Comparative assessment of technologies to produce sustainable aviation fuels from lignocellulosic biomass

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Abstract:

The growing demand for air transport and the limited availability of commercially viable low-carbon alternatives have made the decarbonization of the aviation sector a major challenge. The objective of this study was to compare three technological pathways for the production of sustainable aviation fuels (SAF) from lignocellulosic sugarcane biomass in the Colombian context: Alcohol to Jet (AtJ), Synthesized Iso Paraffins (SIP), and Fischer-Tropsch (FT). The research aims to determine which of these alternatives offers the best technical, economic, and environmental performance in the Colombian context. The processes were simulated in Aspen Plus V15.0. The technical analysis considered product yield (PY), conversion efficiency (CE), and energy consumption (SEC). The economic pre-feasibility study included estimates of CapEx and OpEx, as well as financial indicators such as net present value (NPV). The environmental assessment was conducted using the ISO 14040 methodology and SimaPro 8.3 software, under a cradle-to-gate approach. SIP demonstrated the highest SAF performance and the best economic performance, while FT showed the lowest specific energy consumption. In environmental terms, all routes exceeded the CORSIA sustainability threshold of 80.1 g CO_2 eq/MJ; Nevertheless, FT had the lowest climate impact and results that were closest to the baseline. Overall, SIP was the most competitive option for producing SAF from sugarcane bagasse in Colombia, although FT stood out for its lower energy requirements and better relative environmental profile. Even so, the results suggest that these pathways do not yet fully meet the sustainability criteria required to be considered truly sustainable SAF.

Keywords: Sustainable aviation fuel (SAF), Hydrogen, Synthesized Iso-Paraffins, Fischer Tropsch, Alcohol to Jet.

Abbreviations

Sugarcane bagasse (SCB)
Fisher-Tropsch (FT)
Alcohol-to-jet (AtJ)
Synthesized iso-paraffins (SIP)
Greenhouse gases (GHG)
Steam methane reforming (SMR)
Process Mass Intensity (PMI)
Conversion Efficiency (CE)
Product Yield (PY)
International Organization for Standardization (ISO)

1. Introduction

In the global economy, aviation is a strategic sector that drives connectivity, social integration, and economic development, contributing approximately 3.9% of global gross domestic product (GDP) and transporting more than 4 billion passengers annually [1] . Nevertheless, this sustained growth has historically been driven by the intensive use of fossil fuels, which has led to the sector being responsible for approximately 2.5% of global greenhouse gas (GHG) emissions [2]. As passenger demand is projected to continue increasing over the coming decades, the sector faces growing pressure to reduce its carbon footprint while maintaining operational reliability and energy security. In this context, the development of sustainable aviation fuels (SAF) derived from renewable feedstocks is emerging as one of the most viable alternatives for gradually replacing petroleum-based jet fuel [3]. Among the available feedstocks, lignocellulosic biomass has attracted considerable attention due to its abundance, wide geographic availability, and the fact that it does not directly compete with food production. Agricultural and forestry residues are especially promising, as they enable the valorization of low-cost waste materials into high-value fuels with the potential to significantly reduce life-cycle emissions. In the case of Colombia, a country known for its diverse climate and agricultural production, significant volumes of agro-industrial waste are generated that hold high potential for recovery. Sugarcane bagasse is a prime example, with an estimated annual production of between 6 and 7 million tons, of which approximately 5–6 million tons are currently used in energy cogeneration processes [4]. Nonetheless, its lignocellulosic composition (cellulose, hemicellulose, and lignin) makes it a promising raw material for producing higher-value-added products, such as SAF. Therefore, the feasibility of producing sustainable aviation fuels (SAF) from sugarcane bagasse was evaluated by comparing three representative technological pathways: (i) Fischer–Tropsch (FT) via gasification, (ii) Alcohol-to-Jet (ATJ) via fermentation and ethanol upgrading, and (iii) Hydroprocessed Fermented Sugar to Synthesized Iso-Paraffins (SIP). Each process model incorporated the pretreatment, reaction, and separation stages, as shown in Figure 1.

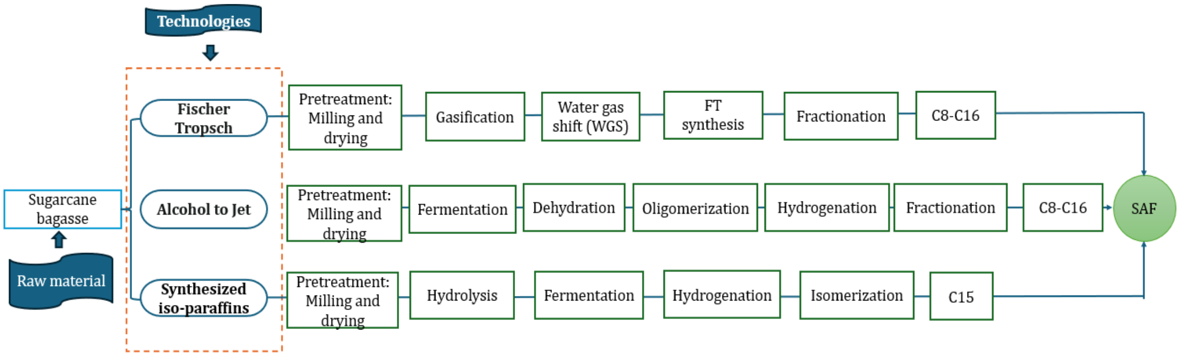

Figure 1. Technological pathways for the production of sustainable aviation fuel (SAF) from sugarcane bagasse.

