CHEMICAL ENGINEERING TRANSACTIONS
VOL. 120, 2025

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Bing Shen How, Viknesh Andiappan, Denny K.S. Ng, Hon Loong Lam, Petar S. Varbanov

ISBN 979-12-81206-21-2; **ISSN** 2283-9216

DOI: 10.3303/CET25120011

Techno-economic Analysis of Sustainable Aviation Fuel Production from Corn Stover in the Philippines

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The growing demand for sustainable aviation fuel (SAF) has driven innovation in alternative fuel technologies, with synthetic paraffinic kerosene (SPK) emerging as a viable candidate as it offers a reduction in environmental footprint compared to conventional fossil fuels. In this study, the feasibility of biomass-derived SPK was explored, utilizing corn stover as the process feedstock. The designed process integrates key thermochemical processes such as gasification, Fischer-Tropsch (FT) synthesis, and hydrocracking, to convert corn stover into SPK. The process was simulated in commercial software Aspen Plus V12, where its material and energy flows were analyzed. Moreover, the Anderson-Schulz Flory distribution model was used to determine the FT product distribution. The simulation results show a 75 % molar conversion of carbon monoxide and a biomass-to-SPK conversion of 6 % was achieved. The sustainability of the developed process was assessed through its carbon dioxide (CO_2) emissions, with syngas cleaning reducing emissions by 30.70 %, resulting in a carbon footprint of 0.58 kg CO_2/kg syngas. The remaining CO_2 in the FT fuel underwent flashing and adsorption, enabling 63.27 % recovery for reuse in steam and power plants. Subsequently, the total capital investment, including working and fixed capitals, were estimated. The FT-SPK pathway was proven to be costly due to the energy-intensive processes. However, a positive ROI and a payback period within 5 y were achieved. The product selling prices were also ascertained alongside a breakeven analysis to ensure that the manufacturing operation remains economically viable.

1. Introduction

The growing demand for sustainable aviation fuel (SAF) has driven innovation in the production of alternative fuel technologies. Synthetic paraffinic kerosene (SPK), a drop-in type of SAF, is a promising candidate as it offers a reduction in environmental footprint compared to conventional fossil fuels. Corn stover, an abundant agricultural waste, presents an excellent renewable feedstock for SPK production, while simultaneously supporting agricultural waste management and sustainable fuel development. Ail and Dasappa (2016) explored switchgrass, residual wood straw, and woody biomass, while Lopez et al. (2024) focused on forest waste, and municipal solid waste as possible feedstock. In contrast, this study focuses on corn stover due to its regional availability and waste potential in the Philippines. Mohsin et al. (2017) identify the supply cost as a major barrier to SAF adoption, as production costs typically exceed those of gasoline and diesel. However, this study demonstrates an economically viable process of producing SPK from corn stover. Several studies have also used corn biomass for bio-aviation fuel using lignin conversion (Shi et al., 2024) and hydrothermal conversion of corn stalk (Wang et al., 2024). Improvements of the upgrading of pyrolysis oil have been made through characterization of catalysts for hydrotreating (Suh et al., 2024). However, the economic and environmental advantages of thermochemical processes such as gasification and Fischer-Tropsch (FT) synthesis have yet to

Paper Received: 23 May 2025; Revised: 4 September 2025; Accepted: 8 October 2025
Please cite this article as: Tapia J.F.D., Abrasia A.M., Dalisay J.A., Halili J.A., Miguel A.F., Mangali K.M., Lopez C.J., Foo D.C.Y., Tan R.R., 2025, Techno-economic Analysis of Sustainable Aviation Fuel Production from Corn Stover in the Philippines, Chemical Engineering Transactions, 120, 61-66 DOI:10.3303/CET25120011

be studied. These processes are key stages that facilitate the conversion of corn stover to SPK. It provides sustainable and cost-efficient SAF production.

2. Process Design

The production process for corn stover-based SPK is analyzed through the following steps: (1) determination of appropriate plant capacity with Philippines as the main market, (2) simulation of the process in Aspen Plus, (3) analysis of environmental impacts through accounting of carbon footprint and (4) analysis of economic benefits through various indicators.

