GEFS

Synthetic fuel manufacture

Proof of Concept LCA (public version)

470291

JULY 2019

RSK GENERAL NOTES

Project No.: 470291-1 (03) Final

Title: Proof of Concept LCA for synthetic fuel manufacture

Client: GEFS

Date: 12 July 2019

Office: Helsby

Status: Final Rev03

Author	Nick Hedges	**Technical reviewer**	Richard Appleyard
Signature		Signature	
Date:	12 July 2019	Date:	12 July 2019

EXECUTIVE SUMMARY

This is a Proof of Concept LCA report produced for and in conjunction with Global Ecofuel Solutions, SL (GEFS) and Allen Taylor and Co (Boral). The report will be submitted by Boral to the Australian Renewable Energy Agency (ARENA) and follows the format specified by ARENA. This summary acts as the 'summary report' and the main document provides the 'background reporting'.

Goal and scope

This report identifies the greenhouse gas emissions associated with the life cycle of a synthetic fuel which can be used to replace fossil derived diesel.

The proposed plant in New South Wales, Australia will use waste sawmill residue and waste lubricating oil in an innovative process which cracks the feedstock to produce a liquid fuel which can be readily treated to meet road fuel standards, yielding a drop-in substitute for diesel. A co-product of bitumen is also produced which has the potential to offer further benefits in reducing greenhouse gas emissions.

Summary of LCA results

The results indicate that synthetic road fuel from the proposed plant will include a biogenic component which meets the current carbon intensity standards for renewable fuels as required in Europe and the USA and will reduce greenhouse gas emissions by 70% compared with fossil derived diesel. The estimated life cycle greenhouse gas emissions impact is 28.2 gCO_2e/MJ of fuel, compared to the European reference figure of 94.0 gCO_2e/MJ of fuel. This benefit will be enhanced by the partially renewable bitumen co-product which offers significant potential to further reduce carbon emissions.

The proposed plant will provide useful products from two existing waste streams with limited beneficial alternative uses. The sawmill residue is available in bulk quantities and the main disposal route in the absence of the proposed process is for garden mulch with low commercial value and the potential to release methane, although the model used in this work conservatively assumes zero methane release. The waste lubricating oil would either be burnt, releasing fossil derived carbon dioxide or reprocessed using additional material and energy resources if not used in the proposed process.

The results are based on pilot trial results from April and May 2019.

Fossil fuel depletion through the life cycle of the product is estimated at 22.9% of the total product energy content.

Documentation of main assumptions and calculation approach

The report structure follows the guidance provided by ARENA and identifies the goals, system boundary and reference system as well as describing the methodology and results.

This report has been produced using data extrapolated from a series of trials on a pilot plant to the proposed commercial scale plant and the LCA environmental impacts are focussed on greenhouse gas emissions. A spreadsheet model has been used to calculate life cycle emissions using readily available data from a range of international sources documented in this report.

Discussion and interpretation

The results should be regarded as preliminary as the commercial scale process plant design is at an early stage. In practice, it is anticipated that economies of scale and plant optimisation will improve upon the results reported here.

Process parameters have been based on pilot trials carried out using samples of the proposed biomass feedstock. These trials have indicated that the process can generate synthetic fuel with a biogenic component in excess of 70%.

Some minor impacts have not been included in this Proof of Concept LCA and may be further investigated in the Commercialisation LCA. These include material extraction for some of the minor raw materials. Given the relatively small quantities of these materials this is not considered to have a significant impact on the results. Scope 3 emissions from electricity, diesel and natural gas are included.

Benefits to the future project

The outputs from this work can be used to inform the design and operation of the commercial scale plant.

CONTENTS

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

This report presents a Proof of Concept LCA for a proposed process plant to manufacture synthetic fuel (known as Renewable Diesel Fuel – RDF).

The core process is known as MECC – Mechanical Catalytic Conversion. It is an innovative process (subject to patent) which converts ligno-cellulosic (LC) material into a renewable diesel fuel (RDF), a drop-in substitute for road vehicle diesel meeting the European EN590 standard and the corresponding Australian standard. A co-product is also produced, this is a renewable bituminous product (RBP) which may be used as a bitumen and filler replacement in asphalt. There are small amounts of additional products which may be used as fuels for stationary combustion plant.

The proposed plant will be located in New South Wales, Australia. A contribution towards funding for the project has been made by the Australian Renewable Energy Agency (ARENA). This Proof of Concept LCA report is required to be submitted to ARENA and presents a Proof of Concept LCA in accordance with the ARENA document *Life Cycle Assessment of Bioenergy products and projects, October 2016*.

Further development and upscaling are required to take the MECC process through to commercialisation. The Technology Readiness Level is assessed as 6-7, moving from Technology Demonstration to System Development, in accordance with the ARENA classifications. In this context, and in accordance with the ARENA guidelines, this Proof of Concept LCA has been targeted at the reductions in greenhouse gas emissions and fossil fuel depletion which the process outputs offer relative to the corresponding conventional fossil derived products of diesel fuel and bitumen.

