Life Cycle Water Footprint Analysis for the Production of Bioslurry Fuels from Fast Pyrolysis of Mallee Biomass in Western Australia

ENG470 Engineering Thesis Project

By

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Abstract

It is projected that, in 2029-2030, coal will continue as a dominant fuel and take up 64% of energy market of Australia, because it supplies cheap and secure electricity generation [1]. However, combustion of coal contributes to various emissions including CO_2, SO_2, particulate matter (PM) and other pollutants [1]. Therefore, renewable energy, especially biomass is believed to be a vital energy source for sustainable development in the foreseeable future [2]. For example, mallee eucalypts as a key second-generation bioenergy feedstock are widely planted in the wheatbelt region of the southwest of Western Australia (WA) (300-600 mm rainfall zone) [1, 3]. However, mallee, as a kind of lignocellulosic biomass, suffers from its low volumetric energy density (about 5 GJ/m^3), high moisture content (about 50%) and poor grindability, which causes the high transport cost [2]. This is unaccepted for a long-distance transport of biomass [2]. Pyrolysis as a chemical process converts biomass to a high energy product like bioslurry that can significantly reduce the transport cost [2]. However, some reports indicated the water consumption of producing bioenergy is larger than the traditional fuel such as coal [4]. Therefore, it is necessary to trace the life cycle Water Footprint (WF) of certain bioenergy production processes from the cradle to the grave. This thesis evaluates the WF of a biomass supply chain and a bioslurry supply chain in the transport and conversion stages in WA. 30 shires having abundant mallee stems resources are selected as the mallee supplying area for the Muja power station C and D units (874 MW). Also, an ideal harvesting and transport model is designed to determine the location of every farm gate of every selected shire for measuring the distances from 286 farm gates to the Muja power station, pyrolysis plant A, and pyrolysis plant B. In addition, Pyrolysis plant A (157.3 dry tonnes/day) is sited on Dalwallinu and pyrolysis plant B (203 dry tonnes/day) is sited on Wickepin, converting biomass to bioslurry, and then transport the bioslurry to the Muja power station. The result shows the annual water consumption of the bioslurry supply chain is approximately 22 times that of the biomass supply chain. However, the cost, energy, and carbon footprint of bioslurry supply chain have been proved by previous reports from Curtin University, having an advantage over the biomass supply chain in WA [2, 5].

Keywords: mallee biomass, bioslurry, fast pyrolysis, Muja power station, and water footprint.

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Chapter 1 Introduction

1.1 Background and Motive

Renewable energy has become increasingly important for the energy market to address energy supply and security [6]. Besides, compared to coal, biofuel is beneficial to reduce CO_2, SO_2, and PM emissions [1]. Therefore, biomass as the most important renewable energy sources will be developed in the future [2]. For example, mallee eucalypts as a key second-generation bioenergy feedstock are widely planted in the wheatbelt region of the southwest of WA (300-600 mm rainfall zone) [1, 3]. By employing an “alley farming” configuration, mallee eucalypts are planted into existing wheat belts and only occupy <10% of agricultural land, minimising competition with food production and having better water utilization, economic and environmental performance [2]. In the beginning, mallee is used to be a byproduct of controlling land degradation, such as dryland salinity [2]. Since 2000, with the increase in the mallee biomass production, mallee biomass is considered as a biofuel to sustain industries for energy development. Moreover, co-processing biomass and coal has been tested in the Muja power station [2]. However, mallee, as a kind of lignocellulosic biomass, suffers from its low volumetric energy density (about 5 GJ/m^3), high moisture content (about 50%) and poor grindability [2]. These problems will cause the high transport cost when delivering raw mallee biomass to a processing plant for a long distance [2]. One of the possible paths is that via fast pyrolysis, as a moderate temperature technology (500°C), converting biomass into a higher value product, such as bioslurry that is produced by mixing bio-oil with biochar [7]. It has been proved that bioslurry has an obvious advantage over raw mallee biomass in the cost and carbon footprint of transport [2, 5]. Furthermore, because of raw biomass’s poor grindability and mismatch in fuel properties during co-processing coal, only up to 5% biomass (on an energy basis) could be directly fired with coal in existing coal-fired plants [2]. However, the properties of bioslurry are close to coal, and up to 15% (on an energy basis) of coal could be substituted by bioslurry [2]. Therefore, in the foreseeable future, raw mallee biomass will be one of the most important renewable energy sources in WA.

Fresh water, which is a precious resource and critical for humans, is always consumed and polluted through agricultural, industrial and domestic uses [8]. Compared to traditional fuel like coal, gas, and oil, the Water Footprint (WF) of producing bioenergy is larger [4]. Therefore, it is necessary to trace the life cycle WF of bioenergy production processes from the cradle to the grave. Moreover, ISO 14046 standard, as an international life cycle WF assessment method, is widely used in academic studies [9]. This report is based on this standard.

1.2 Scope, Objective, and Methodology Overview

The present study aims to assess and compare the WF of the biomass supply chain and the bioslurry supply chain from every farm gate of every selected shire to the Muja power station in the transport stage. The scope of scenario (a) is mallee chips are delivered from a farm gate to the Muja power station. The scope of scenario (b) is that mallee chips are delivered from a farm gate to pyrolysis plant A or B first. Then, mallee chips are converted to bioslurry in pyrolysis plan A or B. Final, bioslurry is delivered from pyrolysis plant A or B to the Muja power station.

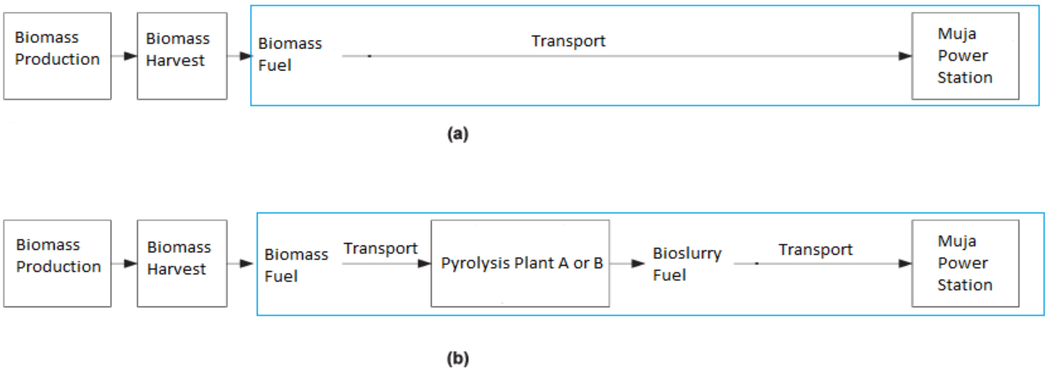

Figure 1: Two scenarios studied in this thesis

The detailed objectives and methodologies of this study are to:

1. To determine which shires should be selected to be the mallee supplying areas in this report. The major objective is the oil mallee stems of every shire in WA.

2. To design an ideal harvesting and transport model to determine the detail location of every farm gate of every selected shire for measuring the distance from farm gate to the Muja power station. Based on the harvester, tractor, truck information, and assuming the coverage area of a farm gate, and the land area of every selected shire, the detailed location of every farm gate of every selected shire can be determined.

3. To calculate the water consumption of the biomass supply chain on the basis of the oil mallee stems in every selected shire, the detailed location of every farm gate, the truck fuel consumption per 100 km, and the water use factor for diesel.

4. To design the bioslurry production process and determine the water consumption of the five major processing areas: (1) feedstock pre-treatment, (2) pyrolysis and quench, (3) heat recovery, (4) product recovery, storage and recycle, (5) power generation and use. This is based on some previous studies about a bio-oil pyrolysis design and the water consumption data in the five areas is from a previous Canadian research report.

5. To calculate the water consumption of the bioslurry supply chain on the basis of pyrolysis A and B design information, the truck fuel consumption per 100 km, and the water use factor for diesel.

6. To compare the water consumption of the biomass supply chain and the bioslurry supply chain based on the analysis and calculation in Chapter 3 and 4.

1.3 Thesis Outline

There are 6 chapters in this thesis and each chapter is listed as follows.

- Chapter 1 introduces the background, scope, objective and methodologies.

- Chapter 2 reviews the up to data literature on the carbon, energy, cost footprint of the biomass supply chain and the bioslurry supply chain in WA and identifies the existing research gaps in the field.

- Chapter 3 designs an ideal harvesting and transport model to calculate the water consumption of the biomass supply chain in the transport stage. Also, the performance of biomass as feedstock for the Muja power station is calculated and assessed

- Chapter 4 designs a bioslurry pyrolysis plant to calculated the water consumption of the bioslurry supply chain in the transport and conversion stage.

- Chapter 5 compares the water consumption of the biomass supply chain and the bioslurry chain.

- Chapter 6 concludes the thesis and recommends future work

Chapter 2 Literature Review

2.1 Introduction

It is projected that, in 2029-2030, coal will continue as a dominant fuel and take up 64% of energy market of Australia because it supplies cheap and secure electricity generation [1]. In WA, Collie coal is being used for electricity generation in coal-fired power stations such as the Muja power station (1094 MW), playing a significant role in supplying cheap energy to the development of WA's economy [1]. However, combustion of coal will contribute to various emissions including CO_2, SO_2, PM, and other pollutants, which are widely considered to be responsible for global warming, acid rain and respiratory disease [1]. Therefore, renewable energy, especially biomass is believed to be a vital energy source for sustainable development in the foreseeable future [2]. For instance, International Energy Agency (IEA) predicts that biomass energy will increase to 11.7% of the total global energy supply in 2030 [1].

In WA, at present, the markets and relevant mature convention technologies have been established for the first-generation biofuels which are directly derived from food crops like starch, sugar and vegetable oil [1]. However, first-generation biofuels are considered to be low energy efficiency, high carbon footprint, and decrease partly food production [1]. Hence, second-generation bioenergy is regarded as the sustainable development energy. In the wheatbelt region of the southwest of WA (300-600mm rainfall zone), mallee biomass as a key second-generation bioenergy feedstock is planted for managing dryland salinity [3]. Mallee is a type of short cycle woody crop which could be easily established, and has fast-growing and short period prior harvesting (3-5 years) [3]. In addition, by employing an "alley farming" configuration, mallee eucalypts are planted into existing wheat belts and only occupy <10% of agricultural land, minimising competition with food production and having better water utilization, economic and environmental performance [2].

Since 1988, according to the data provided by Oil Mallee Association of Australia (OMA), over 12,000 ha of mallee have been established in WA [10] (see Table 1). If the cultivation and utilization could be proved commercially viable, about 10 million tonnes of dry mallee biomass annually are supplied as a bioenergy feedstock for various power stations [11].

Table 1:Over 25 million and 12,000 ha mallee have been planted in WA [10]

Year Planted	No.Trees Planted	Hectares (using 2,000 stems per ha)
1988	20,000	10
1992	29,980	15
1993	22,175	11
1994	784,691	392
1995	1,992,628	996
1996	2,292,748	1,146
1997	909,083	455
1998	1,438,022	719
1999	2,552,778	1,276
2000	4,084,486	2,042
2001	2,217,364	1,109
2002	995,954	498
2003	2,550,119	1,275
2004	980,700	490
2005	775,080	388
2006	1,870,771	935
2007	2,036,530	1,018
Total	25,553,109	12,777

Since 2010, a series of reports about the life cycle footprints of biomass supply in WA in terms of dollar, energy, and carbon have been published by researchers at Curtin University [2, 5]. Part 1 of this series has assessed the economic feasibility of the biomass supply chain [2]. The base case of this report is that biomass is transported to a 300 MWe coal-based power station with 31% efficiency, with a distance of 100 km between the biomass collection area and the power station at a transport rate of \$A0.2 km^{-1} gt^{-1} [2]. In Table 2, the delivered cost of green mallee biomass is \$A9.44 GJ^{-1}, and the transport cost accounts for over 65% of the total cost, reaching \$A6.14 GJ^{-1} [2]. If the distance and transport rates data are modified to 200 km and \$A0.3 km^{-1} gt^{-1}, the delivered cost exceeds \$A20 GJ^{-1}, which is not economically feasible [2]

Table 2:The delivered costs of biomass and bioslurry for the base case [2]

	Biomass delivered cost		Bioslurry delivered cost	
Bioenergy cost	(\$A GJ^{-1})	%	(\$A GJ^{-1})	%
Biomass production	1.28	13.6	1.76	21.7
Biomass harvest	0.65	6.9	0.90	11.2
Biomass on-farm haulage	1.36	14.4	1.88	23.3
Biomass road transport	6.14	65.1	0.88	10.9
Bioslurry road transport			1.11	13.7
Plant capital and operating costs			1.56	19.2
Total	9.44	100.0	6.30	100.0

Part 2 of this series, which mainly focusses on the energy and carbon footprint assessment of the biomass supply chain, also arrived at the same conclusion [5]. The total biomass energy and carbon footprints in the base case are 43.6 MJ GJ^{-1} and 3.9 kg of CO_2-e GJ^{-1} respectively [5] (see Table 3). Also, for the greenhouse gas (GHG) emissions and energy input of biomass, more than 50% result from the biomass road transport [5]. In conclusion, in comparison to bioslurry, the economic, energy and carbon footprint assessment of biomass has certain disadvantages in the base case, and with the increase of distance and transport rates, these disadvantages become more and more obvious.

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Table 3: The energy and carbon footprint assessment of biomass and bioslurry [5]

	Energy Footprint						Carbon Footprint					
	Biomass			Bioslurry			Biomass			Bioslurry		
	MJ GJ^{-1}	MJ ha^{-1} $year^{-1}$	%	MJ GJ^{-1}	MJ ha^{-1} $year^{-1}$	%	kg of CO_2-e GJ^{-1}	kg of CO_2-e ha^{-1} $year^{-1}$	%	kg of CO_2-e GJ^{-1}	kg of CO_2-e ha^{-1} $year^{-1}$	%
Seed	0.2	42	0.5	0.2	42	0.7	0.02	4.2	0.6	0.03	4.2	0.8
Seedling	0.5	85	1.1	0.5	85	1.4	0.05	8.3	1.2	0.05	8.3	1.5
Crop establishment	0.4	64	0.8	0.4	64	1.4	0.03	5.4	0.8	0.03	5.4	1.0
Sapling and coppice management	6.8	1234	15.6	7.3	1234	20.2	0.7	128	18.3	0.8	128	23.5
Biomass harvest	5.4	978	12.4	5.8	978	16	0.4	74.9	10.7	0.4	74.9	13.8
Biomass on-farm haulage	7.7	1391	17.6	8.3	1391	22.8	0.6	107.3	15.3	0.6	107.3	19.7
Biomass road transport	22.7	4106	52.0	3.7	623	10.2	2.1	371.4	53.1	0.3	56.7	10.4
Pyrolysis plant construction				1.7	286	4.7				0.2	25.8	4.8
Pyrolysis plant operation				2.2	376	6.2				0.2	37.2	6.8
Bioslurry preparation				3.3	555	9.1				0.3	58.3	10.7
Bioslurry transport				2.8	467	7.7				0.2	37.7	6.9
Total	43.6	7901	100.0	36.2	6100	100.0	3.9	699.6	100.0	3.2	543.8	100.0

Mallee, as a kind of lignocellulosic biomass, suffers from its low energy density, high moisture content and poor grindability [2]. For example, in contrast with the typical black coal (28 GJ/m^3), chipped mallee (length of 10 cm, 45% moisture content) has a very low energy density of about 5 GJ/m^3, which leads to high transport costs [2]. Also, although large-scale power stations usually have milling systems, it is unsuitable to grind large biomass particles, which consumes a great deal of extra power [2]. In addition, because of its poor grindability, only up to 5% biomass could be directly fired with coal in existing coal-fired plants [2, 5]. Moreover, biomass mismatch with coal properties occurs during co-processing [2]. This is because, when biomass is burned with coal in existing coal-based power stations, it generates more flue gas than coal and affects the combustion stability, which causes a reduction in the residence time of fuel in the boiler and overall plant efficiency [2]. All in all, using biomass directly as an energy fuel poses various problems.

2.2 Bioslurry from Biomass Pyrolysis

2.2.1 Overview of the Bioslurry Production Process

With the development of chemical engineering, several approaches have been used to address the natural disadvantages of biomass as a direct fuel. Fast pyrolysis, as a moderate temperature technology (500 °C), converts biomass into bio-oil and biochar, the mixing of which produces bioslurry [8]. First, the heat rate of pyrolysis is affected by the feedstock size and moisture, so chipped biomass needs to be ground further to 2 mm-3mm diameter particles and dried by steam from the quench area to 7 wt% moisture before fast pyrolysis [8]. Second, these feedstocks are put into a fluidised bed undergoing fast pyrolysis at one standard atmospheric pressure, approximately 500 °C -550 °C and < 1 s residence time to produce 60 wt% bio-oil yield and by-product biochar [8]. Third, bio-oil vapors are condensed by water and air and recovered by an electrostatic precipitator [12]. On the other hand, biochar is separated from pyrolysis products by a cyclone cluster [12]. Finally, in the combustion area, some of the total biochar and pyrolysis gas is fired to supply enough electricity for the whole production process. In the mixing area, the rest of the biochar is ground and mixed with bio-oil to produce bioslurry [8]. In Figure 2 the bioslurry production process via fast pyrolysis is shown.

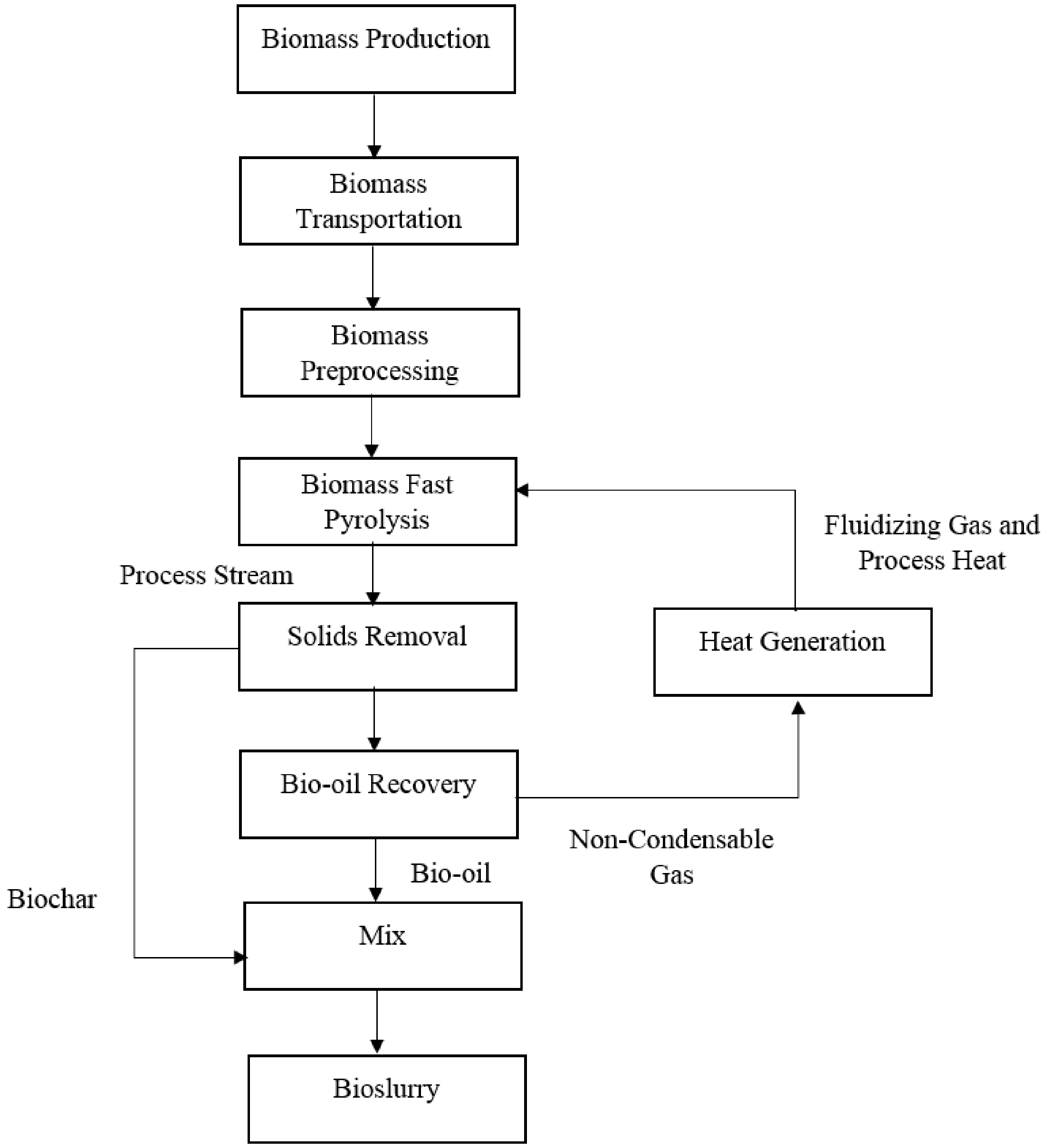

Figure 2: Life system boundary for the bioslurry production process via pyrolysis

2.2.2 Properties of Bioslurry

The application of bioslurry as a direct fuel overcomes two main disadvantages of biomass: low energy density and the co-combustion issue. Bioslurry has a higher volumetric energy density of up to 23.2 GJ/m^3 compared to that of raw biomass (5 GJ/m^3), which means that long-distance transport of bioslurry could be feasible [13]. Moreover, bioslurry could match coal properties well and ensure the combustion stability during co-processing [2]. Therefore, compared to biomass, bioslurry could substitute more coal (up to 20%) in a typical coal-fired power station, which significantly reduces CO_2 and other pollutant emissions [2, 5]. Furthermore, the co-fired technology could widely and rapidly be applied in existing coal-based plants. For example, in WA, Muja power station located on the Collie Coal Field, has been tested using relevant coal-fired boilers [2].

