Project: Life Cycle Analysis

Life Cycle Assessment of Biodiesel Production from *Moringa Oleifera* Oilseeds

Final Report
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EXECUTIVE SUMMARY

When considering the global scarcity of petroleum products and the associated environmental consequences, such as global warming, resulting from the combustion of the petroleum products, biodiesel is now being recognised as one alternative to petroleum-based diesel. Although biodiesel produces less emissions than petroleum diesel during its utilisation stage, it requires investigation as to what the various stages of biodiesel production produce in terms of environmental impacts. A life cycle assessment analysis has been carried out in order to determine the ecological and carbon footprints associated with biodiesel production from *Moringa Oleifera* oilseeds.

Life cycle assessment is the compilation and evaluation of the inputs and outputs and the potential environmental impacts of a production system throughout its life cycle. This has the advantage of identifying the environmental impacts of all stages of the production cycle, rather than focusing on a single source of emission (e.g: use of biodiesel in the transportation sector). Furthermore, LCA enables evaluation of environmental impacts for comparative or improvement purposes.

The current LCA analysis used the '*cradle to gate*' approach, which means that it is limited to the production of biodiesel and did not incorporate the utilisation stage in the analysis. This LCA analysis consists of pre-farm, on-farm and post-farm stages. Pre-farm data included the information on the production of inputs, on-farm stage included environmental emissions from diesel use and nitrous oxide (N_2O) emissions from N fertiliser applications and the post-farm stage included dehusking of oilseeds and the conversion of the production of biodiesel from *Moringa Oleifera* oilseeds.

In this research, global warming and fossil fuel resource scarcity have been found to be the predominant impacts in the production of biodiesel. Greenhouse gas (GHG) emissions during the production of 1,000 litres of biodiesel was equivalent to 832 kg of CO_2, when the biodiesel was produced from *Moringa Oleifera* oilseeds, grown under irrigated conditions. The GHG emissions under dryland conditions were found to be 13% higher CO_2 (i.e.942 kg CO_2 equ-) than that for irrigated conditions for the same level of biodiesel production. This is because the application of inputs, including fertilizer, herbicide, pesticide, gypsum (and their transportation to paddock), for the dryland *Moringa oleifera* oil seed production is twice as high as that which is required by irrigated production.

Fossil fuel usage (largely attributed to farm machinery) is a major environmental impact from biodiesel production from *Moringa Oleifera* oilseeds, with dryland production utilising 14% more fossil fuel for the same level of production than that under irrigated conditions.

When CO_2 sequestration by the *Moringa Oleifera* plants is considered, the net life cycle global warming impacts of 1,000 litres of biodiesel production from the *Moringa Oleifera* seeds would be -14,188 kg of CO_2 equivalent and -14,125 kg of CO_2 equivalent, under irrigated and dryland conditions, respectively.

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1 INTRODUCTION

There are four important reasons that justify the need for the use of alternative fuels in the transport sector in Australia. 1. The most common reason is that the future supply of oil and natural gas is limited. The Australian transportation sector relies almost exclusively on petroleum as a source of energy. 2. The burning of these fuels over the past century has dramatically increased the level of greenhouse gases, which cause climate change (CSIRO, 2008). 3. The price of petroleum has reached record levels in Australia, and will continue to rise as domestic supplies of oil decline (ABC, 2008). 4. Due to increased volumes of transport and traffic congestion, the public health risks associated with exposure to particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), sulfur oxides (SOx), nitrogen oxides (NOx) and air toxins are also increasing (Sheehan *et al.*, 1998).

With its ability to be used directly in existing diesel engines, biodiesel offers the immediate potential to reduce the demand for fossil fuel based diesel in the transportation sector. Biodiesel is a renewable resource and could play a role in reducing greenhouse gas emissions from the transportation sector. For example, the LCA analysis of alternative fuels for Australian heavy vehicles (Beer *et al.* 2002) found that pure biodiesel produces 40% less emissions than petroleum diesel. Biodiesel can be produced domestically from agricultural oils or animal fats and alcohol (e.g. methanol or ethanol), in order to substitute diesel in heavy vehicles and farm machinery. For example, oil produced from canola and perennial oil seed plants can be potentially used to produce biodiesel in Australia (Beer *et al.*, 2000; Brockman, 2008).

Perennial tree species, such as *Moringa oleifera* and *Pongamia pinnata,* which can be grown in Albany, Carnarvon, Esperance and Geraldton regions in Western Australia have the potential to produce oil seeds for biodiesel production. There are three main advantages from the production of biodiesel from *Moringa Oleifera* plants, when compared with canola.

- Firstly, the plantation of these trees can potentially increase green coverage to sequester more CO_2 than other vegetable oil crops (e.g. canola) (Brockman, 2008).
- Secondly, the production of biodiesel from the *Moringa Oleifera* oil will reduce the demand for canola oil for biodiesel production, reducing pressure on the Australian grain industry to meet increasing canola oil food demands.
- Thirdly, these perennial plants are highly tolerant to salinity, water logging, frost and drought. A large amount of Western Australian salinity affected land could be potentially used to grow these plants to increase its productivity and carbon sequestration.

Whilst there are environmental and economic benefits involved in the plantation of these perennial plants for biodiesel production, a detailed life cycle assessment is required to assess the environmental implications of the different stages of biodiesel production to confirm these benefits.

2 METHODOLOGY

Life cycle assessment is the compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle (ISO, 1997). The life cycle assessment consists of four steps as shown in Figure 1.