The MECC system is modular and for this project a MECC 16 unit is proposed.

This study has been carried out with data based on a series of pilot plant tests undertaken in April and May 2019.

2 PROOF OF CONCEPT LCA REQUIREMENTS

This section broadly follows the structure of the ARENA guidance document *Life Cycle Assessment of Bioenergy products and projects, October 2016*.

2.1 Goals of the study

The goals of the study are:

- to meet the requirements of ARENA for the funding milestones; and
- to provide insight into the contribution to greenhouse gas emissions and fossil fuel depletion of each stage of the process.

The audiences for the study are ARENA, the project development team and their sponsors.

2.2 Functional units and system boundary

The primary functional unit considered in this Proof of Concept LCA is the supply of 1 MJ of road vehicle fuel to the end user at the retail filling station pump and its subsequent combustion. This is selected for consistency with the chosen reference system discussed in Section 2.7. The main function of the process is to provide a substitute fuel to be used as a direct drop-in replacement for diesel. The focus of this Proof of Concept LCA is to compare the greenhouse gas emissions of the RDF with conventional fossil fuel derived diesel.

A secondary co-product is RBP. In this process the RBP may be suitable for direct replacement for imported bitumen. The functional unit used for this is the supply of 1kg of RBP at the blending plant gate. Greenhouse gas reduction benefits from this co-product are calculated separately as credits to the primary product.

The system boundary starts with the available raw material which is sawmill residue generated as a by-product in the Heron's Creek Timber Mill and ends with the combustion of the RDF in vehicles and the dispatch of the RBP from the asphalt manufacturing site.

System components are:

- Preparation of raw material at the point of arising;
- Transport of biomass and other raw materials to the MECC plant;
- MECC biomass to fuel conversion process;
- RDF upgrade process to meet sulphur limits in fuel;
- Transport of RDF to blending plant;
- RDF Blending process;
- RDF Transport to market via wholesale and retail outlets;
- Combustion of biogenic RDF product in road vehicles;
- Transport of RBP to blending plant;

- RBF blending process;
- Transport of bitumen to site (technically not part of the bitumen reference system but included for comparison).

2.3 Environmental impact categories

The minimum requirements of climate change, fossil fuel resource depletion and fossil fuel energy use are considered in this Proof of Concept LCA.

Climate change is measured as greenhouse gas emissions in kg of carbon dioxide equivalent (kg CO_2e).

Fossil fuel depletion and energy use are measured as MJ of coal, gas, oil etc based on net calorific value.

2.4 Temporal aspects

The Proof of Concept LCA considers the annual emissions and resource use during one year of normal operation including plant downtime for routine maintenance. At this early stage of technology development and demonstration more specific information on equipment specifications and economic life is not available. Start up and decommissioning impacts are considered negligible in comparison to the lifetime benefits and impacts. There is no cultivation of biomass within the system boundary so considerations of carbon capture and release over extended time do not apply.

2.5 Multi-functionality and allocation

The four options for allocation of material inputs and emissions between multi-functional outputs identified in the ARENA guidance are:

- sub-division of inputs to separate the inputs to each product;
- physical relationships between inputs and outputs quantified mathematically;
- system expansion to enable a co-product to replace part of the inputs;
- economic allocation of inputs and impacts according to the economic value of co-products.

Considering these options in turn;

- The process creates the synthetic RDF substitute and the RBP concurrently from a single process, so there can be no clear sub-division of inputs.
- At this stage of development of the process it is not possible to mathematically relate the inputs between products based on carbon content of the feedstock.

The remaining two options are:

- Provide a credit to the RDF equal to the beneficial impact of the alternative use of the RBP; however, the RBP does not have a comparable functional value to that of any of the inputs.
- Allocate the impacts based on energy content (or other measure of value).

For the Proof of Concept LCA the allocation between the synthetic RDF and the synthetic RBP has been done based on net calorific value of the products.

Although the products comprise two main streams, a further distinction is made to meet the requirements of the ARENA guidance. Each product stream is considered to comprise a fossil-based component and a biogenic based component (see Section 2.9). For each product stream, these two components are modelled separately in two parallel routes and the inputs and emissions allocated according to the ratio of fossil to biogenic feedstock carbon content. The main outputs are summarised below:

<table>
<tr><td rowspan="4">Main product streams:</td><td rowspan="2">Primary product:</td><td rowspan="2">RDF (synthetic road fuel) components:</td><td>RDF - biogenic</td></tr>
<tr><td>RDF- fossil</td></tr>
<tr><td rowspan="2">Co-product:</td><td rowspan="2">RBP (synthetic bitumen) components:</td><td>RBP - biogenic</td></tr>
<tr><td>RBP - fossil</td></tr>
</table>

In practice the biogenic and fossil components for each product stream are homogeneous and go through the same process steps, so the allocation is the same to biogenic as it is to fossil. The two product streams share the initial processes up to and including the MECC process. They are then separated and follow different paths, see Section 3.1.

