Science of the Total Environment 481 (2014) 17–26

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Life cycle assessment of camelina oil derived biodiesel and jet fuel in the Canadian Prairies

Xue Li, Edmund Mupondwa *

Bioproducts & Bioprocesses, Science and Technology Branch, Agriculture and Agri-Food Canada, Government of Canada, Saskatoon Research Centre, 107 Science Place, Saskatoon S7N 0X2, Canada

HIGHLIGHTS

- LCA of camelina-derived biodiesel and jet fuel was based on the Canadian Prairies.
- Overall, camelina-derived biodiesel had lower GHG emissions than is biojet fuel.
- Camelina jet fuel had lower non-renewable energy (NRE) use than its biodiesel.
- Camelina biofuels reduced GHG emissions and NRE use relative to petroleum fuel.

ARTICLE INFO

Article history:
Received 26 November 2013
Received in revised form 2 February 2014
Accepted 2 February 2014
Available online xxxx

Keywords:
Camelina
Biodiesel
Hydroprocessed renewable jet fuel
Life cycle assessment
Greenhouse gas emissions

ABSTRACT

This study evaluated the environmental impact of biodiesel and hydroprocessed renewable jet fuel derived from camelina oil in terms of global warming potential, human health, ecosystem quality, and energy resource consumption. The life cycle inventory is based on production activities in the Canadian Prairies and encompasses activities ranging from agricultural production to oil extraction and fuel conversion. The system expansion method is used in this study to avoid allocation and to credit input energy to co-products associated with the products displaced in the market during camelina oil extraction and fuel processing. This is the preferred allocation method for LCA analysis in the context of most renewable and sustainable energy programs. The results show that greenhouse gas (GHG) emissions from 1 MJ of camelina derived biodiesel ranged from 7.61 to 24.72 g CO_2 equivalent and 3.06 to 31.01 kg CO_2/MJ equivalent for camelina HRJ fuel. Non-renewable energy consumption for camelina biodiesel ranged from 0.40 to 0.67 MJ/MJ; HRJ fuel ranged from −0.13 to 0.52 MJ/MJ. Camelina oil as a feedstock for fuel production accounted for the highest contribution to overall environmental performance, demonstrating the importance of reducing environmental burdens during the agricultural production process. Attaining higher seed yield would dramatically lower environmental impacts associated with camelina seed, oil, and fuel production. The lower GHG emissions and energy consumption associated with camelina in comparison with other oilseed derived fuel and petroleum fuel make camelina derived fuel from Canadian Prairies environmentally attractive.

1. Introduction

Conventional transportation fuels from petroleum are one of the primary sources of greenhouse gas (GHG) emissions that promote global warming. Renewable fuels including ethanol, biodiesel, and jet fuel are practical and effective alternative energy sources (Agusdinata et al., 2011; Campbell et al., 2011; Fan et al., 2013). The Canadian federal and provincial governments have supported the expansion of renewable fuels in recent years in terms of policy, legislated mandates, and commercial promotion. From 2005 to 2010, the Canadian industry invested \$2.3 billion in the construction of new renewable fuel facilities across the country, representing approximately 2.0 G l of capacity per year (CRFA, 2010). However, this is only 2% of biofuels produced worldwide and 4% of US production (CRFA, 2010). Tremendous opportunities remain for exploring new sources of alternative fuels and increasing domestic production capacities, especially with the growing importance of biodiesel and jet fuel in the trucking and aviation industries.

