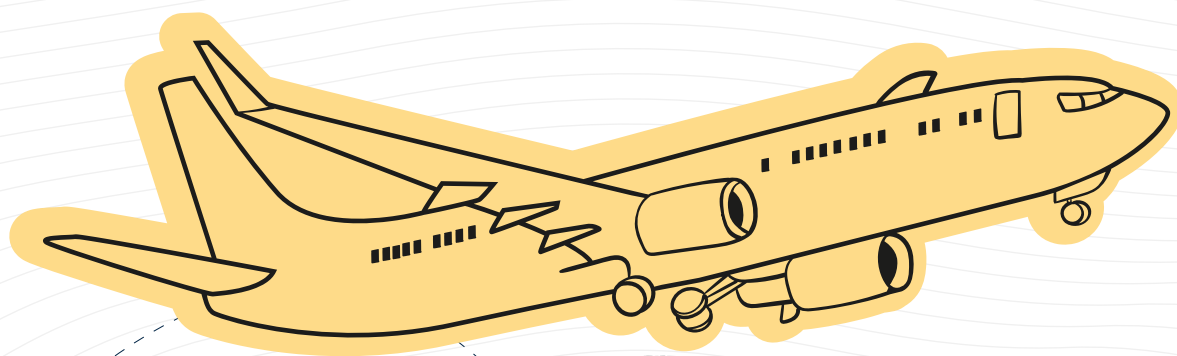




Fueling Africa's Flight:

A Techno-Economic Assessment of Sustainable Aviation Fuels in Africa



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Megersa Abate, Robert Malina, Gonca Seber, Charles E. Schlumberger

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Abbreviations

ASTM	American Society for Testing and Materials
ATJ	Alcohol-to-Jet
BPD	Barrels Per Day
BPSD	Barrels Per Stream Day
Br	Birr
CAPEX	Capital Expense
CO₂	Carbon Dioxide
CO₂e	Carbon Dioxide Equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
e-SAF	Synthetic Fuel
ETP	Energy Transition Plan
EU	European Union
EU ETS	European Union Emissions Trading System
FT	Fischer-Tropsch
gCO₂e/MJ	Grams of Carbon Dioxide Equivalent per Megajoule of Energy
HEFA	Hydrotreated Esters and Fatty Acids
IATA	International Air Transport Association
IBL	Inside Battery Limit(s)
ICAO	International Civil Aviation Organization
ILUC	Induced Land-Use Change
KNBS	Kenya National Bureau of Statistics
K Sh	Kenya Shilling
LCA	Life Cycle Analysis
LEC	Landfill Emissions Credit
LPG	Liquefied Petroleum Gas
MJ	Megajoule(s)
MSP	Minimum Selling Price
MSW	Municipal Solid Waste



Mt	Million Ton(s)
NBO	Jomo Kenyatta International Airport
NDC	Nationally Determined Contribution
NO	Naira
OEM	Original Equipment Manufacturer
PJ	Pentajoule(s)
PtL	Power-to-Liquid
PV	Photovoltaic
R	Rand
R&D	Research and Development
REC	Recycling Emissions Credit
SAF	Sustainable Aviation Fuel
UCO	Used Cooking Oil



Executive Summary

Context

Africa's aviation sector is poised for rapid growth, with passenger traffic expected to double over its 2023 level by 2043, according to the International Air Transport Association (IATA 2024). This expansion opens up significant economic opportunities, including increased connectivity, tourism, and trade, which are essential for the continent's economic integration and growth.

This growth also underscores the urgent need to address the environmental challenges associated with aviation emissions. Without action, the sector's carbon footprint could significantly undermine sustainability goals, increasing the pressure on Africa's ecosystems and global commitments to climate change mitigation.

This study explores the potential for producing sustainable aviation fuels (SAF) in four African countries: Ethiopia, Kenya, Nigeria, and South Africa. Rather than serving as a full feasibility analysis or detailed project proposal, it uses a techno-economic approach to showcase Africa's potential through examples from these countries. The analysis highlights strategies for cost reduction and risk management, with a focus on the higher selling prices of SAF in Africa, which are driven by elevated risk premiums and green premiums. By assessing feedstock availability, production technologies, and policy frameworks, the study provides actionable insights to accelerate SAF adoption in Africa. The aim is to bridge the cost gap with conventional fossil-based jet fuel, position Africa as an integral part of sustainable aviation value chain, and contribute significantly to reducing carbon emissions.

The aviation industry sees SAF as essential for achieving net-zero emissions and transitioning to renewable energy sources. The "basket of measures" of the International Civil Aviation Organization (ICAO) for reducing aviation emissions includes four components: improving aircraft technology, enhancing operational efficiency, promoting SAF, and implementing market-based measures such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to offset residual emissions (ICAO 2019). SAF can significantly reduce aviation's lifecycle greenhouse gas (GHG) emissions, with ambitious adoption potentially lowering emissions by 57 percent by 2050 compared with business-as-usual scenarios (Malina, Abate, Schlumberger, and Navarro Pineda 2022). To do so, however, SAF production must scale from 0.5 metric tons (Mt) in 2024 (0.5 percent of total jet fuel consumption) to 500 Mt by 2050—a 1,000-fold increase—presenting both opportunities and challenges (IATA 2024).

SAF represents a transformative opportunity for Africa's aviation industry, enabling a shift toward greener, more resilient operations. The ICAO projects that a significant portion of SAF production will come from developing countries and emerging markets, where biogenic feedstock is abundant and renewable energy potential high (ICAO 2022a). However, countries outside the Organisation for Economic Co-operation and Development (OECD) remain significantly underrepresented in the SAF supply chain, often relegated to just exporting raw feedstocks while importing refined SAF.

This disparity is particularly concerning given the immense capital investment required to scale SAF production. Projections by the World Bank indicate that scaling SAF globally will require annual greenfield investments of up to \$124 billion, culminating in over 370 SAF-producing facilities by the



late 2030s and early 2040s (Malina and others 2022). For context, a single 4,000-barrel per day (BPD) hydrotreated esters and fatty acids (HEFA)–based SAF facility requires \$200–\$300 million in upfront capital.¹ The size of this investment underscores the opportunity for developing countries to move beyond raw material exportation to becoming integral players in SAF production.

The stakes are particularly high for Africa. Locally produced SAF can reduce dependency on imported jet fuel, conserving foreign exchange reserves and stabilizing costs in a sector vulnerable to volatile global oil prices. SAF production also presents a significant opportunity to enhance energy security and drive economic resilience by creating value-added industries. Although the greatest environmental benefits of SAF are realized in local production and consumption, exporting SAF to foreign markets or selling through book-and-claim platforms presents an economic diversification opportunity for many African countries.² Without active integration into the SAF production chain, African countries risk missing out on these benefits, exacerbating their dependency on imports.

Despite its promise, SAF development in Africa faces significant challenges. The continent's aviation industry must contend with high production costs, limited infrastructure, and fragmented policy frameworks that hinder scalability. Jet fuel prices in Africa are about 17 percent higher than the global average, because of logistical inefficiencies, limited refining capacity, and risk premiums associated with currency volatility.³ Feedstock availability, while abundant in many regions, requires improved supply chain management to ensure consistent production at competitive prices. The cost disparity between SAF and conventional jet fuel underscores the need for targeted interventions. With coordinated policy support, international partnerships, and investments in infrastructure and technology, Africa has the potential to overcome these challenges and position itself as a global player in sustainable aviation practices.

Country Insights

This report identifies pathways for overcoming shared challenges and leveraging advantages to establish an SAF industry across the continent. Kenya, Ethiopia, Nigeria, and South Africa were chosen because of their strategic importance in Africa's aviation sector, abundance of an array of feedstocks, and varying infrastructure and policy levels. Kenya's emphasis on biofuel feedstocks such as used cooking oil (UCO), and castor together with strong renewable energy policy ambitions makes it vital for SAF development. Ethiopia's access to sugarcane and municipal solid waste (MSW) and its strong aviation presence highlight its potential. South Africa's industrial infrastructure and expertise in Fischer-Tropsch (FT) technology position it well for synthetic fuel (e-SAF) production using green hydrogen. Nigeria's jet fuel refining capabilities and proximity to major airports provide a logistical advantage for lipid co-processing. These countries exemplify Africa's SAF potential.⁴

¹ HEFA-based SAF—produced from feedstocks such as used cooking oil, tallow, and oil plants—has reached commercial scale and constitutes virtually all the SAF currently available on the market.

² A book-and-claim system is a chain-of-custody model that allows buyers to purchase SAF credits without physically receiving the fuel, enabling decarbonization even in locations where SAF is not available. This system promotes SAF market growth by incentivizing production while allowing airlines and companies to claim environmental benefits through a certified tracking mechanism (ICAO 2022b).

³ Fuel—airlines' largest cost—is often distributed by cartel-like entities on the continent that squeeze cash out of airlines. It needs to be transported over long distances, as a quarter of countries on the continent are landlocked, a problem exacerbated by poor infrastructure (Abate and others 2022).

⁴ These countries must explore multiple SAF pathways and feedstocks, as the examples provided, though based on realistic local market data, are not definitive.



Investment Needs and Production Costs

The report outlines the investment needs and potential economic benefits of establishing SAF production facilities in the four countries (table ES1). Each country's unique resources and infrastructure are considered, in order to highlight viable pathways for SAF development and their respective impacts on local economies and jet fuel demand:

- **Kenya:** A 4,000-BPD HEFA plant producing SAF from UCO and castor oil requires an estimated investment of \$235 million. This facility could meet 15 percent of Kenya's current jet fuel demand and 10 percent of its projected demand in 2030.
- **Ethiopia:** An investment of \$376 million in ATJ for 1,445 BPD of SAF would meet 6 percent of jet fuel demand. 2,000-BPD MSW-FT facility requires a significantly higher investment (\$547 million) but offers higher production capacity, potentially meeting 4 percent of the projected jet fuel demand and 1.2 percent of projected diesel demand in 2030.
- **Nigeria:** Co-processing offers a cost-effective approach to SAF production in Nigeria, leveraging existing refinery infrastructure.⁵ The Dangote refinery, with a capacity of 650,000 BPD, or other refineries in the country could produce 3,321–5,950 BPD of SAF through co-processing.
- **South Africa:** A 1,000-BPD power-to-liquid (PtL) facility using green hydrogen and industrial waste carbon requires an investment of \$156 million. It could produce 39 million liters of SAF annually, meeting about 3 percent of South Africa's jet fuel demand. The investment costs for the PtL facility do not include the cost of green hydrogen production, which could amount to several billion dollars for a large-scale facility.

The techno-economic analyses present promising pathways, such as FT from municipal solid waste and alcohol-to-jet (ATJ) from sugarcane and molasses. However, these pathways are at a low technology readiness level, consequently introducing uncertainty into the results.⁶ The gasification of biomass or MSW and the subsequent FT conversion process involve complex steps that can create operational challenges, such as managing syngas impurities that can affect catalyst efficiency. ATJ solutions are also uncertain related to the scale-up and optimization of dehydration, oligomerization, and hydrogenation processes using specific African feedstocks. These risks may affect the feasibility and investment decisions for entities other than very large corporations with substantial technical and financial resources. Further research and development, along with pilot projects, will be crucial to mitigate these uncertainties and ensure the successful deployment of these SAF production technologies in the African context.

⁵ Recent estimates suggest that maximizing global co-processing could save up to \$347 billion in capital investments by 2050 (IATA 2024). Deep decarbonization will eventually require shutting down fossil fuel-based petroleum refineries, making co-processing a short- to medium-term solution.

⁶ Capital expense (CAPEX) estimates for ATJ and FT production pathways are derived from techno-economic modeling and nth plant assumptions, which introduces inherent uncertainty in projecting actual deployment costs at scale in Ethiopia, Kenya, Nigeria, and South Africa. Factors such as the novelty of large-scale SAF projects, potential feedstock variability (particularly for MSW), and unforeseen logistical or infrastructure challenges could affect final capital expenditures. The CAPEX figures provided should therefore be considered preliminary estimates that may vary in real-world project implementation.



Table ES.1. Production technology, feedstock, favorable contextual aspects, and potential cases of SAF use in four African countries

Country	Production technology	Feedstock	Favorable contextual aspects	Potential cases
Kenya	Hydroprocessed esters and fatty acids (HEFA)	Used cooking oil (UCO) and castor oil	- Existing petroleum infrastructure - Presence of a regional aviation hub (Nairobi) - Government commitment to energy transition - Expertise in fuel production and certification - Abundance of vegetable oils	Investment of \$235 million could supply 15 percent of current jet fuel demand, driving job creation and economic growth.
Ethiopia	Alcohol-to-jet (ATJ) and Fischer-Tropsch (FT)	Sugarcane/molasses and municipal solid waste (MSW)	- High jet fuel consumption because of the presence of an aviation hub - Favorable climate for sugarcane - Existing sugarcane facilities - Large quantities of MSW - Heavy reliance on imported jet fuel	Investment of \$376 million in ATJ for 1,445 BPD of SAF would meet 6 percent of jet fuel demand. Investment of \$547 million in FT for 853 BPD SAF would meet 4 percent of demand, reducing waste and fostering economic development.
Nigeria	Co-processing	Lipids (vegetable oils, waste oils, animal fats, soybean oil, UCO, tallow)	- Strategic Gulf of Guinea location - Existing refinery infrastructure - Jet fuel refining capabilities - Abundance of vegetable oils	Production of 3,321–5,950 BPD SAF could be made without major new investments, reducing import dependence and boosting agriculture and refinery utilization.



Country	Production technology	Feedstock	Favorable contextual aspects	Potential cases
South Africa	Power-to-liquid (PtL)	Green hydrogen and industrial waste carbon	• Expertise in FT technology • Ambitions for producing green hydrogen • Availability of industrial waste carbon • Development of “hydrogen valleys”	Investment of \$156 million, not including costs for green hydrogen, could supply 3 percent of jet fuel demand, drive economic growth, create jobs, and enhance role in low-carbon aviation fuels.

Source: Original table for this publication.

The deep dives on each country yield the following insights:

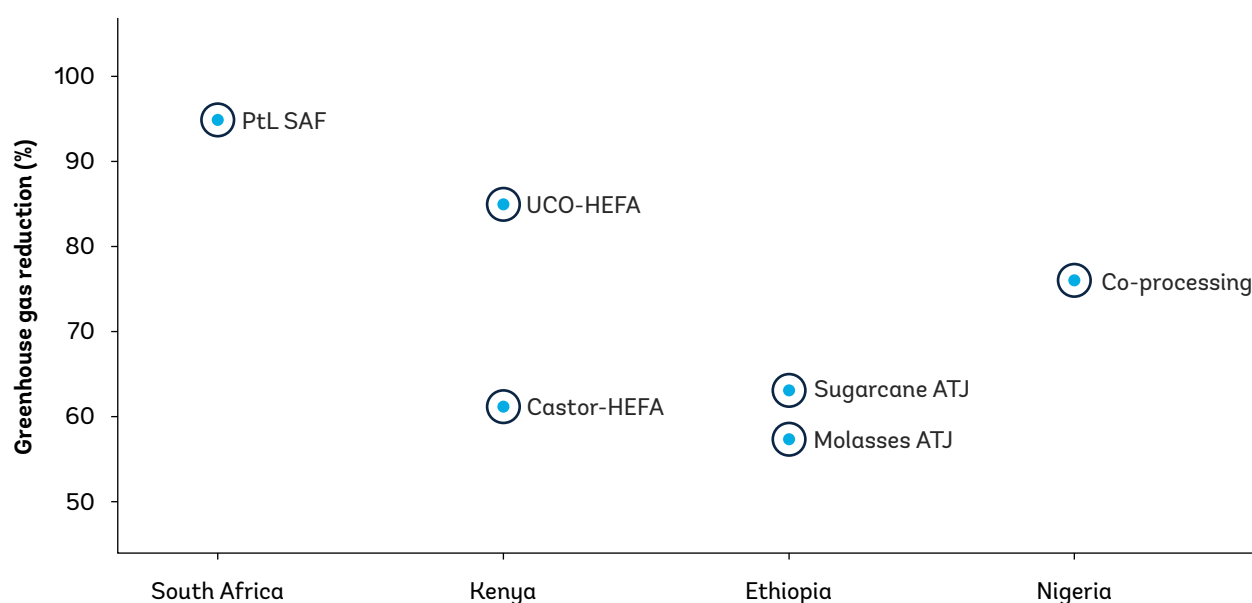
- Kenya has the potential to produce HEFA-based SAF using castor oil and UCO. Its existing infrastructure, including its petroleum pipeline network and Nairobi's role as a regional aviation hub, provides a strong foundation for SAF production. However, significant upfront investment—estimated at \$235 million for a 4,000-BPD plant—is required. Policy interventions such as accelerated depreciation, tax breaks, and loan guarantees are crucial to bridge the cost gap between SAF and conventional jet fuel. Kenya's strategic advantage lies in its government's strong commitment to decarbonization and the country's technical expertise in jet fuel production.
- Ethiopia's SAF potential is anchored by its large and concentrated jet fuel demand, driven by Ethiopian Airlines, the continent's largest carrier. The country's favorable climate for sugarcane production and access to MSW offer viable feedstock options for SAF production via alcohol-to-jet (ATJ) and FT pathways. Challenges include limited existing infrastructure and the need for significant investment in feedstock-processing facilities. Ethiopia's heavy reliance on imported jet fuel makes local SAF production a strategic priority for enhancing energy security and reducing operational costs for its aviation sector.
- Nigeria, one of the few Sub-Saharan African countries producing conventional jet fuel, can adopt lipid co-processing pathways. Proximity between major airports and refineries offers logistical advantages, and the scale of its aviation market ensures significant demand for SAF. However, fragmented domestic aviation and challenges in feedstock scalability may limit Nigeria's potential for SAF production at scale. The integration of SAF into existing refinery processes provides a cost-effective entry point for the country's SAF ambitions.
- South Africa's SAF strategy focuses on e-SAF production using green hydrogen and industrial waste carbon. The country's FT expertise and ongoing green hydrogen projects provide a strong technical foundation. However, the high costs associated with renewable energy and carbon capture technologies pose significant barriers. Despite these challenges, South Africa's ambition to develop export-oriented SAF corridors highlights its potential to become a regional SAF production hub, leveraging its industrial leadership and relatively mature infrastructure.



The Environmental Benefits of SAF

The environmental benefits of SAF pathways are substantial, with each country offering unique advantages (figure ES.1). In Kenya, UCO-HEFA achieves reductions of 83–88 percent in GHG emissions per unit SAF used, making it highly efficient; with careful land-use management, castor-HEFA delivers 58–61 percent reductions. It provides scalable, near-term benefits. Ethiopia's ATJ and FT pathways provide significant reductions, with MSW-FT potentially achieving carbon-negative emissions. Nigeria's co-processed SAF from UCO and tallow offers moderate reductions but necessitates sustainable palm oil sourcing to minimize land-use change emissions. South Africa's PtL SAF, which relies on renewable energy, aligns with global decarbonization goals, although its current coal-dependent grid may affect lifecycle emissions.

Figure ES.1. Projected reductions in greenhouse gas emissions in four African countries per unit of SAF used



Note: Power-to-liquid (PtL) SAF (e-SAF) in South Africa assumes renewable electricity. Co-processing in Nigeria assumes waste and residue lipids. No emissions from potentially induced land-use change were considered here.

Source: Original figure for this publication.

Risk and Green Premiums

The minimum selling price (MSP) of SAF is central to structuring projects, as it affects financial viability and investment decisions. The MSP is the price at which SAF must be sold for an investor to meet the expected rate of return (Brandt, Martinez-Valencia, and Wolcott, 2022). It is price at which the net present value of the refinery project equals zero. Investors use MSP to assess return on investment and project risk; governments use it to evaluate the effectiveness of SAF policies and incentives. The MSP also guides technology and feedstock choices, contract negotiations, and the likelihood of securing government support. Projects with a pathway to competitive MSPs are more likely to get funding, making MSP analysis critical in the pre-feasibility stage, especially when considering plant maturity and the use of incentives to lower MSP.



Two cost drivers affect the financial feasibility of SAF production in Africa: risk premiums and green premiums. Risk premiums arise from the higher capital costs associated with loan rates and discount rates, which are higher in African markets than in OECD countries. Green premiums, on the other hand, represent the additional cost associated with choosing a greener fuel alternative. The analysis of risk and green premiums in Kenya, Ethiopia, and South Africa highlights the critical challenges of narrowing the cost gap between SAF and conventional jet fuel.⁷ Investment de-risking can significantly lower SAF production costs, with estimated reductions of 24 percent in Kenya, 17 percent in Ethiopia, and 28 percent in South Africa if risk profiles match those of the United States and the European Union (figure ES.2). However, a substantial green premium persists across all countries, ranging from 47 percent in Kenya to 64 percent in Ethiopia and 69 percent in South Africa, driven by the higher global costs of SAF production compared with conventional jet fuel.

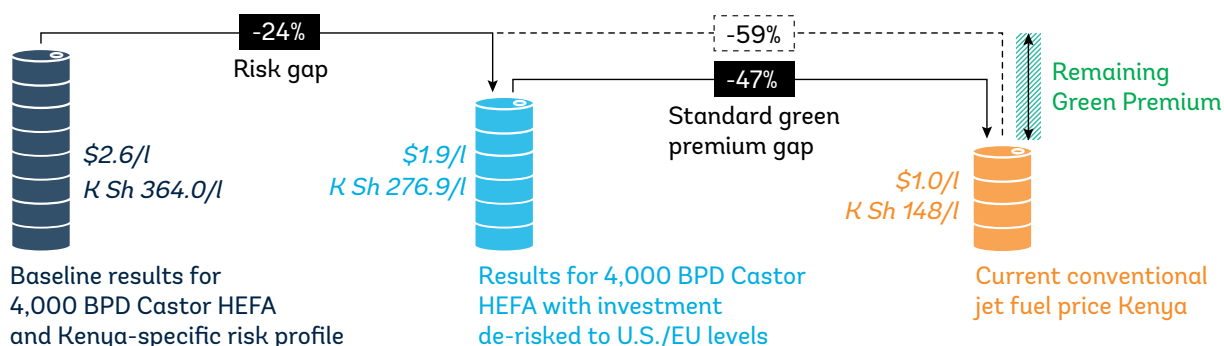
⁷ As co-processing does not require significant additional CAPEX, no de-risking analysis was conducted for Nigeria.



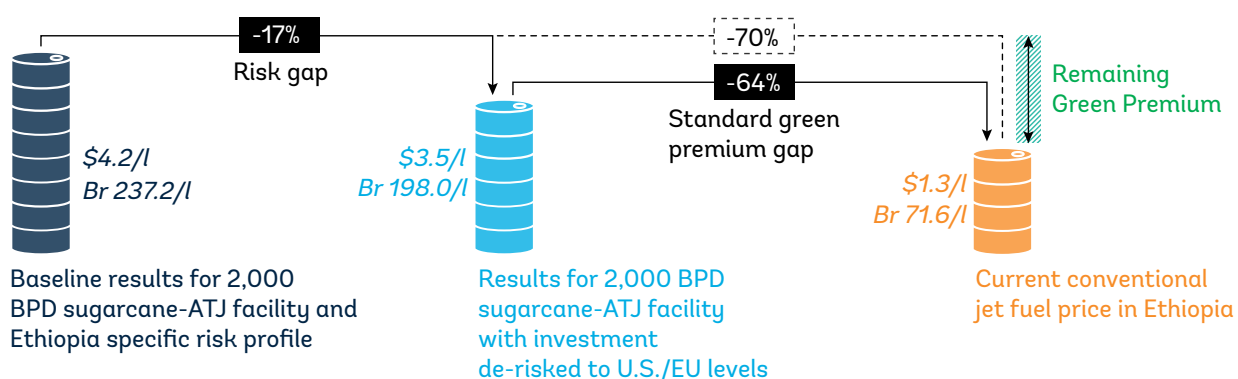


Figure ES.2. Risk and green premiums on SAF in Kenya, Ethiopia, and South Africa

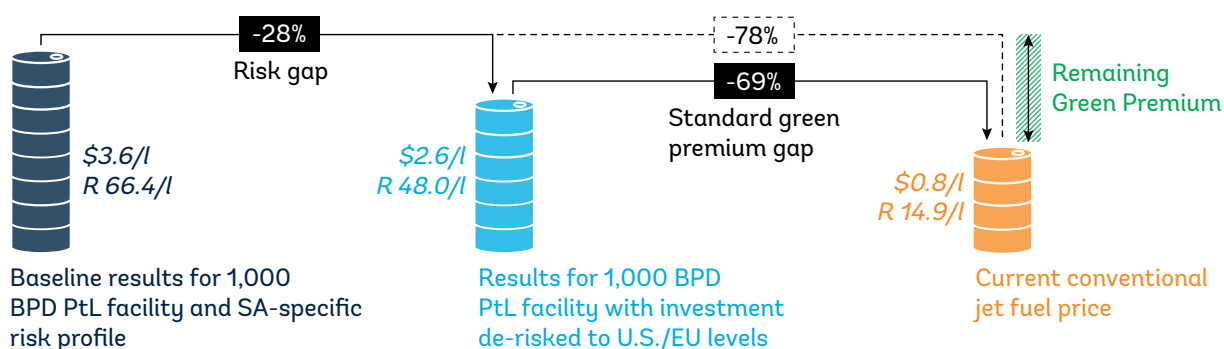
a. Castor-HEFA SAF, Kenya



b. Sugarcane-ATJ SAF, Ethiopia



c. Risk and green premium gap for e-kerosene, South Africa



Source: Original figure for this publication.

The report highlights the importance of addressing the risk and green premium gaps to reduce the costs of producing SAF in developing countries. Implementing measures such as financing agreements with development banks and using their de-risking instruments, offtake agreements with international airlines and original equipment manufacturers (OEMs), Scope 3 credit purchases



by corporates, and government commitments through tax incentives, expertise, and regulation could lower risk premiums.⁸ Reducing risk premiums to OECD levels would bring costs down significantly, but a cost gap with conventional jet fuel would still remain. Addressing this gap requires advanced technological improvements, low-cost hydrogen, and the leveraging of carbon markets and tax reforms.⁹

To provide a robust financial evaluation, this report includes a detailed sensitivity analysis examining the impact of variations in capital expenditure (CAPEX) and other key determinants of the MSP of SAF across the four African countries studied. This analysis accounts for uncertainties related to factors such as location-specific costs, loan and discount rates, feedstock prices, and the scale of production facilities. In Kenya, for instance, a sensitivity analysis demonstrated that repurposing existing refinery infrastructure (brownfield investment) could significantly reduce CAPEX and, consequently, the MSP of HEFA-based SAF. Economies of scale were shown to reduce the per unit CAPEX for SAF production in Ethiopia and South Africa. The estimated MSPs offer valuable insights into the economic feasibility of SAF production in Africa, but it is important to keep in mind that they are based on techno-economic modeling and rely on some proxy data because of data limitations.

Benchmarking against the current global average SAF price of approximately \$1.83 per liter reveals a cost gap that indicates the need for the supportive policies and de-risking strategies highlighted in this report. With such support, the countries analyzed could achieve cost levels comparable or below current SAF world-market prices (figure ES.3). These analyses provide an accurate financial evaluation within the context of these uncertainties, underscoring the need for continued efforts to optimize production processes and secure favorable investment conditions to achieve cost competitiveness with conventional jet fuel.

⁸ Development banks offer various de-risking instruments to support environmentally sustainable and climate friendly development projects, especially in emerging markets and developing economies. They include guarantees, political risk insurance, partial credit guarantees, and concessional finance. Blended finance combines public and private capital to reduce costs and risks. Currency hedging and technical assistance mitigate financial and project-related risks. Other instruments include loan loss reserves and reimbursable development loans to enhance project viability and attract investment. These instruments aim to improve the risk-reward profile and attract private capital (see OECD and World Bank 2024 for details).

⁹ For a comprehensive examination of strategies to promote SAF production through supply, demand, and policy levers, including policies to reduce risk premiums and address the green premium, see the report by the World Economic Forum (2021).

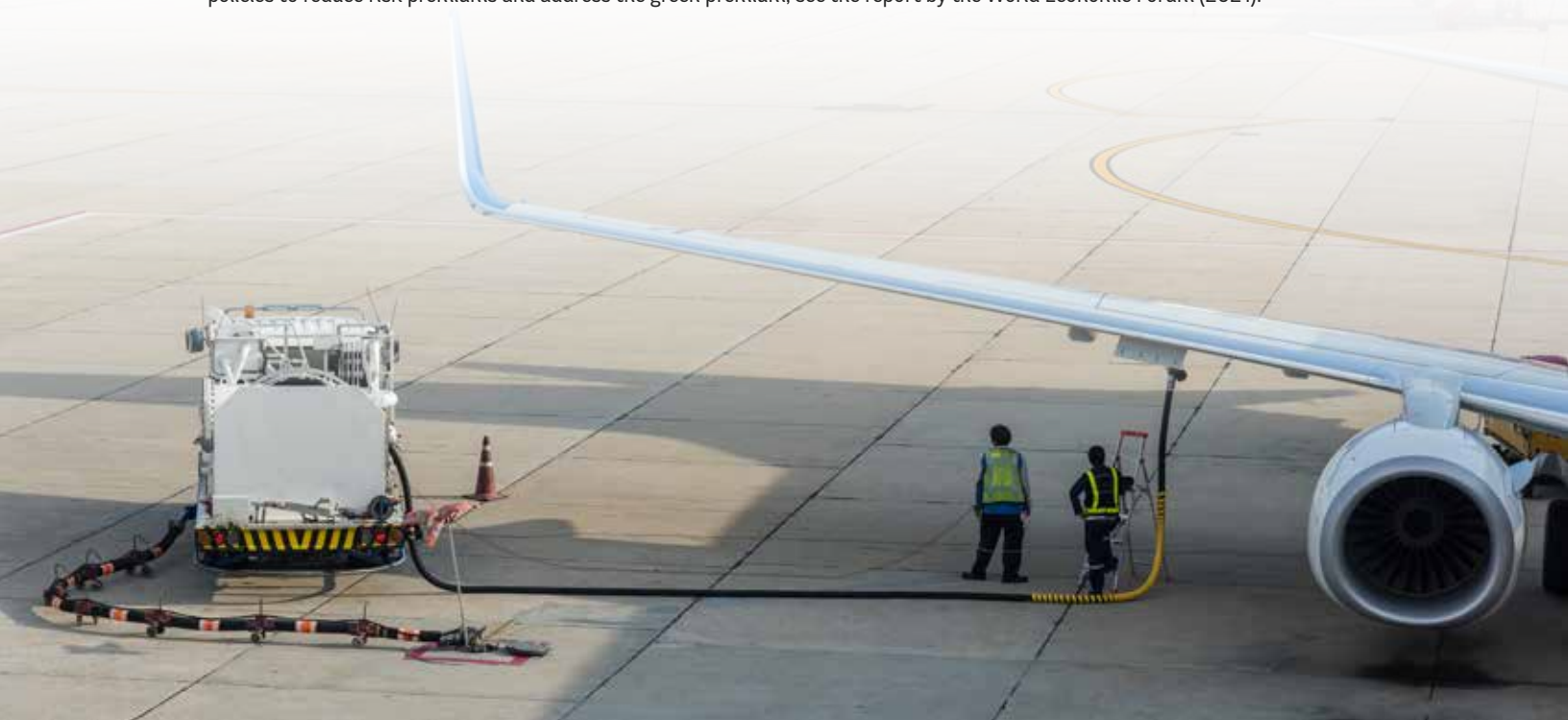
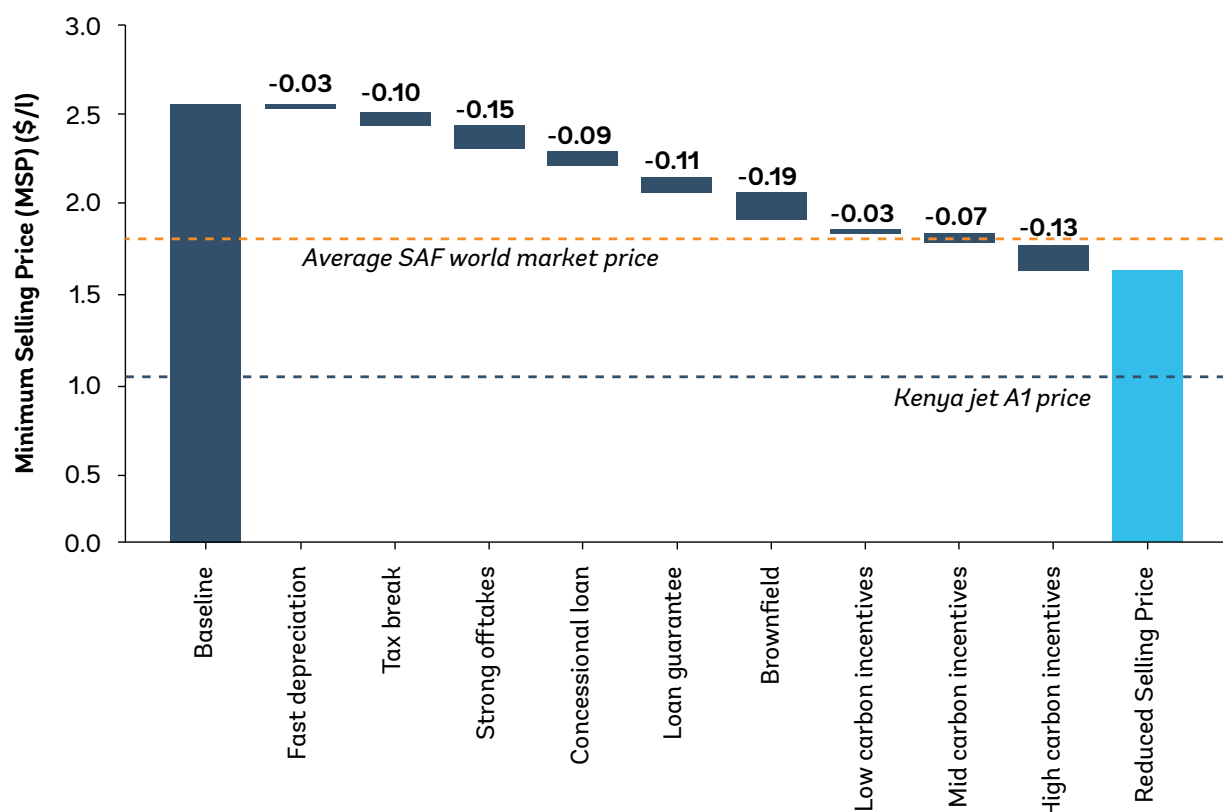




Figure ES.3. Impact of policy scenarios on the minimum selling price in Kenya of SAF produced using castor oil



Note: Figure is based on a 4,000-BPD fuel facility and the maximum jet product slate. The black dashed line shows the dual-purpose kerosene price in Kenya (\$1.04/l) and the red dashed line shows average world market price of SAF in 2024 (\$1.83/l), for comparison purposes. Global SAF prices are based on IATA (2024) data.
Source: Original figure for this publication.