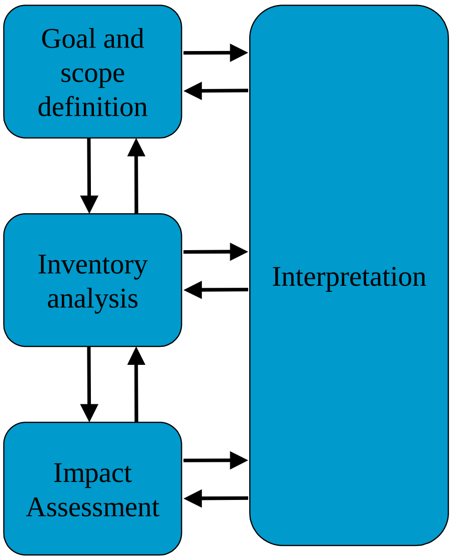

Figure 1: Four step procedure for Life Cycle Assessment (LCA).

The LCA approach used in this research assessed environmental emissions from pre-farming (e.g. manufacture of farming equipment), on-farm (e.g. plantation) and post-farming stages (e.g. conversion of oil into biodiesel) separately for biodiesel production at the Carnarvon Research Station study site. Using this approach enabled the environmental emissions from fertiliser use (manufacture and application), transportation, storage, and combustion of diesel to be calculated. The LCA follows the ISO14040-43 guidelines ISO (1997) and is divided into four steps: 1) goal and scope definition; 2) inventory analysis; 3) impact assessment; and 4) interpretation (as presented in the 'Results and discussions' section of this report).

Goal: The *goal* of this life cycle assessment is to evaluate the environmental impact of biodiesel produced from *Moringa Oleifera* oilseeds in Western Australia.

Scope: The scope of the LCA must establish the functional unit, select the relevant system boundaries, determine data requirements and choose relevant environmental indicators. The functional unit of this LCA is to assess the environmental impact of the production of 1,000 litres of biodiesel from *Moringa oleifera* oilseeds. This LCA analysis also compares the environmental performance of biodiesel production, from *Moringa Oleifera* plant seeds, grown under both dryland and irrigated conditions.

About 1 kg of *Moringa Oleifera* seeds is required to produce 0.33 litres of seed oil, with 1,000 litres of biodiesel consists of 1,000 litres of oleifera oil and 100 litres of methanol. Using this information, it was calculated that about 3,030 kg of oilseeds is required to produce 1000 litres of biodiesel. Accordingly, the input output field data, including chemicals, energy and outputs of emissions, has been ascertained for the production of 3,030 kg of oilseeds. The land usage information for growing *Moringa Oleifera* perennial plants on both dryland and irrigated land was obtained from H. Brockman, Department of Agriculture, Albany, Western Australia. An equivalent 3.03 t/ha of oil seed was harvested from the dryland site, and 6.06 t/ha was harvested from the irrigated land. The information obtained from H. Brockman is given in Annex I.

Since some of the databases for certain chemicals, (e.g. some herbicides and pesticides), are not available, surrogate values were used. For example, "Basta", which is used as herbicide, has been replaced by an equivalent amount of "Glyphosate" for this LCA analysis. The database for one particular pesticide, known as "Rogor", was not found to be available, therefore, the generic Australian emission data for pesticide was used (RMIT, 2005).

This LCA takes a '*cradle to gate*' approach, as it does not take into account the final use of biodiesel in trucks or farm machinery and therefore, it does not take into account the emissions, resulting from the combustion of biodiesel. The LCA analysis has been carried out for three main stages: pre-farm, on-farm and post-farm biodiesel production (Figure 2). Pre-farm data included the information on the production of inputs, such as NPK fertiliser, herbicide, pesticides, gypsum and farm machinery, also combustion of the diesel in transporting the inputs to the farm. The on-farm stage included environmental emissions from diesel use, and nitrous oxide (N_2O) emissions from N fertiliser applications. The on-farm application of gypsum, which replaces the use of lime in the acid soil, does not emit any pollutants, including GHGs, significantly and therefore, this was not included in the on-farm stage. The post-farm stage included dehusking of oilseeds from the *Moringa Oleifera* pods, and the production of biodiesel from oilseeds.

Pre-farm activities

- Mining of raw materials
- Processing materials
- Manufacturing farm inputs:
  - Chemicals
  - Energy
  - Machineries

→

On-farm activities

- Farm operations
  - Rip and mound
  - Pruning
  - Harvesting
  - Threshing
- Application of chemicals

→

Pre-farm activities

- Conversion of oleifera seed to oil
- Conversion of seed oil to biodiesel

Figure 2: Three stages of LCA of biodiesel.

Life cycle inventory (LCI): A Life cycle inventory (LCI) considers the amount of each input and output for processes which occur during the life cycle of a product. Undertaking an LCI is a necessary initial step in order to carry out an LCA analysis. Table 1 shows the LCI of 1,000 litres of biodiesel, produced from the *Moringa Oleifera* plants, grown under both dryland and irrigated conditions. Firstly, the table shows the inputs, which are required to produce 3,030 kg of *Moringa Oleifera* seeds. Next step of the LCI was the biodiesel production activities of two components: conversion of 3,030 kg oleifera seeds into 1,000 litres of oleifera seed oil and then the production of 1000 litres biodiesel from 1,000 litres of *Moringa Oleifera* oil and 100 litres of methanol. The LCI also contains some outputs, which are environmental emissions from paddock due to the application of chemicals during the on-farm stage.

