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Life Cycle Assessment of Environmental Outcomes and Greenhouse Gas Emissions from Biofuels Production in Western Australia

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to

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Acronyms, Abbreviations and Glossary

a	annum (year), e.g. t/a indicates tonne per annum
ABS	Australian Bureau of Statistics
AGO	Australian Greenhouse Office
ARF	Australian Renewable Fuels
B5	Diesel containing 5% biodiesel by volume, also denoted BD5
B20	Diesel containing 20% biodiesel by volume, also denoted BD20
BSFC	Brake specific fuel consumption
CH_4	Methane, the major constituent of natural gas and biogas, also a potent greenhouse gas
CO	Carbon monoxide
CO_2	Carbon dioxide, the major greenhouse gas causing climate change
CO_2 e	Alternative way of denoting CO_2-e
CO_2-e	Carbon dioxide equivalent – used in climate science to measure total impacts of all greenhouse gases relative to the most common, Carbon dioxide. For example, methane (CH_4) has a radiative forcing (over a 100 year time scale) that is 21 times that of CO_2, which is expressed as a greenhouse warming potential of 21, so 1g of CH_4 has a CO_2-e value of 21g
CSIRO	Commonwealth Scientific and Industrial Research Organization
CUEDC	Composite Urban Emissions Drive Cycle
DAF	Department of Agriculture and Food (Western Australia)
DAP	Di-ammonium phosphate
DEWHA	Commonwealth Department of Environment, Water, Heritage and the Arts
DPI	Department of Primary Industries
E10	Petrol containing 10% ethanol by volume
EtOH	Ethanol
FC	Fuel Consumption
FFA	Free fatty acids
FFC	Full fuel cycle (cradle to grave or well-to-wheel analysis)
Gg	10^9 grams – equivalent to 1000 tonne (1 kt). Used in the scientific community for measurements of atmospheric greenhouse gas
GHG	Greenhouse Gas
GWP	Global Warming Potential – see also CO_2-e
glycerol	A sugar alcohol produced as a by-product in several chemical processes, including soap making and the transesterification of oils to make biodiesel, usually contaminated with other materials and hence not suitable for pharmaceutical or food use without further processing. High grade glycerol suitable for these purposes is usually referred to as glycerine (or glycerin)
ha.a	or “ha a” – indicates the use of one hectare of land over one year (annum)
HHV	High Heating Value
HV	Heavy Vehicle
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organisation
K	Potassium
kL	Kilolitre (thousand litres)
kt	Kilotonne (thousand tonne) – equivalent to Gg
kWh	Kilowatt hour (3.6 MJ)

LCA	Life Cycle Analysis/Assessment
LHV	Low Heating Value
LP	Leaded petrol
MAP	Mono-ammonium phosphate
MBM	Meat and bonemeal
MCPA	2-methyl-4-chlorophenoxyacetic acid is a powerful, selective, widely-used phenoxy herbicide
Mt	Million tonne
MWh	Megawatt hour
NAPL	Non-aqueous phase liquids
N_2O	Nitrous oxide, also known as dinitrogen oxide, a potent greenhouse gas
NGGIC	National Greenhouse Gas Inventory Committee
PE	Primary Energy
PULP	Premium unleaded petrol
RON	Research Octane Number
SD	Standard Deviation
Std.	Standard
t	tonne (1000 kg, 1 Mg, 10^6 g)
t.km	Or tkm – tonne kilometre. Used in transport to indicate the movement of one tonne of freight one kilometre
Tailpipe	Generally used to refer to emissions from a vehicle at the tailpipe directly into the atmosphere, without taking into account emissions created in fuel extraction, growing, production and/or refining
ULP	Unleaded petrol
Upstream	Generally used to refer to atmospheric emissions resulting from the production of a fuel, including extraction, growing, production and/or refining, i.e. fuel related emissions not including those from the actual combustion of the fuel

Executive Summary

This study examines the full life-cycle of greenhouse gas emissions from the production of ethanol and biodiesel by undertaking a life-cycle analysis (LCA) to assess the greenhouse gas emissions and other environmental outcomes as a result of Western Australian biofuels use. The LCA compares the Western Australian situation with, and without, biofuel production; specifically biofuel from two plants – 45 ML of biofuel from Picton ARF biodiesel facility and 160 ML of ethanol from Primary Energy proposed biorefinery.

The greenhouse benefits of biofuel are normally derived from the substitution of fossil based carbon emissions (which are the result of the combustion of fossil fuels), with biogenic carbon dioxide emissions (which are the results of combusting fuels that have only recently absorbed the carbon from the atmosphere during the cropping cycle). In the Western Australian case there are a number of other significant greenhouse contributors and savings. The most dominant of these is the electricity production from the Primary Energy biorefinery. Because Western Australian electricity is largely based on coal combustion, the greenhouse benefits of substituting this electricity with electricity from the bio-refining are significant. In fact, the greenhouse gas savings from electricity production (281 Gg)[1] are more than the savings generated from ethanol production (205 Gg) as is shown in Figure 0-1. To some extent the biorefinery could be considered to be an electricity plant that produces ethanol and fertilisers as co-products.

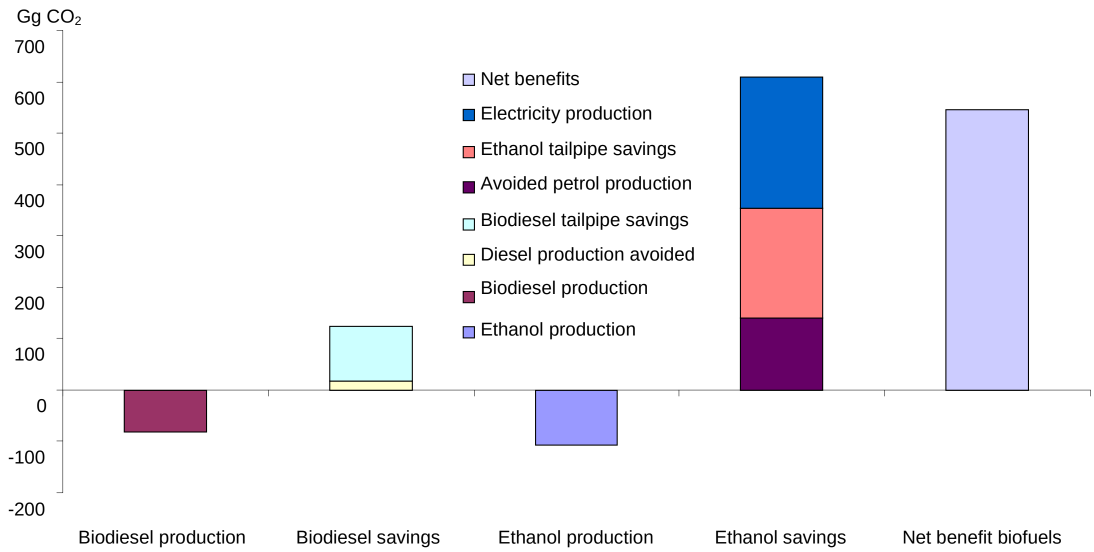

Figure 0-1: Summary of greenhouse savings from biofuel implementation - $GgCO_2$ e per year

Without the biodigester part of the biorefinery the ethanol production and utilisation are still beneficial from a greenhouse gas perspective though the savings per year are more than halved from 486 Gg to 220 Gg for the 160ML of production. In terms of fuel security

[1] The SI unit, the Gigagram (Gg) is the same as a thousand tonne.

the ethanol production has relatively low crude oil inputs over the lifecycle with 20 more times energy being produced than crude oil energy utilised through the life cycle.

These benefits come at the cost of land use with very little land utilisation in the crude oil to petrol supply chain compared with the land needed for wheat production. The overall sustainability of this use is beyond the scope of this LCA, as is the sustainability of the continued crude oil utilisation.

There is also a net greenhouse benefit from biodiesel production (from tallow) and its subsequent use as a biodiesel blend. This benefit is entirely from tailpipe emission savings due to biogenic carbon dioxide emissions replacing fossil derived carbon dioxide emissions. The production stage of biodiesel is significantly higher than the equivalent volume of diesel production but this is more than offset by the tailpipe emission savings. Co-products from biodiesel production, namely glycerol and potassium sulfate make little impact on the final environmental profile of biodiesel. The benefit from the biodiesel per year is 44 Gg of greenhouse gases for the 45 ML of production as shown in Figure 0-1.

The combined reduction from biodiesel and ethanol implementation is 530 Gg per year, which represents 0.76% of the 2006 greenhouse gas emissions in WA and 6% of WA transport related emission for the same year.

The biodiesel and ethanol facilities both reduce the total demand for fossil fuels and especially the demand for crude oil. Table 0.1 shows that for each unit of fossil energy (oil and natural gas) into the biodiesel life cycle, 3.3 units of usable energy are produced. For ethanol this ratio is 9.7.

If one focuses on fuel security by examining only the crude oil and liquid transport fuels (rather than the overall fossil) as the inputs, then each unit of crude oil input produces 16.3 and 15.0 units of usable liquid fuels for the biodiesel and ethanol process respectively. When energy offsets during the production of ethanol are included then the ratio can increase to 20.3.

Table 0.1: Energy return on fossil energy inputs

	Biodiesel	Ethanol	Ethanol without biorefinery	Diesel	ULP	PULP
Ratio of liquid fuel energy content per unit of crude oil energy	16.27	15.01	17.37	0.962	1.009	0.980
Ratio of total effective energy output per unit fossil energy input	3.32	9.68	1.47	0.942	0.991	0.955

In relation to urban air pollutants, the benefits of biodiesel blends in reducing particulate matter are well established but are also highly variable, as is the increase in emissions of oxides of nitrogen.

For ethanol only an E10 blend was assessed in this study, but for biodiesel blends from 5% to 100% were assessed; the environmental impacts per unit of biodiesel utilised did not vary. This suggests that the most convenient and practical blend should be based on vehicle requirements.

1 Background, Objectives and Scope of Work

1.1 Background

Recently, the Food and Trade Development Branch at the Department of Agriculture and Food (DAFWA) in Western Australia, on the basis of advice from the Minister for Agriculture and Food, confirmed the need for a life cycle analysis (LCA) of environmental outcomes (including a quantitative calculation of greenhouse gas reductions) of biofuels production in Western Australia. In April 2008, DAF requested CSIRO to undertake this study.

The background to this decision lies in the final report of the Western Australian Biofuels Taskforce (Western Australia, 2007), released in April 2007. That report noted that

> "The extent to which biofuels provide environmental and health benefits depends not only on the type of fuel, but also on how it is produced and used. Life cycle analysis (LCA) analysis of locally produced biofuels will give credibility to their greenhouse potential, particularly for export markets or where carbon trading is involved. While LCA is required as part of the environmental assessment of any large new project, funding for LCA of new technologies may help their development. LCA will lead to a greater understanding of the greenhouse gas impacts of fuels produced and consumed in Western Australia. It will also be used in the longer term as part of the low carbon intensity certification process."

As a result, the Taskforce recommended (as Recommendation 17):

> "That the State Government provide funding for full life cycle analysis on greenhouse gas emissions for biofuels."

Since April 2007, considerable changes to Western Australia's biofuels landscape have occurred. Production from the Australian Renewable Fuels (ARF) biodiesel plant at Picton, with a capacity of 45 ML, was suspended in late 2007 despite the continuing rise in oil price. However, production has recently recommenced. There are also plans by Primary Energy to produce a 160 ML ethanol plant at Kwinana, as well as other proposals to construct additional ethanol facilities in the State. However these plans are uncertain following a 4 June 2008 announcement that BP has pulled out of an agreement with Primary Energy to build a $300 million ethanol plant at Kwinana[2].

1.2 Objective of the study

The objective of the study is to provide DAF with quantified life cycle analyses (LCAs) of the environmental outcomes and greenhouse gas emissions arising from full biofuel supply in the State, namely the operation of a 45 ML biodiesel plant in Picton, and a 160 ML ethanol plant in Kwinana. It is assumed that the biofuels produced by these two plants will be consumed in the form of E10 (10% of ethanol blended with petrol), B5 (5% of biodiesel blended with diesel) and B20 (20% of biodiesel blended with diesel). The environmental outcomes associated with these blends will be compared to those of conventional fossil fuel from BP's refinery in Kwinana. Each LCA will provide a cradle-to-grave analysis of

[2] http://tinyurl.com/3gglqv

greenhouse gases and other emissions associated with each plant's upstream and downstream activities. The results of this analysis are intended to assist with Government decision-making.

1.3 Scope of Work

The work consists of the following items:

(1) A literature review and data collation, undertaken jointly with DAF, to provide the background information and the background data needed to quantify the emissions from likely biofuel operations in Western Australia.

(2) The use of the standard CSIRO methodology to undertake a comparative LCA of transport biofuels that compares the emissions (on a g/km travelled basis) to a standard reference fuel. The reference fuel in the case of ethanol is petrol and the reference fuel in the case of biodiesel is diesel.

CSIRO's LCA model SimaPro has been used to determine the life cycle of tailpipe and upstream environmental emissions: greenhouse gases, criteria pollutants (CO, NOx, PM and HC), water use and energy use. This report is restricted to an examination of Western Australian greenhouse gas emissions on the basis of the ARF biodiesel plant at Picton and Primary Energy's ethanol plant at Kwinana as the biofuels producers. To provide a comparison of biofuel greenhouse gas emissions to conventional fossil fuel emissions, BP Australia's refinery at Kwinana is assumed to be the supplier of the reference fuels.

The assumptions made in this LCA are that the ethanol will be used as a blend of 10% (by volume) mixed with the reference fuel (petrol) and that the biodiesel will be used as blends of 5% and 20% (by volume) with the reference fuel (diesel). E10 was chosen because the Australian Fuel Quality Standards standard for petrol limits the maximum ethanol content to 10%. Although no limits for biodiesel exist in the national fuel standard for diesel fuel, blends of up to 5% (B5) are accepted by most vehicle manufacturers provided the resulting blend complies with those accepted international fuel standards and vehicle manufacturer recommendations. A blend of 20% (B20) may be viewed as an upper limit on acceptable biodiesel blends in the near future, though most vehicle manufacturers in Australia currently refuse to endorse the use of B20 blends in their vehicles and state that its use will void the vehicle warranty. As a result, any damage caused when using these fuels is not covered under the majority of car warranties. A list of warranties available from different diesel producers is given in Appendix 3.

The CSIRO's standard methodology requires a set of testing data that uses the reference fuel and the test fuel. In the case of biodiesel, we are unaware of any Australian emission studies, so we have used the results of the US EPA Biodiesel Emissions Analysis Program[3]. In the case of ethanol, though we are aware that the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) commissioned CSIRO and Orbital Engine Corporation to undertake testing of ethanol fuelled vehicles, the results of this study have not yet been released. The results of the NSW petrohol study (APACE, 1998) were used.

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[3] http://www.epa.gov/otaq/models/biodsl.htm

2 An Introduction to Biofuels

2.1 Ethanol from Wheat

Ethanol can be produced in two forms: hydrated and anhydrous. Hydrated ethanol is usually produced by distillation from biomass fermentation, and is suitable for use as a straight spark ignition fuel in warm climates or for use as diesohol which is a blend of 15% ethanol in diesel or biodiesel. A further process of dehydration is required to produce anhydrous ethanol (100% ethanol) for blending with petrol. Anhydrous ethanol can be used as an automotive fuel by itself or can be mixed with petrol in various proportions to form an ethanol/petrol blend that is called petrohol.

This study assumes that ethanol produced at Primary Energy’s Facility will be made from several varieties of wheat grown in Western Australia and that it will be combined with petrol to make E10, a blend of 10% ethanol (by volume) and petrol, which will then be used as a fuel for spark-ignition vehicles.

Beer et al. (2003) assessed emissions (greenhouse gases, carbon monoxide, particulate matter, oxides of nitrogen, hydrocarbons and air toxics), viability and functionality, health and environmental issues, and Australian Design Rules (ADR) compliance. The tailpipe emissions in Beer et al. (2003) were used in this report.

2.2 Biodiesel from Tallow

Biodiesel is a fatty acid ester with similar combustion properties to those of diesel. In Australia, the most common feedstocks are used vegetable oil (the cheapest), tallow, imported palm oil, and canola (a proprietary derivative of rape seed). Any product containing fatty acids, such as vegetable oil or animal fats, can be used as a feedstock.

Table 2.1: Comparison of some properties of diesel, oils and fats and their methyl esters.

	Diesel	**Canola**	**Canola methyl ester**	**Palm oil**	**Palm oil methyl ester**	**Beef Tallow**	**Tallow methyl ester**
Density (kg/L) at 15.5°C	0.835	0.91	0.875-0.900	0.92-0.93	0.859-0.875	0.92	0.877
Gross calorific value (MJ/kg)	45.9	39.78	40.07	39.3	41.3	40.05	39.9
Viscosity (mm^2/s @ 37.8°C)	3.86	37.7	3.5-5.0	36.8-39.6	4.3-6.3	N/A	4.47-4.73
Cetane number	40-58	39-44	49-62	42-62	50-70	-	58

Source: Beer, Grant and Campbell (2007)

Table 2.1 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 lower carbon contents 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 a typical vegetable oil such as canola oil and diesel is in the viscosity. Canola is more than 12 times as viscous as diesel at 20°C, and remains more than six times as viscous even after heating to 80°C.

Tallow is rendered animal fat and a by-product of the livestock processing industry. Australian tallow production in 2000-2001 was about 567,000 tonne (Australian Renderers' Association, 2002), most of which was exported (68%). Using traditional processing technology, the biodiesel yield from tallow is about 894 litres a tonne (Beer, Grant and Campbell, 2007). However, the Energea technology adopted in the Picton plant claims a yield of 100%, meaning that 1 tonne of tallow produces 1 tonne of biodiesel. Under these conditions, the yield is about 1,140 litres per ton.

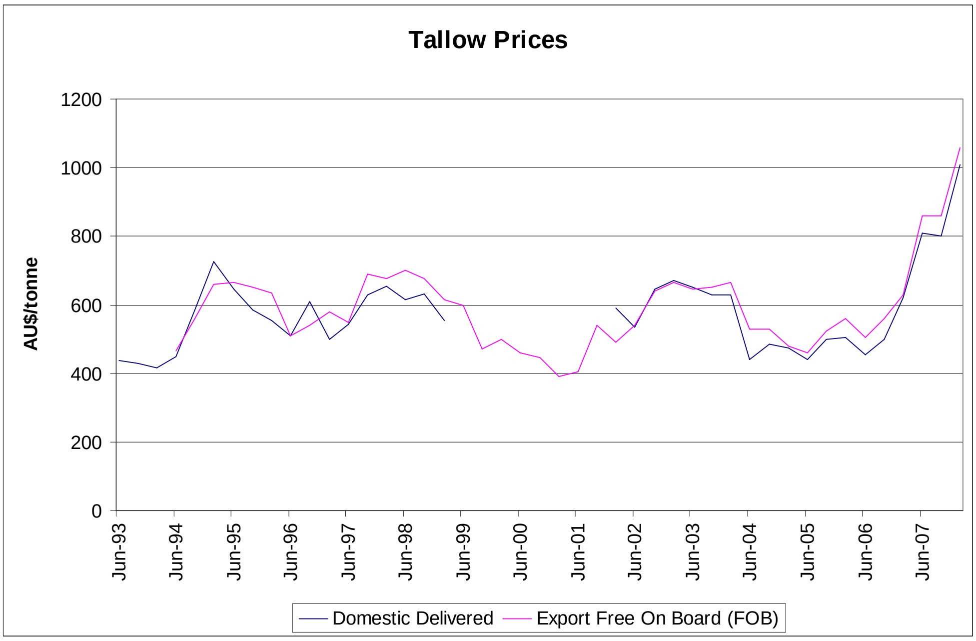

Figure 2-1: Tallow Prices (high grade, max 1% FFA)

Source: Beer, Grant and Campbell (2007)

From June 1994 until February 2007, tallow prices in Australia ranged between $400 and $700 a tonne (Figure 2.3). If we adopt a trend average of $550/tonne from Figure 2.3 and production costs from the spreadsheet provided by DAFWA, biodiesel production costs were 72 c/L. At a price of $850/tonne (June 2007), tallow biodiesel would cost 98 c/L to make. Since the initial spike last year, prices have reached $1,100/tonne (see Figure 2.3), which corresponds to a biodiesel production cost of 120 c/L. As the cost of producing tallow-based biodiesel is highly sensitive to the cost of the feedstock, biodiesel producers such as ARF face a volatile marketplace for their key feedstock.

Tallow is sold in several different grades, depending mainly upon the percentage of free fatty acids (FFA). Although the name differs from country to country, it is usually top white (edible) that has under 1% FFA, prime 1-2% FFA, extra fancy 2% FFA, bleachable fancy (good) 2-4% FFA, unbleachable (low grade) 10% FFA, medium gut 10-15% FFA, K grade 21% and low gut (dark) up to 60% FFA.

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3 Western Australia's Fuel-producing Facilities

3.1 Primary Energy Pty. Ltd.

Primary Energy Pty Limited proposes to establish an ethanol biorefinery in the Kwinana Industrial Area, south of Fremantle in Western Australia (see Figure 3-1). The proposed facility will use Western Australian wheat to produce up to 160 million litres of fuel grade ethanol per year. Umwelt (Australia) Pty Limited submitted environmental documentation for Primary Energy's project to the Western Australian Environment Protection Authority (EPA) and the Department of Environment in June 2006. Umwelt's website (http://www.umwelt.com.au/kwinana-ethanol/) provides information on Primary Energy and the Kwinana Ethanol Biorefinery proposal, suggesting that this facility could reduce net greenhouse gas emissions from the transport sector by 400 gigagrams (Gg) of carbon dioxide per year.

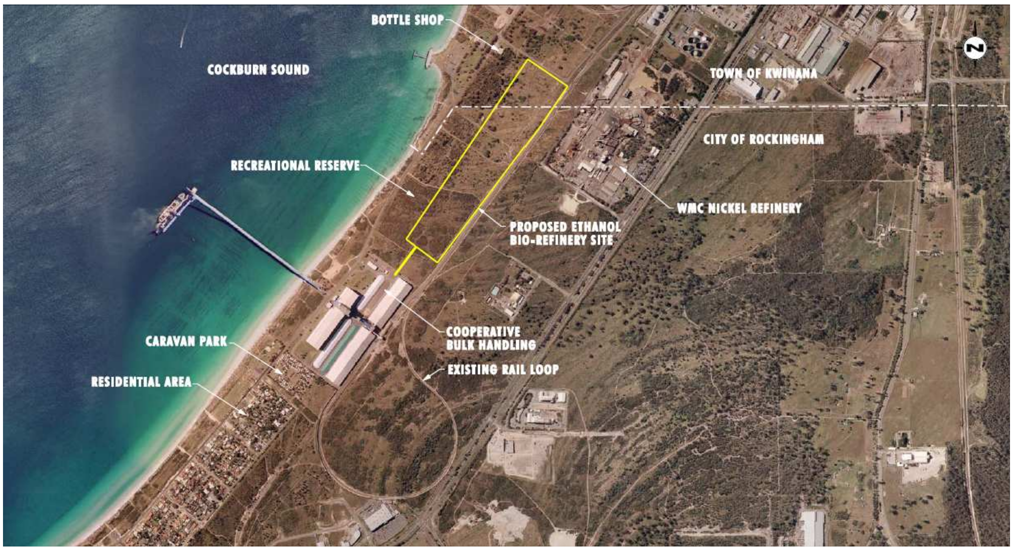

Figure 3-1: Location of the Kwinana ethanol biorefinery

Primary Energy's biorefinery will use wheat, electricity, natural gas, water and other additives such as enzymes to produce fuel grade ethanol, fertiliser, aqueous ammonia and green electricity. Production will occur in four integrated processing units, namely:

- An ethanol plant producing fuel grade ethanol from grain (Delta-T technology)
- An anaerobic digester plant producing biogas (consisting mostly of methane) to be used to generate heat and green electricity and a sludge to be used in fertiliser production (Bioscan technology)
- A fertiliser plant for drying the 'sludge' from the anaerobic digesters and production of fertiliser (Flo-Dry technology)
- A combined heat and power plant (CHPP) which uses the biogas from the anaerobic digester plant to produce green electricity and heat. Heat from the CHPP will be used to dry the 'sludge' in the fertiliser plant.

Water will be recovered from the process and recycled through the biorefinery, ensuring that there is no waste water released from the process.

3.1.1 Sources of Feedstock

There are two main wheat varieties that Primary Energy will most likely use as feedstock for ethanol production at Kwinana: (1) a hard wheat called *Wyalkatchem*, of which about

1.0 million tonne is produced in WA; and (2) a soft wheat called *Calingiri*, of which about 0.5 million tonne is produced.

3.1.2 Refinery and distillery operations – process and energy inputs

Wheat transported by road and train is cleaned, milled, and then slurried with water to form a mass that converts starch to dextrin, a type of sugar. Fermentation of mash produces ethanol and results in CO_2 sent to a scrubber to recover residual ethanol and a second CO_2 scrubber (if recovered). The beer resulting from fermentation is then distilled to 95.5%v/v purity and dehydrated. The distillation-dehydration system is integrated and is based on Delta-T molecular sieves technology.

Distilled grains and condensed solubles are fermented within an anaerobic digester to produce biogas which is combusted in steam used in the plant. Aqueous ammonia and water are also produced. The flow diagram of the complete process is shown in Figure 3-2.