Conclusion and Recommendations

Several important findings emerge from this report:

- Abundant feedstock—ranging from UCO in Kenya to sugarcane in Ethiopia and industrial waste carbon in South Africa—provides a diverse resource base for SAF production in Africa. Feedstock scalability remains a critical challenge, however, particularly in Kenya and Nigeria, where supply constraints could hinder long-term growth.
- Infrastructure readiness varies widely, with South Africa and Kenya benefiting from relatively advanced industrial and logistical networks and Ethiopia and Nigeria facing greater infrastructure deficits.
- All four countries grapple with high capital costs and elevated risk premiums, driven by macroeconomic factors such as currency volatility, limited access to affordable financing, and higher loan rates than in OECD markets.



- Kenya and South Africa emerge as leaders in infrastructure and policy readiness, with clear government commitments to SAF development and decarbonization. Ethiopia stands out for its concentrated aviation demand and feedstock diversity. Nigeria's existing jet fuel production infrastructure offers a distinct competitive edge. These differences underscore the need for tailored approaches to SAF development that account for each country's unique strengths and challenges.

Insights from this report underscore the continent's potential to establish a competitive SAF industry. By leveraging commonalities such as feedstock diversity and addressing shared challenges like risk premiums, African countries can collaborate to create regional SAF production hubs. Such collaboration could enable economies of scale, reduce production costs, and position Africa as an important global player in sustainable aviation.

The development of SAF in Africa is not just a national priority for individual countries but a continental imperative with the potential to transform aviation across the region. Local production of SAF is instrumental in mitigating future emissions associated with anticipated growth, reaping economic and energy security advantages, and positioning Africa within the evolving global landscape of sustainable aviation. Achieving this vision requires coordinated policy frameworks, robust financial support, and investment in infrastructure and technological capacity.

This report provides recommendations for policy interventions and private sector engagement to establish a thriving SAF industry in Africa:

- Feedstock management is crucial. Governments need to prioritize sustainable and cost-effective sources such as waste oils (UCO, tallow) and oilseed crops (castor, croton), which can be cultivated on marginal lands. Developing local supply chains for these feedstocks can generate rural employment and improve economic resilience while minimizing competition between food and fuel.
- Policy frameworks play a critical role in SAF adoption. Governments can introduce financial incentives such as tax breaks, grants, and streamlined permitting processes to attract investment.
- Gradual SAF blending mandates for airlines can create a stable market while reducing dependence on imports.
- Book-and-claim mechanisms allow international stakeholders to support SAF production by purchasing SAF credits, reinforcing global collaboration.
- Investing in research and development (R&D) through pilot projects and international partnerships can optimize SAF technologies, lower costs, and ensure equitable benefit distribution.

A comprehensive SAF roadmap is necessary to coordinate efforts, set clear production targets, and monitor progress while aligning with just transition plans to boost local employment and economic benefits. Expanding renewable energy capacity to support e-SAF pathways, ensuring that electricity for green hydrogen production comes from new renewable sources, is also critical.

Private sector engagement is essential for driving demand. Airlines and corporations are encouraged to enter offtake agreements, invest in SAF production, and support infrastructure development.



Development support from multilateral development banks and development finance institutions can help de-risk projects through concessional loans, grants, and innovative financing models such as blended finance and risk-sharing instruments, making SAF investments more attractive. Addressing the green premium through de-risking instruments like loan guarantees and political risk insurance can enhance project bankability. Strengthening public-private partnerships and leveraging international collaboration will be instrumental in scaling SAF production, reducing aviation emissions, improving energy security, and fostering economic growth.

In all countries, transport and logistics infrastructure play an important role in SAF production by enabling efficient feedstock collection, cost-effective processing, and seamless fuel distribution to airports and export markets. Well-developed road, rail, and pipeline networks are essential for transporting raw materials such as used cooking oil, sugarcane, and municipal solid waste to SAF production facilities, reducing supply chain inefficiencies. Modernizing aviation fuel infrastructure at key airports and integrating SAF into existing fuel distribution systems would accelerate adoption and reduce operational costs. Strengthening regional connectivity and export logistics could position African countries as players in the global SAF market, enhancing energy security and fostering economic growth.

In the short term (one to three years), efforts should focus on sustainable feedstock management, financial incentives, supportive policy frameworks, and demand stimulation through book-and-claim mechanisms and offtake agreements. It is also crucial to undertake a full cost-benefit analysis to build a comprehensive case for the widespread adoption of SAF production in Africa. This report provides a techno-economic evaluation and highlights the sensitivity of SAF economics to various factors. A broader analysis should encompass the significant macroeconomic benefits that these industries could generate in each country, including job creation across the value chain; contributions to GDP growth through new industries and supply chains; enhanced energy independence, by reducing reliance on imported fossil fuels; and potential for rural economic development, through additional feedstock sourcing. Recognizing these potential national-level advantages would provide additional motivation for governments to consider implementing supportive policies, such as tax breaks or other financial incentives, and engaging in strategic policy measures at the country level to foster the SAF sector.

The medium term (three to seven years) should prioritize a continental SAF roadmap, R&D investment, carbon pricing mechanisms, and renewable energy expansion to reduce costs and improve feasibility. Over the long term (more than seven years), Africa must establish robust certification systems, integrate SAF into broader decarbonization strategies, strengthen public-private partnerships, and leverage innovative financing models to scale production and position the continent as an important player in sustainable aviation supply and value chain.



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Unlocking Africa's potential for Sustainable fuel production



Global projections by the International Civil Aviation Organization suggest that developing countries will play a major role in Sustainable Aviation Fuel (SAF) production. Four African nations — Kenya, Nigeria, Ethiopia, and South Africa — show strong potential due to abundant feedstock, existing infrastructure, and rising demand. The report *Fueling Africa's Flight: A Techno-Economic Assessment of Sustainable Aviation Fuels in Africa* explores the prospects, challenges, and opportunities of SAF development across these countries.

The global picture

\$124 billion

Investment needed to scale SAF production globally

\$200-\$300 million

Upfront capital needed for a single SAF facility producing 4,000 barrels per day (BPD)

Benefits of SAF production in Africa

- Economic diversification through foreign export
- Sustainable transition for Africa's rising passenger aviation

Four main challenges



1 High capital costs



2 Elevated risk premiums and green premiums



3 Feedstock scalability



4 Infrastructure and policy readiness

Four countries, four opportunities

SAF production potential in these countries is shaped by diverse feedstock availability, strong local and international demand, and opportunities for scalable, sustainable fuel development.

1

The potential:

A 4,000-BPD hydrotreated esters and fatty acids (HEFA) plant using used cooking oil and castor oil could supply 15 percent of Kenya's current jet fuel needs and 10 percent of its projected 2030 demand.

Kenya



Challenges

Requires significant upfront investment
Requires policy interventions such as accelerated depreciation, tax breaks, and loan guarantees

Opportunities

Strong potential for HEFA-based SAF production, supported by existing infrastructure, technical expertise, and government decarbonization efforts.
Strategic advantage from Nairobi's role as a regional aviation hub.

Investment needed:

\$235 million

2

Ethiopia



The potential:

A 2000 BPD facility producing 1445 BPD SAF meets 6% of jet fuel demand.

Challenges

Limited existing infrastructure
Requires significant investment into feedstock-processing facilities
Existing reliance on imported jet fuel

Opportunities

High demand for jet fuel driven by large airline carriers
Diverse feedstock options such as sugarcane and municipal solid waste (MSW) for SAF production

Investment needed:

\$376 million

3

Nigeria



The potential:

Through cost-effective co-processing, the Dangote refinery or others could produce 3,321–5,950 BPD of SAF.

Challenges

Low feedstock scalability

Opportunities

Logistical and spatial advantages such as proximity between major airports and refineries
Significant demand for SAF due to the scale of its aviation market

4

South Africa



The potential:

A 1,000-BPD PtL facility using green hydrogen and industrial waste carbon could yield 39 million liters of SAF annually, covering about 3 percent of the country's jet fuel demand.

Challenges

High investment and processing costs

Opportunities

High potential to become an SAF hub
Existing technical foundation and expertise in the Fischer-Tropsch process for production

Investment needed:

\$156 million

(excl. cost of Green Hydrogen)

Recommendations: Rather than a one-size-fits-all approach, this report makes a case for a tailor-made approach to SAF production development in Africa.



Manage feedstock by prioritizing sustainable and cost-effective sources.



Invest in R&D through pilot projects and international partnerships.



Develop policy frameworks by introducing financial incentives like tax breaks and grants.



Reduce investment risk by leveraging support from multilateral development banks and other financial institutions.



Leverage book-and-claim mechanisms to incentivize decarbonization efforts to international stakeholders.



Scale production by strengthening public-private partnerships.

01

Introduction

With projections of doubling passenger aviation by 2043, Africa is primed to switch to Sustainable Aviation Fuels (SAF) production. This chapter examines the opportunities and challenges of SAF production in Africa through case studies in Kenya, Ethiopia, Nigeria and South Africa.





Africa's aviation industry faces the dual challenge of reducing its carbon footprint while experiencing rapid growth, as passenger traffic is projected to double over its 2023 level to 340 million by 2043 (IATA 2024b). Sustainable aviation fuels (SAF) offers a critical pathway to decarbonization. However, production must scale from 0.5 metric tons (Mt) in 2024 to 500 Mt by 2050—a 1,000-fold increase—globally amid high costs and jet fuel prices in Africa, which are higher than global average (IATA 2024a). Addressing cost disparities and understanding factors that drive them, including risk and green premiums, is crucial for promoting SAF adoption. With abundant feedstock and the potential to reduce reliance on imported jet fuel, SAF can drive sustainability while enhancing intra-African connectivity, trade, and economic growth, transforming the continent's aviation landscape.

This study examines the feasibility of producing SAF locally in four African countries: Ethiopia, Kenya, Nigeria, and South Africa. It employs techno-economic analysis to explore how to reduce the cost difference between SAF and conventional jet kerosene, focusing on managing risks and addressing the higher selling prices of SAF. These higher prices stem from increased risk premiums from investing in infrastructure projects in Africa and a green premium, representing the extra cost associated with green fuel alternatives. The study also evaluates the potential of SAF to significantly reduce carbon emissions.

The SAF Opportunity and Challenge

SAF is the term used by the aviation industry to describe a set of fuels that can be sustainably produced, generate lower greenhouse gas (GHG) emissions than conventional kerosene on a life-cycle basis, and be blended with conventional jet fuel for use in traditional fueling and aircraft systems.¹⁰ It plays a critical role in achieving net-zero emissions for the aviation industry, offering benefits to all industries by reducing reliance on fossil fuels and promoting a transition to renewable energy sources (IATA 2024c). According to a World Bank study (Malina, Abate, Schlumberger, and Navarro Pineda 2022), with ambitious SAF adoption driven by industry commitments and strong policy support, aviation's lifecycle GHG emissions could be reduced by 57 percent by 2050 compared with a business-as-usual scenario. Over 85 percent of current SAF production plans and offtake agreements are from companies based in Organisation for Economic Co-operation and Development (OECD) countries, however, which account for less than 60 percent of total air traffic.

The absence of SAF production announcements in non-OECD countries does not reflect the lack of sustainable feedstock. Non-OECD countries have an estimated annual SAF feedstock production potential equivalent to 510 million tons, with about two-thirds derived from non-food sources (Malina and others 2022).

SAF presents a promising opportunity to address the issues confronting the African aviation sector. By decreasing reliance on imported jet fuel, local production of SAF could help conserve foreign exchange reserves, stabilize fuel costs, and enhance energy security through local production. It offers environmental benefits, by reducing carbon emissions and supporting compliance with international standards. Developing a local SAF industry could stimulate economic growth, create jobs, and position Africa as an important part of sustainable aviation value chains.

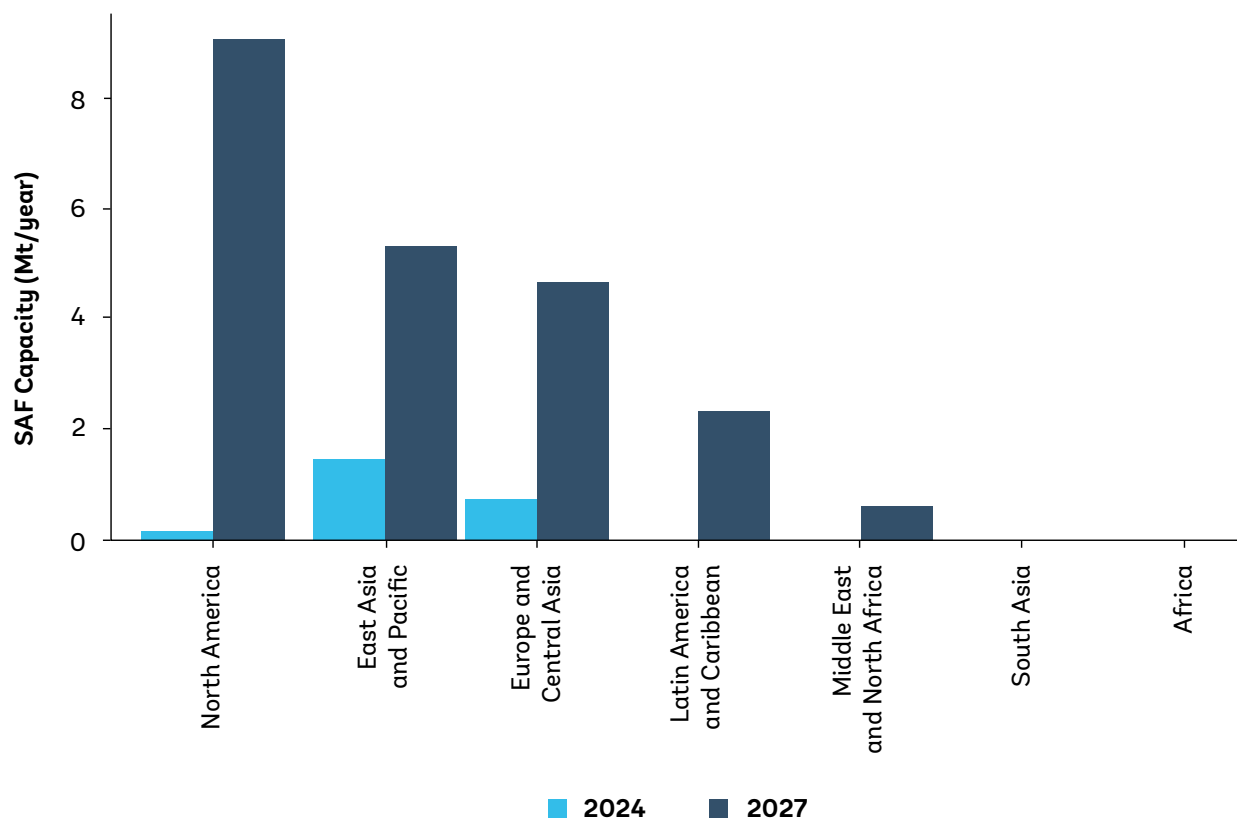
¹⁰ See appendix A for brief background on SAF. Malina and others (2022) provide detailed background.



In 2024, most SAF production capacity was concentrated in high-income regions like North America, Europe, and East Asia; Africa, the contributions of Latin America and other lower-income regions were negligible (figures 1.1 A and 1.1 B). By 2027, global SAF capacity is projected to grow significantly. High-income countries are projected to produce 19.8 Mt/year and upper-middle-income countries 1.98 Mt/year. Africa, the Middle East, and low-income regions are expected to see little to no growth, highlighting the stark geographic and economic disparity in SAF development.

Figure 1.1. Installed and announced capacity

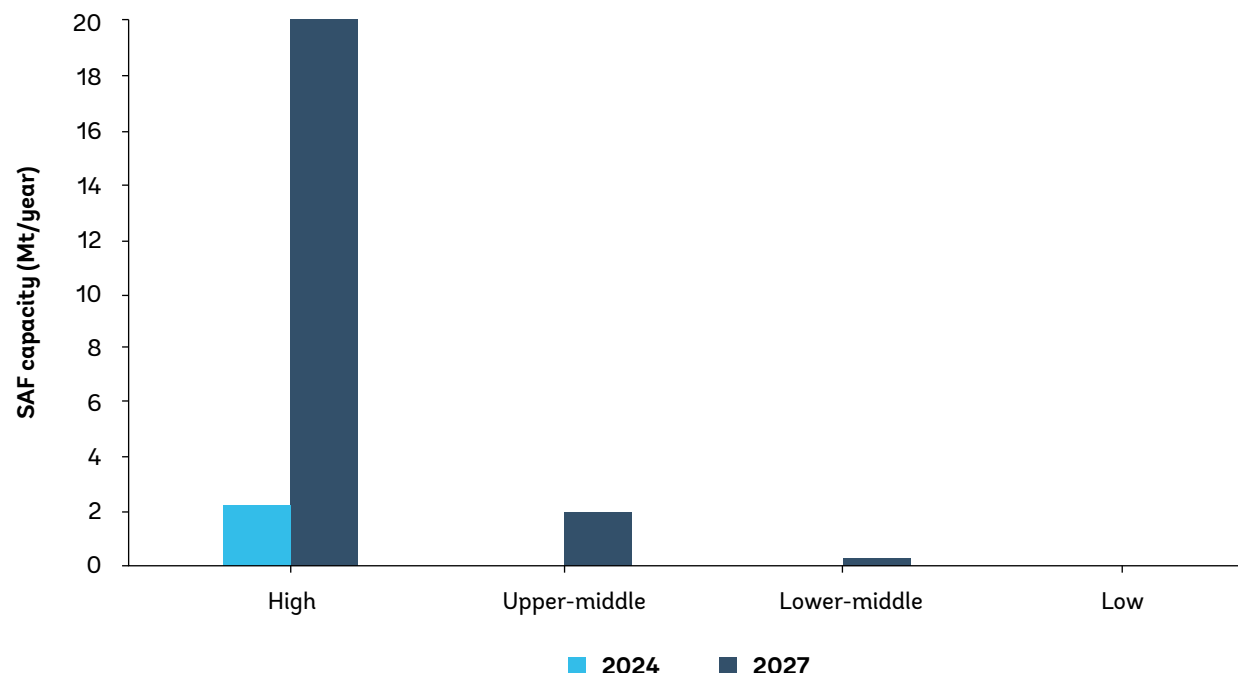
A. Installed SAF capacity in 2024 and announced capacity by 2027, by region



Note: The figure is based on analysis of publicly available data on operational SAF facilities and announcements of planned SAF facilities in millions of tons per year. It includes only concrete announcements of facilities at specific locations. In cases where only total production was provided, SAF output was estimated using the following assumptions about the SAF product share: Hydrotreated esters and fatty acids (HEFA): 0.51; co-processing: 0.1; alcohol to jet: 0.7; Fischer-Tropsch: 0.57, power to liquid: 0.47, catalytic hydrothermolysis: 0.4. Mt = million tons.



B. Installed SAF capacity in 2024 and capacity announced to be operational by 2027, by income

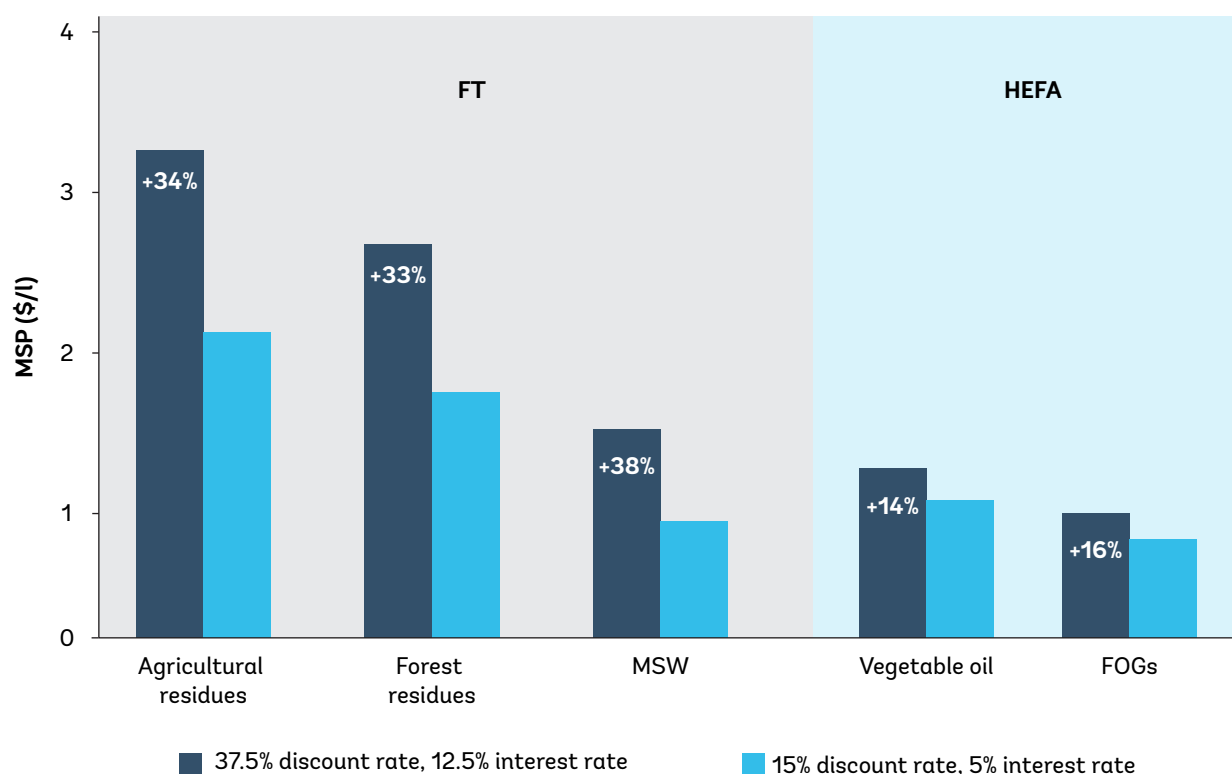


Note: The figure is based on analysis of publicly available data on operational SAF facilities and announcements of planned SAF facilities capacity in millions of tons per year. It includes only concrete announcements of facilities with location. In cases where only total production is provided, SAF output was estimated using the following assumptions about the SAF product share: Hydrotreated esters and fatty acids (HEFA): 0.51; co-processing: 0.1; alcohol to jet: 0.7; Fischer-Tropsch: 0.57, power to liquid: 0.47, catalytic hydrothermolysis: 0.4. Mt = million tons.
Source: Original figure for this publication.

Developing countries and emerging economies are underrepresented in SAF production plans for several reasons, including the higher capital costs (because of higher risk premiums) and the lack of sufficient economic incentives for the production or uptake of SAF. Malina and Abate (forthcoming) quantify the impact of higher risk premiums on the economics of SAF production (figure 1.2). They find that for capital-intensive technologies, such as Fischer-Tropsch (FT) gasification, the selling price is about a third higher for SAF produced in non-OECD-countries with a credit rating of B-than it is for SAF produced in the United States or the European Union; for less capital-intensive technologies, such as SAF made from hydroprocessed esters and fatty acids (HEFA), the selling price increases by about one-sixth. These figures are not the net difference in selling prices between these two groups of countries, as other country-specific differences in operating expenses and capital expenses, such as differences in the costs of feedstocks, utilities, and construction and labor, also affect the SAF selling price. The importance of many of these factors differs by production technology.



Figure 1.2. SAF minimum selling price of selected feedstocks at various discount rate/interest rate combinations



Source: Own calculations based on publicly available DCFROR models for SAF (Hydroprocessed esters and fatty acids TEA V2.2 developed by Kristin Brandt et al. 2022, Fischer Tropsch TEA V2.2 developed by Kristin Brandt et al. 2022)
Key Assumptions: Equity/loan split: 70/30, Duration 20 years, inflation: 2%. Discount rate and loan interest assumed as mentioned above. No monetary incentives included.
FOG: Fats, Waste Oils and Greases
MSW: Municipal solid waste.

High jet fuel costs, inefficient logistics, and economic constraints, pose a significant barrier to the growth and development of Africa's air transport sector. Africa faces additional challenges, such as minimal refinery capacity (just 3.8 percent of global capacity), which is unlikely to see significant expansion by midcentury (IATA 2024a). African airlines also face jet fuel costs that are 17 percent higher than the global average, increasing the financial burden in an operating environment already strained by high fixed costs, skilled workforce expenses, and the need to make payments in hard currencies.¹¹ These high fuel costs significantly hinder the growth of the air transport sector in Sub-Saharan Africa, where many countries rely on imported jet kerosene and grapple

¹¹ In addition to the high cost of fuel, running an airline in Africa involves substantial financial overheads because of the region's high operating costs and credit-constrained environment. Airline operators face significant infrastructure fees, charges, taxes, and above-average costs for fuel and ticket distribution. Other factors making operations in Africa more expensive include borrowing costs, which are markedly higher in many parts of the continent (10-year government bond yields can reach as high as 30 percent in Ghana, 20 percent in Nigeria, 17 percent in Kenya, and 10 percent in South Africa) (Abate and Others 2022). Ticket taxes and charges vary widely across the continent, further inflating travel costs in some countries and contributing to the overall financial burden of operating flights within and from Africa (Button and other 2019; Heinz and O'Connell 2013).



with additional costs because of inefficient transport logistics and currency volatility.¹² Fuel costs account for a substantial portion of operating expenses (more than 40 percent) for major carriers like Ethiopian Airlines. In addition, a quarter of countries in Sub-Saharan Africa are landlocked and have underdeveloped infrastructure, severely restricting the potential for air connectivity to foster economic and developmental benefits such as regional integration and increased tourism and foreign direct investment (Abate 2016).

Scaling up SAF production requires greenfield plant investment of up to \$124 billion a year (Malina and others 2022). This level of investment would facilitate the establishment of over 370 SAF-producing facilities during the peak years in the late 2030s or early 2040s—a period coinciding with the highest growth in SAF production. Although the SAF industry is still nascent, substantial volumes are expected to become operational in the coming years. Market share must increase from 0.5 percent in 2024 to more than 90 percent by midcentury for the aviation sector to achieve the sector's net-zero goals (IATA 2024a).

The International Civil Aviation Organization (ICAO) projects that a significant portion of SAF will come from developing countries and emerging markets, which have abundant biogenic feedstock and high renewable energy potential (ICAO 2022). The lack of integration of these markets into the SAF supply chain poses significant challenges, however, potentially relegating developing countries to exporting feedstock while importing SAF. This scenario underscores the need for developing countries and emerging markets to play a more active role in the aviation sector's energy transition, which presents a significant opportunity to enhance national energy security and resilience. To capitalize on this opportunity, innovative and ambitious national energy strategies are required, supported by robust policy implementation and financing mechanisms. Policy support is crucial to attract investments and incentivize production. Options include tax credits for SAF blender production, revenue certainty mechanisms, grants, and low-interest loans. Co-processing (integrating bio-based materials into existing refineries) presents a viable short-term solution to increasing SAF production without extensive new plant construction (IATA 2024a).

Scope of Analysis

This study estimates the costs of production in four Sub-Saharan African countries for a set of SAF conversion technologies that are already commercialized or are currently being commercialized (figure 1.3). The report presents a deep dive on Kenya, based on HEFA production from castor oil, followed by three country cases (Ethiopia, South Africa, and Nigeria) that leverage insights from the Kenya deep dive with regard to the effect of policies in driving down SAF selling prices. The country cases cover five SAF production technologies that account for more than 95 percent of current and planned production capacity globally.

¹² Africa, which is highly dependent on imported oil, stands to gain significantly from a 20 percent decrease in global oil prices, according to IATA (2024b). Such a reduction could increase economic growth and improve the financial stability of oil-importing countries, thereby benefiting the African aviation industry. The report projects continued demand growth for African airlines and a modest net profit margin of 0.9 percent in 2025, despite high operational costs, low air travel expenditure, and a shortage of US dollars.



Technologies Analyzed

SAF is the term used to describe a set of fuels made from biomass, renewable electricity, or fossil waste carbon that can be blended with conventional, petroleum-derived jet fuel to be used within the existing aircraft fuel system, both on the ground and in aircraft. This report describes five production routes for SAF, all of which have been approved by the American Society for Testing and Materials (ASTM) International for use as a blend in aircraft engines:¹³

- **Hydroprocessed esters and fatty acids (HEFA):** HEFA SAF is produced through the hydroprocessing of vegetable oils (waste or virgin) or animal fats. Significant cost reductions in the technology for producing HEFA are unlikely in the coming years, because of its mature state and rising feedstock costs, driven by increased demand. Sustainability challenges associated with purpose-grown oil-yielding plants limit the potential for scaling HEFA production by 2050. HEFA is allowed to be blended up to 50 percent with conventional jet fuel.¹⁴
- **Alcohol to jet:** The alcohol to jet (ATJ) pathway involves converting ethanol—typically derived from renewable biomass sources such as sugarcane or corn—into SAF through a series of chemical processes, including dehydration, oligomerization, and hydroprocessing. Bioethanol, which is already widely produced, could be quickly redirected to scale up SAF production through 2030. Local processing of biomass into alcohol facilitates larger-scale centralized production, leading to further cost savings. All necessary technologies are well understood and have already been implemented at industrial sites. ATJ is allowed to be blended up to 50 percent with conventional jet fuel.¹⁵
- **Fischer-Tropsch (FT) jet fuel:** The FT pathway involves converting syngas—which can be derived from various feedstocks, including various types of biomass or municipal solid waste (MSW)—into liquid hydrocarbons through a catalytic process. The technologies for SAF production are well understood; scaling could lead to cost improvements. A major cost factor is the selection and energy content of the feedstock, which typically necessitates smaller, decentralized production. However, preprocessing biomass near the source can facilitate larger, centralized SAF production sites. FT jet fuel is allowed to be blended up to 50 percent with conventional jet fuel.¹⁶
- **Power to liquid (PtL) via FT:** The PtL pathway—often called the e-SAF pathway—involves using renewable electricity to generate hydrogen through electrolysis, which is then combined with CO₂ captured from industrial point sources or directly from the atmosphere to produce syngas. This syngas is subsequently converted into liquid hydrocarbons using the FT process. A major cost driver in SAF production is the affordability and accessibility of large amounts of renewable energy. Affordability depends largely on local conditions and policies, making the strategic placement of production facilities essential. Although electrolysis and direct air capture (DAC) are emerging technologies that may see significant capital expenditure savings in the coming decades, PtL is currently the most expensive option. By 2030, green SAF export corridors are expected to emerge, serving global demand from the most competitively priced production sites.¹⁷ e-SAF produced via the FT process is allowed to be blended up to 50 percent with conventional jet fuel.

¹³ ASTM International sets standards, such as ASTM D7566, to ensure that SAF meets safety, performance, and environmental requirements. These standards enable SAF to be blended with conventional jet fuel and integrated seamlessly into aviation operations.

¹⁴ Companies producing HEFA include Neste, World Energy, Total Energies, and Sinopec.

¹⁵ Companies developing SAF via this route include LanzaJet and Gevo.

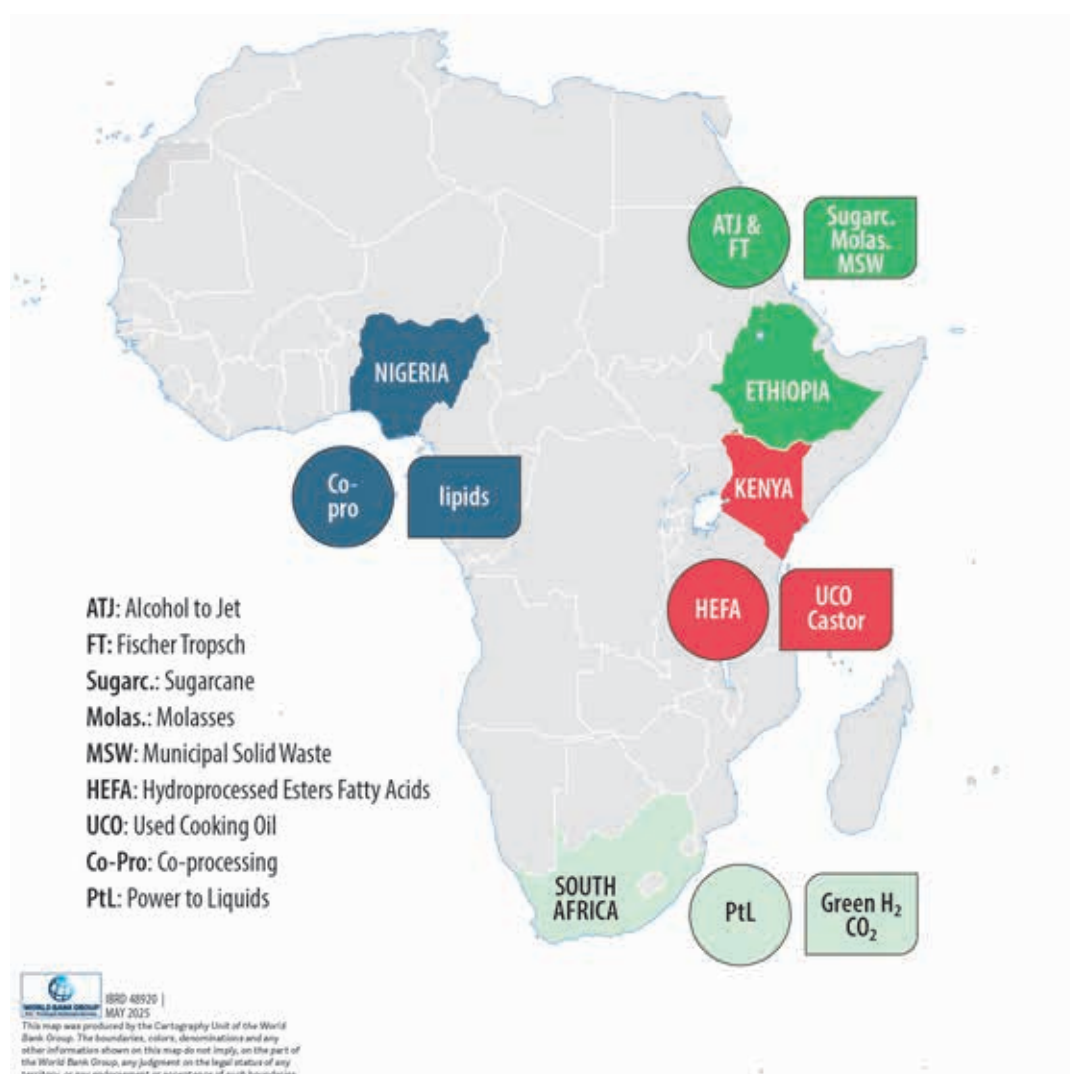
¹⁶ Companies developing this pathway include Sasol and Velocys.