Small amounts of additional products can be used as fuels for stationary combustion plant. By energy content these are equivalent to less than 10% of the total aggregated energy content of final outputs. At this stage there has been no allocation of greenhouse gas emissions to these additional products – the full impact of emissions has been allocated to the RDF and RBP.

2.6 Inventory analysis

For this Proof of Concept LCA, site specific data are used where readily available, for example for transport distances and measured process parameters from pilot scale testing, but most data are from generic internationally recognised sources.

For road vehicle impacts, generic data from internationally recognised databases such as BioGrace (see Section 2.7) have been used. For chemicals, data from Ecoinvent and suppliers have been used. Australian Government greenhouse gas data have been used for electricity, fuels and local material. Sources of data are shown in Appendix 2.

2.7 Reference system and benchmarking

The ARENA guidance states that results shall be compared to a reference system. The reference case used is ARENA's stated preference of business as usual scenario rather than the projected future option. The AusLCI database is being continuously improved but currently does not include directly relevant reference data for the RDF or the bitumen. There is extensive data for Europe; for example, the BioGrace project ran from 2010 to 2012 and was financed by the Intelligent Energy Europe programme. The overall objective of the BioGrace project was to harmonise the European calculations of biofuel GHG emissions that must be made to comply with the Renewable Energy Directive

(RED, 2009/28/EC) and the Fuel Quality Directive (2009/30/EC). This is considered to be highly relevant to the process under consideration and appropriate BioGrace data have been used as described in Appendix 2.

The reference system from the BioGrace project has been reviewed for the RDF and this gives a Greenhouse Gas Emission figure of 87.64 g CO_2e associated with the production and combustion of 1 MJ of diesel. This carbon intensity reference value increases over time as fossil fuel extraction becomes more energy intensive, and has been revised in the European Union Directive 2018/2001 of 11 December 2018 on the promotion of renewable sources (known as "RED 2"). The latest value of the fossil fuel comparator is 94 g CO_2 equivalent/MJ of diesel and this is used as the reference baseline for RDF.

A directly applicable reference system for bitumen has not been identified, however, the UK's Institution of Civil Engineers has carried out work with BSRIA (Building Services Research & Information Association) and the University of Bath and has developed a database of embodied carbon for construction materials. This identifies a range of embodied carbon in bitumen of 0.43-0.55 kgCO_2e per kg of bitumen "cradle-to-gate" and this is used as a baseline for RBP.

2.8 Land use change

Land use change does not need to be covered by the Proof of Concept LCA. However, there is no planned Land Use Change because of the construction or operation of the MECC plant. The raw material feedstock is existing sawmill residue and there is no impact on forestry.

The plant footprint is very small and equipment will be located in existing industrial areas, in the vicinity of the Heron's Creek Timber Mills near Port Macquarie in New South Wales.

2.9 Treatment of fossil, biogenic and atmospheric carbon

The process converts biomass feedstock but requires some fossil fuel input in the form of waste lubricating oil to act as a carrier oil, some of which can be recycled within the process. As required by ARENA, biogenic and fossil carbon flows have been calculated and documented separately.

At this stage of process development, it is not possible to accurately quantify and track the fossil carbon component between products, however estimates have been made as follows.

The main input sources of biogenic and fossil carbon are the biomass feedstock and the reprocessed waste lubricating oil respectively. These account for 96% of the total raw material inputs.

The biogenic carbon component of the products is calculated in the spreadsheet model as 72.9% with the remaining 27.1% being of fossil origin. This same ratio applies to the relative energy contents of biogenic and fossil feedstocks. This ratio is applied to allocate all the inputs and emissions through the system to biogenic and fossil components of the RDF and RBP. Separate calculations from the pilot trials gave a weighted average figure of 75.63% biogenic content of the RDF, so the 72.9% figure used here may be considered slightly conservative.

3 INVENTORY OF INPUTS AND OUTPUTS

The process flow is under development and data have been collected from the operation of a pilot plant. The current proposals for the commercial scale plant are shown schematically below in Figure 3.1.

The inventory of inputs and outputs is included in Appendix 1. Minor material flows below 1% of the main feedstock are excluded. The inputs are:

- Waste ligno-cellulosic material from sawmill residues (main feedstock, a fully biogenic waste)
- Waste lubricating oil (acts as a carrier oil)
- Catalyst (small quantity)
- Lime (small quantity)
- Desulphurisation chemical (small quantity for fuel treatment)
- Natural gas, electricity and diesel top-up.