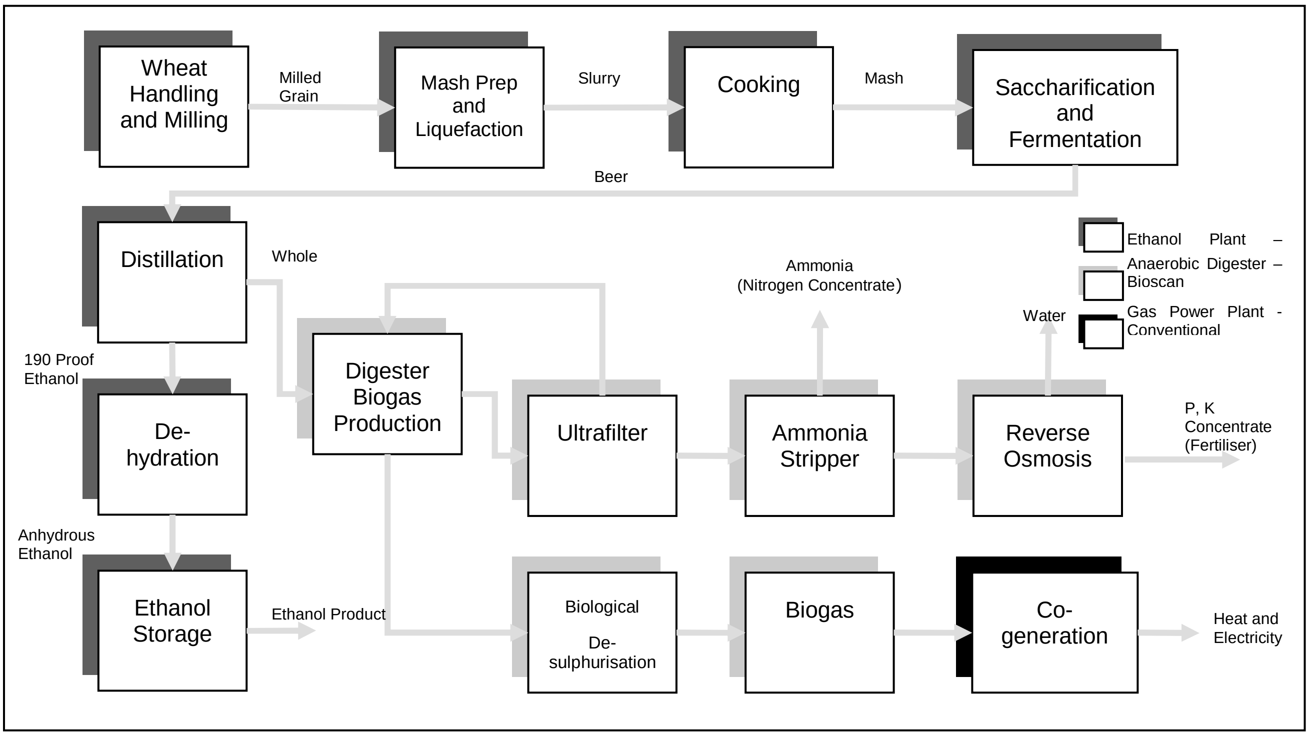

Figure 3-2: Process description for proposed Kwinana bioethanol plant

Source: Grant, Beer and Olaru (2005)

3.1.3 Production capacity

The Primary Energy biorefinery plant will produce 160 ML ethanol per year, requiring about 435,000 tonne of wheat (dry basis) or 475,000 tonne of wheat (as received). The wheat is assumed to possess a starch content of 69%, moisture content (as received) of 9.2% and to yield 0.42 kg of ethanol per kg of starch.

3.1.4 Downstream use of ethanol as fuel – emission factors applicable to E10

The Federal Government is presently conducting a study on the emissions associated with the use of E5 and E10 as a motor vehicle fuel. Because the results of their study are not yet available, APACE Research (1998) provided the main source of data for assessing the tailpipe emissions from ethanol blended with petrol against petrol. For uncertainty analysis, we have also examined Orbital Engine Company (2004) data on trials conducted in 2003-2004.

3.2 Australian Renewable Fuels Pty Ltd

Australian Renewable Fuels Ltd was founded by Amadeus Energy Ltd in 2001. Until the company shutdown both plants late in 2007, ARF produced biodiesel at Picton and at Largs Bay (near Adelaide). Both plants were opened in 2006 and have an annual capacity of 45 million litres (ML) each. However, in June 2008, Australian Renewable Fuels announced renewed production at Picton of about one-tenth plant capacity. The technology used in these plants was developed in Austria by Energea. ARF has secured the rights to the Energea technology for a continuous biodiesel manufacturing process using tallow, used cooking oil and canola in Australia and North America. By-products include 4,000 tonne of raw glycerol and 1,200 tonne per annum of sulfate of potash fertiliser in paste form.

Figure 3-3: Australian Renewable Fuel's Biodiesel Plant at Picton

3.2.1 Sources of Feedstock

Tallow production in Western Australia is approximately 40,000 tonne (Western Australia, 2007) and about 20,000 tonne would be available for the biodiesel industry. All tallow produced and transported in WA is by trucks. The breakdown of the available 20,000 tonne from the main tallow producers is given in Table 3.1.

Table 3.1: Tallow Producers in WA

Company	Location	Distance (km)	Source(s)	Tonnage
Harvey Beef	Harvey	30	Beef	10,000
Tallowman	Midland	180	Beef, sheep, poultry, pigs	7,000
Walshes	Bunbury	5	Sheep	500
Fletchers	Mt Barker	240	Sheep	1,500
Furtels	Midland	180	Beef, sheep, poultry, pigs	1,000

Source: Department of Agriculture and Food, WA, (2008)

Australian Renewable Fuels (ARF) has an exclusive five-year feedstock supply agreement for fat or tallow with Gardner Smith, Australia's market leader for the delivery and storage of fats. Gardner Smith has advised that most of the tallow for the Picton plant would be sourced from within WA (see Table 2.1) and, if additional tallow was required, it would be shipped from Brisbane to Fremantle and then trucked to Picton which is approximately 180 km south of Fremantle. Also, Gardner Smith has a global network of offices in Australia, New Zealand, Singapore, China and South Africa, giving ARF access to additional regional supplies from New Zealand, Indonesia, Malaysia and some South American countries.

3.2.2 Plant operations – description of process and energy inputs

ARF's biodiesel plant at Picton uses Energea's "Continuous Trans Esterification Reactor" (CTER), a pressurised and continuous technology developed in Austria. Energea's main innovation in biodiesel technology has been described as "microelement-enhanced reaction kinetics" (Holecek, 2007). This patented CTER process is reputed to lower investment costs and achieve almost 100% yield, meaning that 1 tonne of feedstock makes 1 tonne of fuel. Plant installations are built in container-sized modules that require less space than other biodiesel modules of a similar capacity[4].

Energea's multi-feed-stock technology can process various feedstocks, like used cooking oil, tallow and vegetable oils. It produces biodiesel that meets international fuel quality standards such as EN 14214. Transesterification occurs at elevated temperatures and the whole process is completed in about 20 minutes. CTER uses acid, an alkaline catalyst, and relatively low ratios of methanol to oil. According to Australian Renewable Fuel's website[5], ARF personnel have "further optimised and developed the Energea process to produce excellent conversion, yield and no environmental discharges".

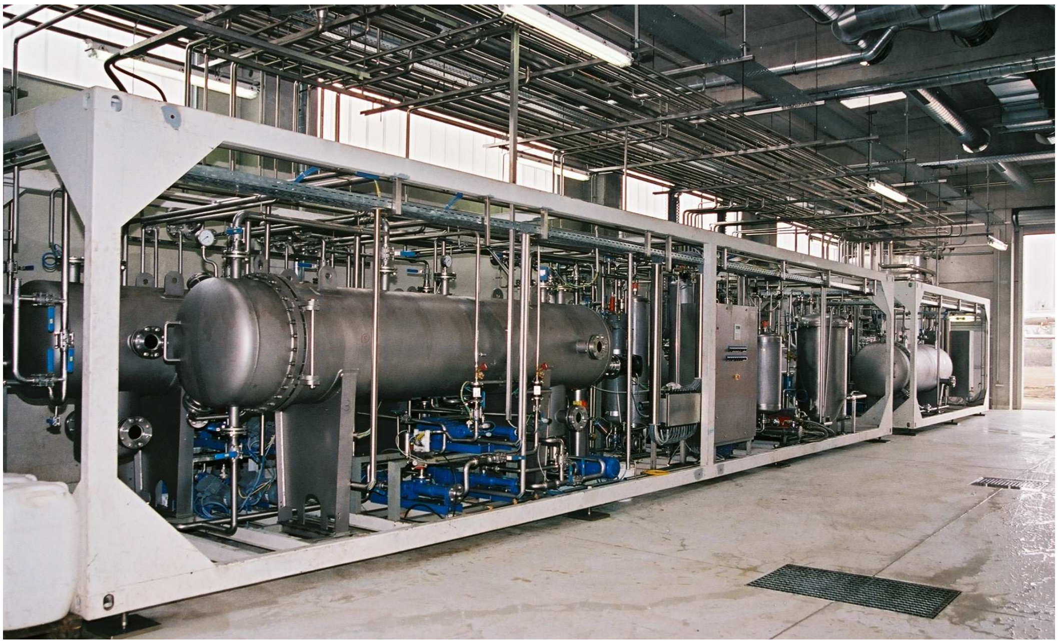

Figure 3-4: Energea's CTER processing units - 120 tonne/day (Source: Holecek, 2007)

[4] http://www.energea.at/

[5] http://www.arfuels.com.au/

3.2.3 Production capacity

ARF's plant at Picton can produce 45 ML of biodiesel each year, for which about 39,600 tonne of tallow is needed.

3.2.4 Downstream use of biodiesel as fuel

The results of the US EPA Biodiesel Emissions Analysis Program[6] contains a bibliography of biodiesel studies, a biodiesel emissions database (that does not contain any information on B5 emissions, although it does contain data on B10, B20 and B100 emissions) and a comprehensive report that summarised the results of biodiesel studies conducted up to 2002. This report (US EPA, 2002[7]) consists of a compilation of 39 different studies (extracted from 80 studies of which 39 were considered to be credible); the majority were on B20 and B100, but there was also a fair number of B50, B40, B30 and B10 tests with a small number on B70, B80, B60 and B90. These results were collated and curves produced to indicate the variation in tailpipe emissions as the biodiesel content of the blend varies. The results of this study were used to determine the tailpipe emissions for all biodiesel blends.

3.3 BP Refinery (Kwinana) Pty Ltd

BP's refinery at Kwinana is Australia's largest oil refinery, producing approximately 140,000 barrels of refined crude oil per day. Opened in 1955, the refinery produces a range of fuel and petroleum products for the domestic and export markets. At Kwinana, BP produces various products made from oil, including BP Ultimate™ and BP Ultra Low Sulfur Diesel (ULSD).

Figure 3-5: BP Australia's Refinery at Kwinana

Courtesy of BP Refinery (Kwinana)

[6] http://www.epa.gov/otaq/models/biodsl.htm

[7] http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf

Four basic processes are carried out by BP at their Kwinana refinery to convert crude oil into a range of marketable products.

1 SEPARATION: Physical separation using distillation is the basic process carried out in the refinery. When crude oil is heated, vapours are generated which differ in composition from the remaining liquid. This principle is used to separate the crude oil into a number of different components. Vacuum distillation is also used to remove waxy high boiling range components which remain in the atmospheric residue. This process enables heavy oils to be boiled at temperatures below their normal boiling points, thus avoiding thermal breakdown of the hydrocarbon molecules.

2 CONVERSION: Kwinana's catalytic reformer uses a platinum based catalyst within the reactors to convert low octane naphtha feedstock from the crude distillation units to a very high octane product that is used in petrol and aviation gasoline blending. The catalyst within the reformer is continuously regenerated to enable maximum processing efficiency. Hydrogen, a by-product of catalytic reforming, is used in a number of the other refinery processes. Isomerisation is another conversion process used within the refinery. Light naphtha feed is passed over two reactor beds containing a palladium catalyst. The straight chain low octane molecules are changed or 'isomerised' into branched high octane molecules. These are then recovered and blended into petrol and aviation gasoline. In the Residue Cracking Unit, heavier and less valuable components are converted into lighter and more useful substances. The products from the catalytic cracking process require further treatment, usually to remove sulfur, before they can be blended into petrol or other products. Alkylation converts several refinery gas streams into a liquid product suitable for blending into aviation gasoline or petrol. Isobutane is combined with butylene to form alkylate. Hydrofluoric acid is used as a catalyst.

3 PURIFICATION: The main purification process used at Kwinana is desulfurization, in which sulfur is removed from the different hydrocarbon components. An example of a purification unit is the Diesel Hydrofiner Unit which treats gasoils from the Crude Distillation Units and the Residue Cracking Unit. The gasoil is combined with hydrogen at a high temperature and pressure in the presence of a catalyst containing nickel, cobalt and molybdenum. The sulfur in the hydrocarbon compounds is converted into hydrogen sulfide gas. Clean low sulfur diesel is produced as a result. The hydrogen sulfide gas is converted into sulfur at the Sulfur Recovery Units.

4 BLENDING: Blending in the refinery's tankfarm is the final step in production of refinery products. Different refinery components are blended together in suitable proportions to meet various product specifications.

4 Life Cycle Assessment (LCA)

4.1 Goal

The main goal of the study is to perform a Life Cycle Assessment of environmental outcomes and total greenhouse gas emissions associated with the operation of ARF's 45 ML biodiesel plant in Picton and Primary Energy's proposed 160 ML ethanol plant in Kwinana. A secondary goal is to compare the outcomes of using E10, B5 and B20 blends with the environmental and greenhouse gas emissions associated with production and use of petrol and diesel produced at BP's petroleum refinery in Kwinana.

4.2 Scope

This and the following sections describe in general terms how the LCA is undertaken, the system boundaries and allocation procedures, greenhouse gas emissions, air pollution and other aspects of the study. A more general introduction to LCA may be found in Graedel & Allenby (1995) and Weidema et al. (2004). The international standards contained in the 14040 series (International Standards Organisation, 2006) provide a basic framework in which to undertake LCA. When LCA is applied to greenhouse gas emissions in agriculture, all pre-farm, on-farm and post-farm emissions of carbon dioxide, methane and nitrous oxide should be included. A full life-cycle analysis of emissions takes into account not only the direct emissions from vehicles (which are referred to as downstream emissions) but also those associated with the fuel's:

- Extraction
- Production
- Transport
- Processing
- Conversion
- Distribution

Emissions at the above stages are referred to as upstream emissions and, in the context of automobile fuels, they are also referred to as pre-combustion emissions.

The Bureau of Transport and Communications Economics (BTCE, 1994) uses the term 'full fuel cycle' for the situation that takes into account emissions from all energy used in achieving a given transport task with a particular fuel. The full fuel cycle contrasts with the more basic analysis of tailpipe emissions. A life-cycle basis for estimating fuel emissions for a particular fuel takes into account emissions in vehicle manufacture and vehicle life, whereas a full life-cycle analysis sets the system boundaries much wider and incorporates emissions from the associated infrastructure. The term "well to wheel emissions" is also used in the analysis of automotive fuels.

Life-cycle analysis is often used to determine the amount of upstream energy used to construct a particular object. The term 'embodied energy' has achieved widespread use to denote such energy. However, the term 'embodied emissions', to cover the full fuel-cycle emissions of gases or pollutants, would be a misnomer, because emissions are emitted, not embodied. Thus, in this report, we use the term cumulative life cycle emissions.

Emissions related to vehicle manufacture, maintenance and disposal, and road building are relevant to total transport emissions, but they are not likely to vary significantly with the nature of the fuel used. The infrastructure associated with refuelling will, however, vary with the different alternative fuels.

4.2.1 System functions

LCA results are always calculated relative to the delivery of utility or function, commonly a product or service. Most product systems are focused around a primary function while, along the way, contributing to other product systems or providing other utilities that can be seen as secondary functions.

Bioethanol Plant

The ***primary function*** of the biorefinery is the production of fuel-grade ethanol for use in transport fuels in Australia. By virtue of the design of the biorefinery, a number of other significant functions (products) are produced which could arguably be the primary product; for example, electricity. However, given that the focus of the refinery is ethanol production, ethanol has been identified as the primary function.

The ***secondary functions*** of the biorefinery, as configured with the anaerobic digester, are assumed to be: greenhouse-neutral electricity production; compost production; and ammonia production.

Potentially, the process can also be used to produce carbon dioxide and thermal energy, although markets for these products are not clear in the current plans.

Biodiesel Plant

The ***primary function*** of the biodiesel plant is the production of fuel-grade biodiesel for use in transport fuels in Australia. Because of price volatility in the marketplaces for tallow, biodiesel and glycerol, conditions might arise when the main co-product, namely glycerol, could be regarded as the plant's primary function.

The ***secondary function*** of the biodiesel plant is assumed to be glycerol production.

4.2.2 Functional units

The functional unit in LCA quantifies the system functions and defines the basis for comparison of systems alternatives. The functional unit should incorporate all the services provided by all the scenarios.

The functional unit for our study of the bioethanol refinery is:

- production and utilisation of fuel as E10 (a blend by volume of 10% ethanol in petrol) for 1 kL of pure ethanol (blended with 9 kL of ULP), enough to fuel a family vehicle for 80,000 kilometres

This results in several outputs/co-products (amounts in parentheses for basic scenario):

- production of electricity (1.764 MWh or 6.35 GJ)
- production of phosphorus in compost (41.6 kg of triple super phosphate)
- production of potassium in compost (21.9 kg of potassium chloride, KCl)
- production of nitrogen in compost and ammonia (80 kg urea and 20.6 kg ammonia)

The functional unit for our study of the biodiesel refinery is:

- production and utilisation of fuel as B5 (a blend by volume of 5% biodiesel in automotive diesel) for 1 kL of pure tallow biodiesel (blended with 19 kL of automotive diesel), enough to fuel a medium rigid truck for 70800 kilometres

This results in two co-products (amounts in parentheses for basic scenario):

- production of low quality glycerol (97.78 kg)

- production of potassium in potassium sulfate (18.67 kg K_2SO_4)

For BP Kwinana the functional units are production and utilisation of 1 kL of the various fuels (automotive diesel, 91 RON ULP, 95 RON PULP and 98 RON PULP) in a medium rigid truck or family car as appropriate, as per above.

4.2.3 System boundaries and co-production.

4.2.3.1 Introduction

Life cycles of products consist of many individual processes which describe the flow of material and energy along a supply chain to deliver goods and services. The processes which are included in an LCA are defined by the system boundary which separates included and excluded processes in an LCA. Ideally all connected processes in an LCA would be included; however there are a number of reasons for excluding processes from an LCA. These are:

- the process is considered small enough to ignore, given the study's aims; and
- processes which will be the same for all options assessed which could be either:
    - process common to both production systems, such as vehicle production for fuels LCA
    - processes that would be expected to be different but are not due to other market drivers and constraints, such as beef production from tallow utilization. Beef production is driven by demand for beef and not tallow, so beef operations and rendering will not change as demand for tallow increases.

4.2.3.2 Approach for dealing with co-production in life cycles

In this LCA co-production is both an issue for the feedstock used (e.g. tallow is a by-product of beef production processes) and for the fuel production processes (such as electricity produced from the ethanol biorefinery or bitumen from the petroleum refinery). A methodology needs to be applied to determine the appropriate environmental impacts of these co-produced materials. The two main options available for dealing with co-production are:

- to split emissions between the product streams – known as allocation, or
- to expand the system boundary to take into account how the potential flow-on effects change demands for each co-product – known as system boundary expansion.

The two basic approaches are shown in Figure 4-1. The international standards on life cycle assessment (International Organization for Standardization, 2006) state that allocation should be avoided where possible through the use of system boundary expansion. Where this is not possible allocation should be undertaken using either causal relationships, based on economic, or physical properties of the co-products.

These two approaches – allocation and system boundary expansion are referred to as ***attributional*** and ***consequential*** *LCA* respectively (Ekvall, 2002).

Consequential LCA (sometimes referred to as change-oriented LCA, market-based LCA, marginal LCA, or prospective LCA) sees LCA as a tool for measuring the consequence of a product or process substitution (including product modifications, material substitutions, regulation of interference in consumer behaviour and so on). ***Consequential LCA*** attempts to measure the impacts of additional production or a reduction in production.

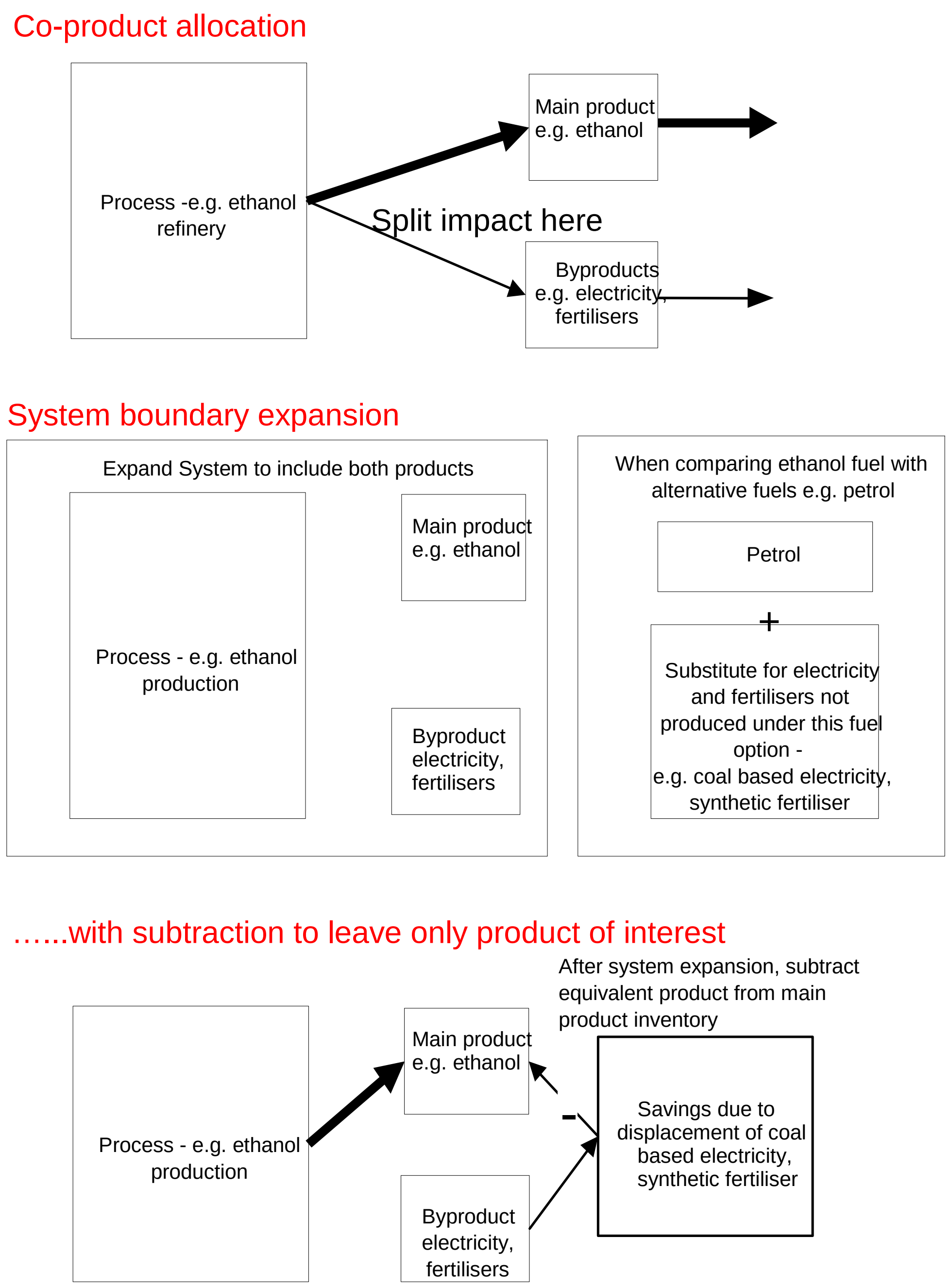

Figure 4-1: Approaches to allocation in LCA

Attributional LCA (also referred to as retrospective or descriptive LCA) is a more traditional approach to LCA and describes a product system that allocates co-products based on economic value, mass, energy, or other attributes of the system (when physical causation cannot be used to allocate co-products). ***Attributional LCA*** intends to measure the average impact of production. One of the most common ***attributional*** allocations is economic allocation because it represents the main driver behind production, and may be the only comparable attribute between all co-products.

The difficulty with system boundary expansion is that it requires a good knowledge of the market forces that result in the product substitution. It is also complicated by the fact that many co-products are competing with other co-products (Weidema et al. 2004). It is necessary then to follow the product substitution chain back to a point where a “determining” or “main” product is found for which production can be expanded or contracted in line with economic demand. Allocation has been avoided in this study, where possible, through the use of an expanded system boundary approach.

In the LCA studies reported here, system boundary expansion has been used wherever the fuel is produced from the non-determining co-product (e.g. tallow). Where a determining product is to be used as a fuel, such as for wheat, economic allocation was applied due to difficulties and additional work in applying expanded system boundaries.

Table 4.1: Allocation approaches in bio-fuels LCA

Process	Main product of interest	Co-product(s)	Allocation approach
Integrated farming system	Wheat crops	Sheep, canola, pasture, lupins crops	Each crop carries the burdens of its own production. No impacts from Lucerne or legume crops are carried over into the wheat crops, although the state averages of these crop systems would incorporate some effect from intercropping.
Wheat crop	Food grade wheat	Off specification wheat, wheat straw	Off specification wheat is assumed to be used in beneficial uses such as blended with higher quality wheat for export. When off specification wheat is not available food-grade wheat will be used - therefore off specification wheat is included as part of overall wheat yield and not discounted in this study Straw is ignored as it is either worth very little as saleable product or is incorporated as part of the no till system.
Co-production at the biorefinery	Anhydrous ethanol	Electricity Compost with high phosphate and potassium content Ammonia	System boundary expansion is used. Electricity is taken to offset average WA grid power (2005-6 data) Nitrogen, phosphate and potassium offset urea, triple super phosphate and potassium chloride respectively based on NP and K concentrations
Beef production	Beef	Tallow	System boundary expansion is used. Tallow is assumed to compete in the world market with palm oil, therefore the diversion of tallow into biodiesel is assumed to increase demand and production of palm oil.
Biodiesel production	Biodiesel	Glycerol	System boundary expansion is used. Glycerol is used for pig-feed which offset the need for production for pig-feed.
Fuel production	Premium unleaded petrol (PULP)	Other fuels	Energy content used for basic fuel production (unleaded petrol (ULP)) and then economic allocation for upgrading of ULP to PULP

4.2.3.3 System boundaries

The system boundary describes the processes to be included into the study. In this study all fuel production processes and feedstock supply processes are included. Capital equipment and infrastructure are universally excluded from the study, based on its expected low contribution to the overall environmental impact of the fuel used.