¹⁷ Companies developing E-SAF projects include Norsk E-Fuel, Twelve, Sosal, and HIF Global.



- Lipid co-processing:** Lipid co-processing of SAF entails integrating lipid feedstocks, such as waste or virgin oils or animal fats, into existing petroleum refinery infrastructure. The biomass feedstocks are co-processed with fossil feedstock into liquid fuels, part of which is then considered SAF. Co-processing biogenic feedstocks like lipids and biocrudes in existing petroleum refineries offers a quick and effective way to boost production of drop-in, low-carbon fuels. Although this approach can yield large volumes, it demands substantial volumes of biogenic feedstocks. Lipid co-processing is currently limited to 5 percent bio-feedstock inserted into a refinery.^{18,19}

Figure 1.3. Technology and feedstocks considered in Ethiopia, Kenya, Nigeria and South



Source: Original figure for this publication.

¹⁸ Companies producing co-processed SAF includes Repsol, Total Energies, OMV, and Philips 66.

¹⁹ The current limitation of lipid co-processing to a maximum of 5 percent bio-feedstock in petroleum refineries primarily reflects the constraints set by ASTM D1655. The restriction ensures that the final fuel products meet the stringent quality and performance standards required for aviation fuels. There is ongoing industry discussion about increasing this limit to 30 percent to enhance SAF production. Raising the co-processing limit could significantly boost the production of renewable fuels within existing refinery infrastructures (ICAO 2024).



Country Cases and Rationale, Feedstock Scope, and Technology Matching

Kenya, Ethiopia, Nigeria, and South Africa were selected based on an SAF investment decision framework crafted by the World Bank. Together these countries represent over 60 percent of Sub-Saharan Africa's pre-Covid-19 aviation passenger demand. They also offer favorable supply and policy environments for a renewable energy transition in Africa.

Kenya

Kenya was chosen for a deep dive on SAF production via the HEFA pathway using castor oil and used cooking oil as feedstocks. HEFA requires lipids as feedstocks. An East African country was selected because of ample availability of this feedstock category in the region. Within the region, Kenya was chosen because of its leadership in decarbonization ambition; knowledge and experience in producing jet fuel; and the role of Nairobi as a main economic center in the region, with headquarters of large companies and international organizations as well as Jomo Kenyatta International Airport, a regional hub with relatively high fuel uplift and the strong presence of international carriers.

Ethiopia

Ethiopia was chosen for the ATJ pathway from molasses and sugarcane and the FT pathway from MSW. Ethiopia is home to Ethiopian Airlines, Africa's largest carrier (by passengers carried, number of destinations served, fleet size, and revenue), which has substantial and highly concentrated demand for jet fuel. The country has favorable climate conditions for the production of sugarcane and, by extension, molasses and existing production facilities for both feedstocks. MSW is a feedstock of interest for Ethiopia, given the large quantities of waste in Addis Ababa that is currently landfilled and could be a low-cost source of feedstock for SAF production. MSW is particularly relevant for developing countries, which often fail to collect waste or dump it in landfills. Using the feedstock for SAF could help address health and environmental concerns of current waste management, as well.

Nigeria

Nigeria was selected for the lipid co-processing case study because it is one of the few Sub-Saharan African countries that produces conventional jet fuel. Co-processing can occur with various types of lipids; this report analyzes a generic mix of oils and fats. Although fragmented with regard to domestic carriers, Nigeria is a major African aviation market. The Murtala Muhammed International Airport—the largest airport in Nigeria in terms of jet fuel uplift, number of passengers, and international connections—is less than 100 km from the only refinery in Nigeria producing jet fuel.

South Africa

South Africa was selected as for the e-SAF pathway because it has relatively favorable cost conditions for green hydrogen and advanced industrial and governmental ambitions for producing it. It is known for its industrial leadership in FT conversion technologies and is developing several large-scale green hydrogen projects. It has relatively abundant industrial waste carbon at point sources that can be captured at relatively low costs and that can serve as low-cost entry into the e-SAF market. Although the aviation market has struggled in recent years, South Africa remains one of the largest aviation markets in Africa.²⁰

²⁰ South Africa's Revised Green Hydrogen Commercialization Strategy identifies SAF as a key future application of green hydrogen. The strategy highlights the HyShiFT project in Secunda, where Sasol, in collaboration with partners such as Enertrag, Linde, and Hydregen, is developing a project to produce SAF using green hydrogen and sustainable carbon sources, primarily targeting the export market. This initiative underscores the strategy's emphasis on leveraging green hydrogen to decarbonize the aviation sector through the production of sustainable fuels (Department of Trade, Industry and Competition 2024).



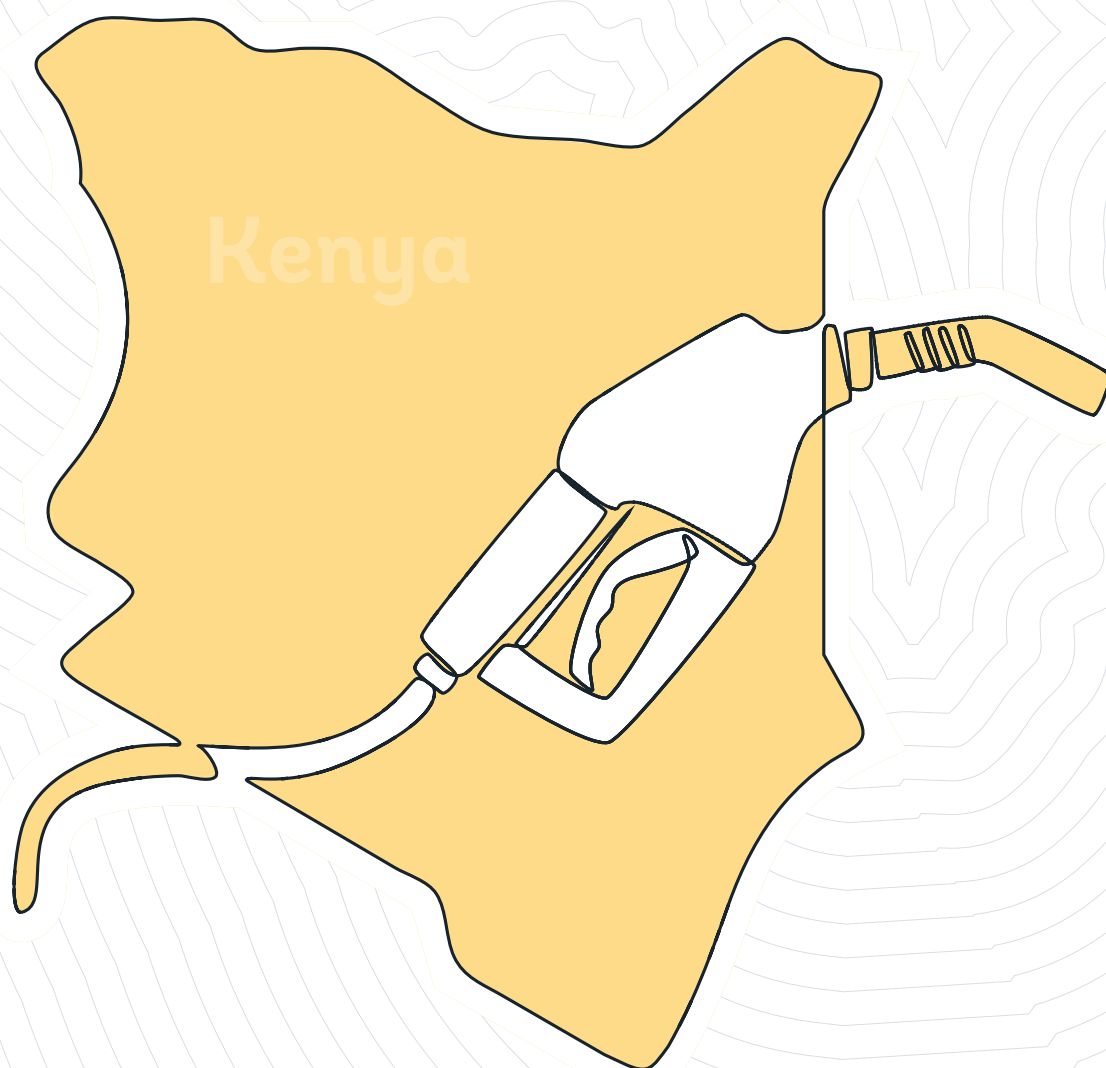
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02

Kenya Deep Dive

Kenya's position as a leader in decarbonisation and jet fuel production makes switching to SAFs an attractive proposition. This chapter analyses the feasibility of hydrotreated esters and fatty acids as alternative fuel sources in Kenya.





Overview

This chapter explores the feasibility of producing sustainable aviation fuel (SAF) in Kenya using the hydrotreated esters and fatty acids (HEFA) pathway with castor oil and used cooking oil (UCO) as feedstocks, leveraging the country's abundant lipid resources. Kenya's leadership in decarbonization, its expertise in jet fuel production, and Nairobi's role as a regional economic and aviation hub make it an ideal case for analysis.

Kenya has the potential to establish a thriving SAF industry. By leveraging its history in petroleum refining, expertise in fuel production and certification, strategic multiproduct pipeline connecting the Port of Mombasa to major airports, and strong government commitment to the energy transition, it could position itself to lead the region in SAF production and distribution. Realizing this vision requires addressing several challenges, however, primarily the substantial upfront investment needed to establish SAF production facilities and the persistent "green premium" associated with SAF compared with conventional jet fuel.

The chapter estimates that establishing a 4,000-barrel per day (BPD) HEFA facility in Kenya would require an investment of \$235 million. This facility could supply up to 15 percent of the country's current jet fuel demand and 10 percent of projected 2030 needs. However, the SAF industry faces a "risk premium," because of Kenya's higher capital costs and investment risks compared with developed markets. Scaling up production facilities significantly reduces capital expenses, with a 4,000-BPD plant achieving 27 percent savings over a 2,000-BPD facility, and a 6,500-BPD plant yielding even greater savings.

Feedstock selection plays a crucial role in cost-effectiveness and sustainability. UCO offers affordability and emissions benefits but faces supply constraints. Castor oil, which is native to Eastern Africa, presents a promising alternative but requires investment in large-scale cultivation. Optimizing production by maximizing distillate yield through catalytic cracking, and repurposing Mombasa's idle refinery could lower costs by 25–35 percent.

Policy interventions such as tax breaks and loan guarantees have the potential to significantly lower the minimum selling price (MSP) of SAF. However, uncertainties remain regarding the scalability of feedstock supply, particularly for UCO, which faces competition from other uses. The revival of large-scale castor oil cultivation requires investment and careful management of land-use change impacts. The MSP estimates are sensitive to capital expenses and discount rates, which are elevated because of the higher risk premiums in Kenya than in countries in the Organisation for Economic Co-operation and Development (OECD).

To develop Kenya's SAF industry, a collaborative effort by the government, the private sector, and international partners is needed. Policy measures include SAF uptake mandates, tax incentives, levies on international arrivals, and the leveraging of state-owned enterprises like Kenya Petroleum Refineries Limited (KPRL) and the Kenya Pipeline Company (KPC). Private sector engagement—particularly through long-term offtake agreements with airlines such as Kenya Airways and international carriers—is essential. Safari tourism could drive the adoption of premium SAF within Kenya; large corporations could support demand through Scope 3 carbon credit purchases. International collaboration, including partnerships with multilateral development banks and participation in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) could help secure financing and carbon credit incentives.



Description of Country Case

Aviation and the Economy

Kenya is the second-largest economy in East Africa (after Ethiopia), home to the continent's seventh-largest and region's second-largest airport, Jomo Kenyatta International Airport (NBO), a vital hub for Kenya Airways. The aviation sector plays a significant role in the country's economic development by enhancing connectivity and supporting tourism. It facilitates a large share of Kenya's agricultural exports and transports about 80 percent of its international tourists (Tourism Research Institute 2024). It employs about 410,000 people and contributes \$3.2 billion to GDP (4.6 percent of total GDP). By 2037, it is projected to boost its GDP contribution to \$11.3 billion and support nearly 859,000 jobs, underscoring its important role in Kenya's economic expansion and integration into the global market (IATA 2018).

Better air connectivity helps reduce poverty, through its effect on tourism. Njoya and Seetaram (2018) find that a 5 percent increase in tourist spending generates an average annual GDP increase of 0.24 percent. This growth benefits the poor through increased income and labor demand. Their findings suggest that tourism expansion leads to a fall in the poverty headcount and an even greater decline in the poverty gap and severity of poverty. Tourism thus improves income distribution among the poor and enables more households to move closer to the poverty line.

The aviation industry is a cornerstone of Kenya's economy, contributing significantly to GDP, supporting tourism and trade, and aiding in poverty reduction through increased connectivity and economic opportunities. It is also responsible for significant environmental challenges, however, exacerbating climate change, air pollution, and noise pollution. The sector is highly dependent on kerosene-based fuel, a major source of greenhouse gas emissions. As the industry propels forward, the urgency to find sustainable solutions intensifies.

Air Transport Decarbonization Policies and SAF Initiatives

Kenya has committed to reduce its greenhouse gas emissions by 32 percent compared with the business-as-usual scenario by 2030, as outlined in its Nationally Determined Contribution (NDC) under the Paris Agreement (Ministry of Environment and Forestry 2020). This commitment prioritizes the use of clean, efficient, and sustainable energy technologies to decrease reliance on fossil fuels. The State Action Plan for the Reduction of CO₂ Emissions in the Aviation Sector, issued by the Kenyan Civil Aviation Authority (KCAA 2022), includes commitments to promote SAF, by, for example, forming a task force to develop a supportive policy framework; initiating pilot projects; and establishing partnerships with multilateral development banks, the US Federal Aviation Administration, the German Development Corporation (GIZ), and the European Union. This international coalition creates a unique opportunity to position Kenya as a test case for developing the SAF industry in Sub-Saharan Africa, building on studies and experiences with SAF testing, blending, certification, and usage.

In 2018, under the guidance of the International Civil Aviation Organization (ICAO), Kenya conducted a feasibility study on domestic SAF production that identified priority feedstocks and recommended further development of SAF policy and regulatory frameworks (White 2018). This study led to a directive for the collection of UCO, which benefited local companies such as Zijani by facilitating the



collection and export of UCO. In a landmark move in June 2023, Kenya Airways became the first African airline to operate a commercial flight using a blend of SAF and conventional jet fuel, on a flight from Jomo Kenyatta International Airport (NBO) to Amsterdam (Eni 2023). The SAF and jet fuel were imported from Italy, blended at Nairobi's Wilson Airport, and then transported to NBO.

In 2024, Kenya established a national steering committee on the accelerated development and deployment of SAF. Under the leadership of the KCAA, the committee—consisting of representatives of ministries, other governmental agencies, the private sector, and international collaborators—is tasked with making tangible progress toward establishing the first SAF facility in Kenya. Its State Action Plan for Reducing Emissions in 2022–28 envisages pilot projects for the production of SAF (ICAO 2022a).

Jet Fuel Demand and Supply

Kenya no longer refines crude oil domestically, relying instead on imports of refined oil products such as jet fuel. This shift came after the closure of the Mombasa petroleum refinery in 2014, which had served both domestic demand and export needs within East Africa (Reuters 2013). Currently, jet fuel enters Kenya through the Port of Mombasa and is distributed across the country via a pipeline system connecting the port to Kenya's main airports (NBO in Nairobi and Moi International Airport in Mombasa).

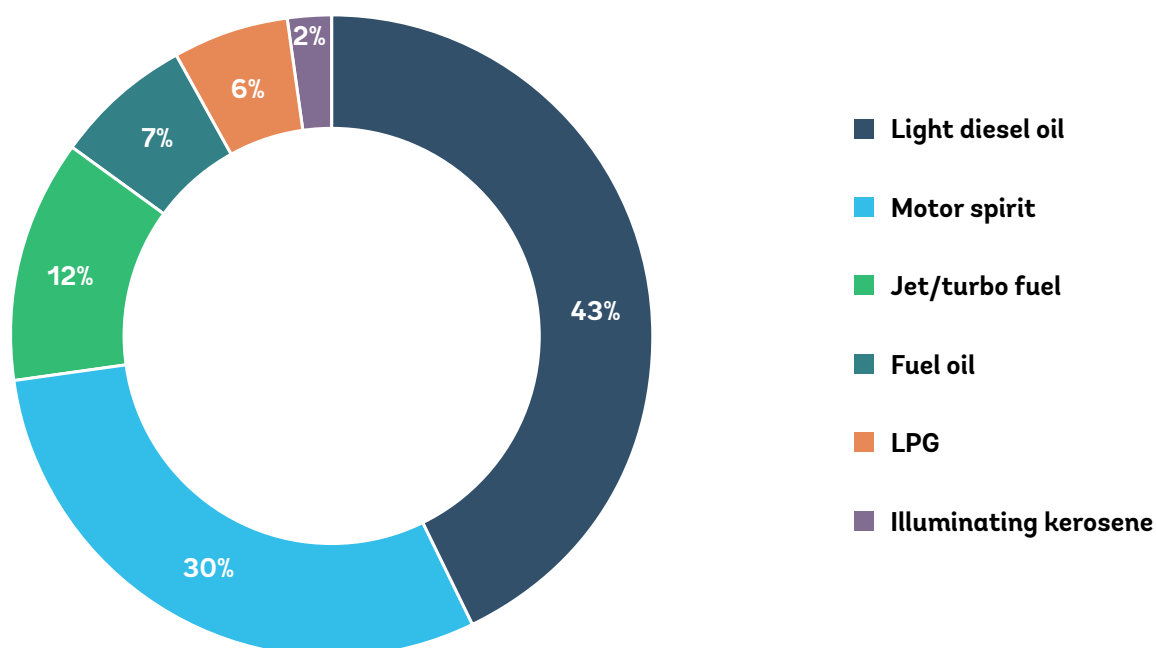
Kenya's history with petroleum refining and its established pipeline infrastructure position it well for SAF production. Existing pipelines connect the Port of Mombasa with major airports, facilitating efficient fuel distribution. This setup, which is rare in many Africa, along with Kenya's technical experience in refining, offer a foundation for transitioning to SAF that could help Kenya become a regional leader in the field.

Jet fuel accounted for 12 percent of Kenya's total petroleum product demand in 2022, according to the Kenya National Bureau of Statistics (KNBS 2023) (figure 2.1). Demand for jet fuel has varied over the years, ranging from 395,000 to 699,000 tonnes a year between 2018 and 2022 (table 2.1). Demand plummeted in 2020 because of the global downturn in air transport activities caused by the COVID-19 pandemic. By 2022, it had recovered to 592,000 tonnes.





Figure 2.1. Shares of petroleum demand in Kenya, by fuel category, 2022



Source: Data from KNBS (2023).
Note: LPG = liquefied petroleum gas.

Table 2.1. Domestic demand for petroleum products in Kenya, 2018–22 (thousands of tonnes)

Product	2017	2018	2019	2020	2021	2022
Liquefied petroleum gas	189	222	312	326	371	334
Motor spirit	1,267	1,359	1,434	1,395	1,554	1,561
Aviation spirit	4	19	10	2	1	1
Jet turbo fuel	650	674	699	395	507	592
Illuminating kerosene	448	339	168	127	111	89
Light diesel oil	2,086	2,173	2,199	2,158	2,306	2,220
Heavy diesel oil	1	0.2	1	2	0.8	0
Fuel oil	525	402	383	274	340	337
Total	5,171	5,189	5,207	4,679	5,192	5,134

Source: Data from KNBS (2023).



Conversion Technology and Feedstocks

The HEFA technology was chosen for Kenya for several reasons. HEFA is the most technologically mature and commercially popular SAF conversion technology: 83 percent of announced SAF production capacity by 2025 will use it, according to a World Bank study (Malina and others 2022). This maturity translates into lower technology risk premiums, which are particularly beneficial in developing countries and emerging markets, where country risks can amplify technology uncertainties. HEFA plants also generally require lower capital expenditures than other technologies, such as Fischer-Tropsch (FT), making them economically favorable in regions with higher capital costs (Bann and others 2017).

The study evaluates two primary feedstocks: UCO and castor oil. UCO is favored for its cost-effectiveness and larger reductions in greenhouse gas emissions. Its scalability is limited by availability, however, even in regions with established collection systems, where it often competes with other uses, such as biodiesel production. Castor oil, which is indigenous to Eastern Africa and particularly suitable for cultivation in Kenya, offers higher oil yield and is well suited for biodiesel production. Despite its potential, large-scale commercial cultivation of castor in Kenya has not taken place since the 1970s. It could be revived, however, given its high oil content and versatility. The recent \$250 million investments by the International Finance Corporation and the Italian company Eni to establish a significant agri-hub in Kenya indicates the growing interest and potential for scaling up domestic SAF feedstock production. Substantial output is planned by 2026.²¹ The potential for domestic lipidic feedstock for SAF production in Kenya could reach up to 4,000 BPD; further expansion might require importing additional feedstocks.

²¹ IFC and the Italian Climate Fund invested \$210 million in Eni's Kenyan biofuel initiative to increase oilseed production, including crops like castor, croton, and cottonseed, to 500,000 tons annually and build processing plants. The project supports farmers with inputs, training, and logistics, focusing on degraded lands, while ensuring sustainability through ISCC certification (IFC 2024).



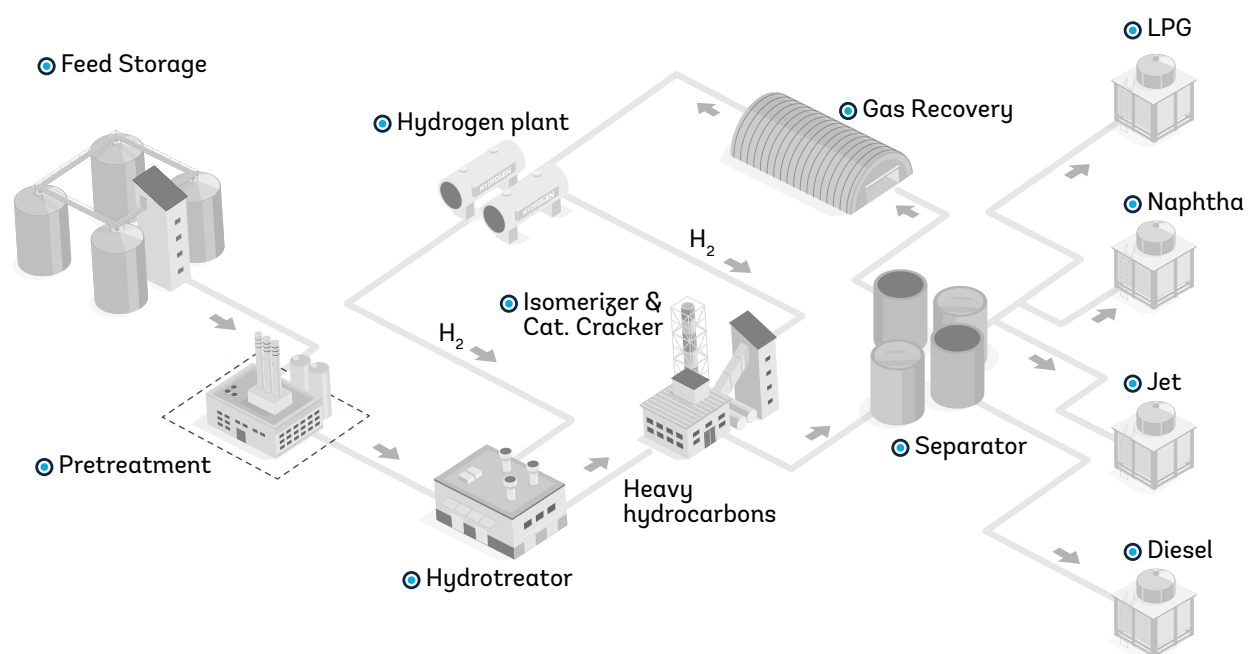


Methodology²²

Hydroprocessing Plant Design

This study uses Pearlson's (2011) process model, adapted to reflect conditions in Kenya for producing SAF. The revised model encompasses nine stages (figure 2.2). Key to this process is the pretreatment unit, which removes impurities from UCO before hydroprocessing it. This tailored approach optimizes the SAF production process for local resource availability and environmental considerations.

Figure 2.2. Simplified process flow diagram of production of SAF using the hydrotreated esters and fatty acids (HEFA) fuel production pathway



Source: Adapted from Pearlson (2011).

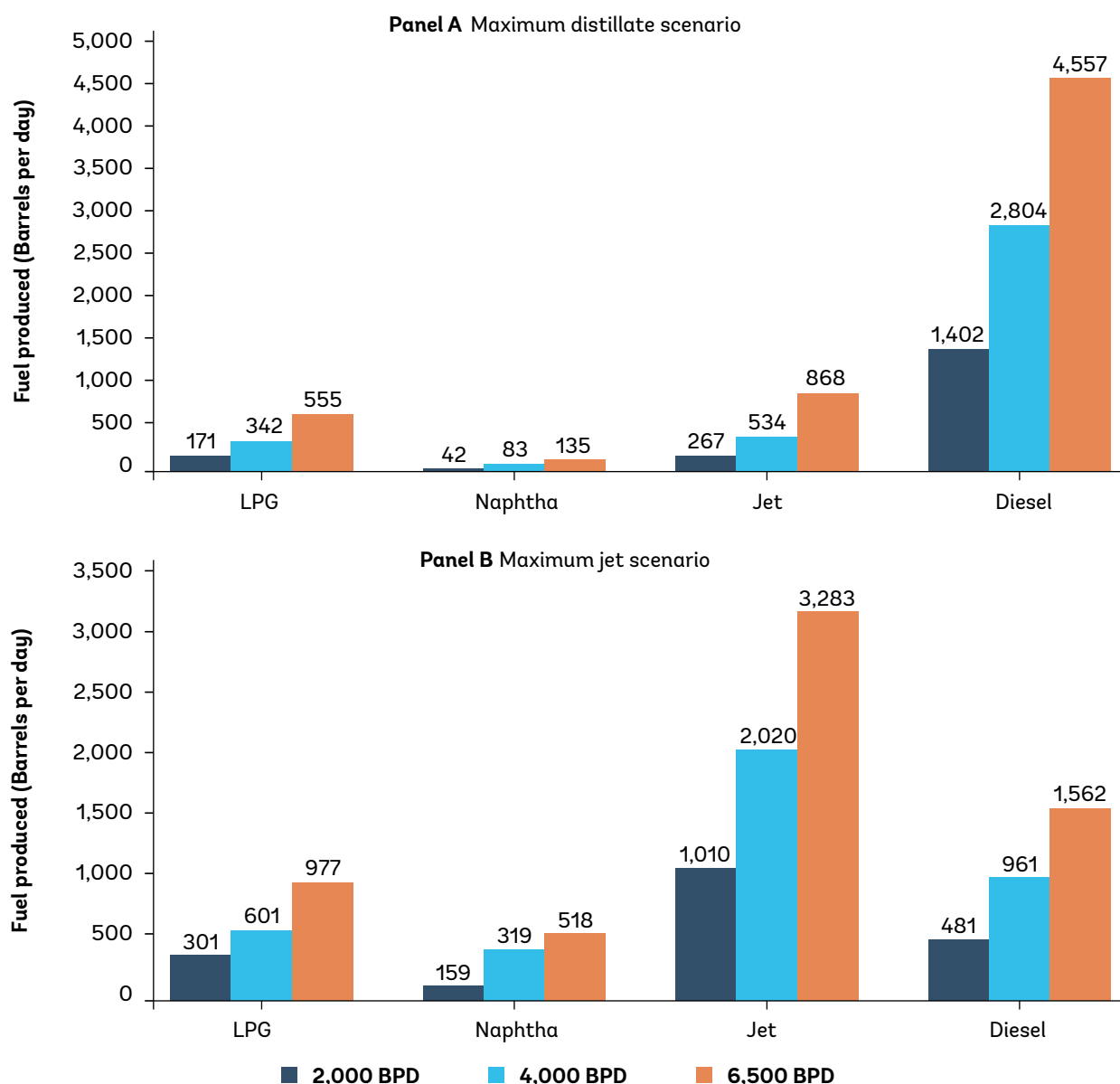
HEFA fuel production begins with the cleaning of the oil, followed by hydrotreatment to remove impurities and structural modifications. The oil then undergoes isomerization to adjust molecular structures. It is then cooled before being separated into various fuel types, such as liquefied petroleum gas (LPG), naphtha, jet fuel, and diesel. These processes involve recycling gases and treating wastewater. The model, based on Pearlson's research on soybean oil, highlights the effect of fatty acid profiles on the efficiency of hydroprocessing. UCO requires no adjustment in hydrogen use, because of its similarity to soybean oil. Castor oil, with its distinct fatty acid makeup, requires a 14 percent reduction in hydrogen use. This tailored approach optimizes the processing based on the specific characteristics of each feedstock.

²² For details of the modeling methodology and key assumptions, see Annex 2A.



Two production scenarios are analyzed (figure 2.3). The first focuses on maximizing the distillate yield to meet diesel specifications (Panel A) while minimizing the production of LPG and naphtha co-products. This scenario allows for the separation of the jet fuel fraction from the distillate stream. The second scenario (Panel B) enhances the production of jet fuel through the catalytic cracking of diesel-range molecules. Both scenarios' output levels are measured in barrels per stream day (BPSD), at facility sizes of 2,000, 4,000, and 6,500 BPSD, to reflect the balance between local feedstock availability and economies of scale. Typically, commercial-scale SAF projects using HEFA technology range produce 2,000–4,000 BPSD, with some exceeding this range. The cost analysis for these scenarios assumes greenfield investment; potential cost saving from using infrastructure from an idle petroleum refinery in Mombasa is explored in a sensitivity analysis.

Figure 2.3. Fuel products that could be produced from maximum distillate and maximum jet scenarios

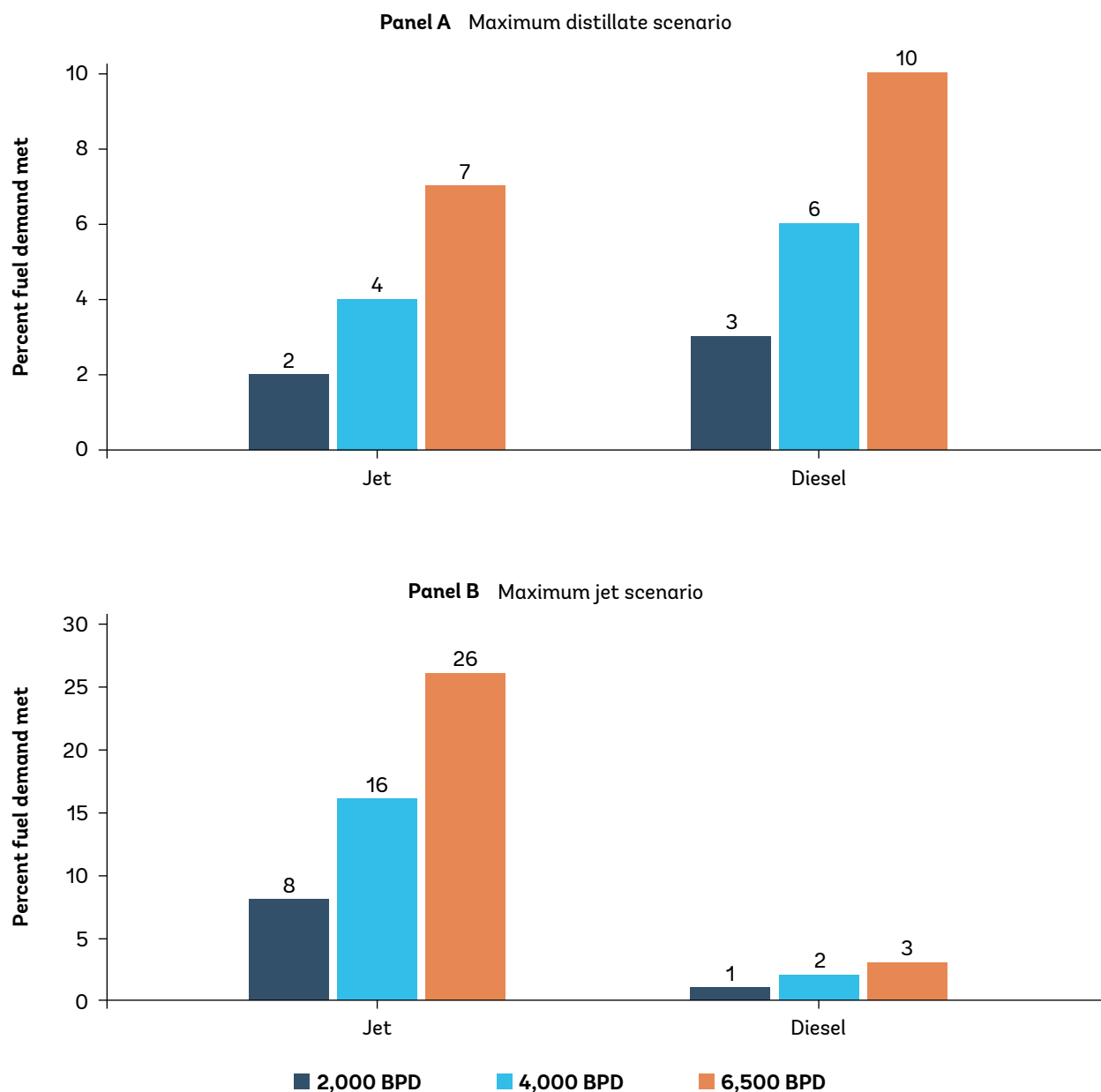


Note: BPD = barrels per day. | Source: Data from KNBS (2023).



