Biomass and Bioenergy 96 (2017) 162–171

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Life cycle assessment of a mallee eucalypt jet fuel

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A R T I C L E I N F O

Article history:
Received 24 February 2016
Received in revised form
23 November 2016
Accepted 24 November 2016
Available online 2 December 2016

Keywords:
Life cycle analysis
Biofuels
Greenhouse gas
Biomass
Eucalyptus spp

A B S T R A C T

This study uses life cycle assessment to quantify and compare the greenhouse gas emissions and fossil fuel depletion impacts of a theoretical mallee jet fuel value chain, operating in the Great Southern region of Western Australia, with those of fossil-based jet fuel. Relative to fossil-based jet fuel, the mallee jet fuel was found to reduce greenhouse gas emissions by 40% and result in a net fossil fuel depletion benefit. Further greenhouse gas reductions could be achieved by optimizing the supply chain through measures such as capturing methane emissions for hydrogen production and utilizing co-produced biodiesel. The magnitudes of the environmental benefits are sensitive to a number of methodology assumptions, including the approach to potential food displacement and co-production.

1. Introduction

The aviation industry contributes to an estimated 3.5%–4.9% of global radiative forcing impacts [1,2] associated with the combustion of aviation and jet fuels. Environmental pressures on the aviation sector [3] have contributed to the development of fuels based on biomass. A number of technologies can produce biomass-based jet fuels, including Fischer-Tropsch synthesis [4], hydroprocessing [5], and pyrolytic (pyrolysis) processing [6]. The biomass feedstock can include microalgae [7,8], oil-rich crops such as rapeseed and soybeans [9,10], and other crops, including corn and sugarcane [11]. Indirect land use change effects, including deforestation and displacement of food, together with low biomass yields and soil degradation are often cited as major environmental concerns associated with biomass production [11–13]. Plant biomass, produced on marginal or degraded lands, has been suggested as a way of limiting indirect land use change effects [12,14]. The use of lignoceullosic biomass can improve effective yields [13]. One potential lignoceullosic biomass is from harvested mallee eucalypt trees, including *Eucalyptus loxphleba* subspp. *lissophloia* and *gratiae*, *Eucalyptus kochii* subspp. *plenissima*, *borealis* and *kochii*, *Eucalyptus polybractea*, *Eucalyptus myriadena*, and *Eucalyptus angustissima* subsp. *angustissima* [15]. The mallee biomass can be processed to produce bio-oil and subsequently gasoline, diesel fuel, and kerosene-like fuel suitable for use jet in aircraft. After the biomass is harvested, the mallee eucalypts regenerate, allowing for ongoing harvests.

A critical aspect to the implementation and approval for use biomass jet fuels is environmental performance [16]. Life cycle assessment (LCA) is one of the main methodologies used to quantify environmental performance of biomass fuel systems [13,17–22]. Previous LCAs on mallee biomass focus on energy balances of the biomass production activity in isolation of further processing [23,24] and it is not known if mallee jet fuel results in environmental benefits over the full life cycle. This paper addresses this knowledge gap by assessing the full life cycle environmental performance of jet fuel produced from mallee biomass (mallee jet fuel) relative to those produced from crude oil (fossil jet fuel). Drivers of environmental impacts are discussed, and effects of potential food displacement are critically evaluated. Opportunities for reduced environmental impact are outlined and variations in results with LCA approaches co-production are explored. Finally, limitations on the applicability of the outcomes are outlined together with directions for future research.

2. Methods

The LCA study was undertaken in accordance with ISO 14044:2006 [25]. The LCA process includes defining the study goal and scope, establishing a life cycle inventory, translating environmental flows into quantified environmental impacts, and interpreting the relationship between process flows and environmental impacts. The study goal, scope, and inventory are described in this

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http://dx.doi.org/10.1016/j.biombioe.2016.11.014
0961-9534/

section, while the environmental impacts and interpretation are reported in the results and discussion, respectively. Life cycle inventory modeling and life cycle impact assessment were performed using SimaPro 8.0.4.6 software.

2.1. Goal of the study

The goal of the LCA study was to compare the climate change impacts and fossil fuel depletion impacts of jet fuel derived from mallee biomass and fossil fuels. The outcomes of this LCA were used by Future Farm Industries Cooperative Research Centre Ltd. (FFICRC) as part of a broader sustainability assessment report (not publicly available) submitted to the Roundtable on Sustainable Biomaterials. This LCA study was commissioned by the FFICRC, and involved participants from Airbus S.A.S. Manchester Metropolitan University, Virgin Australia Pty. Ltd., Enecon Pty. Ltd, Dynamotive Energy Systems Corporation, and IFP Energies Nouvelles.

2.2. Scope of the study

2.2.1. Description of product systems

The mallee jet fuel system was based on a theoretical supply chain, operating over a thirty year period from 2022 to 2052. This theoretical supply chain was established as part of a business case, developed in 2011 by Renewable Oil Corporation Pty. Ltd. (ROC) in partnership with FFICRC [26]. The growing and harvesting schemes, and the location of processing facilities were modelled and selected by experts, based on technical and financial analyses, government regulations and the presence of existing infrastructure. Details of the theoretical supply chain are reported elsewhere [26]; however, an overview is provided below.

