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Original Research Article

Techno-economic assessment of hydrogenation-derived renewable diesel production from canola and camelina

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ABSTRACT

In this study, production cost of hydrogenation-derived renewable diesel (HDRD) was estimated using canola oil and camelina oil as feedstocks. Process simulation models were built based on experimental data to simulate the conversion of vegetable oil to *n*-alkanes primarily in the range of C9–C22. These models were used to estimate capital and operating costs to conduct a techno-economic assessment for a range of HDRD plant sizes (15–1161 million L/year, or 250–20,000 bbl/day) operating in Western Canada. The minimum costs of production for HDRD occurred at a plant optimum size of 812 million L/year (14,000 bbl/day). These minimum costs were $1.09/L for HDRD from canola oil, $0.85/L for HDRD from camelina oil if camelina meal can be sold, and $1.37/L for HDRD from camelina oil if camelina cannot be sold. The HDRD production cost varies significantly for small production plants but only varies by a few cents per liter for plants in the size range of 290–1161 million L/year (5000–20,000 bbl/day). Sensitivity analyses conducted indicate that HDRD production cost is not very sensitive to capital and operating costs, but is highly sensitive to feedstock cost, solvent price, and solvent recovery.

Introduction

Over the past decade, governments and environmental groups have pushed energy companies towards energy sources that are more sustainable than fossil fuels. However, when it comes to transportation fuels, fossil fuels are hard to displace because they are extremely convenient to use. In order to smooth the transition to sustainable energy, people have started to turn to biofuels, which can make use of the infrastructure already in place for fossil fuels like gasoline and diesel. To offset diesel consumption, consumers have two main options for alternative fuels: biodiesel and hydrogenation-derived renewable diesel (also known as HDRD or green diesel). Both biodiesel and HDRD can be produced from vegetable oils such as canola oil, camelina oil, sunflower oil, soy oil, or palm oil to name a few.

The differences between biodiesel and HDRD lie in the processing methods and final product composition. Biodiesel is composed of fatty acid methyl-esters and is produced via transesterification, which consists of reacting the triglycerides in the vegetable oil with an alcohol (usually methanol) in the presence of an alkaline or acid catalyst. On the other hand, HDRD is generally composed of *n*-alkanes, which can be produced by reacting the triglycerides in the vegetable oil with hydrogen under high pressure, high temperature conditions in the presence of a catalyst (a process commonly referred to as hydroprocessing). Several different catalysts and processing methods can be used for HDRD production and are discussed later in this paper. Energy companies are becoming increasingly interested in producing HDRD rather than biodiesel because HDRD's chemical composition is much closer to that of petroleum diesel and HDRD can have better cold flow properties than biodiesel [1–3].

Although the use of biodiesel and HDRD is not yet widespread in North America, production levels are increasing. Production growth for these fuels is mostly due to recently implemented renewable fuel standards legislation, such as the legislation in the Province of Alberta, Canada, which requires diesel sold to contain two percent biodiesel or HDRD [4]. Currently in Canada, production growth of biodiesel and HDRD must be driven by legislation because these fuels are more expensive to produce than conventional diesel. Many studies have been completed on the cost of producing biodiesel [5–7] but fewer authors have looked into the cost of producing HDRD. Some of the economic studies in literature include the cost of producing HDRD from bio-oil [8,9], the cost of producing Fischer–Tropsch liquids [10], and the cost of co-processing biofeedstocks with petroleum feedstocks in oil refineries [11]. Kalnes et al. [12] and Marker [11] examined the economics of producing HDRD from vegetable oil but did not

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analyze the impact of processing plant size on production cost and did not quote overall HDRD production costs. Wright and Brown [10] analyzed the influence of processing plant size on the production cost of various alcohols, hydrogen, and Fischer–Tropsch liquids but did not include HDRD. This study was an effort to fill a significant gap in the literature by estimating the cost of production of HDRD from canola or camelina oil at various production plant sizes, and by identifying the factors that have the greatest influence on production cost.

The overall objective of this research was to conduct techno-economic assessment of production of HDRD from canola and camelina. In this study, data intensive techno-economic models were developed for assessment of canola and camelina-based HDRD production. The models include detailed cost estimates for all aspects of HDRD production and the technical characteristics of the plants. The specific objectives of the study are given below.

- Estimate the economic optimum size and the minimum cost of production for an HDRD production plant using canola oil and camelina oil as feedstocks.
- Compare the techno-economics for canola and camelina-based HDRD production plants.
- Determine the economic sensitivity to yield, capital, operating, field, and transportation costs.