2.2.3 Economic, Energy, and Carbon Footprint Analysis of Bioslurry

In Table 2, the delivered cost of bioslurry is \$A6.30 GJ^{-1}, which has a superiority compared to the biomass (\$A9.44 GJ^{-1}) [2]. After pyrolysis, biomass is converted to bioslurry, and the total road transport cost of bioslurry (including biomass and bioslurry road transport) is \$A1.99 GJ^{-1}, which is much smaller than the transport cost of biomass (\$A6.14 GJ^{-1}) [2]. According to Yu report, the delivered costs of both bioslurry and biomass increase with transport rates and distance (Case 2 vs Case 1), but the value of bioslurry is much less sensitive than that of biomass [2].

In Table 3, the values of the energy and carbon footprint assessment of bioslurry are 36.2 MJ GJ^{-1} and 3.2 kg of CO_2-e GJ^{-1}, respectively. Similarly, these values are smaller than those of the biomass; this means lower energy input and GHG emissions [5]. Also, according to Yu report, the carbon footprints of both bioslurry and biomass decrease with distance, but the values of biomass are much more sensitive than those of bioslurry [5]. Besides, in the bioslurry supply chain, pyrolysis plant construction, pyrolysis plant operation and a series of requisite processes should be considered; according to Table 3, it also consumes extra energy and emits GHG emissions of 10 MJ GJ^{-1} and 0.9 kg of CO_2-e GJ^{-1} [5]. Therefore, according to the reports from Part 1 and Part 2 [2], whether the bioslurry supply chain is feasible is mainly determined by the trade-off between the decrease in cost, energy input and GHG emissions in biomass transport and the increase in those aspects in pyrolysis plant construction, pyrolysis plant operations and relevant processes [5].

2.3 Importance of Life Cycle Water Footprint Analysis in Assessing the Sustainability of Bioslurry Fuels

Although renewable energy, particularly biomass, is considered to be a promising energy fuel to address energy supply and to slow global warming, the environmental viability, especially water supply and quality, has also raised concerns [6]. Fresh water, which is a precious resource and critical for humans, is always consumed and polluted through agricultural, industrial and domestic uses [8]. Also, some evidence implies that the WF of bioenergy is larger than that of fossil energy [6]. Besides, when a large-scale biofuel production is in a small area with a water crisis, it causes high pressure on the water supply [6]. Hence, it is necessary to trace the life cycle WF of certain bioenergy production processes from the cradle to the grave. The volume of water used for producing a product is defined as the WF, and it consists of three components: green, blue and grey WF [6]. Furthermore, WF analysis has been developed as a tool to calculate and assess the water sustainability in certain cases [6]. In brief, when a local government like Perth combines techno-economic analysis (TEA), environmental life cycle assessment (LCA) and WF analysis, these contribute to the creation of sustainable public policy [6].

2.4 Life Cycle Water Footprint Assessment

2.4.1 Background and Methodology

WF analysis is not only used to calculate the volume of water consumed; it is also divided into three different water types [6]. Green water refers to rainwater stored in the soil and the top of plants in the growth process [6]. Generally, the value is calculated by empirical formulas or by a model developed depending upon some relevant input data like crop and soil [6]. Grey water is calculated as an index of water pollution according to the local water quality standards [6]. It usually consists of the various volumes of wastewater from chemical fertiliser plants and pyrolysis plants [6]. Blue water is mainly related to the amount of surface water or groundwater and is always used in pyrolysis operations and producing diesel to transport feedstock to a power station [6]. Also, ISO 14046 standard, as an international life cycle WF assessment method, is widely used in academic studies [9]. First, the goal and scope of this study had to be unambiguously stated, and all of the relevant data were collected to develop a WF inventory analysis [9]. Then, according to the different simulation models and software, related data were input and calculated [9]. Finally, the total volume of green, blue and grey water was counted as a WF report for assessing the sustainability [9].

2.4.2 Previous Studies Review

Several previous studies have been published to assess the whole biomass/bioslurry supply chain life cycle WF. Rui studied a WF analysis for rapeseed used to produce jet fuel in North Dakota [6]. In this study, green, blue and grey WF are analysed and calculated in cultivation, extraction, conversion, and transportation processes [6]. Also, Tingting assessed the WFs of biofuels from different types of biomass, such as sweet sorghum, cassava, and Jatropha curcas L, in different locations, using various biofuel pathways to examine the differences amongst the results [14]. In a blue WF assessment of fast pyrolysis, in Canada, Alain showed the volume of water for bio-oil/bio-oil vapor cooling, ash quenching, recycle gas compression and feedstock grind, and biomass was divided into three parts: whole tree, forest residue and agricultural residue [8].

2.4.3 A Calculation Analysis of Life Cycle Water Footprint

Rui examined the life cycle WF of jet fuel production from rapeseed in North Dakota [6]. First, the EPIC model is a biophysical simulation model that has been widely used around the world, and it could not only simulate crop growth and land processes but also assess effects on water quality and land-use change for assisting the blue WF analysis [6]. In this study, the relevant data, including soil, climates, rapeseed yield and characteristics and management decisions in a rapeseed-wheat region in North Dakota, were simulated and analysed by the EPIC model [6]. Then, according to the ISO 14046 standard, the calculated results (evapotranspiration data) were combined with moisture content to get the green WF [6]. It was noted that no water is irrigated in wheat and rapeseed agricultural systems, and rapeseed was assumed to represent 9% of moisture content [6]. Second, in a certain watershed, grey WF is usually used to reflect the water quality based on the local water standard. Gray WF could be calculated by the formula [6]:

$$WF_{proc,grey} = \frac{L}{C_{max} - C_{nat}} \left[\frac{volume}{time}\right]$$

"In this formula, C_{max} is maximum acceptable concentration (mass/volume), C_{nat} is natural background concentration (mass/volume) and L is pollutant load (mass/time)" [6]. Also, this study focused on the nitrate and phosphorus runoff [6]. Because, in US, a strict and high standard is enforced for wastewater treatment, only the grey WF of cultivation was considered in this study [6]. Besides, the method 3 of the grey WF guideline was used to calculate the leaching-runoff fraction (α). The formula was given by [6]:

$$\alpha = \alpha_{max} + [\frac{\sum_i S_i W_i}{\sum_i W_i}](\alpha_{max} - \alpha_{min})$$

"In this formula, the weight of factors W_i, $\alpha_{max}$is maximum leaching-runoff fraction and α_{min} is minimum leaching-runoff fraction" [6]. In North Dakota, the 0.09 and 0.015 α for nutrients and phosphorous respectively were determined [6]. Finally, in this study, the blue water consumption (including direct and indirect blue water) was counted in cultivation, oil extraction and conversion to jet fuel along with transportation aspects [6]. During the rapeseed cultivation step, due to the fuel and chemical consumption, a small amount of indirect blue water was used [6]. These data were converted based on the GREET model and presented on an energy basis of 1 m^3/GJ [6]. In the oil extraction and conversion aspects, when oil and hydrogen gas produce the relevant chemical reactions in a hydrotreater with catalysts, both direct and indirect blue water were used [6]. Indirect blue water used included the amount of hexane solvent used and power consumption, which were provided by the GREET model [6]. Moreover, the industry partner UOP offered material and energy inputs during the HEFA jet conversion process [6]. For direct blue water, the volume was assumed to be 0.012 m^3 per kg of oil for cooling boilers, towers and evaporators during the whole reaction process [6]. During the transportation step, after calculating plant capital costs, assuming transportation costs and confirming the plant capacity, the AFTOF model was used to optimise the transport scenario [6]. Rapeseed was transported from local storage to the biorefinery plant by trucks, rail cars, and barges; then, a HEFA jet fuel was transported to Minneapolis airport by the traffic pathway above adding pipeline [6]. The volume of indirect blue water was calculated based on the diesel fuels consumed. A total modeling scheme and inputs for assessing WF of rapeseed have been showed [6].

2.5 Summary and Research Gaps

Biomass, as a kind of future feedstock for electricity generation, has more advantages in the sustainability and climate change mitigation aspects than fossil fuels, such as coal, natural gas and oil [1]. However, this does not mean that firing biomass directly with coal is a feasible and economic method because of its low energy density, high-moisture content and poor grindability [2]. At present, these problems could be solved via fast pyrolysis; biomass could be converted to bio-oil and biochar to produce bioslurry to increase the volumetric energy density [2, 5]. Also, the economic, energy and carbon footprint assessments have been published by a series reports from Curtin University [2, 5]. These reports have shown that bioslurry has more advantages than biomass in cases involving long distances and high transport rates [2, 5]. On the other hand, because fresh water is an unsustainable resource in certain areas, it is necessary to look at an overall life cycle WF. Also, WF has been developed to be an effective tool to make a trade-off between feedstock yields and environmental impacts [6]. In addition, some previous studies have been conducted to assess the WF of the biofuel supply chain. For example, in North Dakota, Rui looked into the WF of rapeseed to generate jet fuel [6]. Meanwhile, in Canada, Alain investigated the WF of renewable diesel production from lignocellulosic biomass [8]. Unfortunately, however, in WA almost no data are available on the WF of mallee biomass/bioslurry. In particular, no data about the blue and grey WF of bioslurry production in a typical pyrolysis plant exist. However, such data are vital for assessing the sustainability of biomass/bioslurry.

Chapter 3 Water Footprint of Biomass Supply Chain for Muja Station

3.1 Mallee Biomass and the Selected Shire Information

According to statistical data from the Australian Renewable Energy Agency (AREA), oil mallee stems data of 66 shires in WA has been got and given in Appendix A, and on the basis of this data, a map of mallee density is shown in Figure 3 [16]. The dark green areas indicate that these shires have more oil mallee stems than other shires (those that are light green and yellow in colour).

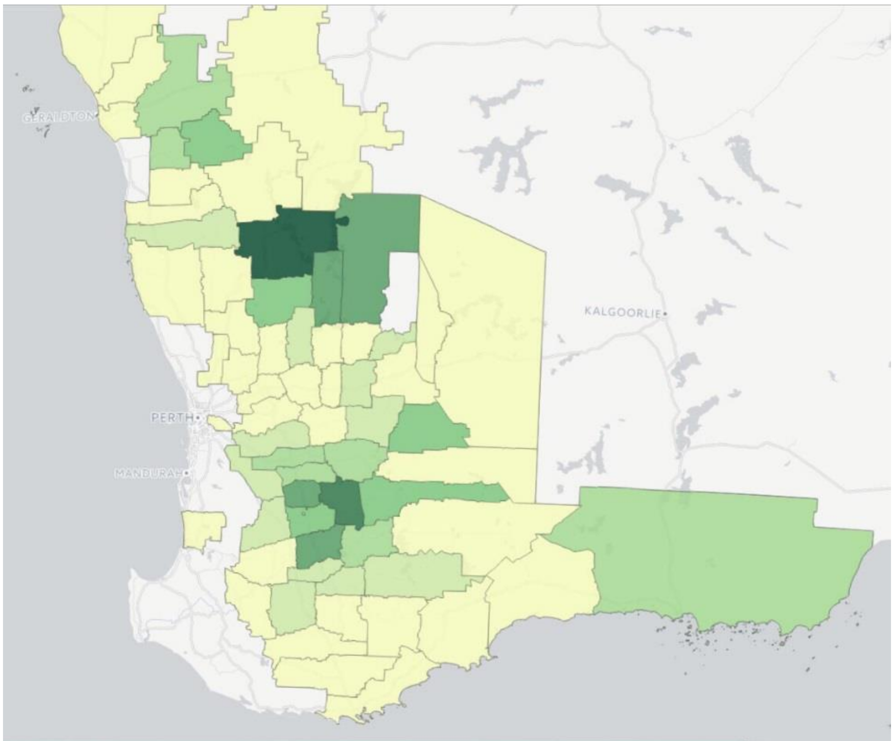

Figure 3: A map of mallee density in WA

Also, in mallee harvesting and transport systems, the mallee density and local transport efficiency in a region will directly affect the profitability and sustainability of the whole mallee supply market [17]. That means the area what is close to a processing plant and has abundant mallee stems will have a distinct advantage in economic performance and should be considered first as the mallee supplying area. Therefore, in the following analysis, only green regions are selected as the mallee supplying areas in this report. The selected shire name, the number of mallee stems in every selected shire, and the planting years are presented in Table 4.

Table 4: 30 selected shires information

Number	Selected shire name	Number of stems	Planting years
1	Mullewa	778,275	1998
2	Mingenew	632,411	1996
3	Morawa	1,077,397	1996
4	Coorow	206,702	2001
5	Dalwallinu	3,995,246	1999
6	Mount Marshall	1,615,997	2001
7	Wongan-Ballidu	1,064,791	2001
8	Koorda	1,439,652	2001
9	Dowerin	460,143	2002
10	Nungarin	264,852	2003
11	Kellerberrin	396,000	2000
12	Bruce Rock	384,590	1999
13	Narembeen	1,158,862	1997
14	Beverley	236,895	2001
15	Wandering	275,119	2003
16	Brookton	758,192	2004
17	Corrigin	598,086	2005
18	Pingelly	667,409	2002
19	Cuballing	1,378,502	2000
20	Wickepin	2,125,780	2000
21	Kulin	1,178,060	2004
22	Williams	310,322	2004
23	Narrogin	1,183,105	2003
24	Wagin	1,508,343	2005
25	Dumbleyung	527,641	2003
26	Woodanilling	399,535	1996
27	Kojonup	318,504	2000
28	Katanning	386,131	1998
29	Kent	255,430	2000
30	Esperance	856,172	1997

3.2 Design a Harvesting and Transport System for Mallee Biomass Supply Chain

3.2.1 Harvester, Tractor and Truck Information

Reliable and high-efficiency harvesters, such as grapple harvesters and feller bunchers, have been developed and used in the agricultural harvesting system for a long time [17]. However, no single mature harvester can completely overcome the problems with the nature of mallee, like its non-uniform size and weight, low production per paddock hectare, and many stems [17]. Therefore, according to the demand from the OMA, the Dumbleyung Company developed a prototype mallee harvester that can efficiently cut mallee stems at ground level and a chipper system that can feed bark, leaves, and wood and chip it into 10 cm mallee chips [17]. The advantage of this is that mallee chips, as a flowable biomass material, raise the its bulk density and, thus, improves the transport efficiency. Also, the pour rate of the prototype mallee harvester is 30 tonnes/h [17]. Because it does not have storage bin, a tractor and a harvester must march side by side at the same speed during the harvesting process.

In fact, many mallee planting areas are close to minor roads, rather than primary and secondary roads, so heavy and long-distance transport trucks cannot access these areas [17]. Therefore, a tractor is used to not only collect and store the mallee chips from a harvester but also transport it to the adjacent farm gate (transport landing) for road transport. Besides, to cooperate with the development and popularisation of the prototype mallee tractor, a Claas Xerion 5000 tractor has been developed to meet future mallee harvesting system demands [18]. One advantage of the tractor is that its payload is up to 15 tonnes, and the maximum speed is 50 km/h on minor roads [18]. This means the tractor can match a prototype mallee harvester for a long time and minimise the round-trip time between the farm gate and the mallee harvesting area. This will significantly improve the coordination between harvesters and tractors. Thus, the whole efficiency of the mallee harvesting system can be increased. A report shows that it is possible for the harvester utilisation rate to be 70 to 80% [17]. In addition, another advantage of the tractor is that its fuel tank is up to 930 L [18]. This means it has an excellent sustainability for a long time and a long distance work. The detailed Claas Xerion 5000 tractor parameter is given in Appendix B.

Because the distance between the mallee harvesting area and the Muja power station or pyrolysis plants is relatively long, the truck should have a high load capacity to improve the road transport efficiency. Also, in the existing mallee road transport system, a 70 m^3 volumetric capacity bin has been used for long-distance transport [17]. The bulk density of mallee chips is 0.4 tonnes/m^3, so the weight of a bin full of mallee chips is about 28 tonnes [17]. Therefore, the combined weight of 70 m^3 of mallee chips and one bin might be 30 tonnes. According to a report published by Australian Trucking Association (ATA), the payload of the Seven Axle 124 HML (configuration code: A124) is about 30.15 tonnes, and it is suitable for transporting biomass long distances [19]. Its nominal diesel consumption per 100 km is 51 L, which is based on the feedback from the operator survey for a long time [19]. The detailed truck parameter is given in Appendix C.

3.2.2 An Ideal Harvesting and Transport Model

The lowest cost mallee harvesting and transport system is the use of a tractor to collect mallee chips from a harvester and takes it to the closest farm gate [17]. Then, trucks will take a bin full of mallee chips to Muja power station or a pyrolysis plant. The farm gate is defined as a road transport landing that is used to temporarily store mallee chips at the roadside for long distance transport [17]. Thus, the choice of the location of the farm gate will have a direct impact on the efficiency of the whole mallee harvesting and transport system [17]. For example, if there are too many farm gates in one region, then the efficiency of harvesting will be increased, but the efficiency of transport will be reduced. So, the farm gate quantity and location can directly affect the feasibility and sustainability of a mallee harvesting and transport system. In addition, factors like the fuel bin size and the speed of a tractor and the available class of road for a specified heavy truck will indirectly affect the choice of the location of the farm gate.

Although some previous reports suggested the use of mature sugarcane harvesting and transport systems in the mallee industry in WA, the assessment result showed that this is unsuitable and unfeasible [17]. One reason is that mallee harvest yields per hectare are significantly limited by an “alley farming” configuration, typically around 1–2 tonnes per paddock hectare, which is much lower than 30–40 tonnes of sugarcane per paddock hectare [17]. For improving the efficiency of the whole system of harvesting mallee, infield transport should be relatively long distance, which also means a farm gate should cover a great mallee harvesting area. Another reason is that sugarcane is usually planted in high rainfall areas (over 1,000mm per year), but mallee is planted in areas where get 300–600 mm of rainfall annually [1, 17]. This means the harvesting and transport system of sugarcane cannot entirely cover the mallee planting area. However, no harvesting and transport model has been developed for the mallee biomass supply chain in WA.

In this part, an ideal harvesting and transport model is designed to calculate the water consumption of transport for mallee biomass supply chain in WA. Firstly, because the high payload (15 tonnes) and high speed (50 km/h) of the Claas Xerion 5000 tractor, the mallee harvest coverage area of each farm gate is assumed to be 500 km^2. Moreover, to improve the efficiency of infield transport, the distance between each tractor and the closest farm gate is specified less than 25 km. That ensures one tractor takes the full mallee chip bin to the nearest farm gate, one tractor takes the empty bin back, and one tractor collects the mallee chips from the harvester, which will maximize the work efficiency of each agricultural harvesting vehicle. Besides, all the selected shire land area data can be retrieved from the Australia Bureau of Statistics (ABS), except the land area data about Mullewa [20]. Mullewa Shire's land area (8452 km^2) can be approximately estimated using Digimzer, which is an image analysis software (see Figure 4). The detailed land areas of the all selected shires are given in Appendix D.

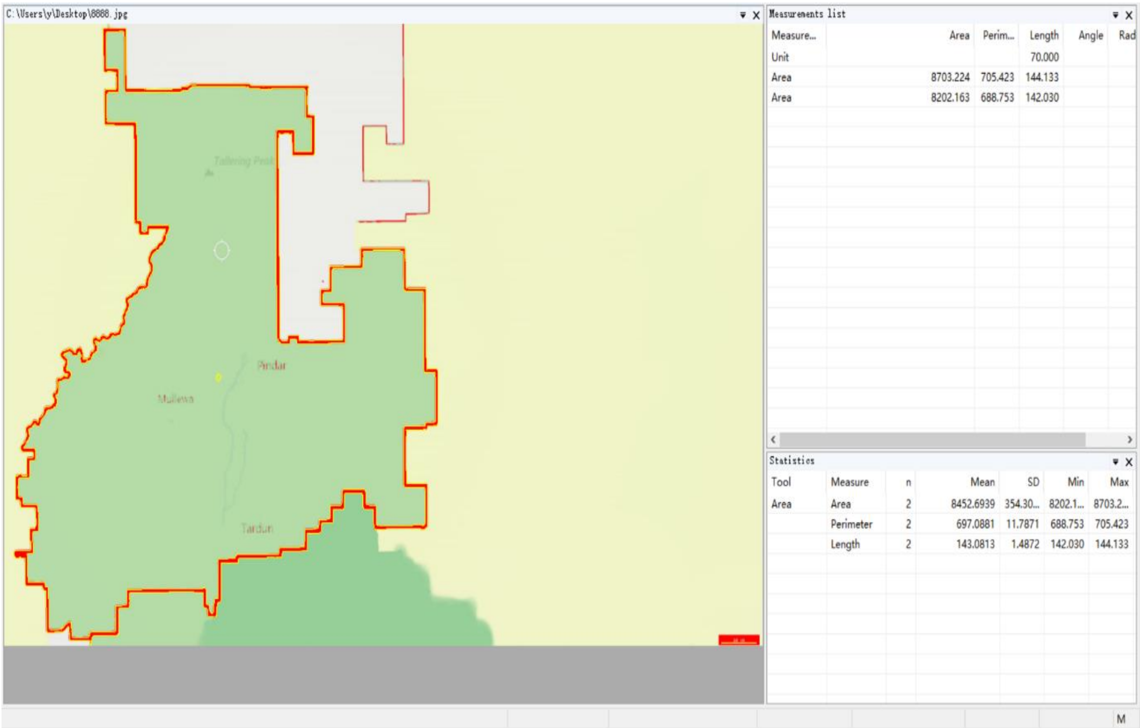

Figure 4: Using Digimzer to measure every selected shire

Then, every selected shire land area is divided by 500 km^2 to calculate the number of farm gates in every selected shire. Secondly, because heavy trucks can only drive on primary and secondary class roads, the location of each farm gate is established at the roadside along these roads in every selected shire. Besides, the total distance of the primary and secondary class road in every selected shire can be measured using a roadmap from the AREA [16]. Then, it is divided by the number of farm gates in every selected shire to calculate the space between each farm gate in every selected shire. Finally, the detailed location and layout of each farm gate are based on the terrain shape, local road layout and the space of each farm gate of every selected shire for as large as possible, covering more mallee planting area to improve the harvesting and transport system efficiency. The location of each farm gate is shown in Figure 5, and the specific latitude and longitude of each farm gate are given in Appendix F.

