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Short Communication

Techno-economic Analysis of Jet Fuel Production from Vegetable Oil Using Self-produced Solvent and Non-noble Metallic Catalyst

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Abstract

Biojet fuel has been successfully utilized in commercial flights. However, the widespread adoption of biojet fuel still presents certain challenges, one of the most significant of which is the high cost of the production process. This is primarily reflected in the fact that the production of commercial biojet fuel necessitates the operation of a high-temperature environment and multiple reaction units, which increases operational costs. Consequently, the development of an efficient and cost-effective process paves the way for the industrialization of biofuels. A novel biphasic catalytic process has been developed that can scale down the multiple unit operations of the process line and perform process simulation in Aspen Plus. In addition, inexpensive nickel-based catalyst is proposed as the catalyst instead of precious metal catalysts. The process utilizes the intermediate product, n-heptadecane, and water as a novel mixed solvent to achieve a new biphasic catalytic process for the one-pot production of biojet fuels under mild conditions. A comparison of two similar innovative options was carried out through a series of analyses of raw material costs, capital costs, operating costs, product selling prices, and net present value. These analyses demonstrated that Scenario 2 with a nickel-based catalyst and self-produced solvent was more economical. The selling price of jet paraffin was calculated to be lower than 2300 $/tonne based on market data, with a payback period of 1~2 years. Reducing feedstock costs represents a viable strategy for improving the economics of biojet fuels.

Keywords: jet fuel, biomass, vegetable oil, catalytic process, techno-economic analysis

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1 INTRODUCTION

The rapid increase in greenhouse gas emissions, especially carbon dioxide, stems largely from the intensive and long-term reliance on fossil fuel extraction and combustion, leading to serious environmental degradation[1,2].The aviation sector is widely recognized as one of the most challenging industries to decarbonize due to its strong dependence on liquid hydrocarbon fuels with high energy density and strict safety standards[3]. Global demand for aviation fuel is projected to continue growing, with the International Air Transport Association forecasting that passenger traffic will double by 2050[4]. At the same time, ambitious commitments have been made to achieve net-zero carbon emissions by mid-century. These dual pressures have placed unprecedented emphasis on the development and deployment of sustainable aviation fuels[5], particularly bio-derived jet fuels, as a viable pathway toward reducing greenhouse gas emissions while maintaining the operational reliability of current aircraft fleets.

Biojet fuel, produced from renewable feedstocks such as vegetable oils[6], animal fats[7], lignocellulosic biomass[8], and waste lipids[9], has already been successfully demonstrated in commercial flights and

certified under ASTM D7566 standards[10]. However, the commercialization of biojet fuels faces significant economic barriers. Conventional production pathways, such as hydroprocessed esters and fatty acids (HEFA), require multiple reaction units, high hydrogen consumption, and severe operating conditions, all of which contribute to elevated capital and operating costs[11,12]. Moreover, the reliance on noble metal catalysts such as Pt, Pd, or Ru further increases the financial burden[12], limiting large-scale adoption despite the technological maturity of these processes. Consequently, developing cost-effective catalytic strategies and simplified process configurations is essential to enhance the competitiveness of biojet fuels in comparison to conventional fossil-based jet fuels[13,14].

Recent advances in heterogeneous catalysis have highlighted the potential of non-noble metal catalysts[15,16], particularly nickel-based systems, for hydrodeoxygenation and hydroisomerization reactions relevant to jet fuel production[17]. Nickel catalysts not only reduce reliance on scarce and expensive precious metals but also exhibit promising activity and selectivity under mild reaction conditions[18]. Meanwhile, biphasic reaction systems have emerged as an innovative approach to intensify reaction processes, allowing simultaneous upgrading and separation of products while minimizing the number of downstream operations[19]. In particular, the use of self-produced intermediates or reaction products as solvents offers a closed-loop strategy that improves process sustainability and reduces the need for external solvents[20,21].