The experimental scenarios were carried out using simulation software (Aspen Plus V15.0) to determine the material and energy balances. This allowed for the calculation of technical indicators such as product yield, conversion efficiency, mass intensity, specific energy consumption, and resource energy efficiency. Subsequently, an economic prefeasibility analysis was conducted following the methodology described by Moncada et al., (2014) [5]. The economic evaluation was carried out by estimating the capital expenditures (CapEX) and operating costs. (OpEX). Economic metrics were also estimated to assess the process's viability, such as net present value (NPV) and payback period. The environmental analysis was conducted using the methodology specified in ISO 14040 and SimaPro V8.3 software, based on the input and output flows from the simulation. A cradle to grave approach was adopted, and 1 MJ of SAF was selected as the functional unit. All results were reported per unit mass of processed sugarcane bagasse, thereby enabling a comparative evaluation of the technologies in technical, economic, and environmental terms.

2. Methodology

2.1 Raw materials and physicochemical characterization

For the purposes of this case study, the department of Risaralda (Colombia) was selected—a region with significant agro-industrial activity related to the cultivation and processing of sugarcane, where the Risaralda

S.A. sugar mill is located (4°54′30.9153″ N, 75°53′49.8587″ W). The constant availability of sugarcane bagasse (SCB) in this area, together with its well-established agroindustrial infrastructure, makes it a suitable setting for evaluating biorefinery schemes aimed at producing sustainable aviation fuels. Based on the mill's operational capacity, approximately 4,210.8 tons of crushed sugarcane are processed per day [6], of which about 30% on a wet basis consists of sugarcane bagasse, a byproduct of the sugarcane juice extraction process [7]. Consequently, the available bagasse flow was estimated at 1,263.24 $t \cdot day^{-1}$ (wet basis), representing a significant fraction with potential for energy and chemical recovery.To develop the process models in Aspen Plus V15, the elemental and structural composition of sugarcane bagasse was defined using experimental data reported for Colombian bagasse. The lignocellulosic composition adopted in the simulations, including the contents of cellulose, hemicellulose, lignin, extractives, and ash, is presented in Table 1.

Table 1. Composition of sugarcane bagasse on Rosa Virginia Garcés Paz et al., (2007) and Ortiz-Sanchez et al., (2024) [8][9].

Component	**Composition (%)**
Cellulose	43.26
Hemicellulose	28.72
Lignin	13.44
Extractives	12.05
Ashes	2.53

2.2 Biomass processing

Prior to conversion, the bagasse underwent physical conditioning aimed at homogenizing the feed and improving feed conversion efficiency. The operating conditions adopted are presented in the Table 2.

Table 2. Preparation of raw materials for all processes.

Stage	**Modeled Process Equipment**	**T (°C)**	**P (bar)**	**Specifications**	**Reference**
Drying	Shortcut Dryer	60	1	Moisture loss: 42%	[10]
Milling	Rotary Mill	25	1	Particle size: 3–5 mm	[11]

For these studies, maintaining the same feedstock composition across all routes ensures comparability between scenarios, thereby ensuring that differences in energy yield, conversion efficiency, and SAF production are attributed solely to the conversion stages and not to variations in the feedstock.

2.2 Alcohol to Jet

The ATJ process comprises a series of physicochemical operations focused on converting biomass-derived alcohols into hydrocarbons in the C_8–C_{16} range for aviation fuels. This process has been approved as a method for producing synthetic aviation fuels certified under the ASTM D7566 specification, establishing itself as an industrially viable alternative for the production of SAF [12]. The Alcohol-to-Jet (AtJ) process was modeled based on the process diagram shown in the Figure 2. The process is divided into sub-units that group the main stages involved in the conversion of sugarcane bagasse into sustainable aviation fuel (SAF). Unit 10 corresponds to the storage and initial handling of raw materials, including sugarcane bagasse and process reagents. Unit 20 comprises the biomass pretreatment stage, in which the feedstock is conditioned to facilitate subsequent conversion. Unit 30 represents dilute acid hydrolysis, where hemicellulose is solubilized and fermentable sugars are released. Unit 40 includes enzymatic hydrolysis, during which cellulose is converted into glucose. Unit 50 corresponds to hydrolysate neutralization and conditioning of the fermentation medium. Unit 60 comprises ethanol recovery and purification through separation operations. In Unit 70, ethanol undergoes catalytic dehydration to produce ethylene. Unit 80 corresponds to the oligomerization of ethylene to form hydrocarbons in the C_8–C_{16} range. Unit 90 includes the hydrogenation of olefinic compounds to obtain saturated paraffins. Finally, Unit 100 corresponds to the final fractionation stage, where the SAF stream is separated from lighter hydrocarbons (C_7-) and other non-target fractions.

