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Financial analysis and risk assessment of hydroprocessed renewable jet fuel production from camelina, carinata and used cooking oil

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HIGHLIGHTS

- Financial and uncertainty analyses of hydroprocessed renewable jet fuel production.
- Hydroprocessed renewable jet fuel production from oilseeds are highly dependent on the sale of the meal co-product.
- Probabilities that NPV > 0 are 29% for camelina, 18% for carinata and 8% for used cooking oil.
- The projects are highly sensitive to fuel product prices and feedstock prices.
- RIN would have a large impact on the projects' viability.

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ABSTRACT

This paper evaluates the financial viability of renewable jet fuel production, from two oilseed crops *Camelina sativa* (camelina) and *Brassica carinata* (carinata) and used cooking oil (UCO), by the hydrodeoxygenation pathway. A Monte Carlo analysis is performed to examine the robustness of the financial performance by taking into consideration key uncertain parameters, including capital cost, oil content of seeds, and prices of feedstocks, gas, electricity, water, meal co-product, and crude oil (indicator of fuel product prices). The Monte Carlo analysis revealed that under the conditions analyzed, the probabilities that the net present value would be positive are 29% for camelina, 18% for carinata and 8% for UCO, indicating that the three projects are risky for investors. Sensitivity analysis determined that the projects' financial performance is highly sensitive to prices of fuel products and feedstocks. The impacts of two different hypothetical biofuel economic incentives were assessed: Carbon trading and tradable credits similar to the Renewable Identification Number (RIN). Income earned in the form of a RIN would have a large positive impact on the projects' viabilities. By assuming an incentive of $0.20/L of renewable fuel, the probabilities that the NPV would be positive are 85% for camelina, 75% for carinata and 58% for UCO.

1. Introduction

Jet fuel is one of the most valuable products obtained from crude oil processing, and is traded in global financial markets. Increased globalization and international trade has led to a steady rise in air travel and forecast demand for jet fuel. The International Air Transport Association commitment to reduce carbon emissions by 50% by 2050 compared to the 2005 level [1] and the inclusion of aviation in the European Union Emissions Trading Scheme [2] has created interest in biomass-derived jet fuel. Biomass-derived jet fuel from feedstocks grown in an economically sustainable manner while minimizing the use of arable land holds long-term promise to help reduce aviation sector greenhouse gas (GHG) emissions and dependence on fossil fuels. However, the production volume of biomass-derived jet fuel is still comparatively small, and requires further expansion and development to be considered as a near-term partial replacement for conventional jet fuel.

Biomass-derived jet fuel can be produced by several pathways: a gas fermentation process [3–5], gasification-Fischer-Tropsch synthesis [6,7], hydroprocessing [8–10], catalytic hydrothermolysis [11], a direct sugar to hydrocarbon process [12], and alcohol to jet [13,14]. The hydroprocessing pathway converts fats and oils (e.g. plant oils, animal fats, waste cooking oils, algae oil, pyrolysis

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oil) in the presence of hydrogen into hydroprocessed renewable jet fuel (HRJ), hydroprocessed renewable diesel (HRD), liquefied petroleum gas (LPG) and naphtha. At present, Fischer-Tropsch and hydroprocessing pathways are more developed and already produced at pilot/commercial scale, particularly for flight tests. ASTM has approved 50:50 blends of petroleum-derived jet fuel with either Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT-SPK) or synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids (HEFA-SPK), often termed hydroprocessed renewable jet fuel, or HRJ, a term analogous to hydroprocessed renewable diesel (HRD) [15].

Several factors may affect the life cycle GHG emissions of biomass-derived jet fuel, including the production technology, the feedstock, and the emissions from land use change. If appropriate renewable feedstocks are used, both Fischer Tropsch fuels and HRJ could provide aviation with modest (~10%) to large (~50%) reductions in emissions [16]. Research is ongoing in evaluating different feedstocks and pathways.