The analysis shows that for the same level of chemical and energy inputs, irrigated production (6.06 tonne/ha) produces twice as much oil as dryland production (3.03 tonne/ha). Since the number of harvestings under irrigated conditions is double of that for the dryland conditions, the annual amount of diesel consumption for harvesting will be same under dryland and irrigated conditions. Furthermore, carbon sequestration has been assumed to be the same for both scenarios, because the number of plants or green coverage per hectare would be more or less the same in both land applications. Farm machinery requirements have been assumed to be the same for both irrigated and dryland production, but the electrical power requirements for irrigated production is about 10 times higher than that for dryland production. It is assumed that the same amount of pipe for irrigation network is used under irrigated and dryland conditions for *Moringa Oleifera* plantation. This is due to the fact that even under 'dryland conditions' some irrigation is utilised during very dryland production periods (pers comm.. H. Brockman).

Some operations, such as the initial establishment of the irrigation system for dryland *Moringa Oliefera* plantation, and ripping and mounding of the planting rows, were carried out once during the 15 years lifetime of the *Moringa Oliefera plantation and* , therefore, the raw data provided was divided by 15 to arrive at the annual values. The same once in 15 years calculation allowance has been made for the irrigation materials such as polyvinyl chloride plastic pipes and for the one-off pre-planting gypsum application. Some inputs, such as fertilizer and gypsum, are not used every year, and therefore, we had to determine the annual values of these inputs. For example, we halved the value of fertiliser as it was applied once in every two years. Gypsum was used once in a lifetime.

Table 1: Life Cycle Inventory of 1000 litres of Biodiesel production from *Moringa Oleifera* plants, grown under irrigated and dryland conditions.

Input types	Input names	Unit	Dryland land	Irrigated land
Production of 3,030 kg of oleifera oil seed				
Chemicals	Herbicide	kg	2.66	1.33
	Insecticide	kg	3.03	1.52
	Fertilizer (NPK)	kg	75.00	37.50
	Gypsum	kg	66.67	33.33
Energy	Rip and mound	litre	1.2	0.6
	Pruning	litre	30.00	15.00
	Threshing/dehusking	kWh	60.00	60.00
	Harvest	litre	90.00	90.00
	Pumping water	kWh	8.00	75.00
Machinery	Production of machinery	US$	20.92	20.92
Irrigation pipe (Plastics)	Polyvinyl Chloride	kg	12.14	12.14
Transportation of inputs	Herbicide	tkm	19.98	9.99
	Insecticide	tkm	18.18	9.09
	Fertilizer	tkm	450.00	225.00
	Gypsum	tkm	400.00	200.00
Paddock emission	N_2O	kg	0.01	0.007
	CO_2 sequestration	kg	-15,000	-15,000
Conversion of 3,030 kg oil seed into 1,000 litres of biodiesel				
Energy	Conversion of seed to oil	kWh	72.0	72.0
	Conversion of oil to biodiesel	kWh	7.2	7.2

Impact assessment: The environmental impact assessment of biodiesel production for pre-farm, on-farm and post-farm activities includes two steps. The first step classified the total emissions produced due to the production, transportation and application of these inputs and the second step converted these gases to the equivalent for different environmental impact categories, including global warming, photochemical oxidation, euthrophication, carcinogens, land use, water use, solid waste, fossil fuels and minerals.

Step 1: The input and output data in LCI were inserted into the Simapro 7 (2007) software to calculate the emissions for different environmental impact categories due to the production of 1000 litres of biodiesel. The input/output data of the LCI were linked to relevant libraries in Simapro 7.

The LCA Library is a database that consists of energy consumption, emission and materials data for the production of one unit of a specific product. The units of input and output data of the LCI depend on the units of the relevant materials (i.e. kg, l, MJ, $ etc.) in Simapro 7 (2007) or the LCA libraries. For example, the farm machinery library has information on the environmental emissions for the production of a US$1 equivalent of machinery. Accordingly, input data for farm machinery for wheat production were converted into US dollars. Input data (e.g. US$ 20.92 worth of machinery for 3,030 kg of oleifera seed harvested) in the LCI was multiplied by the emission factors (e.g. 0.15 kg CO_2/US$ of machinery) in the farm machinery library in order to determine total emission due to use of an input (i.e. farm machinery) to produce one tonne of *Moringa Oleifera* oil seeds. Since chemical libraries use mass units instead of volumetric units. Units of some field data (e.g. herbicide, pesticide etc.) have been converted from volumetric to mass units.

Libraries for chemicals: The Australian LCA database (RMIT, 2005) was used to calculate GHG emissions from the production of chemical inputs, such as pesticides, gypsum and NPK. The supply chain of NPK and pesticide, including production and transportation to the point of use, was incorporated in order to assess the environmental emissions during the pre-farm stage. For the Geraldton site, a 30t articulated truck, which is widely used in rural Australia, travelled 400 km to carry NPK, lime, herbicide and pesticide to the farm. The unit for transport library is tonne-kilometre (tkm). The emissions due to transportation were equivalent to 0.48, 80 x 10^{-4} and 76x 10^{-3} kg/tkm for CO_2, SO_X and NO_X, respectively (Altham *et al*., 2004).

Libraries for plastic pipes: Approximately 12.14 kg of plastic materials was used for dripper, connector and PVC pipe production for the irrigation system. The library for polyvinyl chloride (PVC) was used to assess the environmental impacts of the production of the irrigation network (RMIT, 2005).