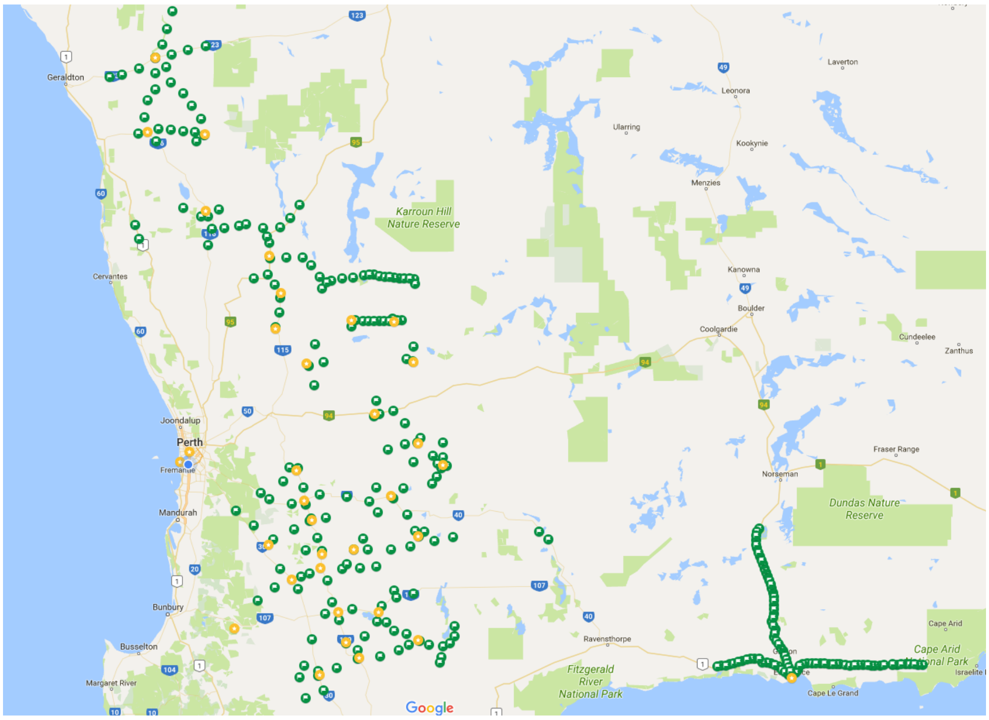

Figure 5: 286 farm gates in WA

To estimate whether the 30 selected mallee planting shires are covered by the harvesting and transport model, a circle was drawn with every farm gate in Figure 5 and 25 km as a radius. Comparing to Figure 3 and Figure 6, almost all selected planting area can be covered by the harvesting and transport model. This means the model is feasible and can be used into the following analysis.

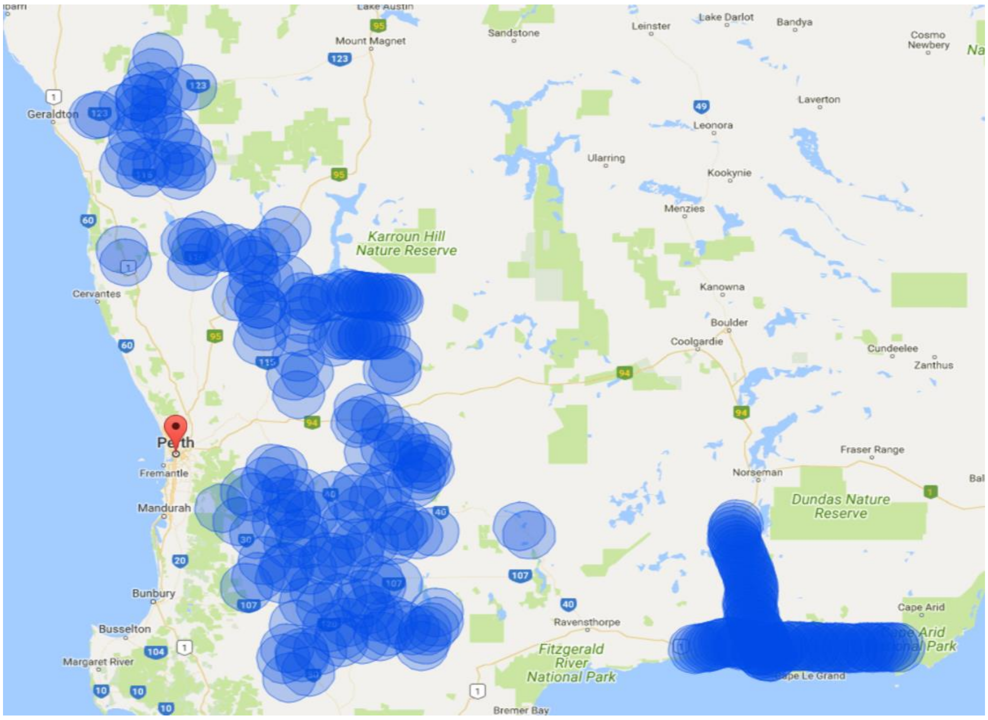

Figure 6: An ideal harvesting and transport model

3.3 The Assumption About the Weight of a Mallee Tree and Harvest Cycle Period

According to a research report from the OMA, many different mallee eucalyptus species were planted in WA (see Table 5) [4].

Table 5: Mallee eucalyptus species in WA

Species	Proportion of total trees established (%)
Eucalyptus loxophleba subsp. Lissphloia	39
Eucalyptus kochii subsp. Plenissima	23
Eucalyptus kochii subsp borealis	18
Eucalyptus loxophleba subsp. Gratiae	8
Eucalyptus polybractea	8
Eucalyptus kochii subsp. Kochii	2
Eucalyptus myriadena	1
Eucalyptus angustissima subsp, Angustissima	1
Total	100

Therefore, it is difficult to determine the mallee maturity conditions because each mallee specie has a different weight and harvest cycle period. A study report from Curtin University assessed the mallee planting situation depending on the latest field data from nine sites in WA [21]. These selected nine sites were considered to be representative because they are sited at the 300 to 600 mm rainfall zone, where mallee is widely planted to manage dryland salinity. The detailed site location and a series of data for the life cycle inventory of mallee biomass in the nine sites are given in Appendix E [21]. Moreover, the data of the biomass yield, harvest cycle period, and the number of trees per hectare of these nine sites are been given in Table 6. Then, the weight of each dry mallee tree from every site could be calculated by the biomass yield multiplied by the harvest cycle period and divided by the number of trees per hectare. Also, the moisture content of green mallee is assumed to be 50%. Therefore, the weight of each green mallee tree from every site could be calculated by the weight of each dry mallee tree from every site divided by 0.5.

Table 6: Site location, biomass yield, harvest cycle period, number of trees per ha, the weright of dry mallee

Site	Nearest town-site	Biomass yield (dt/ha/y)	Harvest cycle period (years)	Number of trees per ha	The weight of a dry mallee tree (kg)	The weight of a green mallee tree (kg)
1	Alexander	15.4	4	1667	37	74
2	Bird	5.4	5	1875	14.5	29
3	Fuchbichler	4.7	5	1667	14	28
4	Morrell	6.0	5	1667	18	36
5	Quicke	4.4	5	1667	13	26
6	Stanley 2	7.5	4	1667	18	36
7	Strahan	3.9	4	1875	8.5	17
8	Sullivan 1	13.4	4	2143	25	50
9	Sullivan 2	7.0	4	2143	13	26
						Average: 36

Based on the calculation, the range of the weight of a green mallee tree in the nine sites is between 17 kg and 74 kg. Because this range is large, in this report, the weight of each green mallee is assumed to be the average value (36 kg). Furthermore, for the sake of analysis, the harvest cycle period is determined to be four years.

3.4 The Calculation of Water Consumption in Every Selected Shire

In a WF calculation, there are two types of blue water: direct blue water and indirect blue water. Direct blue water is fresh water that is consumed along biofuel pathways, such as irrigation [6]. Indirect blue water refers to the summation of the WF of all input materials and energies, like diesel [6]. In the transportation steps in the mallee biomass supply chain, only diesel is consumed as transport fuel, therefore, in this part, only indirect blue water need to be considered.

Based on the design in Section 3.2.2, the detailed location of every farm gate in every selected shire was determined. Therefore, the distance between each farm gate and the Muja power station were measured using Google Maps, and these data are given in Appendix F. Then the indirect blue water consumption of transport in every selected shire can be calculated using the following Formula [1]:

$$W = \sum_{i=1.2.3\ldots n}^{n} (R_i * 2) * H * F * S_i \ [1]$$

where n is the number of farm gates in every selected shire, and i is the serial number of every farm gate in each shire. These data are given in Appendix F. R_i is the distance between the i

farm gate and the Muja power station. H is the nominal fuel consumption value per 100 km of the truck (Seven Axle 124 HML), 51 L of diesel per 100 km used in this report [19]. F is the water use factor for diesel (2.2 L H_2O/ diesel) from a previous Canadian research report [8]. S_i is the total number of needed trucks at the farm gate i. The number of trucks for each farm gate is given in Appendix F. Base on the calculation, the annual water consumption of every selected shire is shown in Figure 7.

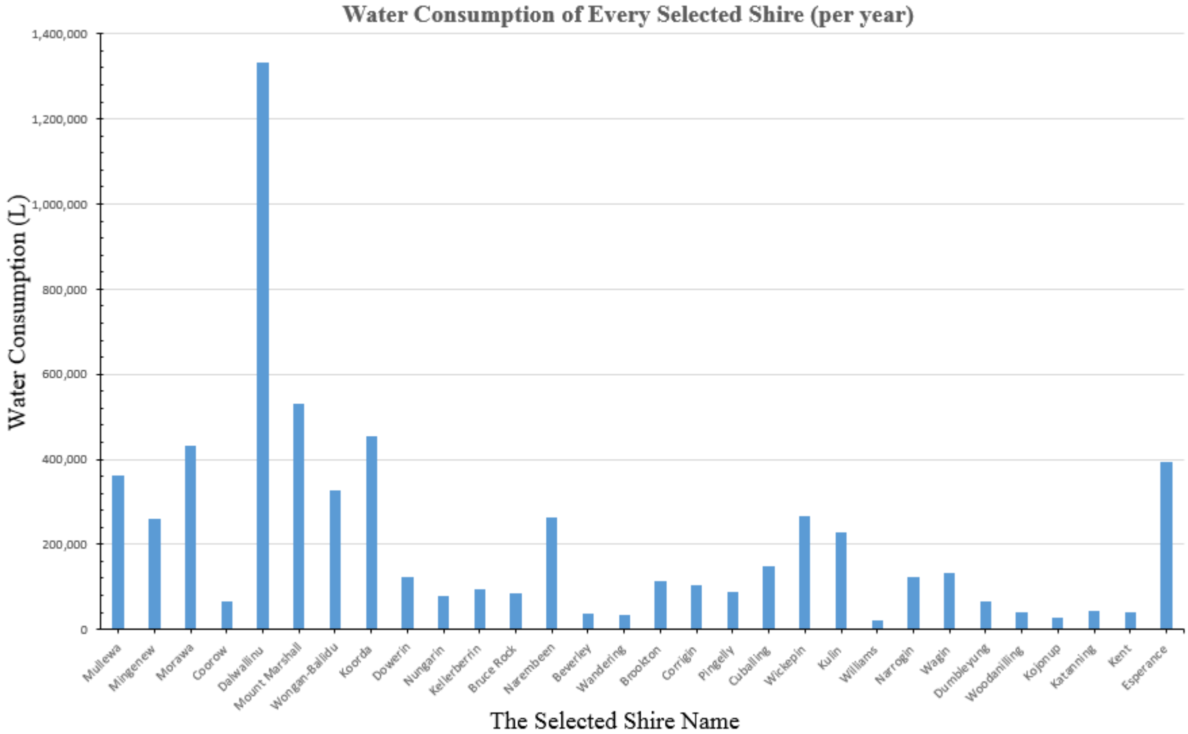

Figure 7: The water consumption of every selected shire in the biomass supply chain

According to Formula [1], the water consumption of every selected shire is proportional to the distance (R_i) and the number of truck (S_i). Also, S_i is directly affected by the number of mallee stems in every selected shire. Therefore, it is obvious that Dalwallinu is the shire in which the most water is consumed (over 1.3 million litres of indirect blue water per year). This is because the most abundant mallee resources are in this shire (3 million mallee stems), and the average distance between the shire and the Muja power station is 470 km (Appendix F). Besides, areas like Mullewa, Mingenew, and Esperance do not have abundant mallee resources (over 1 million mallee stems), but the water consumption levels in these shires are still large (over 0.2 million per year). This is because the distances between these shires and the Muja power station are over 600 km (Appendix F). From the perspective of blue water consumption, these shires have more advantages than Dalwallinu. However, from the perspective of energy, Dalwallinu can provide more energy than these shires. Therefore, which selected shires are valuable depends on the ratio of water consumption to provided energy in every selected shire (Figure 8). It can be calculated by dividing the amount of blue water consumed in mallee transport in a selected shire by the weight of dry mallee harvested in the selected shire and multiplying the LHV of dry mallee (0.0172 GJ/kg). These data are shown in Appendix D&F and the result are shown in Figure 8.

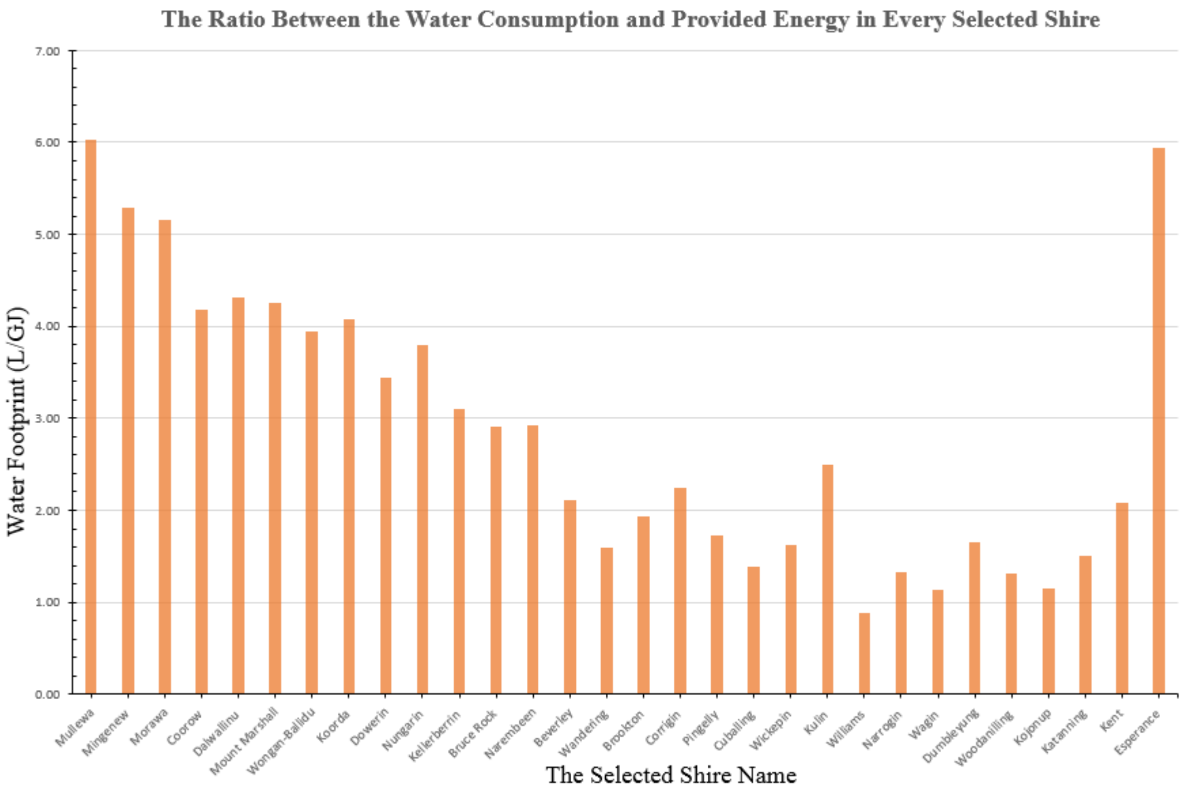

Figure 8: The water footprint in the biomass supply chain

It is obvious that the ratio values of the four shires (Mullewa, Mingenew, Morawa, and Esperance) are over 5 litres of blue water per GJ (see Figure 8). This means that, compared to other shires, these shires provide the same amount of energy but consume more blue water. The main reason for this is that the four shires are far away from the Muja power station. Therefore, the four shires should not be considered first as areas to provide mallee chips for the Muja power station.

3.5 Mallee Biomass as Feedstock for the Muja Power Station

3.5.1 Muja Power Station Overview

Muja power station that is a coal-fired thermal power station and is located on the Collie coal field and provides electricity to Perth [2]. It has eight steam turbines to generate a total capacity of 1094 MW of electricity. Muja AB units (4 x 60 MW) were built from 1965 to 1969 and refurbished in 2013 [22]. However, according to Schmidt research report, they will be closing by the end of 2018, and Muja C unit (2 x 200 MW) and Muja D unit (2 x 227 MW) will continue to work beyond 2030 [23]. Therefore, in this report, only Muja C and D units are used for co-processing biomass with coal.

According to a previous report, co-firing of biomass and coal has been tested in the Muja power station [2]. However, there is a mismatch between the property of biomass and coal, which will generate a large quantity of flue gas during co-processing [2]. This leads to the whole plant efficiency loss, because coal particles are blown out of the boiler by the flue gas, which causes that coal particles not to be burned completely. Therefore, at present, only up to 5% of coal (on an energy basis) could be substituted by raw biomass during co-processing in Muja power station [2].

3.5.2 Case One: Mallee Chips as Feedstock for Muja C and D Units

The total LHV of dry mallee chips in every selected shire is calculated by multiplying the weight of dry mallee chips in every selected shire by the LHV of dry mallee chips (0.0172 GJ/kg). These relevant data are in Appendix D, and the total energy supplied by all selected shires is 2,046,312 GJ per year. Besides, the annual input energy of the Muja C and D units is calculated (on a GJ basis):

$$E = \frac{P * N * 3.6}{\eta} \quad [2]$$

where P is the generating capacity of Muja C and D units (854 MW) or Muja C unit (400 MW), or Muja D (454 MW). N is the number of hours for which the Muja power station operates per year (8,760 hours). η is the efficiency of the steam turbines in the Muja C and D units. According to Hussy studies, in the Australian the average efficiency value of the steam turbines is 35% that is used in this thesis [24].

Based on the result of Formula [2], the input energy of Muja C and D units is approximately 76,947,840 GJ per year, and 5% of that total is 3,847,392 GJ that could be provided by raw mallee chips. However, this value is higher than the total annual energy supplied of all selected shires (2,046,312GJ), which means that, with the existing mallee biomass supply chain, only 2.66% of coal (on an energy) could be substituted by raw mallee chips in the Muja C and D units each year.

3.5.2 Case Two: Mallee Chips as Feedstock for Muja C Unit

Based on the result of Formula [2], the input energy of Muja C unit is 36,041,143 GJ per year, and 5% of that total is 1,802,057 GJ. This value is smaller than the total annual energy supplied in all selected shires (2,046,312 GJ), which means 244,255 GJ is unnecessary. Therefore, some selected shires do not need to provide mallee chips to the Muja power station. Based on the analysis in Section 3.4, the four shires (Mullewa, Mingenew, Morawa and Esperance) should not be chosen first to supply mallee chips, because these shires consume more blue water than other shires. Moreover, according to Figure 8, in the four shires, the ratio value of Morawa is smallest. Therefore, when mallee chips are used as feedstock in the Muja power station C unit, the three shires (Mullewa, Mingenew, and Esperance) are not used as the supplying mallee chips shires, and Morawa Shire only provides 68,800 GJ.

3.5.3 Case Three: Mallee Chips as Feedstock for Muja D Unit

Based on the result of Formula [2], the input energy of Muja D unit is 40,906,697 GJ per year, and 5% of that total is 2,045,334 GJ. This value is smaller than the total annual energy supplied in all selected shires (2,046,312 GJ), which means 977 GJ is unnecessary. However, compared to this value (244,255 GJ) in Section 3.5.2, 977 GJ is small and can be ignored. Also, the redundant energy could be used as the standby energy to protect the Muja power station from an emergency, so this value (977 GJ) could be accepted.

Chapter 4 Water Footprint of Bioslurry Supply Chain for Muja Station

4.1 Bioslurry and the Location of the Pyrolysis Plants A and B

Although mallee biomass chip can be used as a fuel to sustain the Muja power station, it suffers from its low energy density and high moisture content [2]. These problems will increase the transport cost and CO_2 emission [2]. One of the solutions is to convert biomass to higher value product [7]. Via pyrolysis, raw mallee biomass can be converted to bioslurry, which is composed of bio-oil and biochar. Compared to the green mallee biomass (volumetric energy density, 5 GJ/m^3), bioslurry fuel (about 23 GJ/m^2) has a significant advantage in transport cost and CO_2 emission [2]. Therefore, mallee biomass chips can be substituted by bioslurry as fuel in the Muja power station. Moreover, via fast pyrolysis, the properties of bioslurry are similar to those of coal, which means much less flue gas produced in the boiler [2]. Therefore, up to 15% of the energy input of the Muja power station can be substituted by bioslurry [2].

