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Research article

Process simulation and techno economic analysis of renewable diesel production via catalytic decarboxylation of rubber seed oil – A case study in Malaysia

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A B S T R A C T

This work describes the economic feasibility of hydroprocessed diesel fuel production via catalytic decarboxylation of rubber seed oil in Malaysia. A comprehensive techno-economic assessment is developed using Aspen HYSYS V8.0 software for process modelling and economic cost estimates. The profitability profile and minimum fuels selling price of this synthetic fuels production using rubber seed oil as biomass feedstock are assessed under a set of assumptions for what can be plausibly be achieved in 10-years framework. In this study, renewable diesel processing facility is modelled to be capable of processing 65,000 L of inedible oil per day and producing a total of 20 million litre of renewable diesel product per annual with assumed annual operational days of 347. With the forecasted renewable diesel retail price of 3.64 RM per kg, the pioneering renewable diesel project investment offers an assuring return of investment of 12.1% and net return as high as 1.35 million RM. Sensitivity analysis conducted showed that renewable diesel production cost is most sensitive to rubber seed oil price and hydrogen gas price, reflecting on the relative importance of feedstock prices in the overall profitability profile.

1. Introduction

Diesel is the primary fuel workhorse supporting the provision of goods movement in various industrial sectors such as manufacturing, construction, mining and agricultural. The global transportation sector alone consumes nearly 61% of the non-renewable petroleum oil annually (Kliucininkas et al., 2012). Like many developing countries, the principal driver of diesel fuel demand in Malaysia is essentially stimulated by emerging freight transportation sector. According to Energy Commission of Malaysia, transportation sector is the largest energy consumer in Malaysia, accounted for more than 40 percent of the total end-use energy consumption (Malaysia Energy Commission, 2015). Diesel fuel contributed one-third of the total energy consumption in transportation sector, making it the second largest energy source in transportation sector after gasoline (Abdul, 2015). As indicated in Fig. 1, over 65 percent of the annual diesel fuel demand in Malaysia constituted for on-road applications and more than 7300 million litres of liquid diesel fuel were consumed annually by road freight transport, postal and warehousing industry from 2005 to 2015 (Abdul, 2015). With increasing average income per capital, total number of on-road diesel powered vehicles such as trucks, buses, trains and other heavy duty vehicles is expected to grow steadily in near future. Malaysia, being a fast growing developing country, is envisaged to have a continuous rise in diesel fuel demand, at which the annual diesel fuel consumption is projected to climb as high as 13570 million litres in the next 10 years.

Apart from biodiesel, renewable diesel (RD), also referred as green diesel or hydro-treated vegetable oil (HVO) has drawn considerable attention as a viable fuel substitute to petroleum derived diesel. It is a new breed of low-carbon biofuel derived from triglyceride based feedstock through hydroprocessing/hydrotreating processes. The long chain fatty acid esters undergo a series

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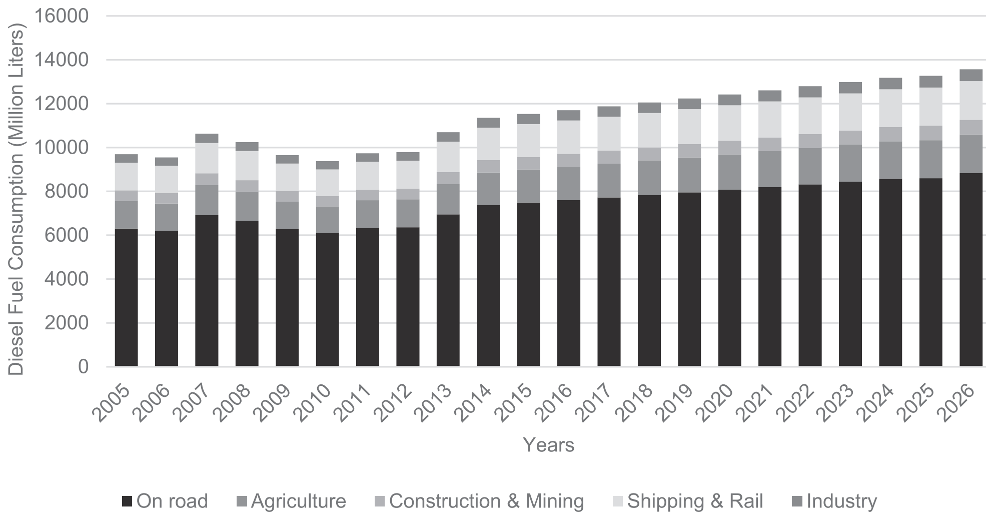