In this work, we propose a novel biphasic tandem catalytic process (biTCP) for biojet fuel production from vegetable oil that integrates two key innovations: (1) the use of nickel-based catalysts as an economical alternative to noble metal systems, and (2) the utilization of an in situ generated solvent system composed of n-heptadecane and water. This configuration enables a one-pot conversion of vegetable oil to jet-range hydrocarbons under moderate conditions, thereby reducing process complexity and operational costs. To rigorously evaluate the industrial potential of this strategy, we conducted a techno-economic analysis using Aspen Plus simulation. The TEA compares two process scenarios: one employing conventional noble metal catalysts and external solvents[13], and another utilizing nickel-based catalysts with self-produced solvents. The results provide a quantitative assessment of feedstock costs, capital investment, operating expenses, product pricing, and net present value (NPV).

By integrating process intensification with cost-effective catalysis, this study seeks to advance the economic feasibility of biojet fuels and contribute to the broader goal of sustainable aviation. Our findings highlight not only the importance of catalyst innovation but also the strategic role of solvent management in reducing costs and shortening payback periods, offering practical insights for industrial-scale deployment.

2 METHODOLOGY

This study simulated the process technology for the preparation of biojet fuels using vegetable oil as raw material in a one-pot biTCP, based on the concept of efficient, economic, and sustainable development of biomass-based fuels. The entire process was modeled using the process software Aspen Plus. Techno-economic analyses were conducted on the different working conditions of the production process. A comparative analysis of different methods used in each section of the process is conducted. In previous studies, the catalytic mechanism for converting triglycerides to jet fuel alkanes on TiO_2-modified Ru/C catalysts in biTCP was explored[13]. It is proposed that Ni/SiO_2-Al_2O_3 catalysts can be obtained by modifying the loaded target catalysts with Ni[22,23]. Simultaneously, the excessive cracking of long-chain alkanes is inhibited by the formation of a mixed solution of the generated intermediate product n-heptadecane with water. This increases the yield of the desired product. Additionally, the impact of loaded metal catalysts and reaction conditions on jet fuel yield is discussed. The techno-economic feasibility of producing jet fuel from vegetable oils is also demonstrated to optimize the process and reduce costs.

The one-pot biTCP for the production of jet fuel from vegetable oil consists of four main stages: a raw material pre-treatment stage, a "one-pot" reaction stage, a three-phase separation stage for the crude product, and a distillation stage for the product.

In this paper, two similar one-pot two-phase tandem catalytic process schemes are proposed for comparison. The first scheme (Figure 1A) is a one-pot production of vegetable oil-based biojet fuel under mild conditions of 260℃ and 28 bar hydrogen partial pressure using a suitable ratio of cyclohexane and water mixed solvent to modulate the cracking selectivity and utilizing a ruthenium-loaded Ru/C-TiO_2-modified catalyst to enable a higher deoxygenation reaction rate[13]. The second scheme (Figure 1B) is a design based on the economic effectiveness of the first scheme, i.e., the hydrodeoxygenation reaction was first carried out in the reactor under the conditions at a temperature of 350℃ and a hydrogen partial pressure of 28 bar to generate n-heptadecane and water as intermediate and by-products, which acted as the natural mixed solvents to regulate the cracking reaction, and utilized a cheaper loaded nickel Ni/SiO_2-Al_2O_3 modified catalyst to increase the rate of deoxygenation reaction and achieve one-pot production of biojet fuel from vegetable oil. A detailed economic analysis of the optimization of the reaction mechanism is presented.