As shown in Figure 3, the mallee planting areas are mainly focused in the north and south of WA. Therefore, one pyrolysis plant should be built in the north, and another should be built in the south. Also, a pyrolysis plant should be in an area with more mallee stems than other shires. This would reduce the whole transport distance of green mallee chips and the fuel consumption of trucks. Therefore, according to Figure 3 and the mallee stems data from every selected shire in Appendix D, pyrolysis plant A is sited on the Dalwallinu, and its capacity is 157.3 dry tonnes/day. Pyrolysis plant B is located in the Wickepin, and its capacity is 203 dry tonnes/day. The data about pyrolysis plants A and B like the operating day (per year), the detailed location and covering the mallee planting shires are given in Appendix G&I

4.2 The Pyrolysis Plant Feedstock

To calculate the water consumption in five major processing areas in Section 4.6.2, the composition of the feedstock (mallee chips) is crucial. Like other green lignocellulosic biomass, a whole mallee tree usually consists of three major components, bark, leaf and wood [25]. Also, because each major component property is very different for the others, estimating the composition of a whole mallee tree should be based on the proximate and ultimate analysis of the three major components. As shown in Table 7, the relevant data have been reported by a previous report [25].

Table 7: Properties of mallee wood, leaf and bark components

Sample	Bark	Leaf	Wood
Proximate analysis (wt%)			
Moisture (air-dry basis)	5.7	8.3	5.3
Ash (dry basis)	4.7	3.8	0.4
Volatile matter (dry basis)	77.3	74.6	80.7
Fixed carbon (dry basis)	18	21.6	18.9
Ultimate analysis (wt%, dry and ash-free basis)			
C	48.9	59.1	48.9
H	5.0	7.4	6.7
N	0.26	1.24	0.43
S	0.03	0.12	0.02
Cl	0.41	0.24	0.05
O (by difference)	45.4	31.9	43.9

However, this ultimate analysis of Table 7 was presented on an ash-free basis, that means the ash component was not included in the ultimate analysis. However, the ash component, as an important parameter in the feedstock information, would affect the value of cooling water consumed in the ash quenching process of a pyrolysis plant. So, other components in Table 7 like Carbon, Hydrogen, Nitrogen, Sulphur, Chlorine and Oxygen should be convert from dry and ash-free basis to dry basis (Figure 9).

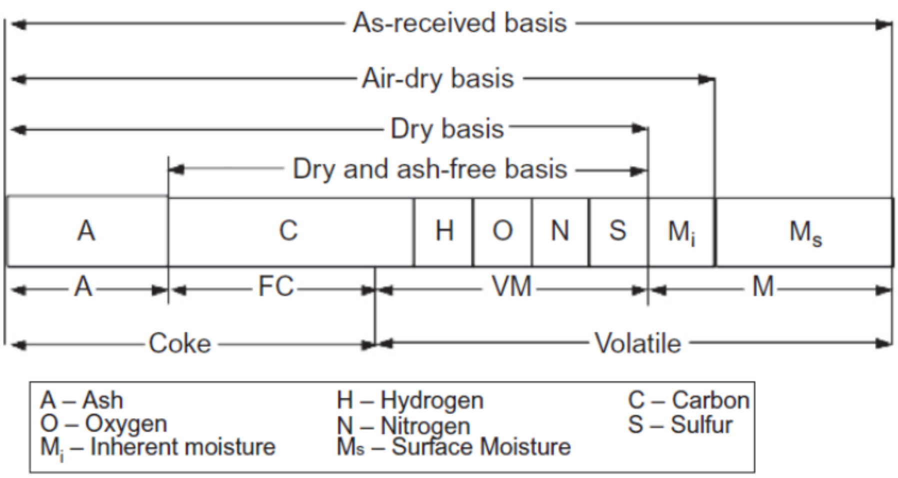

Figure 9: Different basis conversion

Take carbon content from dry and ash-free basis to dry basis for example:

$$C_{dry\ basis} = C_{dry\ and\ ash-free\ basis} * \left(1 - \frac{Ash_{dry\ basis}}{100}\right)$$

$$= 48.9 * \left(1 - \frac{4.7}{100}\right)$$

$$= 46.6\%$$

The ultimate analysis of three major components (dry basis) have been shown in Table 8.

Table 8:The ultimate analysis of three major components

Sample	Bark	Leaf	Wood
Ultimate analysis (wt%, dry basis)			
C	46.6	56.9	48.7
H	4.8	7.1	6.7
N	0.2	1.2	0.4
S	0.03	0.12	0.02
Cl	0.4	0.2	0.05
O (by difference)	43.3	30.7	43.7
Ash	4.7	3.8	0.4

Then, according to the dry mass mixed ratio (15% bark, 35% leaf and 50% wood), the property of a real whole mallee tree can be calculated [25]. Take carbon content from three major components to the real whole mallee tree for example:

$$C_{whole\ mallee\ tree} = C_{bark} * 0.15 + C_{leaf} * 0.35 + C_{wood} * 0.5$$

$$= 46.6017 * 0.15 + 56.8542 * 0.35 + 48.7044 * 0.5$$

$$\approx 51.2\%$$

The ultimate analysis of a real whole mallee tree (dry basis) is shown in Table 9.

Table 9:The ultimate analysis of a real whole mallee tree

Sample	Real Mallee Tree
Ultimate analysis (wt%, dry basis)	
C	51.2
H	6.5
O (by difference)	39.1
N	0.7
S	0.05
Cl	0.2
Ash	2.3

Also, according to the previous report [26], the LHV of raw mallee biomass is 0.0172 GJ/kg (on dry basis).

4.3 The Pyrolysis Plant Design Basis

For the bioslurry plant technical analysis, the conversion pathway via fast pyrolysis includes five major processing areas: (1) feedstock pre-treatment, (2) pyrolysis and quench, (3) heat recovery, (4) product recovery, storage and recycle, (5) power generation and use [8]. Each major processing area should be simulated using ASPEN Plus, a chemical process simulation software, to calculate the total water consumption of every major processing area. However, due to time constraints for this report, establishing a pyrolysis plant model using ASPEN Plus is very difficult for a student who does not major in chemical engineering. Therefore, in this report, a pyrolysis plant (550 dry tonnes/day) ASPEN Plus model designed by the National Renewable Energy Laboratory (NREL) is used to calculate the water consumption in the five major processing areas [7]. Moreover, some key parameters of the pyrolysis plant design and the feedstock composition are shown in Table 10. It should be noted that the feedstock composition in Table 10 is similar to the real mallee tree composition shown in Table 9, except the ash content. This means the pyrolysis plant designed by the NREL can handle the mallee biomass, but burning mallee chips will produce more ash than burning wood chips. Therefore, when the pyrolysis plant is used to convert the mallee chips to bio-oil, the water consumption in the ash quench area needs to be multiplied by 2.45 (2.3/0.92). Furthermore, under the same pyrolysis conditions (500°C and a 2.75 air carrier ratio), because the used feedstock is different, the yields of bio-oil, char and gas will be changed. According to a pervious experimental report, the yields of bio-oil, biochar and gas is 62%, 14% and 12% of the dry mallee mass at 500°C [27]. The relevant design and feedstock information about the plant A and plant B are given in Table 11.

Table 10: Design basis based on the National Renewable Energy Laboratory

Parameter	Value
Feedstock	
Type	Wood Chips
Moisture Content	50%
Throughput	550 dry tonnes/day
Particle	3-45 mm
Feedstock Composition (wt%, dry)	
Carbon	50.93%
Hydrogen	6.05%
Oxygen	41.93%
Nitrogen	0.17%
Sulfur	0.0%
Chlorine	0.0%
Ash	0.92%
Pyrolysis Design	
Pyrolysis Type	Bubbling Fluidized Bed
Temperature	500°C
Air Carrier Ratio	2.75 ib air/ib
Feed Moisture Content	7%
Ground Particle Size	2-3mm
Yields (Dry Basis)	
Oil	59.9%
Water	10.8%
Char and Ash	16.2%
Gas	13.1%

Table 11:Table 11: Pyrolysis plant A and B design basis

Parameter	Value
Feedstock	
Type	Mallee Chips
Moisture Content	50%
Throughput of Plant A	157.3 dry tonnes/day
Throughput of Plant B	203 dry tonnes/day
Particle	10 cm
Feedstock Composition (wt%, dry)	
Carbon	51.24%
Hydrogen	6.54%
Oxygen	39.09%
Nitrogen	0.67%
Sulfur	0.05%
Chlorine	0.16%
Ash	2.25%
Pyrolysis Design	
Pyrolysis Type	Bubbling Fluidized Bed
Temperature	500°C
Air Carrier Ratio	2.75 ib air/ib
Feed Moisture Content	7%
Ground Particle Size	2-3mm
Yields (Dry Basis)	
Oil	62%
Water and Ash	12%
Biochar	14%
Gas	12%

4.4 The Pyrolysis Plant Product

Via fast pyrolysis, mallee chips are converted to bio-oil, biochar and gas. Some biochar and all gas are burned by a combustor to supply the heat to a pyrolysis reactor. The detail pyrolysis plant process is introduced in Section 4.5. The rest of biochar is ground and mixed with the bio-oil produced to produce the bioslurry. Therefore, the LHV of bioslurry is based on the biochar mixed ratio. The weight of the burned biochar per day in pyrolysis plant A can be calculated by using the Formula [3]:

$$C = \frac{\frac{(E * B)}{\eta} - G * G_i}{C_i} \quad [3]$$

where E is the overall net energy required to pyrolyse mallee chips (735 kJ/kg at 500°C), according to a study from Macquarie University [28]. B is the weight of mallee chips handled by pyrolysis plant A per day (157,300 kg). G is the total weight of the gas produced per day (18,876 kg) by the pyrolysis reactor, which can be calculated by multiplying the weight of mallee chips handled per day (157,300 kg) by the yield of gas (12%). G_i is the LHV of gas (5.5 MJ/kg), according to a study from Macquarie University [28]. η is the efficiency of the combustor, 80% used in this report. C_i is the LHV of biochar (23.4 MJ/kg), according to a study from Macquarie University [26]. Based on the calculation, 1,739.4 kg of biochar is burned in pyrolysis plant A per day. The total weight of the biochar produced per day (22,022 kg) by the pyrolysis reactor can be calculated by multiplying the weight of mallee chips handled per day (157,300 kg) by the yield of biochar (14%). Therefore, the weight of the rest biochar per day is 20,282.6 kg. Moreover, the total weight of the bio-oil produced per day (97,526 kg) by the pyrolysis reactor can be calculated by multiplying the weight of mallee chips handled per day (157,300 kg) by the yield of bio-oil (62%). According to an experimental data, the LHV of bio-oil is 19.5 MJ/kg (on a dry basis) [27]. The LHV of the bioslurry produced by pyrolysis A can be calculated by

$$The\ LHV\ of\ the\ bioslurry = \frac{20282.6 * 23.4 + 97526 * 19.5}{20282.6 + 97526} \approx 20.2\ MJ/kg$$

Besides, the weight of the bio-slurry produced per day (117,808.6 kg) is calculated by the weight of bio-oil per day (97,526 kg) adding the weight of rest biochar per day (20282.6 kg). Therefore, the total LHV of bioslurry produced (2,379.7 GJ) by pyrolysis plant A per day can be calculated by multiplying the weight of the bio-slurry (117,808.6 kg) by the LHV of the bioslurry (20.2 MJ/kg). Based on the same method, the total LHV of bioslurry produced by pyrolysis plant B per day is 3074.7 GJ. The pyrolysis plants A and B are assumed to operated 24 hours/day, 330 days/year (7,920 hours/ years), hence the annual total LHV of bioslurry produced by pyrolysis plants A and B are 785,301 GJ and 1,014,651GJ, respectively.

4.5 Pyrolysis Process

4.5.1 Feedstock Pretreatment

The A area of Figure 10 shows the pretreating process of feedstock. It includes three unit operation models: a grinder, a heater, and a flash. The green mallee chip (A101) with a length dimension of 10 cm and a moisture content of 50% is ground and dried in AGR-101 and AHDR-101 units to the dry mallee particle with a length dimension of 2-3 mm and a moisture content of 7%. Then, the evaporated water (A104) from the green mallee chip (A101) is flashed in the unit (AFR-101), and the dried mallee wood particles (A105) are sent to the Pyrolysis area (B area).

All of the necessary heat for drying is from the dried hot air (A102) that is supplied from the secondary condenser (CHX-302). And, the moisture in the hot air (308) can be dried by the unit (ACC-101) to become the non-moisture hot air (A102). In the electricity consumption aspect, the feedstock grinder consumes a significant energy is of about 400 kWh from mallee chips (10 cm) to mallee particles (2 mm) (see Table 11).

4.5.2 Pyrolysis and Quench

As shown in B area of Figure 10, the recycled pyrolysis vapors (F608) at 200°C fluidizes the dried mallee particles in a 2.75:1 gas-to-feed ratio in the unit (BMX-201). It has an advantage that it uses the energy inside the system rather than depending on extra energy, that avoids energy waste. Then, to reach the pyrolysis temperature of 500°C, the mixture (of solid and gases) is heated by BHX-201 using heat from the char combustor (DCB-401). Next step, the heated mixture is converted to biochar, gas (e.g., CO), bio-oil constituents (e.g., $C_3H_6O_2$), and ash in the pyrolysis reactor (BPY-201). Similarly, the heat for pyrolysis is also provided from the char combustor (DCB-401). Then, the bio-oil liquids and gases (B204) are separated from the hot mixture (solids, liquids and gases) by a high efficiency cyclone (BCY-201) and sent to the quench area (C area). Based on the calculation from Section 4.4, 20,282.6 kg/day biochar

(B206) from the solids (B205) is taken and sent to the E area to be mixed with the 97,526 kg/day bio-oil to produce 117,808.6 kg/day bioslurry. The remaining solids including 1,739.4 kg/day biochar and ash (B207) are mixed with gases (F606) like CH_4 by a mixer (BMX-202) and these new solids/gases mixture (B208) is sent to the combustion area suppling heat for the system.

As shown in C area of Figure 10, the bio-oil vapors (B204) are rapidly condensed by the two condensers (CHX-301 and CHX-302). In the first condenser, quench water (C309) is used as the cooling medium. Because the temperature of bio-oil vapors is high (500°C), all cooling water is heated to generate 515-psig steam (C310), which is stored in the steam drum (GV-701) for power production. It should be noted that at this stage, no bio-oil vapors are condensed to become the bio-oil liquids. Air (C306) is pumped by the unit (CCP-301) and used as the cooling medium in the second condenser (CHX-302). Then the heated air (C308) having 200°C is recycled back to the feedstock dryer (AHDR-101). A scrubber (CSC-301) removes any remaining aerosols in the pyrolysis vapor stream (C303). The recovered bio-oil liquids (C304) are sent to the product recovery area (E area), and the rest of vapor stream (C305) is sent to a wet electrostatic precipitator (CESP-301) for the further removal of aerosols in the rest of the vapor stream (C305) to maximize the production of bio-oil. Then, the cleaned vapor stream (C320) as the fluidizing medium are sent to the recycle area (F area), and the recovered bio-oil liquids (C321) are sent to the product recovery area (E area).

4.5.3 Heat Recovery

C area, as the combustion area, supplies enough heat for all thermal reactions in the system. The solids/gases mixture (B208) and air (D411) that are pumped by the unit (DCP-401) are combined by the unit (DMX-402), and this new mixture (D412) is used as the feedstock for the combustor (DCB-401). Then, the ash and non-combusted solids (D402) are removed by a cyclone (DCY-401) from the very hot (over 1,850°C) combustion solids and gases (D401). Quench water (D400) is used to cool the hot combustion products from over 1,850°C to 60°C in the unit (DMX-401), and cooled combustion products (D403) is separated by a rotary filter (DSP-402). The quenching water (D413) is sent to a wastewater treatment plant, and the solids (D414) are sent to dump.

To utilize the heat from the hot flue gases (D404), a series of heat exchangers are used. DHX-401 and FHX-602, as the first exchanger, are used to preheat the split of recycle gas (F607) from about 105°C to 700°C (F608), at the same time it also cools the clean hot combustion gases (D405) from the about 1,800°C to 982°C. The DHX-402 and GHX-703, as the superheater, heat the 515-psig steam (G704 and C310) from 242°C to 620°C (G705). At the same time, they also cool the clean hot combustion gases (D406) from 982°C to 792°C.The DHX-403 and GHX-702, as the economizer, are only used to cool the clean hot combustion gases (D407) from 792°C to 402°C. The DHX-404 and GHX-701, as the boiler water preheater, control that the temperature of the outlet flue gas is under 155°C and at the same time preheat the boiler feed water from 31°C to 242°C.

4.5.4 Product Recovery, Storage, and Recycle

All bio-oil liquids (C321, C304 and F603) are converged and mixed by a mixer (EMX-501). The mixed product (E501) is pumped by a pump (EP-501) to the condensed (EHX-501), where it is cooled from 36°C to 25°C (E503) using quench water (E500). Any aerosols in the air (E505) are separated by the split from the bio-oil liquid (E503). The air containing aerosols (E505) are sent to the scrubber (CSC-301) in the quench area (C area), and are caught to become C305 or C304. The clean bio-oil (E504) and the ground biochar (E506) is sent to the EMX-502 to produce the bioslurry (E507). A Storage tank will be used to store the product, then it will be sent to Muja power station as the feedstock.

In the recycle area (F area) of the system, the cleaned vapor stream (F601) from the quench area (C area) is cooled by the condenser (FHX-601) from 33.1°C to 7°C (F602) using the quench water (F600) for further product recovery. Then, any remaining water and gases like CH_4 in the chilled vapors (F602) is moved in the unit (FFL-601), and the non-moisture bio-oil liquids (F603) are sent to the product recovery and storage area (E area) where it is combined with other cleaned bio-oil liquids (C321 and C304). The flashed water and gases (F604), as a fluidizing medium, are compressed by a pump (FCP-601) to be F605, and the temperature of the water and gases is raised from 7°C to 105°C. Most of the water and gases (F607), from the F605, are separated by the unit (FSP-601) and heated to 700°C by the first exchanger (DHX-401 and FHX-602). Then these cooled water and gases (F607) are sent to the pretreatment area (A area) as the recycled pyrolysis vapors (F608) to fluidize the feedstock (A105). On the contrary, the rest of the water and the gas (F606) are directly sent the pyrolysis area (B area) and mixed with the ash and biochar (B207) as the feedstock for the combustion area (D area).

4.5.5 Power Generation and Use

In the power production area (G area), to produce enough steam to generate electricity by a steam turbine, additional water (G701) is introduced into the system. It is compressed by the pump (GP-701) and heated by a series of heat exchanger that have been discussed in combustion area (D area). In the superheater GHX-703 and DHX-402, 515-psig steam (C310) and the heated steam (G704) are combined, and the temperature of mixed steam (G705) have been raised to 620°C. Then the high temperature and pressure steam drive the steam turbine (GTB-701) to generate over 1,400 kW of electrical power for the system. In the steam turbine outlet, the low temperature and pressure steam are cooled to become water (G712) by the condenser (GHX-701) from 50°C to 21°C using the quench water (G700). Part of the water (G713) is waste water. It is separated from by the unit (GBD-701). Then it is sent to a wastewater plant.

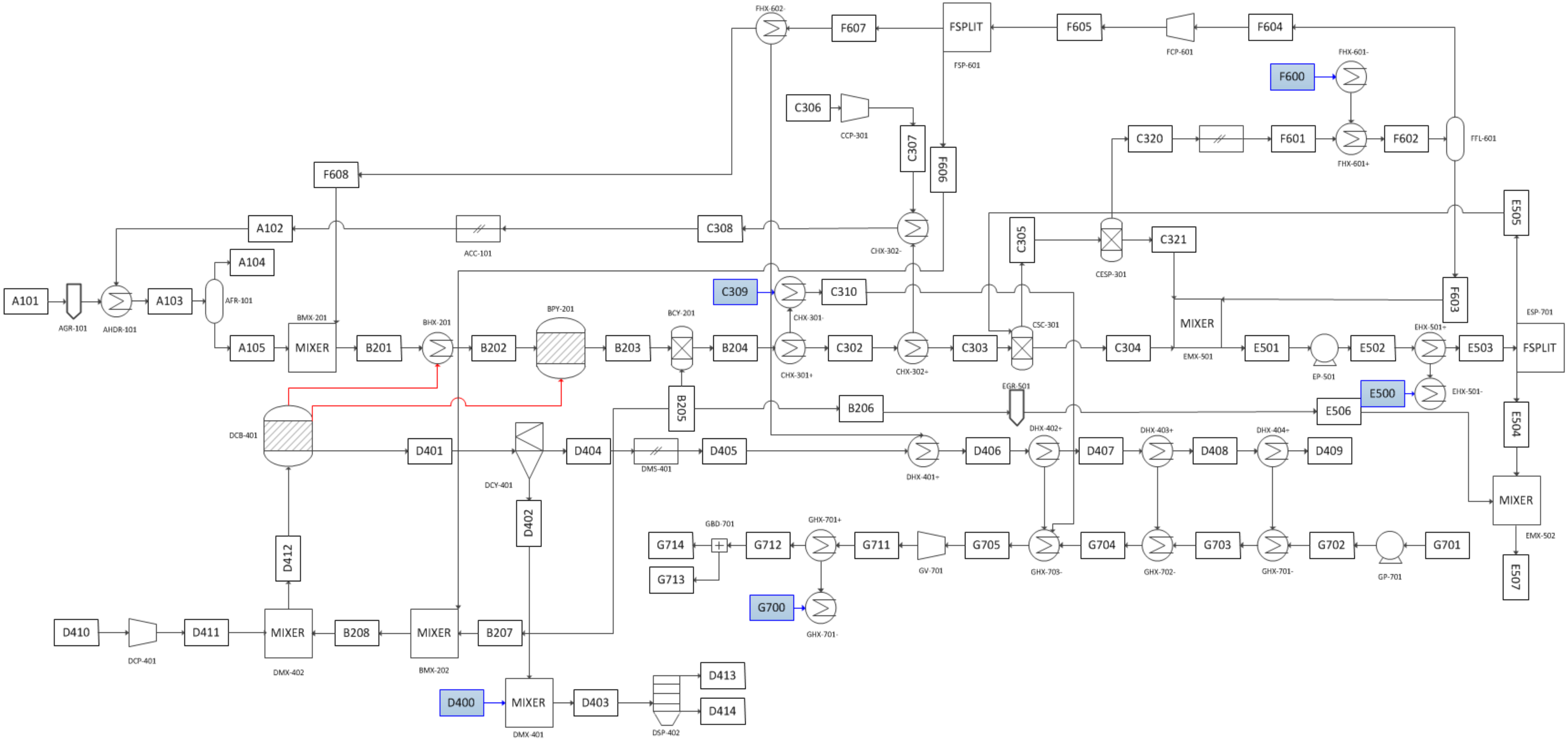

Figure 10: Pyrolysis A and B design diagram

4.6 The Calculation of Water Consumption for Bioslurry Supply Chain

4.6.1 Transport Mallee Chips from Every Selected Shire to Pyrolysis Plants A and B

In this part, the method used to calculate the amount of water consumed during the transport stage is the same as that used in Section 3.4. Based on the design in Section 3.2.2 and Section 4.1, the location of every farm gate of every selected shire and pyrolysis plants A and B have been determined. Also, the distances between every farm gate of every selected shire to pyrolysis plants A and B have been measured by Google Maps and given in Appendix G&I. Therefore, according to Formula [1], the indirect blue water consumption of transport in every selected shire can be calculated, and the result is shown in Figure 11.