A HEFA facility optimizing jet fuel production could satisfy up to a quarter of Kenya's current daily jet fuel demand (figure 2.4). In 2022, Kenya's jet fuel demand was 12,700 BPSD, and diesel demand was 45,200 BPSD. A HEFA facility focused on maximizing jet fuel production could meet 8.0–25.9 percent of daily jet fuel demand, depending on the facility size. If the facility were optimized for maximum distillate production, it could satisfy 2.1–10.1 percent of daily diesel demand. These projections highlight the facility's potential impact on national fuel supplies, which varies significantly with the scale of operations.

Figure 2.4. Shares of jet and diesel fuel demand that a hydrotreated esters and fatty acids (HEFA) facility could meet



Note: BPD = barrels per day. | Source: Original figure for this publication.



Techno-Economic Model

Cost projections for a hydrotreating facility in Kenya are based on established petroleum cost curves.²³ The capital costs were sourced from Pearlson's model, which lacks a pretreatment unit cost; they were supplemented with the techno-economic analysis spreadsheet of Brandt and others (2021), adjusted for inflation via the Chemical Engineering Plant Cost Index (CEPCI) to 2022 values, which were 74 percent higher than 2005 prices.²⁴ The study also adjusted costs for location, using South Africa's location factor of 0.95 as a proxy for Kenya, because of similar construction wages, updated to 0.75 based on exchange rate changes between 2015 and 2023. This location factor is a critical variable in the sensitivity analysis. The model also includes direct costs for storage and offsites and lists specific process utilities requirements for each kg of feedstock processed (detailed in the accompanying tables).

Financial Analysis Methodology

Figure 2.5 shows the cost structure for estimating the fixed capital investment of a plant, which includes essential costs within the plant's boundaries, known as inside battery limits (ISBL). It includes equipment costs for the pretreatment unit, the hydrotreating and isomerizing reactors, a steam-methane reforming hydrogen production facility, and a saturated gas plant, as well as installation and instrumentation. Other direct costs—including the cost of storing feedstock and fuel products, cooling systems, and improvements to infrastructure such as buildings and service facilities—are often calculated at about 30 percent of equipment costs, using petroleum industry heuristics.

Figure 2.5. Assumptions and cost structure for estimation of fixed capital investment in Kenya

Fixed capital investment (FCI)		
Direct costs (DC)		Indirect costs (IC)
Inside battery limits (ISBL)	Other direct costs	Engineering & supervision (30% DC)
Purchased equipment cost (PEC)	Storage: feedstock/products	Construction & fees (30% DC)
Installation	Buildings (45% PEC)	Contingency (20% DC)
Instrumentation/controls	Service facilities (40% PEC)	
	Yard improvement (15% PEC)	

Source: Original figure for this publication.

²³ The hydrotreating facility is analyzed as an nth plant, not a pioneer plant, with the assumption that it will be built from traditional and well-established petrochemical plant designs and equipment.

²⁴ See <https://www.chemengonline.com/pci-home>.



Indirect costs—such as project contingency, field expenses, office, and construction costs—are calculated as a percentage of the direct costs (figure 2.6). The sum of these direct and indirect costs, along with necessary working capital, is the total plant investment. Variable operating expenses (utilities such as electricity and water) are crucial for maintaining operational efficiency and directly affect the refinery's cost-effectiveness.²⁵

The financial viability of the plant is evaluated through the sales of its fuel products, including propane, liquefied natural gas (LNG), naphtha, jet, and diesel fuel. Current market prices suggest potential gross income from sales averaging \$200 million a year, based on the latest 12-month average prices for these fuels. This revenue estimate underpins the financial feasibility of the project, highlighting the plant's potential for profitability given the substantial initial and operational investments.

Discounted cash flow rate of return (DCF ROR) analysis is the primary method for evaluating the economic feasibility of the process. This method adjusts for key financial parameters—including internal rate of return, taxes, inflation, loan rates, and the costs of labor, utilities, and co-products—tailored to the Kenyan context. Table 2.2 summarizes the financial assumptions.

Table 2.2. Financial assumptions for the discounted cash flow rate of return analysis of Kenya

Item	Value
Facility size (BPD)	2,000, 4,000, 6,500
Equity (percent)	30
Loan interest rate (percent)	15
Loan term (years)	10
Working capital (percent of fixed capital investment)	5
Type of depreciation	Straight-line
Depreciation period (years)	10
Construction period (years)	3
Percent spent in year 3	8
Percent spent in year 2	60

²⁵ Total plant investment averages around \$150 million for a 4,000-BPD facility. Fixed operating expenses—which include insurance, taxes, maintenance, and salaries for plant staff—are calculated as a percentage of capital expenses; they typically constitute about 10 percent of the fixed capital investment (FCI) annually, or roughly \$15 million. Variable operating expenses average \$0.17 per kWh, and water is sourced at \$0.0006 per liter. Natural gas is not directly available in Kenya; the pricing strategy uses propane, which costs about \$0.40 per kg, as a proxy. These expenses are crucial for maintaining operational efficiency and directly affect the refinery's cost-effectiveness. Tables 2A.1 and 2A.2 in annex 2A provide details.



Item	Value
Percent spent in year 1	32
Discount rate (percent)	35
Income tax rate (percent)	30
Operating hours per year	7,878
Inflation rate (percent)	7.7

Source: Original table for this publication.

The analysis looks at three facility sizes—2,000, 4,000, and 6,500 BPD—to reflect the constraints posed by limited local feedstock availability and the benefits of economies of scale. The construction timeline for the facility is projected at three years, with the financial outlay for construction costs spread across this period at 8 percent, 60 percent, and 32 percent of the total plant investment for the first, second, and third years, respectively. This staggered investment approach aids in managing cash flow during the intensive construction phase. Depreciation of the facility is calculated using a straight-line method over a 10-year period, in line with standard accounting practices, to evenly distribute the cost of the asset over its useful life. This method simplifies financial planning and reflects a consistent annual expense, facilitating clearer long-term financial forecasts and investment analysis.

In assessing the financial viability of a new or risky operation, such as a facility in Kenya, a minimum acceptable rate of return of 35 percent was set, to reflect Kenya's S&P credit rating and associated risks. This rate is significantly higher than in more stable economies like the United States and Canada, where a 15 percent return is typical (Lin and others 2017). The adjustment reflects the heightened financial risk and the need for higher potential rewards in less stable environments. Table 2.3 illustrates this disparity, showing required returns on solar projects in various countries.

Table 2.3. Return required for solar projects in selected countries

Country	S&P rating	Required return on solar projects (percent)
Germany	AAA	7
United States	AA+	9
United Arab Emirates	AA	10
Chile	A	12
Saudi Arabia	A-	12
Peru	BBB	20



Country	S&P rating	Required return on solar projects (percent)
India	BBB-	17
Morocco	BBB-	15
Brazil	BB-	22
Namibia	BB-	21
Oman	BB-	18
Nigeria	B+	22
Bolivia	B+	24
Algeria	B	18
Costa Rica	B	21
Egypt	B	28
Tanzania	B	24
Ghana	B-	22
Argentina	CCC+	52
Zambia	CCC-	38

Source: Songwe and others (2022).

Tax considerations also play a crucial role in the financial setup, with both resident and nonresident companies in Kenya subject to a uniform income tax rate of 30 percent as of June 2023 (Kenya Revenue Authority n.d.). An inflation rate of 7.7 percent (the rate in 2022) was used (KNBS 2023). Operational assumptions include an annual operational uptime rate of 90 percent, accounting for periodic maintenance shutdowns, which results in an average of 7,878 operating hours per year over a projected 20-year facility lifespan (Jones and others 2013).

A detailed cash flow model incorporates these factors, using input and product prices from previous tables to calculate the minimum selling price (MSP) for jet and diesel fuels necessary to achieve a break-even net present value. Sensitivity analyses explore how variations in plant size, equity structure, loan rates, input costs, location factors, and discount rates might affect the MSP, providing a comprehensive financial framework for decision making under varying economic conditions.



Results

Costs of Production

Total plant investment is estimated \$235.1 million for a baseline 4,000-BPD production facility. The financial summary in the annex to this chapter showcases the breakdown of capital expenses required for establishing the plant. The ISBL costs—which include essential processing units like pretreatment, hydroprocessing, isomerization/cracking, hydrogen production (H₂ island), and a saturated gas plant—total \$83.4 million. Additional direct costs for storage, cooling, buildings, yard improvements, and auxiliary facilities push the total direct cost to \$165.2 million.

The total indirect cost—which encompasses engineering, supervision, and construction expenses—is calculated as 30 percent of the total direct cost, amounting to \$99.1 million. Adding a 20 percent contingency to the sum of the direct and indirect costs results in a fixed capital investment of \$297.3 million. Adjusting this figure for location factors yields a fixed capital investment of \$223.9 million. Adding 5 percent for working capital yields total plant investment of \$235.1 million.

Economies of scale play a significant role in the financial strategy for different plant capacities. Increasing the plant size from 2,000 to 4,000 BPD results in a 27 percent reduction in capital expense for a doubling of capacity (table 2.4). Expanding to 6,500 BPD reduces capital expense by 40 percent compared with the 2,000-BPD setup, for a 325 percent increase in capacity. These statistics underline the cost-effectiveness and efficiency gains associated with larger production scales, highlighting the financial advantages of scaling up operations within the facility.

Table 2.4. Total investment for an SAF facility in Kenya, by size

Size of facility (barrels per day)	Total investment	
	Millions of dollars	Billions of K Sh
2,000	162	23
4,000	235	33
6,500	317	45

Source: Original table for this publication.

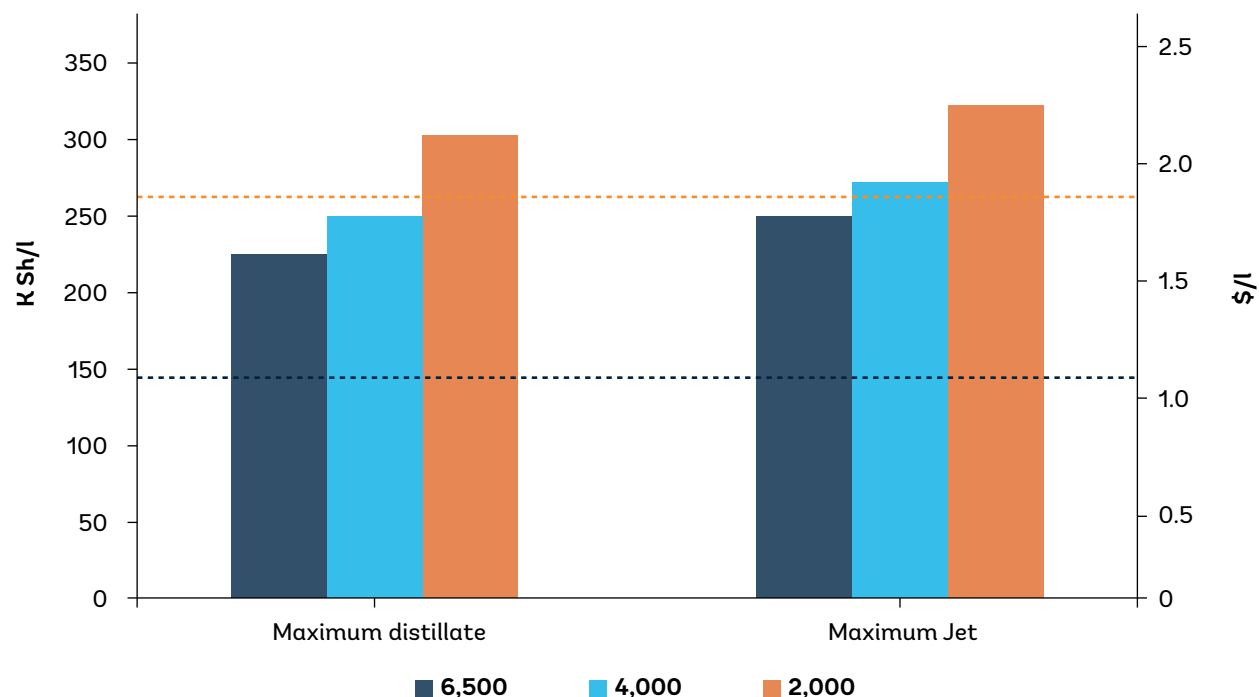
The financial analysis of jet and diesel fuel production from UCO–HEFA reveals how the MSP depends on both the facility's production capacity and the specific fuel production scenario (figure 2.6).²⁶ For jet fuel, under a maximum distillate scenario, the per liter MSP decreases as facility size increases, falling from \$2.1 for a 2,000-BPD plant to \$1.7 for a 4,000-BPD plant and \$1.6 for a 6,500-BPD plant (\$1 = K Sh 142.5). In scenarios optimized for jet fuel production, the MSP ranges from \$1.7 to \$2.3 per liter.²⁷ The 4,000-BPD facility (at an MSP of \$1.9 per liter), serves as the baseline, because of Kenya's feedstock constraints.

²⁶ The financial analysis of jet and diesel fuel production from UCO–HEFA determines the MSP required to achieve a net present value of zero.

²⁷ When production targets jet fuel, the MSP is higher, because of the extra hydrogen needed to convert diesel into jet.



Figure 2.6. Minimum selling prices for maximum distillate and maximum jet production in Kenya using the used cooking oil hydrotreated esters and fatty acids (HEFA) pathway, by facility size (2,000, 4,000 and 6,500 barrels per day)



Note: The lower (in black) dashed line shows the 12-month average for the dual-purpose kerosene pump price based on prices between August 15, 2022 and August 14, 2023 in Nairobi (\$1.04 per liter). The upper (in red) dashed line shows the average SAF world market price during this period (\$1.83 per liter, IATA 2024).

Source: Original figure for this publication.

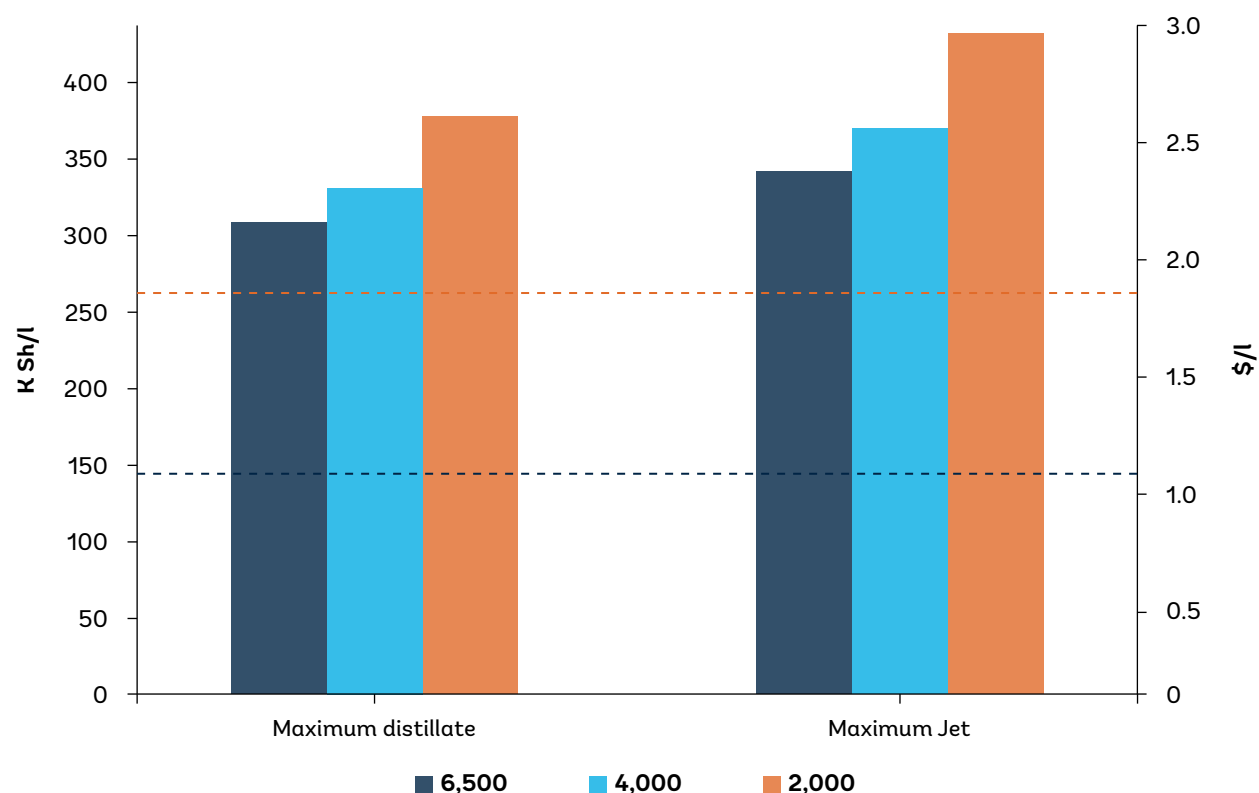
This baseline MSP for UCO–HEFA is 80 percent higher than the price of conventional jet fuel in Kenya (\$1.04 per liter). For diesel, the MSP is set at \$0.06 per liter above that of jet fuel, mirroring the historical price gap observed between 2018 and 2023. Should diesel be sold at the current market rate of \$1.1 per liter, the MSP for jet fuel under the baseline scenario would need to rise to \$2.3 per liter. This pricing reflects the substantial economic challenges involved in producing biofuels in countries like Kenya, where feedstock is limited and production costs are higher than they are for conventional fuels.





The baseline MSP for castor-HEFA in a 4,000-BPD facility stands at \$2.6 per liter, 145 percent higher than the 12-month average price of conventional jet fuel in Kenya (figure 2.7). This stark difference underscores the premium associated with this sustainable fuel alternative. As facility size increases in the maximum distillate scenario, the MSPs rise, to \$2.2 per liter for a 2,000-BPD, \$2.3 per liter for a 4,000-BPD, and \$2.7 per liter for a 6,500-BPD plant. For scenarios optimized for maximum jet fuel production, MSPs range from \$2.4 to \$2.9 per liter.

Figure 2.7. Minimum selling prices in Kenya for maximum distillate and maximum jet production using the castor oil/hydrotreated esters and fatty acids pathway (HEFA), by facility size (2,000, 4,000 and 6,500 barrels per day)



Note: The lower (in black) dashed line shows the 12-month average for the dual-purpose kerosene pump price based on prices between August 15, 2022 and August 14, 2023 in Nairobi (\$1.04 per liter). The upper (in red) dashed line shows the average SAF world market price during this period (\$1.83 per liter, IATA 2024).

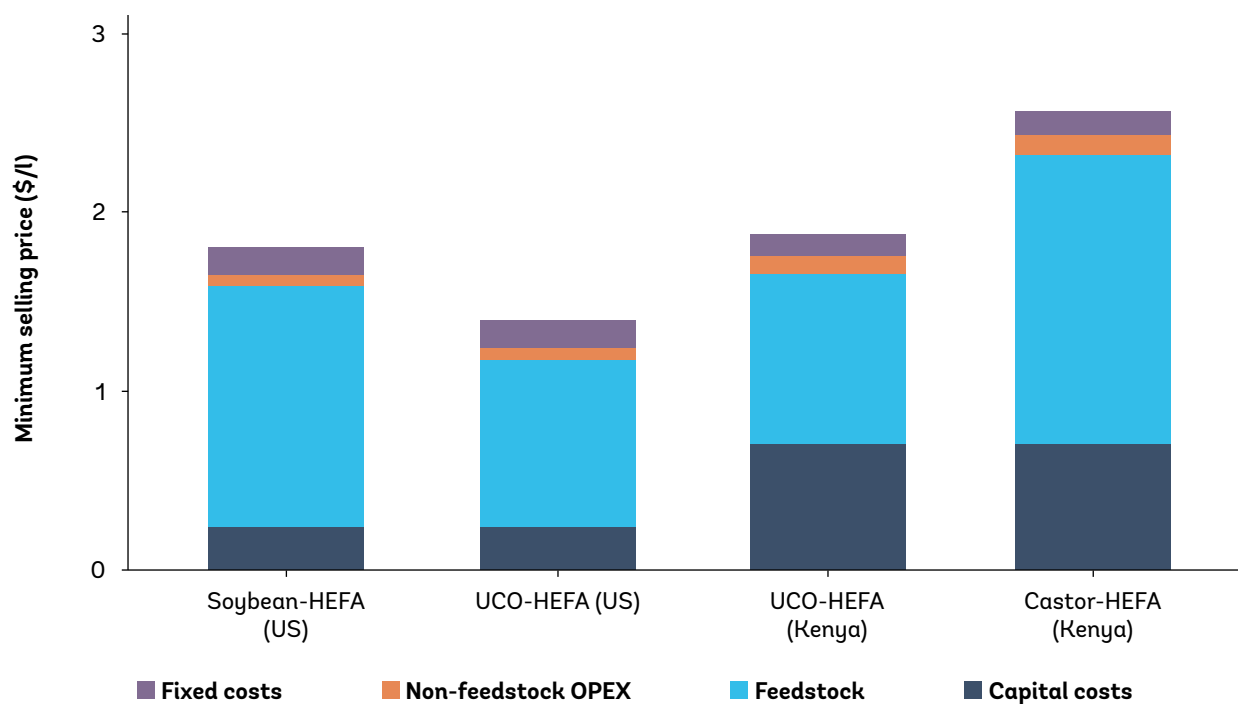
Source: Original figure for this publication.

The MSP for diesel is consistently set \$0.06 per liter above the MSP of jet fuel, reflecting the historical price difference between the two fuels between 2018 and 2023. Should diesel be sold at the current market price of \$1.1 per liter, the MSP for jet fuel under the baseline scenario would need to increase to \$3.3 per liter. This analysis highlights the substantial cost premium of castor-HEFA fuels compared with traditional fuels, driven by the higher production and raw material costs associated with sustainable alternatives. These insights underscore the significant economic challenges for the adoption of castor-HEFA fuels, especially in markets accustomed to lower-cost conventional fuels.



Figure 2.8 illustrates the MSP distributions for castor- and UCO-HEFA fuels. Capital investment per liter, which contributes 28–40 percent of the total jet production cost, is identical in the two fuel types, encompassing capital depreciation and return on capital. Non-feedstock operational expenses—which include natural gas consumption during oil upgrading, catalyst costs, and additional utilities—significantly affect the MSP. The substantial variation between different oil feedstocks primarily reflects fluctuations in oil prices. HEFA fuels require price support of \$0.7–\$1.5 per liter to be economically competitive.

Figure 2.8. Minimum selling prices in Kenya and the United States of SAF produced using the hydrotreated esters and fatty acids (HEFA) pathway, by feedstock



Note: OPEX = operating expenditures; UCO = used cooking oil; HEFA = hydrotreated esters and fatty acids.

Source: Original figure for this publication.

HEFA fuel production costs in Kenya and the United States differ widely. For castor-HEFA in Kenya, where no local castor production exists, soybean-HEFA from the United States serves as a benchmark. The input data for US cases suggests a significant capital cost penalty for SAF production in Kenya, where capital costs contribute more than twice as much to the fuel selling price as they do in the United States. This increased cost is attributed to higher risk premiums in Kenya, which elevate both loan rates and discount rates, making the financial viability of SAF production more challenging than in the United States.

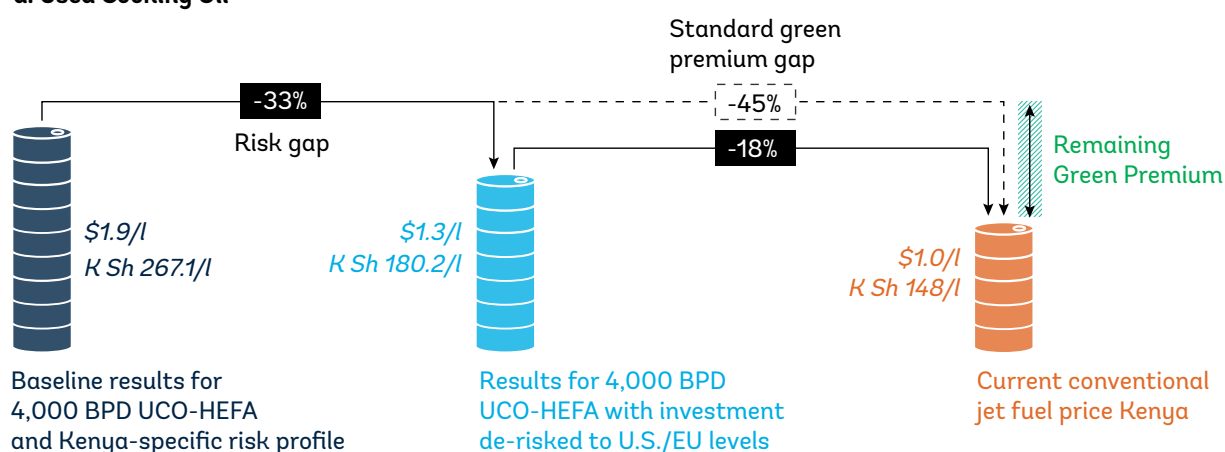
The higher selling prices in Kenya can be broken down into two main cost components: higher risk premiums in Kenya and a residual green premium typical of any green products (figures 2.9 and 2.10). The green premium is the cost difference between SAF and conventional jet fuel caused by higher SAF production costs. It can be reduced by implementing financial incentives, such as tax credits and grants; setting SAF blending mandates; using book-and-claim mechanisms; investing in R&D; securing offtake agreements; promoting Scope 3 credit purchases; leveraging carbon markets;



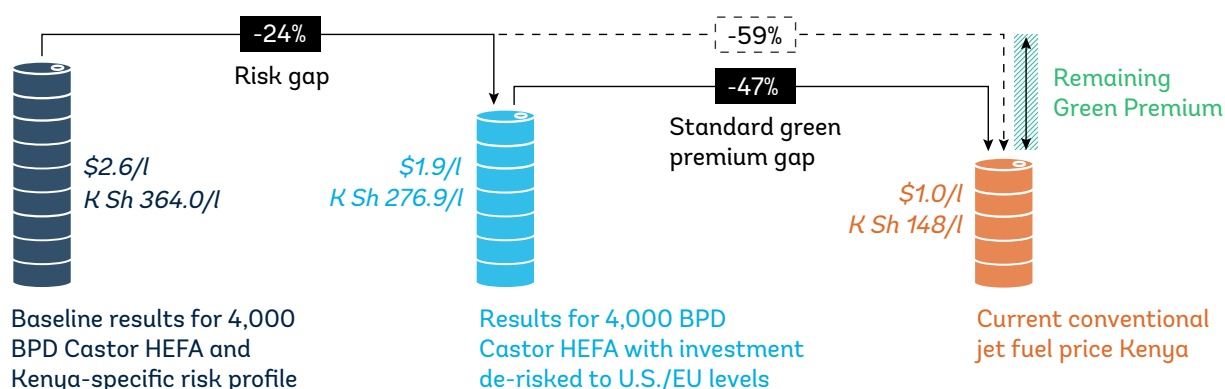
and fostering international financial support. The risk premium arises because capital costs (loan and discount rates) are higher in African markets than in OECD countries. It can be reduced by de-risking instruments such as loan guarantees and political risk insurance; securing strong offtake agreements; promoting public-private partnerships; and establishing supportive government policies, such as tax incentives and loan guarantees. Reducing risk premiums can significantly reduce SAF production costs in Africa. The risk premium in Kenya for all HEFA fuel contributes about \$0.6 per liter (24 percent) to the costs; the green premium adds \$0.9 per liter for castor-HEFA and \$0.2 per liter for UCO-HEFA, an additional 47 percent over the price of conventional jet fuel.

Figure 2.9. Risk and green premium gaps on SAF produced in Kenya using used cooking oil and castor oil as the feedstock

a. Used Cooking Oil



b. Castor Oil



Source: Original figure for this publication.



Reducing the risk premiums associated with SAF production would significantly lower costs. A green premium would still remain, however, necessitating a collaborative approach to close the cost gap with conventional fuels. Such an approach could involve coalitions that establish financing agreements with development banks; secure offtake agreements from international airlines and original equipment manufacturers (OEMs); facilitate Scope 3 credit purchases by corporations; and leverage government support through tax incentives, expertise, and regulation. Such efforts are crucial for making SAF economically viable and competitive.

Lifecycle Greenhouse Gas Emissions

Using waste-derived feedstocks yields significant environmental benefits.²⁸ Emissions from UCO–HEFA are 83 percent or 88 percent per megajoule (MJ) lower than emissions from conventional jet fuel in maximum jet and maximum distillate scenarios, respectively. UCO is treated as a waste stream, with its lifecycle assessment beginning at the collection and processing stage. Use of UCO creates no land use change emissions. This aspect is crucial, as it emphasizes the minimal environmental footprint from the outset. The transportation logistics for UCO involve a mix of rail and truck, using the Kenyan electricity mix for operational energy.

Castor–HEFA involves a broader system boundary that starts from the cultivation of feedstock and includes transportation, oil extraction, and conversion to HEFA. This process also involves the production of oilseed meal, a potential animal feed post-detoxification, which adds complexity to the lifecycle. Greenhouse gas emissions are significantly higher for castor–HEFA than for UCO–HEFA, reflecting the additional environmental costs associated with cultivating and processing non-waste-based SAF.

Excluding land-use change impacts, the greenhouse gas emission analysis for castor oil–HEFA shows promising environmental benefits. It could achieve greenhouse gas reductions of 58 percent or 61 percent per MJ of SAF combusted in maximum jet and maximum distillate scenarios, respectively, compared with a conventional jet fuel baseline of 89 grams of carbon dioxide equivalent per megajoule of energy (gCO₂e/MJ) set by CORSIA (figure 2.10). These figures highlight the potential of castor oil–HEFA as a sustainable fuel option, assuming no significant emissions from land conversion.

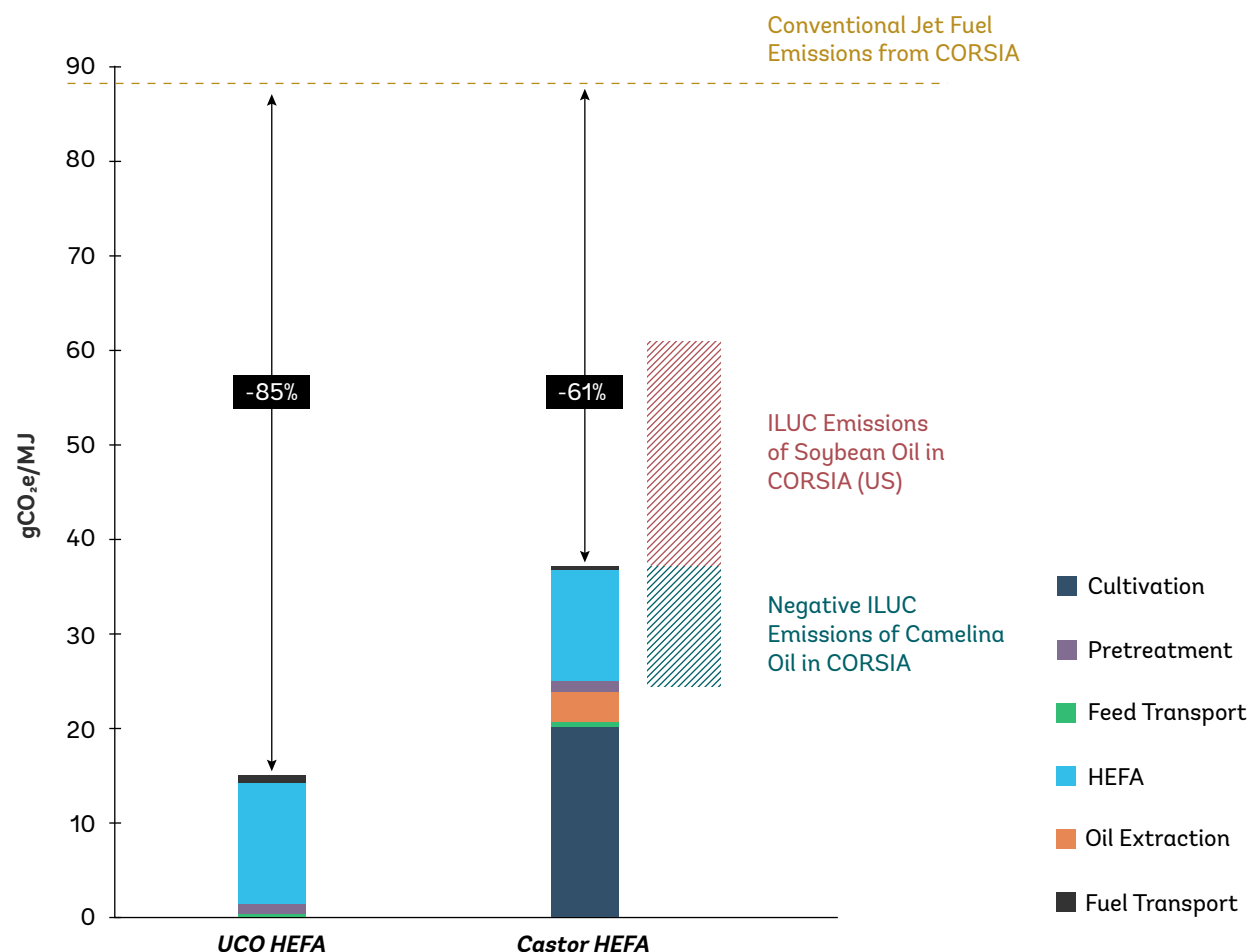
Consideration of emissions from induced land-use change (ILUC) could alter these results substantially. Estimating ILUC emissions accurately requires sophisticated modeling techniques, such as partial (GLOBIOM) or general equilibrium models (GTAP), which are not covered in this study. The impact of ILUC on total lifecycle emissions could vary greatly. It might increase emissions if high-carbon stock land is converted for agriculture or decrease emissions if the feedstock is cultivated on marginal, abandoned, or underutilized agricultural land or rotated with other crops. This aspect underscores the importance of carefully selecting and managing land for biofuel crop production to harness the environmental benefits of biofuels like castor–HEFA while mitigating potential negative impacts from land-use changes.²⁹

²⁸ Methodologies from CORSIA (ICAO 2022b) and the GREET model (Seber and others 2014) were used for this analysis.

²⁹ Adopting rigorous certification processes from standards like CORSIA or the European Union's Renewable Energy Directive is essential to maximize the environmental benefits of biofuels like castor oil–HEFA and ensure responsible management of greenhouse gas emissions. These certifications help accurately assess and set lifecycle greenhouse gas emissions, safeguard against ecological impacts, and enhance the market competitiveness of SAF by validating their sustainability claims.



Figure 2.10. Greenhouse gas emissions from hydrotreated esters and fatty acids (HEFA) SAF produced from used cooking oil and castor oil



Note: Figure shows effect of emissions from land use change for castor oil–HEFA using induced land-use change (ILUC) emissions from CORSIA for soybean and camellina oils.