Fig. 1. Diesel fuel use history and projection in Malaysia (Abdul, 2015).

of parallel reactions, namely saturation of olefins via hydrogenation, removal of heteroatom molecules (sulphur, oxygen, nitrogen) via hydrodeoxygenation (HDO), decarboxylation (HCO2) and decarbonylation (HCO) and lastly hydro-cracking of hydrocarbon molecules to produce synthetic liquid transportation fuels that are chemically equivalent to petroleum diesel fuels. This second generation biodiesel is a premium diesel fuel enriches in long chain alkanes and short-branched alkane ranges from C15 to C18 with negligible aromatic, sulphur and oxygen contents. It retains a much higher cetane number and better cold-flow properties than that produced from tranesterification. Moreover, the boiling point range of these paraffin-rich hydrocarbon are well comparable to the typical petroleum based diesel. Unlike biodiesel produced from tranesterification, catalytic hydro processing promotes a more sustainable production as the process does not require any alkali and acid homogenous medium such as methanol or ethanol, which further lowers the additional post treatment costs (Pitakpoolsila and Hunsomb, 2014).

Despite its superior characteristics, there are few technical and economic limitations encountered by this renewable middle distillate fuels production. Several commercial RD production facilities have been successfully demonstrated promising technical feasibility of RD production from edible vegetable oils. Neste Oil Corporation, a European world's leading renewable hydrocarbon manufacturer, refiner and supplier employed a highly effective hydroprocessing technology process which capable in producing high quality of green diesel from vegetable oil (Nestle Oil Corporation, 2015). Others renewable fuel producers such as Conoco Philips and UOP Honeywell has started to emulate the success of Neste Oil Corporation by converting non edible second generation natural oil to green diesel (UOP, 2015). However, exploitation of edible oil in fuel production is threatening the availability of food crops and lead to a steep rise in food commodity import bills. Moreover, RD production via HDO route is an energy intensive process as it consumes enormous quantity of high pressure molecular hydrogen. Between HDO, HCO and HCO2, HDO pathway consumes much more hydrogen molecules than the other two reaction routes, HCO and HCO2. At least 3 mol of hydrogen molecules are required for complete deoxygenation of 1 mol of fatty acid. According to a team of petroleum refinery development experts from Haldor Topsoe and Preem, molecular hydrogen consumption in hydrotreating triglyceride feed via HDO can reach up as high as 200 Nm^3 hydrogen per m^3 liquid feed, even co-processing at the lowest percentage (Egeberg et al., 2011). That is twice over as much as that is required for hydroprocessing conventional fossil diesel oil, which is approximately around 100 Nm^3/m^3 (John, 1992).

To address such food versus fuel issue and high hydrogen consumption limitation, an alternate RD production is catalytic decarboxylation of non-food grade oil. Up to date, only a limited number of studies have been attempted in evaluating the economic viability of RD hydroprocessing technology. Wright and Brown (2007) evaluated the influence of alcohols, hydrogen and Fischer-Tropsch liquids production capacity on its respective production cost. However, the authors did not include RD in the analysis. Miller & Kumar (2014) reported the economic feasibility of RD production from canola oil and camelina oil as feedstocks. Both edible oils showed promising potential to be served as RD production feedstock, provided future trials for camelina meals as animal feed are successful. Davis et al. (2011) assessed the production economics of renewable diesel from autotrophic microalgae as raw material and the results are in good agreement with Sun (2009) as the economics of commercial microalgae biofuel production would not be competitive with the current transportational fossil fuels. However, the techno-economic analysis conducted by Ou et al. (2015) indicated promising commercial potential of transportation fuel production from hydrothermal liquefaction of deflatted microalgae followed by bio-crude upgrading. The contradictory results between Davis et al. (2011) and Ou et al. (2015). Are due to the fact that defatted microalgae provides a much lower feedstock price than raw microalgae, rendering the fuel production economically feasible to that of Davis et al. (2011).

To the best of our knowledge, none of the previous work has attempted in evaluating the economic viability of RD production technology from non-edible oil via catalytic decarboxylation. Hence, the novelty of this study was attained by investigating the technical design and economic feasibility of RD production from non-edible rubber seed oil in Malaysia. Rubber seeds collection and oil extraction were out of the scopes of this study. The baseline assessment of this study is modelling a rubber seed oil decarboxylation processing facility of annual nameplate capacity 20 million litres RD fuels. Unlike the industrial RD refineries, the present model capacity was considerably smaller than the existing RD refineries as those refineries were not designed for dedicated feedstock. The authors acknowledge that commercial fuel production with dedicated feedstock will usually suffer from poor operation flexibility and may necessitate long term contracts with local