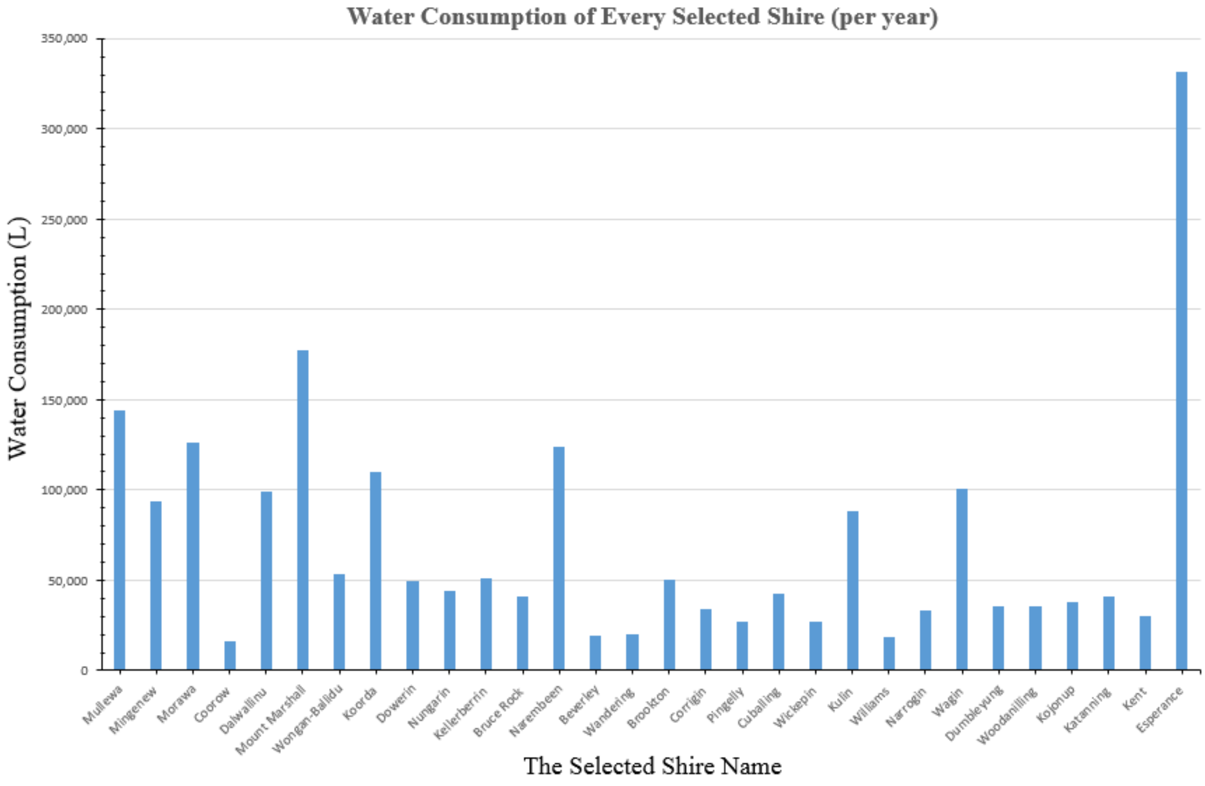

Figure 11:The water consumption of every selected shire in the bioslurry supply chain

Compared to Figure 7, it is obvious that the water consumption of every selected shire has undergone a significant reduction. This means the overall annual water consumption of the bioslurry supply chain consumes less than the biomass supply chain during the mallee chips transport stage. However, the annual water consumption of Esperance is still large. This is because the distance from Esperance to pyrolysis plant B is still far (over 500 km). Also, it should be noted that the water consumption of Dalwallinu in the biomass supply chain is over 1.3 million litres per year (Figure 7). This is because the shire has the most abundant mallee resources (over 3 million mallee stems), and the average distance from the shire to the Muja power station is 470 km. However, in this part, the water consumption of Dalwallinu is found to be only 90 thousand litres per year. This is because pyrolysis plant A is in this shire, so the average distance from the planting areas of Dalwallinu to pyrolysis plant A is reduced to 34 km. Similarly, pyrolysis plant B is in Wickepin. The water consumption of Wickepin is decreased from 0.2 million litres per year (Figure 7) to 25 thousand litres per year (Figure 11). In the mallee chip transport stage, the bioslurry supply chain has an obvious advantage over the biomass supply chain concerning water consumption.

4.6.2 Pyrolysis Plant

Based on the pyrolysis plant model designed by NREL, a pervious report has calculated the water consumption in the five major processing areas [8] (see Table 12).

Table 12:The water consumption of the five major processes in a pyrolysis plant

Operation	Value
Bio-oil cooling (L H_2O/kg bio-oil)	0.027
Bio-oil vapor cooling (L H_2O/kg bio-oil)	0.003
Steam condensing (L H_2O/kg bio-oil)	1.077
Steam system (L H_2O/kg bio-oil)	0.026
Ash quenching (L H_2O/kg bio-oil) (wood)	0.203
Ash quenching (L H_2O/kg bio-oil) (mallee)	0.497
Total (L H_2O/kg bio-oil) (mallee)	1.630

According to the analysis in Section 4.3, mallee chips produce about 2.45 times more ash than wood chips during a pyrolysis process. Hence, the amount of water used for ash quenching is 0.497 L H_2O/kg bio-oil (see Table 12). Also, as shown in Figure 10, the remaining biochar (B205) is ground by the grinder (EGR-501) and mixed with the bio-oil produced (E504) in the mixer (EMX-502) to produce the bioslurry (E507). In this process, no quenching water is used. Quenching water only is consumed in the bio-oil production process. Therefore, the total daily water consumption of pyrolysis plant A can be calculated by multiplying the weight of bio-oil produced per day by 1.63. Based on the calculation in Section 4.4, the total weight of the bio-oil produced by pyrolysis plant A per day is 97,526 kg, so the water consumption of pyrolysis plant A is 158,967.4 L H_2O per day. Similarly, based on the same method and the data about pyrolysis plant B in Appendix I, the water consumption of pyrolysis plant B is 205,372.5 L H_2O per day.

4.6.3 Transport of Bioslurry from Pyrolysis Plants A and B to the Muja Power Station

Compared to the bulk density of mallee chips (0.4 tonnes/m^3), the average bulk density of bioslurry (1.004 tonnes/m^3) is high [29]. Also, the volumetric energy of bioslurry is about 23 GJ/m^3, which is over four times that of mallee chips (5 GJ/m^3). Therefore, bioslurry is denser and can be used to produce more energy than biomass, under the same volume. This means a truck with a higher payload than the Seven Axle 124 HML can be used to transport bioslurry from pyrolysis plants A and B to the Muja power station, which would increase the efficiency of transport. In this part, a Type 1 Road Train Triaxle Dolly (configuration code: A123T33) is selected as the truck [19]. Its payload is 60 tonnes and its nominal diesel consumption per 100 km is 72 L [19]. Furthermore, the distances from pyrolysis plants A and B to the Muja power station are 460 km and 148 km, respectively. The indirect blue water consumption of transport from pyrolysis plant A or B to the Muja power station can be calculated using the following Formula [4]

$$W = (R * 2) * H * F * S \text{ [4]}$$

R is the distance between pyrolysis plant A or B and the Muja power station. H is the nominal fuel consumption rate of truck type 1 (road train triaxle dolly) per 100 km. 72 L of diesel per 100 km is the value used in this report [19]. F is the water use factor for diesel (2.2 L H_2O/ diesel) that was from a previous Canadian research report [8]. S is the total number of trucks needed at pyrolysis plants A and B, this data is given in Appendix H&J. Based on the above calculation, the total amounts of water consumed during the transport of bioslurry per year from pyrolysis plants A and B to the Muja power station are 944,324 L H_2O and 392,513 L (Appendix G&I). It is should be noted that although the transport weight of bioslurry per year of pyrolysis plant B is more than that of pyrolysis plant A, the distance from pyrolysis plan B to the Muja power station is shorter than that from pyrolysis plant A. Hence more water is used to transport bioslurry from pyrolysis plant B to the Muja power station that from pyrolysis plant A to the Muja Power Station.

4.7 Bioslurry as Feedstock for the Muja Power Station

The annual input energy of the Muja C and D units and the annual energy provided by pyrolysis plants A and B have already been calculated and has been discussed in Section 3.5.2 and Section 4.4, so that information is not repeated here.

Table 13: Bioslurry as feedstock for Muja power station at present

Muja power station	Value	Provided energy by bioslurry supply chain per year (GJ)	Substitution rate (on an energy basis %)
Muja C unit input energy per year (GJ)	36,041,143	1,799,952	5.0
Muja D unit input energy per year (GJ)	40,906,697	1,799,952	4.4
Muja C and D units input energy per year (GJ)	76,947,840	1,799,952	2.3

As shown in Table 13, in the existing bioslurry supply chain, bioslurry can substitute 2.3% of coal (on an energy basis) in the Muja C and D units. This value is smaller than at same condition that of the biomass supply chain (2.66%) (Section 3.5.2). This is because some energy can be consumed to supply the heat and power required for the pyrolysis process. Also, although the bioslurry can substitute up to 15% of coal (on an energy basis) in the Muja power station, the present quantity of the mallee stems in WA bioslurry cannot realised its full potential.

Chapter 5 Comparison of the Biomass Supply Chain and Bioslurry Supply Chain

5.1 Water, Cost, and Carbon Footprint

Based on the analysis and calculation in Chapter 3 and Chapter 4, the WF of biomass supply chain and the bioslurry supply chain have been assessed. As shown in Figure 12, the water WF of the bioslurry supply chain is 68 L H_2O/GJ, which is larger than that of the biomass supply chain (3 L/GJ). The WF of bioslurry production (66 L H_2O/GJ) occupies 97% of the WF of the whole bioslurry supply chain. If the WF of bioslurry production is not considered, then the overall WF of biomass transport (0.8 L H_2O/GJ) and bioslurry transport (0.7 L H_2O/GJ) will have a large advantage over the WF of the biomass supply chain (3 L H_2O/GJ). One of main reasons is because pyrolysis plants A and B are sited near the mallee planting areas. This significantly reduces the total distance of biomass transport from the planting area to a processing plant. Another reason is that the biomass chips are converted to bioslurry fuel in a pyrolysis plant. This causes the bulk density of the transported product to increase from 0.4 tonnes/m^3 (biomass chips) to 1.004 tonnes/m^3 (bioslurry) [17] [29]. This makes the transport system convenient, so a new heavy truck (Type 1 Road Train Triaxle Dolly) is used to transport the bioslurry fuel between pyrolysis plant A or B to the Muja power station. The new truck has a higher payload and more economical fuel consumption than the Seven Axle 124 HML. This causes the WF of biomass and bioslurry transport in the bioslurry supply chain to be lower than the WF of biomass transport in the biomass supply chain. However, in the whole supply chain, the bioslurry supply chain has almost no advantages over the biomass supply chain concerning water consumption during transport from the planting area in every selected shire to the Muja power station.

The economic feasibility and carbon footprint assessment have been reported by Curtin University [2] [5]. The result showed when a processing plant is distant from biomass planting area, a bioslurry supply chain is competitive. This is because a bioslurry supply chain significantly reduces the delivery cost of fuel. Similarly, for coal-based energy plants, such as the Muja power station, the bioslurry supply chain have a smaller CO_2 emission at a longer distance transport than the biomass supply chain. The detailed analysis has been discussed in Chapter 2.

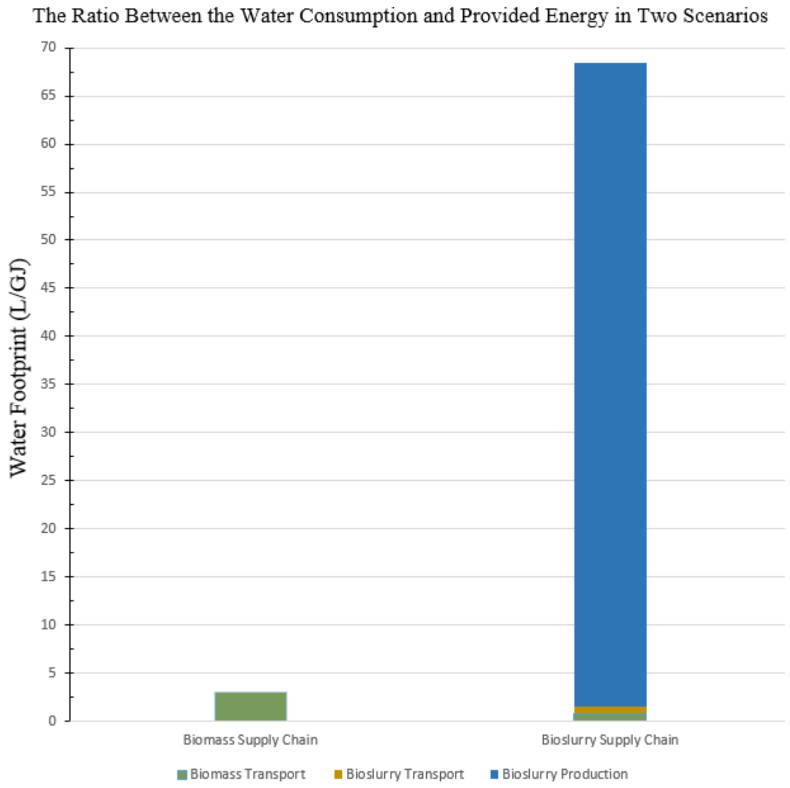

Figure 12: Comparison of the biomass supply chain and bioslurry supply chain in the water footprint

5.2 Potential Energy Provided to the Muja Power Station

Based on the analysis in Section 3.5.1, because the properties of raw mallee chips mismatch with those of coal during co-processing in coal fired boilers, only 5% of coal (on an energy basis) can be substituted by raw mallee biomass. For example, the biomass supply chain can only provide up to 3,848,392 GJ to the Muja C and D units. However, because there is no mismatch problem in fuel properties between bioslurry and coal during co-firing, up to 15% of coal (on an energy basis) can be replaced with bioslurry. This means the bioslurry supply chain can provide three times the amount of energy (11,542,176 GJ) to the Muja C and D units than the biomass supply chain. Also, with the increase in the amount of coal that can be substituted by biofuel, the CO_2 emissions of the Muja C and D units will be reduced. This is beneficial to climate change mitigation.

Chapter 6 Conclusion

The water footprint of the biomass supply chain and the bioslurry supply chain in the transport and conversion stages have been assessed in this thesis. Chapter 2 reviewed the mallee biomass resource in WA and producing bioslurry process. Also, cost, energy, and carbon footprint have been developed by researchers from Curtin University, but the water footprint of the biomass and bioslurry supply chain is still a research gap. For solving the research gap, an ideal harvesting and transport model was designed to determine the detailed location of farm gates in WA. In Section 3.2.2, compared to the main mallee production area (Figure 3), this model has been proved to be useful and feasible. In Section 3.4, the water footprint of the biomass supply chain has been calculated on the basis of the truck fuel consumption per 100 km, the water use factor for diesel, the distances from every farm gate of every selected shire to the Muja power station. The result shows when the biomass supply chain provides 1 GJ for the Muja power station, 3.1 L water will be consumed. Moreover, in Chapter 4, a bioslurry pyrolysis plant design diagram was shown in Figure 10, the water consumption of the five major process areas is based on a previous Canadians report. The water consumption of the bioslurry supply chain can be calculated based on the harvesting and transport model in Section 3.2.2. The result shows the annual water consumption of the bioslurry supply chain is approximately 22 times than that of the biomass supply chain. This is because the water footprint of bioslurry production occupies 97% of the water footprint of the whole bioslurry supply chain. However, this thesis also assessed the potential providing energy for the Muja power station in the future. Because bioslurry match in fuel properties with coal, the energy provided from the bioslurry supply chain can be three times than that of the biomass supply chain. For the bioslurry supply chain, future works could focus on establishing small distributed pyrolysis that within the biomass producing area.

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Appendix

Appendix A

The oil mallee stems data of 66 shires in WA

LGA_NAME_2011	Number of Stems	LGA_NAME_2011	Number of Stems
Albany (C)	28641	Mingenew (S)	632411
Beverley (S)	236895	Moora (S)	136357
Boyup Brook (S)	20000	Morawa (S)	1077397
Brookton (S)	758192	Mount Marshall (S)	1615997
Broomehill-Tambellup (S)	90791	Mullewa (S)	778275
Bruce Rock (S)	384590	Chapman Valley (S)	153811
Carnamah (S)	37700	Narembeen (S)	1158862
Chittering (S)	43500	Narrogin (S)	1183105
Coorow (S)	206702	Northam (S)	6605
Corrigin (S)	598086	Northampton (S)	13000
Cranbrook (S)	4000	Nungarin (S)	264852
Cuballing (S)	1378502	Perenjori (S)	84677
Cunderdin (S)	158600	Pingelly (S)	667409
Dalwallinu (S)	3995246	Plantagenet (S)	57708
Dandaragan (S)	46012	Quairading (S)	150000
Dowerin (S)	460143	Ravensthorpe (S)	47200
Dumbleyung (S)	527641	Tammin (S)	10500
Esperance (S)	856172	Three Springs (S)	151720
Geraldton-Greenough (C)	141907	Toodyay (S)	52190
Gnowangerup (S)	30180	Trayning (S)	148976
Goomalling (S)	74740	Victoria Plains (S)	123740
Harvey (S)	15000	Wagin (S)	1508343
Jerramungup (S)	15800	Wandering (S)	275119
Kalamunda (S)	10000	West Arthur (S)	65554
Katanning (S)	386131	Westonia (S)	48600
Kellerberrin (S)	396000	Wickepin (S)	2125780
Kent (S)	255430	Williams (S)	310322
Kojonup (S)	318504	Wongan-Ballidu (S)	1064791
Kondinin (S)	150244	Woodanilling (S)	399535
Koorda (S)	1439652	Wyalkatchem (S)	77130
Kulin (S)	1178060	Yalgoo (S)	49136
Lake Grace (S)	161326	Yilgarn (S)	92667
Merredin (S)	166060	York (S)	8900

Appendix B

XERION

		5000	4500	4000
Engine				
Manufacturer		Mercedes-Benz	Mercedes-Benz	Mercedes-Benz
Number of cylinders/intake		6	6	6
Cubic capacity	cm^3	12800	12800	10600
Nominal engine speed	rpm	1900	1900	1900
Lower engine idling speed	rpm	800	800	800
Upper engine idling speed	rpm	1976	1976	1976
Type approval value (97/68/EC)[1]	kW/hp	382/520	352/479	308/419
Output at nominal engine speed (ECE R 120)[2]	kW/hp	382/520	352/479	308/419
Max. output (ECE R 120)[2]	kW/hp	390/530	360/490	320/435
Max. torque (ECE R 120)[2]	Nm	2450	2300	2100
Fuel tank	l	740	740	740
Auxiliary tank (190 l)	l	●	●	○
Urea tank	l	90	90	90
Electrical system				
AC generator	V/A	150/24 + 240/12	150/24 + 240/12	150/24 + 240/12
Batteries	V/Ah	4 x 75 Ah, total 150/24, 150/12	4 x 75 Ah, total 150/24, 150/12	4 x 75 Ah, total 150/24, 150/12
CMATIC transmission				
Transmission type		Eccom 4.5 / Eccom 5.0	Eccom 4.5 / Eccom 5.0	Eccom 4.5 / Eccom 5.0
Transmission type		Hydrostatic-mechanical, split-power		
Output		Four-wheel drive, permanent	Four-wheel drive, permanent	Four-wheel drive, permanent
Max. speed	km/h	50/40	50/40	50/40
Longitudinal differential		Eccom 4.5: 100% lockable, lamella construction		
		Eccom 5.0: rigid (without longitudinal differential)		
PTO speed	rpm	1000	1000	1000
Automatic PTO engagement/disengagement		●	●	●
Powered steering axles				
Differential locks		100% lockable, electrohydraulic actuation, lamella construction, with automatic function		
Brakes				
Service brake		Hydraulically actuated wet multi-disc brakes, auxiliary-power-reinforced, acting on all wheels		
Parking brake		Electrohydraulically released spring-loaded brake		
Hydraulics				
Max. hydraulic tank capacity	l	120	120	120
Max. drawable volume	l	80	80	80
Main circuit (linkage, auxiliary spool valves)				
Max. operating pressure	Mpa (bar)	20 (200)	20 (200)	20 (200)
Max. flow rate	l/min	195	195	195
Number of spool valves		Max. 7 rear, max. 3 front	Max. 7 rear, max. 3 front	Max. 7 rear, max. 3 front
Max. flow rate per disc	l/min	105	105	105
Max. hydraulic output total	kW	58	58	58