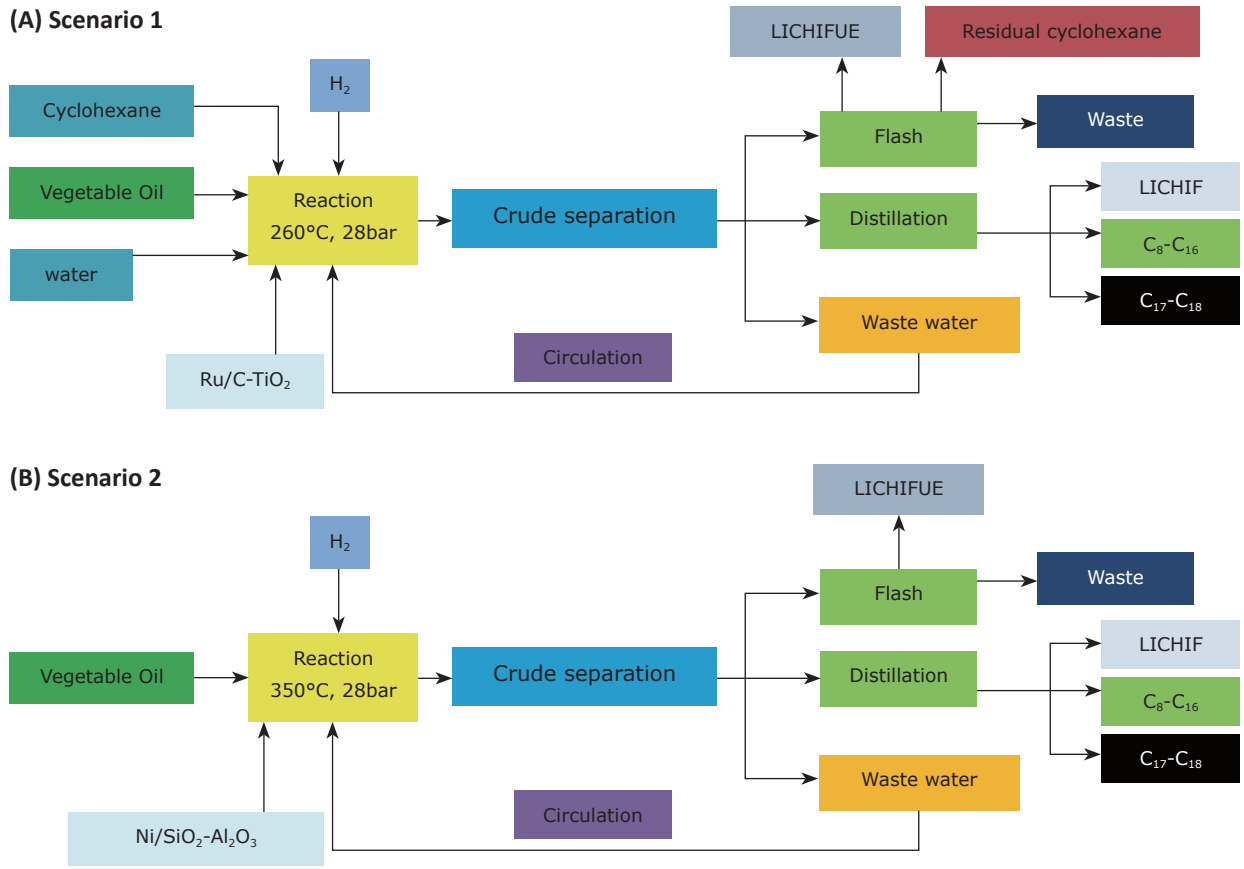

Figure 1. Conceptual Design of the Traditional (A) and Innovative (B) biTCP Platforms to Convert Vegetable Oil into Jet Fuel.

The raw materials include vegetable oil (vegetable oil) and hydrogen (H_2), which were used as reactants at a cost of 500$/tonne and 1818.18$/tonne, respectively, as shown in Table 1. Water (H_2O) and cyclohexane (C_6H_{12}) were used as solvents in the reaction process at a cost of 0.4$/tonne and 580 $/tonne, respectively. The reaction products include C_8-C_{16}, C_1-C_7 and C_{17}-C_{18}, which have a market price of 2,300$/tonne, 562$/tonne and 2,600$/tonne, respectively. These data provide an important basis for the economic analysis of raw materials and products. The catalytic conversion of vegetable oils, with hydrogen under specific conditions yields high value-added products, including liquid hydrocarbons and long-chain hydrocarbons. The choice of water and cyclohexane as solvents not only affects the reaction efficiency, but also is closely related to the economics.

3 RESULTS AND DISCUSSION

Tables 2 and 3 provide a summary of the capital and operating costs for producing jet fuel and converting vegetable oil for Scenarios 1 and 2 at different temperatures.

Table 2 shows that Scenario 1 (precious metal catalyst) at 200-260℃ generally requires higher equipment purchase and installation costs compared with Scenario 2 (Ni-based catalyst). For instance, the equipment cost at 260°C in Scenario 1 (1,042,900 USD) is considerably higher than in Scenario 2 at 320-350°C (687,000-871,900 USD). However, Scenario 2 still bears relatively large expenses in piping, insulation, and auxiliary items, and at the lower temperature of 320°C the capital cost is low but the jet fuel yield remains insufficient. Overall, Scenario 2 at 350°C achieves both a lower capital investment and improved product yield, making it economically superior to Scenario 1.