The theoretical mallee jet fuel supply chain starts with the establishment of mallee crops in the Great Southern region of Western Australia, a region which currently produces canola, wheat and barley. Establishment of the mallee crop will involve the application of herbicides, soil preparation, site preparation and planting. Nutrient build-up in soils from prior agricultural activities means that fertilizers will not be typically needed prior to planting. The first harvest should typically occur six years after plantation, followed by subsequent harvests every four years. Following harvesting, the biomass will be transported by articulated road freight to one of two drying and pyrolysis processing facilities, located within a 100 km radius of supporting farms. At each of these facilities, the biomass will be ground and then stored. Following storage, the biomass moisture will be reduced using an electric rotary drum dryer, heated using a fraction of the outgoing dried biomass. The dried biomass will then be pyrolytically processed, producing non-condensable gases (NCGs), char and bio-oil. The bio-oil will be stored on site, before transportation to Kwinana via articulated road freight for upgrading. The bio-oil is typically unstable, low in energy density, and acidic [6], and requires upgrading for end-use. The IFP Energies Nouvelles process of upgrading bio-oil will be used and occurs in three steps: hydro-reforming (to UBA), hydro-treatment (to UBB) and fractionation to fuels. The hydro-reforming and hydro-treatment require compressed hydrogen inputs. The source for the hydrogen inputs are yet to be finalised, but were assumed to be steam-reformed natural gas. The current ASTM D7566 standards limit the use of jet biofuels to blends with traditional jet fuel of between 10% and 50% by volume [27]. However, it is anticipated that ASTM D7566 will allow for the certification of 100% synthetic jet fuel in the future [28]. As such, this study assumed that a 100% mallee jet fuel will be used. Following fractionation, the mallee jet fuel will be transported via articulated truck from Kwinana for intermittent storage at Perth Airport and subsequent use in aircraft.

The alternative system assessed in the LCA study is based on conventional jet fuel production. This involves the exploration and extraction of crude oil from the Middle East, the transport of crude oil to a refinery in Kwinana, the processing and fractionation of crude oil to jet fuel, transport to the airport and intermittent storage, and finally combustion in a jet turbine for flight operations.

2.2.2. Function and functional unit

The focus of this study was the use of jet fuel in an Airbus A330-200 aircraft jet, which transports people over a distance. The delivery of the mallee jet fuel at Perth airport means that the aircraft can only refuel with mallee jet fuel at that location. Therefore, the environmental assessment is based on the functional unit of one flight, consisting of one typical Airbus A330-200 commercial passenger aircraft flight, operating twin Rolls Royce Trent 772B turbines, between Perth and Sydney (Kingsford Smith) airports. The operation of an Airbus A330-200 on the return leg (from Sydney to Perth) is outside the scope of this project. It is recognized that for comparison purposes, an alternative functional unit can be useful. As such, key results are also reported per MJ of jet fuel.

2.2.3. System boundary

The system boundary outlines the processes to be included in the assessment, Fig. 1. These include farming, biomass processing, transport, aircraft operation, infrastructure, the production of electricity, natural gas, fertilizers and soil modifiers, herbicide and pesticides, reticulated water and wastewater treatment. Some infrastructure processes were excluded (e.g. factories, roads), along with human labour, wetting agents, surfactants and administration overheads. The estimated cut-off of elementary flows was 1% of the cumulative mass flows.

2.2.4. Allocation procedures

The ISO 14044:2006 [25] hierarchal procedure for partioning was applied to handle processes with multpiple functions. Weidema's [29] system expansion approach was applied to avoid allocation in two processes: pyrolysis, where char is co-produced with bio-oil, and the upgrading of bio-oil, which produces co-produces UBA oil, methanol and acetic acid. The production of bio-oil was ascribed the environmental impacts of the pyrolysis process, as well as char storage. Environmental credits were applied to the pyrolysis process for the avoidance of coal production. No environmental credits were applied for avoided emissions from coal combustion as no char is combusted in the pyrolysis process. For the upgrading of bio-oil, the refined UBA oil was ascribed all process impacts, with credits applied for avoided acetic acid and methanol production. Mass allocation were applied to these processes in a sensitivity study. Energy allocation was applied to fractionation processes. Freight processes were allocated by mass. Energy and economic allocation was applied to the refining of unleaded petroleum products, in line with previous literature [30].

2.2.5. Life cycle impact assessment methodology and types of impacts

The scope of the environmental assessment was limited to climate change impacts and fossil fuel depletion. An assessment of eutrophication, land-use, soil salinity, indirect land use change and water stress impacts were outside the scope if this study, but were addressed in the FFICRC report. LCIA was performed for greenhouse gas emissions and fossil fuel depletion by multiplying environmental flows of the various resources and greenhouse gas emissions by their respective characterization factors. Characterization factors for greenhouse gas emissions were based on global warming potentials (GWPs) for a 100-year time horizon, as reported in the Intergovernmental Panel on Climate Change (IPCC) Fourth