XERION

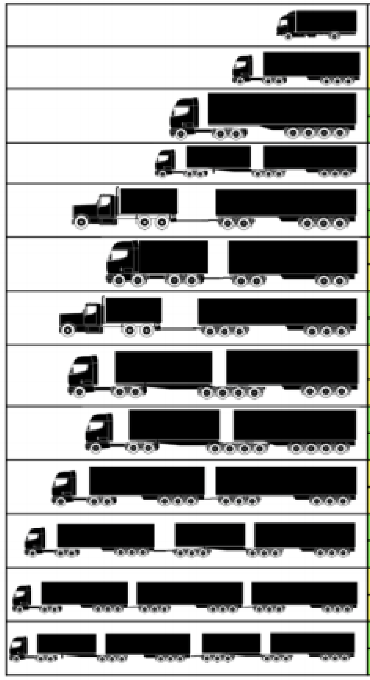
		5000	4500	4000
Power hydraulics (optional)				
Operating pressure	Mpa (bar)	26 (260)	26 (260)	26 (260)
Max. flow rate	l/min	250 at 1650 rpm	250 at 1650 rpm	250 at 1650 rpm SADDLE TRAC: 250 at 1480 rpm
Max. hydraulic output total	kW	90	90	90
Auxiliary hydraulics (optional)				
Operating pressure	Mpa (bar)	20 (200)	20 (200)	20 (200)
Max. flow rate	l/min	80	80	80
Hitch type				
Automatic hitch, D38 pin, spherical	max. kg	Drawbar load 2000	Drawbar load 2000	Drawbar load 2000
Hitch with hitch ball, ball system 80	max. kg	Drawbar load 3000	Drawbar load 3000	Drawbar load 3000
D40, D50 variable drawbar	max. kg	Drawbar load 3000	Drawbar load 3000	Drawbar load 3000
Drawbar ball system	max. kg	Drawbar load 4000	Drawbar load 4000	Drawbar load 4000
Hitch ball	max. kg	Drawbar load 15000	Drawbar load 15000	Drawbar load 15000
Piton Fix	max. kg	Drawbar load 4000	Drawbar load 4000	Drawbar load 4000
Front linkage				
Category	Mpa (bar)	III N, double-acting	III N, double-acting	III N, double-acting
Continuous lift capacity	kN	81	81	81
Max. lift capacity	kN	84	84	84
Max. lifting range	mm	905	905	905
Selectable function		Raise, lower (press)	Raise, lower (press)	Raise, lower (press)
Control function		Position control, vibration damping	Position control, vibration damping	Position control, vibration damping
Rear linkage				
Category		IV N, double-acting	IV N, double-acting	IV N, double-acting
Continuous lift capacity / max. lift capacity / max. lift range	mm	100 kN / 136 kN / 763	100 kN / 136 kN / 763	100 kN / 136 kN / 763
Selectable function		Raise, lower (press)	Raise, lower (press)	Raise, lower (press)
Control function		Position control/draught resistance, vibration damping	Position control/draught resistance, vibration damping	Position control/draught resistance, vibration damping
Dimensions and weights				
Overall length including linkages	mm	7593	7593	7593
Overall width	mm	2490 to 3300	2490 to 3300	2490 to 3300
Overall height depending on tyres	mm	3791 to 3941	3791 to 3941	3791 to 3941
Wheelbase	mm	3600	3600	3600
Ground clearance depending on equipment	mm	375 to 525	375 to 525	375 to 525
Smallest turning circle	m	15	15	15
TRAC tare weight (with tyres/full tank/standard equipment)	kg	16570	16570	16170

Appendix C

Table 10: Truck impact chart – non modular combinations

Truck Impact Chart for PBS and non-modular configuration

AUSTRALIAN TRUCKING ASSOCIATION Truck Impact Chart 13 February 2017 Non Modular



	Configuration Code (ATA TAP)	GCM	Payload	Calculated ESA's 4th Power – Load Status 0%	50%	100%	No Trips per 1000 tonnes	ESA's per 1000 tonnes	Nom Fuel / 100 kilometre	Fuel Required per 1000k lead	Driver Requirement	Overall Length (metres)	EAM ≥ (metres)	Emissions / 1000 tonnes	Convoy Length at 60 km/h (kilometres)	Convoy Length at 100 km/h (kilometres)
Three Axle Rigid GML	R12	22.5	13.12	0.51	1.27	3.58	77	316	28.0	43120	183%	<12.5		109%	4.82	7.38
Six Axle Artic GML	**A123**	**43.0**	**24.04**	**1.7**	**2.6**	**5.5**	**42**	**304**	**47**	**39480**	**1.0**	19.0	10.0	**100%**	2.9	4.3
Seven Axle 124 GML	A124	47.0	26.65	1.6	2.5	5.4	38	267	50	38000	90%	20.0	11.3	88%	2.66	3.93
Seven Axle 124 HML	A124	50.5	30.15	1.6	2.7	6.5	34	274	51	34680	81%	20.0	11.3	80%	2.38	3.52
B.double GML	B1233	63.0	38.84	1.69	2.80	6.91	26	224	62	32240	62%	≤ 26 metres	21.0	82%	1.98	2.85
8 Axle Truck & Dog Trailer - GML	R12T23	59.5	42.00	1.64	2.62	7.60	24	222	61	29280	57%	≤ 23 metres	19.7	68%	1.76	2.56
8 Axle Truck & Dog Trailer - HML	R12T23	63.0	45.20	1.64	2.62	7.60	23	213	64	29440	55%		19.7	68%	1.68	2.45
8 Axle Truck & Dog Trailer - GML	R22T22	60.5	42.20	0.36	1.82	8.26	24	207	61	29280	57%	≤ 23 metres	22.0	68%	1.76	2.56
8 Axle Truck & Dog Trailer - HML	R22T22	62.0	43.70	0.36	1.91	9.04	23	216	64	29440	55%		20.3	68%	1.68	2.45
9 Axle Truck & Dog Trailer - GML	R12T33	63.0	44.80	1.64	2.53	6.91	23	197	62	28520	55%	≤ 26 metres	21.0	66%	1.73	2.5
9 Axle Truck & Dog Trailer - HML	R12T33	68.5	50.30	1.64	2.53	6.91	20	171	65	26000	48%		21.0	60%	1.5	2.17
Super B.double (10 axles) GML	B1243	67.0	39.92	1.87	2.96	6.82	26	226	65	33800	62%	≤ 30 metres	24.7	78%	2.08	2.95
Super B.double (10 axles) HML	B1243	73.0	45.92	1.87	2.96	6.82	22	191	68	29920	52%		24.7	69%	1.76	2.5
Super B.double (11 axles) GML	B1244	71.0	42.78	1.87	2.95	6.73	24	206	67	32160	57%	≤ 30 metres	27.3	75%	1.92	2.72
Super B.double (11 axles) HML	B1244	77.5	49.28	1.87	2.95	6.73	21	181	70	29400	50%		27.3	68%	1.68	2.38
Type 1 Road Train Triaxle Dolly - GML	A123T33	83.0	51.43	1.71	3.10	8.29	20	200	68	27200	48%	≤ 36.5 metres	23.3	63%	1.73	2.4
Type 1 Road Train Triaxle Dolly - HML	A123T33	91.0	59.43	1.71	3.10	8.29	17	170	72	24480	40%		23.3	57%	1.48	2.04
AB.Triple Triaxle Dolly - GML	A123T3B33	103.0	66.70	1.83	3.38	9.67	15	173	80	24000	36%	≤ 42.5 metres	30.0	56%	1.39	1.89
AB.Triple Triaxle Dolly - HML	A123T3B33	113.5	77.20	1.83	3.38	9.67	13	150	85	22100	31%		30.0	51%	1.21	1.64
Type 2 Road Train Triaxle Dolly - GML	A123T33T33	123.0	78.82	1.74	3.62	11.05	13	166	84	21840	31%	≤ 53.5 metres	36.7	51%	1.35	1.78
Type 2 Road Train Triaxle Dolly - HML	A123T33T33	136.0	91.82	1.74	3.62	11.05	11	141	87	19140	26%		36.7	44%	1.14	1.51
BAB Quad Triaxle Dolly - GML	B1233T3B33	123.0	81.03	1.72	3.54	11.05	13	166	84	21840	31%	≤ 53.5 metres	36.7	51%	1.32	1.76
BAB Quad Triaxle Dolly - HML	B1233T3B33	136.0	94.03	1.72	3.54	11.05	11	141	87	19140	26%		36.7	44%	1.12	1.49

For further information contact ATA on 02 6253 6900

EAM (Extreme Axle Measurement)	is the minimum dimensional requirement in regard to Axle Spacing Mass Schedule (ASMS) requirements for the stated Gross Combination Mass. The formula varies depending on the gross mass of the vehicle and whether the vehicle is a road train. In addition to EAM, internal axle groups must also comply to the appropriate ASMS

* The data in this table is provided for general information and does not take into account your specific circumstances. You should obtain professional engineering advice before taking action.

Australian Trucking Association and Barkwood Consulting P/L | **August 2016** | **Truck Impact Chart Non-Modular**

Appendix D

This table is for the biomass supply chain. The weight of a green mallee tree is 36kg, and its moisture content is 50%. The payload of the Seven Axle 124 HML (configuration code: A124) is about 28 tonnes and its nominal diesel consumption per 100 km is 51 L. The water use factor for diesel is 2.2 L H_2O/ diesel. The LHV of raw mallee chips is (17.2 MJ/kg).

Number	Selected Shire Name	Number of Mallee Stems	Green biomss production (tonnes/4years)	Dry biomass production (tonnes/4years)	Shire of area (km^2)	Number of farm gate in every shire	Every farm gate mallee weight (tonnes)	Number of trucks in every farm gate in every shire	Blue water consumption (L/ 4year)	The total provided energy (GJ/4years)	The ratio (L H_2O/GJ)
v1	Mullewa	778,275	28017.9	14009.0	8452.694	17	1648.11	59	1452399.9	240,954	6.03
2	Mingenew	632,411	22766.8	11383.4	1934.886	4	5691.70	203	1036826.7	195,794	5.30
3	Morawa	1,077,397	38786.3	19393.1	3510.593	8	4848.29	173	1721689.6	333,562	5.16
4	Coorow	206,702	7441.3	3720.6	4189.879	9	826.81	30	267569.0	63,995	4.18
5	Dalwallinu	3,995,246	143828.9	71914.4	7224.357	15	9588.59	342	5327712.6	1,236,928	4.31
6	Mount Marshall	1,615,997	58175.9	29087.9	10184.594	21	2770.28	99	2126268.3	500,313	4.25
7	Wongan-Ballidu	1,064,791	38332.5	19166.2	3365.068	7	5476.07	196	1301242.8	329,659	3.95
8	Koorda	1,439,652	51827.5	25913.7	2832.313	6	8637.91	308	1818585.3	445,716	4.08
9	Dowerin	460,143	16565.1	8282.6	1863.085	4	4141.29	148	490208.3	142,460	3.44
10	Nungarin	264,852	9534.7	4767.3	1166.025	3	3178.22	114	311512.7	81,998	3.80
11	Kellerberrin	396,000	14256.0	7128.0	1915.433	4	3564.00	127	381029.3	122,602	3.11
12	Bruce Rock	384,590	13845.2	6922.6	2724.694	6	2307.54	82	345824.4	119,069	2.90
13	Narembeen	1,158,862	41719.0	20859.5	3809.029	8	5214.88	186	1050689.4	358,784	2.93
14	Beverley	236,895	8528.2	4264.1	2370.52	5	1705.64	61	155149.0	73,343	2.12
15	Wandering	275,119	9904.3	4952.1	1903.865	4	2476.07	88	135335.7	85,177	1.59
16	Brookton	758,192	27294.9	13647.5	1601.153	4	6823.73	244	453904.6	234,736	1.93
17	Corrigin	598,086	21531.1	10765.5	2681.271	6	3588.52	128	414998.0	185,167	2.24
18	Pingelly	667,409	24026.7	12013.4	1294.572	3	8008.91	286	355588.7	206,630	1.72
19	Cuballing	1,378,502	49626.1	24813.0	1195.337	3	16542.02	591	591273.4	426,784	1.39
20	Wickepin	2,125,780	76528.1	38264.0	2040.899	5	15305.62	547	1064719.9	658,141	1.62
21	Kulin	1,178,060	42410.2	21205.1	4718.922	10	4241.02	151	911577.3	364,727	2.50

22	Williams	310,322	11171.6	5585.8	2304.712	5	2234.32	80	84894.6	96,076	0.88
23	Narrogin	1,183,105	42591.8	21295.9	1631.302	4	10647.95	380	486413.3	366,289	1.33
24	Wagin	1,508,343	54300.3	27150.2	1946.176	4	13575.09	485	526566.0	466,983	1.13
25	Dumbleyung	527,641	18995.1	9497.5	2539.225	6	3165.85	113	268943.1	163,358	1.65
26	Woodanilling	399,535	14383.3	7191.6	1128.835	3	4794.42	171	162532.9	123,696	1.31
27	Kojonup	318,504	11466.1	5733.1	2930.993	6	1911.02	68	113641.0	98,609	1.15
28	Katanning	386,131	13900.7	6950.4	1518.185	4	3475.18	124	179918.0	119,546	1.51
29	Kent	255,430	9195.5	4597.7	5624.582	12	766.29	27	164033.2	79,081	2.07
30	Esperance	856,172	30822.2	15411.1	44797.546	90	342.47	12	1574491.8	265,071	5.94

Appendix E

Parameter	Alexander	Bird	Fuchbichler	Morrell	Quicke	Stanley	Strahan	Sullivan 1	Sullivan 2
Site number	1	2	3	4	5	6	7	8	9
Biomass yield (dt/ha/y)	15.4	5.4	4.7	6.0	4.4	7.5	3.9	13.4	7.0
Distance to site from regional centre (km)	15	49	111	93	110	128	86	31	33
Distance to nursery from regional centre (km)	56	56	83	56	56	83	83	10	10
Distance to nursery from site (km)	55	33	37	112	70	45	48	31	33
Advisor travel time from regional centre to site (hours)	0.3	1.1	2.5	2.1	2.4	2.8	1.9	0.7	0.7
Advisor travel time from regional centre to nursery (hours)	1.2	1.2	1.8	1.2	1.2	1.8	1.8	0.2	0.2
Travel time from nursery to site (hours)	1.6	0.9	1.1	3.2	2.0	1.3	1.4	0.9	0.9
Harvest cycle period (years)	4	5	5	5	5	4	4	4	4
Row number	2	3	2	2	2	2	3	6	6
Belt width (m)	6	8	6	6	6	6	8	14	14
Space between trees within rows (m)	2	2	2	2	2	2	2	2	2
Number of trees per m of belt	1	1.5	1	1	1	1	1.5	3	3
Number of trees per km of belt	1,000	1,500	1,000	1,000	1,000	1,000	1,500	3,000	3,000
Standard planting in number of trees	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Standard planting (km)	25.0	16.7	25.0	25.0	25.0	25.0	16.7	8.3	8.3
Area of belt per km of length (ha)	0.6	0.8	0.6	0.6	0.6	0.6	0.8	1.4	1.4
Standard planting area (ha)	15.0	13.3	15.0	15.0	15.0	15.0	13.3	11.7	11.7
Number of trees per ha	1,667	1,875	1,667	1,667	1,667	1,667	1,875	2,143	2,143
Fertilizer (urea) kg applied once in each harvest cycle	799	349	267	441	415	420	214	553	380
Fertilizer (DAP) kg applied once in each harvest cycle	163	78	104	116	77	89	46	187	71
Fertilizer (MOP) kg applied once in each harvest cycle	346	149	170	165	179	226	101	293	155

Murdoch UNIVERSITY

Appendix F

This table is for the transport from every farm gate of every selected shire to the Muja power station. The payload of the Seven Axle 124 HML (configuration code: A124) is about 28 tonnes and its nominal diesel consumption per 100 km is 51 L. The water use factor for diesel is 2.2 L H_2O/ diesel.

Nearest town-site	Farm gate	Latitude	Longitude	Every farm gate green mallee weight (kg/4years)	Number of Truck in every farm gate	Distance to Muja station (km)	Blue water consumption (L/4years)
Mullewa	Site 1	-28.917	115.441	1648111.8	59	592	78194.0
	Site 2	-28.821	115.515	1648111.8	59	609	80439.4
	Site 3	-28.673	115.516	1648111.8	59	626	82684.8
	Site 4	-28.539	115.512	1648111.8	59	643	84930.3
	Site 5	-28.423	115.584	1648111.8	59	662	87439.9
	Site 6	-28.283	115.633	1648111.8	59	678	89553.2
	Site 7	-28.131	115.686	1648111.8	59	697	92062.8
	Site 8	-28.635	115.348	1648111.8	59	657	86779.4
	Site 9	-28.688	115.181	1648111.8	59	669	88364.5
	Site 10	-28.706	115.058	1648111.8	59	657	86779.4
	Site 11	-28.540	115.512	1648111.8	59	643	84930.3
	Site 12	-28.509	115.675	1648111.8	59	660	87175.7
	Site 13	-28.472	115.840	1648111.8	59	667	88100.3
	Site 14	-28.440	116.019	1648111.8	59	695	91798.6
	Site 15	-28.852	115.791	1648111.8	59	596	78722.3
	Site 16	-28.754	115.673	1648111.8	59	614	81099.8
	Site 17	-28.621	115.626	1648111.8	59	631	83345.2
Mingenew	Site 1	-29.162	115.545	5691699.00	203	571	260461.1
	Site 2	-29.061	115.408	5691699.00	203	575	262285.7
	Site 3	-29.274	115.521	5691699.00	203	546	249057.4
	Site 4	-29.203	115.342	5691699.00	203	581	265022.6
Morawa	Site 1	-29.271	115.928	4848286.50	173	548	212928.4
	Site 2	-29.171	115.674	4848286.50	173	564	219145.3
	Site 3	-29.188	115.792	4848286.50	173	571	221865.2
	Site 4	-29.195	115.910	4848286.50	173	559	217202.5
	Site 5	-28.963	115.883	4848286.50	173	581	225750.8
	Site 6	-29.077	115.973	4848286.50	173	565	219533.9
	Site 7	-29.218	116.008	4848286.50	173	548	212928.4
	Site 8	-29.852	115.791	4848286.50	173	495	192335.0
Coorow	Site 1	-30.002	115.315	826808.00	30	450	29818.2
	Site 2	-30.127	115.355	826808.00	30	435	28824.3
	Site 3	-29.925	116.045	826808.00	30	452	29950.8
	Site 4	-30.036	116.079	826808.00	30	437	28956.8
	Site 5	-30.178	116.044	826808.00	30	420	27830.4
	Site 6	-29.931	115.973	826808.00	30	463	30679.7
	Site 7	-29.867	116.148	826808.00	30	470	31143.5
	Site 8	-30.006	116.356	826808.00	30	463	30679.7
	Site 9	-30.028	116.205	826808.00	30	448	29685.7

Dalwallinu	Site 1	-30.032	116.595	9588590.40	342	473	363480.2
	Site 2	-30.160	116.654	9588590.40	342	457	351184.9
	Site 3	-30.294	116.666	9588590.40	342	441	338889.6
	Site 4	-30.431	116.642	9588590.40	342	449	345037.2
	Site 5	-30.464	116.503	9588590.40	342	409	314298.9
	Site 6	-30.105	116.633	9588590.40	342	464	356564.1
	Site 7	-30.024	116.765	9588590.40	342	480	368859.4
	Site 8	-29.941	116.866	9588590.40	342	496	381154.7
	Site 9	-29.829	116.956	9588590.40	342	511	392681.5
	Site 10	-29.994	116.421	9588590.40	342	469	360406.3
	Site 11	-30.451	117.161	9588590.40	342	440	338121.1
	Site 12	-30.355	117.075	9588590.40	342	455	349647.9
	Site 13	-30.286	116.989	9588590.40	342	492	378080.9
	Site 14	-30.282	116.825	9588590.40	342	458	351953.3
	Site 15	-30.517	116.714	9588590.40	342	439	337352.6
Mount Marshall	Site 1	-30.833	117.596	2770280.57	99	429	95245.8
	Site 2	-30.834	117.651	2770280.57	99	434	96355.9
	Site 3	-30.832	117.705	2770280.57	99	435	96577.9
	Site 4	-30.834	117.760	2770280.57	99	430	95467.8
	Site 5	-30.835	117.808	2770280.57	99	425	94357.7
	Site 6	-30.833	117.858	2770280.57	99	421	93469.7
	Site 7	-30.816	117.890	2770280.57	99	425	94357.7
	Site 8	-30.825	117.938	2770280.57	99	429	95245.8
	Site 9	-30.824	117.986	2770280.57	99	434	96355.9
	Site 10	-30.439	117.603	2770280.57	99	472	104792.6
	Site 11	-30.433	117.655	2770280.57	99	477	105902.7
	Site 12	-30.433	117.708	2770280.57	99	482	107012.8
	Site 13	-30.444	117.758	2770280.57	99	476	105680.7
	Site 14	-30.451	117.812	2770280.57	99	471	104570.6
	Site 15	-30.451	117.861	2770280.57	99	466	103460.5
	Site 16	-30.457	117.910	2770280.57	99	469	104126.5
	Site 17	-30.469	117.960	2770280.57	99	474	105236.6
	Site 18	-30.467	118.008	2770280.57	99	479	106346.7
	Site 19	-30.463	118.060	2770280.57	99	484	107456.8
	Site 20	-30.475	118.106	2770280.57	99	485	107678.8
	Site 21	-30.510	118.121	2770280.57	99	480	106568.7
Wongan-Ballidu	Site 1	-30.801	117.123	5476068.00	196	418	183446.7
	Site 2	-30.685	117.180	5476068.00	196	433	190029.7
	Site 3	-30.554	117.185	5476068.00	196	448	196612.7
	Site 4	-30.517	116.714	5476068.00	196	439	192662.9
	Site 5	-30.632	116.769	5476068.00	196	424	186079.9
	Site 6	-30.760	116.756	5476068.00	196	409	179496.9
	Site 7	-30.885	116.717	5476068.00	196	394	172913.9
Koorda	Site 1	-30.461	117.494	8637912.00	308	462	319827.3