The system boundary diagram in Figure 4-2 shows the processes included for biodiesel production. It shows that the beef system is not included in the study as tallow is taken as a non expanding co-product of beef. This means that the supply of tallow is constrained by the amount of beef production, so that if some of the existing tallow is used for a new purpose (such as biodiesel production) then the existing users of tallow will need to find a substitute product.

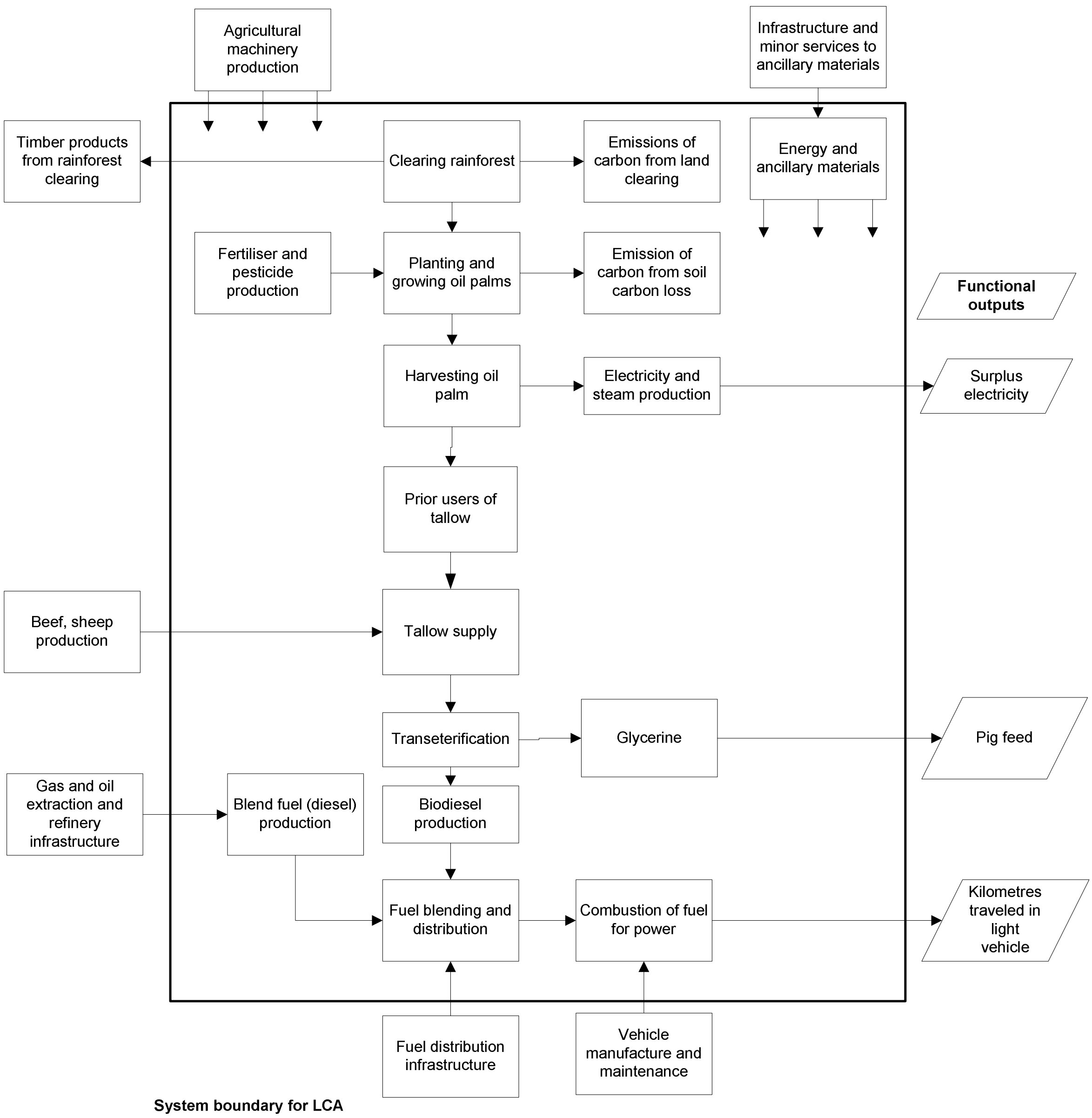

Figure 4-2: System Boundaries for Biodiesel Production

The system boundary for the ethanol biorefinery study is shown in Figure 4-3. It incorporates all farming operations, transport of grain to the biorefinery, all facility operations and inputs, blending and transport of fuel, and, finally, the fuel combustion. For conventional fuel, the processes include oil and gas production, transport, refining, and fuel combustion. For electricity co-production, the system boundary includes fuel extraction, transport and combustion. Line losses in electricity distribution are not included as they are assumed to be similar for all sources of electricity.

For phosphate fertiliser, production includes all processes except those which contribute to Nitrogen (N) content. For potassium fertiliser and ammonia, production includes all processes from raw material extraction to manufacture.

Capital equipment manufacture on the farm and original paddock establishment are excluded from the system boundary. Capital requirements for the biorefinery are also excluded in the main calculations, as they are for refineries for conventional fuel production (see Figure 4-4).

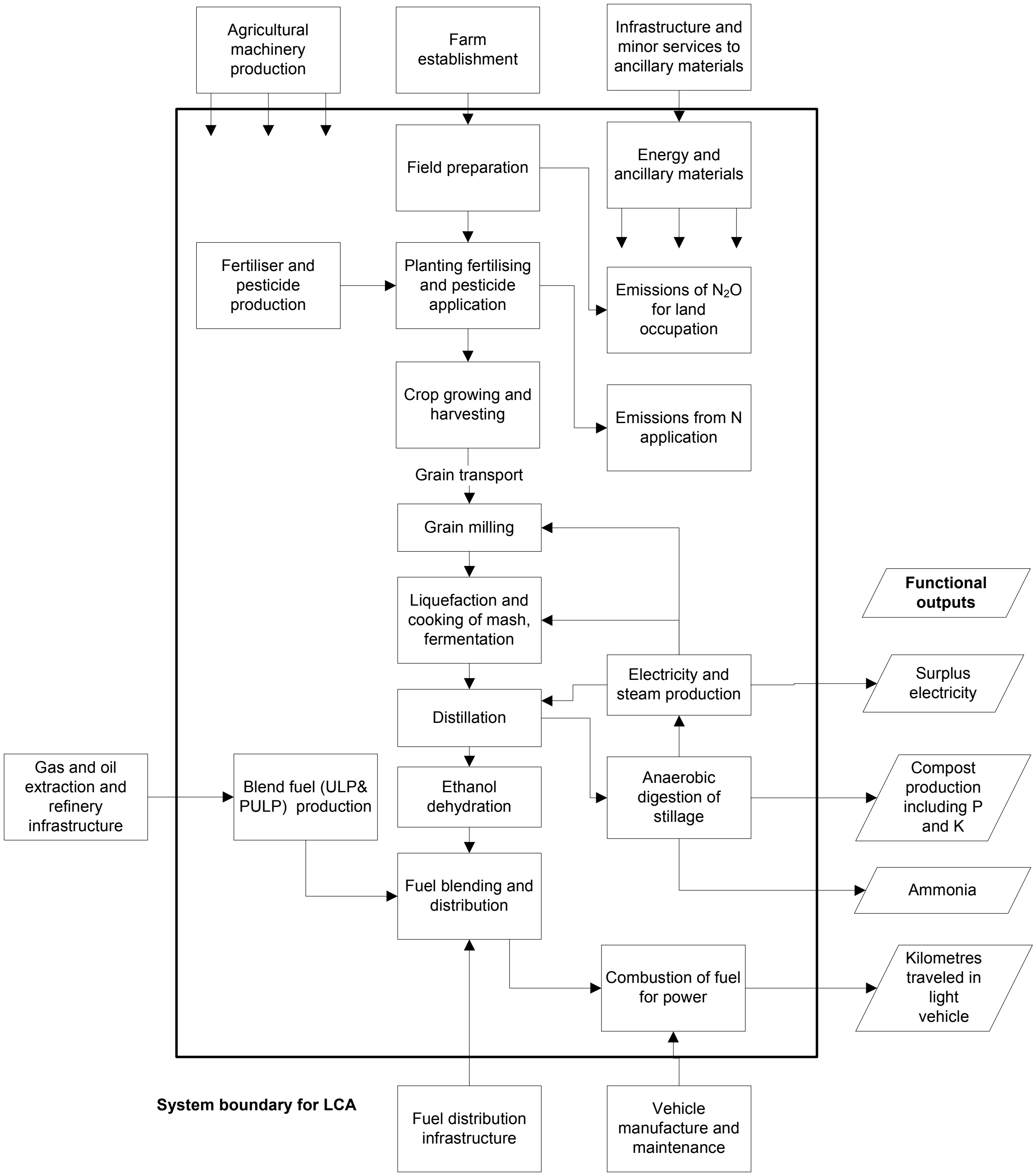

Figure 4-3: System boundary for Ethanol Biorefinery LCA

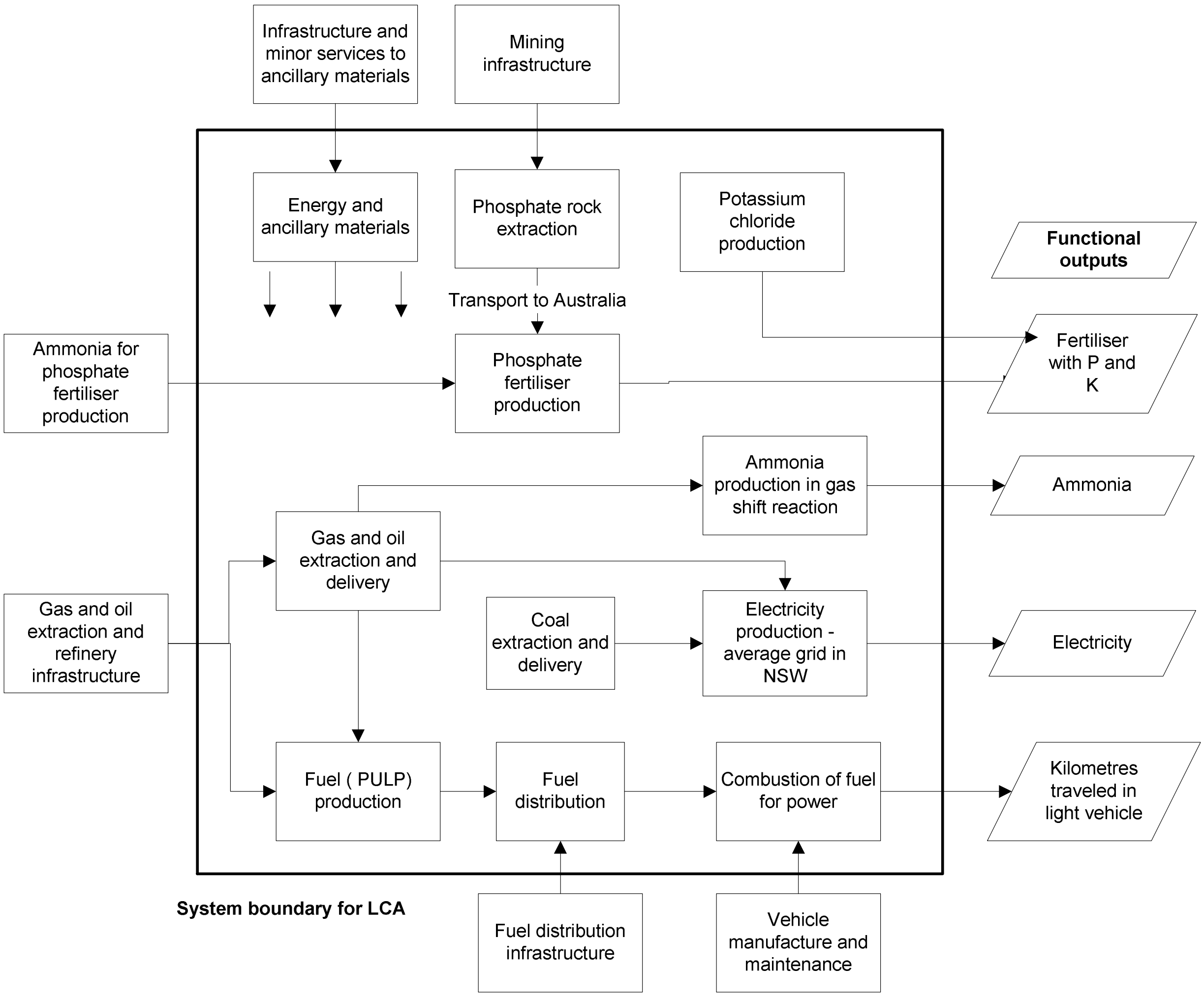

Figure 4-4: System boundary for conventional fuel scenario

4.2.4 Impact assessment

The study is only concerned with greenhouse gas (GHG) impacts arising from substances that have been identified as having global warming potential. Greenhouse gas impacts are calculated using global warming potentials recommended by the Intergovernmental Panel on Climate Change (IPCC).

The greenhouse gases considered in this report are carbon dioxide, methane and nitrous oxide. The concept of a global warming potential (GWP) has been used to enable different greenhouse gases to be compared with each other and expressed in equivalent carbon dioxide. The GWP factors reflect the different extent to which gases absorb infrared radiation and the differences in the time scales in which the gases are removed from the atmosphere. The GWP is used in the National Communications required by the UN Framework Convention on Climate Change. The Kyoto Protocol has adopted GWPs (with a 100 year time horizon) as the basis for defining equivalences between emissions of different greenhouse gases during the 2008–2012 commitment period. These GWPs are given in Table 4.2.

Table 4.2: 100-year GWP[8]

Gas	GWP
Carbon dioxide	1
Methane	21
Nitrous oxide	310

Carbon sequestration from compost application is included as sensitivity from fertiliser application. Carbon sequestered in soil is calculated by the weight of carbon assumed to be sequestered multiplied by the molar ratio of carbon dioxide to carbon (44/12) to give the equivalent amount of carbon dioxide removed from the atmosphere. Other greenhouse gas contributions are tracked through the life cycle; however none rates significantly in the results.

4.2.5 Compliance with ISO14040 series standard on Life-Cycle Assessment

In general the methodologies applied in this study are in compliance with the ISO 14040 series standards[9]. In particular we have endeavoured to follow the standard on the following points:

Allocation procedures: For multi-product systems we have opted first to try expanding the system boundary to eliminate the need for allocation. Where this has not been practical, allocations have been made on energy content (e.g. in refineries) or economic value (e.g. agricultural products). Sensitivity studies have been undertaken using alternative allocation procedures where there is some question over the appropriateness of the allocation procedure and where an alternative method is possible.

Indicators: The two main indicators being examined in the project are global warming and air quality. In the case of comparative assertions released to the public, the standard allows for calculation of indicator results (characterisations) that are internationally accepted. The greenhouse indicator is clearly internationally accepted, with the characterisation factors[10] being developed by the IPCC. For the air quality indicator, the use of such an indicator is not uncommon internationally. However, international acceptance of the characterisation factors that are used is unlikely given the local nature of the air quality impacts and the fact that the values are based on this local situation. Compliance on this point is unclear.

4.2.6 LCA Modelling

Life-cycle analysis was done using SimaPro 7 software. SimaPro 7 is an open structure program that can be used for different types of life-cycle assessments. The production stage, the use stage and the end-of-life scenario can be specified in as much detail as

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[8] http://unfccc.int/ghg_data/items/3817.php

[9] The series include ISO 14040 (International Standards Organisation, 2006) which gives a general framework and ISO 14044 (International Standards Organisation, 2006) which along with ISO 14040 outlines the inventory assessment, impact assessment and interpretation, which used to be in the (now replaced) ISO 14041:1997, 14042:2000 and 14043:2000 documents.

[10] The characterisation factors are considered in this report to be part of the third mandatory stage of impact assessment [see page 3 of International Standards Organisation, 2001] as they apply to one damage endpoint — human health effects from urban air pollution. The values could be considered as weighting factors and thus part of impact weighting [stage three of the optional impact assessment process, which is not allowed by the standard in the case of a comparative assertion released to the public.]

necessary by selecting processes from the database and by building process trees, which can be drawn automatically by the program. The results are presented in scores or graphs, varying from a list of substances (inputs and outputs), characterised scores, normalised scores or evaluated scores.

An alternative life-cycle model for alternative fuels, much used in the United States, is the GREET model developed at Argonne National Laboratories. The GREET model is based on Excel spreadsheets. It is thus easier to use than SimaPro but lacks the flexibility of SimaPro.

5 Life Cycle Inventory Analysis

5.1 Feedstocks

5.1.1 Wheat production

The two most popular wheat varieties used as feedstocks; *Wyalkatchem* and *Calingiri* have yields that are 1.8 t/ha and 1.75 t/ha respectively. It is assumed that material and energy inputs are identical for both varieties. As listed in Delta-T (2007a and 2007b) identical ethanol yields of 0.4225 kg per kg of wheat starch are obtained on average.

Key parameters for wheat production are shown in Table 5.1. The materials input and output data are shown in Table 5.2. The resulting greenhouse gas emission per ha are shown in Figure 5-1. This figure is in the form of a standard SimaPro flowchart. The final result can be found in the top rectangle inside which the values indicate that 1 ha of wheat production produces 1.75 tonne of wheat and has life-cycle greenhouse gas emissions of 361 kg of CO_2-e. The rectangles below the top rectangle indicate that the greenhouse gas emissions are dominantly comprised of emissions from urea manufacture (80.8 kg of CO_2-e), NPKS fertiliser application (141 kg of CO_2-e) and fuel use in tractors (88.5 kg of CO_2-e). Greenhouse gas emissions as a result of soil disturbance are not explicitly shown in the flowchart but are included in the greenhouse gas emissions balance. Stubble retention involves complicated greenhouse gas emissions, and also savings.

We note that the values in Figure 5-1 imply a life-cycle emission of 206.3 kg of CO_2-e for the delivery of one tonne of wheat. This compares with a value for Western Australian wheat of 171 kg of CO_2-e per tonne obtained by Biswas et al. (2007), and 259 kg of CO_2-e obtained by Barton et al. (2008, pers. comm.).

Table 5.1: Key parameters for wheat production in WA for bioethanol

Parameter	Unit	Value	Min	Max	Comment
kg Nitrogen input in form of urea	kg	40	20	50	
NPK used	kg	120			
Nitrogen in NPK	kg N/kg NPK	0.32			
Phosphorus in NPK	kg P/kg NPK	0.1			
Fraction on Nitrogen volatilised	N/kg N applied	0.0002	0.0002	0.0125	Biswas et al. (2007)
Number of pre-cropping spray runs		2			
Number of in crop sprays		2			
Fuel use per spray run	L/ha	2	1.5	3	Tractor use
Fuel use per seeding run	L/ha	7	5	9	Tractor use
Fuel use per harvest run	L/ha	7	5	9	Tractor use
Transport of crop	L/ha	2	1	3	transport on farm
Seed usage	kg/ha	75			
Yield of wheat	t/ha	1.75 or 1.8	1.5	2.5	Yield of wheat 1.8 t/ha for Wyalkatchem and 1.75 t/ha for Calingiri.

Table 5.2: Input and output data for 1 ha wheat production

Flow	Unit	Value
Products		
Central WA Wheatbelt (Calingiri) Wheat, Stubble retention	t	1.75
Resources		
Occupation, arable, non-irrigated	ha.a	1
Materials and Energy		
Urea, at regional store	kg	87
Fertiliser, NPKS 32%/10%/0%/0%, at regional store	kg	120
Glyphosate 41.5%, production and application	kg	2
Diuron, at regional storehouse	kg	0.5
MCPA, at regional storehouse	kg	0.5
Central WA Wheat belt seed wheat, Stubble retention 100%	kg	75
Tractor, per MJ fuel input	MJ	851
Emission to Air		
Nitrogen volatilisation	kg	0.0157
Waste to treatment		
Stubble retention	t	3.06

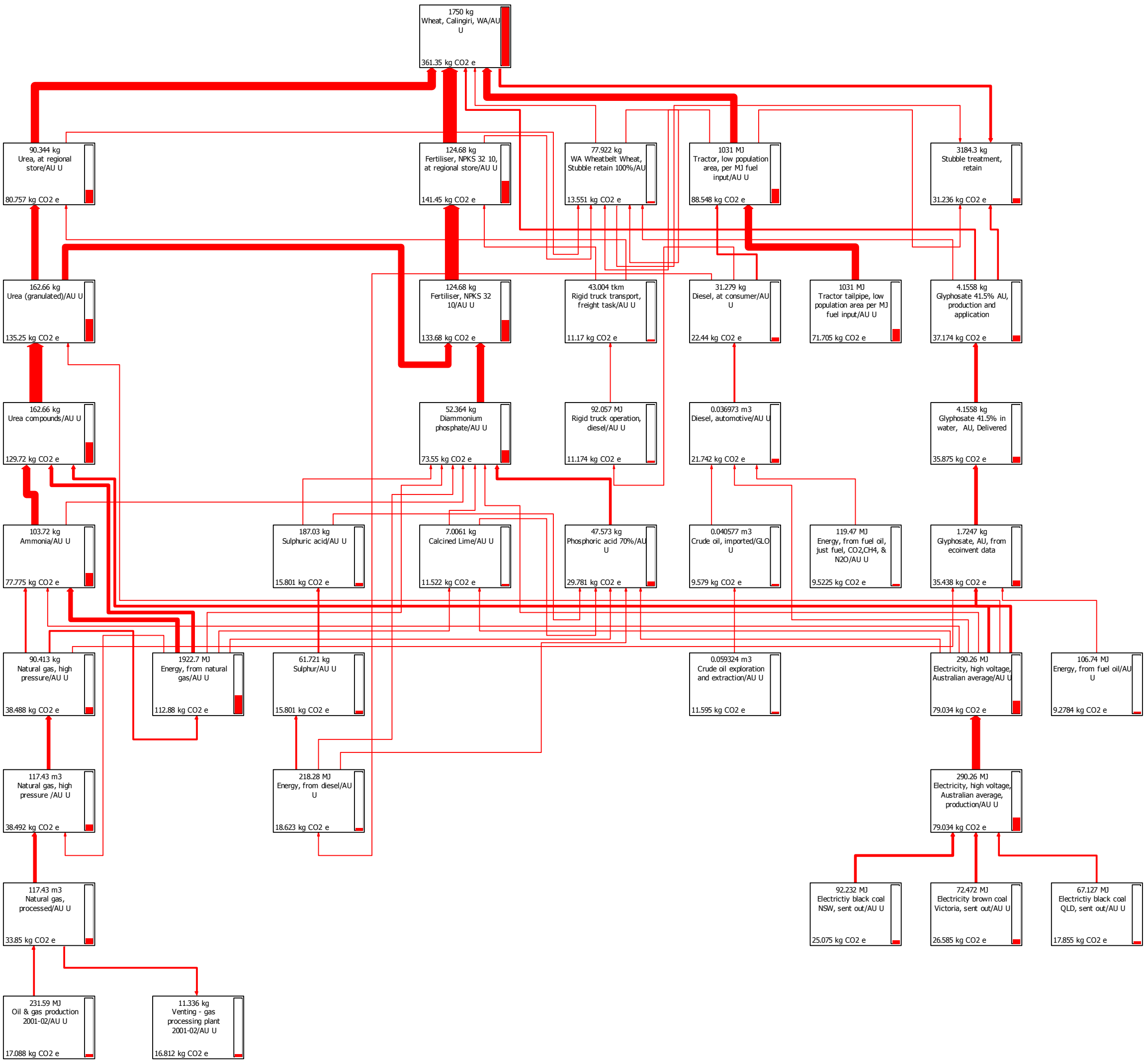

Figure 5-1: Process network showing major (contributing 2.5% or more of the total value) flows (upper value) and cumulative greenhouse gas emissions (lower value) for 1 hectare of Calingiri wheat production

5.1.2 Tallow market substitutes

Using a consequential LCA analysis, the use of tallow is not assumed to result in changes in beef production. Tallow supplied to Picton is assumed to be taken from tallow exports and local tallow sourced in WA will either be from existing users, but more likely from the taken from currently exported tallow. Weidema (2007) asserts that the marginal supply of oil (depot fats) in the world market is palm oil so this is used and the production consequence of tallow utilization in biodiesel in Western Australia. If tallow is taken from local users it would be reasonable to assume they would source canola oil rather than palm oil as a replacement. Given the uncertainties around tallow export distances and palm oil import distance to the displaced users, no transport is included in the change from export of tallow to local use of tallow and import replacements by existing users in existing countries.

There are a number different assumptions that can be made for tallow market substitutes and these are examined in detail in Appendix 2.

5.1.3 Tallow from beef using economic allocation

In the economic allocation approach the emissions from beef production are allocated to each of the many co-products that are derived from that production, as shown in Table 5.3. It is therefore necessary to understand the beef supply sector and its co-products. In order to achieve full scale (45 ML) production, half of the tallow will need to be sourced from Brisbane, as shown in Table 5.7 (based on Table 3.1) and allowance has been made in Table 5.3 for the emissions associated with Queensland land clearing and savannah burning.

Given the focus of this study on greenhouse gas emissions, and the dominance of enteric fermentation and land clearing on the greenhouse profile of beef production, the inventory for beef production has been kept very simple.

