BIOMASS AND BIOENERGY 67 (2014) 108–118

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Environmental and economic assessment of producing hydroprocessed jet and diesel fuel from waste oils and tallow

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ARTICLE INFO

Article history:
Received 10 May 2013
Received in revised form
17 April 2014
Accepted 18 April 2014
Available online

Keywords:
Tallow
Yellow grease
HEFA diesel
HEFA jet
Lifecycle greenhouse gas emissions
Techno-economic analysis

ABSTRACT

Animal fats and waste oils are potential feedstocks for producing hydroprocessed esters and fatty acids (HEFA) jet and diesel fuels. This paper calculates the lifecycle greenhouse gas (GHG) emissions and production costs associated with HEFA jet and diesel fuels from tallow, and from yellow grease (YG) derived from used cooking oil. For YG, total CO_2 equivalent (CO_2 eq.) GHG emissions of jet and diesel were found to range between 16.8–21.4 g MJ^{-1} and 12.2–16.9 g MJ^{-1} respectively. This corresponds to lifecycle GHG emission reductions of 76–81% and 81–86% respectively, compared to their conventional counterparts. Two different system boundaries were considered for tallow-derived HEFA fuels. In System 1 (S1), tallow was treated as a by-product of the rendering industry, and emissions from rendering and fuel production were included. In System 2 (S2), tallow was considered as a by-product of the meat production industry, and in addition to the S1 emissions, cattle husbandry and slaughtering were also included. The lifecycle emissions (CO_2 eq.) from HEFA jet fuel for S1 and S2 were estimated to be 25.7–37.5 g MJ^{-1} and 67.1–83.9 g MJ^{-1} respectively. HEFA diesel lifecycle emissions were found to be 21.3–33.3 g MJ^{-1} for S1 and 63.4–80.5 g MJ^{-1} for S2. Production costs for these fuels were calculated using a discounted cash flow rate of return model. The minimum selling price was estimated to be 880 \$ m^{-3}–1060 \$ m^{-3} for YG-derived HEFA, and 1050–1250 \$ m^{-3} for tallow-derived HEFA fuels.

1. Introduction

In 2012, 299 hm^3 of middle distillates (jet and diesel fuels) were used in the United States (US), which accounted for 28% of US liquid fuel consumption [1]. The US Renewable Fuels Standard (RFS2) of 2007 mandates that by 2022, 136 hm^3 of renewable fuels must be produced in the US, of which up to 79 hm^3 may come from middle distillates that meet certain greenhouse gas reduction thresholds [2]. The Federal Aviation Administration

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http://dx.doi.org/10.1016/j.biombioe.2014.04.024

(FAA) has established a voluntary goal for aviation, which aims at using 3.9 hm^3 of alternative jet fuel annually by 2018 in the US, including both commercial and military applications [3,4]. Hydroprocessed esters and fatty acids (HEFA) fuels are a near-term biofuel technology for the production of middle distillates for road and air transportation [5]. HEFA fuels are produced from bio-derived lipids such as vegetable oils, algae oils, and animal fats; and they are already approved for use in aircraft if blended up to 50% with conventional jet fuel [6]. Since 2008 several airlines have successfully conducted flight tests using blends of conventional and HEFA jet fuels [7,8]. HEFA diesel meets ASTM specifications, and therefore may be used in existing diesel engines and infrastructure [9]. The details of the HEFA process including assumptions, yields and selectivities are described elsewhere [10,11], and will not be discussed herein. While the performance properties of HEFA fuels are comparable to conventional petroleum fuels, the main advantages of HEFA fuels are high cetane numbers, low aromatic and sulfur contents, and potentially lower greenhouse gas emissions from renewable feedstocks [10].