The outputs are:

- Renewable Diesel Fuel (RDF primary product - biogenic with a component of fossil derived product)
- Renewable Bituminous Product (RBP co-product, also a mixture of biogenic and fossil derived products)
- Combustion gases from an on-site biomass fuelled drier
- Off gases from the MECC process (including some carbon dioxide of biogenic origin)
- Process water
- Pyrolysis oil

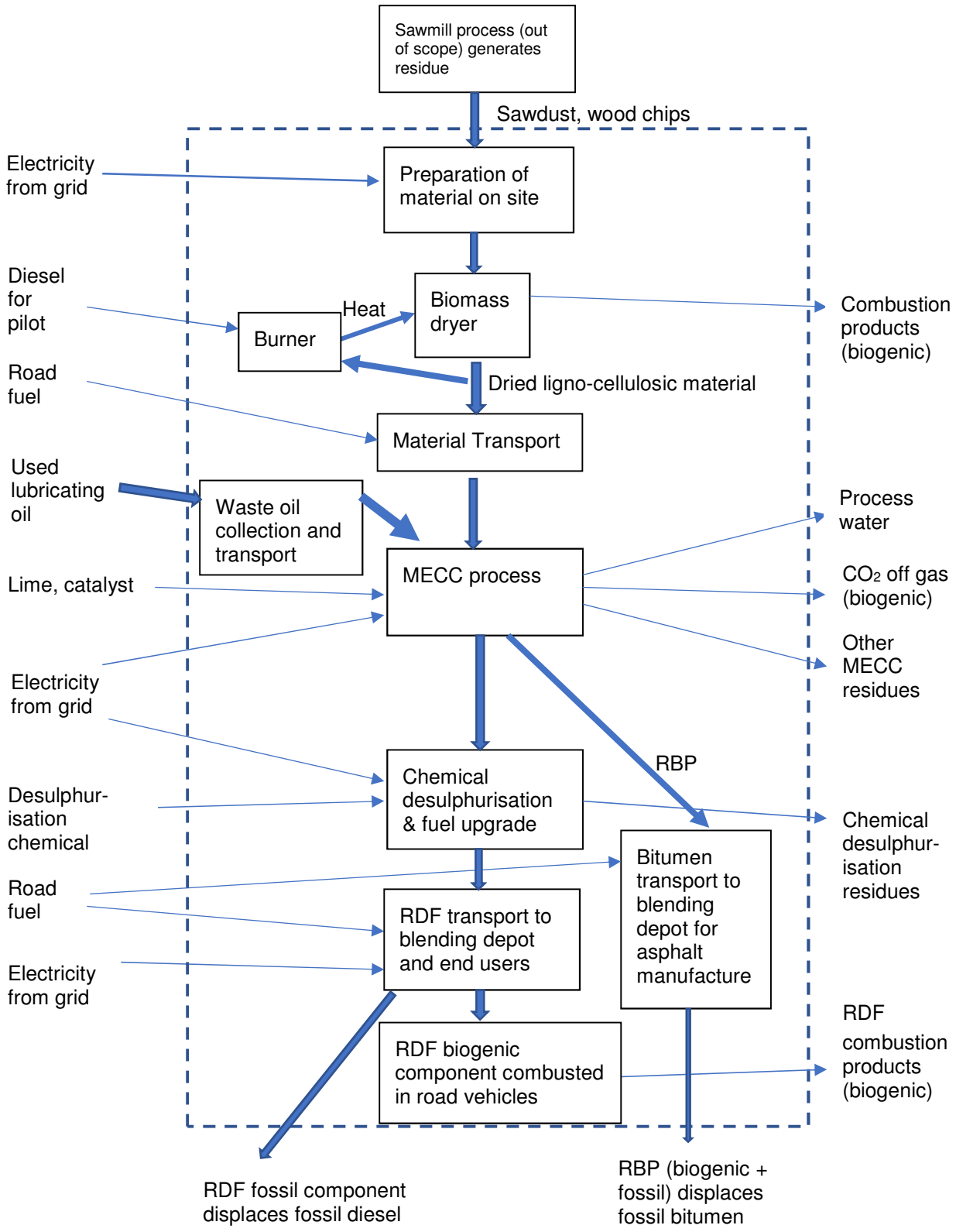

Figure 3.1: Process schematic

3.1 Methodology

The ARENA guidance gives the option of using full LCA software or a simple spreadsheet model. The process has few inputs and is still in the development stage, so it has been modelled using a spreadsheet with multiple steps. At the core is the MECC 16 unit, and inputs have been adjusted pro rata from pilot plant tests as required to match the expected MECC 16 output.

At each stage, the material and energy inputs are identified, and fossil energy requirements are calculated. Greenhouse gas emissions associated with each input are calculated using reference data which is included in Appendix 1.

Given the early stage of project development, the actual sources of secondary raw materials have not been confirmed, so assumptions have been made as described in Appendix 2. In some cases, the greenhouse gas emissions from chemicals and additives have been calculated from suppliers' information. These data may exclude primary raw material abstraction, but this is not considered to have a significant impact on the results as the quantities are relatively very small compared to the main biomass and waste oil feedstock which together account for 96% of the mass inputs.