2.1 Feedstock Profile and Plant Capacity Determination

The jet fuel demand in the Philippines is projected to increase from 640,000 t in 2023 to 1,095,000 t in 2033 based on the jet fuel consumption data of the Philippines from 2013 to 2022 (Department of Energy, 2024). The annual plant capacity to remain market competitive in the Philippines is 20,300 t of SPK, requiring 317,000 t of corn stover. The required corn stover for this production is justified by the selection of Cagayan Valley in the Luzon region as the plant location, as it is the leading area for corn production in the Philippines. The average corn stover production in Luzon is determined to be 1,726,000 t (Philippine Statistics Authority, 2024). Considering market constraints such as allocations to other industries and losses from harvesting, the available corn stover is around 690,000 t annually.

The proximate analysis and elemental composition of corn stover as raw material for the process is shown in Table 1. The high volatile matter content contributes to the fraction of biomass expected to decompose into light organic compounds in the form of syngas, a precursor for various bioenergy synthesis applications. As the model relies on these specific composition values, which are inherently variable, this constitutes a limitation in representing real-world process conditions.

Table 1: Proximate analysis and elemental composition of corn stover (Munu et al., 2021)

Properties	wt %	Composition	wt %
Volatile Matter	66.20	Carbon	34.91
Moisture Content	12.50	Hydrogen	6.22
Fixed Carbon	15.70	Nitrogen	0.56
Ash	5.60	Sulfur	1.06
		Oxygen	57.25

2.2 Steady State Process Simulation

The designed process was modelled in Aspen Plus V12 (www.aspentech.com) to assess the mass and energy flows within the system. The parameters used for the simulation are shown in Table 2, while the simulation flowsheet shown in Figure 1. During gasification, processes such as drying, pyrolysis, oxidation, and reduction occur within the chamber, modelling a downdraft gasifier. In the drying process, the amount of moisture removed was determined based on its fraction in the proximate analysis. Tar formation is modelled based on the study by Marcantonio et al. (2020). A decomposer block is added before pyrolysis to break down the non-conventional biomass component into conventional components. Gibbs-free energy minimization is assumed for production formation in the pyrolysis block. Formation of H_2S and NH_3 as impurities are also simulated. The Power Law model was employed for the kinetic rate equations in the oxidation and reduction processes, which are adopted from the study of Njuguna et al. (2023). For syngas cleaning, the key process is cryogenic distillation. The Radfrac block was utilized to model the process using the parameters in the study of Li et al. (2022). Meanwhile, the bottoms flow rate varied until a removal rate of 98.2 % was achieved. The Fischer-Tropsch (FT) reactor was modeled using the Anderson-Schulz Flory (ASF) distribution to facilitate the calculation of the carbon monoxide conversion and estimate the FT product distribution. In this block, the chain-growth probability constant is 0.91 with the carbon monoxide conversion initially set to 80 %. Then, a series of distillation columns is used to recover and refine the SPK product. The FT liquid undergoes fractional distillation to separate the light fuel from heavy fuel. The light FT fuel is further distilled to separate C_1-C_{10} gas from the SPK. FT gas is sent in a pressure swing adsorber (Sep) to recover the hydrogen from the FT gas, to be used for the hydrocracker. The hydrocracking reactor was simulated as a kinetic reactor following Langmuir-Hinshelwood-Hougen-Watson (LHHW) rate law. Only mono-methyl alkanes of carbon chains $\geq C_{19}$ are cracked to primarily yield products within the SPK carbon range.