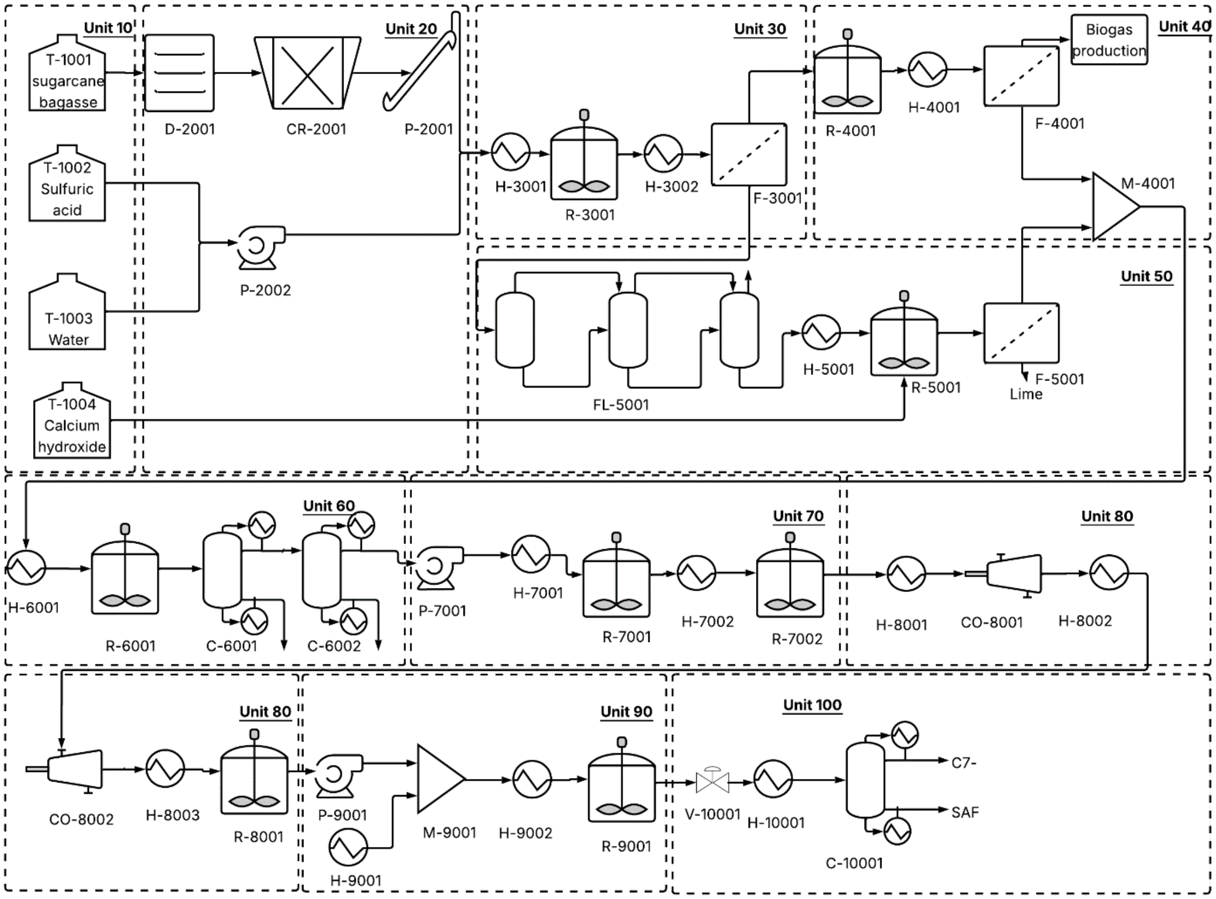

Figure 2. Flowchart of the AtJ process for the production of sustainable aviation fuel.

The operating conditions and assumptions used at each stage are summarized in the Table 3.

Table 3. Operating Conditions for the AtJ Route.

Stage	Modeled Process Equipment	T (°C)	P (bar)	Catalyst / Enzyme	Specifications	Reference
Acid hydrolysis	RStoic	121	1	2 wt% H_2SO_4 dilution (1:20)	80% hemicellulose solubilization	[13]
Solid–liquid separation	Filter	50	1	—	—	[14]
Neutralization	RStoic	60	1	$Ca(OH)_2$	99% acid conversion	[15]
Enzymatic hydrolysis	RStoic	50	1	Cellic CTec	57.5% cellulose conversion	[16]
Fermentation	RStoic	30	1	*Z. mobilis* + *S. stipitis*	0.51 g ethanol/g sugar	[17]
Fractionation	Distillation column (RadFrac)	30–100	1	—	90% ethanol purity	
Dehydration 1	RStoic	400	5.9	ZSM-5	71.5% conversion	[18]

Dehydration 2	RStoic	405	5.9	ZSM-5	98% conversion	[18]
Oligomerization (C8–C16)	RYield	200	10	Ni/Al-HMS	96.3% ethylene conversion	[19][20]
Hydrogenation	RYield	200	35	ZSM-5	99% conversion	[18]
Fractionation	Distillation column (RadFrac)	50–150	1	—	80% jet fuel recovery	

