***ASSESSMENT OF THE PRODUCTION OF ALTERNATIVE AVIATION FUEL FROM CARINATA OIL: A STOCHASTIC TECHNO-ECONOMIC ANALYSIS***

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**Overview**

The extensive use of fossil fuels for transportation in the US is a leading contributor of air pollution, oil dependency, and the rapid depletion rate of natural resources. Decreasing the use of fossil fuels can significantly mitigate these issues. The use of renewable fuels has emerged as one of the prominent methods to achieve such a goal. Different pathway technologies can lead to different fuel products. While the feasibility of many such pathways have been analyzed with mixed results, new technologies have continuously been developed. One such technology is the catalytic hydrothermolysis (CH) process of turning carinata oil into renewable jet fuel.

Carinata oil is known as a clean source of feedstock for producing biofuels. One of its characteristics is that it does not induce land use changes. While some crop feedstock requires new infrastructure designed exclusively to handle their conversion process, the conversion process of carinata allows producers to use existing energy infrastructure without blending. Notably, carinata is among the small number of crops and the first oilseed crop to receive a sustainable certification from the Rountable on Sustainable Biofuels. As such, an analysis to determine the feasibility of producing biofuels from carinata with and without governmental incentive programs can bring some insights into the future of this crop as a feedstock for biofuels.

The catalytic hydrothermolysis process is developed by the Applied Research Associates, in partnership with Chevron Lummus Global. The process comprises three phases: catalytic hydrothermolysis phase, hydrotreating phase, and finally the fractionation phase produces the final products, which include bio-jet fuel, bio-diesel, and naphtha. It should be noted that carinata does not require hydrothermal cleanup, which is a pre-treatment step required for some other feedstock. This reduces the capital costs and operating costs of the conversion process.

McGarvey and Tyner (2018) analyze the feasibility of the CH pathway using stochastic simulation and found that the probability of loss is 100% without governmental incentives and as low as 74.6% with incentives. These results are based off cost data in 2015. However, as the conversion technology is upgraded continuously, these results may not reflect current costs accurately. Governmental incentives such as Renewable Identification Number (RIN) and Low Carbon Fuel Standard program (LCFS) also have changed sufficiently from 2015 to 2019, which may have an impact on the revenues. Their work assumes that natural gas prices correlate over time and tend to decrease, which may produce some caveats in the analysis, given (i) a sudden disruption in the price trend beginning from 2009, and (ii) the prices from 2009 and onward does not appear to show a correlation. They also assume that feedstock costs (soybean oil cost as surrogate for carinata oil) are correlated over time, and are not correlated with fuel prices, which may not precisely represent historical trends. Finally, their work utilizes a deterministic value for the RIN price, which may leave out some aspects of uncertainties, as RIN prices change continuously.

This paper aims to analyze the feasibility of the CH pathway using stochastic simulation, using the most up-to-date technical, financial data and governmental incentives information. Additionally, we construct a forecast for natural gas price based on data from 2009 onwards to better capture recent price dynamics. We also provide an alternative forecast of feedstock cost and fuel prices, in which future soybean oil prices are not correlated over time, and are correlated with future jet fuel prices, as suggested by historical trends. Finally, we model RIN price stochastically to incorporate future uncertainties. Forecast of bio-diesel and naphtha prices are based on jet fuel prices, as they are correlated with jet fuel prices.

**Methods**

We model stochastically the forecasting of soybean oil cost, fuel prices and RIN prices by fitting distribution over historical prices using @RISK, and performing simulation to find the distribution of the correlation between soybean oil cost and jet fuel prices. A stochastic techno-economic analysis was done using @RISK on Excel. All simulations are iterated over 5000 times. The work is done using data for a greenfield plant (newly built facilities), with a real discount rate of 10%, using 2018 as the base year for all prices. The annual inflation rate is 2%.

**Results**

1. Without governmental incentives

Without Renewable Identification Numbers (RIN) and LCFS incentives, mean predicted jet fuel price is $2.21/gal. Biodiesel mean predicted price is $2.24/gal. Gasoline is taken as a replacement for naphtha, as they are close substitutes. The mean predicted price of gasoline is $2.14/gal. The mean correlation coefficient between forecasted jet fuel and forecasted soybean oil is 0.68, which is close to 0.71, the correlation coefficient between historical jet fuel and soybean oil prices. The mean difference between predicted soybean oil and jet fuel price is around $0.563. This shows similar pattern to the historical price series, with an average difference in price close to $0.593.

The results show that the mean net present value (NPV) without RIN and LCFS is -$924.4 million. 90% of the simulated NPV was between -$1,040 million and -$810 million. From the distribution, we can conclude that the probability of loss is 100%. The mean breakeven price of jet fuel is $4.72/gal. If the producer wishes to earn the stipulated rate of return with a probability of at least 75%, the breakeven price of jet fuel would need to be at least $4.86/gal. A price of at least $5/gal will ensure earning the stipulated rate of return with a probability of 90%. Refer to Figure 1 for the distribution of NPV.



Figure 1. Distribution of NPV of the project (without RIN and LCFS)

1. With RIN and LCFS

RIN price is modeled stochastically with mean value $1.2/gal for D4 RIN in real terms. LCFS credit per gallon tend to decrease over time, depending on the pre-determined carbon intensity (CI) benchmark, which is lowered over time, and the carbon price, which is expected to stay at around $200/MT for a number of years. LCFS credit for jet fuel is expected to range from $1.36 to $1.6 per gallon during the 21 years of operation, with $1.6 being the value of the first year, before decreasing over time. As such, mean predicted jet fuel price is expected to be $3.41/gal with RIN and from $4.77 to $5 per gallon with RIN and LCFS credit, with $5 being the price in the first years, before decreasing gradually.

 The mean NPV with RIN and LCFS is reported to be $62.3 million. 90% of the simulated NPV was between -$64 million to $186 million. Finally, the probability of loss is 21%, which is much more promising than a scenario without governmental incentives.

**Conclusions**

Relative to prior research, this techno-economic analysis uses the most up-to-date technical and financial data and governmental incentives, as well as an alternative method of estimating LCFS credit and forecasting costs, fuel prices, and RIN values. The results show that without governmental policies, the CH pathway is not economically viable. With policies such as RIN and LCFS, the pathway becomes much more feasible. The results are based on a pioneer greenfield plant. For a brownfield scenario, capital investment is smaller. In an nth field scenario, capital investments and operating cost decrease by a reduction factor. It should be noted that uncertainties regarding soybean oil price as well as fuel prices remain, given their volatility nature and the unpredicted political environment. If sudden and/or drastic changes in those prices occur, the results of the analysis may alter.

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