In this regard, new crops such as jatropha in Asia, Europe and Africa (Karmakar et al., 2010; Kumar et al., 2012; Zhu et al., 2010), and camelina in Europe and North America (Bernardo et al., 2003; Fröhlich and Rice, 2005; Krohn and Fripp, 2012; Moser and Vaughn, 2010) are gaining attention as new feedstocks for biodiesel and jet fuel production. This is in addition to traditional oilseed crops such as canola/rapeseed, soybean, and palm. Within Canada (and indeed North America), camelina is viewed as the next generation dedicated oilseed platform for a biodiesel and jet fuel biorefinery. As a member of the *Brassicaceae* family (canola, rapeseed, mustard, and crambe), camelina has been shown to be a low-input oilseed crop with the potential to provide sustainable advanced biofuels and fill an energy niche for agricultural producers (Keske et al., 2013; Shonnard et al., 2010). Its other advantages include short growth

---

* Corresponding author at: Bioproducts & Bioprocesses, Saskatoon Research Centre, 107 Science Place, Saskatoon, SK S7N 0X2, Canada. Tel.: +1 306 385 9360.
E-mail address: Edmund.Mupondwa@agr.gc.ca (E. Mupondwa).

http://dx.doi.org/10.1016/j.scitotenv.2014.02.003
0048-9697/Crown Copyright © 2014 Published by Elsevier B.V. All rights reserved.

cycle, high oil content, resistance to common pathogens and pests, high tolerance to drought conditions and cold temperature, and a rotation-crop option for producers (Ciubota-Rosie et al., 2013) that could be produced well in the Canadian Prairies (Gugel and Falk, 2006; Newlands et al., 2012; Steppuhn et al., 2010).

One important reason for developing renewable fuels is to reduce GHG emissions resulting from petroleum fuel. Research has demonstrated that biodiesel and renewable jet fuel significantly reduce GHG emissions in comparison with conventional diesel and petroleum fuel (Campbell et al., 2011; Fan et al., 2013; Hong, 2012; Kumar et al., 2012; Nanaki and Koroneos, 2012; Sprinckx and Ceuterick, 1996; Stratton, 2010), although a Belgian rapeseed study by Sprinckx and Ceuterick (1996) reported that biodiesel represented a higher contributing factor to acidification, eutrophication and the formation of photochemical oxidants, with the contribution to acidification being attributed primarily to nitrogen, sulfur oxides and ammonia which are released during the growing period. In more recent studies, camelina biodiesel has been demonstrated to have better performance in decreasing GHG emissions than traditional soybeans and canola biodiesel (Krohn and Fripp, 2012; Miller and Kumar, 2013). Camelina-based biojet fuel derived from camelina grown in Montana, US, was also reported to reduce CO_2 emissions by 75% compared to traditional petroleum-based jet fuel (Shonnard et al., 2010). Camelina's growing commercial prominence as a good alternative source to traditional petroleum-derived diesel and jet fuels is demonstrated by a recent memorandum of understanding (MOU) between 14 major airlines from the United States, Mexico, Canada, and Germany announced by US-based AltAir Fuels on negotiations to purchase up to 2.84 G l of camelina derived renewable jet fuel and diesel (Williams, 2009). The MOU would enable camelina renewable fuel to be produced at a new facility in Anacortes, Washington State, and is projected to substitute 10% of the petroleum fuel consumed annually at Seattle–Tacoma International Airport; in turn, this would reduce CO_2 emissions by 6.35 G kg over 10 years, a key target stated in the MOU.

The wide adoption of these renewable energy initiatives would contribute to the attainment of global renewable energy targets established in many jurisdiction, such as the European Union (EU) renewable energy targets implemented under the EU's 2010 Renewable Energy Directive (EU, 2009) for the EU to achieve a 20% share of energy from renewable sources by 2020 and a 10% share of renewable energy specifically in the transport sector. This increase in EU demand for biodiesel feedstocks represents new commercial prospects for new crops like camelina. However, in providing this legal framework for promoting renewable bioenergy, the EU also established sustainability criteria for supplying feedstocks to this market, specifically: a) the use of biofuels must result in an overall GHG savings of at least 35% compared to fossil fuel, in order to qualify towards the 10% biofuel target in the EU by 2020 (to be increased up to 50% from 2017 and 60% for new installations from 2018); b) there should be no conversion of land with high carbon stock such as continuously forested areas, wetlands or peatlands; and c) raw materials should not be derived from land with high biodiversity value, such as primary forest, nature protection areas, and highly biodiverse grasslands. Hence, from Canada's perspective, it is useful to contribute to further understanding of environmental and sustainability issues relevant for the development and commercialization of new dedicated energy oilseed crops like camelina to be grown in the Canadian Prairies.