2.3 Fisher tropsch

The FT route was modeled based on the flow diagram shown in the Figure 3, The process is divided into process units that group the main conversion stages. Unit 10 corresponds to the storage and initial handling of raw materials, including sugarcane bagasse and the utilities required for process operation. Unit 20 comprises biomass pretreatment, where the bagasse is conditioned prior to feeding the gasifier. Unit 30 represents the air-blown gasification stage, in which the biomass is converted into synthesis gas composed primarily of CO, H_2, CO_2, CH_4, and N_2, while residual solids such as ash and char are removed. Unit 40 includes the syngas compression and conditioning train. In this unit, the synthesis gas is compressed through multiple stages with intercooling to reach the pressure required for downstream processing. Part of the energy contained in the gas stream is recovered through an expansion turbine, contributing to a partial reduction in the overall energy demand. The water-gas shift reaction is also carried out in this unit, where a fraction of the CO reacts with steam to increase the H_2/CO ratio to values suitable for Fischer–Tropsch synthesis. Unit 50 comprises CO_2 removal by absorption using monoethanolamine (MEA), producing a synthesis gas enriched in CO and H_2. Unit 60 corresponds to the Fischer–Tropsch reactor, where the conditioned synthesis gas is catalytically converted into a mixture of paraffinic hydrocarbons with different carbon chain lengths. Finally, the product stream undergoes cooling and separation. During this stage, light gases and non-condensable compounds are recycled to the process, while the liquid fractions are separated to recover the hydrocarbon stream in the C_8–C_{16} range corresponding to sustainable aviation fuel (SAF).

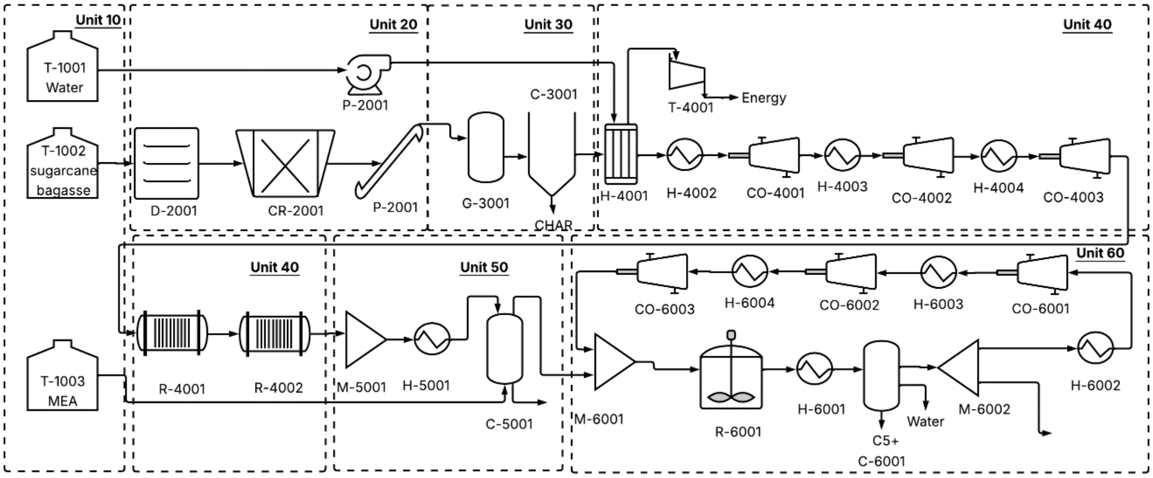

Figure 3. Flowchart of the FT process for the production of sustainable aviation fuel.

The presents the main operating conditions and specifications used in modeling the Fischer–Tropsch Process.

Table 4 presents the main operating conditions and specifications used in modeling the Fischer–Tropsch Process.

Table 4. FT Route Operating Conditions.

Stage	Modeled Process Equipment	T (°C)	P (bar)	Catalyst / Enzyme	Specifications	References
Gasification	RYield	800	25	Air	98% carbon conversion	[21]
Removal	Cyclone	300	24	—	99% solids removal	[21]
Water-gas shift	RStoic	200–350	20	Fe	H_2/CO ratio of 2 (40% CO conversion)	[21]
CO_2 removal	Distillation column (RadFrac)	40	26	MEA (Monoethanolamine)	—	[22]
Fischer–Tropsch synthesis	RStoic	300	20	Fe	80% conversion	[23]
Fractionation	Column	40	20	—	C1–C4 recycled to the Fischer–Tropsch reactor	[23]