	Site 2	-30.467	117.385	8637912.00	308	453	313596.9
	Site 3	-30.488	117.278	8637912.00	308	442	305982.0
	Site 4	-30.501	117.234	8637912.00	308	438	303212.9
	Site 5	-30.880	117.480	8637912.00	308	411	284521.7
	Site 6	-30.827	117.520	8637912.00	308	421	291444.4
Dowerin	Site 1	-31.034	117.115	4141287.00	148	391	129770.8
	Site 2	-31.220	117.052	4141287.00	148	364	120809.6
	Site 3	-31.388	117.107	4141287.00	148	337	111848.5
	Site 4	-31.187	117.201	4141287.00	148	385	127779.4
Nungarin	Site 1	-31.054	118.105	3178224	114	415	105705.5
	Site 2	-31.178	118.091	3178224	114	401	102139.5
	Site 3	-31.157	118.030	3178224	114	407	103667.8
Kellerberrin	Site 1	-31.633	117.761	3564000	127	329	93972.0
	Site 2	-31.601	117.902	3564000	127	343	97970.8
	Site 3	-31.648	117.709	3564000	127	323	92258.2
	Site 4	-31.517	117.730	3564000	127	339	96828.3
Bruce Rock	Site 1	-31.935	117.849	2307540.0	82	310	57329.2
	Site 2	-31.887	118.015	2307540.0	82	315	58253.8
	Site 3	-31.837	118.168	2307540.0	82	316	58438.8
	Site 4	-31.710	118.020	2307540.0	82	329	60842.9
	Site 5	-31.874	118.143	2307540.0	82	311	57514.1
	Site 6	-32.041	118.104	2307540.0	82	289	53445.6
Narembeen	Site 1	-32.223	118.286	5214879.00	186	291	121619.2
	Site 2	-32.164	118.337	5214879.00	186	300	125380.6
	Site 3	-32.089	118.380	5214879.00	186	311	129977.9
	Site 4	-31.998	118.396	5214879.00	186	322	134575.2
	Site 5	-31.874	118.396	5214879.00	186	336	140426.3
	Site 6	-31.985	118.294	5214879.00	186	324	135411.0
	Site 7	-32.056	118.340	5214879.00	186	312	130395.8
	Site 8	-32.070	118.438	5214879.00	186	318	132903.4
Beverley	Site 1	-32.302	116.573	1705644.0	61	228	31166.5
	Site 2	-32.202	116.794	1705644.0	61	221	30209.6
	Site 3	-32.093	116.944	1705644.0	61	234	31986.7
	Site 4	-32.260	116.995	1705644.0	61	213	29116.1
	Site 5	-32.084	116.856	1705644.0	61	239	32670.1
Wandering	Site 1	-32.611	116.909	2476071.0	88	180	35719.1
	Site 2	-32.698	116.692	2476071.0	88	155	30758.1
	Site 3	-32.581	116.505	2476071.0	88	167	33139.4
	Site 4	-32.455	116.325	2476071.0	88	180	35719.1
Brookton	Site 1	-32.401	117.024	6823728.0	244	195	106640.2
	Site 2	-32.355	116.654	6823728.0	244	216	118124.6
	Site 3	-32.394	116.884	6823728.0	244	205	112109.0
	Site 4	-32.318	117.160	6823728.0	244	214	117030.8
Corrigin	Site 1	-32.336	117.431	3588516.0	128	233	67009.4

	Site 2	-32.372	117.660	3588516.0	128	240	69022.5
	Site 3	-32.347	117.897	3588516.0	128	246	70748.1
	Site 4	-32.255	117.731	3588516.0	128	248	71323.3
	Site 5	-32.264	118.000	3588516.0	128	258	74199.2
	Site 6	-32.469	117.742	3588516.0	128	218	62695.5
Pingelly	Site 1	-32.539	117.060	8008908.0	286	181	116176.1
	Site 2	-32.511	117.223	8008908.0	286	193	123878.4
	Site 3	-32.520	117.076	8008908.0	286	180	115534.2
Cuballing	Site 1	-32.682	117.139	16542024.0	591	159	210790.3
	Site 2	-32.793	117.184	16542024.0	591	145	192230.1
	Site 3	-32.786	117.026	16542024.0	591	142	188253.0
Wickepin	Site 1	-32.780	117.646	15305616.0	547	180	220794.4
	Site 2	-32.781	117.500	15305616.0	547	167	204848.2
	Site 3	-32.687	117.599	15305616.0	547	185	226927.6
	Site 4	-32.921	117.732	15305616.0	547	182	223247.7
	Site 5	-32.904	117.430	15305616.0	547	154	188901.9
Kulin	Site 1	-32.780	117.876	4241016.0	151	201	68317.3
	Site 2	-32.487	118.040	4241016.0	151	262	89050.4
	Site 3	-32.756	118.068	4241016.0	151	221	75115.1
	Site 4	-32.626	118.116	4241016.0	151	242	82252.7
	Site 5	-32.711	118.309	4241016.0	151	255	86671.2
	Site 6	-32.627	118.207	4241016.0	151	243	82592.6
	Site 7	-32.669	118.160	4241016.0	151	237	80553.3
	Site 8	-32.677	118.500	4241016.0	151	269	91429.6
	Site 9	-32.699	119.450	4241016.0	151	375	127457.7
	Site 10	-32.631	119.358	4241016.0	151	377	128137.5
Williams	Site 1	-33.010	116.977	2234318.4	80	108	19339.0
	Site 2	-33.112	116.945	2234318.4	80	108	19339.0
	Site 3	-33.103	116.713	2234318.4	80	83.9	15023.5
	Site 4	-33.210	116.539	2234318.4	80	62.2	11137.8
	Site 5	-32.941	116.763	2234318.4	80	112	20055.2
Narrogin	Site 1	-32.981	117.062	10647945.0	380	116	98989.4
	Site 2	-33.040	117.239	10647945.0	380	141	120323.3
	Site 3	-32.937	117.567	10647945.0	380	165	140803.9
	Site 4	-32.946	117.386	10647945.0	380	148	126296.8
Wagin	Site 1	-33.282	117.486	13575087.0	485	130	141433.0
	Site 2	-33.375	117.359	13575087.0	485	124	134905.3
	Site 3	-33.225	117.286	13575087.0	485	126	137081.2
	Site 4	-33.323	117.217	13575087.0	485	104	113146.4
Dumbleyung	Site 1	-33.154	118.103	3165846.0	113	198	50236.5
	Site 2	-33.183	117.931	3165846.0	113	181	45923.3
	Site 3	-33.254	117.784	3165846.0	113	164	41610.1
	Site 4	-33.125	117.909	3165846.0	113	186	47191.9
	Site 5	-33.392	117.827	3165846.0	113	169	42878.7

	Site 6	-33.383	117.735	3165846.0	113	162	41102.6
Woodanilling	Site 1	-33.538	117.087	4794420.0	171	109	41882.0
	Site 2	-33.564	117.424	4794420.0	171	147	56483.1
	Site 3	-33.511	117.612	4794420.0	171	167	64167.8
Kojonup	Site 1	-33.758	117.003	1911024.0	68	103	15775.0
	Site 2	-34.024	117.018	1911024.0	68	142	21748.0
	Site 3	-33.853	116.957	1911024.0	68	120	18378.6
	Site 4	-33.839	117.150	1911024.0	68	122	18684.9
	Site 5	-33.960	117.203	1911024.0	68	136	20829.1
	Site 6	-33.798	117.148	1911024.0	68	119	18225.4
Katanning	Site 1	-33.773	117.332	3475179.0	124	138	38434.5
	Site 2	-33.697	117.546	3475179.0	124	159	44283.2
	Site 3	-33.680	117.770	3475179.0	124	181	50410.5
	Site 4	-33.628	117.544	3475179.0	124	168	46789.8
Kent	Site 1	-33.423	118.514	766290.0	27	259	15905.9
	Site 2	-33.507	118.514	766290.0	27	249	15291.8
	Site 3	-33.564	118.470	766290.0	27	241	14800.5
	Site 4	-33.593	118.400	766290.0	27	232	14247.7
	Site 5	-33.686	118.385	766290.0	27	240	14739.0
	Site 6	-33.729	118.365	766290.0	27	245	15046.1
	Site 7	-33.582	118.055	766290.0	27	206	12651.0
	Site 8	-33.547	118.161	766290.0	27	208	12773.8
	Site 9	-33.583	118.260	766290.0	27	218	13388.0
	Site 10	-33.627	117.951	766290.0	27	200	12282.5
	Site 11	-33.466	117.907	766290.0	27	180	11054.3
	Site 12	-33.490	118.035	766290.0	27	193	11852.6
Esperance	Site 1	-32.601	121.566	342468.8	12	723	19843.8
	Site 2	-32.629	121.543	342468.8	12	719	19734.0
	Site 3	-32.664	121.538	342468.8	12	717	19679.1
	Site 4	-32.700	121.536	342468.8	12	711	19514.4
	Site 5	-32.740	121.533	342468.8	12	707	19404.6
	Site 6	-32.770	121.544	342468.8	12	703	19294.8
	Site 7	-32.805	121.560	342468.8	12	699	19185.1
	Site 8	-32.841	121.577	342468.8	12	695	19075.3
	Site 9	-32.872	121.591	342468.8	12	691	18965.5
	Site 10	-32.906	121.607	342468.8	12	687	18855.7
	Site 11	-32.942	121.624	342468.8	12	683	18745.9
	Site 12	-32.978	121.640	342468.8	12	678	18608.7
	Site 13	-33.007	121.652	342468.8	12	675	18526.3
	Site 14	-33.039	121.668	342468.8	12	671	18416.6
	Site 15	-33.074	121.682	342468.8	12	667	18306.8
	Site 16	-33.108	121.693	342468.8	12	663	18197.0
	Site 17	-33.147	121.706	342468.8	12	659	18087.2
	Site 18	-33.177	121.717	342468.8	12	655	17977.4

	Site 19	-33.212	121.716	342468.8	12	651	17867.6
	Site 20	-33.248	121.716	342468.8	12	647	17757.8
	Site 21	-33.284	121.716	342468.8	12	643	17648.1
	Site 22	-33.323	121.715	342468.8	12	639	17538.3
	Site 23	-33.355	121.705	342468.8	12	635	17428.5
	Site 24	-33.385	121.694	342468.8	12	631	17318.7
	Site 25	-33.418	121.710	342468.8	12	627	17208.9
	Site 26	-33.451	121.727	342468.8	12	623	17099.1
	Site 27	-33.483	121.726	342468.8	12	619	16989.3
	Site 28	-33.516	121.716	342468.8	12	615	16879.6
	Site 29	-33.547	121.738	342468.8	12	611	16769.8
	Site 30	-33.575	121.758	342468.8	12	607	16660.0
	Site 31	-33.604	121.781	342468.8	12	603	16550.2
	Site 32	-33.634	121.805	342468.8	12	599	16440.4
	Site 33	-33.671	121.825	342468.8	12	598	16413.0
	Site 34	-33.701	121.836	342468.8	12	605	16605.1
	Site 35	-33.736	121.849	342468.8	12	601	16495.3
	Site 36	-33.769	121.863	342468.8	12	598	16413.0
	Site 37	-33.803	121.878	342468.8	12	603	16550.2
	Site 38	-33.832	121.895	342468.8	12	605	16605.1
	Site 39	-33.832	121.858	342468.8	12	601	16495.3
	Site 40	-33.809	121.825	342468.8	12	596	16358.1
	Site 41	-33.788	121.792	342468.8	12	593	16275.7
	Site 42	-33.762	121.762	342468.8	12	588	16138.5
	Site 43	-33.748	121.722	342468.8	12	584	16028.7
	Site 44	-33.735	121.684	342468.8	12	581	15946.4
	Site 45	-33.730	121.641	342468.8	12	577	15836.6
	Site 46	-33.726	121.598	342468.8	12	575	15781.7
	Site 47	-33.700	121.567	342468.8	12	575	15781.7
	Site 48	-33.697	121.517	342468.8	12	564	15479.8
	Site 49	-33.694	121.477	342468.8	12	560	15370.0
	Site 50	-33.705	121.440	342468.8	12	557	15287.7
	Site 51	-33.713	121.398	342468.8	12	553	15177.9
	Site 52	-33.725	121.355	342468.8	12	549	15068.1
	Site 53	-33.735	121.314	342468.8	12	544	14930.9
	Site 54	-33.742	121.274	342468.8	12	541	14848.5
	Site 55	-33.753	121.231	342468.8	12	536	14711.3
	Site 56	-33.758	121.185	342468.8	12	532	14601.5
	Site 57	-33.763	121.146	342468.8	12	528	14491.7
	Site 58	-33.749	123.206	342468.8	12	726	19926.1
	Site 59	-33.747	123.163	342468.8	12	722	19816.3
	Site 60	-33.745	123.119	342468.8	12	718	19706.5
	Site 61	-33.744	123.077	342468.8	12	714	19596.7
	Site 62	-33.745	123.033	342468.8	12	710	19487.0

	Site 63	-33.744	122.990	342468.8	12	706	19377.2
	Site 64	-33.750	122.948	342468.8	12	702	19267.4
	Site 65	-33.747	122.906	342468.8	12	698	19157.6
	Site 66	-33.745	122.899	342468.8	12	698	19157.6
	Site 67	-33.751	122.821	342468.8	12	690	18938.0
	Site 68	-33.754	122.777	342468.8	12	686	18828.2
	Site 69	-33.755	122.725	342468.8	12	681	18691.0
	Site 70	-33.753	122.693	342468.8	12	678	18608.7
	Site 71	-33.749	122.651	342468.8	12	674	18498.9
	Site 72	-33.749	122.608	342468.8	12	670	18389.1
	Site 73	-33.748	122.562	342468.8	12	666	18279.3
	Site 74	-33.748	122.521	342468.8	12	662	18169.5
	Site 75	-33.752	122.477	342468.8	12	658	18059.7
	Site 76	-33.746	122.426	342468.8	12	653	17922.5
	Site 77	-33.744	122.377	342468.8	12	649	17812.7
	Site 78	-33.742	122.341	342468.8	12	646	17730.4
	Site 79	-33.740	122.308	342468.8	12	642	17620.6
	Site 80	-33.739	122.265	342468.8	12	638	17510.8
	Site 81	-33.734	122.223	342468.8	12	634	17401.0
	Site 82	-33.736	122.179	342468.8	12	630	17291.2
	Site 83	-33.738	122.137	342468.8	12	626	17181.5
	Site 84	-33.734	122.093	342468.8	12	622	17071.7
	Site 85	-33.734	122.049	342468.8	12	618	16961.9
	Site 86	-33.741	122.005	342468.8	12	614	16852.1
	Site 87	-33.752	121.973	342468.8	12	611	16769.8
	Site 88	-33.788	121.957	342468.8	12	613	16824.7
	Site 89	-33.813	121.929	342468.8	12	609	16714.9
	Site 90	-33.833	121.896	342468.8	12	605	16605.1

Appendix G

This table is for pyrolysis plant A of the bioslurry supply chain. Pyrolysis plant is sited in Dalwallinu shire (Latitude -30.266, Longitude 116.662). The operating time is 24 hours/day, 330 days/year (7,920 hours/ years). The truck for transporting mallee chips from the planting area to pyrolysis plant A is Seven Axle 124 HML (configuration code: A124) in this table. The truck for transporting bioslurry from pyrolysis plant B to the Muja power station is Type 1 Road Train Triaxle Dolly (configuration code: A123T33), the number of truck is 2 per day. Pyrolysis plant A is cover ten mallee planting areas nearby the Dalwallinu. The water use factor for diesel is 2.2 L H_2O/ diesel. The distance from pyrolysis plant A to the Muja power station is 460 km. The annual total energy produced by pyrolysis plant A is 785,301 GJ (117.808*330*20.2).

Number	Selected Shire Name	Number of Stems	Green biomss production (ton/4years)	Dry biomss production (ton/4years)	Dry biomss production (ton/day)	Number of farm gate in every shire	Bio-oil production (ton/4years)	The weight of bioslurry (ton/4 years)	Water consumption during transport biomass (L/4 years)	Water consumption during pyrolysis (L/4years)	Water consumption during transport bioslurry (L/4years)	The ratio (L H_2O/GJ)
1	Mullewa	778275	28017.9	14009.0	10.6	17	8685.5	10492.7	576152.1	14157444.9	254846.8	70.7
2	Mingenew	632411	22766.8	11383.4	8.6	4	7057.7	8526.2	373586.0	11504062.0	207083.5	70.2
3	Morawa	1077397	38786.3	19393.1	14.7	8	12023.8	14525.5	503568.0	19598713.3	352794.5	69.7
4	Coorow	206702	7441.3	3720.6	2.8	9	2306.8	2786.8	65865.2	3760074.7	67684.7	69.2
5	Dalwallinu	3995246	143828.9	71914.4	54.5	15	44586.9	53863.9	395294.3	72676720.9	1308246.6	68.4
6	Mount Marshall	1615997	58175.9	29087.9	22.0	21	18034.5	21786.9	709792.2	29396278.2	529159.5	69.6
7	Wongan-Ballidu	1064791	38332.5	19166.2	14.5	7	11883.1	14355.5	212412.0	19369400.1	348666.7	68.7
8	Koorda	1439652	51827.5	25913.7	19.6	6	16066.5	19409.4	439935.6	26188421.6	471415.2	69.1
9	Dowerin	460143	16565.1	8282.6	6.3	4	5135.2	6203.6	198141.1	8370369.3	150674.2	69.6
10	Nungarin	264852	9534.7	4767.3	3.6	3	2955.7	3570.7	177024.8	4817869.8	86726.0	70.5
	Total				157.3		97.526 (per day)	117,808.6 (per day)	912,942.8 (per year)	158,967.4 (per day)	944,324.4 (per year)	

Appendix H

This table is for the transport from every farm gate of ten selected shires to the pyrolysis plant A. The payload of the Seven Axle 124 HML (configuration code: A124) is about 30.15 tonnes and its nominal diesel consumption per 100 km is 51 L. The water use factor for diesel is 2.2 L H_2O/ diesel.

Nearest town-site	Farm gate	Latitude	Longitude	Every farm gate green mallee weight (kg/4years)	Number of Truck in every farm gate	Distance to Dalwallinu pyrolysis plant (km)	Blue water consumption (L/4years)
Mullewa	Site 1	-28.917	115.441	1648111.8	59	237	31304.0
	Site 2	-28.821	115.515	1648111.8	59	254	33549.4
	Site 3	-28.673	115.516	1648111.8	59	260	34341.9
	Site 4	-28.539	115.512	1648111.8	59	243	32096.5
	Site 5	-28.423	115.584	1648111.8	59	260	34341.9
	Site 6	-28.283	115.633	1648111.8	59	277	36587.4
	Site 7	-28.131	115.686	1648111.8	59	295	38964.9
	Site 8	-28.635	115.348	1648111.8	59	263	34738.2
	Site 9	-28.688	115.181	1648111.8	59	280	36983.6
	Site 10	-28.706	115.058	1648111.8	59	292	38568.6
	Site 11	-28.540	115.512	1648111.8	59	243	32096.5
	Site 12	-28.509	115.675	1648111.8	59	258	34077.8
	Site 13	-28.472	115.840	1648111.8	59	275	36323.2
	Site 14	-28.440	116.019	1648111.8	59	293	38700.7
	Site 15	-28.852	115.791	1648111.8	59	193	25492.3
	Site 16	-28.754	115.673	1648111.8	59	211	27869.8
	Site 17	-28.621	115.626	1648111.8	59	228	30115.2
Mingenew	Site 1	-29.162	115.545	5691699.00	203	195	88949.1
	Site 2	-29.061	115.408	5691699.00	203	220	100352.8
	Site 3	-29.274	115.521	5691699.00	203	190	86668.3
	Site 4	-29.203	115.342	5691699.00	203	214	97615.9
Morawa	Site 1	-29.271	115.928	4848286.50	173	156	60614.7
	Site 2	-29.171	115.674	4848286.50	173	181	70328.6
	Site 3	-29.188	115.792	4848286.50	173	169	65665.9
	Site 4	-29.195	115.910	4848286.50	173	157	61003.2
	Site 5	-28.963	115.883	4848286.50	173	178	69162.9
	Site 6	-29.077	115.973	4848286.50	173	162	62946.0
	Site 7	-29.218	116.008	4848286.50	173	145	56340.6
	Site 8	-29.852	115.791	4848286.50	173	148	57506.2
Coorow	Site 1	-30.002	115.315	826808.00	30	191	12656.2
	Site 2	-30.127	115.355	826808.00	30	186	12324.9
	Site 3	-29.925	116.045	826808.00	30	103	6825.1
	Site 4	-30.036	116.079	826808.00	30	84.3	5586.0
	Site 5	-30.178	116.044	826808.00	30	85.1	5639.0
	Site 6	-29.931	115.973	826808.00	30	115	7620.2
	Site 7	-29.867	116.148	826808.00	30	97.5	6460.6
	Site 8	-30.006	116.356	826808.00	30	58.6	3883.0
	Site 9	-30.028	116.205	826808.00	30	73.5	4870.3