This paper is generated because of significant emerging interest in the development of camelina as an industrial crop and feedstock for biofuel production in Canada. In the Prairie provinces of western Canada, camelina has shown a lot of promise as a dedicated industrial oilseed crop for biofuel production and other biorefinery applications (Blackshaw et al., 2011; Gugel and Falk, 2006; Jiang et al., 2013; Steppuhn et al., 2010). In September 2013, the Canadian Federal Government announced $3.7 million funding for the development of market-ready varieties of camelina for production across Canada for industrial utilization (AAFC). Policy makers and industry stakeholders are looking for pertinent information that would enable the sector to capture benefits from camelina by understanding region-specific factors that have an impact on the development of sustainable biorefinery business models based on locally grown camelina feedstocks. This includes addressing questions related to the carbon footprint and environmental sustainability of biofuels derived from camelina in Canadian regions compared with conventional jet fuel and diesel. Although life cycle assessment (LCA) provides overall environmental impacts of a product or process, most LCA studies have mainly focused on GHG emissions. This study extends this discourse by conducting LCA of camelina in the Canadian Prairies in order to quantify the carbon footprint and other environmental impacts including ecosystem, human health, and energy resources associated with the production of biodiesel and jet fuel from camelina using Canadian agricultural process data.

2. Methods

2.1. Goal and scope

LCA software SimaPro 7.2 (PRé Consultants, Amersfoort, Netherlands) was used to conduct the analysis following ISO 14040 and 14044 methods (ISO, 2006). The goal of this study is to evaluate the impact of camelina derived biodiesel and jet fuel on GHG emissions, resource consumption, ecosystem quality, and human health under several scenarios. The scope of this study encompasses the entire life cycle from camelina cultivation, transportation, oil extraction, and biodiesel or jet fuel conversion.

2.2. System boundary and functional unit

Fig. 1 presents the system boundaries for the LCA of camelina biodiesel and jet fuel production. The boundaries include the burden of all inputs in agricultural production, transportation of seed to the biodiesel plant, direct inputs in oil extraction and fuel conversion (including materials and energy), and transportation of fuel to market. The system boundaries depicted in Fig. 1 for camelina agricultural, oil extraction, and jet fuel production involve more than one co-product. This leads to the typical allocation problem in LCA which refers to criteria for determining how input or output flows of a product or process and their associated environmental burdens should be allocated or partitioned for a product or process that has different co-products. ISO 14041 provides a guide for LCA when there is allocation (ISO, 2006). In cases involving multiple products, the first choice is avoiding allocation; this can be done by either dividing the unit process to be allocated into two or more subprocesses or by expanding the production system to include additional functions related to the co-products (ISO, 2006; Weidema, 2001; Weidema and Schmidt, 2010). Hence, our study addressed the allocation problem by applying the system expansion approach. The functional unit is 1 MJ of lower heating value from fuel combustion for both biodiesel and jet fuel. As a result, the agricultural stage of the system has its own functional unit of 1 kg of camelina seed.

2.3. Methodology and categories

Impact 2002+ method developed by Jolliet et al. (2003) was adopted in this study to conduct LCA using SimaPro software. This method combines two traditionally used in LCA impact assessment approaches: a) mid-point categories and b) damage-oriented categories. Mid-point categories are basically applied by confining quantitative modeling to early stages in the cause–effect chain by classifying LCA results in terms of 14 midpoint categories including global warming, acidification, eutrophication, human toxicity, ecotoxicity, and land occupation. The concept of 'midpoint' simply expresses the fact that the estimated effect is at the intermediate location between the LCA results and the damage (or endpoint) on the impact continuum or pathway. CML and EDIP are classical mid-point impact assessment methods developed by Guinée et al. (2002) and Hauschild and Wenzel (1998). CML 2001 is