As described earlier, the emissions for biogenic and fossil components of the products throughout are allocated based on the relative carbon contents of the main feedstocks, the waste ligno-cellulosic material and the waste lubricating oil.

Certain stages involve the loss of material. The yield at each stage is used to augment the impacts for the previous stages to ensure the correct allocation of impacts from all stages throughout the process to the final products. The method is summarised by stage in Table 3.1, with supporting information in the Appendices. The carbon dioxide equivalent emissions, fossil fuel requirements and allocation to each product are reported in Section 5 for each of these stages.

Table 3.1: Process model steps

Stage	Description	Comments	Energy sources
Sawmill process	Existing process outside scope of LCA	Generates extensive biomass waste with limited market potential.	
Lubricating oil manufacture and use	Source of waste lubricating oil, outside scope of LCA	In accordance with accepted principles, as a waste this carries zero carbon burden at the point of disposal	
	System boundary start	Start of LCA.	
Material preparation	Waste biomass material size reduction through hammers plus warm air drying. Material is prepared at the point of the waste arising	Material transport on site by electric conveyors using grid electricity. Drying uses some of the biomass material plus a small quantity of diesel for the pilot burner. Biomass yield is 72%.	Grid electricity Biomass material (waste wood) Diesel
Material transport (biomass, plus other materials)	Road transport of materials using conventional diesel fuelled trucks	Biomass is within 2 km of origin. Oil, catalyst and lime transported a nominal 200km from an industrial area. Generic GHG impact values per tonne.km are used.	Diesel road fuel
MECC process	Core process converts raw materials to liquid RDF and RBP.	All energy is supplied by electricity from the grid.	Grid electricity
	Separation of co-product streams – RDF and RBP	Allocation of impacts between RDF and RBP up to this stage is based on the relative calorific values of the co-products at this point.	
Chemical desulphurisation & upgrade process	Process to desulphurise the liquid RDF (only) to meet Australian and EN590 standards for road transport fuel	Electricity used for pumping and heating. Material yield of 96.76% applies to RDF only, RBP bypasses this stage. All impacts allocated to RDF.	Grid electricity
Transport to blending plants	Road transport of liquid RDF fuel plus RBP in road tankers	Nominal distance of 200km to blending plants.	Diesel road fuel
Blend and storage	RDF and RBP are processed separately	Electricity used for processing in existing plants. End of LCA scope for bitumen.	Grid electricity
Transport to retail	Only applies to RDF	Nominal distance of 150km.	Diesel road fuel
Retail outlet	Only applies to RDF	Electricity used for filling station heating, lighting, fuel dispensing. Combustion of RDF in vehicles is within scope of LCA and reference system.	Grid electricity
	System boundary - end	End of LCA scope.	

4 SUPPORTING INFORMATION

4.1 Emission factors

These are documented in Appendix 2.

4.2 Data sources and quality assessment

Data sources are documented in Appendix 2. Data at this stage is preliminary and has not been subjected to a quality assessment, which will need to be undertaken for the Commercialisation LCA.

4.3 Assumptions and calculations

These are documented in Appendix 1 and Appendix 2.

5 RESULTS

ARENA seeks to compare the environmental impact profile of different biofuels. The guidance requires the Proof of Concept LCA to report on climate change, fossil fuel resource depletion and fossil energy use. Climate change is reported as greenhouse gas emissions in carbon dioxide equivalent (CO_2e) per MJ of product; fossil fuel resource depletion and energy use are reported as GJ of fossil fuel.

A spreadsheet model of all process inputs of material and energy, with associated greenhouse gas emissions and fossil fuel equivalent inputs has been developed for the processes described in Section 3 of this report. The model shows the following product outputs:

Table 5.1: MECC product outputs

	Renewable Diesel Fuel (RDF) (%)	Renewable Bituminous Products (RBP) (%)
Biogenic component	72.9	72.9
Fossil component	27.1	27.1
Total	100	100

The energy contents of the two products are significantly different – RDF has an energy content of 43.7 MJ/kg and the corresponding RBP value is 24.75 MJ/kg.

Table 5.2 identifies the climate change impact in the form of CO_2e per MJ of each product. Note the RDF is passed through an additional stage (chemical desulphurisation process). Transport of bitumen to the point of end use is not included in the reference system. The impact of this difference is relatively small.

Table 5.2: Allocation of greenhouse gas emissions to renewable diesel and bituminous products

Product	gCO_2e/MJ
Renewable Diesel Fuel	28.2
Renewable Bituminous Products	20.9

The main contributors to the carbon intensity figure for RDF are the MECC process, the desulphurisation process and the biomass preparation.

The MECC process requires significant electrical power input. This is provided from the Australian grid which has a relatively high carbon emission factor. The MECC process accounts for over 50% of the contribution to the carbon intensity figure for the RDF.