Table 3 indicates that the most significant difference between the two scenarios lies in raw material costs. Scenario 1 shows extremely high raw material expenses (~75.15 million USD per period), while Scenario 2 reduces this cost drastically to ~44.19–44.50 million USD per period due to the use of self-produced solvent instead of external solvents. Other operating costs such as labor, utilities, maintenance, and plant overhead remain comparable between the two scenarios. This sharp reduction in feedstock expenses highlights that solvent generation in Scenario 2 is the key driver for improving overall process economics, making it considerably more competitive than Scenario 1.

The data from the simulation with two Scenarios, as presented in Figure 2, indicates that the capital and operating costs are different. Figure 2A shows the capital cost comparison, where Scenario 1 at 260°C has the highest investment, while Scenario 2 at 320–350°C maintains relatively lower capital costs. Figure 2B highlights operating costs, with Scenario 1 at both 200°C and 260°C

Table 1. Raw Materials Costs and Product Prices

Matter	Basis	Price	Unit	Source
Vegetable oil	mass	500	$/tonne	[24]
H_2	mass	1,818.18	$/tonne	[25]
C_8-C_{16}	mass	2,300	$/tonne	[26]
H_2O	mass	0.4	$/tonne	[27]
C_6H_{12}	mass	580	$/tonne	[28]
C_1-C_7	mass	562	$/tonne	[29]
C_{17}-C_{18}	mass	2,600	$/tonne	[30]

Table 2. Capital Cost Estimation for Scenario 1 and Scenario 2, with Only C_8-C_{16} Fractions Sold

Project Capital Summary	Scenario 1		Scenario 2	
	200°C (USD)	260°C (USD)	320°C (USD)	350°C (USD)
Purchased Equipment	833,000	1,042,900	687,000	871,900
Equipment Setting	29,586	39,078	25,006	33,062
Piping	500,076	652,502	567,284	713,955
Civil	100,818	123,093	94,433	112,730
Steel	85,506	95,553	83,965	93,531
Instrumentation	789,220	822,075	799,905	822,734
Electrical	545,353	545,395	537,242	537,279
Insulation	184,213	234,908	184,708	225,237
Paint	28,633	31,374	29,141	31,902
Other	2,517,100	2,762,600	2,471,500	2,701,700
G and A Overheads	125,127	145,775	122,360	140,872
Contract Fee	295,481	325,558	291,497	320,187
Contingencies	1,086,140	1,227,750	1,060,930	1,188,920

Notes: The Raw Material Price is 0.5$/kg and the Product Price of C_8-C_{16} is 2.3$/kg

Table 3. Operating Cost Estimation for Scenario 1 and Scenario 2, with Only C_8-C_{16} Fractions Sold

Operating Cost Summary		Scenario 1		Scenario 2	
		200°C (USD)	260°C (USD)	320°C (USD)	350°C (USD)
Total raw materials cost	Cost/period	75,153,100	75,153,100	44,192,300	44,497,500
Operating labor cost	Cost/period	657,450	657,450	657,450	657,450
Maintenance cost	Cost/period	68,923	91,276	62,019	81,414
Total utilities cost	Cost/period	520,516	188,624	544,184	186,314
Operating charges	Cost/period	164,362	164,362	164,362	164,362
Plant overhead	Cost/period	363,186	374,363	359,735	369,432

Notes: The Raw Material Price is 0.5$/kg and the Product Price of C_8-C_{16} is 2.3$/kg

exceeding 8.2×10^7 USD, almost twice as high as Scenario 2 (~$4.96–4.97\times10^7$ USD). These results emphasize that although capital costs are comparable between the two scenarios, the drastic reduction in operating costs achieved in Scenario 2, mainly due to lower raw material expenses, making it far more economically attractive.