Dalwallinu	Site 1	-30.032	116.595	9588590.40	342	30.3	23284.2
	Site 2	-30.160	116.654	9588590.40	342	14.3	10988.9
	Site 3	-30.294	116.666	9588590.40	342	3.0	2305.4
	Site 4	-30.431	116.642	9588590.40	342	19.5	14984.9
	Site 5	-30.464	116.503	9588590.40	342	35.1	26972.8
	Site 6	-30.105	116.633	9588590.40	342	21.3	16368.1
	Site 7	-30.024	116.765	9588590.40	342	37.3	28663.4
	Site 8	-29.941	116.866	9588590.40	342	53.3	40958.8
	Site 9	-29.829	116.956	9588590.40	342	69.1	53100.4
	Site 10	-29.994	116.421	9588590.40	342	51.7	39729.2
	Site 11	-30.451	117.161	9588590.40	342	65.5	50333.9
	Site 12	-30.355	117.075	9588590.40	342	50.2	38576.5
	Site 13	-30.286	116.989	9588590.40	342	33.9	26050.7
	Site 14	-30.282	116.825	9588590.40	342	18.1	13909.1
	Site 15	-30.517	116.714	9588590.40	342	11.8	9067.8
Mount Marshall	Site 1	-30.833	117.596	2770280.57	99	141	31304.6
	Site 2	-30.834	117.651	2770280.57	99	158	35078.9
	Site 3	-30.832	117.705	2770280.57	99	152	33746.8
	Site 4	-30.834	117.760	2770280.57	99	157	34856.9
	Site 5	-30.835	117.808	2770280.57	99	161	35744.9
	Site 6	-30.833	117.858	2770280.57	99	166	36855.0
	Site 7	-30.816	117.890	2770280.57	99	171	37965.1
	Site 8	-30.825	117.938	2770280.57	99	176	39075.2
	Site 9	-30.824	117.986	2770280.57	99	181	40185.3
	Site 10	-30.439	117.603	2770280.57	99	117	25976.1
	Site 11	-30.433	117.655	2770280.57	99	122	27086.2
	Site 12	-30.433	117.708	2770280.57	99	127	28196.3
	Site 13	-30.444	117.758	2770280.57	99	132	29306.4
	Site 14	-30.451	117.812	2770280.57	99	137	30416.5
	Site 15	-30.451	117.861	2770280.57	99	142	31526.6
	Site 16	-30.457	117.910	2770280.57	99	147	32636.7
	Site 17	-30.469	117.960	2770280.57	99	152	33746.8
	Site 18	-30.467	118.008	2770280.57	99	157	34856.9
	Site 19	-30.463	118.060	2770280.57	99	162	35966.9
	Site 20	-30.475	118.106	2770280.57	99	167	37077.0
	Site 21	-30.510	118.121	2770280.57	99	172	38187.1
Wongan-Ballidu	Site 1	-30.801	117.123	5476068.00	196	104	45642.2
	Site 2	-30.685	117.180	5476068.00	196	92.6	40639.2
	Site 3	-30.554	117.185	5476068.00	196	77.9	34187.8
	Site 4	-30.517	116.714	5476068.00	196	29.8	13078.3
	Site 5	-30.632	116.769	5476068.00	196	44.8	19661.3
	Site 6	-30.760	116.756	5476068.00	196	59.7	26200.4
	Site 7	-30.885	116.717	5476068.00	196	75.2	33002.9
Koorda	Site 1	-30.461	117.494	8637912.00	308	106	73380.3

	Site 2	-30.467	117.385	8637912.00	308	95.1	65834.6
	Site 3	-30.488	117.278	8637912.00	308	83.9	58081.2
	Site 4	-30.501	117.234	8637912.00	308	79.5	55035.2
	Site 5	-30.880	117.480	8637912.00	308	137	94840.6
	Site 6	-30.827	117.520	8637912.00	308	134	92763.8
Dowerin	Site 1	-31.034	117.115	4141287.00	148	123	40823.0
	Site 2	-31.220	117.052	4141287.00	148	146	48456.6
	Site 3	-31.388	117.107	4141287.00	148	169	56090.2
	Site 4	-31.187	117.201	4141287.00	148	159	52771.2
Nungarin	Site 1	-31.054	118.105	3178224	114	222	56546.1
	Site 2	-31.178	118.091	3178224	114	240	61130.9
	Site 3	-31.157	118.030	3178224	114	233	59347.9

Appendix I

This table is for pyrolysis plant B of bioslurry supply chain. Pyrolysis plant is sited in Wickepin shire (Latitude -32.775, Longitude 117.503). The operating time is 24 hours/day, 330 days/year (7,920 hours/ years). The truck for transporting mallee chips from the planting area to pyrolysis plant A is Seven Axle 124 HML (configuration code: A124) in this table. The truck for transporting bioslurry from pyrolysis plant B to the Muja power station is Type 1 Road Train Triaxle Dolly (configuration code: A123T33), the number of truck is 3 per day. Pyrolysis plant B is cover twenty mallee planting areas nearby the Wickepin. The water use factor for diesel is 2.2 L H_2O/ diesel. The distance from pyrolysis plant B to the Muja power station is 146 km. The annual total energy produced by pyrolysis plant B is 1,014,651GJ (152,210.5*330*20.2)

Number	Selected Shire Name	Number of Stems	Green biomass production (ton/4years)	Dry biomass production (ton/4years)	Dry biomass production (ton/day)	Number of farm gate in every shire	Bio-oil production (ton/4years)	The weight of bioslurry (ton/4years)	Water consumption during transport biomass (L/4years)	Water consumption during pyrolysis (L/4years)	Water consumption during transport bioslurry (L/4years)	The ratio (L H_2O/GJ)
1	Kellerberrin	396000	14256.0	7128.0	5	4	4419.4	5338.9	205367.4	7203556.8	41720.1	69.1
2	Bruce Rock	384590	13845.2	6922.6	5	6	4292.0	5185.0	154811.0	6995999.8	40518.0	68.7
3	Narembeen	1158862	41719.0	20859.5	16	8	12932.9	15623.8	131659.6	21080626.9	122090.4	67.6
4	Beverley	236895	8528.2	4264.1	3	5	2643.7	3193.8	110372.0	4309309.6	24957.8	68.9
5	Wandering	275119	9904.3	4952.1	4	4	3070.3	3709.2	84699.2	5004634.7	28984.8	68.3
6	Brookton	758192	27294.9	13647.5	10	4	8461.4	10221.9	114843.3	13792119.0	79878.4	67.7
7	Corrigin	598086	21531.1	10765.5	8	6	6674.6	8063.4	112254.2	10879662.8	63010.6	67.9
8	Pingelly	667409	24026.7	12013.4	9	3	7448.3	8998.0	107446.0	12140703.6	70314.0	67.8
9	Cuballing	1378502	49626.1	24813.0	19	3	15384.1	18585.0	79706.1	25076054.2	145230.3	67.4
10	Wickepin	2125780	76528.1	38264.0	29	5	23723.7	28659.8	101803.9	38669638.8	223958.9	67.4
11	Kulin	1178060	42410.2	21205.1	16	10	13147.1	15882.6	130992.0	21429853.8	124113.0	67.6
12	Williams	310322	11171.6	5585.8	4	5	3463.2	4183.8	168845.9	5645005.4	32693.6	69.2
13	Narrogin	1183105	42591.8	21295.9	16	4	13203.5	15950.6	234043.8	21521626.4	124644.5	67.9
14	Wagin	1508343	54300.3	27150.2	21	4	16833.1	20335.5	252850.9	27437965.8	158909.6	67.8
15	Dumbleyung	527641	18995.1	9497.5	7	6	5888.5	7113.7	263299.2	9598211.9	55589.0	69.0
16	Woodanilling	399535	14383.3	7191.6	5	3	4458.8	5386.5	264135.1	7267861.3	42092.5	69.6
17	Kojonup	318504	11466.1	5733.1	4	6	3554.5	4294.1	262463.4	5793842.6	33555.6	70.2
18	Katanning	386131	13900.7	6950.4	5	4	4309.2	5205.8	191414.4	7024031.8	40680.3	69.0

19	Kent	255430	9195.5	4597.7	3	12	2850.6	3443.7	142049.6	4646476.0	26910.5	69.2
20	Esperance	856172	30822.2	15411.1	12	90	9554.9	11542.9	96743.1	15574453.6	90200.9	67.6
	Total				203		125,995.4 (per day)	152,210.5 (per day)	802,450.0 (per year)	205,372.5 (per day)	392,513.2 (per year)	68.0

Appendix J

This table is for the transport from every farm gate of twenty selected shires to the pyrolysis plant B. The payload of the Seven Axle 124 HML (configuration code: A124) is about 30.15 tonnes and its nominal diesel consumption per 100 km is 51 L. The water use factor for diesel is 2.2 L H_2O/ diesel.

Nearest town-site	Farm gate	Latitude	Longitude	Every farm gate green mallee weight (kg/4years)	Number of Truck in every farm gate	Distance to Wickepin pyrolysis plant (km)	Blue water consumption (L/4years)
Kellerberrin	Site 1	-31.633	117.761	3564000	127	177	50556.4
	Site 2	-31.601	117.902	3564000	127	184	52555.8
	Site 3	-31.648	117.709	3564000	127	171	48842.6
	Site 4	-31.517	117.730	3564000	127	187	53412.6
Bruce Rock	Site 1	-31.935	117.849	2307540.0	82	159	29404.3
	Site 2	-31.887	118.015	2307540.0	82	149	27555.0
	Site 3	-31.837	118.168	2307540.0	82	150	27739.9
	Site 4	-31.710	118.020	2307540.0	82	163	30144.1
	Site 5	-31.874	118.143	2307540.0	82	145	26815.3
	Site 6	-32.041	118.104	2307540.0	82	123	22746.7
Narembeen	Site 1	-32.223	118.286	5214879.00	186	125	52241.9
	Site 2	-32.164	118.337	5214879.00	186	134	56003.3
	Site 3	-32.089	118.380	5214879.00	186	145	60600.6
	Site 4	-31.998	118.396	5214879.00	186	156	65197.9
	Site 5	-31.874	118.396	5214879.00	186	170	71049.0
	Site 6	-31.985	118.294	5214879.00	186	159	66451.7
	Site 7	-32.056	118.340	5214879.00	186	147	61436.5
	Site 8	-32.070	118.438	5214879.00	186	152	63526.2
Beverley	Site 1	-32.302	116.573	1705644.0	61	125	17086.9
	Site 2	-32.202	116.794	1705644.0	61	118	16130.0
	Site 3	-32.093	116.944	1705644.0	61	113	15446.6
	Site 4	-32.260	116.995	1705644.0	61	90.8	12411.9
	Site 5	-32.084	116.856	1705644.0	61	117	15993.3
Wandering	Site 1	-32.611	116.909	2476071.0	88	72.9	14466.2
	Site 2	-32.698	116.692	2476071.0	88	89	17661.1
	Site 3	-32.581	116.505	2476071.0	88	113	22423.7
	Site 4	-32.455	116.325	2476071.0	88	137	27186.2
Brookton	Site 1	-32.401	117.024	6823728.0	244	72.8	39812.4
	Site 2	-32.355	116.654	6823728.0	244	113	61796.7
	Site 3	-32.394	116.884	6823728.0	244	89.2	48781.1
	Site 4	-32.318	117.160	6823728.0	244	92.4	50531.1
Corrigin	Site 1	-32.336	117.431	3588516.0	128	92.9	26717.5
	Site 2	-32.372	117.660	3588516.0	128	74.5	21425.7
	Site 3	-32.347	117.897	3588516.0	128	80.4	23122.6
	Site 4	-32.255	117.731	3588516.0	128	82.0	23582.7
	Site 5	-32.264	118.000	3588516.0	128	92.4	26573.7
	Site 6	-32.469	117.742	3588516.0	128	52.4	15069.9
Pingelly	Site 1	-32.539	117.060	8008908.0	286	59.0	37869.5

	Site 2	-32.511	117.223	8008908.0	286	52.8	33890.0
	Site 3	-32.520	117.076	8008908.0	286	58.1	37291.9
Cuballing	Site 1	-32.682	117.139	16542024.0	591	48.5	64297.7
	Site 2	-32.793	117.184	16542024.0	591	32.9	43616.4
	Site 3	-32.786	117.026	16542024.0	591	47.7	63237.1
Wickepin	Site 1	-32.780	117.646	15305616.0	547	13.8	16927.6
	Site 2	-32.781	117.500	15305616.0	547	1.1	1349.3
	Site 3	-32.687	117.599	15305616.0	547	18.9	23183.4
	Site 4	-32.921	117.732	15305616.0	547	31.8	39007.0
	Site 5	-32.904	117.430	15305616.0	547	22.0	26986.0
Kulin	Site 1	-32.780	117.876	4241016.0	151	35.4	12032.0
	Site 2	-32.487	118.040	4241016.0	151	96.0	32629.2
	Site 3	-32.756	118.068	4241016.0	151	55.7	18931.7
	Site 4	-32.626	118.116	4241016.0	151	76.1	25865.4
	Site 5	-32.711	118.309	4241016.0	151	89.1	30283.9
	Site 6	-32.627	118.207	4241016.0	151	77.6	26375.2
	Site 7	-32.669	118.160	4241016.0	151	70.8	24064.0
	Site 8	-32.677	118.500	4241016.0	151	104	35348.3
	Site 9	-32.699	119.450	4241016.0	151	223	75794.8
	Site 10	-32.631	119.358	4241016.0	151	212	72056.1
Williams	Site 1	-33.010	116.977	2234318.4	80	59.1	10582.7
	Site 2	-33.112	116.945	2234318.4	80	79.9	14307.3
	Site 3	-33.103	116.713	2234318.4	80	87.9	15739.8
	Site 4	-33.210	116.539	2234318.4	80	110	19697.1
	Site 5	-32.941	116.763	2234318.4	80	84.9	15202.6
Narrogin	Site 1	-32.981	117.062	10647945.0	380	50.5	43094.5
	Site 2	-33.040	117.239	10647945.0	380	51.2	43691.9
	Site 3	-32.937	117.567	10647945.0	380	20	17067.1
	Site 4	-32.946	117.386	10647945.0	380	36.1	30806.2
Wagin	Site 1	-33.282	117.486	13575087.0	485	102	110970.5
	Site 2	-33.375	117.359	13575087.0	485	95.3	103681.3
	Site 3	-33.225	117.286	13575087.0	485	74.8	81378.4
	Site 4	-33.323	117.217	13575087.0	485	96.8	105313.2
Dumbleyung	Site 1	-33.154	118.103	3165846.0	113	96.9	24585.5
	Site 2	-33.183	117.931	3165846.0	113	79.8	20246.9
	Site 3	-33.254	117.784	3165846.0	113	92.0	23342.2
	Site 4	-33.125	117.909	3165846.0	113	70.4	17861.9
	Site 5	-33.392	117.827	3165846.0	113	114	28924.1
	Site 6	-33.383	117.735	3165846.0	113	110	27909.2
Woodanilling	Site 1	-33.538	117.087	4794420.0	171	120	46108.6
	Site 2	-33.564	117.424	4794420.0	171	118	45340.1
	Site 3	-33.511	117.612	4794420.0	171	129	49566.8
Kojonup	Site 1	-33.758	117.003	1911024.0	68	159	24351.6

	Site 2	-34.024	117.018	1911024.0	68	183	28027.4
	Site 3	-33.853	116.957	1911024.0	68	174	26649.0
	Site 4	-33.839	117.150	1911024.0	68	155	23739.0
	Site 5	-33.960	117.203	1911024.0	68	169	25883.2
	Site 6	-33.798	117.148	1911024.0	68	150	22973.2
Katanning	Site 1	-33.773	117.332	3475179.0	124	149	41498.1
	Site 2	-33.697	117.546	3475179.0	124	142	39548.5
	Site 3	-33.680	117.770	3475179.0	124	155	43169.2
	Site 4	-33.628	117.544	3475179.0	124	146	40662.6
Kent	Site 1	-33.423	118.514	766290.0	27	171	10501.6
	Site 2	-33.507	118.514	766290.0	27	180	11054.3
	Site 3	-33.564	118.470	766290.0	27	186	11422.8
	Site 4	-33.593	118.400	766290.0	27	177	10870.0
	Site 5	-33.686	118.385	766290.0	27	186	11422.8
	Site 6	-33.729	118.365	766290.0	27	191	11729.8
	Site 7	-33.582	118.055	766290.0	27	152	9334.7
	Site 8	-33.547	118.161	766290.0	27	153	9396.1
	Site 9	-33.583	118.260	766290.0	27	164	10071.7
	Site 10	-33.627	117.951	766290.0	27	163	10010.3
	Site 11	-33.466	117.907	766290.0	27	126	7738.0
	Site 12	-33.490	118.035	766290.0	27	138	8474.9
Esperance	Site 1	-32.601	121.566	342468.8	12	623	17099.1
	Site 2	-32.629	121.543	342468.8	12	619	16989.3
	Site 3	-32.664	121.538	342468.8	12	617	16934.4
	Site 4	-32.700	121.536	342468.8	12	611	16769.8
	Site 5	-32.740	121.533	342468.8	12	607	16660.0
	Site 6	-32.770	121.544	342468.8	12	603	16550.2
	Site 7	-32.805	121.560	342468.8	12	599	16440.4
	Site 8	-32.841	121.577	342468.8	12	595	16330.6
	Site 9	-32.872	121.591	342468.8	12	591	16220.8
	Site 10	-32.906	121.607	342468.8	12	587	16111.1
	Site 11	-32.942	121.624	342468.8	12	583	16001.3
	Site 12	-32.978	121.640	342468.8	12	579	15891.5
	Site 13	-33.007	121.652	342468.8	12	575	15781.7
	Site 14	-33.039	121.668	342468.8	12	571	15671.9
	Site 15	-33.074	121.682	342468.8	12	567	15562.1
	Site 16	-33.108	121.693	342468.8	12	563	15452.3
	Site 17	-33.147	121.706	342468.8	12	559	15342.6
	Site 18	-33.177	121.717	342468.8	12	555	15232.8
	Site 19	-33.212	121.716	342468.8	12	551	15123.0
	Site 20	-33.248	121.716	342468.8	12	547	15013.2
	Site 21	-33.284	121.716	342468.8	12	543	14903.4
	Site 22	-33.323	121.715	342468.8	12	539	14793.6
	Site 23	-33.355	121.705	342468.8	12	535	14683.8

	Site 24	-33.385	121.694	342468.8	12	531	14574.1
	Site 25	-33.418	121.710	342468.8	12	527	14464.3
	Site 26	-33.451	121.727	342468.8	12	523	14354.5
	Site 27	-33.483	121.726	342468.8	12	519	14244.7
	Site 28	-33.516	121.716	342468.8	12	515	14134.9
	Site 29	-33.547	121.738	342468.8	12	511	14025.1
	Site 30	-33.575	121.758	342468.8	12	507	13915.3
	Site 31	-33.604	121.781	342468.8	12	503	13805.6
	Site 32	-33.634	121.805	342468.8	12	499	13695.8
	Site 33	-33.671	121.825	342468.8	12	498	13668.3
	Site 34	-33.701	121.836	342468.8	12	505	13860.4
	Site 35	-33.736	121.849	342468.8	12	501	13750.7
	Site 36	-33.769	121.863	342468.8	12	498	13668.3
	Site 37	-33.803	121.878	342468.8	12	504	13833.0
	Site 38	-33.832	121.895	342468.8	12	505	13860.4
	Site 39	-33.832	121.858	342468.8	12	501	13750.7
	Site 40	-33.809	121.825	342468.8	12	497	13640.9
	Site 41	-33.788	121.792	342468.8	12	493	13531.1
	Site 42	-33.762	121.762	342468.8	12	489	13421.3
	Site 43	-33.748	121.722	342468.8	12	485	13311.5
	Site 44	-33.735	121.684	342468.8	12	481	13201.7
	Site 45	-33.730	121.641	342468.8	12	477	13091.9
	Site 46	-33.726	121.598	342468.8	12	475	13037.1
	Site 47	-33.700	121.567	342468.8	12	475	13037.1
	Site 48	-33.697	121.517	342468.8	12	464	12735.1
	Site 49	-33.694	121.477	342468.8	12	460	12625.4
	Site 50	-33.705	121.440	342468.8	12	457	12543.0
	Site 51	-33.713	121.398	342468.8	12	453	12433.2
	Site 52	-33.725	121.355	342468.8	12	449	12323.4
	Site 53	-33.735	121.314	342468.8	12	444	12186.2
	Site 54	-33.742	121.274	342468.8	12	441	12103.9
	Site 55	-33.753	121.231	342468.8	12	436	11966.6
	Site 56	-33.758	121.185	342468.8	12	432	11856.9
	Site 57	-33.763	121.146	342468.8	12	428	11747.1
	Site 58	-33.749	123.206	342468.8	12	626	17181.5
	Site 59	-33.747	123.163	342468.8	12	622	17071.7
	Site 60	-33.745	123.119	342468.8	12	618	16961.9
	Site 61	-33.744	123.077	342468.8	12	614	16852.1
	Site 62	-33.745	123.033	342468.8	12	610	16742.3
	Site 63	-33.744	122.990	342468.8	12	606	16632.5
	Site 64	-33.750	122.948	342468.8	12	602	16522.7
	Site 65	-33.747	122.906	342468.8	12	598	16413.0
	Site 66	-33.745	122.899	342468.8	12	598	16413.0
	Site 67	-33.751	122.821	342468.8	12	590	16193.4

	Site 68	-33.754	122.777	342468.8	12	586	16083.6
	Site 69	-33.755	122.725	342468.8	12	581	15946.4
	Site 70	-33.753	122.693	342468.8	12	578	15864.0
	Site 71	-33.749	122.651	342468.8	12	574	15754.2
	Site 72	-33.749	122.608	342468.8	12	570	15644.5
	Site 73	-33.748	122.562	342468.8	12	566	15534.7
	Site 74	-33.748	122.521	342468.8	12	562	15424.9
	Site 75	-33.752	122.477	342468.8	12	558	15315.1
	Site 76	-33.746	122.426	342468.8	12	554	15205.3
	Site 77	-33.744	122.377	342468.8	12	549	15068.1
	Site 78	-33.742	122.341	342468.8	12	546	14985.7
	Site 79	-33.740	122.308	342468.8	12	543	14903.4
	Site 80	-33.739	122.265	342468.8	12	538	14766.2
	Site 81	-33.734	122.223	342468.8	12	534	14656.4
	Site 82	-33.736	122.179	342468.8	12	530	14546.6
	Site 83	-33.738	122.137	342468.8	12	527	14464.3
	Site 84	-33.734	122.093	342468.8	12	522	14327.0
	Site 85	-33.734	122.049	342468.8	12	518	14217.2
	Site 86	-33.741	122.005	342468.8	12	514	14107.5
	Site 87	-33.752	121.973	342468.8	12	511	14025.1
	Site 88	-33.788	121.957	342468.8	12	513	14080.0
	Site 89	-33.813	121.929	342468.8	12	509	13970.2
	Site 90	-33.833	121.896	342468.8	12	505	13860.4