2.4 Synthesized Iso-Paraffins

The SIP pathway stars with the fermentation of sugars to produce β-farnesene, which is then hydrogenated to produce farnesane, an isoparaffin within the range of hydrocarbons suitable for use as sustainable aviation fuel. The modeling of this process was developed based on the process flow diagram shown in the Figure 4. Unit 10 corresponds to the storage and initial handling of raw materials, including sugarcane bagasse and the reagents required for process operation. Unit 20 comprises biomass pretreatment, where the feedstock is conditioned to facilitate subsequent conversion. Unit 30 represents dilute acid hydrolysis, in which hemicellulose is solubilized and fermentable sugars are released, improving cellulose accessibility. Unit 40 includes enzymatic hydrolysis, during which cellulose is converted primarily into glucose. Unit 50 corresponds to hydrolysate neutralization and conditioning to adjust the process stream to the requirements of the biological conversion stage. Unit 60 comprises fermentation using genetically modified microorganisms, in which fermentable sugars are converted into β-farnesene, the direct precursor to the final fuel product. Finally, Unit 70 integrates product recovery and upgrading stages, including emulsification with Tergitol, liquid-liquid separation, distillation for β-farnesene purification, and catalytic hydrogenation to convert β-farnesene into farnesane. Farnesane is an isoparaffinic hydrocarbon with physicochemical properties suitable for use as sustainable aviation fuel (SAF).

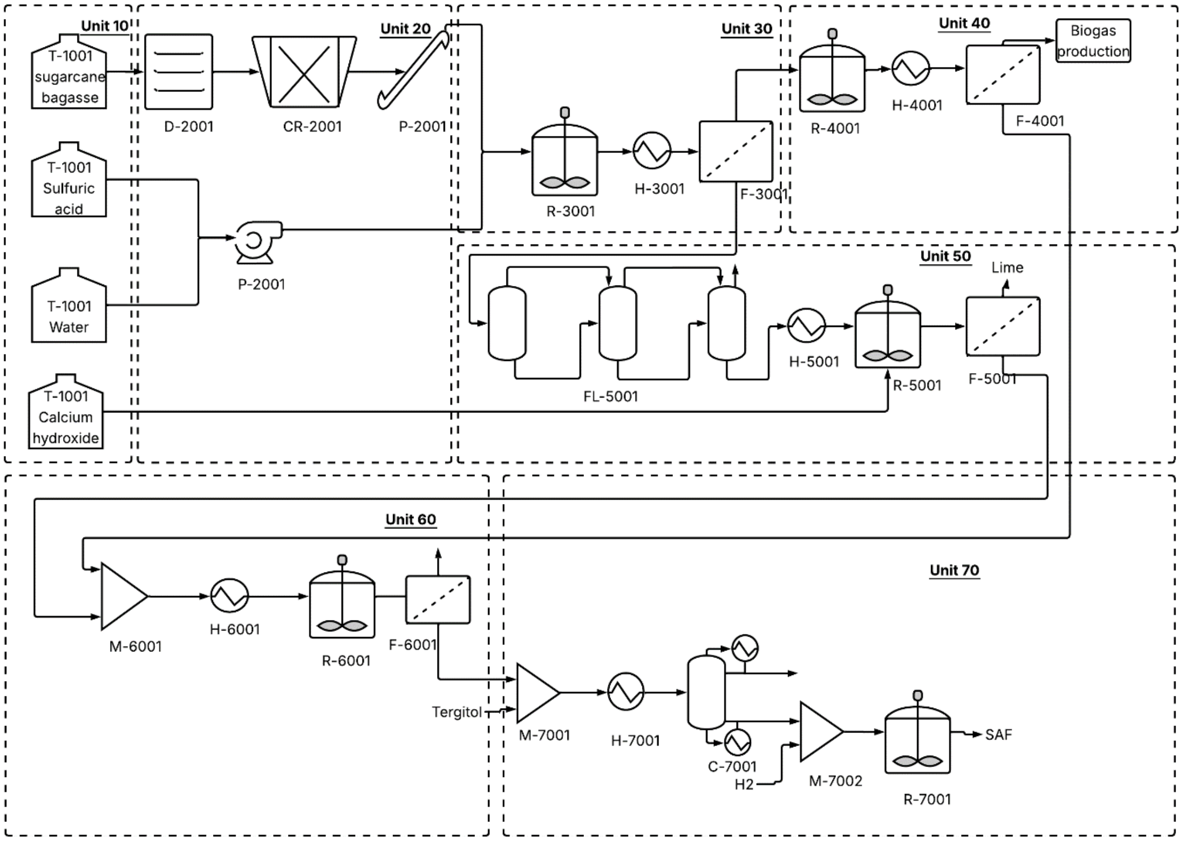

Figure 4. Flowchart of the SIP process for the production of sustainable aviation fuel.

The Table 5 presents the operating conditions and specifications used for modeling the Synthesized Iso-Paraffins (SIP) route.

Table 5. SIP Route Operating Conditions.