Scope of work and rationale

Biodiesel vs. renewable diesel

The terms "biodiesel" and "renewable diesel" (HDRD) are often used interchangeably by the public to describe diesel fuel substitutes derived from biomass. However, there are many important distinctions between the two fuel types. The most notable difference is that the chemical compounds in biodiesel contain oxygen, whereas the chemical compounds in HDRD do not. The presence of oxygen in biodiesel causes a reduction in heating value [11] and a reduction in fuel stability compared to HDRD [2,12]. In terms of general fuel properties, biodiesel and HDRD fall under different standards. In North America, the ASTM standard D6751 is used for biodiesel. However, since the composition of HDRD is so similar to petroleum diesel, the ASTM standard D975 for petroleum diesel can also be used for HDRD. Some of the main requirements of each standard are shown in Table 1 below. Note that although the minimum cetane number for ASTM D975 is 40, the cetane number of HDRD is much higher (approximately 55–90) [12–14], thereby increasing its value with refiners as a blending component.

Table 1
ASTM standards for biodiesel and HDRD [15,16].

Requirement	ASTM D6751 Biodiesel	ASTM D975 No. 2 Diesel
Kinematic viscosity (at 40 °C)	1.9–6.0 mm^2/s	1.9–4.1 mm^2/s
Cetane number	47 min	40 min
Flash point	130.0 °C min	52 °C min
Cloud point	Report	Report
Pour point	–	Report
Phosphorous content	10 mg/kg max	–
Oxidative stability (at 110 °C)	3 h	–
Distillation temperature	360 °C max	282–338 °C

Note: Cloud points and pour points only need to be reported because depending on the ambient temperature, equipment design, fuel additives, and operating conditions, there can be a variety of acceptable low temperature properties [15]. Items with "–" in the table do not have any requirements specified in the applicable ASTM standard.

For geographic regions with cold climates, the most important difference between biodiesel and HDRD is the difference in low temperature properties. Low temperature properties of concern include cold filter plugging point (CFPP) and cloud point (CP). For biodiesel, the CFPP can range from −40 °C to −7 °C and the CP can range from −4 °C to 13 °C [17] – likely not acceptable for northern climates. For HDRD, the low temperature properties are highly dependent on processing conditions. If HDRD is produced at higher temperatures, greater proportions of *i*-alkanes and short chain *n*-alkanes are produced, which improves the fuel's low temperature properties [3,18]. Unfortunately, at higher temperatures, undesirable aromatics also tend to form [3]. If the production process includes an isomerization step, the low temperature properties can be drastically improved [2,3]. NESTE, a major producer of HDRD in Finland, uses an isomerization step in its process and can vary the CP of its HDRD from −5 °C to −30 °C [18,19]. This flexibility in low temperature properties for HDRD is very beneficial for producers in climates with wide temperature variations.

In addition to advantageous fuel properties, HDRD also has some economic advantages over biodiesel. First, biodiesel production creates a co-product called glycerol, and as biodiesel production increases it is likely that the price of glycerol will drop, which will negatively impact biodiesel economics. HDRD is not sensitive to co-product prices because the co-product from HDRD production is propane [1,11], which does not need to be sold; propane can be used as fuel gas at the production plant or steam-reformed to provide hydrogen for the HDRD production process. Second, current biodiesel production technology uses a homogeneous catalyst (usually NaOH), which is consumed in the process and must be repurchased. HDRD uses one of several heterogeneous catalysts that are not consumed in the process and can be re-used. Recent research has shown that in terms of investment cost, HDRD is comparable to biodiesel [1,2,12] and overall production cost for HDRD could be less than biodiesel [11]. The superior fuel properties of HDRD may also allow it to command a price premium as a diesel-blending component [12], and allow for higher blending concentrations compared to biodiesel.

From an environmental perspective, HDRD appears to have advantages as well. Biodiesel production consumes significant quantities of methanol, which is usually derived from natural gas and the methanol production process is energy-intensive [11]. Thus, methanol consumption increases the life-cycle greenhouse gas emissions (GHGs) for biodiesel production. Biodiesel advocates might counter with the fact that HDRD production requires hydrogen, which is also typically derived from natural gas. However, the propane produced in HDRD production could be re-formed to provide more than enough hydrogen to run the process [2]. Therefore, from a life-cycle perspective, some researchers claim that life-cycle GHGs are lower for HDRD than biodiesel [2,11,12].

Commercial renewable diesel production

Renewable diesel is produced commercially by a variety of companies. Some of the major producers are Neste, ConocoPhillips, Petrobras, and Syntroleum. Further details regarding each company's plant size(s), and location(s) are shown in Table 2.

Renewable diesel production methods

The Renewable Diesel Subcommittee in the United States defines renewable diesel as "any of several diesel fuel substitutes, produced from renewable feedstocks, that chemically are not esters and thus are distinct from biodiesel" [19]. Based on this definition, there are a number of different chemical processes that can be used to create a product that meets the criteria for renewable diesel. Each process uses reactions between the triglycerides in vegetable oil and hydrogen to form a primary product of *n*-alkanes and a smaller proportion of *i*-alkanes, aromatics and