The allocation factors for beef co-products are shown in Table 5.4 and the allocation of rendering feed stocks is shown in Table 5.5. Rendering feedstock is 4.5%, by value of total beef products. There are two types of rendering products produced: meat and bonemeal (MBM) comprising 36.8% and tallow comprising 63.2% by value. By combining these tables, tallow is allocated 63.2% of 4.5% which is 2.83% of the total beef production being allocated to tallow supply. This is up from 1.6% which was used in comparison of transport fuels in 2001, which is due to the increased value of tallow on the world market. The inputs to rendering given in Table 5.6 are taken from EcoInvent but are modified to Australian energy sources.

The resulting greenhouse impacts and process flows are shown in Figure 5-2. The tallow supplied carries a small proportion of the beef section impacts, which is why 177 kg of beef sector production is allocated to the 1170 kg of rendering feedstock even though approximately 4000 kg of beef production is required physically to produce 1170 kg of rendering feedstock. Rendering feedstock is then allocated between meat and bone meal

Table 5.3: Inventory data for beef production 2006-07

Flow	Unit	Value	Comment
Products			
Beef production	kg	1000	
Materials and Energy			
Corn, off specification, used for silage	kg	88.6	$39M dollars of grain at $200 per tonne for 2.2M tonne beef
Emissions to air			
Methane	kg	796	Enteric fermentation. Based on 36,800 Gg CO_2-e or 1752 kg CH_4 and 2.2Mt beef production 2006-07
Carbon dioxide, land transformation	kg	22955	Land clearing based on 50500 Gg CO_2-e and 2.2Mt beef production 2006-07
Nitrous oxide	kg	1.97	Urine deposition
Nitrous oxide	kg	107	Savannah burning N_2O 12000 t/a based on CO_2-e value being made up of 43% nitrous oxide contribution
Methane, biogenic	kg	5.45	Savannah burning 234790 t/a based on CO_2-e value being made up of 57% methane contribution

Table 5.4: Allocation of beef co-product based on value

Input parameters	Mass	Price per kg	Value ($/kg)	Allocation
Beef carcass	550	$8.20	4510	87.6%
Hides	60	$0.23	13.5	0.3%
Offal	98	4.00	392	7.6%
Rendering feedstock	292	0.79	230	4.5%
Total	1000		5146	0

Source: Prices from MLA Meat co products monthly report and internet spot prices (2008)

Table 5.5: Allocation of rendering co-products based on value

	Mass	Price per kg	Value ($/kg)	Allocation
MBM Mass	460	$0.65	$299	36.8%
Tallow Mass	540	$0.95	$513	63.2%
	1000		$812	

Table 5.6: Inventory data for rendering 1000 kg beef

Flow	Unit	Value
Products outputs		
Tallow, from beef	T	0.54
Meat and bone Meal, from beef	T	0.46
Materials and Energy Inputs		
Rendering feedstock	T	1
Energy, from natural gas	GJ	8.39
Electricity, high voltage, Australian average	MWh	0.175
Water – reticulated	T	5.4

Delivery from tallow sites is described in chapter 2 and the calculation of the average transport needs per tonne is provided in Table 5.7.

Table 5.7: Transport distance calculation for delivery of tallow.

Company	Distance to Picton by truck (km)	Shipping distance (km)	Mass from this source
Harvey Beef	30		10000
Tallowman	180		7000
Walshes	5		500
Fletchers	240		1500
Furtels	180		1000
Brisbane	179	4500	20000
Average per tonne	162	2250	

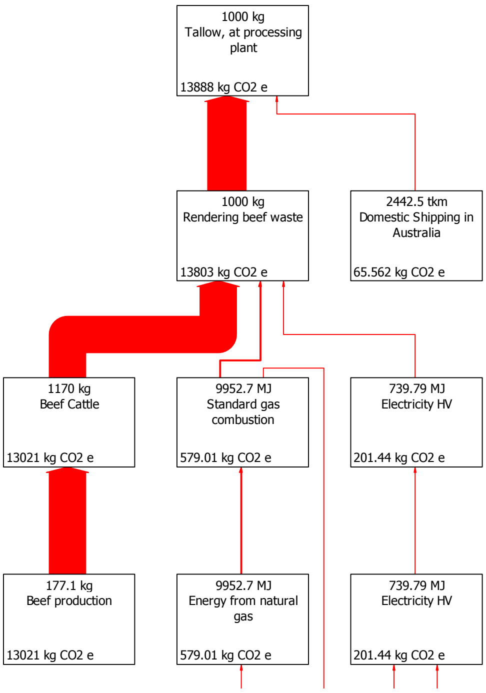

Figure 5-2: Process network showing greenhouse emissions for tallow supply to biodiesel based on economic allocation per tonne of tallow supplied.

5.1.4 Canola

While the underling assumption is that biodiesel will be derived from tallow in Western Australia, canola is of interest for two reasons. The first is that canola may be used directly for biofuel production: either to increase the fuel quality of biodiesel or when tallow supplies are limited. The second reason is that the use of tallow in biofuel may, in some instances, lead to increased demand for canola oil due to current users of tallow switching to canola, as tallow is diverted to biodiesel. Note that while this is possible, the underlying baseline assumption in the study is that most of the tallow used for biodiesel production will be taken from currently exported tallow, and in these instances the overseas users are expected directly or indirectly to substitute with palm oil.

Key parameters for canola production are shown in Table 5.8. The materials input and output data are shown in Table 5.9. The resulting greenhouse gas emission per ha are shown in Figure 5-3. This figure is in the form of a standard SimaPro flowchart. The final result can be found in the top rectangle inside which the values indicate that 1 ha of production produces 1.2 tonne of canola and has life-cycle greenhouse gas emissions of 398 kg CO_2-e. The rectangles below the top rectangle indicate that the greenhouse gas emissions are dominantly comprised of emissions from urea manufacture (102 kg CO_2-e), Nitrogen fertiliser application (77 kg CO_2-e) and fuel use in tractors (103 kg CO_2-e).

Canola production is only one part of the upstream stage of biodiesel production. Canola oil production is the next stage. Figure 5-4 shows the process network for production of crude canola oil from canola seed. There is a greenhouse credit to canola production from the use of canola feel in cattle feed that is worth 308 kg CO_2-e. The net greenhouse impacts of crude canola production are 868 kg CO_2-e. Apart from the canola input other significant contributions are steam and electricity.

Table 5.8: Key parameters for canola production in WA

Parameter	Unit	Value	Min	Max	Comment
Nitrogen input	kg	50	30	70	
Phosphorus input	kg	20			
Fraction of Nitrogen volatilised	N/kg N applied	0.003	0.003	0.0125	Biswas et al. (2007)
Number of pre-cropping spray runs		2			
Number of in crop sprays		2			
Fuel use per spray run	L/ha	2	1.5	3	Tractor use
Fuel use per seeding run	L/ha	7	5	9	Tractor use
Fuel use per harvest run	L/ha	7	5	9	Tractor use
Transport of crop	L/ha	2	1	3	Transport on farm
Seed usage	kg/ha	60			
Yield of Canola	t/ha	1.2	0.	2.5	Suggested yield at 50kg per ha of N

Source: Yield and Nitrogen use from Oilseed Industry of Australia, (2006) other data from internal estimates

Table 5.9: Input and output data for 1 ha canola production

Flow	Unit	Value
Products		
Western Australian Canola	t	1.2
Resources		
Occupation, arable, non-irrigated	ha.a	1
Materials and Energy		
Urea, at regional store	kg	108
Triple superphosphate	kg	100
Glyphosate 41.5%, production and application	kg	2
Diuron, at regional storehouse	kg	0.75
MCPA, at regional storehouse	kg	0.75
Canola seed	kg	60
Tractor, per MJ fuel input	MJ	1145
Emission to Air		
Nitrogen volatilisation	kg	0. 15

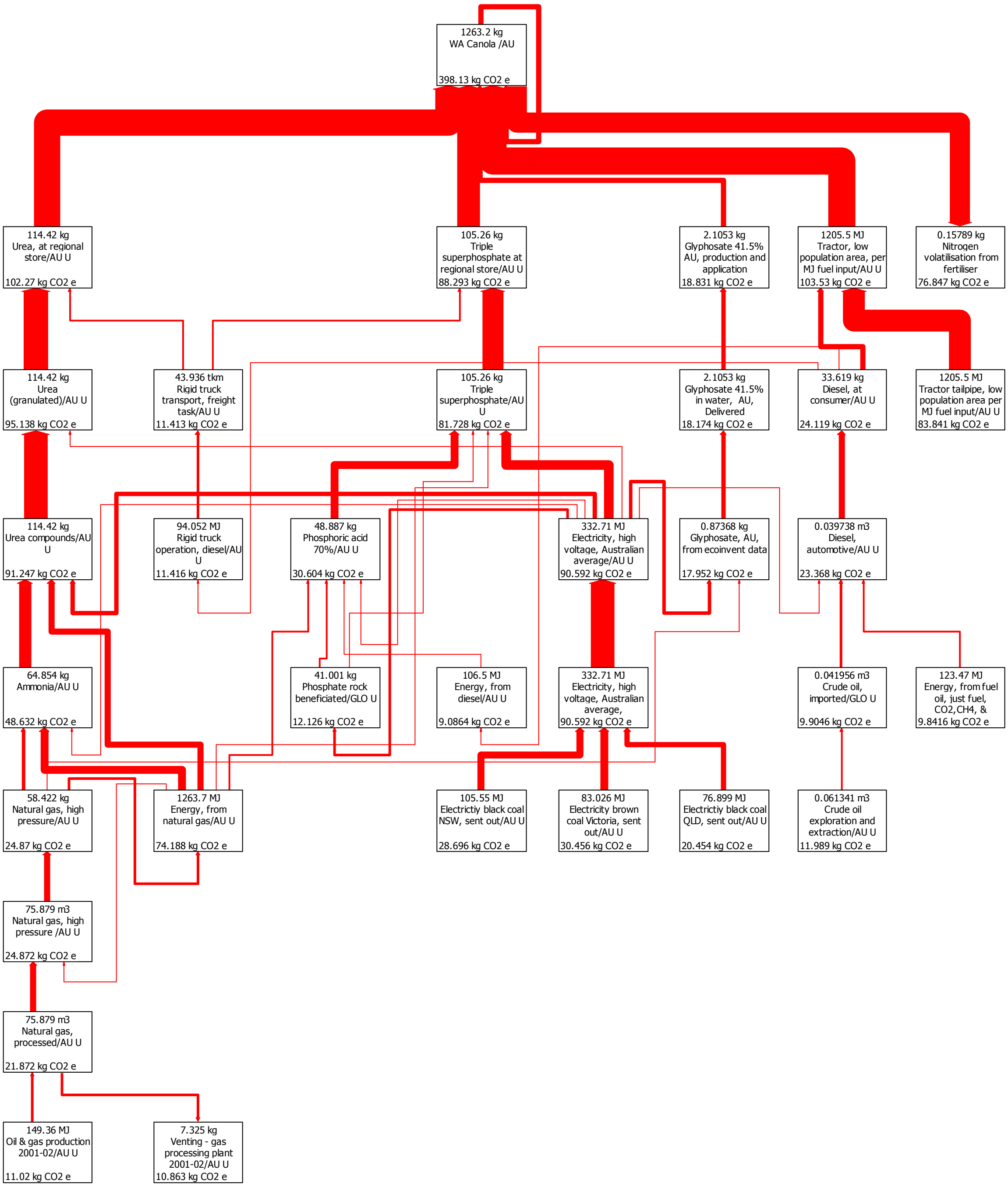

Figure 5-3: Process network showing major (contributing 2.0% or more of the total value) flows (upper value) and cumulative greenhouse gas emissions (lower value) for 1 hectare of canola production in WA

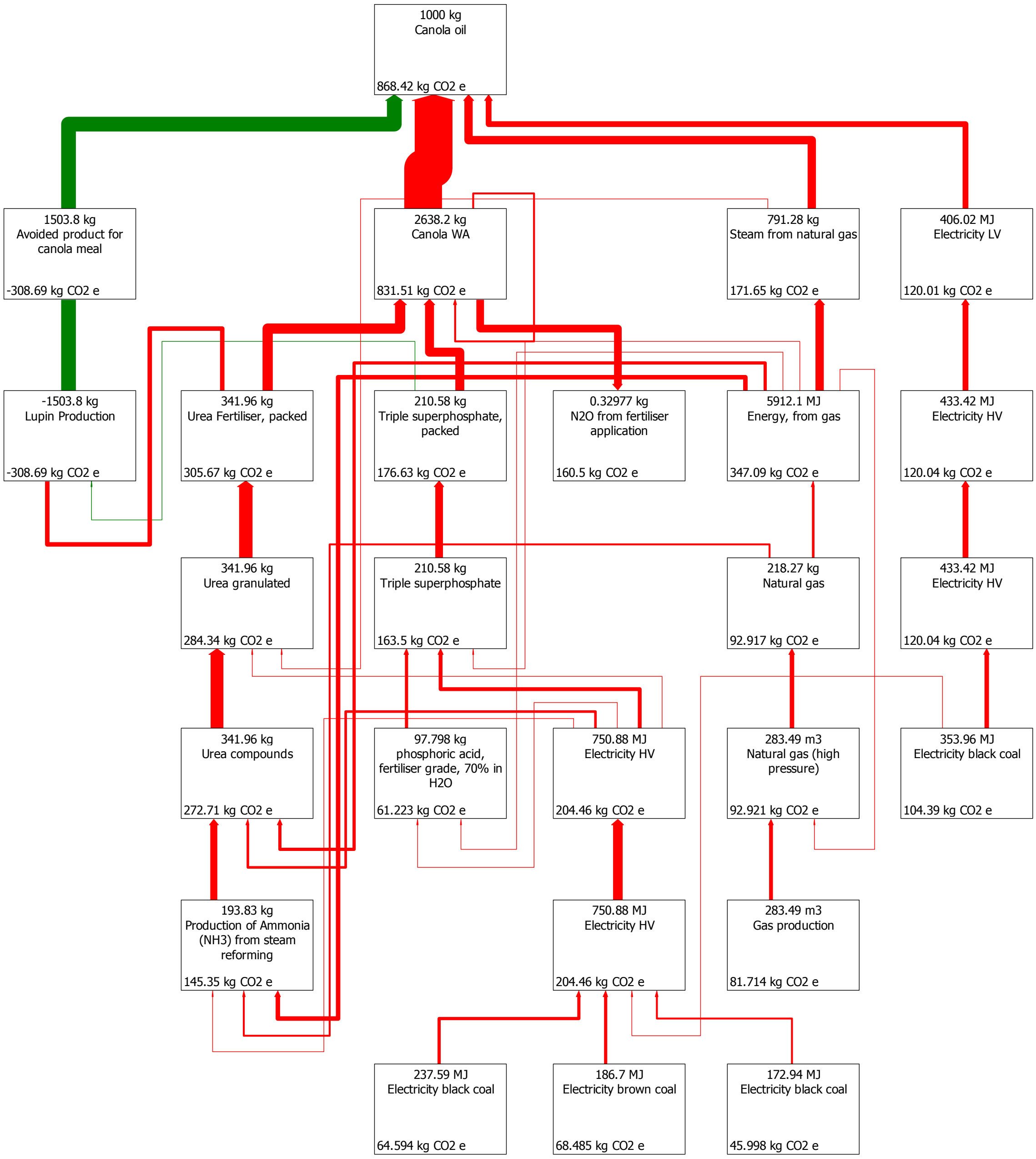

Figure 5-4: Process network showing major (contributing 5% or more of the total value) flows (upper value) and cumulative greenhouse gas emissions (lower value) for 1 tonne of crude canola production in WA

5.1.5 Crude oil supplies

Crude oil supply to Kwinana comes from large variety of sources; Table 5.10 lists a summary of the sources and the transport distances assumed from each region that are used to derive an average shipping distance (5294 t.km) and an average trucking distance (192 t.km).

Table 5.10: Crude oil supply and transport assumptions

	Input (t)	Assumed port	Shipping (km)	Trucking (km)
African crude	169370	Port Harcourt	13208	
Middle East crude	2691207	Dubai	9215	
South-east Asian crude	716966	Singapore	4111	
Australasian crude	2312310	70% Either north west shelf or cooper basin	2000 for 70%	463 for 30%
Middle east condensate	33072	Dubai	9215	
Australasian condensates	116353	70% Either north west shelf or cooper basin	2000 for 70%	463 for 30%
Total crude oil and condensate	5869910			
Transport per tonne		Average	5294 t.km	192 t.km

Source: Pers. Comm. BP Refining (2008)

Oil and gas production data is taken from national Australian data from Australian Petroleum Production & Exploration Association (2007) and ABARE (2007). This data is show in Table 5.11 along with the associated atmospheric emissions. There are three types of emissions – direct process emissions, fugitive emissions and emissions arising from flaring and venting. The emissions are allocated between oil production and gas production based on the energy content of each product, which means only 37% of these emissions are allocated to the crude oil production. This allocation can be seen on the left hand side of Figure 5-5 where the flowchart indicates that 238.52 kg of CO_2-e is emitted from Australian crude oil exploration and extraction to produce 1.2204 m^3 of Australian crude oil, which results in the delivery of 1.2107 m^3 (1 tonne) at the refinery.

This production data is added to trucking and shipping impacts for crude oil supply. The resulting inventory is shown in Figure 5-5 for 1 tonne of crude oil production. The import of overseas crude oil is accounted in the average transport for crude supply, otherwise overseas crude in assumed to have the same production impacts as average domestic crude.

Table 5.11: Inputs for crude oil and gas production for 2005/06

Products		
Crude oil exploration and extraction	39.2 Mm^3	Allocated 36.63% of inventory
Natural gas exploration and extraction	59.1 Gm^3	Allocated 63.37% of inventory
Resources		
Oil, crude, 42.8 MJ per kg, in ground	4.60 Mt	Oil used for energy in oil and gas exploration and extraction
Gas, natural, 35.9 MJ per m3, in ground	118 Mm^3	Oil used for energy in oil and gas exploration and extraction
Emissions to air		
Carbon dioxide	10533 kt	
Methane	1.4696 kt	
Nitrous oxide	0.013996 kt	
Nitrogen oxides	41.107 kt	
Carbon monoxide	9.8533 kt	
NMVOC, non-methane volatile organic compounds, unspecified origin	0.7418 kt	
Sulfur oxides	1.69978 kt	From 2001 inventory factor based on 2002 energy use
Carbon dioxide	4860 kt	Fugitives
Methane	92.822 kt	Fugitives
NMVOC, non-methane volatile organic compounds, unspecified origin	52.884 kt	Fugitives
Carbon dioxide	2780 kt	Flaring and venting
Methane	35.124 kt	Flaring and venting
Nitrous oxide	0.080632 kt	Flaring and venting
Nitrogen oxides	1.6005 kt	Flaring and venting
Carbon monoxide	8.7569 kt	Flaring and venting
NMVOC, non-methane volatile organic compounds, unspecified origin	15.057 kt	Flaring and venting

Based on (Australian Petroleum Production & Exploration Association (APPEA), 2007) (ABARE, 2007).

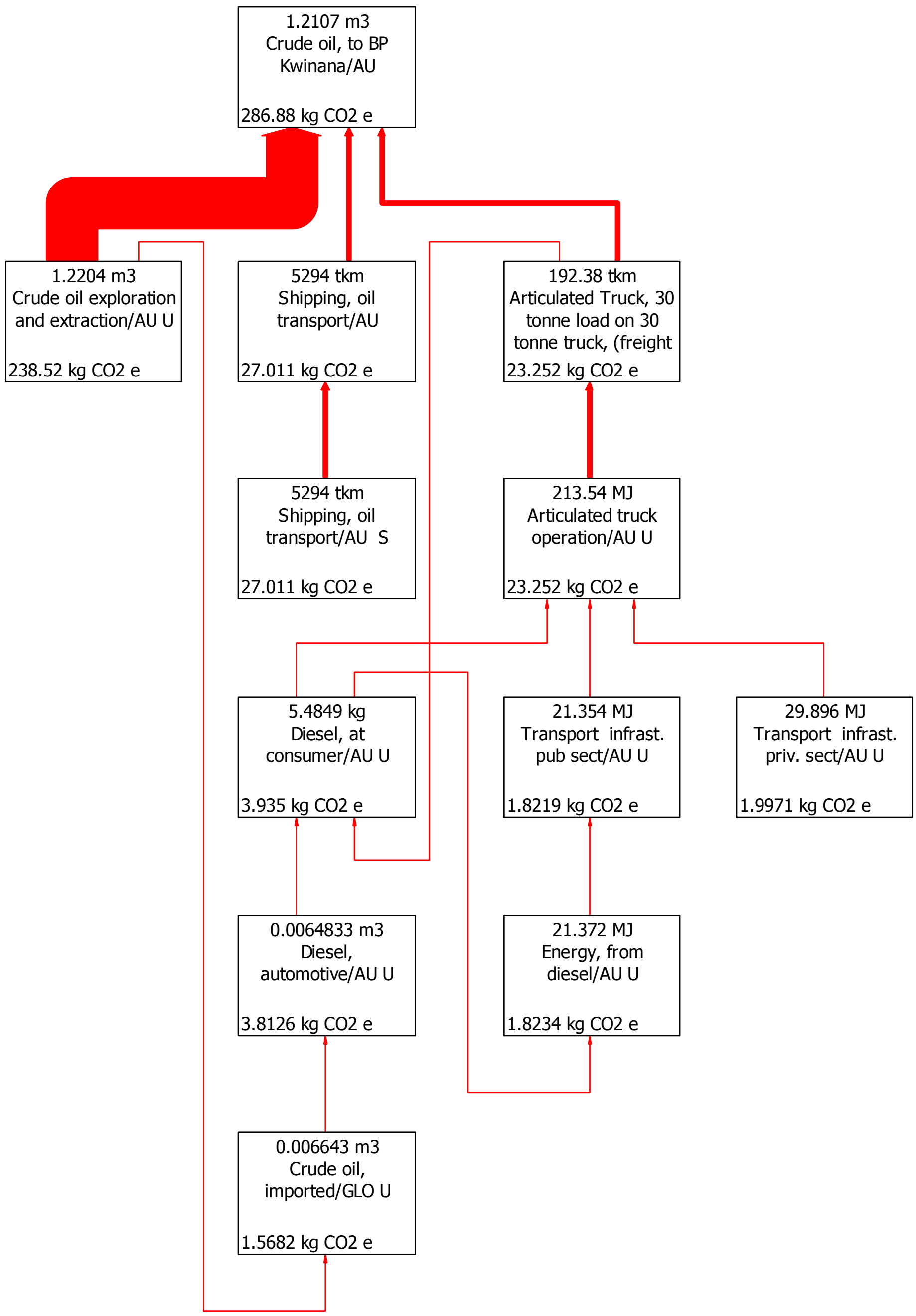

Figure 5-5: Process network of crude oil production showing cumulative greenhouse emission in kg CO_2-e for 1 tonne crude oil

5.2 Fuel production

5.2.1 Kwinana BP refinery

The BP refinery at Kwinana produce a range of petroleum grades, diesel and aviation kerosene that make up more than 90% of production volume, with the remaining volume being fuel oils, bitumen and other products. Two steps have been used in the allocation of refining impacts. Firstly all inputs and pollutants are allocated based on energy content of the output products. Secondly, to account for the fact that higher octane fuels have substantially higher proportion of refining impacts than regular unleaded, the allocation to 95 and 98 RON fuel was increased based on the different refining costs as outlined in Table 5.12, which indicates that relative to 92 RON, multipliers of 1.5 apply to 95 RON and 2.0 apply to 98 RON. These multipliers are then used to determine the final results of the allocation shown in Table 5.13. This indicates that 35% of refinery emissions are attributed to the diesel that is produced, 27% to the unleaded petrol and 17% to the premium unleaded brands. Note that this allocation only applies to refining impacts, with the crude oil feedstock being allocated to each of the fuels based on their mass.

Flowcharts showing the life-cycle of greenhouse gas emissions for petrol and diesel are given in Figure 5-6, Figure 5-7 and Figure 5-8. Total impacts for fuels from BP Kwinana (not including transport) are summarised in Table 5.14

Table 5.12 Calculation of PULP production energy in 2008 based on prices

Fuel	Unleaded 92 RON	95 RON	98 RON	Comment
Prices	$1.53	$1.59	$1.64	From fuel watch website[11] on June 16 2008
Refiner Profit	$0.02	$0.03	$0.03	Estimate based on 2005 data on Caltex website for ULP and 2007 data submitted by Caltex to the Queensland government[12] Premium is assumed to have a slightly higher margin; it could be higher still
Difference after profit relative to ULP	0	$0.05	$0.10	
Estimate of average refining cost per litre of crude oil input	$0.09			
Estimate of average refining cost per litre of petrol output	$0.10	$0.15	$0.20	
Multiplier used for allocation of premium fuels relative to ULP		1.5	2.0	

[11] http://www.fuelwatch.wa.gov.au/

[12] See http://tinyurl.com/5tfcuy. An average of 2.6 cents per litre profit for 2007 (first half) is stated across all petroleum products.