Source: Original figure for this publication.

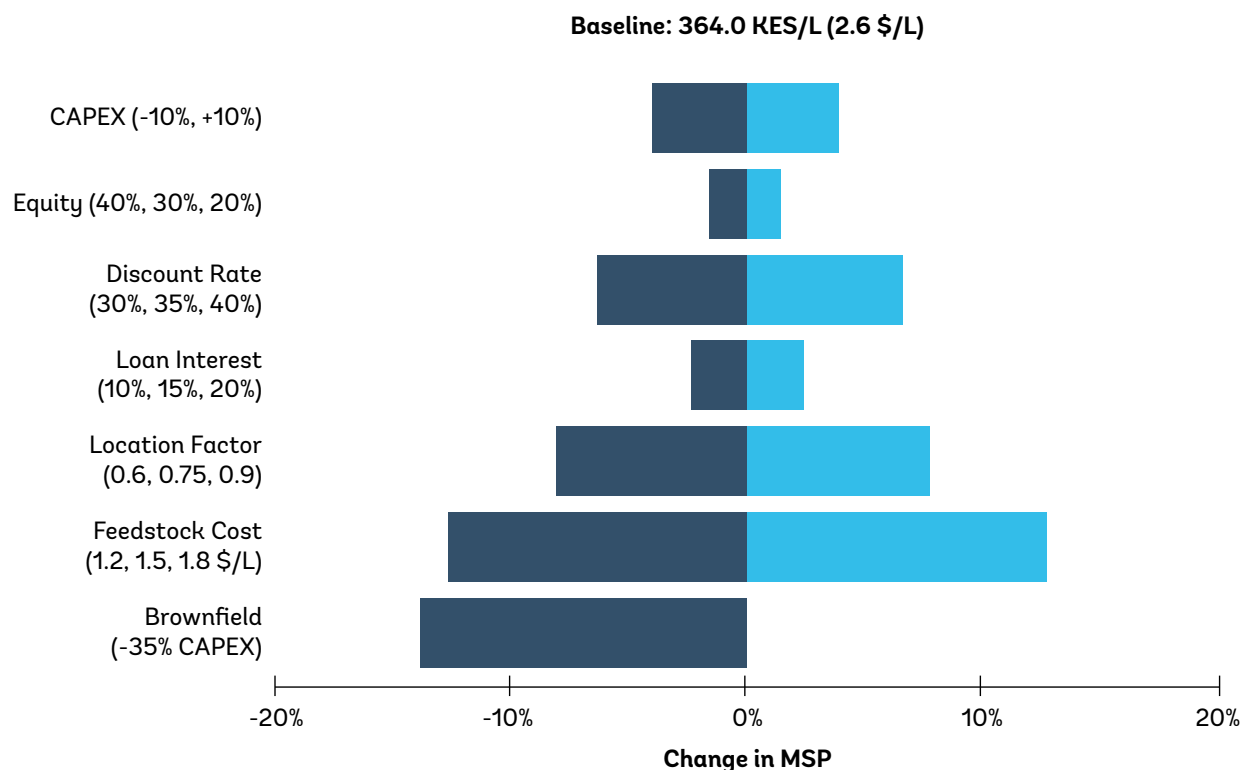
Sensitivity Analysis

A sensitivity analysis was conducted to understand how various financial and operational parameters affect the MSP of SAF. Variables considered include capital expenses for constructing the SAF facility, location factors, loan rates, discount rates, equity shares, and the costs of feedstock and hydrogen. A brownfield investment scenario—which is expected to reduce capital expenses by 35 percent by repurposing existing refinery assets—is investigated (Gary, Handwerk, and Kaise 2007).

The analysis also examines the sensitivity of these factors for the MSP of castor oil–HEFA. It shows that availability is greater for virgin vegetable oils than used oils (figure 2.11).



Figure 2.11. Sensitivity of minimum selling price of SAF in Kenya to various parameters



Note: CAPEX = capital expenditure.

Source: Original figure for this publication.

Similar percentage variations in MSP are projected for the UCO-HEFA case. Financial parameters such as discount rates, capital expenses, and loan rates, along with the type of investment (brownfield versus greenfield) can significantly affect the SAF selling price. Subsequent sections delve more deeply into how these factors can be optimized to reduce fuel selling prices.

For hydrogen, a crucial input in the HEFA production process, we analyze the use of green hydrogen instead of hydrogen from steam-methane reforming. We assume a green hydrogen cost of \$4.0/kg, based on Kenya-specific cost modeling of various hydrogen derivative products (International PtX Hub 2022). Using green hydrogen increases the SAF selling price for the 4,000-BPD max jet facility by K Sh 19 (\$0.13) per liter.

The sensitivity analysis points to the importance of financial parameters for the economic feasibility of SAF production in Kenya. In what follows, we explore how different actions by private and particularly public stakeholders can help reduce the Kenya-specific risk premium and the SAF cost premium (table 2.5). We also explore how a potential brownfield investment that yields similar benefits to those observed in the literature affects the fuel selling price.


Table 2.5. Policy scenarios for lowering the minimum selling price of SAF in Kenya

Parameter	Baseline	1: Accelerated depreciation	2: Tax break	3: Strong offtake agreements	4: Concessional loan	5: Loan guarantee	6: Brownfield investment	Carbon incentives		
								7a: CORSIA	7b: EU ETS	7c: Social cost of carbon
Equity (percent CAPEX)	30	30	30	30	30	20	20	20	20	20
Discount rate (percent)	35	35	35	30	30	25	25	25	25	25
Concessional loan (percent CAPEX)	n.a.	n.a.	n.a.	n.a.	50	50	50	50	50	50
Commercial loan (percent CAPEX)	70	70	70	70	20	30	30	30	30	30
Interest rate-concessional loan	n.a.	n.a.	n.a.	n.a.	0	0	0	0	0	0
Interest rate-commercial loan (percent)	15	15	15	13	13	5	5	5	5	5
Income tax (percent)	30	30	15	15	15	15	15	15	15	15
Type of depreciation	Straight-line	Double declining balance (DDB)	DDB	DDB	DDB	DDB	DDB	DDB	DDB	DDB
Carbon credits (\$/ton CO ₂)								28–58	78	150

Note: CAPEX = capital expense; CORSIA = Carbon Offsetting and Reduction Scheme for International Aviation; EU ETS = European Union Emissions Trading System. n.a. = Not applicable.

Highlighted boxes indicate the parameter changes in a scenario

Source: Original table for this publication.

Scenario 1: Accelerated Depreciation

Scenario 1 assumes that the Kenyan government allows the SAF facility to depreciate the investment in an accelerated way. Instead of a straight-line depreciation over 10 years, as assumed in the baseline model, we apply the double declining balance depreciation method.



Scenario 2: Scenario 1 Plus an Additional Tax Break

Scenario 2 assumes that the Kenyan government provides an income tax break for 10 years, reducing the rate from 30 percent to 15 percent, in addition to the faster depreciation.

Scenario 3: Scenario 2 Plus Strong Offtake Agreements

Strong, multiyear offtake agreements improve access to finance for a borrower and can reduce investment costs. Scenario 3 assumes that a strong offtake reduces the discount rate by 5 percentage points and the commercial loan rate by 2 percentage points. These effects are added to the effects of Scenario 2.

Scenario 4: Scenario 3 Plus Concessional Loan

Scenario 4 assume that the SAF facility obtains a concessional loan for 50 percent of the capital expense (CAPEX) for 10 years. This concessional loan has a 0 percent interest rate. The resulting MSP effects are added to the results of Scenario 3.

Scenario 5: Scenario 4 Plus Loan Guarantee

Scenario 5 includes all measures from Scenario 4 plus the presence of a partner, such as a development bank, that guarantees the borrower's debt obligation if the borrower defaults. This guarantee reduces the interest rate for the commercial loan by reducing the consequences of a potential default, allowing the borrower to raise a larger share of the needed capital from debt. The guarantee also reduces the risk for investors, which leads to a lower expected rate of return (discount rate). We assume that the loan guarantee drives down the interest rate to 5 percent for the commercial loan, that the debt-equity split can be increased to 80–20 because of the loan guarantee, and that the discount rate decreases by an additional 5 percentage points.

Scenario 6: Scenario 5 Plus Brownfield Investment

Scenario 5 assumes that the HEFA facility is erected at the site of the idle petroleum refinery in Mombasa. Repurposing the existing infrastructure (buildings, service facilities, land and yard works) reduces costs (Gary, Handwerk, and Kaiser 2007). Using the existing hydrotreaters, isomerizers, and other processing infrastructure could yield even greater savings (Brandt and others 2021). No site-specific analysis was conducted for the case in Mombasa. According to the literature, typical brownfield benefits amount to 25–35 percent of the capital investment (EPA 2011; Mupondwa, Li, and Tabil 2022). When the cost of buildings, yard improvement, and auxiliary facilities are subtracted from the capital costs for the baseline facility, a 35 percent investment costs savings is achieved from locating the HEFA plant at the existing refinery.

Scenario 7: Scenario 6 Plus Carbon Incentives

Scenario 7 evaluates the effect of carbon credits from different sources. In Scenario 7a, CO₂ offset costs projected under CORSIA are used to estimate a greenhouse gas emission reduction–defined output incentive. Adjusting these values for inflation in Kenya (7.7 percent) yields an estimate of \$28–\$58 per ton CO₂e abated. Greenhouse gas emissions abated by castor oil–HEFA are 51.4 gCO₂e/MJ SAF in the absence of land-use change emissions (1.7 kg CO₂e per liter SAF). Incentive values from table 2.6 are applied to the jet fuel fraction as revenue (in dollars per ton CO₂e abated).


Table 2.6. Projected CORSIA–determined incentive values adjusted for Kenya conditions 2026–45

Year	Incentive value (\$/ton CO ₂ e abated)	Year	Incentive value (\$/ton CO ₂ e abated)
2026	27.8	2036	44.6
2027	31.3	2037	46.1
2028	32.7	2038	47.6
2029	34.1	2039	49.1
2030	35.5	2040	50.6
2031	37.0	2041	52.1
2032	38.6	2042	53.6
2033	40.1	2043	55.1
2034	41.6	2044	56.7
2035	43.1	2045	58.2

Source: Original table for this publication.

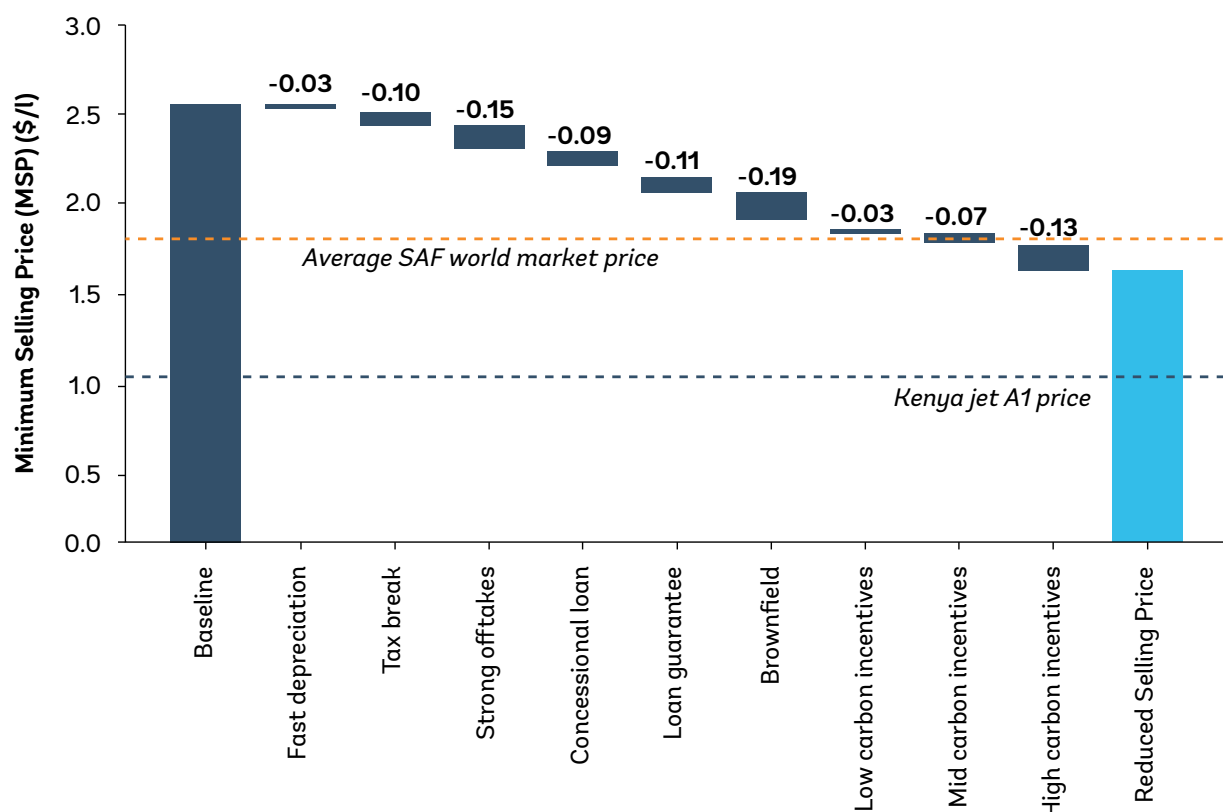
Scenario 7b considers a European Union Emissions Trading System (EU ETS) carbon credit of €70 (\$78) per tonne of CO₂ abated, assuming that castor oil–HEFA fuels provide a 50 percent decrease in CO₂ emissions compared with the fossil kerosene baseline. Scenario 7c uses a relatively high estimate for the costs of carbon, assuming a carbon credit of \$150 per tonne of CO₂ abated.

Figure 2.12 presents the results of the scenario analysis. The incremental MSP reductions from each scenario are highlighted in yellow. The largest reduction occurs when an existing facility is repurposed. Actual savings from such repurposing projects are highly case specific and depend on the circumstances of the facility.





Figure 2.12. Impact of policy scenarios on the minimum selling price in Kenya of SAF produced using castor oil



Note: Figure is based on a 4,000-BPD fuel facility and the maximum jet product slate. The black dashed line shows the dual-purpose kerosene price in Kenya (\$1.04/l) and the red dashed line shows average world market price of SAF in 2024 (\$1.83/l), for comparison purposes. Global SAF prices are based on IATA (2024) data.
Source: Original figure for this publication.

Financial de-risking strategies further reduce the MSP. For instance, securing strong offtake agreements and loan guarantees reduces the discount rate, effectively lowering the MSP and underscoring the importance of financial security for the economics of SAF production. In Scenario 7c, the application of a higher carbon credit—reflecting the social cost of carbon—illustrates how environmental incentives like CORSIA and the EU ETS can meaningfully reduce MSPs through carbon pricing mechanisms.

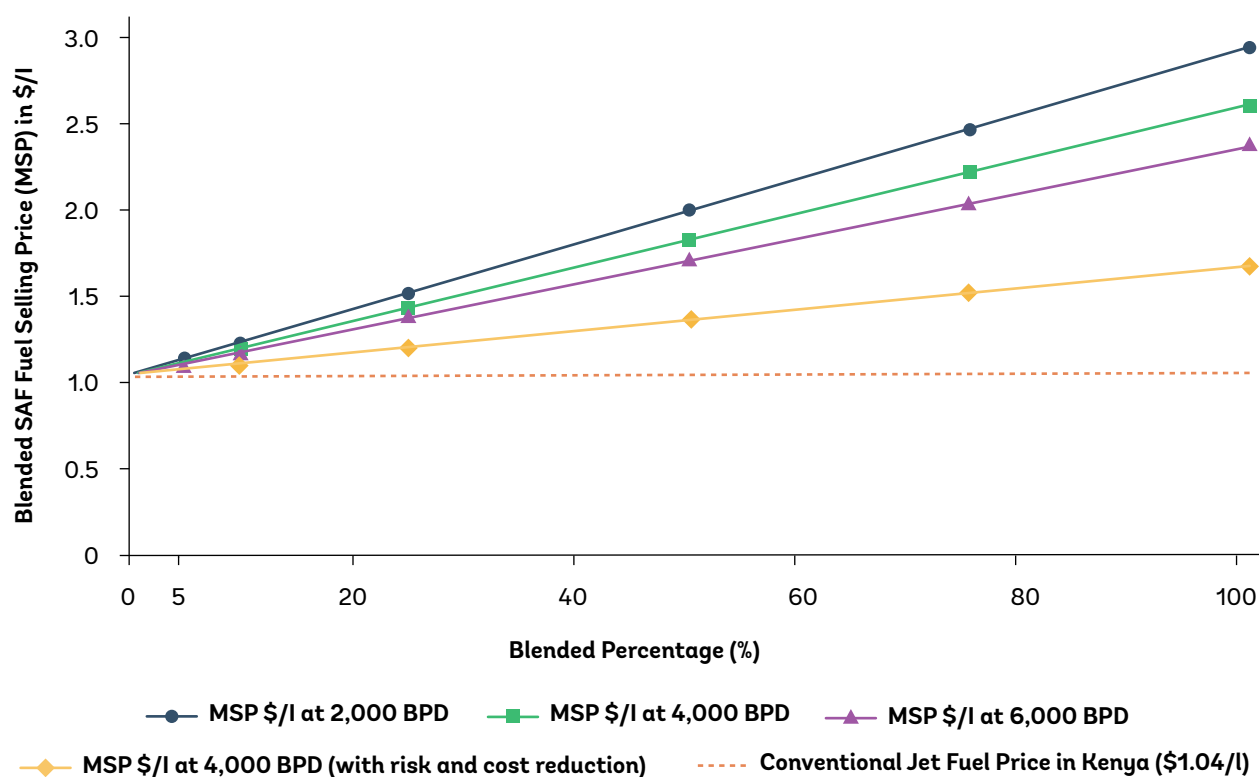
Tax incentives also play a crucial role, with temporary tax breaks resulting in reductions in the selling price comparable to those achieved through aggressive carbon pricing strategies. This similarity points to the potential effectiveness of domestic policy measures in bridging the gap between the costs of conventional jet fuel and SAF.

The modeled scenarios collectively reduce the MSP of castor oil–HEFA by 35 percent, resulting in an MSP of \$1.7 per liter of “neat” SAF. This price is still about \$0.7 per liter higher than conventional jet fuel in Kenya, but it is competitive with the global average SAF price paid by airlines in 2024 of \$1.83 per liter. To contextualize the economic implications of this remaining price premium compared with conventional jet fuel, if the total SAF green premium for a 4,000-BPD facility were

distributed among the 2.4 million outgoing international passengers from Kenyan airports in 2022, each ticket would need to increase by about \$42.80 to cover the cost. This calculation highlights the broader economic considerations that need to be taken into account in integrating SAF into the market and the potential impact on consumer costs.

To further contextualize the premium airlines face, figure 2.13 plots the selling price per unit fuel as a function of the blend ratio of conventional jet fuel and neat SAF. It shows the calculated MSP per unit neat SAF as previously calculated for the three facility sizes as well for the scenario with ambitious risk- and cost-reduction measures. The MSP linearly decreases in the four cases as the blend ratio of neat SAF decreases. For example, the MSP for a 50 percent blend of conventional jet fuel and neat SAF produced in a 4,000-BPD facility with ambitious risk- and cost reduction measures applied is \$1.36 per liter. It decreases to \$1.1 per liter for a 10 percent blend. Reducing blend ratios does not reduce the total green premium of a SAF facility but rather provides an opportunity for allocating that premium over larger fuel volumes.

Figure 2.13. Impact of blending percentage on fuel selling price of SAF produced from blended castor oil–hydrotreated esters and fatty acids (HEFA) in Kenya



Note: Conventional jet fuel price is based on the 12-month average for dual-purpose kerosene pump price between August 15, 2022 and August 14, 2023 in Nairobi. The minimum selling prices are calculated for the maximum jet fuel product slate.
Source: Original figure for this publication.



Conclusion and Recommendations

Kenya presents a compelling case for the development of a SAF industry. It has a robust history of petroleum refining, expertise in fuel production and certification, and a strategic multiproduct pipeline that can efficiently distribute fuel from the Port of Mombasa to major airports. Its existing infrastructure, coupled with the government's strong commitment to the energy transition, position Kenya to become a regional frontrunner in SAF production and distribution.

Establishing a SAF facility requires a substantial upfront investment, typically reaching hundreds of millions of dollars even for relatively cost-effective technologies like HEFA. The analysis in this chapter indicates that a 4,000-BPD HEFA facility, optimized for jet fuel production, would require an initial investment of about \$235 million. This facility could potentially meet around 15 percent of Kenya's current jet fuel demand and 10 percent of projected demand in 2030.

The green premium associated with SAF poses another major challenge. SAF production in Kenya is not only burdened by the typical cost premium seen globally; it also faces elevated capital costs, because of the country's higher risk profile compared with high-income countries.

Bridging this cost gap and fostering a financially viable SAF industry in Kenya necessitates a multipronged approach:

- **Leveraging economies of scale:** Economies of scale reduce production costs. Increasing the plant size from 2,000 to 4,000 BPD, for example, leads to a 27 percent reduction in capital expense for a doubling of capacity. Expansion to 6,500 BPD offers even greater cost savings, underscoring the financial benefits of scaling up operations.
- **Selecting the feedstock:** The choice of feedstock significantly affects the economics and environmental sustainability of SAF production. UCO is favored for its cost-effectiveness and superior greenhouse gas emission reductions. Its scalability is limited by availability, however. Castor oil, which is indigenous to Eastern Africa and particularly suitable for cultivation in Kenya, presents a promising alternative. However, reviving large-scale commercial cultivation of castor requires investment and careful consideration of land-use change impacts.
- **Optimizing production scenarios:** Maximizing distillate yield while minimizing the production of LPG and naphtha co-products can reduce costs. Enhancing jet fuel production through catalytic cracking of diesel-range molecules presents another potential avenue for optimization.
- **Exploring brownfield investments:** Repurposing existing infrastructure, particularly the idle petroleum refinery in Mombasa, presents a significant opportunity for cost reduction. Brownfield investment could reduce capital expenses by 25–35 percent.
- **Implementing supportive government policies:** A range of government measures can significantly enhance the financial viability of SAF production:
 - **Reducing income tax:** Enabling construction in special economic zones or offering tax breaks could boost investment
 - **Mandating the uptake of SAF:** A mandate could create demand certainty for domestic SAF production. It needs careful evaluation to avoid potential negative impacts on air connectivity, however
 - **Imposing a levy on international arrivals:** A well-designed levy could help offset the SAF green premium



- **Guaranteeing loans:** Guarantees could lower both loan rates and discount rates, reducing capital costs.
- **Leveraging government-owned enterprises:** Entities like Kenya Petroleum Refineries Limited (KPRL) and the Kenya Pipeline Company (KPC) could contribute valuable assets and expertise.
- **Incentivizing or mandating renewable diesel use:** Incentives or mandates could distribute the cost burden across multiple markets.
- **Securing strong offtake agreements:** Robust commitments from airlines, particularly Kenya Airways and major international carriers operating at NBO, are essential. Kenya's position as a major safari destination presents an opportunity to leverage premium domestic flights with lower price elasticity for securing SAF offtake.
- **Facilitating Scope 3 credit purchases:** Large corporations and international organizations based in Nairobi can align their sustainability commitments with their air travel needs by purchasing Scope 3 credits for SAF produced in Kenya. Doing so could provide a valuable source of revenue for SAF producers and incentivize corporate participation in the transition to sustainable aviation.
- **Harnessing international collaboration and financial mechanisms:** Collaboration with multilateral development banks is vital for securing financing at favorable rates and accessing loan guarantees. Engaging with international initiatives like CORSIA could unlock opportunities for carbon credits and ensure the environmental integrity of the produced SAF, enhancing its international acceptance.

Kenya's petroleum fuel consumption in the transport sector is expected to continue climbing rapidly, presenting an opportunity for a strategic shift toward more sustainable fuels and enhanced operational efficiency. As the World Bank's 2023 *Country Climate Change Development Report* for Kenya notes, by ramping up the production of locally sourced biofuels, Kenya can leverage its abundant oil crop feedstocks and agricultural residues, creating a domestically produced, lower-carbon energy option. Because biofuels already integrate seamlessly into existing distribution infrastructure, SAF offers a pragmatic transition path that simultaneously reduces emissions and stimulates local industry.

Alongside SAF, Kenya can explore emerging alternative fuels such as natural gas, hydrogen, and battery or fuel cell systems, all of which complement a broader agenda of decarbonizing transport. Embracing digital platforms to optimize freight and logistics can amplify these efforts, helping Kenya chart a more resilient and climate-friendly path for its rapidly growing transport sector.

Establishing an SAF industry in Kenya faces significant financial hurdles, but the country's unique strengths and opportunities make the ambition achievable. By leveraging existing infrastructure, implementing supportive policies, fostering robust partnerships, and capitalizing on international collaborations, Kenya can overcome the challenges it faces and emerge as a leader in the transition toward a more sustainable aviation future.



Annex 2A Key Assumptions and Data for Techno-Economic Analysis of Kenya

This annex presents key data and assumptions used in the techno-economic analysis of a HEFA-based SAF production facility in Kenya. The tables provide insights into capital and operating expenses, workforce requirements, product pricing, and associated greenhouse gas emissions. Collectively, these tables illustrate the cost structure and environmental performance of the HEFA-based SAF production process, providing crucial insights for decision making in Kenya's SAF market development.

Table 2A.1. Estimated utility requirements in Kenya per kilogram of feedstock

Process	BFW (kg)	Cooling water (kg)	Power (kW)	Natural gas (kg)
Pretreatment	—	—	0.017	—
Hydrotreater	0.250	—	0.006	0.015
Isomerization	—	—	0.003	0.030
Gas-processing unit	—	5.256	0.014	0.004
Hydrogen SMR	0.225	0.250	0.004	0.055 in maximum distillate scenario, 0.11 in maximum jet fuel scenario
Total	0.475	5.506	0.044	0.104/0.159

Adapted from Pearson (2011).

Note: BFW = boiler feed water; SMR = steam methane reforming. — = Not available.





Table 2A.2. Estimated fixed operating expenses in Kenya based on fixed capital investment for a 4,000-barrel per day SAF facility

Type of expense	Description	Annual cost	
		Billion K Sh	Million Dollars
Catalyst		0.3	2.3
Insurance	0.5 percent of fixed cost investment	0.2	1.1
Local taxes	1.0 percent of fixed cost investment	0.3	2.2
Maintenance	5.5 percent of fixed cost investment	1.7	12.3
Miscellaneous supplies	0.15 percent of fixed cost investment	0.05	0.3
Plant staff and operators	Calculated	0.03	0.2
Subtotal		2.6	18.6
Contingency	10 percent of subtotal	0.3	1.9
Total		2.9	20.4

Source: World Bank.

Table 2A.3. Estimated number and annual cost of workers required to operate a 4,000-barrel per day SAF facility

Type of worker	Number of workers	Cost per worker (K Sh)	Total cost (K Sh)
Plant manager	1	3,000,000	3,000,000
Plant engineer	1	1,440,000	1,440,000
Maintenance supervisor	1	1,164,000	1,164,000
Lab manager	1	1,008,000	1,008,000
Lab technician	3	720,000	2,160,000
Shift supervisor	5	864,000	4,320,000
Shift operators	20	864,000	17,280,000
Yard employees	4	504,000	2,016,000
Clerks and secretaries	3	600,000	1,800,000

Source: World Bank.

Number of workers adapted from Brandt et al. 2021.



Table 2A.4. Estimated variable operating expenses for the hydrotreated esters and fatty acids (HEFA) facility in Kenya, July 2023

Expense type	K Sh	Dollars
Makeup water (per L)	0.080	0.0006
Power (per kwh)	24.5	0.17
Natural gas (per kg)	56.4	0.4
Used cooking oil (per kg)	107.5	0.75
Castor oil (per kg)	213.8	1.5

Source: World Bank.

Table 2A.5. Gate prices of refinery products in Kenya (K Sh per liter)

Product	July 2023	12-month average	Five-year average
Propane	45.8	45.8	32.8
Liquefied natural gas	45.8	45.8	32.8
Naphtha	194.7	176.7	120.6
Jet	169.5	148.4	99.9
Diesel	179.7	160.6	108.8

Note: Gasoline prices were used as a surrogate for naphtha. Propane prices were used as a surrogate for liquefied natural gas.

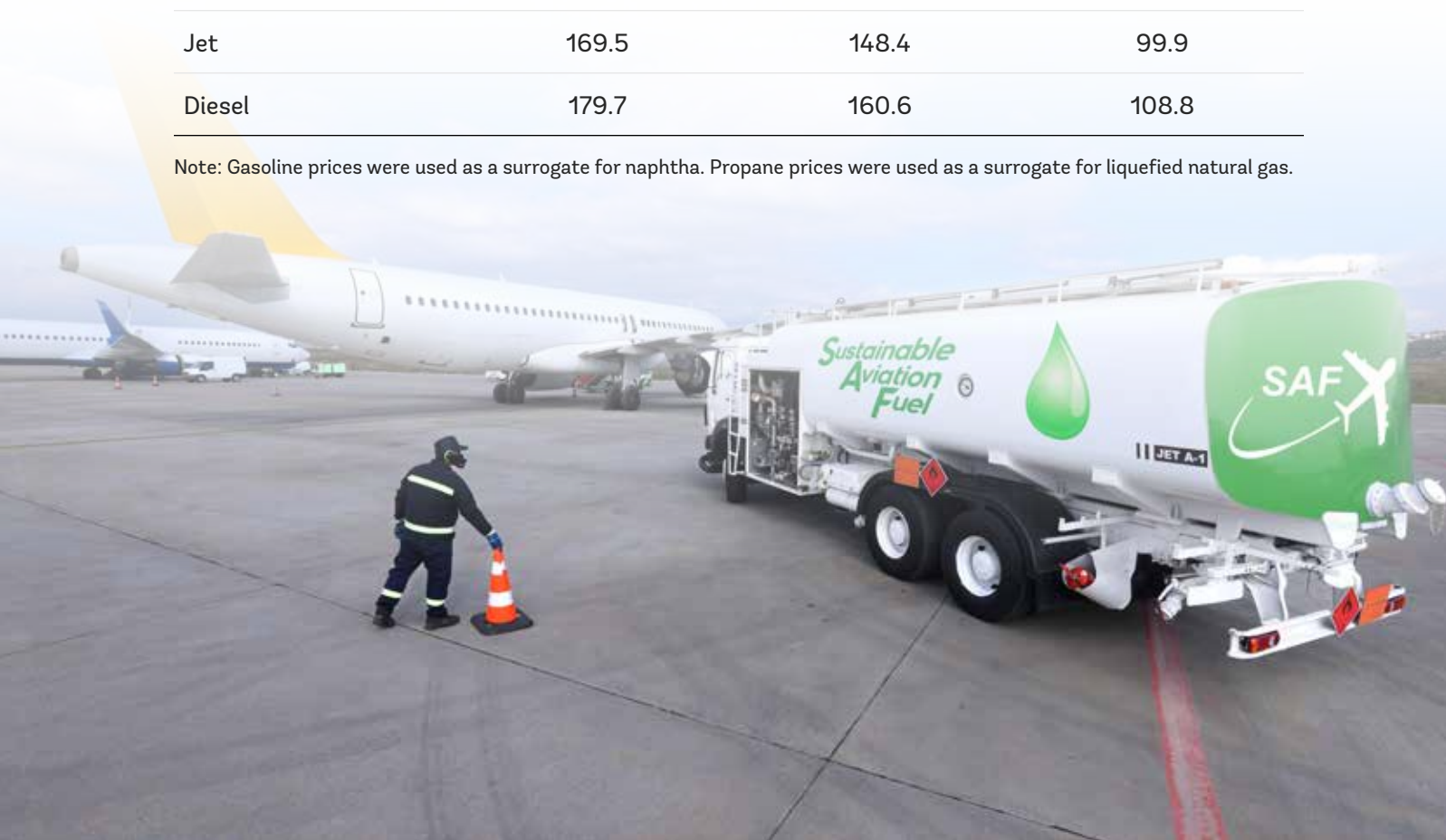



Table 2A.6. Estimated capital expenditures for a 4,000-barrel a day HEFA SAF plant in Kenya

Category	Description	Millions of dollars	Billions of K Sh
Total direct costs			
Inside battery limit costs (ISBL)			
Pretreatment	Calculated	7.3	1.0
Hydroprocessing	Calculated	17.1	2.4
Isomerization/cracking	Calculated	35.0	5.0
H2 island	Calculated	15.8	2.2
Saturated gas plant	Calculated	8.2	1.2
Total ISBL		83.4	11.9
Other direct costs			
Storage, feedstock (13 days)	Calculated	8.2	1.1
Storage, product liquid (25 days)	Calculated	15.7	2.2
Storage, product gas (25 days)	Calculated	0.5	0.07
Cooling water	Calculated	0.1	0.02
Buildings	45 percent of PEC	25.8	3.7
Yard improvement	15 percent of PEC	8.6	1.2
Auxiliary facilities	40 percent of PEC	22.9	3.3
Total direct costs		165.2	23.5
Total indirect costs			
Engineering and supervision	30 percent of total direct costs	49.5	7.1
Construction and expenses	30 percent of total direct costs	49.5	7.1
Total indirect costs		99.1	14.1



Category	Description	Millions of dollars	Billions of K Sh
Contingency	20 percent of total direct and indirect costs	33.0	4.7
Fixed capital investment	Total costs plus contingency	297.3	42.4
Fixed capital investment with location factor		223.9	31.9
Working capital	5 percent of fixed capital investment	11.2	1.6
Total plant investment (total plant investment)	Fixed capital investment plus working capital	235.1	33.5

Note: PEC = Purchase equipment cost; TDC = total direct costs.

Table 2A.7. Estimated greenhouse emissions from production of SAF from used cooking oil–hydrotreated esters and fatty acids (HEFA) (gCO₂e/MJ)

Category	Maximum distillate	Maximum jet	CORSIA MIT (maximum distillate)
Rendering	—	—	3.6
Transport	0.4	0.4	0.3
Pretreatment	1.2	1.1	—
Hydrotreated Esters and Fatty Acids (HEFA)	8.7	12.9	10.5
Transport	0.4	0.4	0.5
Total	10.6	14.8	14.8

Note: gCO₂e/MJ = grams of carbon dioxide equivalent per megajoule; — = Not available; CORSIA MIT = Corresponding data set from the CORSIA document.