Farm machinery library: A USA input-output database last updated in 1998 was used to assess the GHG emitted from manufacturing farm machinery to produce one tonne of *Moringa Oleifera* oil seeds (Suh, 2004). This database contains environmental emission data for the production of US$ 1 equivalent farm machinery (see Annex II). The current price of farm machinery was deflated to 1998 prices (in AUD) at 3% per year. Following this, the 1998 price of machinery in AUD/hectare has been converted into 1998 US dollars (by multiplying by 0.6).

Farm machinery operation library: Except for the harvester, other farm machineries(i.e. rip and mound, and pruning operations) were consider as light duty agricultural machinery (Field data provided by H. Brockman, Department of Agriculture, Albany, Western Australia). Therefore, the library for heavy duty agricultural machinery (RMIT, 2005) was used to calculate the potential GHG emitted from harvesting operation. For calculating GHG emissions from the rip and mound and pruning operations, the library for light duty agricultural machinery (RMIT, 2005) was considered. In the case of the irrigation pump, the electricity was used instead of diesel. Therefore, the library for Western Australian electricity generation mix was used to calculate the environmental emissions from the electricity usage (RMIT, 2005).

Paddock emissions library: Local value for the N_2O emission factor, which was measured in the wheat paddock in Cunderdin WA, was used in this LCA analysis. Total soil N_2O emissions measured during the on-farm stage were 0.11 kg N/ha/yr (0.02% of applied N, Barton *et al.* 2007).

Biodiesel production library: The first task of the biodiesel production is to dehusk oilseeds from the *Moringa Oleifera* seed pods with a thresher, which consumes about 60 kWh of electricity to produce 3030 kg of oilseeds. About 72 kWh of electricity is required to produce 1000 litres of *Moringa Oleifera* oil and 7.2 kWh to produce 1000 litres of biodiesel. The library for Western Australian electricity generation mix was used to calculate the GHG emission from the electricity generation, required to produce 1000 litres of biodiesel (RMIT, 2005).

Step 2: The Australian impact assessment method was used to assess eight impact categories, including global warming, photochemical oxidation, eutrophication, carcinogens, land use, water use, solid waste, fossil fuels and minerals. Firstly, Simapro 7 (2007) software calculated the relevant emissions resulting from the production of biodiesel, once the inputs and outputs were linked to the relevant libraries. The program then sorted emissions for different impact categories from the selected libraries, and then converted them to equivalents for the corresponding impact category.

In addition, the Simapro 7 (2007) LCA software determines the relative value for each greenhouse impact to be assessed for Australian conditions. The “damage assessment network” chart provided in Annexes III and IV shows the ‘environmental damage’ generated by each stage of production of biodiesel from *Moringa Oleifera* oil seeds.

Limitations to this analysis: A number of limitations to this analysis must be considered in reviewing the results.

1. The analysis assumes that there are no run-off water management issues associated with the drip irrigation systems utilised.
2. The analysis assumes that there are no environmental impacts associated with the water utilised in the irrigated production system.
3. The analysis notes that a number of chemical and pesticide inputs have been replaced with surrogate input values given the lack of LCI data available on these inputs (eg: “Basta” herbicide was replaced with the “Glyphosate” LCI and “Rogor” was replaced with the LCI for generic pesticides).

RESULTS AND DISCUSSIONS

Firstly, this section will present results on eight environmental impacts, resulting from the production of 1,000 litres of biodiesel, produced from *Moringa Oleifera* oilseeds, grown under irrigated and dryland conditions. Secondly, the global warming impacts associated with the production of biodiesel will be discussed. Thirdly, global warming performance of one tonne of *Moringa Oleifera* oilseeds will be compared with that for the production one tonne wheat in WA.

All environmental impacts: The comparative environmental performance of biodiesel production, produced from *Moringa Oleifera* oilseeds, grown under irrigated and dryland conditions, has been evaluated. Table 2 shows nine environmental impact categories, including global warming, photochemical oxidation, eutrophication, carcinogens, land use, water use, solid waste, fossil fuels and minerals, which permit comparison of the environmental performance of biodiesel production from *Moringa Oleifera* oilseeds, grown under irrigated and dryland conditions. As can be seen in Table 2, out of nine environmental impact categories, global warming and fossil fuel usage and associated impacts are the predominant environmental impacts with the production of biodiesel from *Moringa Oleifera* oilseeds grown under dryland and irrigated conditions. Photochemical oxidation, eutrophication, water use, and solid waste appear to have insignificant impacts under both growing conditions. Fossil fuel usage (largely attributed to farm machinery) due to biodiesel production from *Moringa Oleifera* oilseeds, with dryland production (929 MJ[1]), is 14% more for the same level of production than that under irrigated production. Global warming impact has been discussed in more detail below.

Table 2: Environmental impacts of biodiesel production, from *Moringa Oleifera* oilseeds, grown under irrigated and dryland conditions.

		Irrigated land				Dryland			
Impact category	Unit	Post-farm	On-farm	Pre-farm	Total	Post-farm	On-farm	Pre-farm	Total
Global Warming	kg CO_2	199.0	466.0	167.0	832.0	199.0	457.0	286.0	942.0
Photochemical oxidation	kg C_2H_2	0.0	0.2	0.1	0.3	0.0	0.2	0.2	0.4
Eutrophication	kg PO_4	0.1	0.6	0.1	0.8	0.1	0.6	0.3	0.9
Carcinogens	DALY[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land use	Ha a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Use	KL H_2O	0.2	6.1	2.0	8.3	0.2	0.3	2.8	3.3
Solid waste	kg	2.3	1.4	2.1	5.8	2.3	0.4	3.3	5.9
Fossil fuels	MJ surplus	117.0	481.0	199.0	797.0	118.0	485.0	326.0	929.0
Minerals	MJ Surplus	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.2

Version: 30 May 2008

[1] MJ =Mega Joule
[2] Disability adjusted life years

Version: 30 May 2008

Global warming impacts: Firstly, global warming impacts due to emissions for greenhouse gases from the production of 1000 litres of biodiesel will be discussed. Secondly, results of the net global warming impacts, that includes CO_2 sequestration by plants will be discussed.