Table 5.13: Allocation of refinery products from BP Kwinana refinery

	kL fuel	Assumed energy content	Total energy GJ	Allocated	Adjustment for 95 and 98 RON	Normalised back to 100%
LPG	129754.6	25.7	3334693	1.2%	1%	1.13%
Unleaded Petrol	2301062.808	34.68	79792737	29.4%	29%	27.09%
Premium Unleaded 95	311957.124	35.42	11048601	4.1%	6.1%	5.63%
Premium Unleaded 98	487633.053	35.42	17270524	6.4%	12.7%	11.73%
Light oil blending components	95344.243	35.42	3376812	1.2%	1%	1.15%
Light oil intermediates	1486.333	39.7	59007	0.0%	0%	0.02%
Kerosene	898077.633	36.8	33049257	12.2%	12%	11.22%
Automotive diesel	2700414.571	38.6	104236002	38.4%	38%	35.38%
Automotive diesel blending components	852.007	38.6	32887	0.0%	0%	0.01%
Light cycle oil	20627.728	39.7	818921	0.3%	0%	0.28%
Fuel oil	177994.91	39.7	7066398	2.6%	3%	2.40%
Fuel oil components	141519.79	39.7	5618336	2.1%	2%	1.91%
Residue process oils	44517.194	38.8	1727267	0.6%	1%	0.59%
Cracker feed	38581.637	38.7	1493109	0.5%	1%	0.51%
Bitumen	45173.626	44	1987640	0.7%	1%	0.67%
Miscellaneous	12696.654	38.7	491361	0.2%	0%	0.17%
Hydrogen	30595.175	12.7	388559	0.1%	0%	0.13%
Grand Total (kL):	7,403,495.18		271,792,111	100.0%	107.8%	100.0%

Figure 5-6, Figure 5-7 and Figure 5-8 indicate that greenhouse gas emissions of 332 kg, 400 kg and 401 kg apply to the production of 1 m^3 (1 kL) of unleaded petrol (92 RON), premium unleaded petrol (95 RON) and diesel respectively.

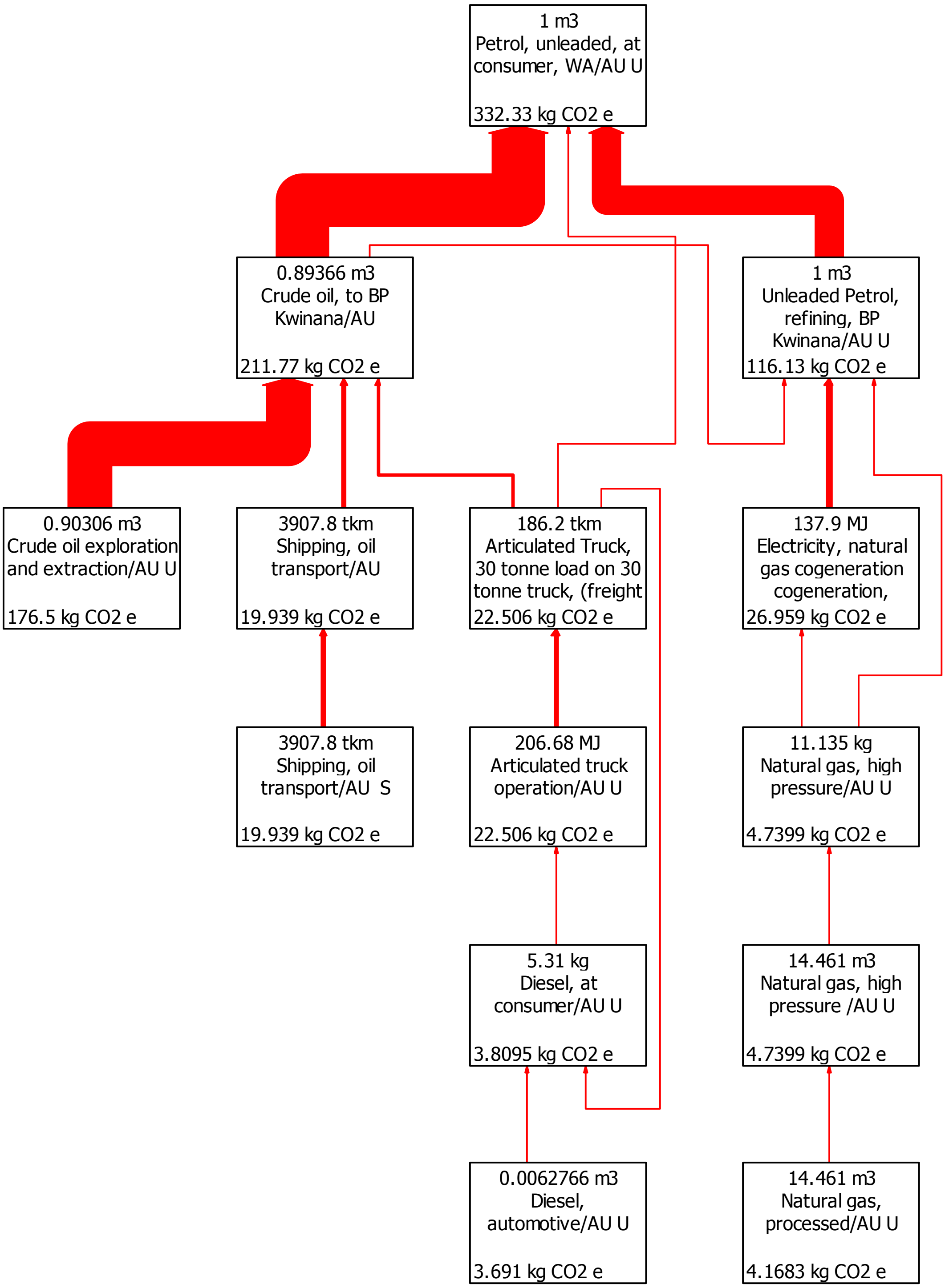

Figure 5-6: Process network for 1 m^3 (1 kL) regular (91 RON) unleaded petrol production

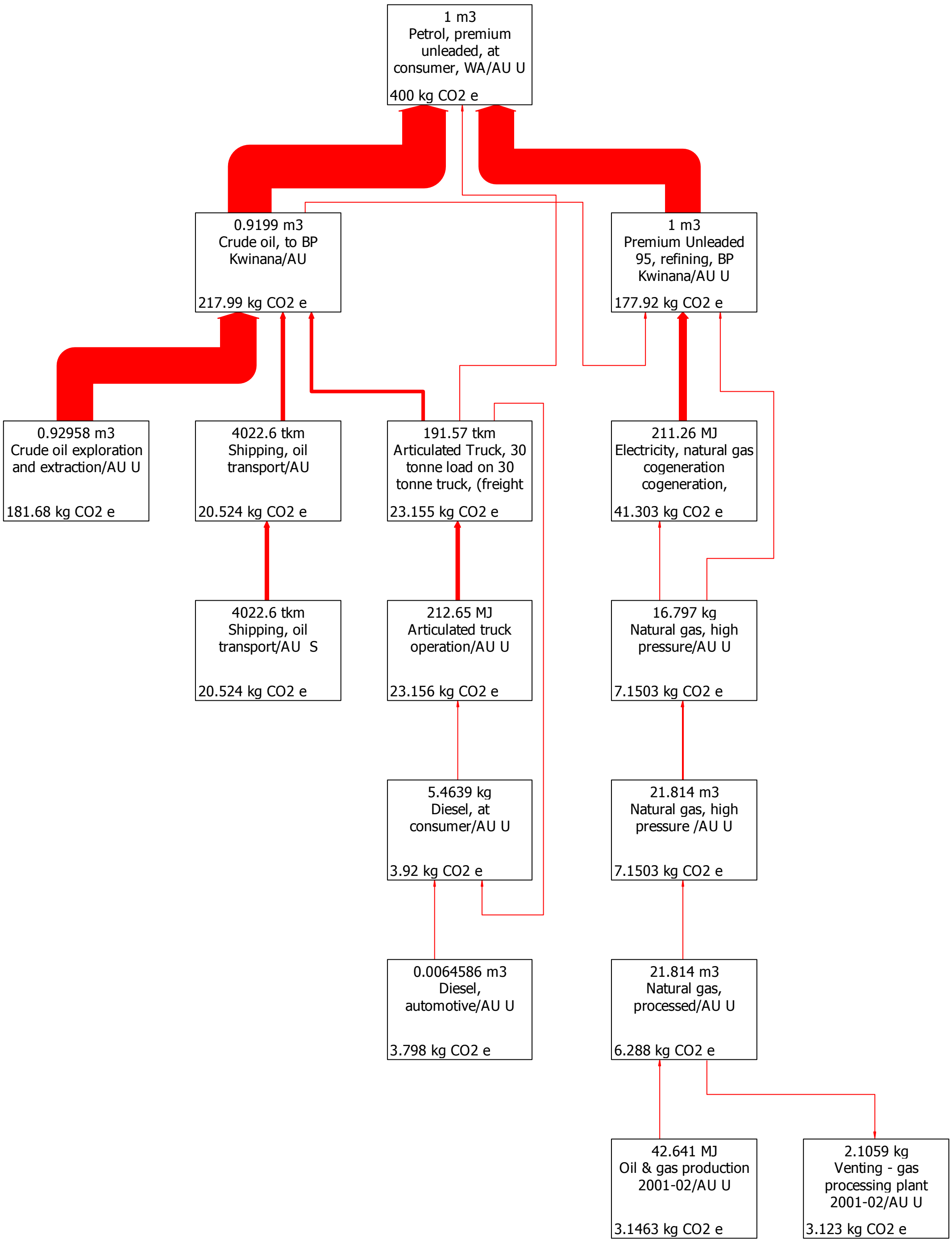

Figure 5-7: Process network for 1 m^3 (1 kL) premium (95 RON) unleaded petrol production

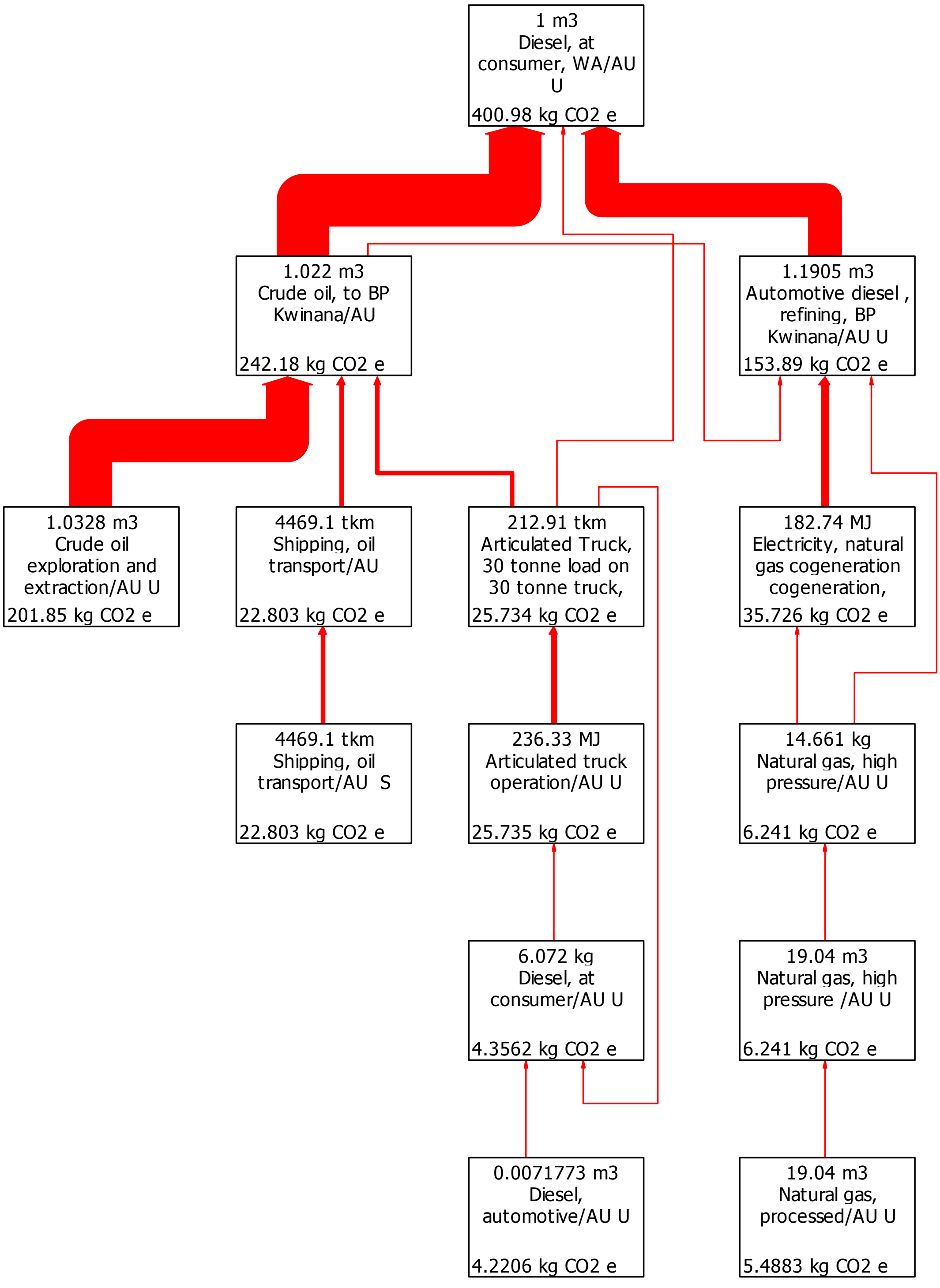

Figure 5-8: Process network for 1 m^3 (1 kL) diesel production

Table 5.14: Total impacts of various fuels per kL from BP Kwinana

Impact category	Unit	Diesel, Automotive BP Kwinana	Petrol, Unleaded	Premium Unleaded 95,	Premium Unleaded 98
Total Upstream	kg CO_2-e	401	332	400	414
Carbon dioxide	kg CO_2-e	372	307	374	383
Methane	kg CO_2-e	28	24	26	30
Nitrous oxide	kg CO_2-e	0.6	0.5	0.5	0.6
Land transformation	kg CO_2-e	0	0	0	0
Other	kg CO_2-e	0.03	0.03	0.03	0.04

5.2.2 Kwinana Primary Energy Refinery

The data for the Kwinana biorefinery have been taken from the Primary Energy LCA with modification for the changed feedstock from sorghum and wheat, which was assumed in the original LCA, to wheat only as will be the case for WA. Also electricity supply and credits are based on WA grid. The nominal ethanol yield (on a dry basis) of 294 kg ethanol per tonne wheat is based on the biorefinery specifications of 435,000 tonne wheat being used to produce 160 ML ethanol. This corresponds to 2.719 kg of wheat per kL of ethanol. On an as-received basis, the plant uses 2.97 kg of wheat per kL of ethanol. The wheat properties assumed by the Kwinana Biorefinery are given in Table 5.15. The right hand column compares these assumed properties with the Western Australian wheat properties given by Wilkins and Hancock[12]

Table 5.15: Assumption on ethanol yield from wheat for biorefinery.

Key parameter	Kwinana Biorefinery Value	Comment	WA Mean Value[13]
Starch Content	69%	Starch content of wheat dry basis	65.3%
Moisture	9.2%	Moisture content of wheat	12.5%
Ethanol yield from wheat starch	42.5%	Mass based yield	49.6%
Ethanol yield from wheat	266	kg/tonne wheat, (1-Moisture)*Starch Content* Ethanol yield from wheat starch	283
Wheat per kL ethanol	2.973	(1/ Ethanol yield from wheat)*ethanol density	2.82

Two options are modelled – one with the biodigester in place which makes electricity and heat for the plant and for export. It also produces ammonia and potassium-rich fertiliser for sale. Without the biodigester the plant would most likely produce distiller's grains which can be sold as stock feed. However there would then be an increased need for water and electricity in the plant from external sources.

[13] http://www.agric.wa.gov.au/content/sust/biofuel/overviewwabiofuelsindustry.pdf

Table 5.16 provides the information on the material flows, both input and output for the ethanol biorefinery. It shows that to produce 1 kL of ethanol will require 2.81 tonne wheat (as received), 1.0 tonne of water, 0.326 MWh of electricity, and $31 worth of other chemicals. However, in addition to producing 1 kL of ethanol, there will be 1.764 MWh of electricity generated (if a biodiegester is used) along with compost. If no biodigester is used then there will be 0.9 t of distiller's dry grain.

Table 5.16: Flow information for biorefinery for 1 kL Ethanol

Flow	Unit	Value	Distribution
Materials/fuels			
Wheat, supply to Primary Energy	t	2.97	Wet wheat
Water – reticulated	t	1.0	Anaerobic technology. Does not have the losses of water that normally occurs with wet DDGS (in the DDGS) or dry DDGS (from evaporation); for DDGS production would normally be 7.46 t
Other chemical products 2005$ purchases prices	A$	31	
Electricity supply/export, primary energy	MWh	0.326	Only energy from electricity production at 30.5% efficiency included steam assumed to be co-generated from this electricity amount.
Biodigester inputs and outputs			
Waste to treatment			
Stillage input	t	0.9	Dry weight of Stillage input
Outputs			
Electricity supply/export, primary energy	MWh	1.764	
Potassium chloride	kg	21.9	Offset for Potassium (K) that is in the compost output
Urea	kg	80	Offset for Nitrogen (N) that is in the compost output
Triple super phosphate	kg	41.6	Offset for Phosphorus (P) that is in the compost output
Ammonia, steam reforming, liquid, at plant	kg	20.6	Offset for Nitrogen outputs that are not in the compost
Inputs and outputs without biodigester			
Waste treatment			
DDGS use	t	0.9	DDGS is not output when using the biodigester

5.2.3 Picton Plant

The data for the biodiesel plant came predominantly from ARF and the total annual plant production is shown in Table 5.17. The plant produced three economic products; biodiesel (45 ML), glycerol (4,400 tonne) and potassium sulfate (840 tonne). The inputs required to produce these products included 39.6 kt of tallow, 4.51 kt of methanol along with other inputs that are listed in the Table.

Table 5.17: Process data for Picton biodiesel plant

Flow	Unit	Value	Comment
Products			
Biodiesel	ML	45	
Glycerol	t	4400	
K_2SO_4	t	840	Potassium Sulfate
Materials and Energy			
Tallow input.	t	39600	
Methanol, imported from NZ	kt	4.51	5.7ML, density of methanol at NTP 0.7918
Potassium hydroxide	t	540	600 tonne of 90% KOH (with 10%, i.e. 60 tonne of inert binder – possibly water)
Water	t	1400	
Sulphuric acid	t	472.5	482 tonne of 98% H_2SO_4 (i.e. 2% inert binder, probably water)
Electricity, Western Australia	MWh	2000	
Nitrogen (gas)	kg	250.2	200 m^3 gaseous nitrogen at 1.251 g/L
Steam, from natural gas	t	12000	7.5 bar, produced on site from natural gas

5.2.3.1 System expansion for biodiesel co-products

As previously discussed, a consequential LCA uses a systems boundary expansion, as explained in Appendix 1, to determine the market changes as a result of an increase or reduction in production.

The production of 45 ML of biodiesel in Western Australia would lead to the production of 4.4 kt of glycerol. For the consequential analysis of biodiesel production, glycerol production is assumed to be used as a supplement to pig-feed. Metabolism studies report glycerol having similar energy content to pig feed although the maximum percentage of glycerol that can be used in the feed is around 20% (High Plains Journal, 2007).

Potassium sulfate is used as an agricultural fertilizer as a source of potassium. In the expanded boundary assessment it is assumed to replace potassium sulfate production from the common industrial route which is reaction of potassium chloride with sulphuric acid[14]. Data for avoided potassium sulfate production has been adapted from EcoInvent LCA database but has been modified for Australian fuel and raw materials (Nemecek, 2007).

5.2.3.2 Economic allocation of biodiesel co-products

Economic allocation of biodiesel production and glycerol are based on typical prices for both in WA. Because B20 is selling at the same prices as diesel, biodiesel is taken to have the same prices as diesel – around $1.80/litre currently. Glycerol prices were previously taken at 6c per litre, however the biodiesel magazine of September 2007[15] reported improvements in prices to the equivalent of nearly 17.5c per kg in Australian dollars. Potassium sulfate prices are taken as $250 per tonne. The resulting allocation is shown in Table 5.18.

The results of Table 5.18 indicate that the using an economic allocation, 98.8% of the emissions associated with biodiesel production are allocated to the biodiesel, 0.9% to glycerol and 0.3% to potassium sulfate.

[14] http://www.impactfertaust.com.au/products/fert_sop.html

[15] http://biodieselmagazine.com/article.jsp?article_id=1797

Table 5.18: Allocation of biodiesel production impacts to three co-products (for attributional LCA sensitivity)

	Production	Price per unit ($)	Value ($)	Allocation
Biodiesel	45,000,000 L	1.8	81,000,000	98.81%
Glycerol	4,400,000 kg	0.1746	768,250	0.94%
Potassium sulfate	840,000 kg	0.25	210,000	0.26%
Total			81,978,250	100.0%

5.3 Fuel Use

5.3.1 Emission change from E10 and PULP

The addition of 10% ethanol to petrol produces a new fuel that has some markedly different chemical properties to those of neat petrol. Both the octane number and the vapour pressure increase. Such changes complicate calculations of fuel efficiency, which thus need to be determined on the basis of actual laboratory or fleet determinations.

Tailpipe emission data are not available in a comparative test of E10 and PULP. The most recent reliable Australian data available are E10 and ULP are from the "Petrohol In-Service Vehicle Emission" data (APACE Research 1998). These data were used as the basis of greenhouse and other emission calculations in the "Appropriateness of 350 ML biofuel study" (Beer et al. 2003, p.72 and 37 Appendices). These data have been used as the basis for a comparison of the impact of E10 as a substitution for PULP and are shown in Table 5.19.

The results of Table 5.19 indicate that a typical Australian family vehicle will use 85 g of ULP to travel 1 km, but will use 89 g of E10 to travel the same distance.

Table 5.19: Raw data and calculated data from New South Wales EPA APACE trials

Emissions	Units	ULP	E10	E10 as % of ULP
CO_2	g/km	264.4	266.2	100.68%
CO_2 Fossil*	g/km	264.4	247.92	93.77%
CO_2 (biogenic)*	g/km		18.28	
Methane	Mg/km	0.053	0.0485	91.51%
Fuel Usage	l/km	0.121	0.125	103.31%
Carbon inferred from CO_2*	g/km	72.109	72.60	
Carbon content of fuel	%	85.0%	81.7%	
Fuel usage (mass) calculated from CO_2 *	g/km	84.83	88.86	104.75%
Fuel usage (volume) calculated from CO_2 *	l/km	0.116	0.121	104.08%
Fuel usage (energy content) calculated from CO_2 *	MJ/km	3.552	3.576	100.68%

* Calculated data Source APACE Research (1998)

5.3.2 *Diesel, B5 and B20 use in trucks*

The most comprehensive biodiesel emissions data is from the US EPA (2002) correlations based on over 100 sets of fuels emission data across a large range of biodiesel blends. This report developed correlations between percentage of biodiesel blended with diesel, and the percentage change in air quality emissions. The results of the correlation of biodiesel emissions are shown Table 5.20 for animal-based biodiesel.

The fuel usage comparison, expressed as brake-specific fuel consumption (BSFC) in US imperial units[16], between biodiesel and conventional diesel is provided by a regression formulae in the US EPA report as shown in Equation 5-1. The result is the mass of fuel in pounds used per brake horsepower hour which is converted to energy input per energy output.

$$\text{BSFC, lb/hp-h} = \exp[0.0008189 \times (\text{vol\% biodiesel}) - 0.855578] \qquad \text{Equation 5-1}$$

Carbon dioxide emissions for tallow-based and used cooking oil-based biodiesel are shown in Table 5.20. Note that US EPA (2002) assumes the same emissions from biodiesel generated from both these feedstocks.

Table 5.20: Tailpipe emissions (per MJ) for tallow and used cooking oil based biodiesel blends with ULS diesel

Emission	Unit	ULSD	B5 tallow	B10 tallow	B20 tallow	B100 tallow
Carbon dioxide	g CO_2	69.17	66.02	62.85	56.41	0.00
Carbon dioxide, biogenic	g CO_2	0.00	3.14	6.32	12.76	69.17
Nitrous oxide	g N_2O	0.00	0.00	0.00	0.00	0.00
Carbon monoxide	g CO	0.28	0.28	0.27	0.26	0.19
Methane	g CH_4	0.001	0.001	0.001	0.001	0.001
NMVOC	g HC	0.072	0.072	0.072	0.072	0.072
Oxides of nitrogen	g NOx	0.84	0.85	0.86	0.87	1.02
Particulate matter <10µm	mg PM10	28.29	27.14	26.04	23.98	12.39

Table 5.20, in an analogous manner to Table 5.19, specifically notes the biogenic (non-fossil) component of the carbon dioxide emitted from the fuel combustion. Table 5.19 provided results on a g/km basis because emission standards for light vehicles are expressed in g/km. However emission standards for heavy vehicles are given in g/MJ, so those units have been used in Table 5.20.

Biodiesel has a lower energy content than conventional diesel. Nevertheless, fuel usage calculations (based on Equation 5-1), combined with engine efficiency and brake efficiency calculations, show that biodiesel is more efficient in combustion than diesel, with the results given in Table 5.21.

[16] Conversion to metric units is 1 lb/(hp-h) = 0.608 kg/ (kWh) = 0.1689 kg/MJ

Table 5.21: Engine conversion efficiency of biodiesel blends from US EPA correlations

	Blend %	lbs per (hp-h)[1]	kg per MJ (2)	Energy content of fuel[3] (MJ/kg)	MJ fuel used per brake-hp	Engine efficiency	Energy % of conventional diesel
Biodiesel	100	0.461	0.078	36.65	2.857	35.00%	93.7%
Biodiesel	20	0.432	0.073	41.30	3.015	33.17%	98.9%
Biodiesel	5	0.427	0.072	42.17	3.041	32.88%	99.7%
Conventional diesel	0	0.425	0.072	42.46	3.050	32.79%	

[1] Calculated from Equation 5-1 [2] MJ/(brake-hp) = 2.68452, kg/lb = 0.453592
[3] Energy contents are lower heating value (LHV) and are taken from US EPA (2002).

6 Life Cycle Results

6.1 Results per km of blended fuel use

Table 6.1 shows the results of the life cycle greenhouse gas impacts, based on greenhouse gas for the split between tailpipe and upstream emissions. These are per km for cars in the case of E10 in ULP and PULP, and per km of (medium rigid) truck use for biodiesel and diesel. Life-cycle emissions are reduced by 12% with E10 and by 1.7% using B5.