Table 2A.8. Estimated greenhouse emissions from production of SAF from castor oil–hydrotreated esters and fatty acids (HEFA) (gCO₂e/MJ/SAF)

Category	Maximum distillate	Maximum jet
Cultivation	20.6	20.2
Transport	0.6	0.6
Oil extraction	3.3	3.2
Transport	0.4	0.4
Pretreatment	1.2	1.1
Hydrotreated esters and fatty acids (HEFA)	8.1	11.7
Transport	0.4	0.4
Total	34.4	37.6

Source: World Bank.





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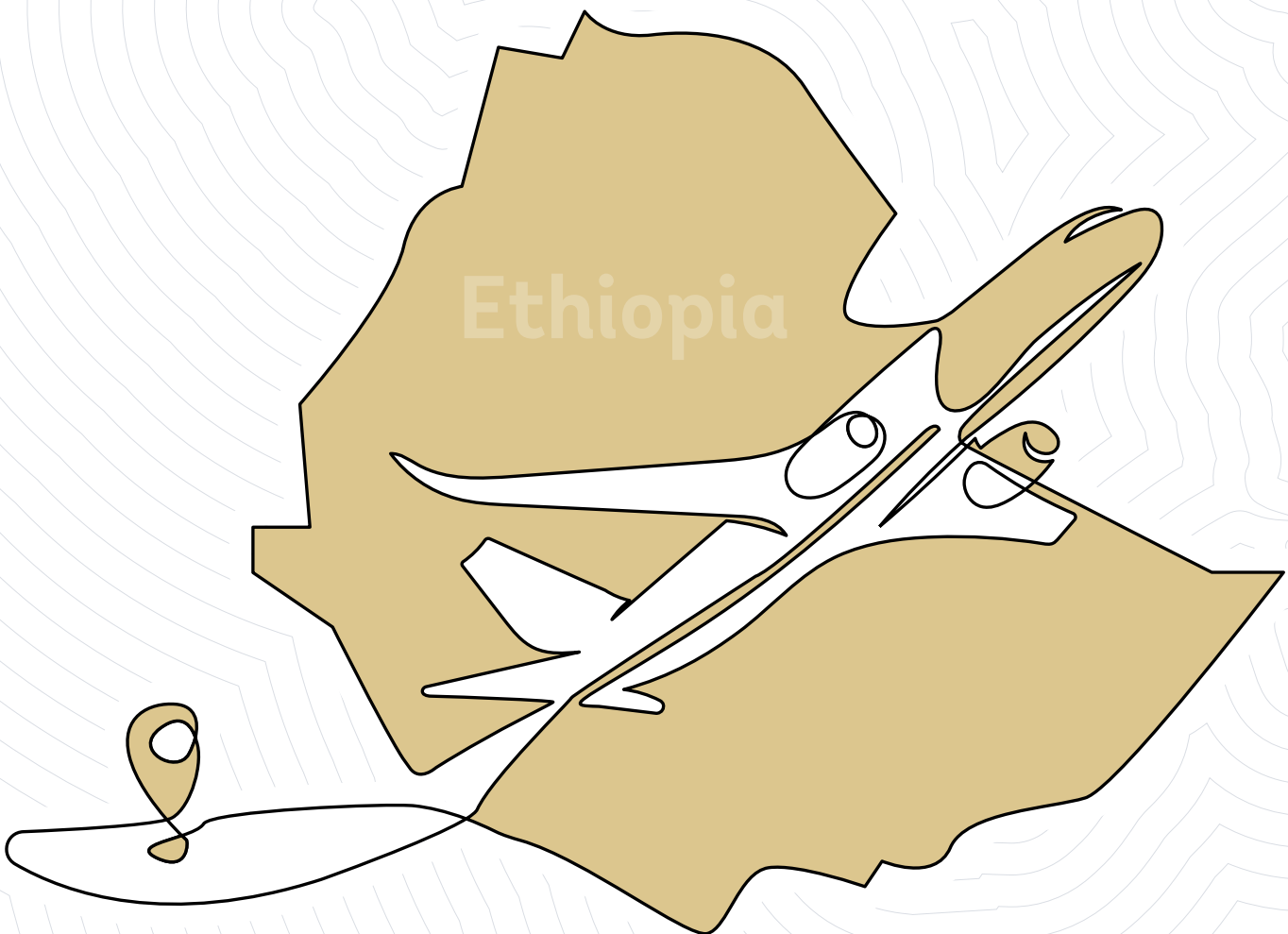
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03

Ethiopia Deep Dive

As a major aviation hub in Africa, Ethiopia has already made strides in SAF initiatives to promote sustainability. This chapter outlines the policy recommendations and regulatory challenges that must be addressed to sustain and boost these initiatives.





Overview

Ethiopia's abundant agricultural resources, pressing waste management needs, and position as a major aviation hub in Africa provide it with the opportunity to establish a sustainable aviation fuel (SAF) industry. Ethiopian Airlines is a driver of Ethiopia's economy, facilitating exports, tourism, and trade. But rising costs because of decarbonization policies in its major destinations—including SAF mandates, carbon-offset programs, and emissions trading schemes—could reduce its competitiveness. Ethiopia has introduced SAF initiatives to reduce reliance on imported jet fuel and promote sustainability, but policy gaps and regulatory challenges hinder progress.

Ethiopia's growing jet fuel demand—which is projected to reach 49,100 barrels per day (BPD) by 2030, almost twice the 2022 level (RSB 2021)—highlights the need for a domestic SAF industry. In 2019, jet fuel imports accounted for 17 percent of total imports, making local production a strategic priority (World Bank 2024).

Ethiopia has promising SAF feedstocks, particularly sugarcane, molasses, and municipal solid waste (MSW). The alcohol-to-jet (ATJ) pathway can use sugarcane and/or molasses, leveraging existing production facilities to reduce initial investment costs and potentially producing 4,700 BPD of SAF. Addis Ababa generates about 750,000 tonnes of MSW annually, 75 percent of which ends up in landfills. Converting this waste through the Fischer-Tropsch (FT) process could yield 1,781 BPD of SAF, simultaneously addressing waste management challenges.

Economies of scale significantly lower SAF production costs. For example, expanding a molasses-ATJ facility from 2,000 to 6,500 BPD reduces per unit capital expenditures (CAPEX) by 52 percent. However, the minimum selling price (MSP) of SAF in Ethiopia remains considerably higher than the current jet fuel market price (\$1.3 per liter), because of high initial capital investments, feedstock costs (especially for sugarcane-based SAF), and risk premiums. A 2,000-BPD MSW-FT facility, for instance, requires an estimated investment of \$547 million. Nonetheless, SAF production offers significant greenhouse emission reductions, with sugarcane- and molasses-ATJ reducing lifecycle emissions by 63 percent and 59 percent, respectively. Depending on the biogenic share of the waste, the MSW-FT pathway could achieve even greater carbon-negative emissions.

To overcome cost barriers and establish a viable SAF industry, Ethiopia must implement strategic interventions across multiple sectors. Government initiatives such as financial incentives, SAF uptake mandates, and a dedicated green energy fund could stimulate investment. The private sector could contribute by securing long-term offtake agreements, promoting corporate SAF purchases, and leveraging existing ethanol production capacity. Multilateral development banks could provide concessional financing and policy and regulatory support and facilitate partnerships among stakeholders. By addressing economic hurdles, fostering a supportive policy environment, and capitalizing on its feedstock advantages, Ethiopia can develop a sustainable SAF industry that enhances energy security, mitigates emissions, and drives economic growth.



Description of Country Case

Aviation and the Economy

Aviation significantly contributes to Ethiopia's economy, generating \$2 billion in GDP and supporting 527,400 jobs in 2023 (IATA 2024). The sector directly employed 19,800 people, and tourism facilitated by aviation added \$1.5 billion to GDP, with international visitors spending \$4.4 billion. Ethiopian Airlines reported a 14 percent increase in revenue in 2023/24, reaching \$7 billion. It carried 17.1 million passengers, 23 percent more than the previous year.

Transport service exports, mostly from Ethiopian Airlines, accounted for \$3.3 billion in 2018, surpassing the country's entire merchandise goods exports that year (\$2.25 billion). The airline enables other essential sectors, particularly the tourism and cut flower industries. Virtually all tourists reach Ethiopia by air. Ethiopian Airlines' robust air freight network is indispensable for the cut flower industry, which accounts for roughly two-thirds of Ethiopian air cargo destined for the European Union. Its extensive network facilitates the air transport of over 50 percent of Ethiopia's exports to the European Union and 40 percent to the United States (World Bank 2024).

Ethiopian Airlines faces growing economic competitiveness challenges from climate and environmental policies in key markets, especially the European Union. It relies heavily on fifth and sixth freedom traffic rights, which constitute a significant portion of its operations and revenues, making it particularly vulnerable to EU mandates such as the requirement for SAF usage.³⁰ The RefuelEU Aviation Initiative mandates that fuel suppliers blend SAF with conventional jet fuels at increasing ratios that will reach 70 percent by 2050, with a 2 percent blend of SAF at European airports kicking in 2025 (EC 2023). Compliance with these regulations increases operational costs for Ethiopian Airlines.

Ethiopian Airlines is also grappling with emissions trading schemes (ETS), especially the EU ETS, which will become more stringent over time. Under the EU ETS, airlines must monitor, report, and offset carbon emissions from flights within and between European Economic Area countries, a process that will increasingly require the purchase of carbon allowances as free allocations are phased out by 2026 (EC 2021). In addition, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) mandates that airlines offset emissions growth by purchasing carbon credits, adding to operational costs (ICAO n.d.). Ethiopian Airlines is currently exempt from some CORSIA requirements, because of Ethiopia's status as a least developed country, but the airline still incurs costs for flights between participating countries. The phased transition to SAF, as mandated by EU regulations, will also affect Ethiopian Airlines, by increasing fuel prices and requiring compliance with sustainability criteria. The pressures from carbon trading, offset programs, and SAF mandates underscore the airline's need to adapt to evolving decarbonization policies to maintain competitiveness in the global aviation market.

³⁰ Fifth freedom traffic rights allow an airline to carry passengers between two foreign countries on a flight that starts or ends in its home country (such as an Ethiopian Airlines flight from Addis Ababa to Stockholm via Rome, picking up passengers in Rome). Sixth freedom traffic rights allow an airline to transport passengers between two foreign countries with a connection in its home country (for example, flying passengers from Amsterdam to Cape Town via Addis Ababa). Ethiopia is a key proponent of air transport liberalization in Africa, positioning the continent as the backbone of the airline's demand base (Abate 2016).



Air Transport Decarbonization Policies

Ethiopia has initiated several measures to promote a low-carbon transport sector. In 2017, it adopted the Climate Resilient Transport Sector Strategy, which aims to reduce greenhouse gas emissions in air transport by incorporating up to 10 percent alternative fuel by 2030 (Ministry of Transport 2017). In 2021, it introduced a 10-year Sustainable Aviation Fuel Development Roadmap, to position Ethiopia as a leading SAF producer in Africa (RSB 2021). This roadmap outlines the steps needed to develop SAF, identifies potential local feedstock sources, and suggests applicable conversion technologies to support the decarbonization of the national airline while ensuring food security and environmental protection.

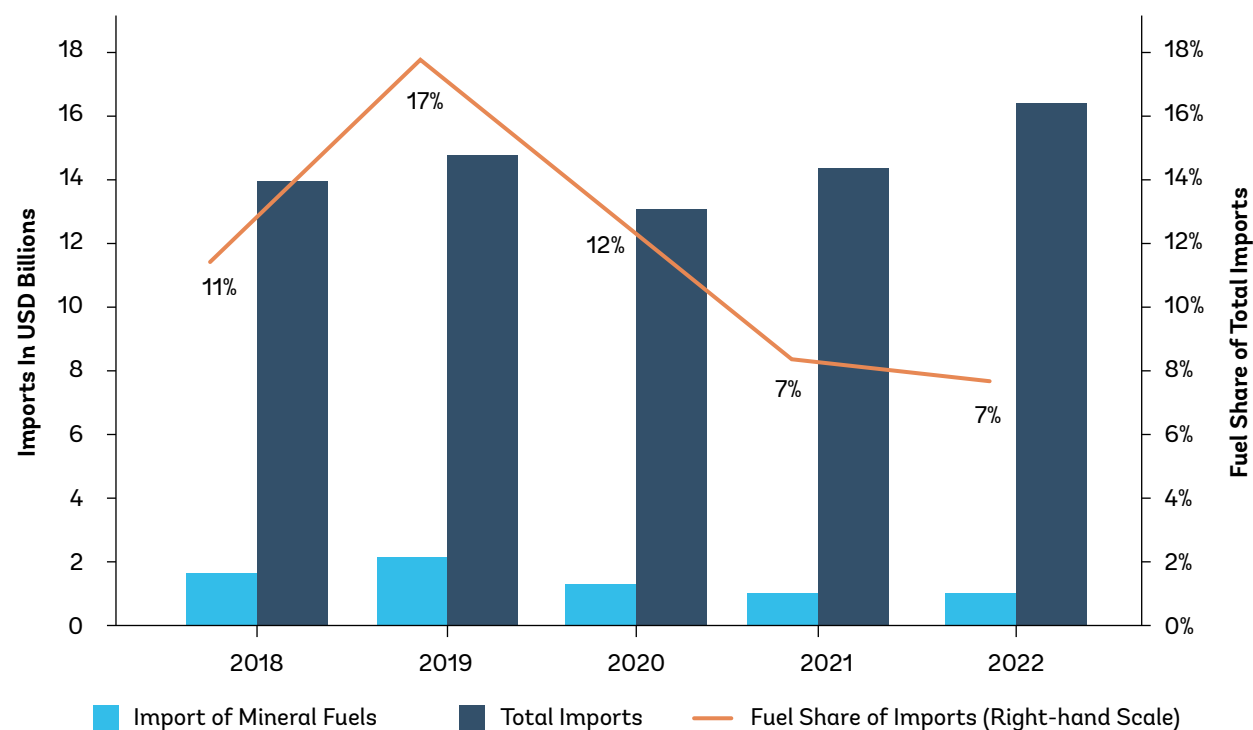
Ethiopia's updated biofuel strategy, currently in draft, builds on the 2007 strategy. It addresses its shortcomings; sets clear objectives; and aligns with broader national policies, including energy security, climate resilience, and economic growth. It supports the Ethiopian Energy Policy (1994), the Climate Resilient Green Economy strategy (2011), the Long-Term Low Emissions Development Strategy (2021), and the Draft Energy Policy (2023). A key addition is the inclusion of SAF as a strategic priority, with targets of 5 percent blending by 2030 and 20 percent by 2035. The strategy highlights hydrotreated esters and fatty acids (HEFA) and ATJ technologies, emphasizes the need for regulatory and infrastructure support, and explores Ethiopia's feedstock potential for SAF production. By integrating sustainability criteria and certification schemes, it aims to enhance market access and contribute to aviation decarbonization in line with International Civil Aviation Organization (ICAO) targets.

These initiatives notwithstanding, Ethiopia's SAF policy framework has notable gaps. There is a lack of an enabling policy and regulatory framework essential for the development and deployment of SAF. Key components such as blending mandates and standards have not been established, hindering new investments and production. Biofuel development efforts are fragmented, with various offices and nongovernmental organizations working independently, lacking strong federal coordination and a coherent national policy. The absence of a comprehensive national SAF policy that defines government roles, sets a regulatory framework, and provides incentives is a significant shortfall. A national action plan that involves all stakeholders and ensures effective monitoring and evaluation systems is needed. Addressing these gaps is crucial for creating a supportive environment for SAF development and realizing Ethiopia's potential as a major SAF producer.

Jet Fuel Demand and Supply

Ethiopia's current and projected jet fuel demand presents a significant opportunity for investment in SAF. In 2022, Ethiopia consumed about 25,200 BPD of jet fuel, making it the largest market for jet fuel in Sub-Saharan Africa (table 3.1). Jet fuel accounted for 21 percent of Ethiopia's total petroleum product demand. This demand is projected to nearly double by 2030, reaching 49,100 BPD (RSB 2021). This massive increase underscores the need for alternative fuel solutions to meet demand sustainably.

Ethiopia imports all of its jet fuel. These imports constituted 17 percent of the country's total imports in 2019 (World Bank 2024) (figure 3.1). With jet fuel and diesel comprising 83 percent of the country's petroleum product demand and the projected increase in overall fuel consumption to about 235,000 BPD by 2030 (table 3.1), the market potential for SAF is substantial. The concentration of jet fuel demand at Addis Ababa Bole International Airport simplifies logistics and distribution, making it an ideal hub for SAF deployment.

Figure 3.1. Value of fuel imports by Ethiopia and share in total imports, 2018–22


Source: World Bank (2024).

Table 3.1. Annual fuel demand in Ethiopia, by product type, 2019, 2022, and 2030

Type of fuel	2019		2022		2030	
	Million liters	Thousand BPD	Million liters	Thousand BPD	Million liters	Thousand BPD
Gasoline	1.8	11.3	3.0	18.9	5.7	35.9
Jet	2.8	17.6	4.0	25.2	7.8	49.1
Diesel	9.1	57.2	11.5	72.3	23.4	147.2
Fuel oil	0.2	1.3	0.5	3.1	0.6	3.8
Total	14.0	88.1	18.5	116.4	37.4	235.2

Source: EPSE (2019).

Note: BPD = barrels per day.



Feedstocks and Conversion Technology

Feedstock Potential

Ethiopia holds significant potential for biofuel production. The government estimates that 23.2 million hectares of “marginal” land (land not competing with food production) could be used for biofuel feedstock (Fischer and others 2019).³¹ A 2021 assessment by the Roundtable for Sustainable Biomaterials highlights Ethiopia’s high biofuel potential among African countries and identifies actions to develop SAF (RSB 2021). The report also notes that production of biofuel feedstock could enhance socioeconomic development, job creation, and rural development.

Ethiopia has three blending facilities and two ethanol distilleries; it lacks biorefineries. Potential feedstocks include agricultural residues, castor, Ethiopian mustard, *Jatropha curcas*, sugarcane, and water hyacinth.³²

The strategic adoption of sugarcane, molasses, and municipal solid waste (MSW) as SAF feedstocks aligns well with Ethiopia’s existing capabilities, resource availability, and environmental goals. These feedstocks make sense for Ethiopia for a variety of reasons.

Ethiopia’s climate is highly conducive to the cultivation of sugarcane. Favorable climate conditions ensure a stable and potentially high yield of sugarcane, which is crucial for producing molasses, a co-product. In addition, Ethiopia already has established production facilities for sugarcane and molasses. This infrastructure could be leveraged for SAF production, reducing the need for significant new investments. Using these facilities could also facilitate a quicker turnaround in establishing a sustainable fuel supply chain.

MSW holds significant potential as a feedstock for SAF in Ethiopia. Addis Ababa, the capital, generates about 750,000 tonnes of MSW a year, 75 percent of which is landfilled (IFC 2018). MSW, the feedstock for the Fischer-Tropsch (FT) pathway, is collected in major cities, with collection rates of 40–60 percent (GIZ GmbH 2023). Using MSW as a feedstock for the FT pathway would transform this waste into a valuable resource. The abundance of MSW in Addis Ababa ensures a steady supply of material for fuel production: If all the landfilled MSW in Addis Ababa were used for liquid fuel production via the FT pathway, it would yield an estimated 1,781 BPD of SAF a year.

The environmental and health benefits of using MSW for SAF production are significant. In many developing countries, waste is often not collected or is simply landfilled, leading to severe pollution and health hazards.³³ By converting MSW to SAF, Ethiopia could reduce the volume of landfilled waste, mitigating pollution and improving public health conditions. This approach aligns with sustainable waste management practices and supports broader environmental goals, including reducing greenhouse gas emissions and improving urban living conditions.

³¹ The definition of marginal land is still debated.

³² Ethiopia’s abundant renewable electricity, primarily from hydroelectric power can be a significant advantage in producing e-SAF, a synthetic fuel made using green hydrogen and carbon dioxide. Ethiopia generates 96 percent of its electricity from renewable sources, offering low-cost energy for the energy-intensive e-SAF production process (IRENA, 2023). This advantage attracts international investors and enhances the country’s competitiveness in the global SAF market. Challenges remain, however, such as the high costs of financing projects and the need for regulatory clarity regarding investment licensing, particularly regarding categorizing hydrogen as a fuel or a chemical.

³³ Sanitary landfilling can avoid environmental pollution and health hazards; methane in landfill gas remains an important source of emissions.



Ethiopia already produces bioethanol from molasses, which is used in a 5 percent blend with gasoline for road transport and household cooking. There is also significant demand for molasses from alcohol distillers, who offer higher premiums to sugar factories. Ethanol distilleries at Metehara and Finchaa have a combined capacity of 32.5 million liters a year but are underutilized because of low sugarcane supply (in 2019 they produced only 8 million liters of ethanol) (Yimam 2022). In 2021, Ethiopia produced 177 million liters of molasses (Knoema 2022), which could be converted into 1,200 BPD of SAF. Future projects are projected to increase molasses production to 680 million liters, potentially producing 4,700 BPD of SAF (RSB 2021). This increase in production capacity would significantly boost Ethiopia's SAF output, making it a player in the SAF market.

Alcohol-to-Jet Plant Design

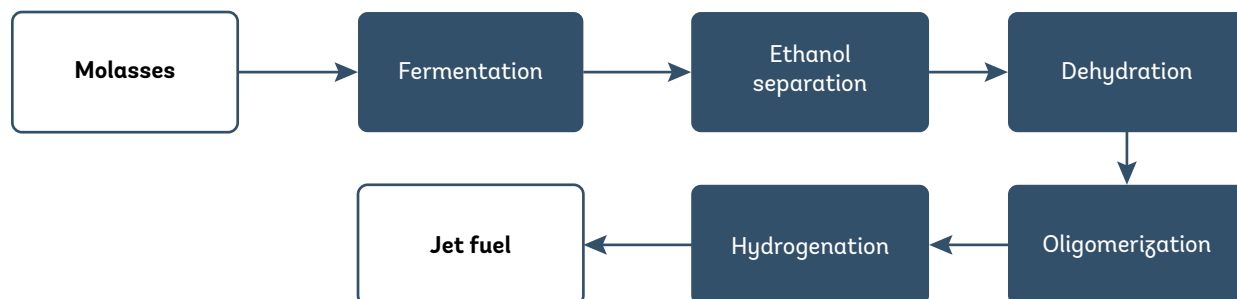
The ATJ plant design for producing SAF from molasses and sugarcane involves fermentation, ethanol separation, dehydration, oligomerization, and hydrogenation (figure 3.2). The ethanol production facility is assumed to be annexed to a sugar mill, from which molasses could be directly purchased. Feedstock is fed into the fermentation unit, where simple sugars are converted to ethanol. Ethanol is then separated from the broth. Conversion of alcohol into jet fuel is a three-step process that includes alcohol dehydration, oligomerization and hydrogenation (for details of these process, see Geleynse and others 2018). Sugarcane can also be used as a feedstock (figure 3.2, panel b).



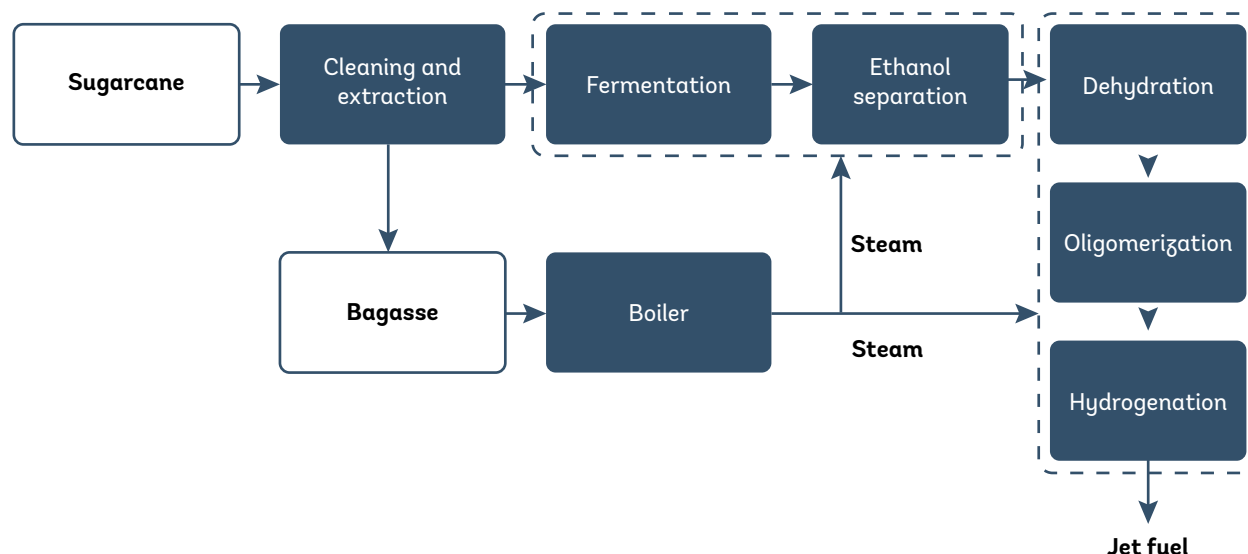


Figure 3.2. Simplified process flow diagram of production of SAF from molasses and sugarcane using the alcohol-to-jet pathway

a. Molasses-ATJ pathway



b. Sugarcane-ATJ pathway



Source: Original figure for this publication.

Three facility sizes are considered for the ATJ plant: 2,000, 4,000, and 6,500 BPD (table 3.2). The costs of fuel production are modeled for a greenfield investment. For a 2,000-BPD facility, projected fuel output includes 1,445 BPD of SAF, 350 BPD of diesel, and 205 BPD of gasoline.



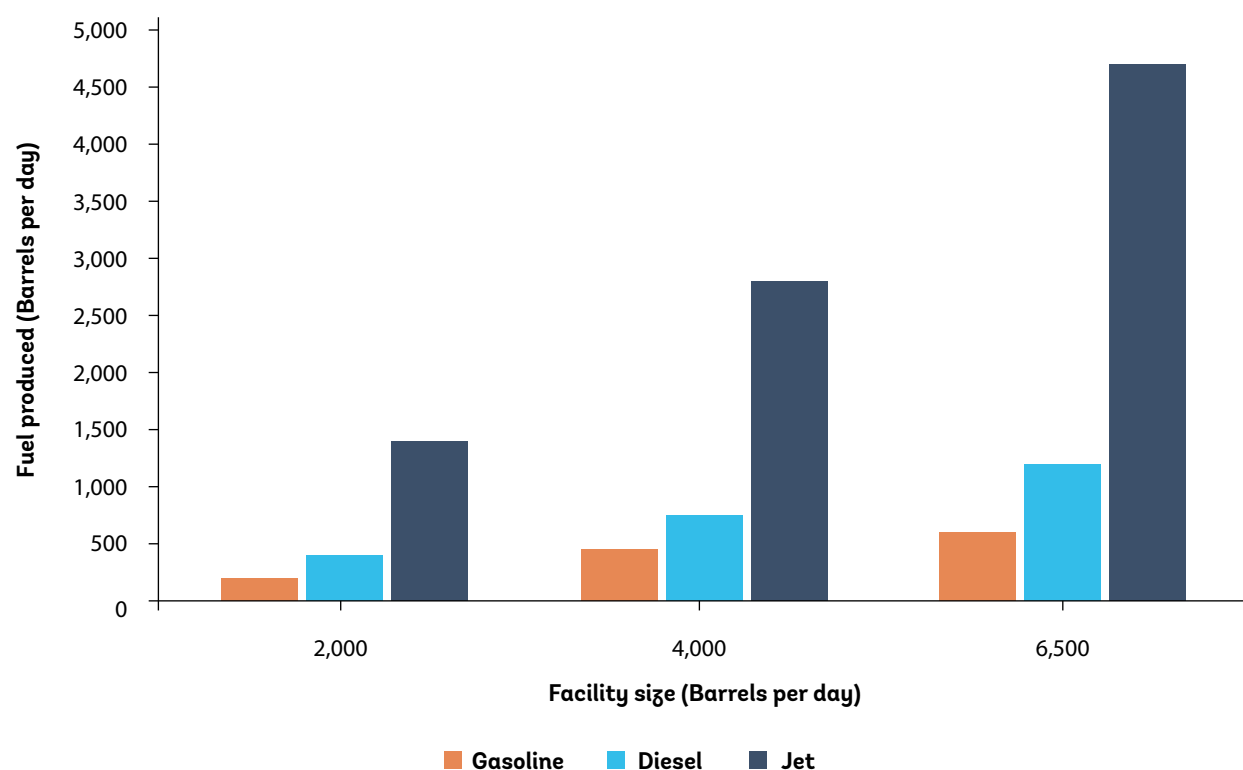
Table 3.2. Projected annual production of SAF, diesel, and gasoline in Ethiopia by a 2,000-barrel per day facility through the alcohol-to-jet pathway

Product	Annual production		
	Millions of liters	Barrels per day	Percent of total production
Sustainable aviation fuel	75	1,445	70
Diesel	18	350	20
Gasoline	11	205	10
Total	104	2,000	100

Source: Original table for this publication.

Figure 3.3 displays the volume of fuel products that could be produced from different plant sizes. A single 6,500-BPD ATJ facility coming online in 2030 could satisfy 6.8 percent of projected total jet fuel demand in Ethiopia and 0.7 percent of projected total diesel demand in 2030.

Figure 3.3. Projected volume of gasoline, jet fuel, and diesel that could be produced in Ethiopia through the alcohol-to-jet pathway, by facility size



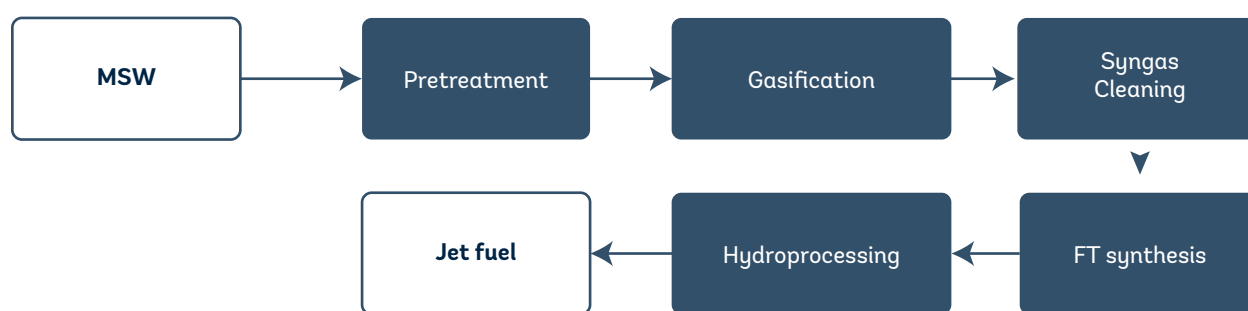
Source: Original figure for this publication.



Fischer-Tropsch Plant Design

The Fischer-Tropsch (FT) pathway starts with pretreatment of the MSW (figure 3.4). Syngas is then produced via gasification of the pretreated feedstock. Syngas is a mixture of carbon monoxide (CO) and hydrogen gas (H₂); raw syngas also contains small amounts of other gases, such as carbon dioxide (CO₂) and methane (CH₄). Syngas from biomass may also contain impurities such as nitrogen oxide (NO_x) and sulfur oxide (SO_x) gases, which can poison and deactivate the FT catalysts, reducing efficiency. These impurities should be removed and the H₂/CO ratio adjusted before FT synthesis. The cleaned syngas is subsequently compressed and sent into the FT reactor for the synthesis of small-chain olefins. After the synthesis, conventional refinery processes such as hydrocracking, hydroisomerization, and fractionation processes are necessary to obtain the finished jet fuel mixture.

Figure 3.4. Transformation of municipal solid waste into jet fuel through the Fischer-Tropsch pathway



Source: Original figure for this publication.

Three facility sizes are considered for the MSW-FT pathway: 2,000, 4,000, and 6,500 BPD. The product profiles show a balanced distribution of output, consisting of 40 percent SAF (853 BPD), 40 percent diesel (723 BPD), and 20 percent naphtha (424 BPD) (table 3.3). This balance ensures that the facility meets both aviation and ground transportation demands, enhancing financial viability by tapping into different transportation markets. The significant SAF share highlights the focus on reducing aviation carbon emissions. Inclusion of naphtha diversifies the product portfolio, tapping into various market segments and bolstering economic resilience.

Table 3.3. Projected annual production of SAF, diesel, and naphtha in Ethiopia by a 2,000-barrel per day facility through the municipal solid waste to Fischer-Tropsch pathway

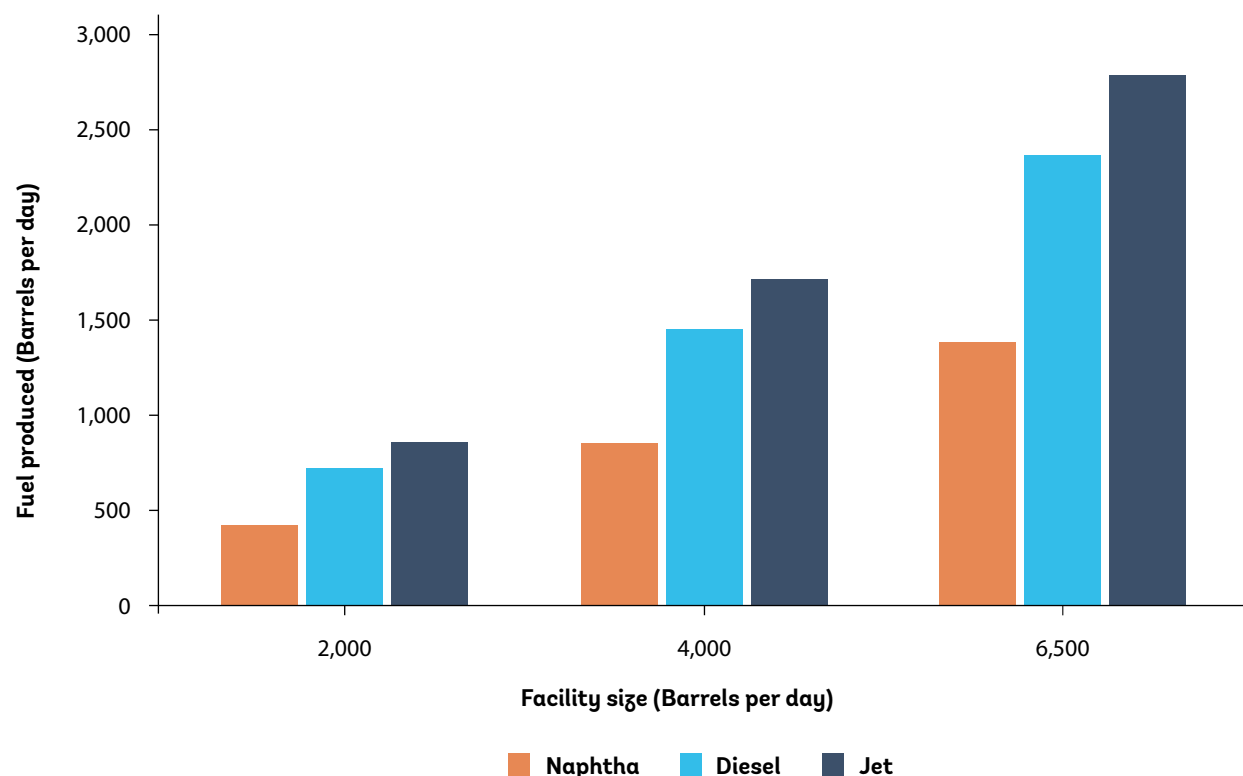
Product	Annual production		
	Millions of liters	Barrels per day	Percent of total
Sustainable aviation fuel	44	853	40
Diesel	38	723	40
Naphtha	22	424	20
Total	104	2,000	100

Source: Original table for this publication.



