NPAH compounds in the exhaust.

Biodiesel caused a dramatic change in the character of the heavier HC species as compared to diesel fuel, with only the esters that made up the biodiesel remaining in exhaust among the higher molecular weight hydrocarbons.

The blending of biodiesel and diesel did not generate any new species not already present in diesel or biodiesel exhaust.

A study by Pedersen et al. (1999) investigated emissions of rapeseed oil and RME burnt in a laboratory reactor. The study found combustion of rapeseed oil and RME resulted in emissions or a range of VOC including 1,3 butadiene, benzene and alkenes. The USEPA considers acrolein to be a high concern pollutant based on acute chronic toxicity. The USEPA classifies acrolein as a Group C, possible human carcinogen. The authors acknowledge that the results need to be checked using engines running RME. The Tier 1 results of Sharp (1998, Table 4.5), indicate that the acrolein emissions are small and seem to be compensated by the decrease in formaldehyde and acetaldehyde.

It is difficult to compare the combustion emissions of substantially different fuels such as LSD and biodiesel. The Taberski et al. (1999) data estimate the HC ratio of REE to diesel of 0.38. This is very different to the ratio of 1.68 between biodiesel HC and LSD found by Beer et al. (2000: Table 3.1) or the value of about 0.04 found in this study. As noted in Table 4.7, studies consistently find that biodiesel emits less hydrocarbons than diesel, so that a ratio of less than 1 appears to be reasonable.

### 4.13.3   Biodiesel emissions summary

Combustion PM emissions from biodiesel are comparable to those from diesel. This study has used the Tier 1 results of Sharp (1998) that found lower PM emissions from biodiesel than from diesel.

It is not possible to estimate robust combustion emissions estimates from the identified biodiesel toxics data. The Tier 2 results (Lovelace Respiratory Research Institute, 2000) for biodiesel found, in a study of health effects in rats, no effects associated with air toxic emissions from biodiesel with respect to mortality, toxicity, fertility or teratology. Rats lungs were adversely affected by exposure to high-level biodiesel exhaust emissions. This was judged to be a normal physiological response to exposure and not a toxic reaction.

### 4.13.4   OHS Issues

The Biodiesel Association of Australia provides a sample material data safety sheet (MSDS) for biodiesel on its web site at www.biodiesel.vtrekker.com/biodiesel.htm that identifies mucous membrane irritation from biodiesel vapours, and eye irritation from direct contact as the only hazards. This is more conservative than the MSDS for soydiesel (methyl soyate) at www.soygold.com/soydiesel-msds.htm, which claims that soydiesel is not classified as an eye irritant.

A range of State and Commonwealth occupational health and safety provisions covers the OHS issues in the lifecycle of biodiesel. While there will be different OHS issues involved in the production process associated with biodiesel compared with LSD, no OHS issues unique to the production and distribution of biodiesel have been identified, provided that normal industrial precautions are followed in the use of the ingredients needed to prepare the biodiesel.

*4.13.5 Vapour pressure issues*

There are minimal evaporative emission issues during the transport and use of biodiesel due to the relatively low volatility of biodiesel. The soydiesel MSDS claims that the vapour pressure is less than 1 mm of mercury (133 Pa) at 72$^{o}$C.

*4.13.6 Warranty issues*

The Austrian Biofuels Institute provided a list of existing European warranties for biodiesel operation that is reproduced in Table 4.35. Our understanding is that these warranties relate to the use of BD100, which is readily available in parts of Europe at a cheaper price than diesel fuel.

According to the summary at www.biodiesel.org/fleets/summary.htm, the biodiesel industry in the United States is working with the Engine Manufactures Association as well as with individual firms to address many of the OEMs' issues and concerns (see below) over biodiesel use. They state that a common misconception is that an engine manufacturer must warranty biodiesel in order to use it in the United States. The reality is that no engine manufacturer warranties any fuel, because they do not produce fuel. If there is a problem caused by the fuel, it is the responsibility of the fuel supplier.

Engine manufacturers do, however, warranty the materials and workmanship of their engines and have the ability to void their materials and workmanship warranties if certain fuels are used in their engines. The question for biodiesel use is whether the use of biodiesel will void their existing warranty. Almost all the companies marketing diesel engines in the United States have confirmed that the use of BD20 will not void their parts and materials warranties. This allows BD20 to be used in most existing engines with no further approvals.

Caterpillar, in its Information Release Memo PMP01-01 of March 2001 states that Caterpillar neither approves nor prohibits the use of biodiesel fuels. The memo lists 23 engines in which biodiesel meeting either ASTM PS 121 or DIN 51606 are acceptable, and notes that for Caterpillar 3003 through 3034, 3054 and 3056 engines use of more than a 5% biodiesel fuel can cause premature failures whose repair would not be covered under Caterpillar warranty.