Table 6.1: Greenhouse gas results in g CO_2-e for biofuel blend and competing fuel per km car and truck for ethanol and biodiesel respectively

	E10 in ULP	PULP	B5	Diesel
Carbon dioxide	270.50	309.64	763.92	797.13
Methane	5.20	4.20	7.95	8.21
Nitrous oxide	0.56	0.40	4.46	0.16
Land transformation	0.00	-	15.38	-
Other	0.01	0.01	0.01	0.01
Upstream	27.71	48.40	131.29	113.20
Tailpipe	248.54	265.85	660.44	692.31
TOTAL	**276.25**	**314.25**	**791.73**	**805.51**

6.2 Results for utilisation of total biofuel production

The total greenhouse savings from implementation of the biofuels are shown in Table 6.2 with different greenhouse gas contributions and in Figure 6-1 and Table 6.3 with the breakdown by major components. The savings from the ethanol production are the electricity exported, avoided tailpipe emissions and avoided petrol production. Figure 6-1 also shows the impacts of biodiesel production with savings mainly from avoided tailpipe emissions and to a lesser extent avoided diesel production.

Table 6.2: Total greenhouse gas savings in Gg CO_2-e from biofuel supply in WA

	Ethanol 160ML with Biodigester	Biodiesel 45 ML	Total	*Ethanol 160ML no Biodigester*
Carbon dioxide	501.09	105.81	606.90	*206.89*
Methane	-12.723	0.81	-11.913	*1.51*
Nitrous oxide	-2.009	-13.69	-15.699	*11.63*
Land transformation	0.016734	-48.98	-48.963	*0.000*
Total	486.38	43.94	530.32	*220.01*

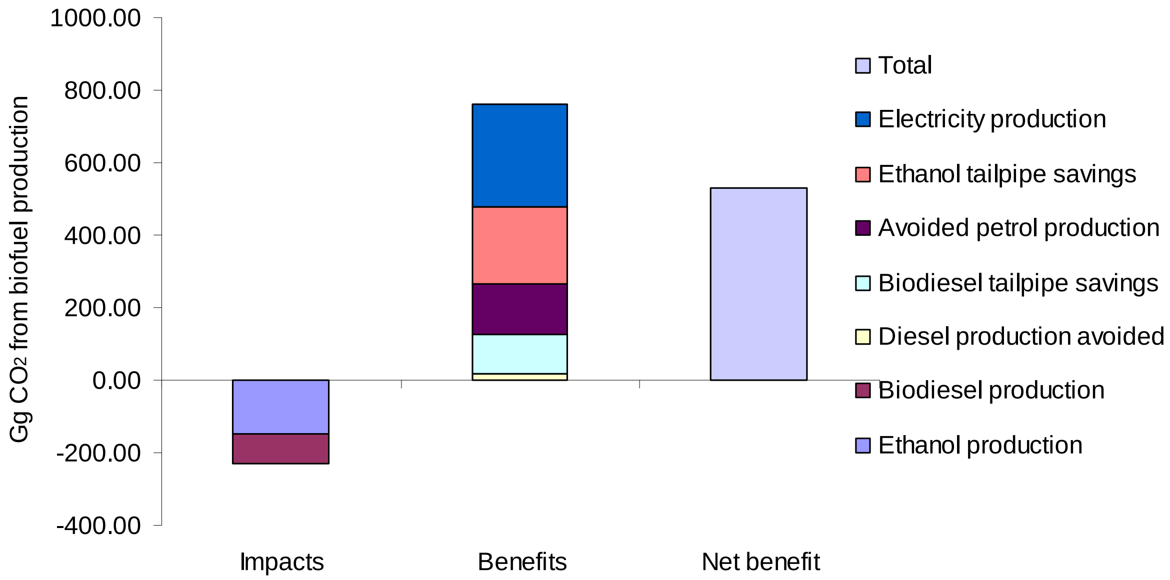

Figure 6-1: Greenhouse Impacts and Savings from biofuel production (160 ML ethanol and 45ML biodiesel blended as E10 and B5 respectively)

Table 6.3: Component Breakdown of Greenhouse Gas Savings from biofuels production

Component	Gg CO_2-e saved
Ethanol production	-148.18
Biodiesel production	-81.11
Diesel production avoided	17.65
Biodiesel tailpipe savings	107.4
Avoided petrol production	140.96
Ethanol tailpipe savings	212.12
Electricity production	281.48
Total	**530.32**

6.3 Results per kilolitre of biofuel utilised

Because of the use of fuels in blends, it is difficult to look at the net impacts of biofuels. Figure 6-2 shows how 1000 litres (1 m^3) of ethanol changes the emissions due to its use in E10 blend with unleaded petrol, being able to offset pure PULP petrol. As noted in Section 5.3.1 and Table 5.19, slightly more fuel is needed to travel a fixed distance using

E10 than is needed when using ULP. Thus, the total blended fuel volume in 10,000 litres of E10 (which drives a typical vehicle 80,000 km) offsets 9680 litres of premium unleaded petrol (which is the amount of ULP needed to drive 80,000 km). The net emissions are shown in the top box with the red arrow flows showing the impacts from the ethanol fuel production and use, and the green arrows show the avoided impacts from the replaced PULP fuel.

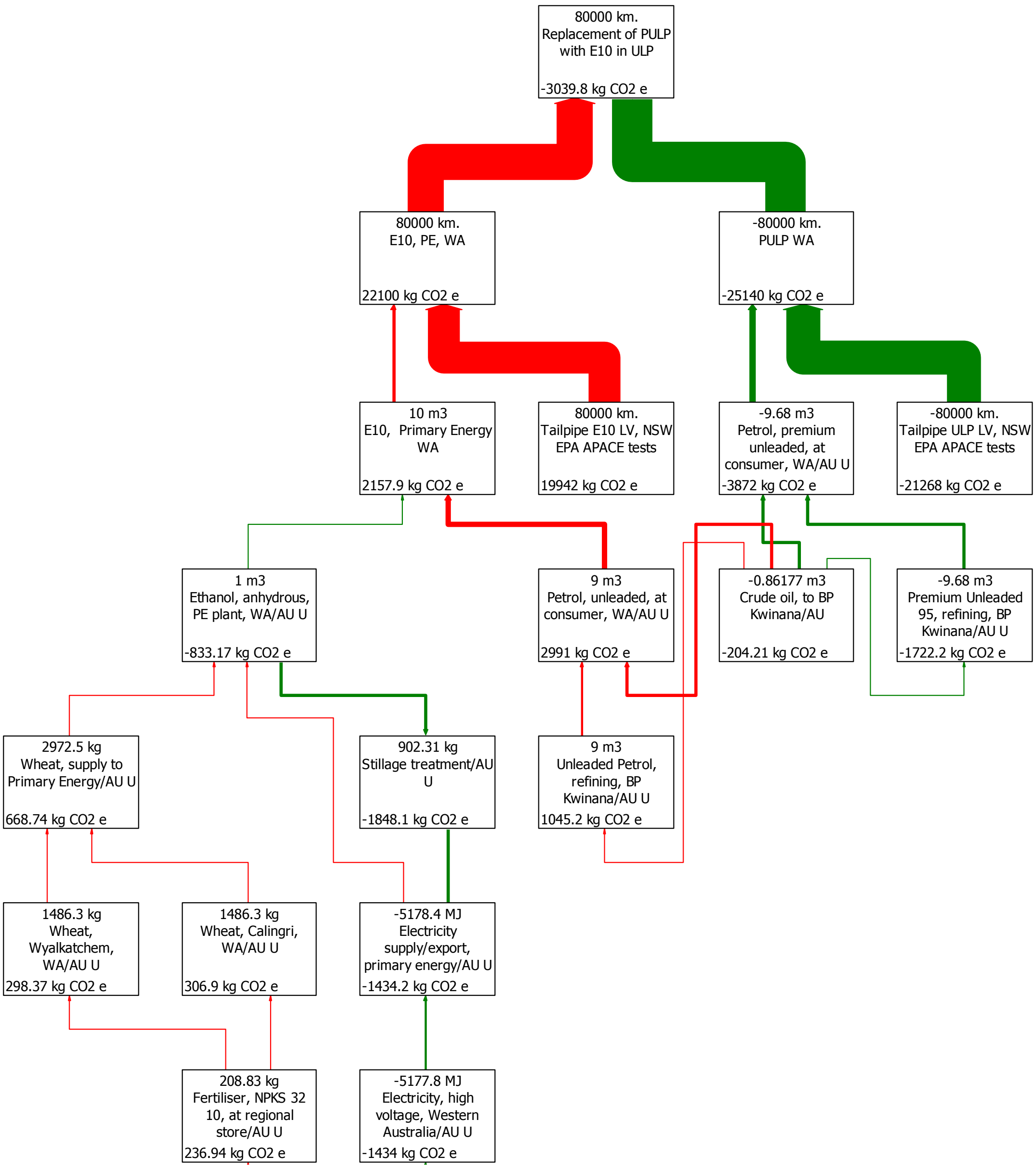

Figure 6-2: Process network showing difference between E10 in ULP and PULP – per 1000 litres of ethanol produced. Red lines and positive numbers show impacts and green lines and negative numbers show avoided impacts.

Figure 6-3 shows the same process network for biodiesel 5% blend in diesel (B5) replacing pure diesel fuel. 1000 litres of biodiesel as 5% blend in diesel takes a truck 70769 km.

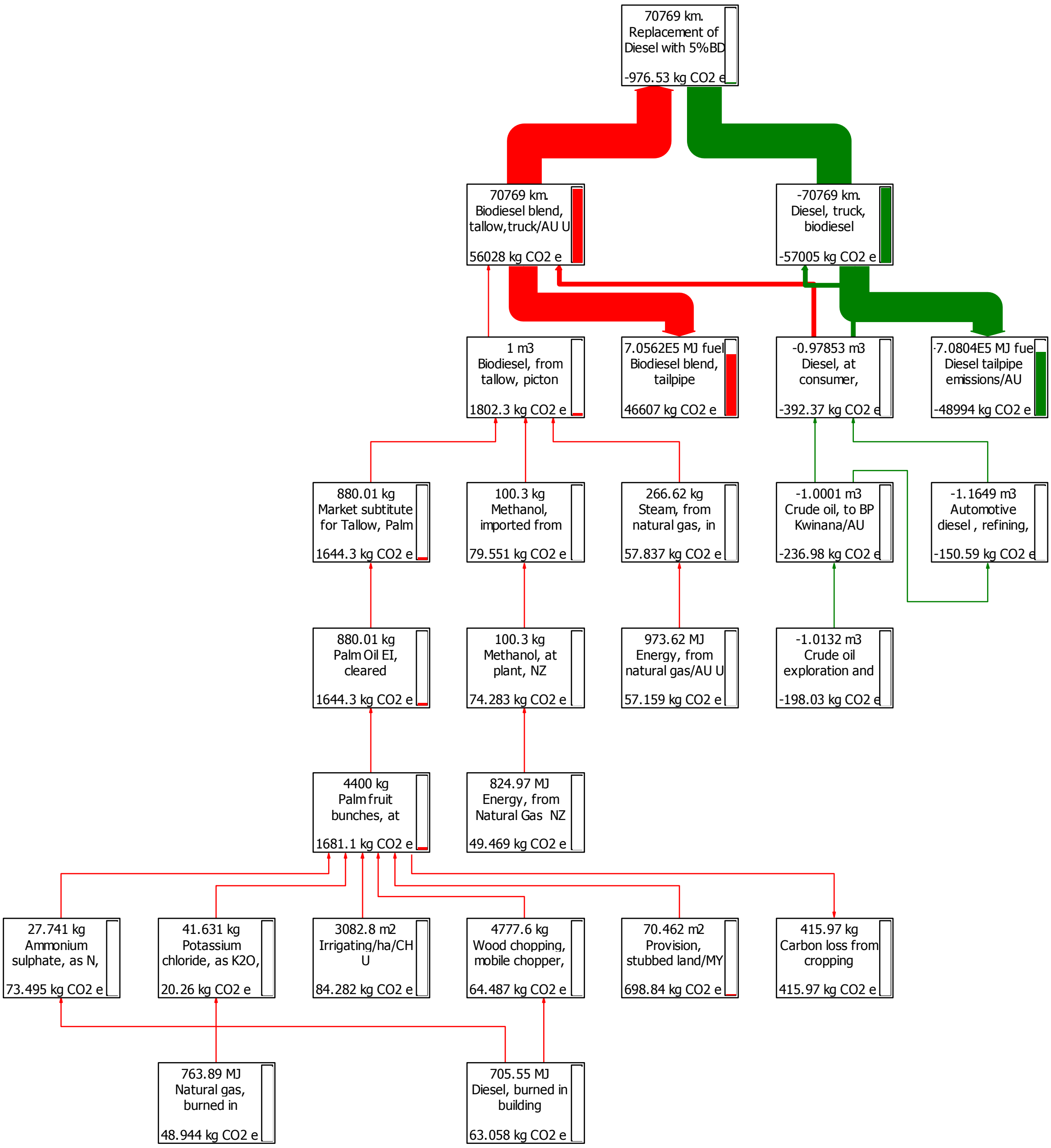

Figure 6-3: Process network showing difference between 5% Biodiesel in diesel and pure diesel – per 1000 litres of biodiesel produced. Red lines and positive numbers show impacts and green lines and negative numbers show avoided impacts.

Figure 6-2 shows that the use of 1 kL of ethanol as E10 ethanol results in a saving 3040 kg CO_2-e, and Figure 6-3 shows that the use of 1 kL of biodiesel as B5 results in a saving of 977 kg CO_2-e.

7 Energy Balance

There is considerable debate in the scientific literature as to whether biofuel production, and especially ethanol, consumes more energy than it produces, or vice-versa. (Farrell, 2006; Dale, 2007).

Table 7.1 shows the total net fossil energy input to the production systems for each of the fuels analysed. For the biofuels this includes credits for avoided fuel use due to electricity and other co-products produced as part of the fuel's life cycle. Both total fossil and crude oil input are shown and the ratio is calculated as the usable transport fuel produced per unit of fossil energy input. The biorefinery is a net consumer of crude oil so this has been used to calculate the ratio of energy produced per unit of crude oil produced.

Table 7.1: Energy return on fossil energy inputs

	Biodiesel	Ethanol	Ethanol without biorefinery	Diesel	ULP	PULP
Production energy balance (MJ/kL) (excludes energy of liquid fuel output)	9,499	-8,716	15,685	40,975	35,739	37,072
Fossil energy input (MJ/kL)	9,802	3,658	15,685	40,975	35,739	37,072
Fossil energy offsets (MJ/kL)	184	12,074	-	-	-	-
Fossil energy balance (MJ/kL)	9,618	-8,416	15,685	40,975	35,739	37,072
Crude oil input (MJ/kL)	1,982	1,539	1,330	40,144	35,102	36,133
Crude oil offsets (MJ/kL)	78	402	-	-	-	-
Crude oil balance (MJ/kL)	1,904	1,137	1,330	40,144	35,102	36,133
Energy content of liquid fuel (MJ/kL)	32,253	23,100	23,100	38,600	35,419	35,420
Excess energy from production (MJ/kL)	303	12,421	-	-	-	-
Total effective energy output (MJ/kL)	32,556	35,421	23,100	38,600	35,419	35,420
Ratio of liquid fuel energy content per unit of crude oil energy	16.27	15.01	17.37	0.962	1.009	0.980
Ratio of liquid fuel energy content per unit of crude oil energy (overall balance)	16.94	20.32	17.37	0.962	1.009	0.980
Ratio of total effective energy output per unit fossil energy input	3.32	9.68	1.47	0.942	0.991	0.955

The results shown in Table 7.1 indicate that biofuels have an energy return on fossil energy expended that is greater than that of fossil fuel.

8 Sensitivity analysis

8.1 Different biodiesel blends

The analysis has so far provided results for B5. Sensitivity analysis, displayed in Figure 8-1 shows that the blend of the biofuel makes very little difference to the net greenhouse benefits achieved. This is because the offsetting of carbon dioxide emissions is a linear relationship to the blend percentage of biodiesel. The extent to which more, or less, diesel is combusted alongside the biodiesel production makes no significant difference, as expected.

This means that the results of Table 6.2, which indicate that the production and use of 45 ML biodiesel per annum would result in annual greenhouse gas emission savings of 44 Gg CO_2-e apply whether the biodiesel is used as B5 or as B20.

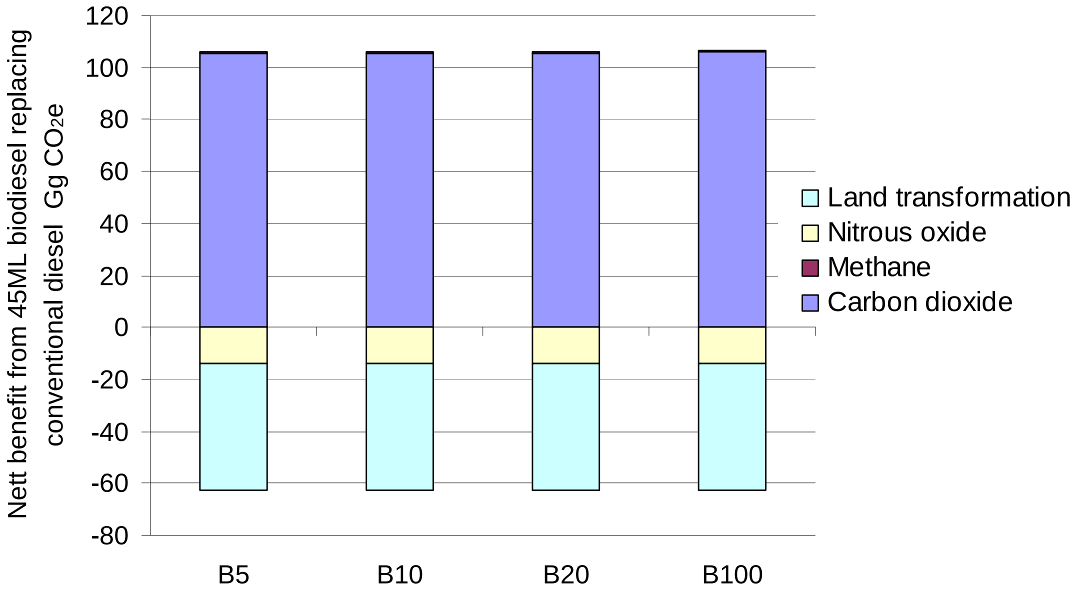

Figure 8-1: Impacts of different blending ratios on total benefit from biodiesel production

8.2 Economic allocation for biodiesel production

Figure 8-2 shows the difference in the results of biodiesel utilisation under the default approach which is system expansion for tallow use and glycerol co-production, and the alternative approach using economic shares to allocate environmental impacts of the beef system as the major provider of tallow and for glycerol and potassium sulfate co-production.

Tallow emanates from beef. Greenhouse gas emissions associated with the cattle industry and beef production include enteric methane production and nitrous oxide production from urine deposition as well as possible emissions from clearing land to provide pasture for the cattle. Including these upstream emissions results in tallow being a large greenhouse contributor, even though the economic allocation to tallow is small. On this method of allocation there are no greenhouse benefits associated with biodiesel production and utilisation, which instead are net greenhouse emitters after accounting for avoided diesel production and tailpipe emission savings. This is shown in Figure 8-2 by the overall sum of the right hand bar chart being negative.

In the previous and following figures the parts of the bar above the zero line are offset by the parts of the bar below the line for an overall total. For example, in Figure 8-2 for tallow substitution (as in Appendix 2) the greenhouse gas benefit from reduced carbon dioxide emissions in the fuel of 105.75 Gg is offset by the losses caused by increased emissions from nitrous oxide and land transformation of 61.94 Gg resulting in an overall benefit of 43.81 Gg, as listed in Table 6.2. If instead we used the economic allocation of beef, the approximately 90 Gg of carbon dioxide as shown below would be offset by over 500 Gg of increased emissions of methane, nitrous oxide and from land clearing, resulting in an overall disadvantage of about 415 Gg.

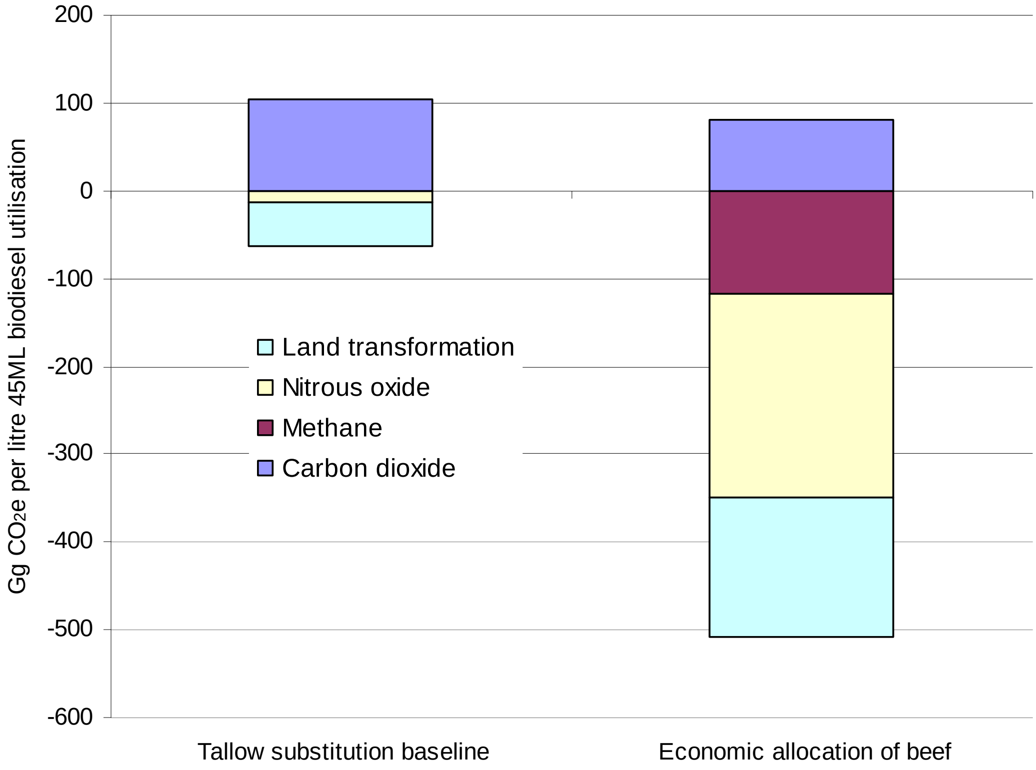

Figure 8-2: Total greenhouse gas benefits from biodiesel production (45 ML) using economic allocation.

8.3 Alternative assumptions on tallow substitution

Figure 8-3 shows the difference in the results of biodiesel utilisation under the different assumptions regarding the commodity substitution for tallow utilised in WA. Within palm oil, as noted in Appendix 2, there is significant uncertainty regarding the land management practice from marginal supply of palm oil, which is required if tallow is used in biodiesel production. The default tallow substitution model used is the data from EcoInvent and this has been compared with palm oil from existing plantations, palm oil on cleared rainforest and palm oil from cleared peat forest (see Figure 8-3). If the tallow utilisation leads to palm oil production from rainforest cleared land the product system has higher greenhouse emissions than the diesel products system it is replacing. If the assumption is that peat swamps are cleared instead, then the emissions are extraordinarily high relative to diesel production system.

Another alternative substitute for displaced tallow is canola and it is also show in Figure 8-3. Canola oil as a substitute gives a higher greenhouse value than palm oil (83 Gg CO_2-e as compared with 44 Gg CO_2-e) using the baseline palm oil. However palm oil from existing plantations, which do not need to account for land use changes, produce even higher benefits than canola (104 Gg CO_2-e). If the palm is assumed to come from cleared rainforest or peat forest there are net emissions of greenhouse gases of 81 Gg CO_2-e and 978 Gg CO_2-e respectively.

It is not suggested here that tallow usage in WA will lead to clearing of rainforest for palm oil production, but we note that production of 45 ML of biodiesel using tallow requires existing users of the tallow to find a substitute. The most likely substitutes are palm oil or canola, and our default tallow substitution values encompass these likely substitutes.

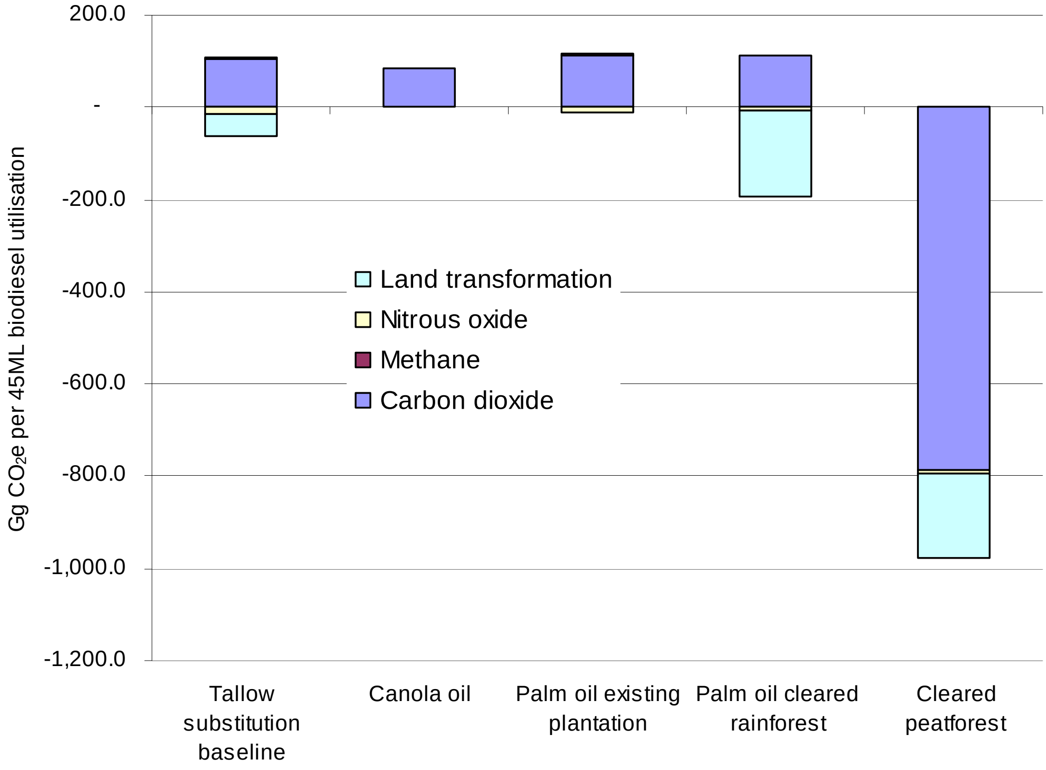

Figure 8-3: Total greenhouse benefits from biodiesel production (45 ML) under different assumptions of palm oil production

8.4 Absence of biodigester in ethanol biorefinery

Figure 8-4 shows the influence of the biodigester on the total greenhouse savings achieved from the ethanol biorefinery. The option without the biodigester requires a use to be found for the distiller's grain which is assumed to be sold as stock feed. In the modelling it is assumed to offset the need for fodder crops such as lupins.