The equivalent of 832 kg of CO_2 was produced with the production of 1000 litres of biodiesel, produced from oleifera seeds, grown on irrigated land. Although additional emissions are created for growing Moringa Oleifera plants under irrigated conditions for the irrigation purposes, the equivalent emissions of CO_2 due to the production of the same amount of biodiesel from the dryland grown *Moringa Oleifera* oilseeds is 9% (i.e.942 kg CO_2 equ-) higher than that produced under irrigated conditions. This is because the application of inputs, including fertilizer, herbicide, pesticide, gypsum (and their transportation to paddock), for the dryland *Moringa oleifera* oil seed production is twice as high as that which is required by irrigated production.

As can be seen in Table 2, the on-farm stage of the biodiesel production accounted for a high proportion of the emissions for both irrigated (56%) and dryland conditions (49%). This is because of the use of farm machinery during on-farm operations (including rip and mound, pruning, and harvesting etc). In the case of oilseeds grown under irrigated conditions, pre-farm, on-farm and post-farm stages accounted for 167 kg of CO_2–equivalents (20%), 466 kg of CO_2–equivalents (56%) and 199 kg of CO_2–equivalents (24%), respectively. By comparison, a total of 286 kg of CO_2–equivalents (30 %), 458 kg of CO_2–equivalents (49%) and 199 kg of CO_2–equivalents (21%) were emitted during pre-farm, on-farm and post-farm stages of biodiesel production from the dryland *Moringa Oleifera* plants.

Table 3 shows CO_2 equivalent of GHGs for different greenhouse gases (ie. CO_2, CH_4 and N_2O). As can be seen in Table 3, CO_2 contributed 816 kg of CO_2 equivalent (98 % of total), N_2O contributed 8.8 kg CO_2-equivalents (1.1%) and CH_4 contributed 6.7 kg of CO_2-equivalents (0.9%) in the production of 1000 litres of biodiesel, produced from *Moringa Oleifera* seeds, grown under irrigated conditions. In the case of biodiesel production from the dryland production, CO_2 contributed 923 kg (98 % of total), N_2O contributed 11.3 kg CO_2-equivalents (1.2 %) and CH_4 contributed 8.3 kg of CO_2-equivalents (0.8%). Overall CO_2 is the dominant GHG emission and is largely a result of significant on-farm machinery usage. Whilst typically N_2O emissions from N fertilisers are high in agricultural applications (where NPK contains 12% nitrogen, against 46% for urea) the local value of N_2O emission factors was used, which is about 50 times less than the IPCC value (Barton *et al.*, 2008) resulting in a N_2O emission value which is relatively low.

Table 3: Different types of GHGs emitted (kg CO_2 equ-) from the three stages of biodiesel production, from oilseeds, grown under irrigated and dryland conditions.

Greenhouse gases	Irrigated land				Dryland			
	Post-farm	On-farm	Pre-farm	Total	Post-farm	On-farm	Pre-farm	Total
CO_2	198.0	457.0	161.0	816.0	199.0	447.0	277.0	923.0
N_2O	0.9	2.2	5.7	8.8	0.9	2.1	8.3	11.3
CH_4	0.3	6.1	0.3	6.7	0.3	7.5	0.5	8.3
				831.5				941.6

Table 4 shows the values of greenhouse gas emissions in terms of inputs and outputs (CO_2 equivalents) and sequestration of CO_2 by *Moringa Oleifera* plants with the production of 1,000 litres of biodiesel from *Moringa Oleifera* oilseeds, grown under irrigated conditions.

As can be seen in Table 4, the farm machinery operation accounted for a large proportion (386.1 kg of CO_2 equivalent or 46%) of the GHG emissions produced from biodiesel production from *Moringa Oleifera* oilseeds, grown under irrigated conditions. Other significant sources of GHG emissions included: CO_2 emission from the oil seed to biodiesel production (24%), which includes dehusking of *Moringa* pods and the conversion of oilseeds to biodiesel, and electricity generation required for the irrigation system (9%). The production of inputs, including farm machinery, fertiliser, gypsum, herbicide, and pesticide, altogether accounted for only 17% of the total GHG emissions. By comparison, farm machinery operation (47.3%), and oil to biodiesel production (21.1%) accounted for significant GHG emissions under dryland conditions.

As can be seen in Table 4, the net GHG emissions is – -14,168 kg of CO_2 equivalent, which is obtained by deducting the emissions from all inputs and outputs (i.e. 832 kg of CO_2 equivalent) from the amount of CO_2 sequestered by the plants (-15,000 kg of CO_2 equivalent/year). For biodiesel production from dryland production, the net GHG emissions would be – 14,085 kg of CO_2 equivalent (see Table 4). The '*cradle to grave*' approach that includes the emissions due to combustion of biodiesel could result in higher emissions than the emissions sequestered by plants.

Table 4 GHG emissions (CO_2 equivalents) in terms of inputs and outputs and GHG sequestration by plants for biodiesel production from irrigated land and dryland plants.