Figure 3.5 displays the volume of fuel products that could be produced by different plant sizes. A 6,500-BPD MSW-FT facility coming online in 2030 could satisfy 3.9 percent of projected total jet fuel and 1.2 percent of total projected diesel demand in Ethiopia that year.

Figure 3.5. Projected production of jet fuel, diesel, and naphtha products in Ethiopia through the municipal solid waste to Fischer-Tropsch pathway, by facility size



Source: Original figure for this publication.

Techno-Economic Model and Results

The techno-economic analysis of the ATJ and FT pathways for SAF production incorporates several empirical assumptions.³⁴ The analysis uses *n*th plant assumptions, indicating that the facilities are based on mature, established petrochemical designs rather than pioneering new technologies. Capital cost data is derived from studies by Brandt and others (2021) and Humbird and others (2011), updated to 2022 using the Chemical Engineering Plant Cost Index (CEPCI).³⁵ A significant assumption involves the adaptation of geographic location factors for cost translation from the United States to Ethiopia (Kenya's economic and industrial conditions serve as a proxy, because of the lack of data for Ethiopia). This adjustment is crucial for accurate financial forecasting and underscores the need to consider regional economic disparities in such analyses.

³⁴ For details of the modeling methodology and key assumptions, see the chapter annex.

³⁵ See <https://www.chemengonline.com/pci-home>.



Costs of Production Results

Cost of the alcohol-to-jet pathway using molasses

For the ATJ pathway using molasses as a feedstock, the analysis estimates total plant investment for a 2,000-BPD production facility at about \$111.2 million (see table 3A.5 in the annex to this chapter). Direct costs total \$58.8 million. Inside battery limit (ISBL) costs include process steps like fermentation, ethanol separation, dehydration, oligomerization, hydrogenation, and fractionation. Purchased equipment costs amount to \$23.7 million, with installation costs calculated as 40 percent of these equipment costs, yielding ISBL costs of \$33.2. Other direct costs include catalyst fill, buildings, yard improvements, and auxiliary facilities. Indirect costs (comprising engineering, supervision, and construction expenses) total \$35.39 million. With a contingency of 20 percent, the fixed capital investment reaches \$105.9 million. After adding working capital (5 percent of fixed capital investment), the final total plant investment stands at \$111.2 million.

The analysis reveals substantial economies of scale in SAF production (table 3.4). Doubling capacity from 2,000 to 4,000 BPD results in a 35.9 percent reduction in CAPEX per unit of capacity; increasing capacity to 6,500 BPD offers a 51.6 percent reduction compared with the 2,000-BPD baseline.

Table 3.4. Total investment required in facility in Ethiopia that produces jet fuel from molasses, by size

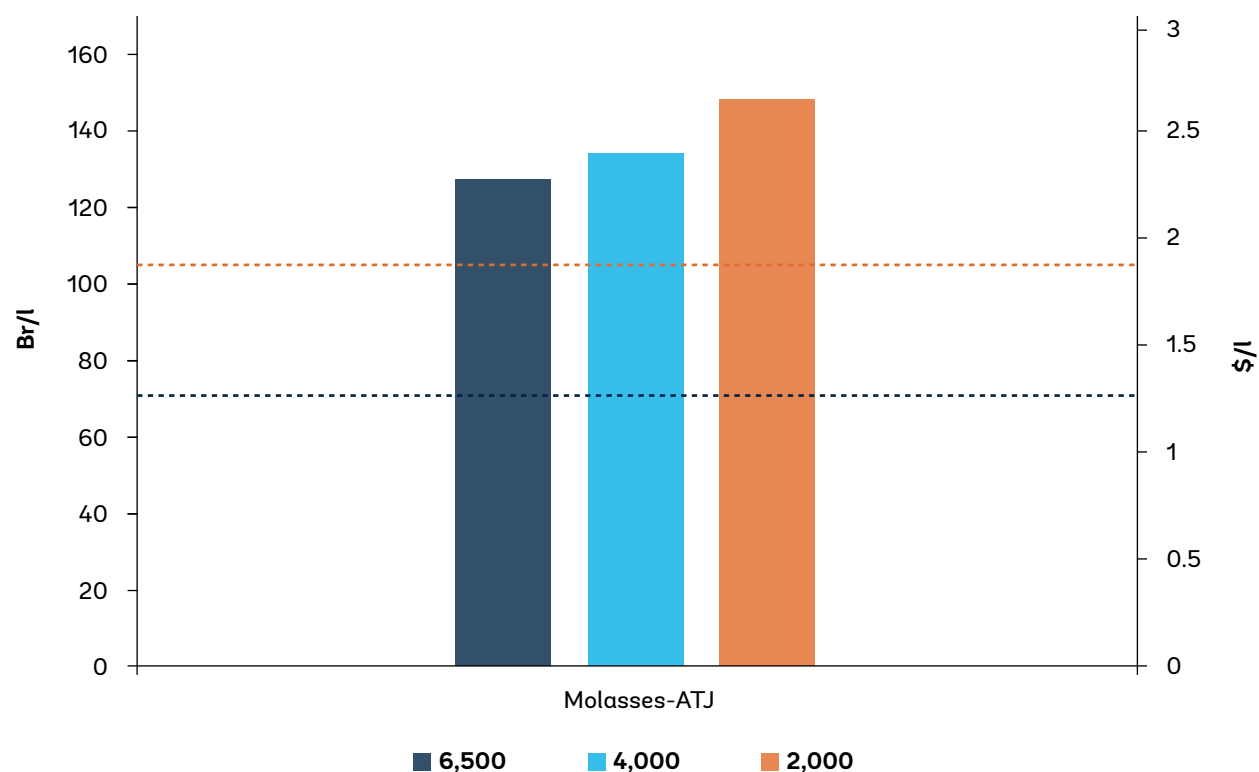
Facility size (barrels per day)	Investment (millions)	
	Dollars	Birr
2,000	111	6.2
4,000	143	8.0
6,500	175	9.8

Source: Original table for this publication.

The minimum selling prices (MSPs) for jet fuel derived from molasses were calculated to achieve a net present value of zero across various production scales. The MSPs are \$2.6, \$2.4, and \$2.3 per liter (\$1 = Br 56.15), for facilities with capacities of 2,000, 4,000, and 6,500 BPD, respectively (figure 3.6). The 2,000-BPD facility is set as the baseline, out of concerns about the availability of feedstock in Ethiopia. This baseline MSP is about twice as high as the 2023 market price of conventional jet fuel in Ethiopia (\$1.3 per liter) and about 50 percent higher than the 2024 average world market price of SAF (\$1.83 per liter). Splitting the costs associated with environmental benefits (the green premium) equally between jet and diesel fuels yields a baseline MSP of \$2.3 per liter for jet fuel and \$2.4 per liter for diesel (the 2023 price of conventional diesel was \$1.4 per liter).



Figure 3.6. Minimum selling price for jet fuel produced in Ethiopia from molasses, by facility size (2,000, 4,000 and 6,500 barrels per day)



Note: The black dashed line shows the conventional kerosene price in Ethiopia (\$1.3 per liter). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).

Source: Original figure for this publication.

Cost of the alcohol-to-jet pathway using sugarcane

Using sugarcane as a feedstock would require estimated total plant investment of about \$376 million for a 2,000-BPD production facility (see table 3A.6 in the annex to this chapter). This investment accounts for specialized processing units beyond those used in the molasses-ATJ scenario, such as sugarcane milling, sugar extraction, and various reactors and processing equipment necessary for the ATJ conversion process.

The breakdown of CAPEX includes ISBL of \$114.9 million, which encompasses equipment for cane milling, extraction, fermentation, ethanol separation, and various stages of fuel synthesis, including dehydration, oligomerization, and hydrogenation. Other direct costs, reflecting expenses for building construction, yard improvement, and auxiliary facilities, add up to \$84.3 million. Total direct cost are \$199.2 million. Indirect costs for engineering, supervision, and construction bring the total to \$318.7 million. After accounting for contingencies and working capital, the adjusted total plant investment totals \$376.4 million.

Expanding the facility size from 2,000 to 4,000 BPD results in a 24.6 percent reduction in CAPEX for a doubling of capacity (table 3.5). Increasing the capacity to 6,500 BPD, is a 225 percent increase from the 2,000-BPD base, achieves a more substantial 37.3 percent reduction in CAPEX compared with the initial size.


Table 3.5. Total investment required in facility that produces jet fuel from sugarcane, by size

Facility size (barrels per day)	Investment (millions)	
	Dollars	Birr
2,000	376	21.1
4,000	567	31.9
6,500	768	43.1

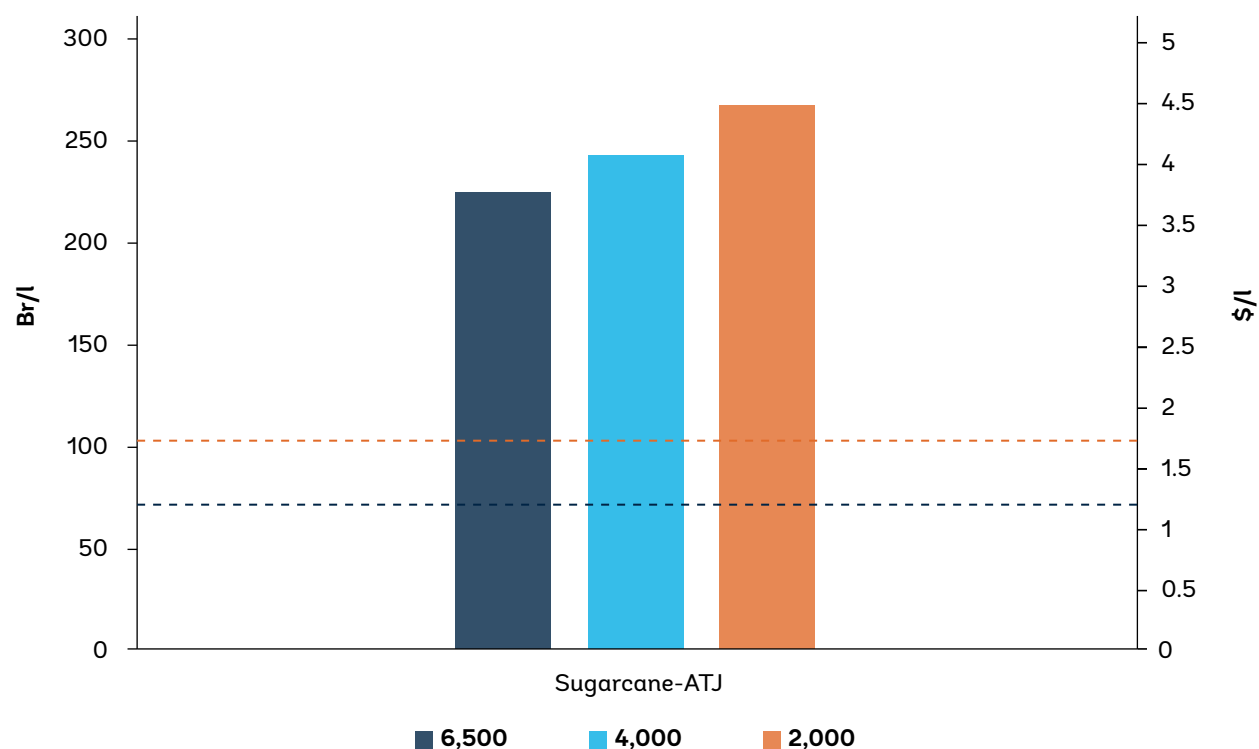
Source: Original table for this publication.

The MSP for combined jet and diesel fuel production demonstrates the cost reduction with increasing scale, but a substantial gap remains with current fuel prices. MSP values are \$4.6, \$4.2, and \$4.0 per liter for facilities with capacities of 2,000, 4,000, and 6,500 BPD, respectively, when the green premium is shared equally between diesel and jet fuel (figure 3.7). When focusing exclusively on jet fuel, the MSP for a 4,000-BPD facility jumps to \$4.9 per liter—383 percent higher than current jet fuel market rates, underscoring the significant premium associated with SAF when the burden is not shared. This pricing structure is based on a decentralized biorefinery model that uses a simplified sugarcane juice extraction process, as described by Klaver, Petersen, and Görgens (2023). Although the process is optimized to yield 94 liters of ethanol per tonne of sugarcane (Petersen and others 2018), the facility functions as a first-generation ethanol plant, where bagasse is used only to generate steam, not to produce ethanol, leading to lower ethanol outputs and consequently higher ATJ fuel costs. This plant was chosen because of its lower technological complexity, which increases the chance that it would be built.





Figure 3.7. Minimum selling price for jet fuel produced in Ethiopia from sugarcane, by facility size (2,000, 4,000 and 6,500 barrels per day)



Note: The black dashed line shows the conventional kerosene price in Ethiopia (\$1.3 per liter). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).

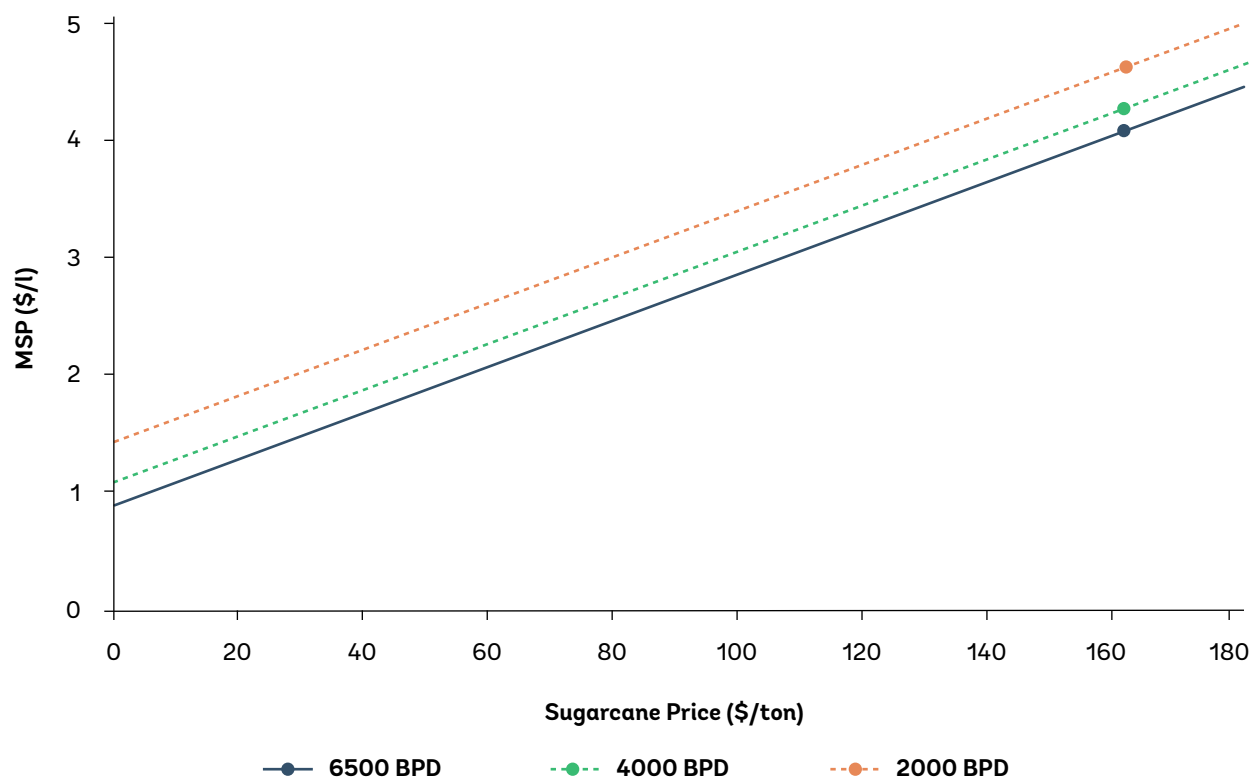
Source: Original figure for this publication.

Given the relatively high selling price of sugarcane-ATJ-SAF, we explore the effect of sugarcane prices on the fuel selling price. Figure 3.8 plots the MSP price of sugarcane-ATJ as a function of the price of sugarcane for the three different plant sizes considered. The MSP per liter changes by \$0.19 when the sugarcane price per ton changes by \$10, revealing the importance of feedstock costs for the financial viability of this pathway.





Figure 3.8. Effect of sugarcane price on minimum selling price of fuel in Ethiopia, by facility size



Note: The baseline sugarcane cost is \$161.37 a tonne.

Source: Original figure for this publication.

Costs of using municipal solid waste to produce jet fuel

The analysis of CAPEX for MSW-FT facilities of varying sizes reveals more modest economies of scale than for ATJ facilities. The data indicate an 18 percent reduction in CAPEX when capacity doubles from 2,000 to 4,000 BPD; this reduction rises to 25 percent when capacity is increased to 6,500 BPD (table 3.6). Fixed capital investment is \$521 million for a 2,000-BPD facility, \$859 million for a 4,000-BPD facility, and \$1,277 million for 6,500-BPD facility.

Table 3.6. Total investment required in facility in Ethiopia that produces jet fuel from municipal solid waste, by size

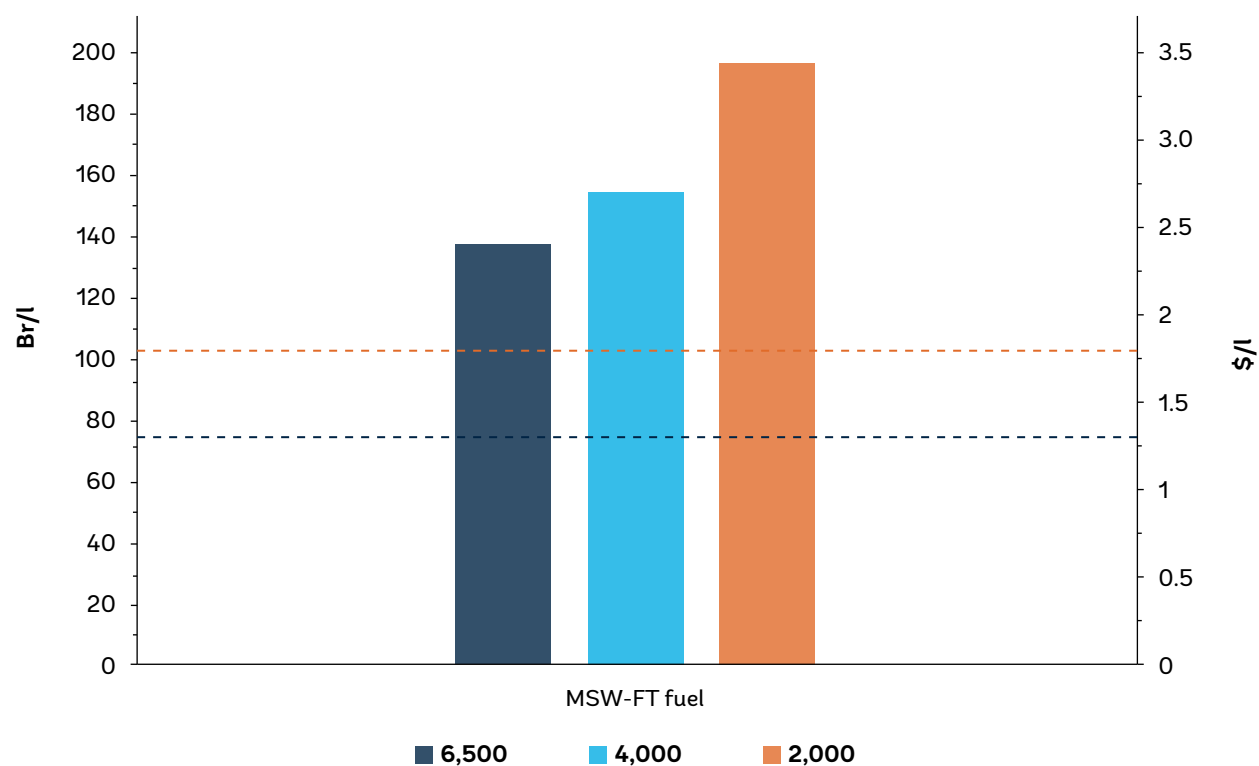
Facility size (barrels per day)	Investment (millions)	
	Dollars	Birr
2,000	547	31
4,000	901	51
6,500	1,340	75

Source: Original table for this publication.



The MSP decreases with the size of the facility, with MSPs of \$3.5, \$2.7, and \$2.4 per liter for facilities with capacities of 2,000, 4,000, and 6,500 BPD, respectively (figure 3.9). The baseline scenario for a 2,000-BPD facility has an MSP for jet fuel that is 2.8 times higher than the 2023 market price of conventional jet fuel in Ethiopia (\$1.3 per liter) and 90 percent higher than the average global price paid for SAF. When the green premium is distributed equally between jet and diesel fuels, the MSPs decrease to \$2.5 per liter for jet fuel and \$2.6 for diesel. The price of renewable diesel in Ethiopia is \$1.4 per liter, highlighting the premium associated with these sustainable fuels and the impact of facility scaling on reducing production costs.

Figure 3.9. Minimum selling prices for jet fuel produced in Ethiopia from municipal solid waste by facility size (2,000, 4,000, and 6,500-barrels per day)



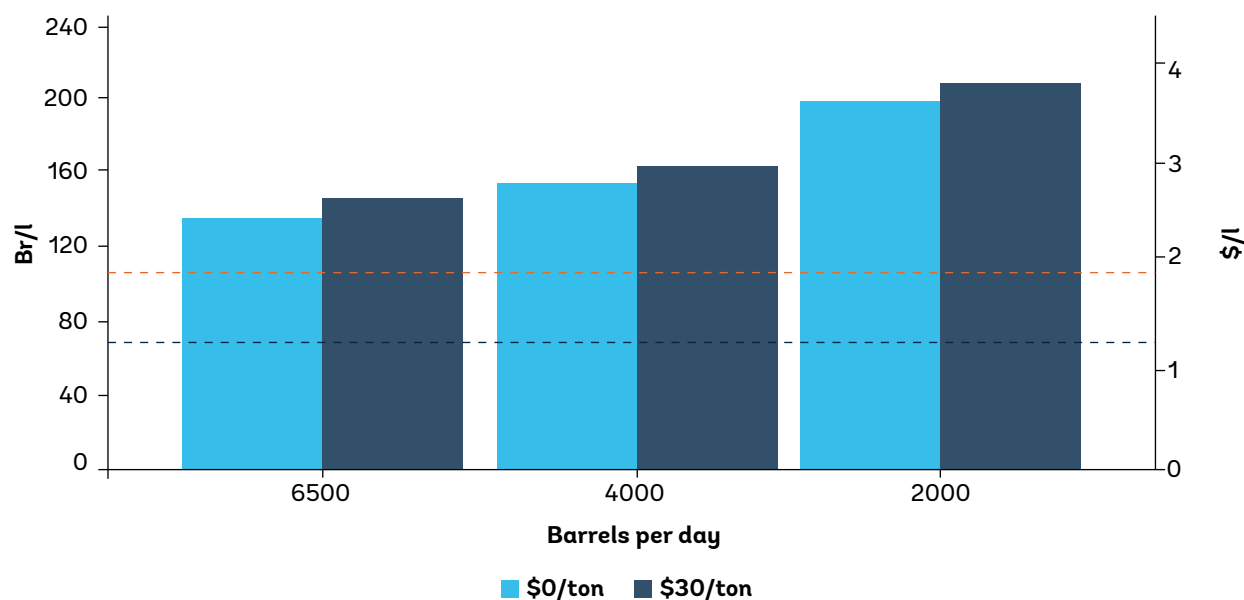
Note: The black dashed line shows the conventional kerosene price in Ethiopia (\$1.3 per liter). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).

Source: Original figure for this publication.

MSW is assumed to be collected free of charge to the fuel producer in the baseline scenario, as the waste management agency benefits from the arrangement by avoiding landfill costs. We also examined a scenario in which MSW is priced at \$30 a tonne. In this case, the MSP increases by \$0.2 per liter (8 percent) in the baseline case of the 2,000-BPD facility (figure 3.10).



Figure 3.10. Sensitivity of minimum selling price of jet fuel produced in Ethiopia from municipal solid waste (MSW) to price of MSW, by facility size



Note: The black dashed line shows the conventional kerosene price in Ethiopia (\$1.3 per liter). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).

Source: Original figure for this publication.

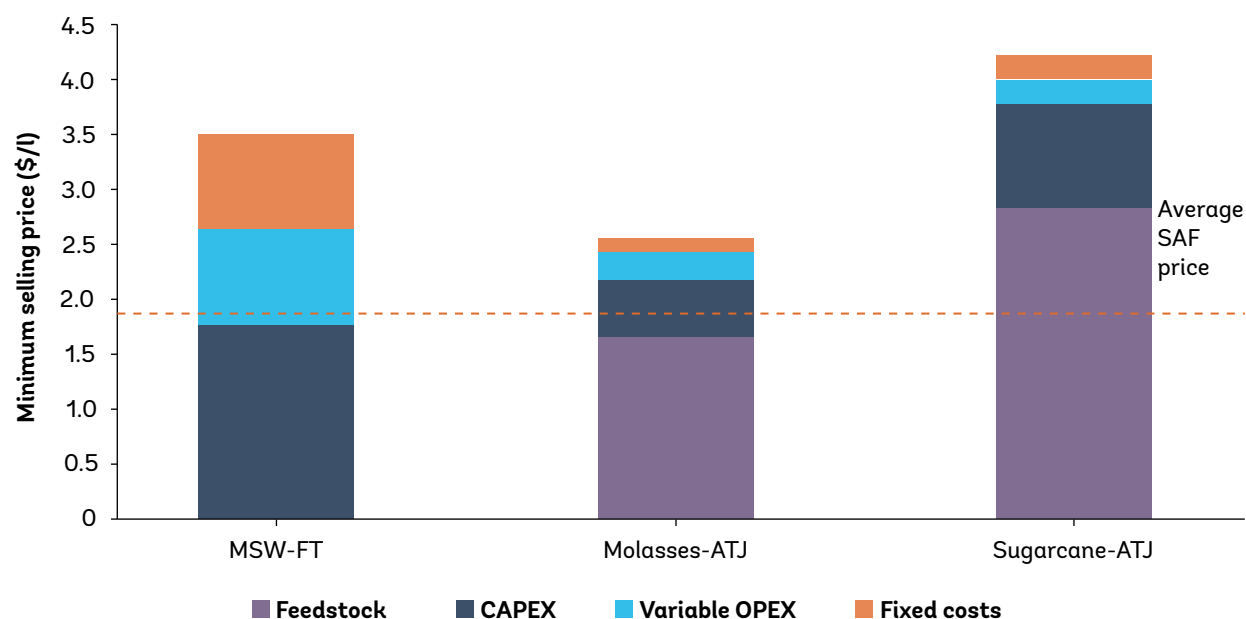
The cost breakdown shows the expected trend, with the costs of MSW-FT fuel highly affected by CAPEX and the two ATJ pathways highly affected by feedstock costs (figure 3.11).³⁶ For the MSW-FT pathway, the risk gap is the main driver of the green premium. De-risking the project could make SAF almost cost-competitive with conventional jet fuel sold in Ethiopia. The gasification of MSW and the subsequent FT conversion process involve complex steps. Operational challenges and performance variability can affect the financial viability of this pathway.

³⁶ It is assumed that feedstock can be secured at zero cost to the SAF producer.





Figure 3.11. Minimum selling prices of jet fuel produced in Ethiopia from municipal solid waste, molasses, and sugarcane, by cost component



Note: Fixed costs are fixed operating costs, such as maintenance and local taxes. Figure uses baseline facility sizes (2,000 BPD for MSW-FT and molasses ATJ and 4,000BPD for sugarcane ATJ). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).

Source: Original figure for this publication.

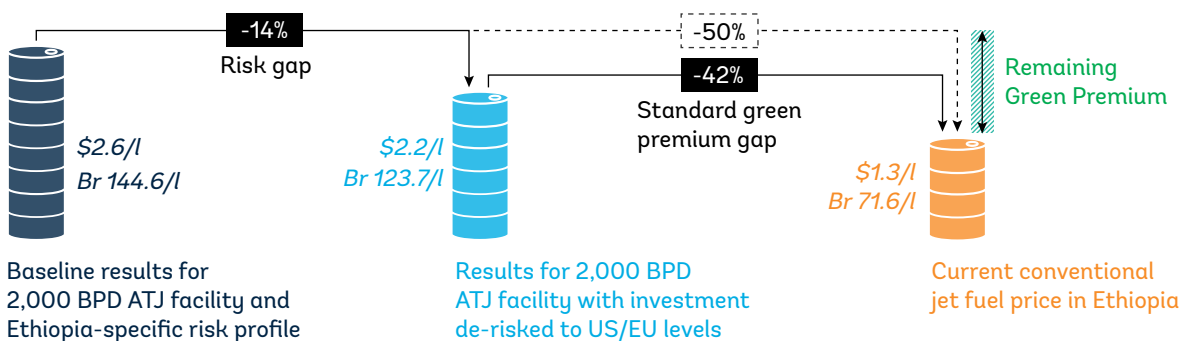
Both feedstock costs and CAPEX are higher for the sugarcane pathway than the molasses pathway, driven by higher feedstock prices and more complex plant configuration for sugarcane ATJ. Sugarcane ATJ production requires cleaning and extraction of the juice and a boiler to burn the bagasse. In contrast, molasses is purchase, mildly pretreated, then fermented.

The cost structures for SAF production in Ethiopia highlight the challenges posed by risk premiums and green premiums, which significantly exceed conventional jet fuel prices (\$1.3 per liter) (figure 3.12). The baseline costs are \$2.6 per liter for the molasses-ATJ pathway, \$4.2 for the sugarcane-ATJ pathway and \$3.5 per liter for the MSW FT pathway. De-risking investments to the levels in high-income countries would lower costs for the AtJ pathway by 14–17 percent, but a large green premium—42 percent for molasses-ATJ and 64 percent for sugarcane-ATJ—would persist, underscoring the need to also address it. For the MSW-FT pathway, de-risking could reduce the costs by 63 percent, given the importance of capital costs, which are highly dependent on risk premiums.

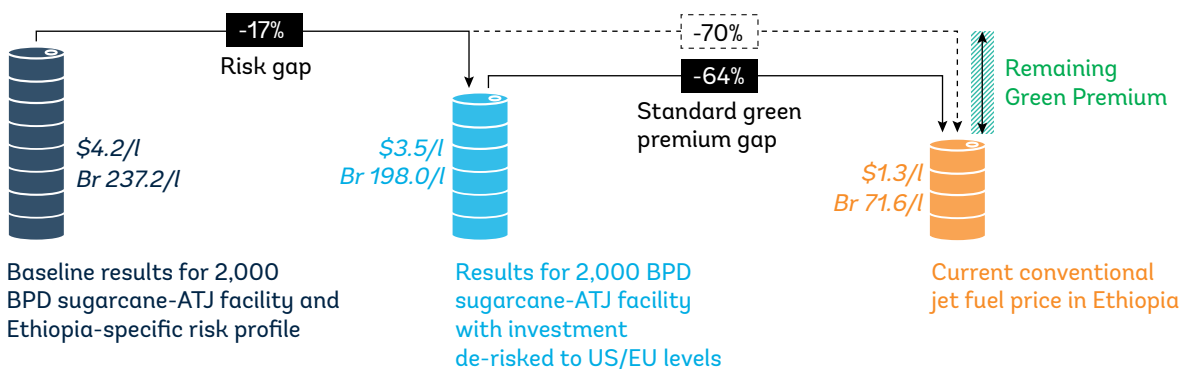


Figure 3.12. Risk and green premium gaps for producing jet fuel in Ethiopia from molasses, sugarcane, and municipal solid waste

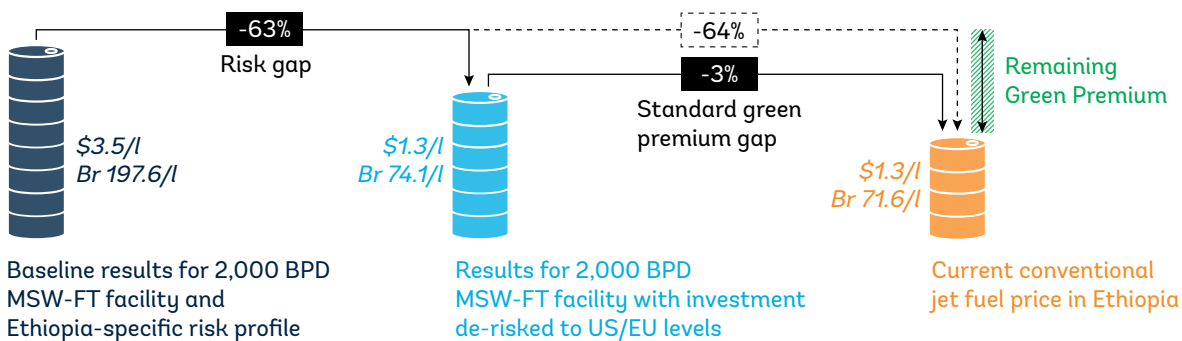
a. Molasses alcohol to jet



b. Sugarcane alcohol to jet



c. Municipal solid waste FT



Source: Original figure for this publication.