The use of the biodigester to produce electricity greatly improves the greenhouse gas benefits of the ethanol biorefinery. This is because electricity in Western Australia is produced from black coal so that its replacement with a renewable energy source results in considerable carbon dioxide emissions savings.

The heat from co-generation is also used in distillation. The heat required for distillation is assumed to come from co-generation with electricity from the biodigester. No replacement for this heat has been included in the option without the biodigester as there is no specific data on how much heat is required. Were this heat requirement to be included, the benefits of ethanol would be further reduced in the non-biodigester option.

The results of this sensitivity analysis of the biodigester option have already been presented in Table 6.2. Figure 8-4 provides a graphical representation of the numbers in that Table, which indicate that a 160 ML ethanol biorefinery will save 486 Gg of CO_2-e with incorporation of a biodigester producing co-generated electricity and heat, but will save only 220 Gg CO_2-e without such a biodigester.

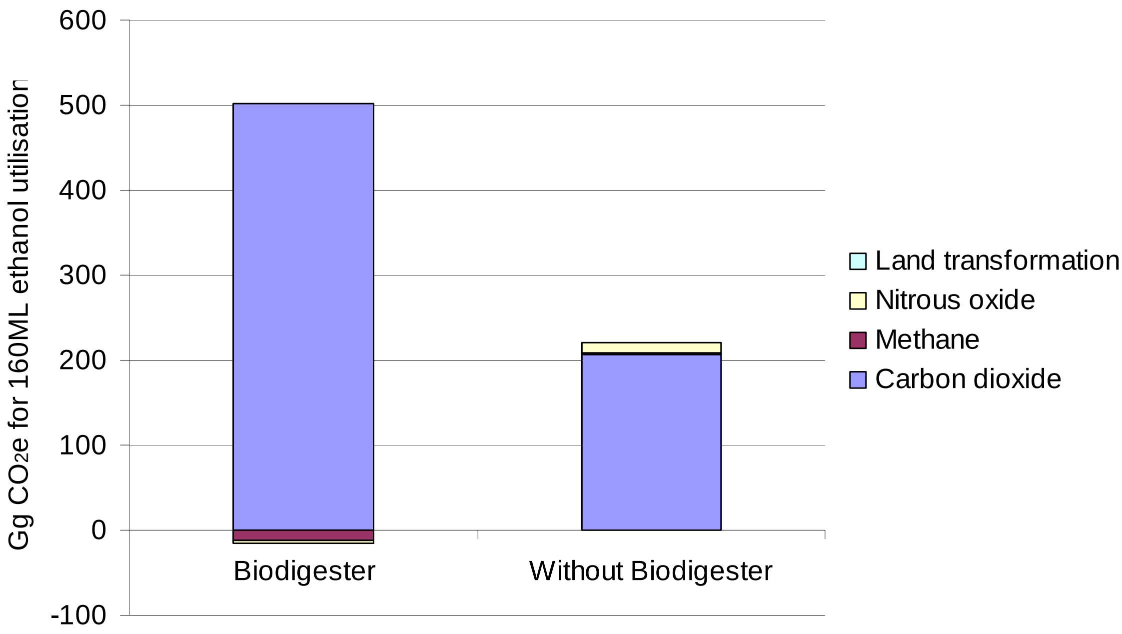

Figure 8-4: Total greenhouse gas benefits from ethanol production (160ML) with and without the biodigester

9 Uncertainty Analysis

9.1 Upper Limits for GHG Savings in WA

It may be noted that the values in Table 6.1 can be used to set an upper limit to the likely greenhouse savings if Western Australia were to produce sufficient biofuel for all cars to run on E10 and all trucks and buses to run on B5. The values in Table 6.1 show that use of E10 leads to savings of 38.00 g CO_2-e per km in family cars (314 g/km for PULP and 277 g/km for E10) and that use of B5 leads to savings of 13.78 g CO_2-e per km in medium trucks (806 g/km for diesel and 792 g/km for B5). In 2006, the total number of kilometres travelled by passenger vehicles and light commercial vehicles in Western Australia was 22,808 x 10^6 km, whereas diesel vehicles (light commercial vehicles, trucks, articulated trucks, other trucks, and buses) travelled 1,784 x 10^6 km. Assuming that passenger vehicles and light commercial vehicles all use E10 and the diesel vehicles all use B5 leads to an extreme upper bound estimate of 891 Gg CO_2-e emission savings. This value is a hypothetical estimate of the greenhouse gas benefits if all Western Australian vehicles were to use biofuels. The greenhouse gas benefits are dominated by the E10 usage, which accounts for 867 Gg CO_2-e.

Ethanol benefits are so much greater than those of biodiesel (24 Gg) because of the higher per kilometre greenhouse gas benefits of E10 compared to biodiesel, and because petrol vehicles, due to their sheer number, travel over ten times the total number of kilometres of diesel vehicles.

9.2 Monte Carlo Analysis of GHG Savings for Ethanol and Biodiesel Refineries

A Monte Carlo analysis has been undertaken using both uncertainty estimates of background life cycle data from the Australian and EcoInvent LCA databases, and from key areas in the LCA such as yields in agriculture and bio-refineries and in fuel use and tailpipe emissions. The results of the uncertainty assessment are shown in the form of 95% confidence limits, which are the values within which 95% of the runs fall.

Table 9.1 shows the results of the Monte Carlo analysis from the production of ethanol and its use in WA fuel as an E10 blend, for the full 160ML of annual production. It shows that carbon dioxide savings could be as high as 530 Gg or as low as 324 Gg. The same data are shown in Figure 9-1; however the uncertainty bounds are graphs relative to their greenhouse contribution to the final results. It demonstrates that the two large contributions to uncertainty in the final greenhouse value for the ethanol production and use relate to carbon dioxide emission and to a lesser extent nitrous oxide emissions. Figure 9-2 shows the probability distribution of the greenhouse gas savings from ethanol production.

Table 9.1: Replacement of PULP with E10 (160ML pure ethanol)

Impact category	Unit	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%
Carbon dioxide	Gg CO_2	-504.9300	-506.7500	38.1250	-0.0755	-575.1500	-429.4600
Land transformation	Gg CO_2-e	-0.0172	-0.0171	0.0004	-0.0242	-0.0180	-0.0164
Methane	Gg CH_4	0.6386	0.6405	0.1111	0.1740	0.4164	0.8568
Nitrous oxide	Gg N_2O	0.1597	0.1417	0.0908	0.5687	0.0346	0.3765
Other	Gg CO_2-e	0.0033	0.0031	0.0122	3.7355	-0.0228	0.0272
		0.0000	0.0000	0.0000		0.0000	0.0000
Single score	Gg CO_2-e	-442.0300	-445.7300	53.4810	-0.1210	-530.4100	-323.6900

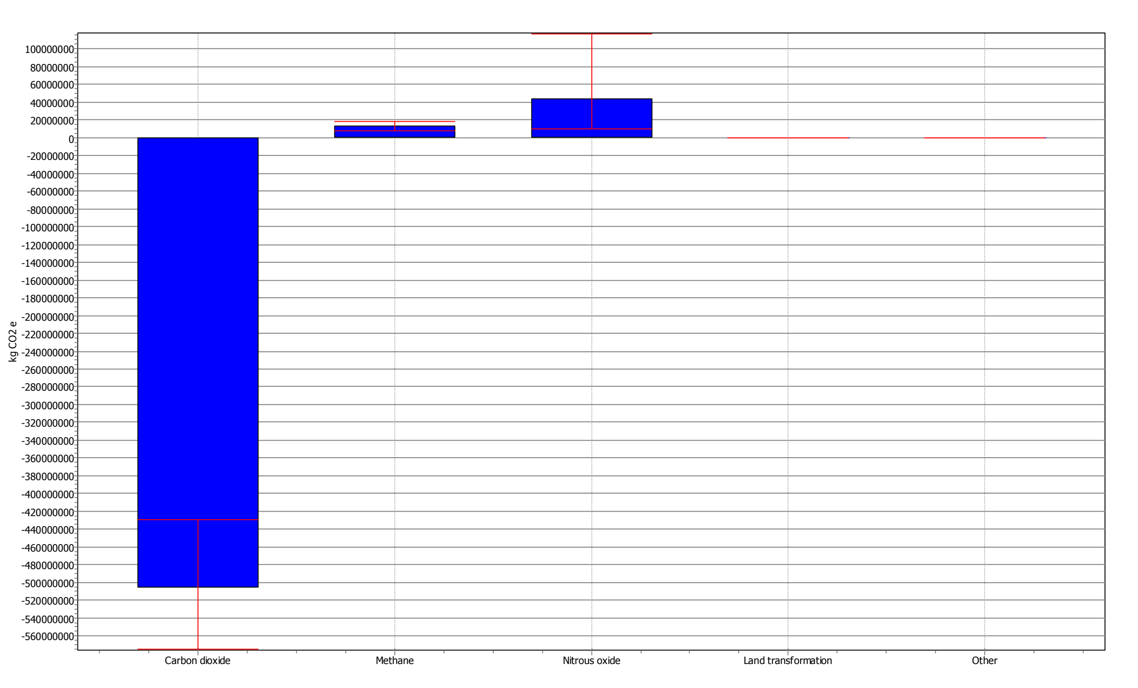

Figure 9-1: 95% uncertainty of different greenhouse gas emission savings due to replacement of PULP with E10 (160ML pure ethanol)

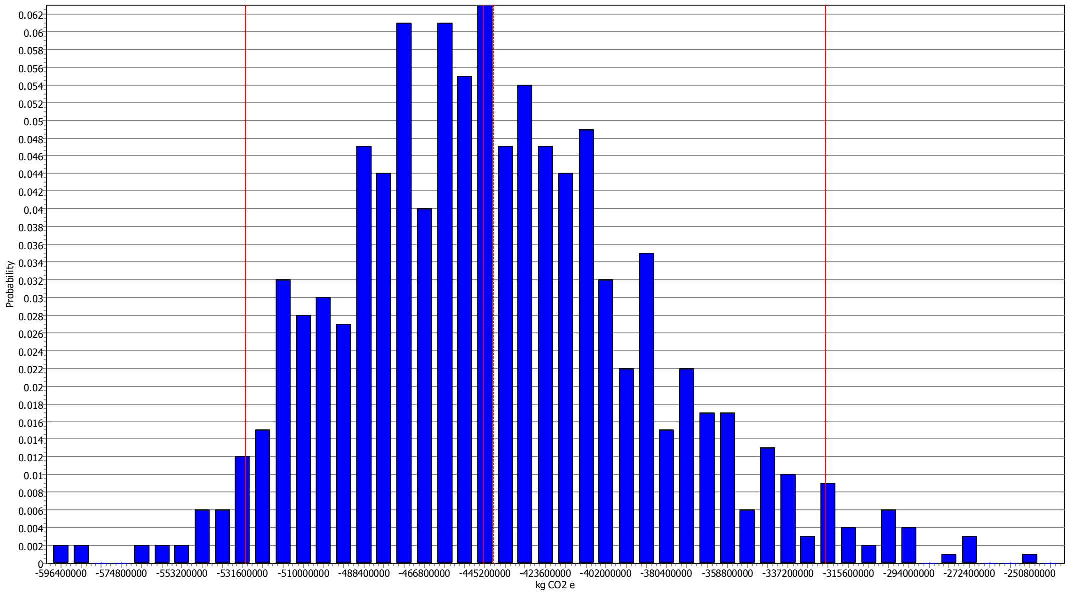

Figure 9-2: Probability distribution of greenhouse gas emission savings due to replacement of PULP with E10 (160ML pure ethanol)

Table 9.2: Replacement of Diesel with B5 biodiesel (45ML pure biodiesel)

Impact category	**Unit**	**Mean**	**Median**	**SD**	**CV (Coefficient of Variation)**	**2.50%**	**97.50%**
Carbon dioxide	Gg CO_2	-105.9900	-106.0300	3.3187	-3.13%	-111.9500	-99.2010
Land transformation	Gg CO_2-e	48.8700	48.1250	6.3234	12.94%	38.0700	62.8870
Methane	Gg CH_4	-0.0386	-0.0392	0.0038	-9.77%	-0.0448	-0.0300
Nitrous oxide	Gg N_2O	0.0440	0.0430	0.0108	24.51%	0.0276	0.0659
Other	Gg CO_2-e	0.0025	0.0023	0.0015	62.28%	-0.0001	0.0064
		0.0000	0.0000	0.0000		0.0000	0.0000
Greenhouse gas emissions	Gg CO_2-e	-44.2770	-44.4620	7.9950	-18.06%	-58.0750	-27.6470

Figure 9-3: 95% uncertainty of different greenhouse gas emission savings due to biodiesel replacement of fossil fuel in B5 blend in WA

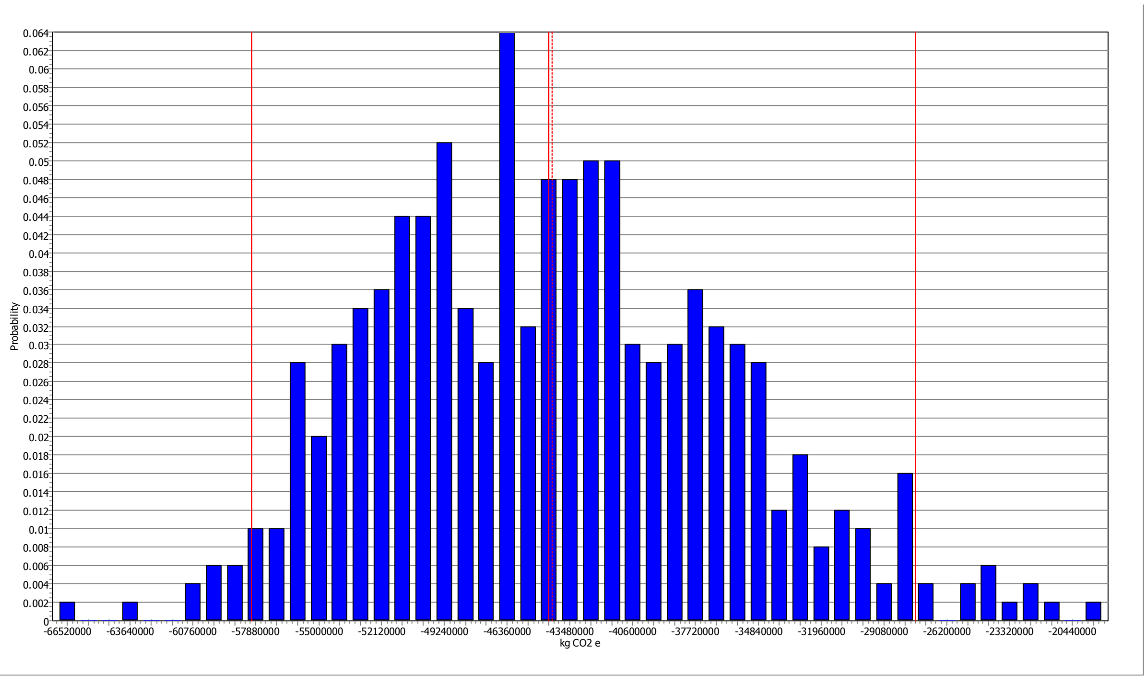

Figure 9-4: Probability distribution of greenhouse gas emission savings due to biodiesel replacement of fossil fuel in B5 blend in WA

Table 9.2 shows the results of the Monte Carlo analysis from the production of biodiesel and its use in WA fuel as a B5 blend, for the full 45ML of annual production. It shows that carbon dioxide savings could be as high as 58 Gg or as low as 28 Gg. The same data are shown in Figure 9-3; however the uncertainty bounds are graphs relative to their greenhouse contribution to the final results. It demonstrates that the two large contributions to uncertainty in the final greenhouse value are carbon dioxide emissions (largely from tailpipe savings) and land transformation emissions (from clearing land). Figure 9-4 shows the probability distribution of the greenhouse savings from biodiesel production.

10 Other Environmental Impacts of Ethanol and Biodiesel

10.1 Water and Land Use

Land use is dominated by land required for growing grain to turn into ethanol. Water and land use from biodiesel production are from the product (palm oil or canola) used for tallow substitution.. Table 10.1 and Figure 10-1 show the land and water use for the various fuels.

Note that the use of ethanol in E10 results in a reduction in water use. This is due to the electricity offset from use of the biodigester; substantial water is required in coal-fired power stations for the production of electricity. Note that water in the form of rainfall for crops is not included; only water that comes from elsewhere that could be used in a different location or industry (e.g. for irrigation or drinking supplies).

Table 10.1: Land use and water use impacts of biofuels and fossil fuel replaced

Land Use	45 ML biodiesel in B5	Replaced diesel	160 ML ethanol in E10	Replaced PULP
Land use (ha)	8706	0.8109	268598	1.576
Water use (ML)	14126	45.53	-133.0	90.49

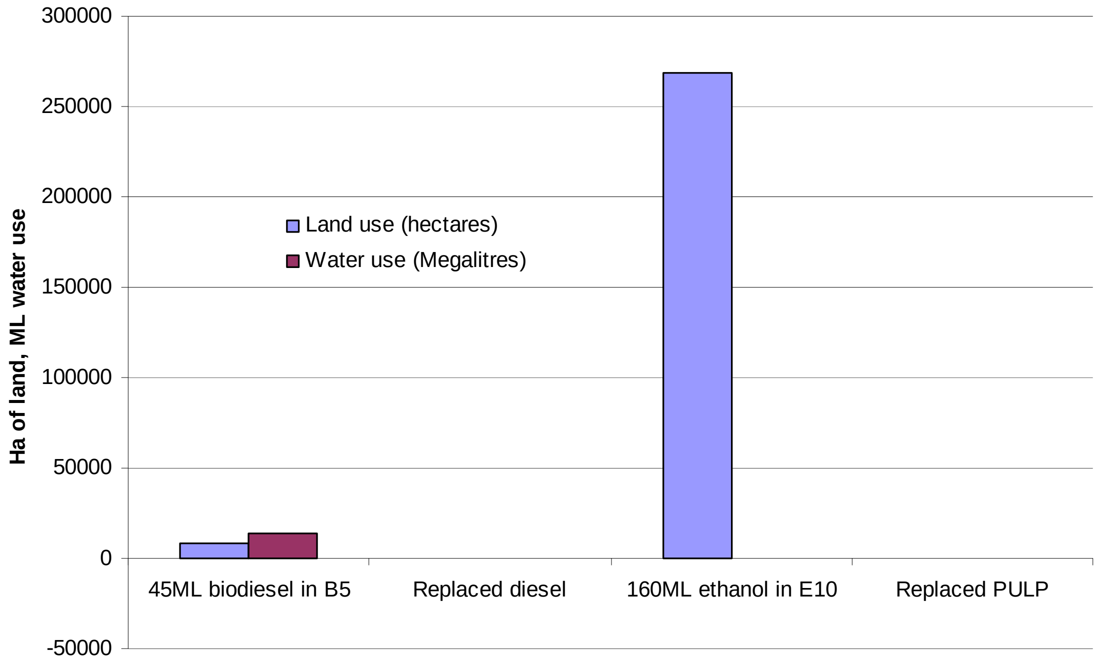

Figure 10-1: Land and Water use Impacts due to Biofuel Production

10.2 Criteria Air Pollutants

Figure 10-2, Figure 10-3, and Figure 10-4 show the distribution of criteria pollutants – particulate matter, oxides of nitrogen and non-methanic hydrocarbons. Petrol vehicles emit far less air pollutants than diesel trucks. The use of ethanol reduces particulate matter emissions on a life-cycle basis, primarily because of the replacement of electricity produced from brown coal with electricity produced from a biodigester. The higher vapour pressure of ethanol means that hydrocarbon emissions increase.

Use of biodiesel reduces particulate matter and hydrocarbon emissions. However the use of biodiesel increase emissions of oxides of nitrogen, which are smog precursors.

Beer et al. (2003) noted that human health effects are dominated by particulate matter in the atmosphere. In this respect, both biodiesel and ethanol reduce emissions of particulate matter.

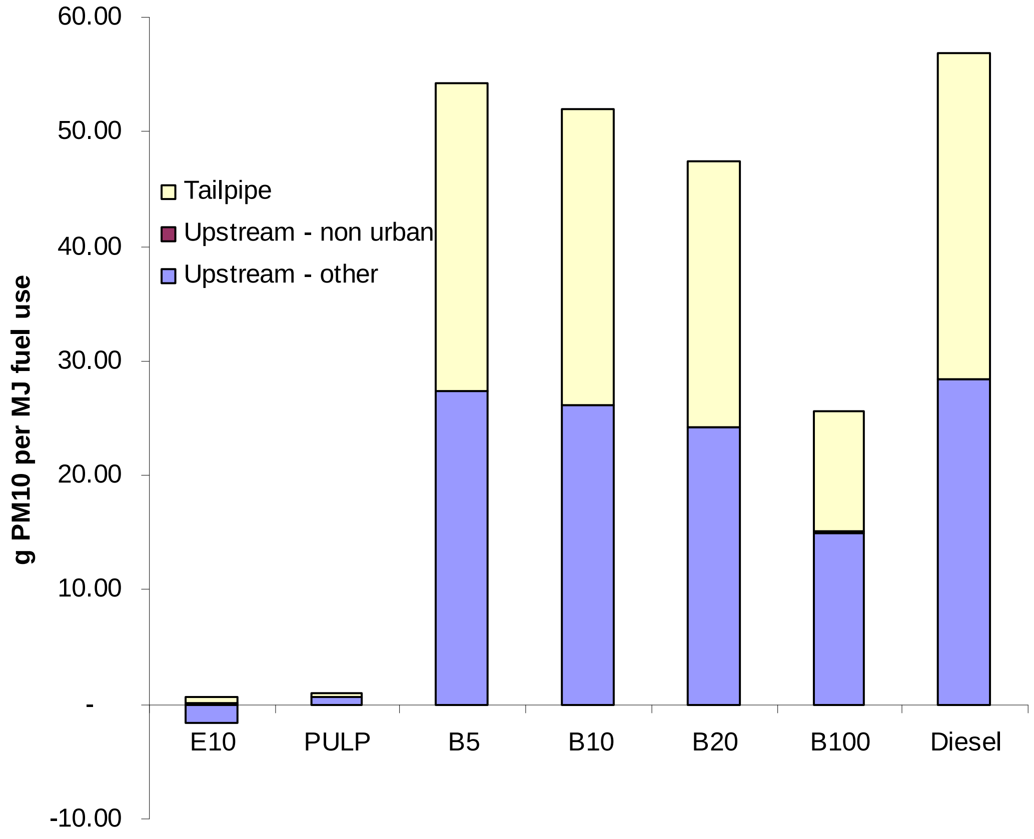

Figure 10-2: Particulate Emissions (PM10) per MJ of fuel

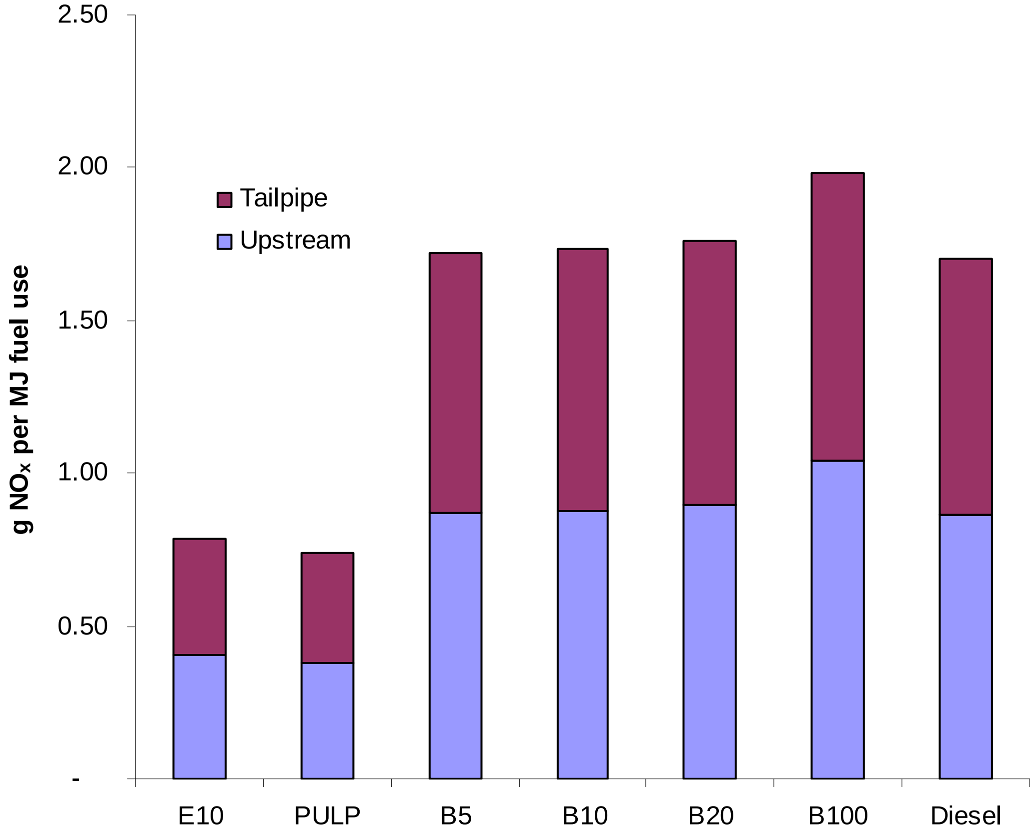

Figure 10-3: Oxide of nitrogen emissions per MJ of fuel

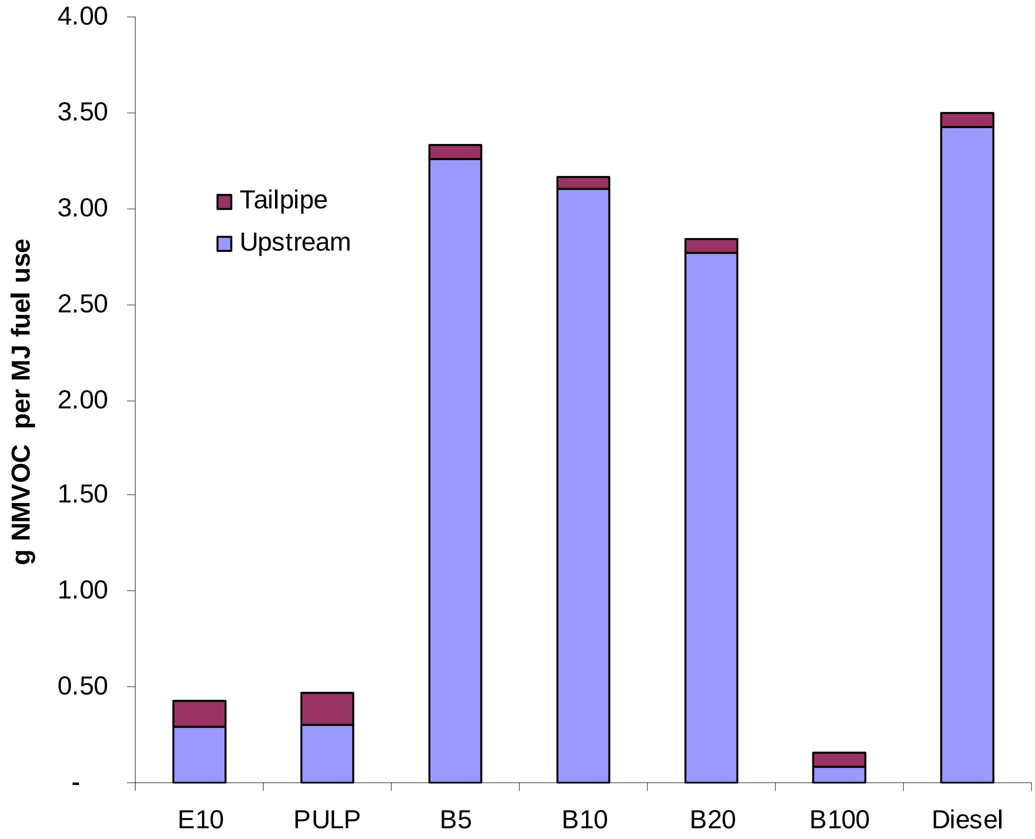

Figure 10-4: Non-methanic hydrocarbon emissions per MJ of fuel

11 Discussion and Conclusions

The LCA compares the Western Australia with and without biofuel production; specifically biofuel from two plants – 45ML of biodiesel from the ARF facility (Picton) and 160ML of ethanol from the Primary Energy proposed biorefinery (Kwinana).