Table 2: Simulation settings in Aspen Plus

Process	Block	Settings
Drying	RStoic	100 °C, 1 bar, Fractional Conversion: 0.125
Decomposition	RYield	700 °C, 4 bar, Component Yields: Ash, C, H_2, N_2, S, O_2
Pyrolysis	RGibbs	700 °C, 4 bar, Calculation Option: Phase and Chemical Equilibrium, Products: C, H_2, CO_2, CO, CH_4, N_2, S, H_2O, O_2
Tar Formation	RStoic	700 °C, 4 bar, Fractional Conversion: 1.00
NH_3 and H_2S Formation	RStoic	700 °C, 4 bar, Fractional Conversion: 1.00 (S); 1.00 (N_2)
Reduction	RPlug	700 °C, 4 bar
Oxidation	RPlug	700 °C, 4 bar
Flash Separation	Flash2	0 °C, 32.3 bar
Cryogenic Distillation	Radfrac	No. of Stages: 44, Reflux Ratio: 2.4, Feed Stage: above 20^{th} Top-stage Pressure: 32.2 bar, 44^{th}-stage Pressure: 32.3 bar
Fischer-Tropsch	RStoic	220 °C, 25 bar
FT Fuel Flash Separation	Flash3	1 bar, 0 kW
Pressure Swing Adsorption	Sep	H_2 recovery: 0.85 %
FT Light-Heavy Fuel Distillation	Radfrac	Reflux Ratio: 1.2, Condenser Pressure: 1.3 bar Reboiler Pressure: 1.5 bar Light Key Component: $C_{14}H_{30}$, Recovery: 0.90 Heavy Key Component: $C_{15}H_{32}$, Recovery: 0.01
FT Gas-SPK Distillation	Radfrac	Reflux Ratio: 1.2, Condenser Pressure: 1.2 bar Reboiler Pressure: 1.3 bar Light Key Component: C_9H_{20}, Recovery: 0.95 Heavy Key Component: $C_{10}H_{22}$, Recovery: 0.05
FT Diesel-Wax Distillation	Radfrac	Reflux Ratio: 1.2, Condenser Pressure: 1.3 bar Reboiler Pressure: 1.5 bar Light Key Component: $C_{18}H_{38}$, Recovery: 0.90 Heavy Key Component: $C_{19}H_{40}$, Recovery: 0.10
Hydrocracking	RPlug	Constant at Specified Reactor Temperature: 425 °C Reactor Length: 6 m, Reactor Diameter: 2 m Catalyst Loading: 6 kg, Bed Voidage: 0.40

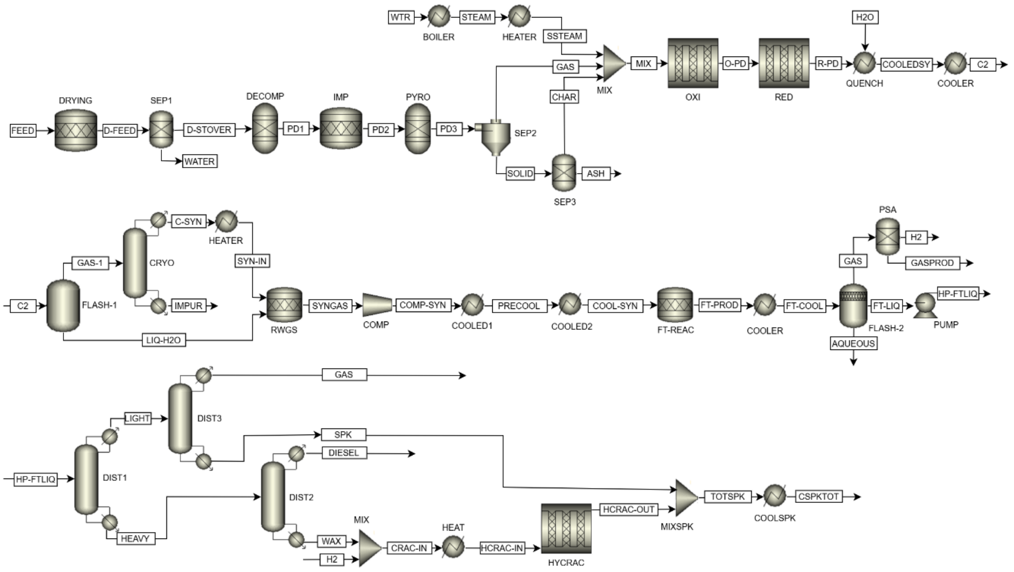

Figure 1: Process simulation flowsheet of SPK production

2.3 Environmental and Economic Analysis

Key metrics for profitability such as total capital investment (TCI), profitability, payback period, and breakeven point were determined. The TCI, which comprises the fixed capital investment (FCI) and working capital (WC), was established based on the equipment cost. The purchased equipment cost, estimated via cost indexing, assumes that the major equipment (cryogenic distillation column, FT reactor, FT fuel distillation column, hydrocracking reactor, and SPK storage tank) comprises 60 % of the total equipment. As a rule of thumb, the local delivery fee is taken as 10 % of the equipment cost. The costs were estimated using ratio factors (Lang) to convert the delivered equipment cost into fixed capital investment as shown in Table 3. The CO_2 emissions are also determined based on conversion of the carbon content of the biomass in several stages, such as gasification and reverse water-gas shift reactions, calculated from the mass flow data in the simulation.