Stage	Modeled Process Equipment	T (°C)	P (bar)	Catalyst / Enzyme	Specifications	Reference
Acid hydrolysis	RStoic	121	1	2 wt% H_2SO_4 dilution (1:20)	80% hemicellulose solubilization	[13]
Solid–liquid separation	Filter	30	1	—	—	[14]
Neutralization	RStoic	60	1	Ca $(OH)_2$	99% acid conversion	[15]
Enzymatic hydrolysis	RStoic	50	1	Cellulases	57.5% cellulase conversion	[16]
Fermentation	RYield	30	1	Genetically modified yeast (*Yarrowia lipolytica*)	0.20–0.27 g/g glucose	[24]
Solid–liquid separation	Filter	30	1	—	—	--
Emulsification	MIX	30	1	0.6% v/v TERGITOL	71% β-farnesene obtained	[25]

Liquid–liquid separation	Centrifuge	40	1	—	—	—
Fractionation	Distillation column (RadFrac)	70–260	1	—	97% β-farnesene obtained	[26]
Hydrogenation	RStoic	200	25	Electroplated Pd (Pd-EP)	98.8% farnesane obtained	[27]

2.5 Technical assessment

The evaluated scenarios were analyzed based on the mass and energy balances obtained from the simulations, with the aim of establishing comparative indicators of the technical performance of each technological pathway. To this end, four key indicators were calculated: product yield (PY), conversion efficiency (CE), mass intensity (MI), and specific energy consumption (SEC). PY relates the mass of SAF obtained to the mass of biomass fed into the process and allows for quantifying each route's capacity to transform the feedstock into the target product. CE is defined as the ratio of the mass of SAF produced to the total mass of raw materials and reagents fed into the process, reflecting the fraction of inputs that is effectively incorporated into the final product. PMI expresses the total amount of inputs required per unit of product; thus, low values indicate a more efficient use of resources and lower waste generation. Finally, quantifies the thermal and electrical energy consumed per unit of SAF produced; in this case, lower values represent processes with lower energy demand and better operational performance. The equations used to calculate the PY, CE, PMI, and SEC indicators are presented below.

$$\mathrm{PMI}=\frac{\sum_{i=1}^{N} m_i^{in}}{\sum_{j=1}^{N} m_j^{Product}} \tag{1}$$

$$\mathrm{PY}=\frac{\sum_{j=1}^{N} m_j^{Product}}{\sum_{i=1}^{N} m_i^{Raw\ material}} \tag{2}$$

$$\mathrm{CE}=\frac{\sum_{j=1}^{N} m_j^{Product}}{\sum_{i=1}^{N} m_i^{in}} \tag{3}$$

$$\mathrm{SEC}=\frac{Q_{Total}+W_{Total}}{\sum m_{Raw\ material}} \tag{4}$$

2.6 Economic assesment

The economic analysis of the evaluated routes was conducted using Aspen Process Economic Analyzer v14 software, which enabled equipment sizing and a semi-detailed estimation of capital costs. This evaluation considered, among other things, mixing and storage tanks, pumping systems, and the construction materials required for each process unit. Capital expenditure (CapEx) was estimated based on the costs associated with major equipment, instrumentation and control systems, civil works, piping, electrical installations, and basic and detailed engineering. Operating costs (OpEx), meanwhile, were calculated based on the mass and energy balances obtained in the simulation and included raw materials, industrial services, labor, maintenance, depreciation, and general operating expenses. Prices for raw materials, utilities, and inputs, as well as product sales prices, were obtained from bibliographic sources and publicly available commercial information. The profitability of each technological alternative was evaluated using Net Present Value (NPV), considering a project lifespan of 20 years, 8,000 annual operating hours, a discount rate of 12%, and straight-line depreciation with a salvage value equivalent to 10% of the initial investment. The NPV was calculated according to the following formula:

$$NPV=\sum_{t=1}^{n}\frac{FC_t}{(1+i)^t}-I_0 \tag{5}$$

2.7 Enviromental analysis

The environmental assessment of sustainable aviation fuel (SAF) production pathways was conducted using the Life Cycle Assessment (LCA) methodology, in accordance with the guidelines established in International Organization for Standardization (ISO) standards 14040 and 14044. The analysis was performed in SimaPro v. 8.3, using a cradle-to-gate approach and a functional unit of 1 MJ of SAF produced. The objective of the study was to quantify and compare the environmental impacts associated with the evaluated technologies, in order to identify the alternative with the best environmental performance and the critical points of each process.

The life cycle inventory was constructed based on the mass and energy balances obtained in Aspen Plus V15.0, supplemented with additional information from the literature for the agricultural stages. The system boundaries, which included the agricultural stage associated with sugarcane cultivation, considering the main activities required for biomass production. These stages included land preparation, planting, the application of fertilizers and herbicides, harvesting, and the conditioning of plant material for subsequent processing. Additionally, the transport of bagasse to the plant and all conversion and separation stages involved in each of the technological pathways evaluated for the production of sustainable aviation fuel were considered. The information corresponding to the agricultural stage was obtained from the literature [28].

3. Discussion and Results

3.1 Technoeconomic analysis of the scenarios

The main technical and economic results for the evaluated routes are presented in Table 6. Overall, the techno-economic evaluation showed that the SIP route was the only economically viable alternative in the context analyzed, while the AtJ and FT routes yielded unfavorable economic results. The difference between scenarios is mainly explained by the yields obtained, the complexity of each process, and the associated energy requirements. The SIP route yielded the highest SAF output, which is attributed to the high selectivity of the fermentation toward β-farnesene and the high conversion rate in the hydrogenation step to farnesane.