The greenhouse benefits of biofuel are normally derived from the substitution of fossil based carbon emissions (which are the result of the combustion of fossil fuels), with biogenic carbon dioxide emissions (which are the results of combusting fuels that have only recently absorbed the carbon from the atmosphere during the cropping cycle). In this LCA there are a number of other significant greenhouse contributors and savings. The most dominant of these is the electricity production from the Primary Energy biorefinery. Because Western Australian electricity is largely based on coal combustion, the greenhouse benefits of substituting this electricity with electricity from the bio-refining are very significant. The greenhouse gas savings from electricity production (281 Gg) are more than the savings generated from ethanol production (205 Gg), so the biorefinery could be treated as an electricity plant which produces ethanol and fertilisers as co-products.

Without the biodigester part of the biorefinery, the ethanol production and utilisation are still beneficial from a greenhouse gas perspective; however the savings per year are more than halved from 486 down to 220 Gg for the 160ML of production. In terms of fuel security, the ethanol production has relatively low crude oil inputs over the lifecycle with 20 more times energy being produced than crude oil energy utilised through the life cycle.

These benefits are offset by land use; with very little land utilisation in the crude oil to petrol supply chain compared with the land needed for wheat production. The overall sustainability of this use is beyond the scope of this LCA, as is the sustainability of the continued crude oil utilisation.

For the biodiesel production the feedstock being utilised is tallow, which is a co-product of the beef industry but has relatively low value within this supply chain. In this study it is assumed that beef production itself is unlikely to be affected by tallow utilisation but other users of tallow, both domestic and overseas, are likely to struggle to compete with biodiesel users, and will therefore shift either directly or indirectly to the next cheapest oil feedstock - palm oil or canola. Under the default assumption used in the study for tallow substitution, there is still a net greenhouse benefit from biodiesel production and use of 44 Gg for the 45 ML of production, although this would be 93 Gg if not for the land clearing effects from palm oil. This 44 Gg benefit is entirely from tailpipe emission savings due to biogenic carbon dioxide emissions replacing fossil derived carbon dioxide emissions. The production stage of biodiesel is significantly higher than the equivalent volume of diesel production but this is more than offset by the tailpipe emission savings. Co-products from biodiesel production, glycerol and potassium sulfate make little impact on the final environmental profile of biodiesel.

There is significant land and water use involved in the biodiesel usage through the additional need for tallow substitutes; however the water may not be an issue if it comes from wetter tropical climates.

In relation to urban air pollutants, the benefits of biodiesel blends on reducing particulate matter are well established but are also highly variable, as is the increase in nitrogen oxide emissions. Human health effects are dominated by particulate matter in the atmosphere. In this respect, both biodiesel and ethanol reduce emissions of particulate matter. This study has assumed that tailpipe emissions of particulate matter are the same when both PULP and E10 are used. Recent results of testing (AEA Technology, 2004) indicate that use of E10 could lead to particulate matter emissions that are up to 40% lower than emissions from the use of petrol. Such large reductions are expected to be found in cold ambient temperatures. The results of a study on particulate matter emissions from the use of E10 at Western Australian temperatures, released in early August 2008 by the Federal Department of Environment, Water, Heritage and the Arts[17], confirm that particulate matter reductions occur but are less than those found by AEA Technology (2004).

For ethanol only an E10 blend was assessed in this study, but for biodiesel blends from 5% to 100% were assessed and the environmental impacts per unit of biodiesel utilised did not vary. This suggests that the most convenient and practical blend should be based on vehicle requirements.

12 Acknowledgements

We wish to acknowledge the assistance of: Peter Scaife, from CSIRO Energy Technology, for the provision of data; Anne Wilkins, from the WA Department of Agriculture and Food, for the provision of the material in Appendix 3 – and to both of them for their careful perusal of this report.

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[17] http://www.environment.gov.au/atmosphere/fuelquality/publications/ethanol-health-impacts.html

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Appendix 1 System expansion method

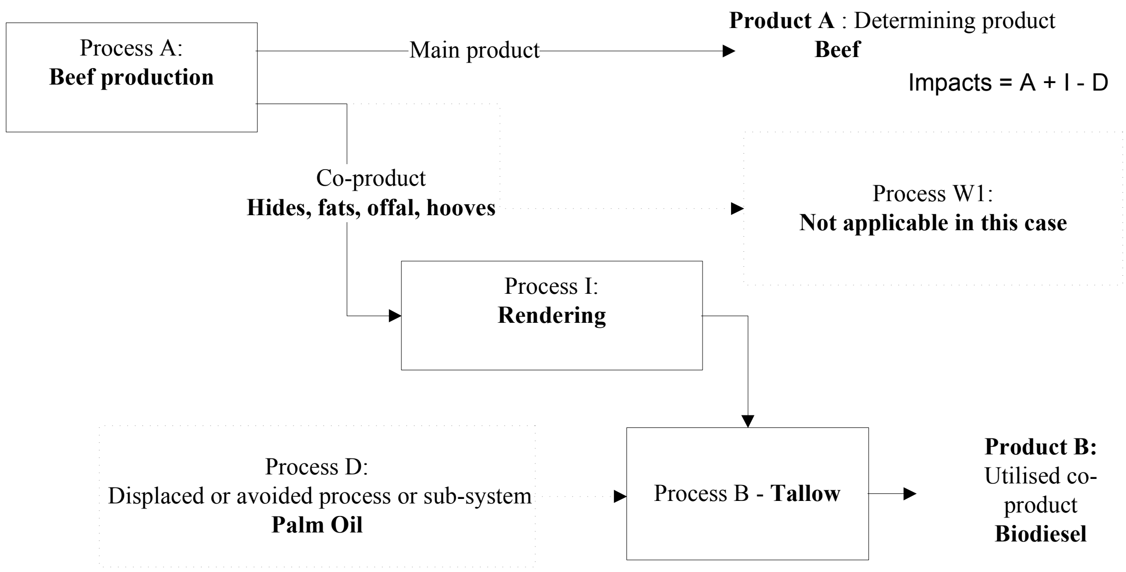

Figure A1-13: Model for system boundary expansion – Adapted from (Weidema, 1999)

Weidema (1999) has developed four simple rules for determining expanded system boundary allocation based on the level of utilisation of the by-product (or waste). Using the model of Figure A1-1 for reference, Weidema (1999) developed the following four rules for ascribing process impact to different products. These are:

1) *The co-producing process shall be ascribed fully (100%) to the determining product for this process (product A.)*

2) *Under the conditions that the non-determining co-products are fully utilised in other processes and actually displace other products there, product A shall be credited for the processes, which are displaced by the other co-products, while the intermediate treatment (and other possible changes in the further life cycles in which the co-products are used, which are a consequence of differences in the co-products and the displaced products) shall be ascribed to product A.*

If the two conditions stated in rule no. 2 are not fulfilled, rule no. 3 and 4 apply, respectively:

3) *When a non-determining co-product is not utilised fully (i.e. when part of it must be regarded as a waste), but at least partly displaces another product, the intermediate treatment shall be ascribed to product B, while product B is credited for the avoided waste treatment of the co-product.*

4) *When a non-determining co-product is not displacing other products, all processes in the entire life cycle of the co-product shall be fully ascribed to product A.*

Appendix 2 Tallow substitute production and its variants

In this study it is assumed that beef production itself is unlikely to be affected by tallow utilisation but other users of tallow, both domestic and overseas, are likely to struggle to compete with biodiesel users, and will therefore shift either directly or indirectly to the next cheapest oil feedstock - canola or palm oil. Canola production has been detailed in Section 5.1.4. This Appendix deals with palm oil.

Palm oil production from Beer et al. (2007) has been used as the environmental profile for palm oil substituting for tallow in the world market. Three versions of palm oil production was included by Beer et al. (2007), from existing plantations, from rainforest cleared land and from cleared peat swamp land. In the case of “palm oil, existing plantations” it was assumed that the land was cleared a long time ago for crop use, and that the palm oil plantation replaced an existing crop or plantation (e.g. rubber trees). As such there has been no assignment of emissions due to land clearing made in this case. Several examples of plantations of this variety can be found in Thailand. For “palm oil from cleared rainforest” we assume that recently the land was a tropical rainforest, and that the trees have been logged and removed before the plantation was established. The net carbon flux is taken to be 252 tonne per hectares.

For modelling purposes an expected life of palm oil plantations derived from cleared forest needs to be assumed. The longer the assumed life, the greater the amount of palm oil which the initial CO_2 flux can be amortised over (Figure A2-1). The EcoInvent LCA database has lower carbon flux from Malaysia palm oil production; 42 tonne (instead of 252 tonne) of carbon emitted from rainforest clearing and soil carbon loss and this is taken over a 25 year timeframe for the emission. EcoInvent notes 20% of biomass burnt on clearing and a similar level of carbon loss from soil during cropping.

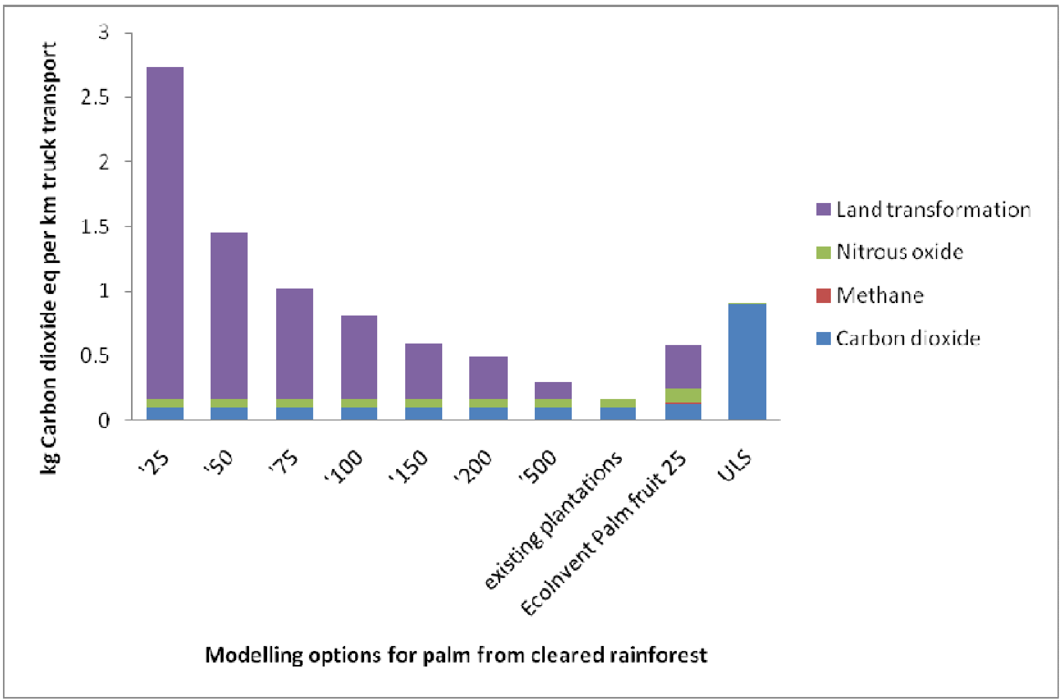

Figure A2-1: Change in greenhouse impacts of palm oil from rainforest clearing with change in assumed life of plantation, compared with EcoInvent data and ULS diesel. The abscissa denotes the assumed life of the plantation in years.

Because of the uncertainty as to the source of palm oil replacing tallow in the world market, and uncertainty in the life time in which clear rainforest impacts should be amortized, the EcoInvent data on palm fruit production are used as it falls between the existing plantation data and the cleared rainforest plantations.

Table A2.1 shows the main inputs for 1 kg of palm fruit production using the data from the EcoInvent LCA database. Figure A2-2 shows a process network for palm fruit production with cumulative greenhouse gas emissions as the lower value.

Table A2.1: Input and outputs for 1 kg palm fruit production

Materials/fuels		
Ammonium sulfate, as N, at regional storehouse	kg	0.006299
Diammonium phosphate, at regional store	kg	0.00128
Potassium chloride, as KCl, at regional storehouse	kg	0.009461
Dolomite, at plant	kg	0.003241
Lime, from carbonation, at regional storehouse	kg	0.001722
Irrigating	ha	7.01E-05
Wood chopping, mobile chopper, in forest	kg	1.0858
Transport, tractor and trailer	tkm	0.001269
Transport, lorry >16t, fleet average	tkm	0.007614
Transport, freight, rail	tkm	0.02635
Provision, stubbed land	m^2	0.016014

Source: EcoInvent 2.0 database (Jungbluth et al., 2007)

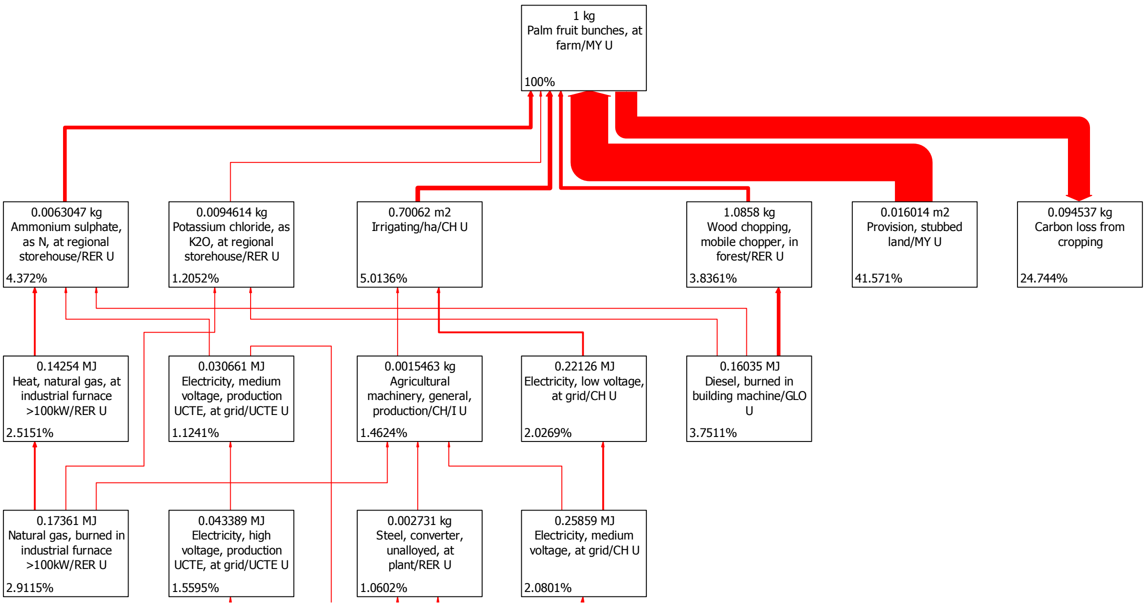

Figure A2-2: Process network showing greenhouse emissions for palm oil production on 1 kg of palm fruit.

Note: Upper value shows total flow, lower value shows cumulative greenhouse emissions. Only processes with at least 0.005% contribution to the cumulative greenhouse emissions are shown in the figure.

Table A2.2 shows the production data for producing crude palm oil from palm fruit. The electricity produced from biomass from palm oil production leads to a credit to palm oil production based on average Malaysian electricity. Figure A2-3 shows a process network for palm oil showing the cumulative greenhouse gas emissions as the lower value in each box.

Table A2.2 Input and outputs to palm oil production from palm fruit

Inputs	**Flow**	**Unit**
Palm fruit	5000	kg
Electricity	320	MJ
Outputs		
Palm Kernel, cleared peat swamp	330	kg
Palm Oil, cleared peat swamp	2500	kg
Electricity	590	MJ
Emissions to air		
Carbon monoxide	5.64	kg
Nitrogen oxides	0.64	kg
Sulfur dioxide	0.02	kg

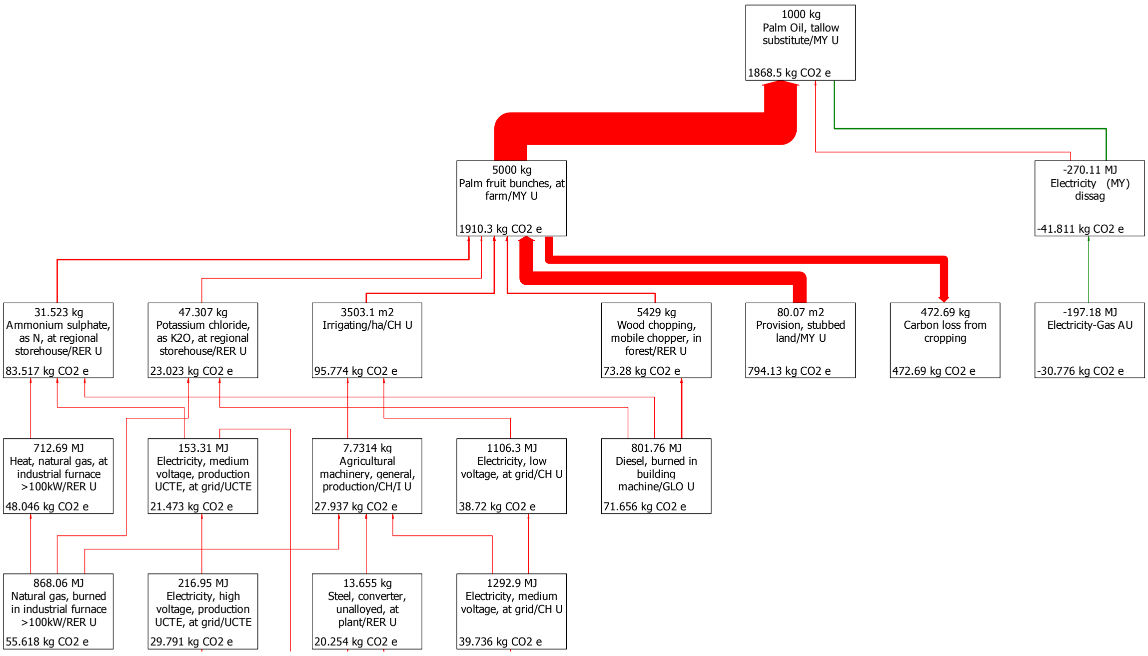

Figure A2-3: Process network showing greenhouse emissions for crude palm oil on cleared rainforest land per tonne palm oil

Note: Upper value shows total flow, lower value shows cumulative greenhouse emissions. Only processes with at least 0.005% contribution to the cumulative greenhouse emissions are shown in the figure.

Appendix 3 Warranties - Diesel engine manufacturers[18]

Warranties for machinery: In Australia and USA

Case IH

Case IH approves the use of blends of up to 5% biodiesel (B5) meeting ASTM 6751 standards. Use of biodiesel fuel meeting these standards will in no way affect any pre-existing or new Case IH product warranty.

Case IH makes no statement about Case IH product warranty issues when using more than 5% in a blend or using 100%. Instead Case IH issues a warning stating that higher biodiesel blends over B5 can have negative effect in diesel engine. It also gives a list of routine practices to follow when using higher biodiesel blends.

New Holland

On Monday, 8 May 2006 New Holland announced that it fully supports the use of B20 blends – 20% biodiesel and 80% petroleum-based diesel - on all of its engines, other than those with a common rail fuel injection system. According to news reports the company's marketing manager, Simon Vigour, stated that “the use of biodiesel is becoming more popular but this is not without its challenges. Cost is one consideration, as blends higher than 5% are more expensive. Biofuels also attract water vapour from the air, so fuel tanks should be kept as full as possible to limit the amount of condensation”.

John Deere

Biodiesel blends up to B5 (5% biodiesel mixed with regular petroleum diesel by volume) can be used in John Deere diesel engines, provided that the neat biodiesel or B100 meets ASTM D 6751 (USA) or EN 14214 (Europe) specification. John Deere product warranty only covers defects in material and workmanship as manufactured and sold by John Deere. Failures caused by the use of poor quality aftermarket fuels, be that biodiesel or regular petroleum diesel, are not defects of material and/or workmanship as supplied by John Deere, hence cannot be compensated under their warranty. On the other hand, using higher biodiesel blends above B5 does not automatically void warranty. Users of John Deere emission certified engines are responsible for obtaining the proper local, state, and national exemptions required for the use of biodiesel.

Both Case IH and John Deere lament the lack of industry standards to regulate the quality and performance of biodiesel blends.

Europe

In Europe, where strict standard exists, the situation is very different to Australia.
A growing number of manufacturers endorse the use of biodiesel both in blend with mineral diesel and pure as a 100% biodiesel fuel. The biodiesel is produced to conform to EN 14214 the proposed European standard. In a 95% diesel / 5% biodiesel blend the fuel

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[18] The material in this Appendix was provided by Anne Wilkins, WA Department of Agriculture and Food.

meets the existing EN 590 automotive fuels specification. Numerous engine manufacturers have already endorsed the use of a 95/5 mix.

Table A3-1: Existing Diesel Vehicle Warranties for 100% Biodiesel Operation*

Audi	Personal cars	All TDI models since 1996
BMW	Personal cars	Model 525 tds 1997 onwards, 3 + 5 series diesel since 2001
Case-IH	Tractors	All models since 1971
Caterpillar	MMT, industrial, marine	All engines except some Perkins
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
Iveco	Truck	Cursor since 2000
John Deere	Combines, tractors	Warranties since 1987
KHD	Tractors	Warranties exist
Kubota	Tractors	Series OC, Super Mini, 05,03
Lamborghini	Tractors	Series 1000
MAN	Truck	Engine numbers 8953591 to 8953001
Mercedes-Benz	Personal cars	Series C and E 220, C200 and C220, a.o.
Mercedes-Benz	Lorry, bus	Series BR300, 400, Unimog 1988 a.o.
Nissan	Personal car	Type Primera since 2001
PSA	Personal car	All HDI up to 30% biodiesel Blend*, Tractors Since 1990
Seat	Personal cars	All TDI since 1996
Skoda	Personal cars	All TDI since 1996
Steyr	Tractors	Since 1988
Steyr	Boats	Series M16, TCAM and M14 TCAM
Valmet	Tractors	Since 1991
Volkswagen	Personal cars	All TDI series since 1996, new SDI series (EURO-3)
Volvo	Personal cars	Series S80-D, S70-TDI, V70-TD

*Except where stated

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