Table 3: Total capital investment estimation via Lang method

	Ratio Factor
Direct Costs	
Delivered equipment	10 % of the purchased equipment cost
Purchased equipment installation	39 % of the delivered equipment cost
Instrumentation and controls	26 % of the delivered equipment cost
Piping	31 % of the delivered equipment cost
Electrical systems	10 % of the delivered equipment cost
Buildings	29 % of the delivered equipment cost
Yard improvements	12 % of the delivered equipment cost
Service facilities	55 % of the delivered equipment cost
Indirect Costs	
Engineering and supervision	32 % of the delivered equipment cost
Construction expenses	34 % of the delivered equipment cost
Other Expenses (Legal, Contractor’s fee, Contigency)	60 % of the delivered equipment cost
Fixed Capital Investment	Sum of direct and indirect costs
Working Capital	75 % of the delivered equipment cost
Total Capital Investment	Sum of FCI and WC

3. Results and Discussion

3.1 Material Flows

Presented in Table 4 is a summary of the mass flow across each section, from pre-treatment to purification. Results show that a total of 674,943 kg/d of syngas was generated after the pre-treatment stage. Upon subjecting the cleaned syngas to the reverse water-gas shift reactor, the molar ratio of hydrogen to carbon monoxide was reduced from 3.26 to 2.00, which is ideal for FT reactions using cobalt-based catalysts. For the FT synthesis, a carbon monoxide conversion of 75 % was achieved, resulting in the production of 125,855.90 kg/d paraffins. The produced FT fuel undergoes a series of purification processes, leading to daily SPK production of 67,728 kg. Additionally, this process yields 19,247 kg/d of green diesel as a valuable by-product.

Table 4: Summary of material flows (all flowrates given in kg/d)

Components	Gasification	Syngas Cleaning	FT Reaction	Separation	Hydrocracking
Syngas	3,297,840.00	674,943.04	549,087.14	0.00	708.91
SPK (C_{11}-C_{14})	0.00	0.00	21,876.61	20,586.56	41,488.45
Diesel (C_{15}-C_{18})	0.00	0.00	19,792.47	51.84	476.11

3.2 Economic Study

The construction of the plant requires a TCI of 27.55 M USD, comprising 4.11 M USD for WC and 23.44 M USD for FCI. The breakeven volume is determined as the minimum production capacity needed. Upon analysis, an annual breakeven volume corresponding to 17.32 ML SPK and 10.17 ML green diesel are needed by the plant after 3 y when the plant operates at full capacity. Figure 2 shows the breakeven analysis for the production plant. The selling prices of both SPK and green diesel were strategically set to ensure profitability and full cost recovery while remaining competitive in the market. The selling prices are projected at 4.46 USD/L for SPK and 4.09 USD/L for green diesel when the plant operates at full capacity. The price range for SPK is from 1.7 USD/L to 5.02 USD/L based on the analysis in Azarova et al. (2024) which shows that the price set is on the higher end. Consequently, the proposed facility demonstrates strong economic viability, with a payback period of 5 y and a total net profit of 27.81 M USD this year—exceeding the TCI of 27.55 M USD. Additionally, the return on investment (ROI) is calculated at 426.17 %, indicating that the SPK production plant not only recovers its initial capital but generates substantial returns. This high ROI reflects the project's ability to cover all associated costs while delivering significant profits, making it an attractive prospect for investors.

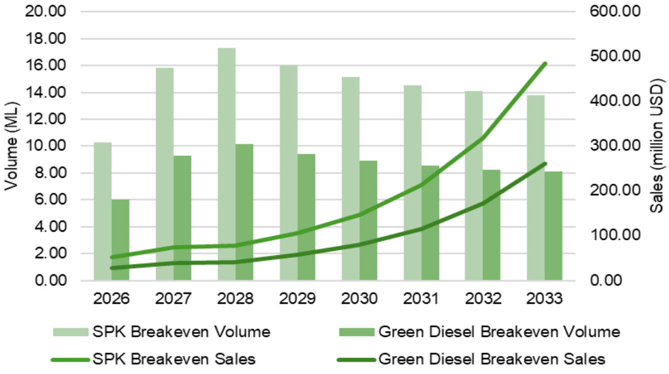

Figure 2: Breakeven volume and sales forecast for the proposed production facility

The strong financial performance underscores the plant's potential for rapid capital recovery and long-term profitability. Furthermore, this positive economic outlook is particularly compelling given the rising global demand for SAF, driven by stricter environmental regulations and decarbonization commitments. The profitability of SPK production, therefore, aligns well with both current market trends and broader sustainability objectives—positioning the project as a competitive and forward-looking investment in the renewable energy sector.