Emission sources	Irrigated land		Dryland	
	kg CO_2 equ-	Per cent	kg CO_2 equ-	Per cent
Emission from paddock	9.82	1.2%	4.32	0.5%
Machinery operation	386.1	46.4%	445.42	47.3%
Fertilizer production	38.7	4.7%	77.4	8.2%
Pesticide production	17.2	2.1%	43.5	4.6%
Herbicide production	11.6	1.4%	23.2	2.5%
Gypsum production	6.08	0.7%	12.2	1.3%
Farm machinery production	19.2	2.3%	19.2	2.0%
Transportation inputs	40.4	4.9%	80.8	8.6%
Oil seed to biodiesel production	199	23.9%	199	21.1%
Irrigation operation	74.6	9.0%	7.96	0.8%
Irrigation pipe production	29.3	3.5%	29.3	3.1%
Gross emissions	**832**	**100%**	**942**	**100%**
CO2 sequestration	-15,000	-	-15,000	-
Net emissions	**-14,168**	**-**	**-14085**	**-**

Comparison of LCAs of *Moringa Oleifera* oilseeds and wheat production: Since post-farm stage of the 1,000 litre of biodiesel production from *Moringa Oleifera* oilseeds is different from the post-farm stage of one of wheat transported to port, only pre-farm and on-farm stages of these two product life cycles have been considered for the comparison purposes. In addition, the farm management practices are same for *Moringa Oleifera* oilseeds and wheat production, because almost same type of inputs, including N fertiliser, pesticide, herbicides and lime/gypsum, are used for *Moringa Oleifera* oilseeds and wheat production.

Figure 3 compares the pre-farm and on-farm stages of one tonnes[3] of *Moringa Oleifera* oilseed production with the same stages of one tonne of wheat production in WA by Biswas *et al*. (2008). As can be seen in Figure 3, global warming impacts of on-farm stage of both wheat production and biodiesel production from the *Moringa Oleifera* plants, grown under both irrigated and dry conditions, are the same. However, the emissions from the pre-farm stage of *Moringa Oleifera* oilseed production, under both irrigated and dryland conditions, are about 1.5 to 2 times lower than the emissions from the same stage of the wheat production. This is because wheat production requires five times more N fertilizer than that for Moringa Oleifera oilseeds, while the production of which causes a significant portion (35%) of the total emission during the life cycle of one tonne of wheat transported to the port (Biswas *et al*. 2008).

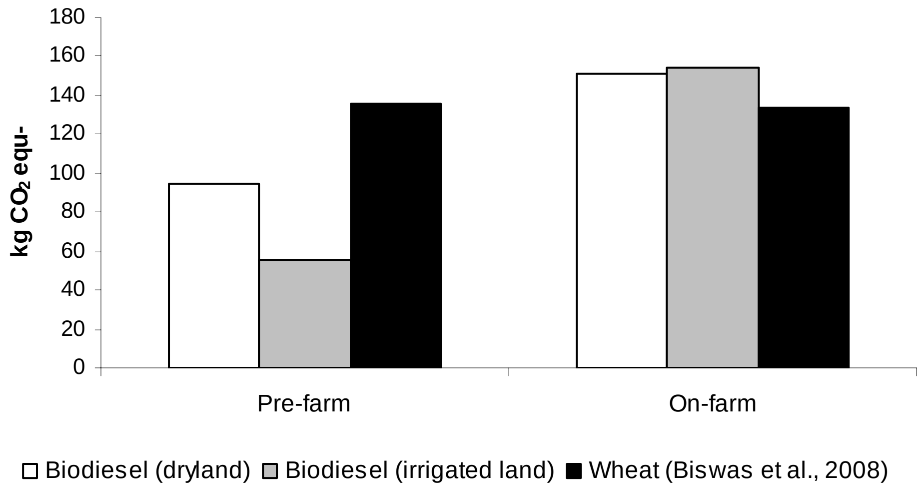

Figure 3: LCA of biodiesel and wheat (Biswas *et al.* 2008)

Version: 30 May 2008

[3] Emissions due to production of 3,030 kg of *Moringa Oleifera* oilseeds has converted into the emissions from the production of 1,000 kg or 1 tonne of *Moringa Oleifera* oilseeds.

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CONCLUSIONS

Life cycle assessment has been found to be a useful tool for determining the environmental impacts from the production of 1,000 litres of biodiesel, from *Moringa Oleifera* seeds (using different growing methods) and for identifying which production stages are mainly responsible for these emissions. Global warming potential from CO_2 emissions and fossil fuel usage and its associated resource scarcity are the predominant environmental impacts of biodiesel production.

The GHG emissions during the production of 1,000 litres of biodiesel was equivalent to 832 kg of CO_2, when the biodiesel was produced from *Moringa Oleifera* oilseeds, grown under irrigated conditions. The GHG emissions due to production of biodiesel from the *Moringa Oleifera* oilseeds, grown under dryland conditions, was found to be 13% (942 kg CO_2–equivalents) higher than those grown under irrigated conditions. The on-farm machinery operation accounted for a large proportion of the GHG emissions during the life cycle of biodiesel production, both under irrigated (46%) and dryland (47%) conditions.

When CO_2 sequestration by the *Moringa Oleifera* plants is considered, the net life cycle global warming impacts of 1000 litres of biodiesel production from the *Moringa Oleifera* seeds would be -14,168 kg of CO_2 equivalent and -14,085 kg of CO_2 equivalent, under irrigated and dryland conditions, respectively.