In terms of energy consumption, the FT route exhibited the lowest specific thermal energy consumption. nonetheless, this result does not fully reflect the process's high demand for electrical energy. Gasification was carried out using air, large amounts of nitrogen entered the system and accumulated in the recirculation streams, significantly increasing the gas flow rate to be compressed. As a result, the compressors' electricity consumption increased considerably, negatively impacting operating costs. This effect is particularly relevant in the Colombian context, where the cost of electricity represents a significant component of operating expenses.

Table 6. Technical and economic indicators of the SAF pathways.

Process	PY	CE	PMI	SEC (GJ/Ton)	CapEX (mUSD)	OpEX (mUSD)
AtJ	0.05	0.03	25.21	53.25	38.27	23.65
SIP	0.06	0.04	23.34	49.88	24.87	19.16
FT	0.04	0.04	23.31	12.57	28.766	28.83

To supplement the economic evaluation, the trend in the cumulative net present value (NPV) over a 20-year period was analyzed. This indicator makes it possible to assess the recovery of the initial investment and each route's ability to generate long-term profitability. In this regard, Figure 5, on the left, shows the cumulative NPV trend for the AtJ and SIP routes. In both cases, an initial decline is observed, associated with the capital investment required to build the plant. Subsequently, the SIP route shows a sustained recovery in NPV, reaching the payback period around year 11 and ending the analysis period with a positive value. This behavior confirms the economic viability of this route and is consistent with its higher returns and lower investment and operating costs. In contrast, the AtJ route exhibits a gradual recovery, but one insufficient to offset the initial investment and operating costs, maintaining a negative NPV throughout the evaluation horizon.

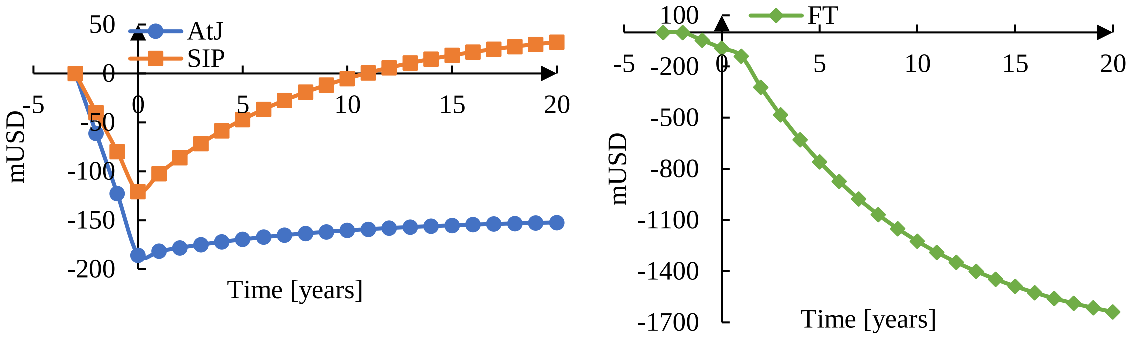

Figure 5. NPV Projections for the AtJ, SIP *and FT* routes.

Figure 5, on the right, shows the evolution of the cumulative NPV for the FT route. Unlike the other alternatives, this route exhibits a continuous downward trend, reaching highly negative values by the end of the evaluation period. This behavior indicates that the revenue generated from the sale of SAF and co-products fails to cover the costs associated with the process. Although the FT route exhibited the lowest specific thermal energy consumption, the use of air as a gasification agent introduced large amounts of nitrogen into the system, which increased the flow of gas to be compressed and, consequently, the electrical energy consumption of the compressors. Given the cost of electricity in Colombia, this factor had a decisive impact on the process's profitability.

In order to identify the main factors that determine operating costs, the distribution of OpEx was analyzed for each of the routes evaluated. This analysis makes it possible to determine which cost categories have the greatest impact on total production costs and, consequently, which ones represent the main opportunities for process improvement. In the FT route, utilities constitute the predominant component of operating costs, accounting for the largest share of total OpEx (Figure 6). This pattern is related to the high demand for electricity required to compress the gas streams. As a result, the operating cost of this route is considerably higher than that of the other alternatives. In the AtJ and SIP routes, the supplies category represents the main contributor to OpEx, followed by costs associated with utilities and overhead. This behavior is related to the consumption of catalysts, enzymes, nutrients, and other inputs required in the conversion and purification stages. However, the SIP route has a lower total operating cost than AtJ, which is consistent with its higher product yield and simpler process configuration

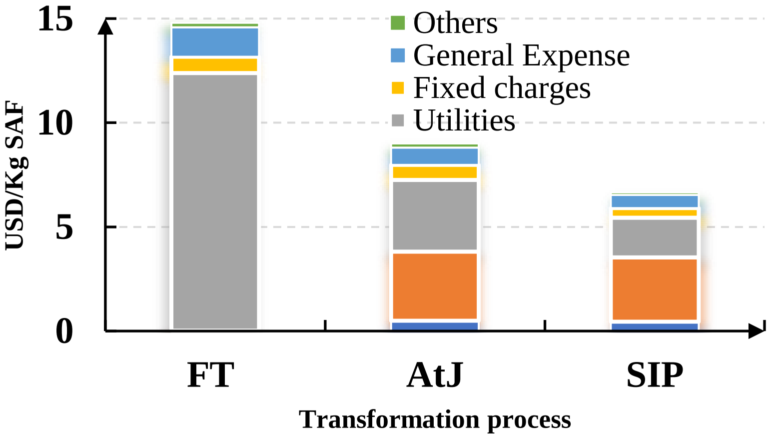

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Figure 6. Breakdown of Operating Expenses (OpEX).