De-sulphurisation accounts for approximately 20% of the carbon intensity figure for the RDF. The main contributions to the desulphurisation process are the chemical treatment and heating required. The process uses a specialist process chemical which has a relatively high carbon intensity and the quantity required depends upon the eventual sulphur content of the RDF which in turn is strongly influenced by the uptake of sulphur in the forestry wood and the sulphur content of the waste oil. The quantity required has been established from a limited number of trials and it is anticipated that process optimisation could reduce the required amount.

Material transport accounts for approximately 10% of the total figure and includes raw material shipping from manufacture to site.

Approximately 70% of the contribution to the carbon intensity figure for the RBP is the MECC process. Other significant contributions come from the material preparation (primarily the electricity used in the hammer mills for biomass preparation).

The fossil fuel requirement is 22.9% of the useful output.

Where grid electricity is used the efficiency of conversion from fossil fuel to electricity is assumed at 37.5%, a typical value for utility scale generators from coal or oil.

It is concluded that the process has a significant net energy benefit. The energy requirement also remains well below the biogenic component of the RDF.

6 DISCUSSION AND INTERPRETATION

This report estimates the life cycle greenhouse gas emissions of a proposed synthetic diesel production process to be installed in New South Wales, Australia. The emissions have been derived from pilot scale tests, extrapolated to the output capacity of the proposed process. Development of the bioenergy system process is continuing, and the design of the commercial plant was not available for this Proof of Concept LCA.

Synthetic fuel product

The synthetic fuel is known as Renewable Diesel Fuel (RDF). This fuel offers several advantages over other synthetic fuels. It requires minimal land use and no land use change as it utilises existing waste streams for most of the raw materials; a large part of the raw materials is biogenic; it can accommodate a range of material sizes including small particles which other existing commercial processes have difficulty in processing; it provides a drop-in fuel which meets the EN590 specification and acts as a direct replacement for conventional fossil diesel in road vehicle transport.

Environmental benefit

To measure the benefit of this biofuel product, a comparison is made between the carbon intensity of the RDF product and the carbon intensity of fossil derived road vehicle fuel.

Under the present UK Renewable Transport Fuels Obligation (RTFO), which complies with the European Union's Renewable Energy Directive requirements, carbon intensity of a renewable fuel refers to the lifecycle emissions of greenhouse gases from the supply chain. To meet the sustainability criteria, renewable fuels produced in installations which started operating after 5 October 2015 must deliver at least 60% greenhouse gas emissions saving over the displaced fuel.

Article 25 of the latest recast Renewable Energy Directive EU2018/2001 (December 2018, European Commission) states that the greenhouse gas emissions savings from the use of renewable liquid and gaseous transport fuels of non- biological origin shall be at least 70% from 1 January 2021, however this does not apply to RDF which is of biological origin. Instead, Article 29 states that the greenhouse gas emissions reduction from the use of qualifying biofuels will be at least 60% produced in installations starting operation from 6 October 2015 until 31 December 2020. This rises to 65% for biofuels…produced in installations starting operation from 1 January 2021.

The US Renewable Fuel Standard requires that biomass-based diesel and advanced biofuels must demonstrate a reduction of lifecycle greenhouse gases by at least 50% from a baseline for diesel of 92 g CO_2e/MJ.

Comparison against reference system

The selection of reference system is discussed in Section 2.7. The available reference systems of diesel for road vehicle fuel have carbon intensity values of 87.6 – 94.0 g CO_2e/MJ of fuel. Over time this figure will increase as the extraction of fossil fuels becomes more difficult and more energy intensive. The Renewable Energy Directive (2018) states that 'biofuels' means liquid fuel for transport produced from biomass. Clause 19 of Annex V of the Renewable Energy Directive states that *For biofuels, …the fossil fuel comparator shall be 94 gCO_2e/MJ.* This value is adopted here for the reference system comparator.

For the proposed MECC process, the model calculates the biogenic RDF fuel product has a carbon intensity value of 28.2 gCO_2e/MJ of fuel. This is a reduction of 70 % from the reference system and exceeds the current and planned qualifying thresholds under the European Union's Renewable Energy Directive and the US EPA Renewable Fuel Standard.

The fossil component of any biofuel product is considered to have the full reference carbon intensity; hence this reduction applies to the biogenic component of the RDF only.

The allocation of input material impacts to the RDF and bitumen is based on the calorific values of the products.

There are further benefits which have not yet been evaluated in detail:

- The RBP co-product may directly replace fossil-based bitumen. Under the ARENA guidelines credit can be claimed for the RDF (primary product) according to the impacts of the material replaced by the RBP (co-product).
- The additional fuel products may also have commercial value, in which case the greenhouse gas emissions for the biogenic RDF may be further reduced by allocation to this additional product. At present no benefit has been included in the results section. Preliminary estimates indicate this may reduce the RDF carbon intensity by 1.0 g CO_2e/MJ of biogenic RDF.
- The intended route for the RBP is for use in asphalt for roads. At the end of life, the material can be removed, re-mixed with additional bitumen and re-laid, ensuring that most of the carbon remains embedded in the road surface. Through its application in road surfacing, the RBP therefore offers the possibility of capture and sequestration of carbon. Depending on the fate of the material, an additional reduction of 9.8 g CO_2e/MJ of biogenic RDF may be achievable. If the sequestration can be demonstrated to be permanent the benefit from the RBP may result in zero effective greenhouse gas emissions from the RDF.
- The process water (Appendix 1) is very mildly acidic and offers the potential to replace an existing wood vinegar product, thus avoiding the need for any treatment prior to disposal. Whether or not treatment was required, the impact on this LCA would be very small.