3.3 CO_2 Emissions

The designed process utilized corn stover with 34.91 % carbon. This is significantly less compared to conventional petroleum sources, whose typical carbon content ranges from 82 % to 85 % by weight (Gordon, 2012). Note that the carbon content of the corn stover comes from the plant metabolism of CO_2 in the atmosphere while the carbon content from fossil fuel source comes from underground reservoir. Presented in Figure 2 is the CO_2 reduction analysis based on the converted and emitted CO_2 across each stage.

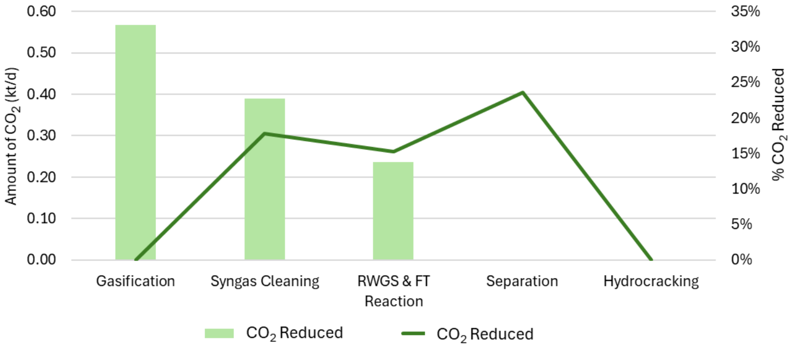

Figure 3: CO_2 mass flow and reduction across each stage

During the gasification stage, the entire carbon content of the biomass is converted into raw syngas, of which 66.64 % is transformed into CO_2. Subsequently, impurities are eliminated during syngas cleaning to attain purity requirements for FT synthesis. This process leads to the release of 30.70 % of CO_2 from the syngas stream, corresponding to a carbon footprint value of 0.58 kg CO_2/kg syngas produced. In comparison, Dion et al. (2013) reported a carbon footprint of 0.64 kg CO_2/kg syngas for the biomass gasification using wood pellets. The relatively lower carbon footprint may be attributed to the lower carbon content of corn stover compared to wood pellets as well as the effectiveness of the syngas cleaning process in the present study. During the reverse water-gas shift reaction, no emissions were observed, as CO_2 was consumed to adjust the ratio between hydrogen and carbon monoxide. The produced FT fuel undergoes cooling and flash separation, during which 0.13 % CO_2 is converted into its liquid form. The effect of this small amount of liquid CO_2 on the atmosphere may be considered less significant compared to that of the gaseous form. The larger fraction of CO_2, which exists as gas, is fed to a pressure swing adsorption (PSA) reactor along with the other components in the syngas stream. The amount of CO_2 produced in the PSA unit can then be further captured after the combustible components such as CO and H_2 are burned for plant utilities. Overall, the net conversion of carbon in the biomass to CO_2 is only 17 %, implying the delayed carbon emissions of 83 % at the end of the production process, through conversion of carbon in the biomass to fuels and CO. Net carbon emission also from production yields.

4. Conclusions and future work

In the designed syngas-to-SPK production process, a daily output of 67,728 kg SPK and 19,247 kg diesel was achieved. The process integrates an effective removal of CO_2 during syngas pretreatment, leading to a carbon footprint of 0.58 kg CO_2/kg syngas produced. In addition, it was determined that a capital investment of 27.55 M USD is needed to construct the plant. Distributing the product at the current market price would take over 5 y to recover the amount of money invested. Hence, selling prices of 4.46 USD/L SPK and 4.09 USD/L green diesel were imposed, to ensure generation of profit in 2028. At these selling points, a payback period of 5 y is achievable with a positive ROI. Generally, the FT pathway for producing SPK is the most expensive due to its inherent energy-intensive processes. It can also be anticipated that partnerships with relevant groups like the Department of Energy (DOE) and airline companies would also help reduce the costs of the project. With all these established, the project is deemed feasible, sustainable, and profitable in the long run. Future work includes process intensification and heat integration to improve the process, and a life-cycle analysis and optimization to consider indirect emissions of the plant, and cost optimization to set a better price for SPK.

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