Yellow grease and tallow are potential alternative feedstocks for HEFA fuels. Tallow, which can be differentiated into edible and inedible tallow, is derived from rendering edible or inedible portions of beef carcasses. While edible tallow is mainly used as shortening for baked goods, inedible tallow is used in animal feed, soap production and lubricants [12]. The rendering process involves the heat-treatment of animal by-products (bones, offal, fats, etc.) from carcasses of livestock in either the presence (wet rendering) or the absence (dry rendering) of water or steam [12,13]. As a result, the animal fat melts and it can easily be extracted from the surrounding nonfat tissues containing proteins and water. Used cooking oil containing excess water is collected from commercial kitchens and restaurants. This water is removed during the rendering process, and yellow grease is obtained. Yellow grease is used as an additive in pet food and animal feed, is buried in landfills, or ends up in municipal sewer lines causing blockages [14]. A recent survey by the U.S. Census Bureau showed that the total production of rendered lipids in the United States in 2010 reached around 4.3 Tg [15]. Tallow and used cooking oil-derived yellow grease accounted for 68% of total waste oils and animal fats available (Table 1).

The purpose of this paper is to quantify the environmental and economic viability of HEFA jet and diesel fuel from tallow and used cooking oil. To the best of our knowledge, this is the first archival publication to estimate a range of production costs (called "minimum selling prices" in this paper) and corresponding local and global sensitivities for HEFA fuels from these feedstocks. The analysis calculates total production costs, identifies main cost drivers and quantifies price supports needed for achieving price parity with conventional diesel and jet fuel. In terms of environmental analysis, this work is the first archival publication to calculate GHG emissions for HEFA fuels derived from used-cooking oil. There is literature on GHG emissions from tallow-derived HEFA, but these analyses have been limited to treating tallow as a waste product of the rendering industry, and neither emissions from rendering process nor cattle husbandry were taken into account [16–18]. This is the first work to quantify lifecycle GHG emissions of tallow-derived HEFA fuels for broader system boundaries that include rendering and cattle husbandry. We also capture variability associated with processing practices from both tallow and used cooking oil, which leads to the definition of three potential scenarios (low, baseline and high) and to calculations of associated lifecycle GHG emissions.

Table 1 – Production of waste oils and animal fats in US in 2010 in Tg [15].

	Production in US in 2010, Tg
Edible tallow	0.84
Inedible tallow	1.46
Lard	0.14
Poultry fat	0.64
Yellow grease	0.64
Other grease	0.60
Total	4.33

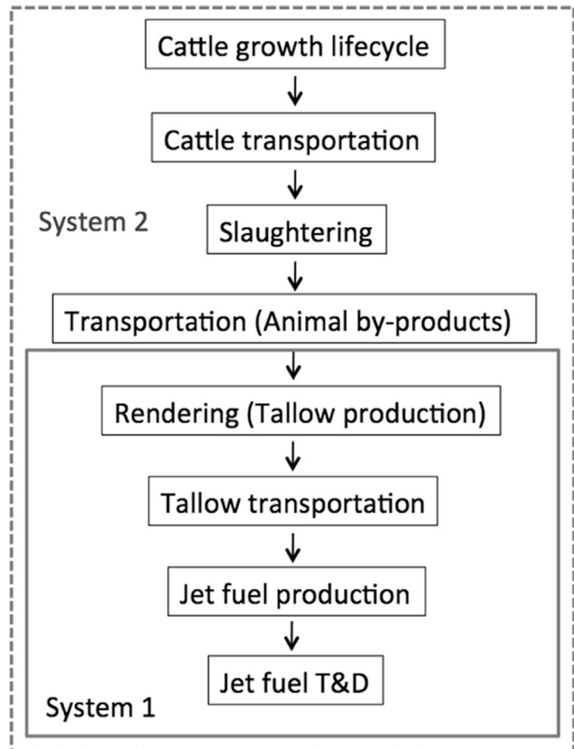

Fig. 1 – System boundaries for lifecycle analysis of tallow-derived HEFA fuels.

2. Lifecycle greenhouse gas emission assessment

The lifecycle GHG emissions associated with HEFA jet fuel and diesel production from tallow and yellow grease were calculated with the GREET1_2011 framework [19] and SimaPro 7.3.3 [20] software using literature data [10,21–24]. In order to capture the variability associated with processing practices, three different emission cases (low, baseline and high) were considered based on the variations of data at certain stages of the fuel lifecycle. For each step of the lifecycle, GHG emissions