The prospective reduction from the reference system is from 94 to less than 18 g CO_2e/MJ of biogenic RDF, a reduction of 80% or more. These are preliminary estimates and further work is needed to justify them once the design of the commercial scale plant is more developed, the markets for the various products and the sources of raw material are confirmed.

This report identifies the key contributors to the CO_2e content of the fuel and so highlights areas for further investigation to reduce this.

7 GLOSSARY

ARENA	Australian Renewable Energy Agency
AusLCI	Australian National Life Cycle Inventory Database
BSRIA	Building Services Research and Information Association
CO_2	Carbon dioxide
CO_2 e	Carbon dioxide equivalent
EN590	European standard for the physical properties of diesel fuel
EU	European Union
GJ	Gigajoules (10^9 J)
ICE	Institution of Civil Engineers in the UK
J	Joules
kg	kilogram
kg/m^3	kilogram per cubic metre
kWh	kilowatt-hour (energy, 1 kWh = 3.6 MJ)
l	litres
LCA	Life Cycle Assessment
l/h	litres per hour
MECC	Mechanical and Catalytic Conversion modular plant
MECC16	Multi-module MECC plant
MJ	Megajoules (10^6 J)
RBP	Renewable Bituminous Product
RDF	Renewable Diesel Fuel
UK	United Kingdom

8 REFERENCES

Life Cycle Assessment of Bioenergy products and projects, ARENA, October 2016

National Greenhouse Accounts 2018, Australian Government, July 2018

Fuel Standard (Automotive Diesel) Determination 2001, Australian Government

Biograce GHG calculation tool – Biograce-I Excel tool version 4d, Intelligent Energy Europe Programme, European Commission, April 2015

also, Biograce Additional standard values version 4d

Directive 2018/2001 on the promotion of the use of energy from renewable sources, European Union, 11 December 2018

Life Cycle Carbon Footprint of Re-Refined versus Base Oil That Is Not Re-Refined; ACS Sustainable Chemistry & Engineering 2014 2 (2), 158-164

US EPA website https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard accessed February 2019

APPENDIX 1
PROCESS FLOWS

Material preparation

The waste ligno-cellulosic material requires initial collection and processing prior to the MECC process. The mixed material requires size refining through hammer mills. The material is also dried using a waste wood fuelled drier. The only significant greenhouse gas contributions are for the electricity for the conveyors, mills and drier motors. Carbon dioxide equivalent emissions associated with the diesel pilot burner for the biomass drier and the production, use and recycling of lubricating oil have also been included in the model but are not significant. The methane and nitrous oxide emissions associated with biomass combustion are considered small and are not included for this Proof of Concept LCA.

MECC process

Biomass feedstock is milled and dried at the point of arising and the prepared material is then transported 2 km to the MECC plant.

Waste oil is assumed to be collected from its end of life locations and transported 200km to a central collection point in Newcastle, prior to being transported 200km to the MECC plant.

The lime acid regulator is transported 200km from Newcastle to the MECC plant.

The catalyst is transported 100km by road in Europe, 20,000km by ocean shipping and a further 200km by road in Australia.

The electricity for the MECC and chemical desulphurisation process is supplied from the Australian grid. Heat for the desulphurisation process is provided by piped natural gas.

The two main product outputs of the process are RDF, the primary output and RBP, a co-product, each of which have a biogenic derived component and a fossil derived component. The benefits of biogenic RDF over conventional diesel are discussed in Section 6 of the report. Appendix 3 discusses the possible additional benefits of the bitumen.

Other outputs include a mildly acidic water stream, which may be of commercial value as a wood vinegar product, and a pyrolysis oil, which may also have commercial value. For the purposes of the Proof of Concept LCA, the greenhouse gas emissions are only allocated to the RDF and RBP.

APPENDIX 2
DATA AND CALCULATIONS

General data

Table A.1 summarises the values used and the sources of data for emission factors, calorific values, densities and other general information.