Fossil fuel usage (largely attributed to farm machinery) is another environmental impact of biodiesel production from *Moringa Oleifera* oilseeds, with dryland production utilising 14% more fossil fuel (929 MJ), for the same level of production than that under irrigated conditions.

Cleaner production strategies can be used to combat global warming impacts due to the production of *Moringa Oleifera* perennial species under dryland conditions. Precision agriculture (PA) could be introduced to reduce the global warming potential associated with dryland *Moringa Oleifera* production. Precision agriculture for example, can reduce the use of energy and chemicals by applying monitoring and mapping techniques to supply exact amounts of fertiliser, water or chemical control agents to crops, at exactly the right time and place. As heavy machinery consumes significant amounts of fuel and produces large amounts of GHG emissions, alternative fuel and renewable energy sources could be used in on-farm operations and transportation. Finally, preventative maintenance of farm machinery to ensure running efficiency and productivity could assist in reducing fuel consumption and therefore, further mitigating greenhouse gas emissions during on-farm operations.

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Annex I: Field data

General	Oil seed	Dryland conditions	3.03	tonne/Ha
		Irrigated conditions	6.06	tonne/Ha
	Seed oil	Dryland conditions	1,000	L/Ha
		Irrigated conditions	2,000	L/Ha

Farm operation	**Power**	**Operating hours**	**Fuel Consumption**	
			Amount	**Unit**
Seeding (by hand)	0	0		
rip & mound yr1	60kw	1.2h	15	l/hour
pruning	60kw	2h	15	l/hour
get seed out of pod/dehusking	15kw	4h	60	kWh
Harvest	120kw	3h	30	l/hour
pumping water - Dryland (once in 15 years, 80 days per year)	0.75kW/ha	2h		
Irrigated (Fully irrigated, 15 years, 100day. Year)	0.75 kW/ha	2h		

Chemical application

Type of chemicals	**Type**	**Amount**	**Application rate**
Herbicide	Basta	3l/ha	
Insecticide	Rogor	3l/ha	
Fertilizer yr1; oilcake yr2 - 15	NPK	150kg/ha	Once in every 2 years
Gypsum yr 1	-	1tonne	Once in a lifetime (15 years)
Irrigation (type, ML)	drip	6,000m³	

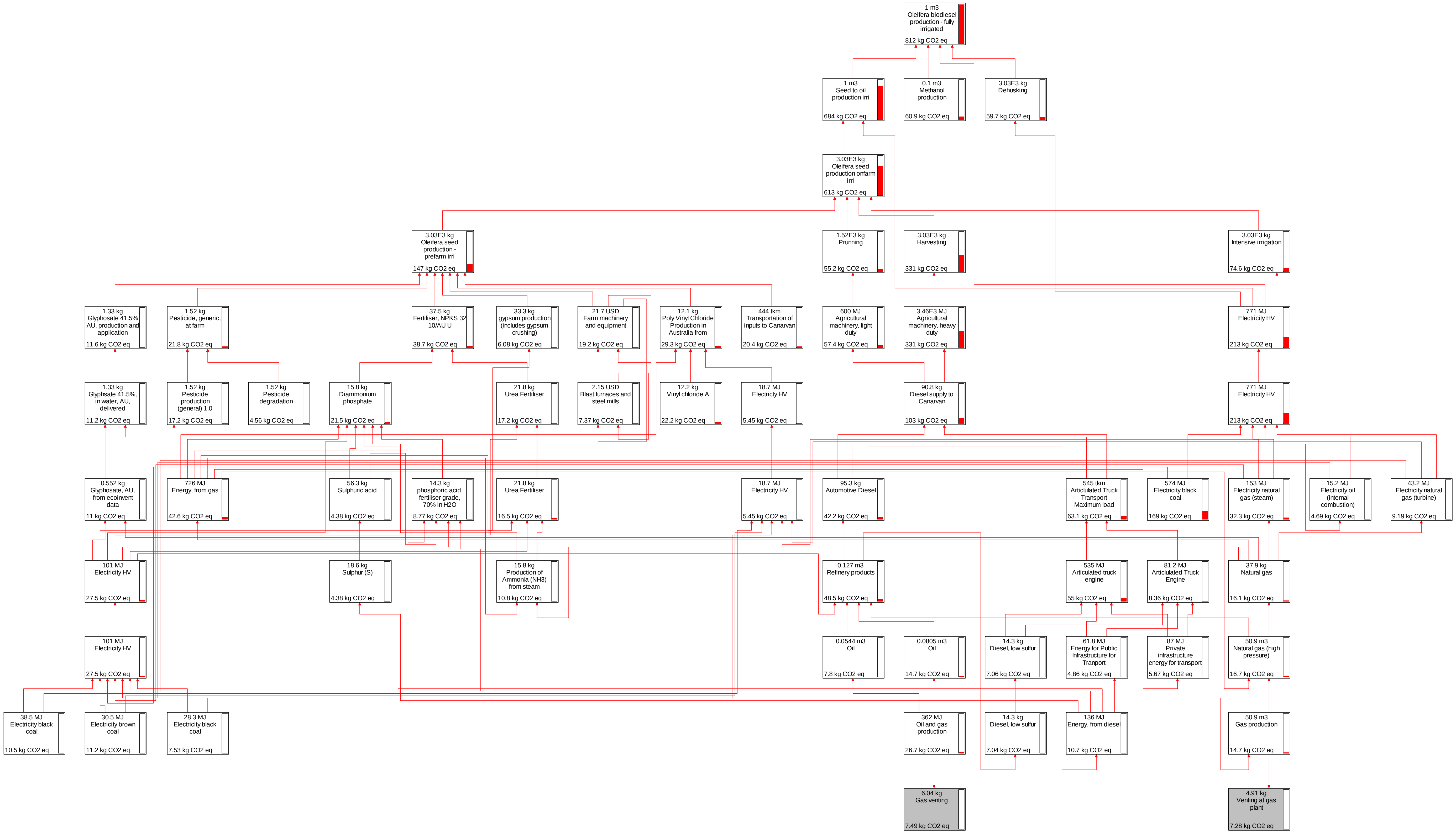
Annex II: Cost and operation of farm machinery production for *Moringa Oleifera* production