In Aspen Plus simulations, different hydrogen partial pressures were set at the same temperature (Scenario 1, 260°C), but there is no significant difference between the simulation results. The production of C8–C16 alkanes shows minimal variation once the H_2 partial pressure surpasses 10 bar[13]. The yield remains nearly constant up to a total reaction pressure of 28 bar, as the catalyst surface becomes saturated with hydrogen at elevated pressures, preventing further enhancement in alkane formation. Consequently, operating at excessively high pressures is unnecessary, since it increases the cost of maintaining pressurized conditions and introduces additional safety risks. A total system pressure of around 28 bar is sufficient for stable performance.

Considering the catalytic mechanism and the assumptions outlined above, Scenario 2 employs nickel-based catalysts. Nickel, a well-established hydrogenation catalyst, is widely applied in industrial processes owing to its strong hydrogenation activity and greater resistance to deactivation compared with most other non-noble metal catalysts. The

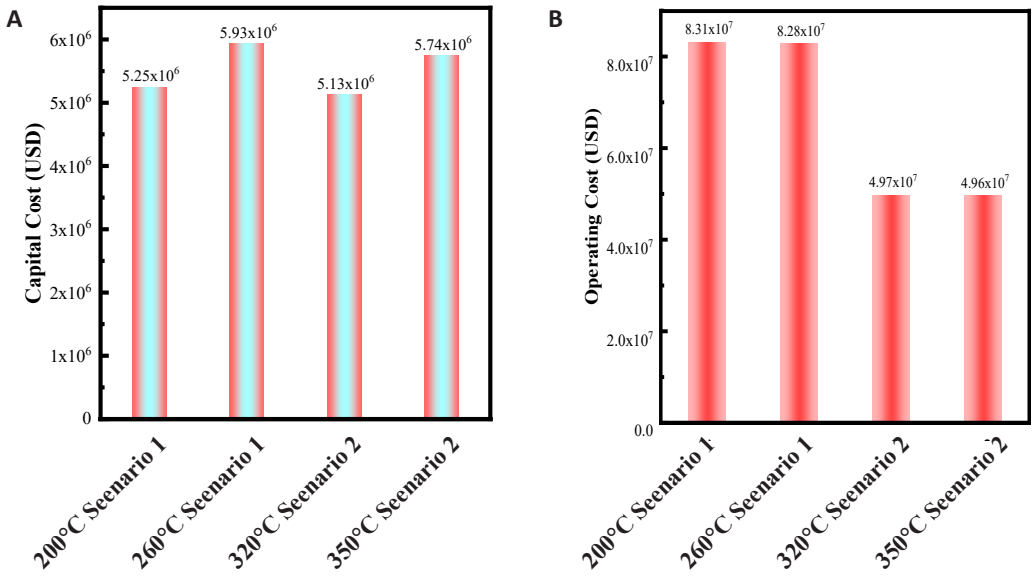

Figure 2. Total Capital Cost and Total Operating Cost Estimates for Scenario 1 and Scenario 2. A: Total capital cost estimates for Scenario 1 (conversion of vegetable oils at 200 and 260°C) and Scenario 2 (conversion of vegetable oils at 320 and 350°C) , with only C_8-C_{16} fractions sold. B: Total operating cost estimates for Scenario 1 (conversion of vegetable oils at 200 and 260°C) and Scenario 2 (conversion of vegetable oils at 320 and 350°C). The raw material price is 0.5$/kg and the product price of C_8-C_{16} is 2.3$/kg.

preparation of supported Ni catalysts typically utilizes metal oxides as carriers. Notably, silicon (Si) and aluminum (Al) are among the most abundant elements in the Earth's crust, aside from oxygen, and are frequently used in catalyst support materials. Previous studies have conducted reaction tests on Ni-based catalysts[4,18,31,32].

A review of the literature indicates that the market price of cyclohexane is $580 per tonne. Scenario 1 is estimated to cost more than Scenario 2 due to the raw materials. To address the economic problem, we aim to identify an organic solvent that satisfies the 'solvent cage' mechanism. Our goal was to reduce production costs using this method, which we referred to as Scenario 2.

The cost of raw materials is subject to fluctuation, as in recent years, it has been on the rise. This increase in raw material costs should result in a corresponding increase in the minimum selling price of jet fuel. To analyze the profitability of the plant, it is necessary to take into account both the cost of raw materials and product prices.

