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Technoeconomic analysis of jet fuel production from hydrolysis, decarboxylation, and reforming of camelina oil

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ABSTRACT

The commercial production of jet fuel from camelina oil via hydrolysis, decarboxylation, and reforming was simulated. The refinery was modeled as being close to the farms for reduced camelina transport cost. A refinery with annual nameplate capacity of 76,000 cubic meters hydrocarbons was modeled. Assuming average camelina production conditions and oil extraction modeling from the literature, the cost of oil was 0.31 $\$ kg^{-1}$. To accommodate one harvest per year, a refinery with 1 year oil storage capacity was designed, with the total refinery costing 283 million dollars in 2014 USD. Assuming co-products are sold at predicted values, the jet fuel break-even selling price was 0.80 $\$ kg^{-1}$. The model presents baseline technoeconomic data that can be used for more comprehensive financial and risk modeling of camelina jet fuel production. Decarboxylation was compared to the commercially proven hydrotreating process. The model illustrated the importance of refinery location relative to farms and hydrogen production site.

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1. Introduction

1.1. General motivation

The development of biofuels can address concerns of sustainability, petroleum demand, and the environment. The U.S. Department of Energy (DOE) forecasts worldwide petroleum use will increase from 14 million cubic meters per day in 2010 to 18 million cubic meters per day in 2040 [1]. Though the U.S. is experiencing a crude oil boom, its future is uncertain. The DOE projects continued crude oil growth until 2036 under its High Oil and Gas Resource scenario, but under its Reference and Low Oil and Gas Resource scenarios, production will begin to decline by approximately 2021 and 2017, respectively [2].

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Moreover, since the Energy Independence and Security Act of 2007, the U.S. has promoted the development of biofuels to reduce greenhouse gas emissions [3].

1.2. *Commercialized biofuel processes*

Ethanol and FAME (fatty acid methyl ester) biodiesel are biofuel replacements for gasoline and diesel, respectively. Several technologies for bio-jet fuel have met ASTM standards, including Fischer–Tropsch Hydroprocessed Synthesized Paraffinic Kerosene (FTH-SPK), Hydroprocessed Esters and Fatty Acids Synthesized Paraffinic Kerosene (HEFA-SPK), and fermented sugars hydroprocessed Synthesized Iso-Paraffins (SIP) [4]. HEFA-SPK utilizes triglyceride feedstocks such as plant oils and animal fats, and removes the oxygen via hydrogen, releasing water. The products are hydrocarbon-only fuels [5,6]. HEFA-SPK refineries of 116 dam^3 per year and 378 dam^3 per year were modeled using soybean oil as feedstock [7]. The refinery requires a large amount of hydrogen for oxygen removal.

Several companies have commercialized refineries utilizing the HEFA-SPK technology. Neste Oil has two refineries of annual nameplate capacity 190 Gg renewable diesel (approximately 238 dam^3) in Finland, and two 800 Gg renewable diesel (approximately 1000 dam^3), one each in Singapore and the Netherlands [8]. The two Finland HEFA-SPK refineries are co-located with a petroleum refinery in the port of Porvoo [9]. The Singapore HEFA-SPK refinery is co-located with a large industrial zone at the coast [10]. The Netherlands HEFA-SPK refinery is co-located with other chemical plants in the port of Rotterdam [11]. The refineries have the capability to produce jet fuel [12]. In 2012 and 2013, the Neste Oil HEFA-SPK refineries used 64.5% and 47.4% crude palm oil respectively, 35.1% and 52.6% waste and residues (waste animal fat, waste fish fat, vegetable oil fatty acid distillates) respectively, and 0.3% and 0.0% other vegetable oils (rapeseed, soybean, camelina) respectively [13]. Renewable Energy Group (REG) has a HEFA-SPK refinery of annual nameplate capacity 284 dam^3 fuel in Geismar, Louisiana [14]. The refinery has the capability to produce jet fuel. Diamond Green Diesel has a HEFA-SPK refinery of annual nameplate capacity over 568 dam^3 diesel fuel in Norco, Louisiana near the Valero St. Charles petroleum refinery [15]. In summary, HEFA-SPK refineries have been commercialized, typically for the production of diesel but with jet fuel capability as well, and close to coasts and petroleum refineries.

An alternative conversion process from triglycerides to hydrocarbons is decarboxylation of the fatty acids [16]. A decarboxylation process has been selected for analysis, with data derived from a patent and additional studies [17–20]. Turner and Roberts [21] modeled the energy balance for the hydrolysis, decarboxylation, and hydrocarbon reforming steps, with a different decarboxylation gas clean-up process than reported here, and found the process to be 89.6% energy-efficient.

1.3. *Camelina*

Camelina is in the Brassicaceae, or mustard, family and has been identified as an energy crop because of low input requirements, fast growing rate, good stress tolerance, high yield potential, and a sustainable life cycle [22–25]. Camelina is typically considered for production in the US. northwest. In 2007, 91 km^2 camelina were planted in Montana, though the value declined to 8 km^2 by 2012 [26]. Another source indicates that in 2009, 80 km^2 of camelina were planted in the U.S. [27]. Due to its short growing season, camelina could be rotated with wheat over a two year cycle. It is projected that from 2012 to 2024, annual U.S. wheat acreage will be 220,000 km^2 [28]. If camelina acreage rose to the level of wheat acreage, then given the calculations described in this paper, 15 hm^3 fuel could be produced. Another way to quickly evaluate camelina potential is observing land use. For one example, in 2012 Montana had 242,000 km^2 “land in farms” (defined as agricultural land used for crops, pasture, or grazing, and including woodland and wasteland not actually under cultivation or used for pasture or grazing [29]) and of that, 28.5% was “total cropland,” 4.4% was “total woodland”, 65.8% was “permanent pasture and rangeland other than cropland and woodland pastured”, and 1.4% was “farmsteads, buildings, livestock facilities, ponds, roads, and wasteland” [30]. While this paper will not explore specific scenarios on land use, clearly, there is potential for camelina as a biofuel feedstock, without infringing on food production, by planting camelina in crop rotations and/or on marginal unused farmland. The crop has been evaluated as a feedstock for on-farm oil production and consumption [31]. Camelina has also been modeled as feed for diesel refineries using the HEFA-SPK technology [32].

1.4. *Purpose*

The purpose of this analysis is to provide knowledge on commercial jet fuel production from camelina. A technoeconomic model for the production of jet fuel from camelina oil via the decarboxylation technology was developed. This is not a comprehensive financial model, so some financial assumptions and determinants such as income tax, amortization, rates of return, and net present value are neglected. Rather, the data is presented simply without many embedded financial assumptions, so future financial modeling and risk management can be more clearly incorporated by the community.

Since the purpose of this paper is camelina jet fuel, the supply chain is very broad, including applications in agriculture, chemical refining, and associated logistics in both sectors. There are limitless variations that could be explored. It is important to characterize the interests and limits of this paper.

The selection of jet fuel as the primary product studied for this paper is because there is no widely available renewable alternative similar to ethanol and biodiesel used as gasoline and diesel replacements, respectively. However, there is unique demand for jet fuel. The United States Department of Defense Directive 4140.43 mandated JP-8, military jet fuel, as the universal military fuel [33]. Also, while military jet fuel demand is expected to remain steady through 2035, the demand for commercial jet fuel is expected to increase by as much as 25% by 2035 [34].

Our baseline assessment is modeling a camelina oil decarboxylation refinery of annual nameplate capacity

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