The information that we received from stakeholders during consultations is that in Australia there is concern at biodiesel blends above 5% (BD5). Fuel Injection Equipment (FIE) Manufacturers (Bosch, Stanadyne, Lucas) issued a joint statement dated 1 May 1998 that states that BD5 "should not give end-users any serious problems". The statement does, however, express concern about possible interaction between the fuels and components in the vehicle low pressure system. The intent of the statement is to inform potential users that if problems arise following the use of biodiesel above a 5% blend, or following the use of a biodiesel that does not meet a national standard, then this will render the FIE manufacturers' guarantee null and void.

The Cummins position on biodiesel states that:

> Cummins neither approves nor disapproves of the use of biodiesel fuel blends. There is a major difference between operating on pure (100% concentration) bio diesel fuels and biodiesel/petrodiesel fuel blends. Cummins is not in a position to evaluate the many variations of biodiesel fuels, and the long-term effects on performance, durability or emissions compliance of Cummins products. The use of biodiesel fuel does not affect Cummins materials and workmanship warranty. Failures caused by the use of biodiesel fuels or other fuel additives are not defects of Cummins parts or workmanship, and therefore would NOT be covered by Cummins' warranty.

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```
Given the current industry understanding of biofuels and
blending with quality diesel fuel, it would be expected that
blending up to a 5% volume concentration should not cause
serious problems. This is consistent with the position taken by
worldwide fuel system manufacturers.
```

**Table 4.35**
**Summary of existing diesel vehicle warranties for biodiesel operation**

| | | |
|---|---|---|
| Audi | personal cars | all TDI-models since 1996 |
| Case – IH | Tractors | all models since 1971 |
| BMW | personal cars | model 525 tds since 1997 |
| Claas | combines, tractors | warranties exist |
| Faryman Diesel | Engines | warranties exist |
| Fiatagri | Tractors | for new models |
| Ford AG | tractors | for new models |
| Holder | tractors | warranties exist |
| Iseki | tractors | series 3000 and 5000 |
| John Deere | tractors | warranties since 1987 |
| John Deere | combines | warranties since 1987 |
| KHD | tractors | warranties exist |
| Kubota | tractors | series OC, Super Mini, O5, O3, |
| Lamborghini | tractors | series 1000 |
| Mercedes-Benz | personal cars | series C and E 220, C 200 and 220 CDI, a.o. |
| Mercedes-Benz | lorry, bus | series BR 300, 400, Unimog since 1988, a.o. |
| Mercedes-Benz | tractors | since 1989 |
| Same | tractors | since 1990 |
| Seat, Skoda | personal cars | all TDI-series since 1996 |
| Steyr | tractors | since 1988 |
| Steyr | boat | series M 16 TCAM and M 14 TCAM |
| Valmet | tractors | since 1991 |
| Volkswagen | personal cars | all TDI- series since 1996 |
| Volkswagen | personal cars | all new SDI-series (EURO-3) |
| Volvo | personal cars | series S80-D, S70-TDI and V70-TDI |

(Provided by Austrian Biofuels Institute)

At present few engine manufacturers have certified BD100 due to the added costs involved with certification and lack of data using BD100, since almost all the research in the United States has been on BD20. The National Biodiesel Board is currently leading an industry wide effort to have BD20 designated as an alternative fuel by the US Department of Energy. Successful designation of BD20 will provide a blend level with which both Original Equipment Manufacturers (OEMs) as well as other third parties (after market converters, fuel suppliers, etc.) can certify cost competitive biodiesel blends.

## 4.13.7  Other issues

The National Biodiesel Board web site also points out that biodiesel over time will soften and degrade certain types of elastomers and natural rubber compounds. Precautions are needed when using high percentage blends to ensure that the existing fuelling system, primarily fuel

hoses and fuel pump seals, do not contain elastomer compounds incompatible with biodiesel. Manufacturers recommend that natural or butyl rubbers not be allowed to come in contact with neat biodiesel. Biodiesel will lead to degradation of these materials. If a vehicle's fuel system does contain these materials, replacement with biodiesel compatible elastomers such as Viton® B is recommended. The recent switch to low sulfur diesel fuel has caused most (OEMs) to switch to components suitable for use with biodiesel, but users should contact their OEM for specific information. (Viton B is a registered trademark of DuPont Dow Elastomers). The FIE manufacturers' position statement on Fatty Acid Methyl Esters of 1 May 1998 also makes similar points and provides a list of potential fuel injection problems.

The Cummins position on the use of biodiesel fuel notes that:

```
For customers intent on blending bio fuels above a 5% volume
concentration, the following concerns represent what is
currently known in the industry. Concentrations beyond 5% by
volume could have an adverse effect on the engine's performance
and the fuel system integrity/durability. The effects are more
serious with increasing concentration levels. Areas of concern
when operating with bio diesel fuels include low temperature
operability (fuel gelation, filter plugging), heat content
(poor fuel economy), and storage and thermal stability (filter
plugging, injector deposits). In addition, from our fuel
systems suppliers, the following issues are also noted:
swelling and hardening/cracking of some elastomer seals within
the fuel system/engine, corrosion of fuel system and engine
hardware - especially aluminum and zinc, solid particle
blockage of fuel nozzles and passages, filter plugging,
injector coking, higher injection pressures due to physical
flow properties - reduced fuel system life, added stress and
heat to injection components - especially rotary fuel pumps –
increased pump seizures and early life failures, poor fuel
spray atomization - reduced fuel economy, poor lubricity -
reduced service life of fuel pump/system. Pure bio diesel fuel
is not stable and its acid content increases over time, which
can damage powder metal components.
```

In contrast to the cautious attitude of the manufacturers, the major case study that we were able to find on the long-term use of biodiesel was the "truck in the park" project detailed by Taberski et al. (1999). This project examined the performance of a new 1995 Dodge pickup truck with a Cummins B5.9 litre turbocharged, direct injected, diesel engine over three years, from 1995 to 1998, using biodiesel. On-road fuel for the truck was 100% canola ethyl ester, whereas during dynamometer testing the fuel used was 100% rapeseed ethyl ester. The performance of the biodiesel fuelled truck was compared with that of a control vehicle running on low sulfur diesel.

 Neither the "truck in the park" project, nor the other road-test projects run by the University of Idaho (http://www.uidaho.edu/bae/biodiesel/research/past_research.html) found any difference in engine viability and functionality between diesel and biodiesel.

### 4.13.8   Cold flow properties

Operation of neat (100%) biodiesel in cold weather will experience gelling faster than petrodiesel. The solutions for this potential issue are much the same as that with low-sulfur diesel (i.e., utilisation of fuel heaters and storage of the vehicle in or near a building). Biodiesel appears to be largely unaffected by conventional pour point depressants. These considerations, though important in the United States, are not relevant to most of Australia.

*4.13.9 Summary*

The advantages of biodiesel are:

- It is a renewable bio-based fuel and, as such, has lower life cycle $CO_2$ emissions than diesel derived from mineral oils.
- Neat biodiesel contains almost no sulfur and no aromatics. In a properly tuned engine this is expected to lead to lower particle exhaust emissions.
- The material is bio-degradable and non-toxic.
- As an oxygenated compound, it reduces the non-soluble fraction of the particles.
- The PAH content of exhaust particles is reduced.
- In a mixture with low-sulfur diesel, biodiesel can act as a lubricity improver (Arcoumanis, 2000).
- The absence of sulfur makes oxidation catalysts more efficient.
- Existing diesel infrastructure could be converted to use biodiesel.
- Biodiesel can be used in existing diesel engines.


The disadvantages of biodiesel are:

- Constraints on the availability of agricultural feedstock impose limits on the possible contribution of biodiesels to transport.
- The kinematic viscosity is higher than diesel fuel. This affects fuel atomisation during injection and may require changes to the fuel injection system.
- Due to the high oxygen content, it produces relatively high NOx levels during combustion.
- Oxidation stability is lower than that of diesel so that under extended storage conditions it is possible to produce oxidation products that may be harmful to the vehicle components.
- Biodiesel is hygroscopic. Contact with humid air must be avoided.
- Production of biodiesel is not sufficiently standardised. Biodiesel that is outside European or US standards can cause corrosion, fuel system blockage, seal failures, filter clogging and deposits at injection pumps.
- There is a possibility of dilution of engine lubricant oil, requiring more frequent oil change than in standard diesel-fuelled engines.
- A modified refuelling infrastructure is needed to handle biodiesels, which adds to their total cost.

## *4.14. Environmental Issues*

Biodiesel is made from agricultural crops and is thus widely perceived to be more environmentally friendly than fossil fuels. It is presented as such by the biodiesel industry. Biodiesel International is an Austrian company that is a leader in developing multi-feedstock facilities for the production of high-quality biodiesel. The company's home page at www.biodiesel-intl.com has pictures of birds with the motto: "a bird in clean air gliding over healthy soil". This emphasises that spillages of biodiesel are less toxic than spillages of crude oil or diesel. There is less likelihood of soil contamination, and the chances of groundwater contamination are greatly reduced.