Both Scenario 1 and Scenario 2 require vegetable oil and hydrogen as raw materials for the reaction. However, Scenario 1 also uses cyclohexane and water to create a 'solvent cage'. Assuming that the cost of vegetable oil is the main factor affecting cost and that the cost of producing jet fuel (C_8-C_{16}) from vegetable oil is 1.0$/kg, setting the product price at 2.3$/kg results in the NPV (Net Present Value). As shown in Figure 3A, both Scenario 1 and Scenario 2 are projected to have a negative NPV within 10 years, as indicated by the downward trend line. This suggests that the plant will not be profitable over its 10-year lifespan, resulting in a payout period of zero, regardless of whether Scenario 1 or Scenario 2 is chosen. Additionally, Scenario 2 has a higher load than Scenario 1, exacerbating the issue of profitability.

Figure 3B compares the NPV of Scenario 1 and Scenario 2 over a 10-year period. Scenario 1 (precious metal catalyst at 260°C) remains in the negative range throughout, indicating that the process cannot achieve profitability within 10 years. In contrast, Scenario 2 (Ni-based catalyst at 350°C) quickly turns positive, reaching payback in less than two years and steadily increasing thereafter to over 8×10^7 USD by year 10. This stark difference demonstrates the critical role of eliminating external solvents: by reducing raw material costs, Scenario 2 achieves profitability even when only the C8–C16 fractions are sold, proving its strong economic viability.

Figure 3C illustrates the impact of raw material price on the NPV for both scenarios when the feed cost is 1.0$/kg and the C_8–C_{16} product price is 4.6$/kg. Under these conditions, both Scenario 1 and Scenario 2 achieve profitability, with payout periods of approximately 3 years and 2 years, respectively. However, Scenario 2 consistently outperforms Scenario 1, generating a significantly higher NPV over the 10-year period, exceeding 2×10^8 USD compared to ~1.2×10^8 USD for Scenario 1. This result further highlights the economic advantage of using Ni-based catalysts and eliminating solvent costs, proving that even with elevated raw material prices, selling only the C_8–C_{16} fractions ensures strong profitability.

The minimum jet selling prices of jet fuel via the HEFA process was estimated to be higher than 8$/gal[33]. As demonstrated by the price fluctuations, using Ni-based

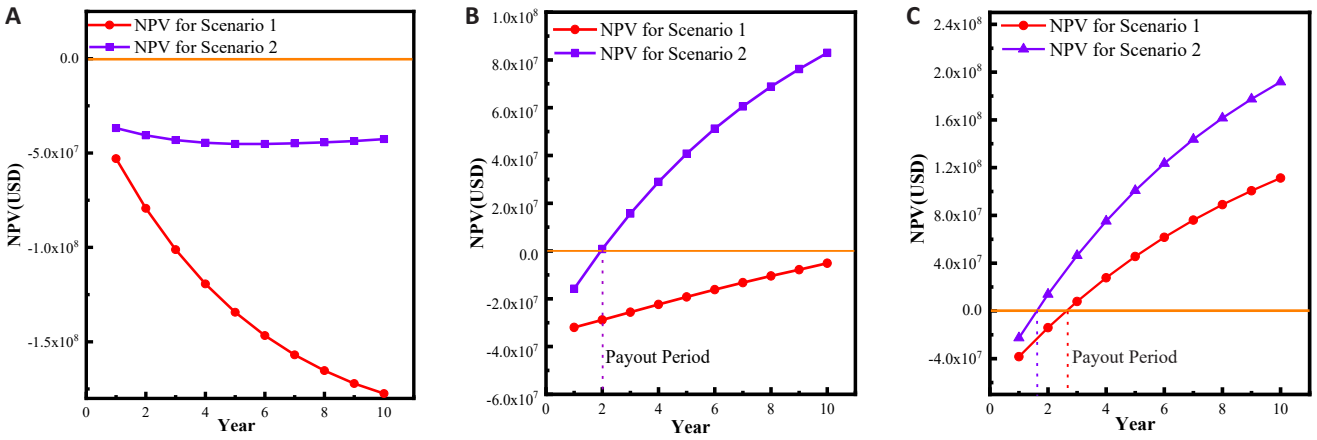

Figure 3. Effect of the Purchase Price of Raw Materials Required for Scenario 1 (260℃ and Total Pressure of 28 bar) and Scenario 2 (350℃ and Total Pressure of 28 bar) on NPV. A: The raw material price is 1.0$/kg and the product price of C_8-C_{16} is 2.3$/kg, with only C_8-C_{16} fractions sold. B: The raw material price is 0.5$/kg and the product price of C_8-C_{16} is 2.3$/kg, with only C_8-C_{16} fractions sold. C: The raw material price is 1.0$/kg and the product price of C_8-C_{16} is 4.6$/kg, with only C_8-C_{16} fractions sold.