These results are consistent with what has been reported in the literature regarding SAF technologies. Where in Z. J. Wang et al., (2021) [29], they noted that, in the absence of incentives or supportive policies, most biofuel production pathways have negative NPV values, and that economic viability depends largely on process efficiency, capital costs, and the price of raw materials.

3.2 Environmental analysis of the scenarios

Figure 7 shows the climate change potential expressed in g CO_2 eq/MJ of SAF produced for each of the routes evaluated, along with the fossil fuel baseline and the sustainability threshold established by the CORSIA scheme. According to the International Civil Aviation Organization, conventional aviation fuel has a carbon footprint of 89 g CO_2 eq/MJ. For a fuel to be considered sustainable, it must achieve a minimum reduction of 10% compared to this value, which corresponds to a maximum limit of 80.1 g CO_2 eq/MJ [30]. Based on this criterion, none of the routes analyzed meets the established requirement, although FT is the option that comes closest to that threshold.

In addition, values reported in the literature for biofuel production pathways using microalgae via the Fischer-Tropsch process were included [31] and hydrothermal liquefaction [32], The comparison shows that the results obtained in this study are within the same order of magnitude as those reported for other raw materials and technologies. Nevertheless, these studies show that the incorporation of low-carbon hydrogen, the use of renewable electricity, and greater energy integration can significantly reduce global warming potential, suggesting that the results obtained in this study could be improved by implementing such strategies.

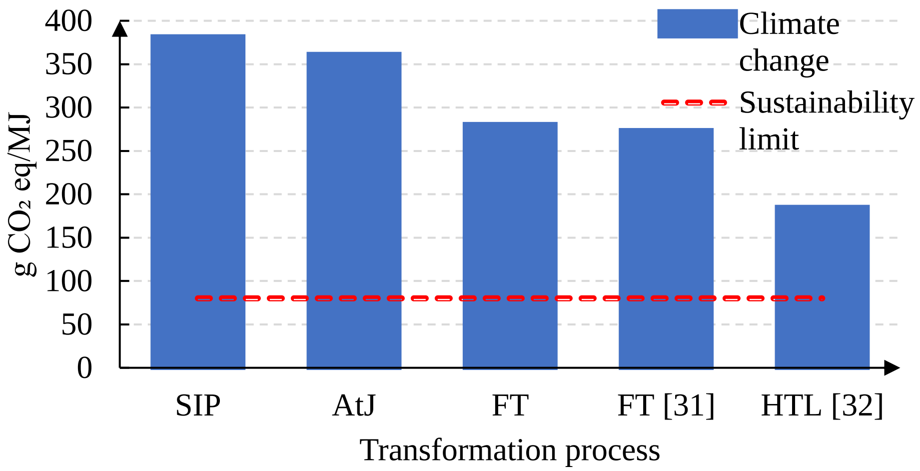

Figure 7. Climate change potential and sustainability limits.

Table 7 provides further details on the environmental analysis of the processes. Overall, FT performed best in the categories of human toxicity and fossil resource use, confirming its lower dependence on non-renewable inputs and its lower potential impact on human health. However, this technology showed a higher water demand compared to the other alternatives. For their part, the AtJ and SIP routes exhibited similar performance in water consumption, although with higher impacts in the other evaluated categories.

Table 7. Environmental impact indicators.

Indicator	AtJ	SIP	FT
Human toxicity (g 1,4-DB eq/MJ)	44.29	52.47	6.65
Water depletion (L/MJ)	69.72	68.16	168.63
Fossil depletion (g oil eq/MJ)	89.96	105.75	4.28

Considering all impact categories, the Fischer–Tropsch (FT) route demonstrated the best overall environmental performance, with lower impacts on climate change, human toxicity, and fossil resource depletion.

Nevertheless, none of the technologies evaluated met the emissions threshold established by CORSIA to be considered sustainable aviation fuels. These results indicate that, although FT represents the most environmentally favorable alternative, strategies must be implemented to improve the sustainability of the routes analyzed.

Conclusion

The results showed that, for the production of sustainable aviation fuel (SAF) from sugarcane bagasse, the SIP pathway is the most competitive option under the conditions analyzed, as it offers the highest product yield and the best economic performance. Meanwhile, the FT route stood out for its lower specific energy consumption and for exhibiting the best environmental performance, with lower impacts on climate change, human toxicity, and depletion of fossil resources. Nevertheless, none of the evaluated routes met the emissions threshold established by the CORSIA scheme to be considered sustainable. Overall, the results confirm the potential of sugarcane bagasse as a feedstock for SAF production in Colombia but highlight the need to incorporate strategies to improve the sustainability of these technologies.

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