	Operating hours[a]	Life time (hours)[b]	Cost[a,c]			
			(AUD, 2006 price)	(AUD 1998 price)	(A$/Ha, 1998 price)	(US$/Ha, 1998 price)
Rip & mound	1.2	8640	45,000	34852	5	3.1
Pruning	2	8640	25000	19362	4	2.9
Thrasher	4	8640	20,000	15490	7	4.6
Harvester	3	8640	60,000	46470	16	10.3
Irrigation pump	2	8640	300	232	0.00	0.002

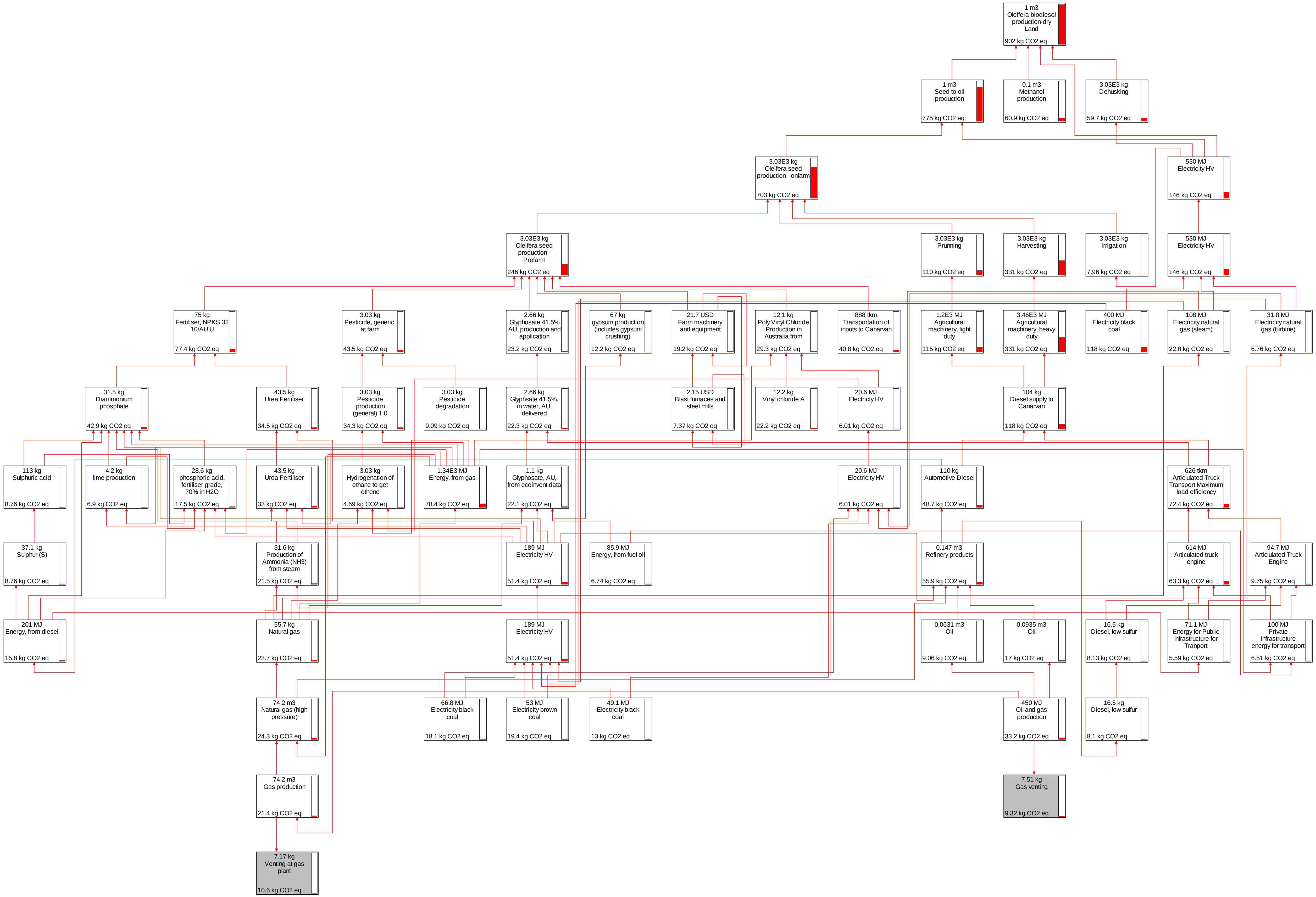
[a] H. Brockman, Department of Agriculture, Albany, Western Australia.

[b] Based on Biswas *et al.* (2008)

[c] Phil Carter, Manager, Experimental Workshop, Department of Agriculture, South Perth, Western Australia.



Annex III: Damage assessment network for 1000L biodiesel production from oilseeds, grown under irrigated conditions



Annex IV: Damage assessment network for 1000L biodiesel production from oilseeds, grown under dryland conditions