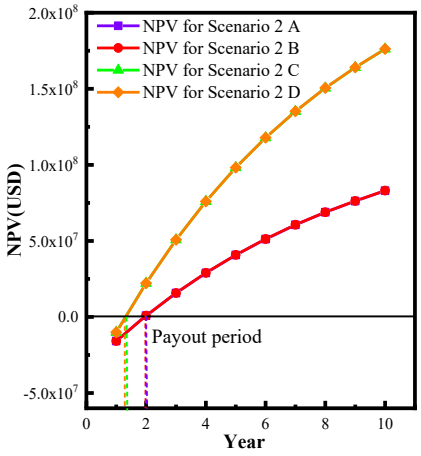

Figure 4. Scenario 2 at 350°C, 28 bar, (A) Unsold By-products; (B) Sale of C1-C7 By-products; (C) Sale of C17-C18 By-products; (D) Sale of All By-products. The raw Material price is 0.5$/kg and the product price of C_8-C_{16} is 2.3$/kg.

catalyst and solvent-free conditions can significantly reduce costs, indicating that our proposed novel process was more attractive.

In order to further reduce production costs, the rational use and sale of by-products represent a further avenue for reducing production costs. The utilization of light alkanes, including hydrocarbons such as methane, and heavy alkanes, such as n-heptadecane, among the by-products is of paramount importance. The process technologies employed in the industrial production of methane offer the potential for further enhancement of the economic competitiveness of renewable jet fuel in comparison to conventional jet fuel. As illustrated in Figure 4, a comparative plot on the impact of selling by-products on the net profit of the plant for Scenario 2 (350°C, 28 Bar) is presented. It is evident that the sale of by-products facilitates the achievement of break-even status at an earlier point in time. In the absence of by-product sales, the plant is projected to reach break-even in the second year of turnover. If the light by-products (C_1-C_7) are sold, the plant will reach break-even in the similar year of turnover. If the heavy by-products (C_{17}-C_{18}) are sold, the plant will reach break-even status faster. In the event that both light and heavy by-products are sold, the plant will reach break-even status in year 1.3 and will do so more rapidly than in the C case.

4 CONCLUSION

In conclusion, a one-pot biTCPwas employed to validate the potential of converting vegetable oils into jet fuel–range alkanes. A comprehensive techno-economic assessment (TEA) estimated the market-based selling price of jet paraffin at approximately 2,300 USD per tonne, with a payback period of around 1.3 years. Sensitivity analysis further indicated that fluctuations in raw material costs are the primary drivers influencing the final product price.

The use of renewable biomass as a feedstock for sustainable aviation fuel provides a promising alternative to petroleum-derived jet fuels, offering both energy security and the potential for substantial reductions in greenhouse gas emissions. Nevertheless, the pathway toward commercialization remains constrained by key challenges, including feedstock supply, cost competitiveness, sustainability considerations, and the need for technological advancement. The gradual replacement of conventional jet fuels with biojet fuels is an inevitable trajectory despite their current cost disadvantage. Strong government policies, financial incentives, and continuous support for innovation and research are essential to accelerate technological breakthroughs and promote the large-scale deployment of biojet fuel.

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Conflicts of Interest

The authors declared no conflict of interest.

Data Availability

All data generated or analyzed during this study are included in this published article.

Author Contribution

Xie S contributed to the conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, software, resources, supervision, validation, visualization, writing – original draft, review & editing. Chen Z contributed to the data curation, formal analysis, investigation, and methodology. Zhang W contributed to the software, resources, supervision, validation, visualization, and writing – review & editing.

Abbreviation List

biTCP, Biphasic tandem catalytic process
HEFA, Hydroprocessed esters and fatty acids
NPV, Net present value

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