There are several challenges to overcome to achieve large scale production of biomass-derived jet fuel, such as large scale feedstock availability at a comparatively low cost, feedstock sustainability, financial and technical issues when scaling-up technologies to commercial scale, and assessment of indirect impacts (social and environmental) [17,18]. Moreover, the commercialization of biomass-derived jet fuel is influenced by uncertainties in emissions regulations, market prices for crude oil and refinery products, and competition from other industries [19]. Production cost data for biomass-derived jet fuel remain scarce. Techno-economic assessments have been done considering different feedstocks, technologies, and pathways, like fermentation [20–22], fast pyrolysis [23], gasification Fischer-Tropsch synthesis [24], hydroprocessing [25,24,21,26], and alcohols synthesis [27]. These studies have calculated costs for biomass-derived jet fuel, with a wide range in the resulting values (between 0.61 and 8.45 $/L). The total cost of Fischer Tropsch jet fuel derived from biomass is expected to differ relative to the production cost for HEFA-SPK, because the FT process is preceded by a large scale biomass gasification technology. Overall, the calculated costs for biomass-derived jet fuel are sensitive to feedstock price, conversion technology, and capital cost. Pearlson et al. [25] developed a techno-economic analysis of HEFA fuel derived from soybean oil, and found that the distillate fuel plant-gate price when maximizing jet fuel production ranged from $1.07/L for a 378 MM L/year HEFA facility to $1.24/L for a 116 MM L/year facility. Some deterministic studies have demonstrated that if biomass-derived jet fuel is produced at the lower end of the cost range, some technologies could be competitive with conventional jet fuel from petroleum. However, only one study [28] outlines a methodology for evaluating the financial metrics of a HEFA refinery by considering uncertainties related to price volatility of fuel and renewable feedstocks.

As previously outlined, HRJ is a promising biomass-derived jet fuel and the aim of this work is to examine the financial viability of projects targeting HRJ production compared to projects targeting HRD, and to evaluate the extent that uncertainties influence the financial parameters and decision making surrounding commercialization of HRJ. The hypothetical HRJ and HRD production facilities were located in Western Canada, using the hydrodeoxygenation (HDO) pathway to convert oilseed crops such as *Camelina sativa* (camelina) and *Brassica carinata* (carinata), as well as used cooking oil (UCO). Finally, the impacts of two different hypothetical biofuel economic incentives were assessed. These incentives include (i) carbon trading and (ii) tradable credits similar to the Renewable Identification Number (RIN) that accompanies many fuels mandated under the U.S. Renewable Fuel Standard and managed by the US Environmental Protection Agency (US EPA) [29].

2. Methods

2.1. Renewable jet fuel and renewable diesel processes, scenarios and facility location

HRJ and HRD production processes using the HDO pathway were modeled by Chu [30], and are described in Fig. 1. The HDO process converts renewable oils into LPG, naphtha, HRJ and HRD. The HDO process and operating conditions can be modified to maximize the production of either HRJ or HRD. Maximizing production of HRJ requires additional processing (isomerization) and more hydrogen gas. However, some production of renewable diesel is inevitable. Similarly, when maximizing HRD production some HRJ is also produced using this pathway. In this study, it was assumed that no additional isomerization was required for a facility with HRD as the primary product. This is acceptable if HRD is used in warm weather conditions, or at low blend levels in cold weather conditions. Generally, to meet renewable fuel regulations, renewable diesel is blended in low concentrations (2–5%) with conventional diesel. For on road-use in cold weather, non-isomerized renewable diesel could be blended with ultra-low sulphur diesel, kerosene and #1 diesel to satisfy cloud point specifications.

For the facility designed to maximize HRJ production, three scenarios were analyzed, using three different feedstocks (camelina, carinata, and UCO). Similarly, for the facility designed to maximize HRD production, three scenarios were analyzed by varying the same feedstocks. In the carinata and camelina feedstock scenarios, protein meal was generated as a co-product in a co-located oilseed crushing facility. A separate process was developed to process UCO, which does not require oilseed extraction equipment, and does not produce protein meal as a co-product. The processes were modeled using the Aspen Plus simulation software [31], with the exception of feedstock production and solvent extraction. Mass and energy flows described in the study of Chu [30] were used for the input and output data of the financial analysis. For all HRJ and HRD scenarios, a fixed feed rate of 39 tonnes of oil/hour was used. The feed rates of each oilseed to the crushing operation were adjusted to produce 39 tonnes/h of oil. Camelina and carinata contain 35 and 44% oil, respectively, on a wet basis of 9% w/w [32]. The required amounts of camelina and carinata processed were 111 tonnes/h and 88 tonnes/h, respectively, taking into account differences in their oil contents. The annual liquid fuel throughput was 398 ML for the HRJ process and 382 ML for the HRD process. The small difference in volumetric throughput was due to differences in process yields and fuel densities.

Western Canada was selected for the facility location because of the camelina and carinata crop development work that has been done specifically in that region. The calculated prices of feedstocks are based on the selected geographical area and assumed transportation distance to the facility. Some of the land in Western Canada is semi-arid, and is therefore less suitable for food and conventional crop production. Camelina and carinata have been developed to tolerate these conditions and have demonstrated high potential for large scale production on these semi-arid lands that are unsuitable for conventional crops. Although these crops present attractive opportunities for Western Canada, they have not yet been produced in large quantities, although they have been grown in rotation with wheat in the US.

2.2. Financial model

Financial forecasts were prepared to examine the financial viability of HRJ and HRD production over a 20-year plant operating life. These forecasts were combined with common financial profitability indicators to predict financial viability and assess

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