When examined on a total life cycle basis it remains unclear whether the planting of large scale crops to be used for biodiesel is to be seen as a positive contribution to sustainability or as a contributor to soil degradation. Such analyses are local in scale and need to be determined for individual projects on the basis of the use of the land before fuel crop cultivation.

Crops in Australia require application of fertiliser and pesticides to be grown successfully. There are concerns as to whether such agricultural practices are sustainable. However, there

are also concerns at the alternatives. Australian farms have experimented with genetically modified canola so as to reduce the amount of pesticide applied. There is sufficient community concern over the risks associated with genetically modified organisms (GMO) that in late 20000, the Commonwealth established an Office of the Gene Technology Regulator.

The main focus of environmental issues related to biodiesel has been that of air emissions (Franke and Reinhardt, 1998). These have been dealt with in earlier sections. We may summarise the environmental issues as follows:

### 4.14.1 ESD issues

The present use of biodiesel is that of a niche fuel. As such, there are no issues related to sustainability.

Biodiesel is made from agricultural crops and is thus widely perceived to be more environmentally friendly and ecologically sustainable than fossil fuels. Our results confirm that, on a life-cycle basis, biodiesel is more climate-friendly than diesel. Vegetable crops much more so than biodiesel made from tallow. The carbon emissions caused by agricultural production and fertiliser production are less than the exbodied emissions from diesel made from fossil fuels.

### 4.14.2 Sustainability issues

Biodiesel is made from either crops or from animal product. Its feedstock is thus a renewable resource. It is less clear whether the high levels of pesticides and fertiliser necessary to conduct present-day agricultural activities are sustainable within the Australian context. Biodiesel will be a niche fuel, albeit a very useful one, because there is not sufficient area to grow the plants needed to convert all of Australia's diesel fuel usage to biodiesel.

### 4.14.3 Groundwater contamination

Not an issue with biodiesel, except for i) the possible use of pesticides or fertiliser during the growth of the crop from which the biodiesel is made, and ii) runoff from cattle feedlots (for biodiesel made from tallow).

## 4.15. Expected Future Emissions

Arcoumanis (2000) developed a model that examines a given alternative fuel relative to the reference diesel engine (Euro2) in terms of a specific regulated pollutant. A value of 1 implies identical performance to the low sulfur diesel/Euro2 combination. A value greater than 1 implies inferior performance, whereas a value less than 1 indicates superior performance.

**Table 4.36**
**Estimated relative emission factors for biodiesel under different technologies.**
**Euro2 diesel values (shown in bold) are taken as 1.0.**

| Technology | CO | CO | HC | HC | NOx | NOx | PM | PM | CO$_2$ | LCA CO$_2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Euro2 | **1.0** | 0.7 | **1.0** | 0.4 | **1.0** | 1.1 | **1.0** | 1.0 | 1.1 | 0.1-0.3 |
| Euro3 | **0.53** | 0.4 | **0.6** | 0.3 | **0.71** | 0.9 | **0.67** | 0.7 | 1.1 | 0.1-0.3 |
| Euro4 | **0.38** | 0.3 | **0.42** | 0.2 | **0.5** | 0.6 | **0.2** | 0.2 | 1.0 | 0.1-0.3 |

Table 4.36 lists the estimated emissions factors for biodiesel (BD100). The columns in bold represent the standards relative to the Euro2 standard. The adjacent column gives the expected

performance of biodiesel. The estimates of Arcoumanis (2000) indicate that biodiesel can be expected to meet all future Australian Design Rules for all pollutants except oxides of nitrogen, which may be slightly above Euro3 and Euro4 standards, and possibly the particulate matter standard for Euro3.

Arcoumanis (2000) notes that a blend of 20-30% biodiesel with diesel in heavy vehicles is expected to meet all Euro4 standards (though not all Euro3 standards), as shown in Table 4.37.

**Table 4.37**
**Estimated relative emission factors for 20-30% biodiesel in diesel under different technologies.**
**Euro2 diesel values (shown in bold) are taken as 1.0.**

| Technology | CO | CO | HC | HC | NOx | NOx | PM | PM | $CO_2$ | LCA $CO_2$ |
|------------|------|-----|------|-----|------|-----|------|-----|--------|------------|
| Euro2 | **1.0** | 0.8 | **1.0** | 0.7 | **1.0** | 1.0 | **1.0** | 1.0 | 1.0 | 0.8 |
| Euro3 | **0.53** | 0.5 | **0.6** | 0.5 | **0.71** | 0.9 | **0.67** | 0.7 | 1.0 | 0.8 |
| Euro4 | **0.38** | 0.3 | **0.42** | 0.3 | **0.5** | 0.5 | **0.2** | 0.2 | 1.0 | 0.7 |