Table A.1: General data

Item	Value	Units	Source
Electricity CO_2 emission factor	0.92	$kgCO_2e/kWh$	Australian Government National Greenhouse Accounts 2018 Scope 2+3 for New South Wales
Diesel CO_2 emission factor	74.1	$kgCO_2e/GJ$	Australian Government National Greenhouse Accounts 2018 Scope 1+3
Natural gas	64.33	$kgCO_2e/GJ$	Australian Government National Greenhouse Accounts 2018 Scope 1+3 for pipeline gas Metro
Diesel density	0.84	kg/litre	Australian Govt Fuel Standard (Automotive Diesel) Determination 2001
Diesel Lower Calorific Value	43	MJ/kg	GEFS figure, consistent with typical reference data
Lubricating oil density	0.95	kg/litre	From MECC trial data
Reprocessed lubricating oil CO_2 emission factor	2.6	$kgCO_2e$ / gallon	Life Cycle Carbon Footprint of Re-Refined versus Base Oil That Is Not Re-Refined; ACS Sustainable Chemistry & Engineering 2014 2 (2), 158-164
Virgin lubricating oil CO_2 emission factor	13.2	$kgCO_2e$ / gallon	
Ligno-cellulosic feedstock post preparation Lower Calorific Value	17.96	MJ/kg	From MECC trial data
Lubricating oil Lower Calorific Value	42	MJ/kg	From MECC trial data
RDF Lower Calorific Value	43.7	MJ/kg	From MECC trial data
MECC off gas Lower Calorific Value	3	MJ/kg	From MECC trial data, see text
RBP bitumen Lower Calorific Value	24.75	MJ/kg	From MECC trial data
Lime CO_2 emission factor	0.675	$kgCO_2e/kg$	Australian Government National Greenhouse Accounts 2018
Catalyst CO_2 emission factor	2.019	$kgCO_2e/kg$	See text below
Desulphurisation chemical CO_2 emission factor	2.319	$kgCO_2e/kg$	See text below
Transport of dry material by road	0.936	MJ/t.km	Biograce
Transport of liquid material by road	1.008	MJ/t.km	Biograce
Diesel CO_2 emission factor (road transport)	87.64	gCO_2e/MJ	Biograce

An efficiency figure of 37.5% is consistent with typical fossil fuel power station efficiencies and is used to calculate the fossil fuel energy input to grid electricity.

Data input calculations

Catalyst

The total energy content of the catalyst is 17MJ/kg according to information from the supplier (personal communication). If generated using 50% natural gas and 50% electricity, then from Biograce figures for EU gas and German grid electricity the embodied carbon content would be:

17 x (67.59 x 0.5 + 169.9 x 0.5) = 2.019 $kgCO_2e/kg$.

This figure has been used in the model. The gas:electricity ratio may be slightly conservative as the production process typically uses thermal synthesis, therefore gas usage might be higher and the corresponding CO_2 emission lower, but this level of detail was not provided by the supplier. It is not known if the embodied energy covers raw material extraction. As a comparison, Ecoinvent has a carbon intensity of 1.59 $kgCO_2e/kg$ for a similar chemical.

Desulphurisation chemical

From Ecoinvent, 0.377 kg of the desulphurisation chemical incorporates from the raw material input 0.18051 $kgCO_2e$;

Plus 0.471 kWh electricity assuming Scope 2 Australian grid electricity incorporates:

- 0.471 x 0.83 0.39093 $kgCO_2e$;

Plus, 2 MJ heat from the chemical industry assumed generated by natural gas at 37.5% efficiency and 0.20437 $kgCO_2e/kWh$:

- 0.20437 x 2MJ/3.6 /0.375 0.3028 $kgCO_2e$.

Total for 0.377 kg of chemical 0.87424 $kgCO_2e$

Total for 1 kg of desulphurisation chemical 2.319 $kgCO_2e$

Combustible gas heating value

The most recent data for the combustible gas heating value is 3 MJ/kg. Previous trial data supplied by GEFS gives a corresponding value of 15.17 MJ/kg for the combustible gases. The gases will be burnt in a heater.

APPENDIX 3
BITUMEN RESULTS INTERPRETATION

Bitumen co-product benefits

The RBP offers benefits in two ways:

- A low carbon intensity replacement for fossil derived bitumen
- A route to sequester carbon in road surfaces.

These are considered in turn below:

Low carbon saving over fossil derived bitumen

The UK Institution of Civil Engineers has produced an inventory of carbon and energy for a range of construction materials (ref: BSRIA Guide: The inventory of carbon and energy (ICE), Hammond and Jones, and associated database icev2.0 Jan 2011).

This inventory includes bitumen with an embodied energy of 51 MJ/kg and embodied carbon of 0.43 to 0.55 kg CO_2e/kg.

The corresponding embedded carbon in the RBP is 8,918 / 17,236 = 0.517 kg CO_2e/kg.

This is within the range for conventional bitumen so for the configuration modelled here there is no credit available to the RDF from the renewable bitumen. The model shows this is because of the relatively high carbon emission factor for Australian grid electricity. If a lower carbon source of electricity can be used, there would be a significant reduction in embedded carbon.

Carbon sequestration

The embedded carbon in the RBP offers significant potential to lock away carbon in road surfaces. Preliminary calculations show that this could contribute a further credit of 9.8 g CO_2/MJ to the biogenic RDF.