Reducing the price difference between SAF and conventional jet fuel requires a multifaceted approach that combines government incentives, technological advancements, and international collaboration. Policy makers can provide subsidies, tax incentives, and support for carbon credit markets to narrow the cost gap. Partnerships with airlines and corporations to secure offtake agreements and Scope 3 credit purchases are also essential for creating demand and reducing production costs. Optimizing feedstock supply chains and improving operational efficiencies are critical, particularly for sugarcane-ATJ, which faces higher baseline costs. Together these measures can help Ethiopia overcome the cost barriers and position SAF as a viable alternative to conventional jet fuel.

Lifecycle Greenhouse Gas Emissions

For all three SAF pathways analyzed for Ethiopia, default values under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) of the International Civil Aviation Organization (ICAO) can provide guidance on the achievable greenhouse gas emission benefits of deploying these pathways in Ethiopia.

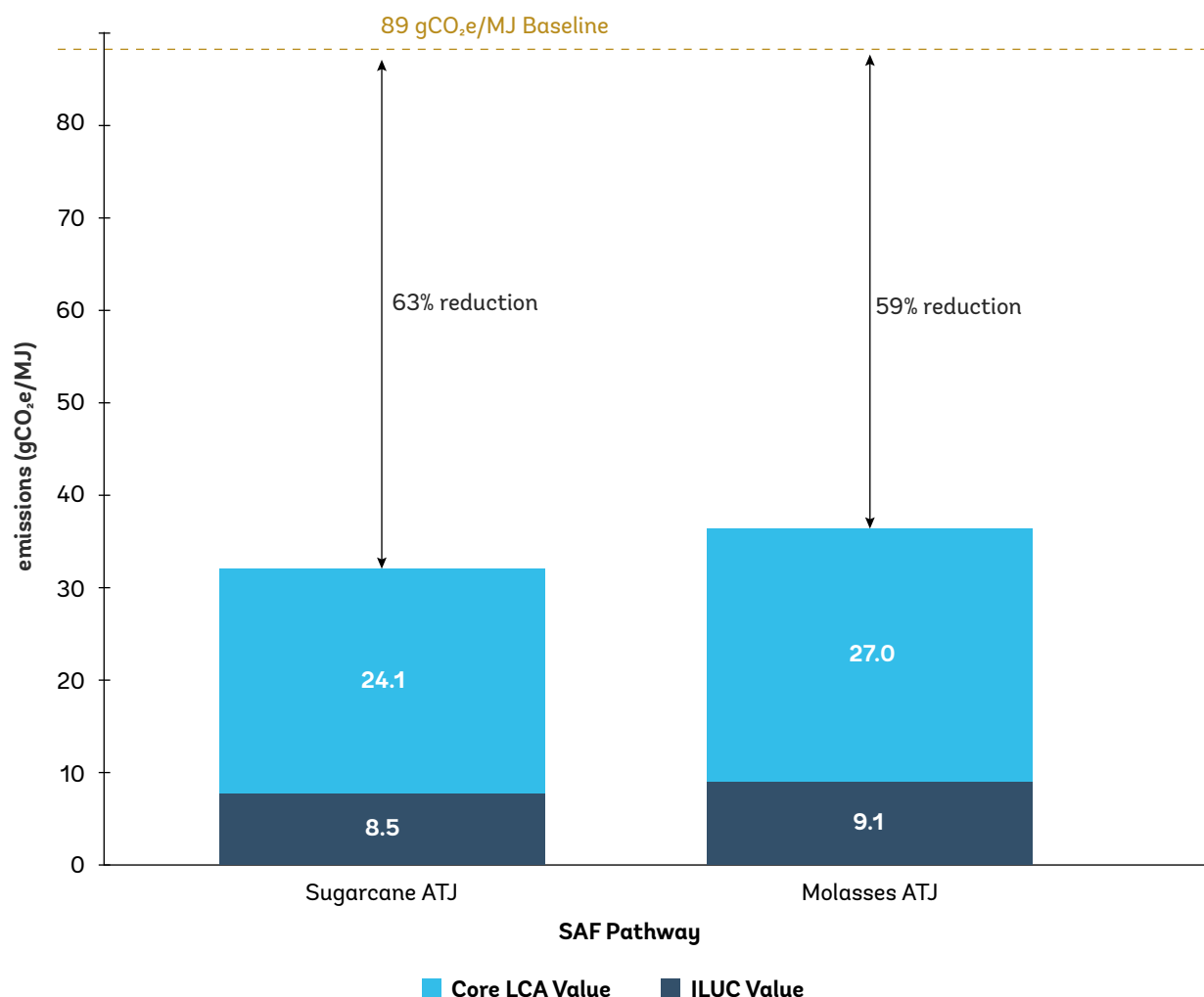
For the sugarcane ATJ pathway, the relevant lifecycle emissions include emissions from induced land use change (ILUC), as sugarcane requires land to grow. Emissions from ILUC includes emissions from both direct land-use change (the conversion of land for sugarcane farming) and indirect land-use change (the conversion of land elsewhere because of changes in land and agricultural prices caused by the direct change in land-use resulting from sugarcane production for SAF). As the latter is not directly observable, the ICAO uses partial and general equilibrium modelling to estimate emissions from land-use change attributable to specific SAF pathways. The default value for sugarcane-ATJ within CORSIA that is applicable to Ethiopia is 32.6 grams of carbon dioxide equivalent per megajoule of energy ($\text{gCO}_2\text{e/MJ}$), consisting of an ILUC value of $8.5 \text{ gCO}_2\text{e/MJ}$ and a core life cycle assessment (LCA) value of $24.1 \text{ gCO}_2\text{e/MJ}$. This value is 63 percent lower than the baseline value for conventional jet fuel of $89 \text{ gCO}_2\text{e/MJ}$.

For molasses, the default value established under CORSIA was developed for a route that uses isobutanol, not ethanol, as an intermediate product. However, the results for other feedstocks for which CORSIA default values are available for both alcohol routes indicate that the difference between the two is very small. The isobutanol molasses default value is therefore a good proxy for the ethanol value. The default value for molasses-ATJ within CORSIA that is applicable to Ethiopia is $36.1 \text{ gCO}_2\text{e/MJ}$, consisting of an ILUC value of $9.1 \text{ gCO}_2\text{e/MJ}$ and a core LCA value of $27.0 \text{ gCO}_2\text{e/MJ}$. This value is 59 percent lower than the baseline for conventional jet fuel of $89 \text{ gCO}_2\text{e/MJ}$ (figure 3.13).





Figure 3.13. Lifecycle greenhouse gas emissions associated with producing jet fuel sugarcane and molasses



Note: Values are based on CORSIA default values. CORSIA = Carbon Offsetting and Reduction Scheme for International Aviation; ILUC = Indirect Land Use Change ; gCO₂e/MJ = grams of carbon dioxide equivalent per megajoule of energy; ATJ = Alcohol-to-Jet.

Source: Original figure for this publication.

For the MSW–FT pathway, the lifecycle emissions under CORSIA are largely a function of the share of nonbiogenic carbon in the MSW used and whether any emissions credits for additional recycling or avoided landfill emissions are applicable. In the absence of emissions credits, the CORSIA default value for MSW jet fuel (LMSWFT) is determined according to the following equation:

$$L_{MSWFT} \text{ (in } gCO_2 \text{ per MJ SAF)} = NBC \times 170 \text{ } gCO_2/MJ + 5.2 \text{ } gCO_2e/MJ,$$

where NBC stands for the share of nonbiogenic carbon in the MSW used for SAF production.

In 2022, around 60 percent of the collected MSW in Addis Ababa was biogenic (Traide 2023). The default value for MSW–FT SAF using MSW with this composition would amount to 73.2gCO₂/MJ without the inclusion of emission credits.



Two emission credits apply under CORSIA: the landfill emissions credit (LEC) for avoided landfill emissions and the recycling emissions credit (REC) for additional recycling required by sorting before using MSW usage for SAF. The LEC is determined primarily by the total share and composition of biogenic waste (the proportion of highly degradable materials, such as food and organic waste, which affect methane generation). Landfill type and location, the efficiency of methane capture measured by landfill gas collection efficiency (LFGCE), and oxidation rates significantly affect noncaptured methane emissions, determining the overall emissions reduction credit under CORSIA. Avoided emissions from landfill are a potentially relevant emissions benefit of using MSW as a feedstock for SAF production.

The annex to this chapter shows the assumptions and step-by-step results when the LEC method is applied to three cases for MSW to jet fuel production with a 60 percent share of biogenic carbon. The cases vary based on the shares of different biogenic carbon categories and the type of landfill and associated methane emissions:

- Case 1 assumes that MSW is diverted from an unmanaged landfill and the organic fraction of MSW consists of equal shares of the different biogenic waste categories.
- Case 2 assumes a managed landfill with equal shares of biogenic waste categories.
- Case 3 assumes a larger share of highly degradable waste within the total biogenic waste share and a unmanaged landfill.

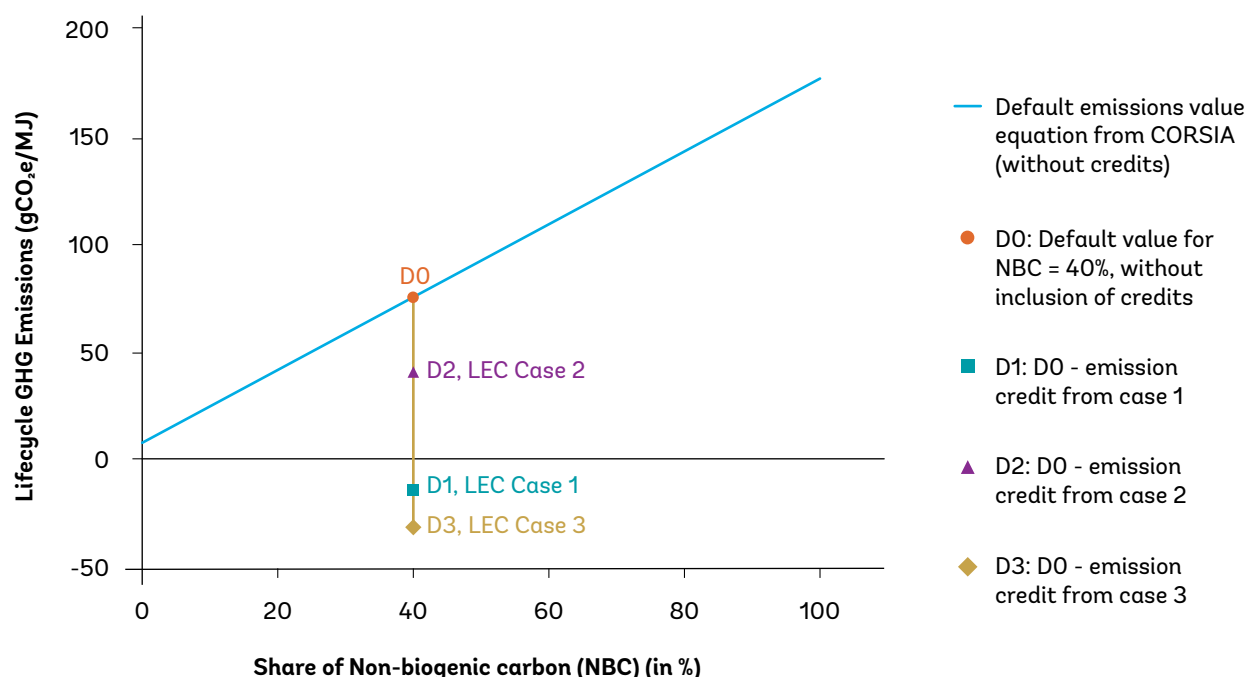
The emissions credits of the three cases are sizable, ranging from 31 (Case 2) to 103 gCO₂e/MJ (Case 3) of SAF.

The REC represents the emissions avoided by recovering and recycling materials, such as plastics and metals, instead of producing them from virgin sources during the SAF production process. Its size is determined by the proportion of recyclable materials diverted from the waste stream, as well as the type of materials involved, as different materials have different energy requirements and emissions associated with their virgin production. For plastics, factors such as the type of plastic (e.g., PET, HDPE) and the emissions associated with their virgin production affect the emissions credit, as they do for metals, where the credit depends on the avoided emissions from virgin metal production. These variables directly affect the REC by quantifying the greenhouse gas emissions prevent by recycling instead of using virgin resources. We did not calculate any cases for the recycling emission credit, because realization of additional recycling as a consequence of using waste in an SAF facility in Ethiopia is highly uncertain.

Figure 3.14 plots the greenhouse gas emissions of MSW-FT SAF within CORSIA as a function of the share of nonbiogenic carbon. It shows the default value when nonbiogenic waste makes up 40 percent of MSW, as is representative of Addis Ababa. We subtract from this value the LEC for three different cases. The results show the importance of avoided emissions from landfilling in all three cases. In case of avoiding landfilling to an unmanaged site, total attributable lifecycle emissions under CORSIA even become negative, underscoring the potential of the MSW-FT SAF pathway as a carbon-negative jet fuel.



Figure 3.14. Lifecycle greenhouse emissions of MSW-FT SAF with 60 percent biogenic municipal solid waste (MSW) share



Note: Analysis is done across three landfill emissions credit scenarios without recycling emission credits. LEC = landfill emissions credit; NBC = share of nonbiogenic carbon in the MSW used for SAF production; gCO₂e/MJ = grams of carbon dioxide equivalent per megajoule of energy; MSW = municipal solid waste; FT = Fischer-Tropsch.
Source: Original figure for this publication.

Policy Impact

We explored the effect of policies on the SAF selling prices for the pathways considered in Ethiopia. A policy mix was assumed that targeted de-risking where conditions favor investments in SAF production. We assumed a lower discount rate of 25 percent and a loan rate of 10 percent. We reduced the percentage of equity to 20 percent and assumed the income tax applicable to the SAF facilities is lowered from 30 percent to 15 percent (table 3.7).





Table 3.7. Sensitivity of minimum selling prices of jet fuel in Ethiopia to policy changes, based on fuel pathway and facility size (dollars per liter)

Alcohol-to-jet pathway						
Facility size (barrels per day)	Molasses		Sugarcane		Municipal solid waste–Fischer-Tropsch pathway	
	Baseline	Policy	Baseline	Policy	Baseline	Policy
2,000	2.6	2.3	4.6	3.9	3.5	1.7
4,000	2.4	2.2	4.2	3.7	2.7	1.3
6,500	2.3	2.1	4.0	3.6	2.4	1.1

Source: Original table for this publication.

For MSW–FT (a highly CAPEX-intensive technology policy), measures that drive down the costs of capital can significantly decrease the selling price of the fuel. For the two ATJ pathways, in which feedstock costs are critical, the effect is limited. For ATJ, this finding points to the need to implement policies that (a) reduce the gap between production costs and the market price of jet fuel by driving down feedstock costs for the SAF producer or (b) increase the de facto price of conventional jet fuel to be paid by airlines (by, for example, appropriately pricing the carbon emissions of conventional jet fuel).

Conclusion and Recommendations

Ethiopia has a unique opportunity to chart a sustainable course for its burgeoning aviation sector. The convergence of a robust agricultural base ripe for feedstock production, a growing need for environmentally sound waste management solutions, and its strategic position as a major African aviation hub makes Ethiopia a good candidate for pioneering SAF production.

The path to a thriving SAF industry is not without challenges, however. Significant financial hurdles must be overcome. Establishing SAF production requires substantial upfront investment, with construction of single facility costing hundreds of millions of dollars. Moreover, even with economies of scale and co-product revenue streams, SAF remains significantly more expensive than conventional jet fuel. Achieving cost parity with fossil jet fuel will require a concerted effort and innovative solutions.

The report identifies key opportunities for SAF production in Ethiopia, utilizing its renewable energy and biomass potential. Techno-economic analyses reveal promising pathways such as FT from MSW and ATJ from sugarcane and molasses. Technological uncertainties remain, however. The gasification of MSW and the FT conversion process involve complexities such as managing syngas impurities affecting catalyst efficiency. ATJ solutions carry uncertainties related to



the scale-up and optimization of processes using African feedstocks. These technological risks may affect feasibility and investment decisions, especially for smaller entities. More R&D and pilot projects will be crucial to mitigate these uncertainties and ensure successful deployment in the country.

To illustrate the scale of the financial commitment, meeting just 10 percent of Ethiopia's projected jet fuel demand in 2030 through domestic SAF production would require investment of about \$200 million–\$1.3 billion, depending on the production pathway and feedstock. The enormous scale of this investment underscores the need for a comprehensive strategy involving strong government support, private sector engagement, and international collaboration. Several steps could be taken toward that end.

Government Initiatives

Possible government initiatives include the following:

- **Strengthening the policy framework for SAF production:** A robust policy framework is essential for improving the economics of SAF production in Ethiopia. Targeted financial incentives should go beyond conventional approaches like loan guarantees and special economic zones to include the provision of production tax credits tied to SAF production volume and lifecycle greenhouse gas emissions reductions, to drive scale and sustainability. Additionally, capital grants and subsidies should help offset the high upfront costs of building SAF facilities, particularly for pioneering projects. To further incentivize the transition from fossil fuels, the government could introduce carbon pricing mechanisms, such as a carbon tax or an emissions trading system, to internalize the environmental costs of fossil jet fuel and give SAF a competitive edge.
- **Creating demand through incentives and market mechanisms:** Stimulating demand for SAF is critical to ensuring a stable market and revenue stream for producers. The government could introduce mandatory SAF blending mandates for aviation fuel sold in Ethiopia, starting with a modest percentage and gradually increasing it to guarantee consistent demand. Setting preferential airport charges, such as reduced landing and gate fees for airlines using SAF, would further incentivize adoption and reward airlines for sustainability initiatives.
- **Establishing a green energy fund to support SAF development:** A dedicated green energy fund for aviation can provide crucial financial support for SAF projects. Financed through a levy on departing international passengers, this fund could be earmarked for supporting SAF production and adoption, with clear allocation and disbursement guidelines.³⁷ To maximize impact, the government could seek contributions from international organizations, development finance institutions, and climate funds to augment the fund and leverage global support for sustainable aviation initiatives in Ethiopia.
- **Building strong public-private partnerships for the MSW-to-SAF value chain:** Facilitating a comprehensive MSW-to-SAF value chain through public-private partnerships is key to ensuring sustainable feedstock supply. Establishing clear frameworks for MSW sourcing is vital, with partnerships supporting waste collection, sorting, and pre-processing to secure a reliable feedstock supply. Additionally, transparent benefit-sharing mechanisms could be implemented to ensure fair distribution of the economic and environmental gains from MSW-to-SAF projects among communities and waste management entities.

³⁷ For example, a \$10 levy on 15 million departing passengers would generate \$150 million in annual revenue, which could be used to cover the cost premium. The proceeds from such a levy could also be used to directly benefit the SAF producer by funding the establishment of price support mechanisms (contract of difference, buyer of last resort). Such a levy would need to be constructed in a way that would ensure compliance with the Montreal Protocol.



- **Investing in research, technology transfer, and capacity building:** Developing local expertise and fostering technological advancement is essential for the long-term sustainability of Ethiopia's SAF industry. The government could invest in R&D and promote partnerships with international institutions and universities to drive technology transfer. Technical training programs could be implemented to build local capacity in SAF production technologies, ensuring a skilled workforce and a strong foundation for the Ethiopian SAF industry.

Private Sector Initiatives

Possible private sector initiatives include the following:

- **Facilitating airline offtake agreements for market stability:** Long-term commitments from airlines are essential to provide revenue certainty and de-risk SAF projects. Ethiopian Airlines and other international carriers operating from Addis Ababa should be encouraged to enter into long-term offtake agreements with local SAF producers. Such agreements would secure demand and support the financial viability of SAF production facilities. Innovative risk-sharing mechanisms, such as indexed contracts that adjust SAF prices based on market fluctuations, could be explored to mitigate financial risks for airlines and promote greater SAF adoption. To further support these agreements, the Green Energy Fund could be leveraged to partially subsidize offtake contracts, reducing costs for airlines and accelerating SAF market penetration.
- **Encouraging corporate SAF purchases to drive demand:**³⁸ Corporations and organizations with a strong presence in Ethiopia can play an important role in advancing the SAF market through direct purchases or investments in SAF certificates. By demonstrating leadership in sustainability, corporate buyers would not only reduce their carbon footprints, they would also send strong demand signals to the market. Integrating SAF procurement into corporate sustainability strategies and supply chain management could further reinforce demand. Doing so would encourage corporate investment in SAF production and establish SAF as a key component of business sustainability initiatives.
- **Leveraging existing infrastructure for SAF production:** Maximizing the use of existing industrial assets can accelerate SAF production in Ethiopia. Ethiopia's established ethanol production capacity presents an opportunity for integration with SAF production. A thorough assessment should be conducted to evaluate the feasibility and economic viability of 'repurposing or upgrading existing ethanol facilities for SAF production. This assessment should consider optimizing feedstock utilization and exploring synergies between the ethanol and SAF industries, which could reduce production costs and improve resource efficiency.

Multilateral Development Bank Initiatives

Possible multilateral development bank initiatives include the following:

- **Providing catalytic financing to de-risk investments:** Multilateral development banks can play a catalytic role by offering concessional financing and risk mitigation tools to lower investment barriers and attract private sector capital. Concessional loans, grants, and guarantees should be

³⁸ Corporate airline clients can play an important role in securing uptake of local SAF production by purchasing SAF (or more precisely, the associated Scope 3 emission reduction). Addis Ababa is a major economic center in Africa, with a significant presence of large corporations and major international organizations. It is therefore well poised for corporate SAF purchases.



prioritized to support early-stage SAF projects, which private investors often perceive as high-risk. Multilateral development banks should also leverage their expertise in blended finance to structure innovative financing packages that combine concessional funding with private sector investments. These blended solutions can maximize the impact of development funds, reduce capital costs, and unlock commercial financing for SAF infrastructure.

- **Supporting policy and regulatory development for the SAF industry:** Creating a transparent and stable regulatory framework is essential for attracting long-term investment in the SAF sector. Multilateral development banks provide the government with technical expertise and policy guidance to help establish an investor-friendly regulatory environment. They can also promote regional cooperation by facilitating the harmonization of SAF standards across African countries. By supporting cross-border trade and encouraging knowledge sharing across countries, they can help position Ethiopia as a regional leader in SAF production and distribution.
- **Facilitating multistakeholder partnerships and knowledge exchange:** Partnerships are crucial for advancing the SAF industry; multilateral development banks are well-positioned to act as conveners and facilitators. They should create platforms that bring together government agencies, private companies, research institutions, and civil society organizations to foster collaboration, knowledge exchange, and a unified approach to SAF development. They should promote South-South cooperation by connecting Ethiopian stakeholders with successful SAF initiatives in other developing countries. Facilitating knowledge transfer and peer learning can accelerate the development of local expertise and inspire innovative approaches to SAF production in Ethiopia.

Implementing these comprehensive recommendations would help Ethiopia the financial and technical challenges associated with SAF production and establish itself as a leader in sustainable aviation. Doing so would not only significantly reduce the environmental footprint of the aviation sector, it would also contribute to economic growth; job creation; technology transfer; and a cleaner, more prosperous future for Ethiopia.





Annex 3A Key Assumptions and Data for Techno-Economic Analysis of Ethiopia

Table 3A.1. Process utility requirements for alcohol-to-jet pathway in a 2,000-barrel per day facility in Ethiopia

Pathway/ process	Feedstock (kg/hr)	Cooling water (kg/min)	Power (kWh)	Natural gas (million BTU/hr)	Hydrogen (kg/hr)
<i>Molasses</i>					
Fermentation	37,399 (sucrose)	160,602	1,319	—	—
Alcohol separation	35,409	79,433	488	121.8	—
Ethylene production	17,203 (alcohol)	12,183	3,038	53.1	—
Finishing		14,203	—	1.2	—
Alcohol-to-jet		45,559	519	34.9	112.5
Total		311,980	5,364	210.9	112.5
<i>Sugarcane</i>					
Sugarcane	253,600	—	2	279	—
Fermentation	37,399 (sucrose)	160,602	1,319	—	—
Alcohol separation	35,409	79,433	488	—	—
Ethylene production	17,203 (alcohol)	12,183	3038	—	—
Finishing	—	14,203	—	—	—
Alcohol-to-jet	—	45,559	519	—	112.5

Note: — = Not available.



Table 3A.2. Process utility requirements for a 2,000-barrel a day municipal solid waste–Fischer-Tropsch facility in Ethiopia

Source	Model flow
Municipal solid waste (kg/hr)	34,170
Electricity (kWh)	12,042
Natural gas (thousand cubic feet/yr)	44,074
Cooling water (kg/hr)	1,281,168
Ash disposal (kg/hr)	4,436
Waste water disposal (cubic feet per hour)	5,461

Source: World Bank.

Table 3A.3. Variable operating expenses for alcohol-to-jet and Fischer-Tropsch facilities in Ethiopia

Expense type	Dollars	Birr
Molasses (kg)	0.46	25.8
Sugarcane (kg)	0.16	9.1
Municipal solid waste (MT)	0	0
Power (kWh)	0.02	1.2
Natural gas (million BTU)	3.69	207.2
Hydrogen (kg)	2.31	129.6
Refrigeration (million BTU)	13.8	776.1
Cooling water (kg)	0.00003	0.0016
Waste water treatment (gallons)	0.0021	0.12
Ash disposal (kg)	0.04	2.4

Note: kg = kilogram; MT = million tonnes; kWh = kilowatt hours; BTU = British thermal unit.


Table 3A.4. Capital expenses for a 2,000-barrel a day molasses alcohol-to-jet facility in Ethiopia

Category	Description	Millions of dollars	Billions of Br
Total direct cost			
Inside battery limit costs (ISBL)			
Fermentation	Calculated	13.5	0.8
Ethanol separation	Calculated	2.1	0.1
Dehydration	Calculated	2.8	0.2
Oligomerization		2.5	0.1
Hydrogenation		2.6	0.1
Fractionation		0.2	0.01
Purchased equipment cost	Calculated	23.7	1.3
Installation cost (40 percent purchased equipment cost)	Calculated	9.5	0.5
Total ISBL		33.2	1.9
Other direct costs			
Catalyst fill	Calculated	2.0	0.1
Buildings	45 percent PEC	10.7	0.6
Yard Improvement	15 percent PEC	3.6	0.2
Auxiliary facilities	40 percent PEC	9.5	0.5
TDC		58.8	3.3
Total indirect costs			
Engineering and supervision	30 percent of TDC	17.7	1.0
Construction and expenses	30 percent of TDC	17.7	1.0
Total indirect costs		35.3	2.0
	TDC + TIC	94.2	5.3



Category	Description	Millions of dollars	Billions of Br
Contingency	20 percent	11.8	0.7
Fixed Capital Investment (FCI)	TDC + TIC + Contingency	105.9	5.9
Working Capital (WC)	5 percent of FCI	5.3	0.3
Total plant investment (total plant investment)	FCI + WC	111.2	6.2

Source: World Bank.

Table 3A.5. Capital expenses for a 2,000-barrel per day sugarcane–alcohol to jet facility in Ethiopia

Category	Description	Million dollars	Billion Br
Total Direct Cost (TDC)			
Inside Battery Limit Costs (ISBL)			
Cane milling, extraction and dewatering	Calculated	17.8	1.0
Detoxification reactor	Calculated	0.1	0.01
Neutralization reactor	Calculated	0.1	0.01
Boiler	Calculated	38.6	2.2
Fermentation	Calculated	14.7	0.8
Ethanol separation	Calculated	2.2	0.1
Dehydration	Calculated	3.0	0.2
Oligomerization	Calculated	2.6	0.1
Hydrogenation	Calculated	2.7	0.2
Fractionation	Calculated	0.2	0.01
Purchased Equipment Cost (PEC)	Calculated	82.1	4.6



Category	Description	Million dollars	Billion Br
Installation cost	40 percent PEC	32.8	1.8
ISBL Total		114.9	6.5
Other direct costs			
Catalyst fill	Calculated	2.2	0.1
Buildings	45 percent PEC	36.9	2.1
Yard Improvement	15 percent PEC	12.3	0.7
Auxiliary Facilities	40 percent PEC	32.8	1.8
OSBL Total		84.3	4.7
TDC		199.2	11.2
Total Indirect Cost (TIC)			
Engineering and supervision	30 percent of TDC	59.8	3.4
Construction and expenses	30 percent of TDC	59.8	3.4
TIC		119.5	6.7
	TDC + TIC	318.7	17.9
Contingency	20 percent	39.8	2.2
Fixed Capital Investment (FCI)	TDC + TIC + Contingency	358.5	20.1
Working Capital (WC)	5 percent of FCI	17.9	1.0
Total plant investment (total plant investment)	FCI + WC	376.4	21.1

Source: World Bank.



Table 3A.6. Capital expenses for a 2,000-barrel a day municipal waste – Fischer-Tropsch facility in Ethiopia

Category	Description	Million dollars	Billion Br
Total Direct Cost (TDC)			
Inside Battery Limit Costs (ISBL)			
MSW pretreatment	Calculated	25	1.4
Gasification	Calculated	54	3.0
Syngas cleaning	Calculated	6.4	0.4
Fuel synthesis	Calculated	19	1.1
Hydroprocessing	Calculated	9	0.5
Air separation	Calculated	7	0.4
Purchased Equipment Cost (PEC)	Calculated	120	6.8
Installation cost	40 percent PEC	48	2.7
ISBL Total		169	9.5
Other direct costs			
Buildings	45 percent PEC	54	3.0
Yard Improvement	15 percent PEC	18	1.0
Auxiliary Facilities	40 percent PEC	48	2.7
OSBL Total		120	6.8
TDC		289	16.2
Total Indirect Cost (TIC)			
Engineering and supervision	30 percent of TDC	87	4.9
Construction and expenses	30 percent of TDC	87	4.9
TIC		174	9.7
	TDC + TIC	463	26



Category	Description	Million dollars	Billion Br
Contingency	20 percent	58	3.2
Fixed Capital Investment (FCI)	TDC + TIC + Contingency	521	29.2
Working Capital (WC)	5 percent of FCI	26	1.5
Total plant investment (total plant investment)	FCI + WC	547	30.7

Source: World Bank.

The landfill emissions credit for municipal solid waste (MSW) under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is calculated as follows:

General Assumptions (Applicable to All Cases)

- **Municipal Solid Waste (MSW) Diverted:** 1 dry tonne.
- **Biogenic Fraction of MSW:** 60%.
- **Methane Content in Landfill Gas (F):** 50%.
- **Global Warming Potential (GWP) of Methane:** 28.
- **Energy Yield of SAF:** 20 MJ per tonne of MSW.
- **Conversion Factor for CH₄ to Carbon Ratio:** 16/12.

Specific Assumptions for Each Case

Assumption	Case 1: Unmanaged Landfill	Case 2: Managed Landfill	Case 3: Unmanaged Landfill with Higher Degradable Content
Landfill Type	Unmanaged	Managed	Unmanaged
Methane Correction Factor (MCF)	0.8	0.6	0.8
Landfill Gas Collection (LFGCE)	0%	50%	0%
Oxidation Rate	0%	10%	0%
Waste Composition	Evenly distributed among 4 categories	Evenly distributed among 4 categories	1/3 for paper/textiles & wood/straw, 2/3 for organic & food waste



Step 1: Determine the Shares of Waste Categories

- **Case 1 and Case 2** (Even Distribution):
 - **Paper/Textiles:** 0.15 tonne.
 - **Wood/Straw:** 0.15 tonne.
 - **Organic Waste:** 0.15 tonne.
 - **Food Waste:** 0.15 tonne.
- **Case 3** (Higher Degradable Content):
 - **Paper/Textiles:** 0.10 tonne.
 - **Wood/Straw:** 0.10 tonne.
 - **Organic Waste:** 0.20 tonne.
 - **Food Waste:** 0.20 tonne.

Step 2: Select DOC and DOCF Values

Waste Category	DOC (%)	DOCF (%)
Paper/Textiles	47%	45%
Wood/Straw	44%	16%
Organic Waste	45%	46%
Food Waste	50%	84%

Step 3: Calculate Methane Generation (Q_j) for Each Waste Category

Using the formula for methane generation:

$$Q_j = W_j \times DOC_j \times DOCF_j \times F \times MCF \times \left(\frac{16}{12} \right) \times 10^6$$

Methane Generation Calculations for Each Case:

Case 1 & Case 2 (Even Waste Distribution):

- **Paper/Textiles:**
 - Case 1 ($MCF = 0.8$): $Q_{\text{paper/textiles}} = 25,350 \text{ g CH}_4$
 - Case 2 ($MCF = 0.6$): $Q_{\text{paper/textiles}} = 19,013 \text{ g CH}_4$
- **Wood/Straw:**
 - Case 1: $Q_{\text{wood/straw}} = 5,633 \text{ g CH}_4$
 - Case 2: $Q_{\text{wood/straw}} = 4,225 \text{ g CH}_4$



- **Organic Waste:**

- Case 1: $Q_{\text{organic waste}} = 25,875 \text{ g CH}_4$
- Case 2: $Q_{\text{organic waste}} = 19,406 \text{ g CH}_4$

- **Food Waste:**

- Case 1: $Q_{\text{food waste}} = 54,000 \text{ g CH}_4$
- Case 2: $Q_{\text{food waste}} = 40,500 \text{ g CH}_4$

Case 3 (Higher Share of Degradable Waste):

- **Paper/Textiles:** $Q_{\text{paper/textiles}} = 16,900 \text{ g CH}_4$
- **Wood/Straw:** $Q_{\text{wood/straw}} = 3,755 \text{ g CH}_4$
- **Organic Waste:** $Q_{\text{organic waste}} = 34,500 \text{ g CH}_4$
- **Food Waste:** $Q_{\text{food waste}} = 72,000 \text{ g CH}_4$

Step 4: Total Methane Generation (Q_{total})

Case	Total Methane Generation (Q_{total})
Case 1	$25,350 + 5,633 + 25,875 + 54,000 = 72,712 \text{ g CH}_4$
Case 2	$19,013 + 4,225 + 19,406 + 40,500 = 54,534 \text{ g CH}_4$
Case 3	$16,900 + 3,755 + 34,500 + 72,000 = 81,914.67 \text{ g CH}_4$

Step 5: Calculate Non-Captured Methane Emissions (CH_4^n)

Case	Non-Captured Methane Emissions (CH_4^n)
Case 1	$72,712 \text{ g CH}_4$
Case 2	$54,534 \times (1 - 0.5) \times (1 - 0.1) = 24,540.3 \text{ g CH}_4$
Case 3	$81,914.67 \text{ g CH}_4$



Step 6: Calculate Biogenic CO₂ Emissions from Non-Captured Methanes (CO₂ⁿ)

$$CO_2^n = CH_4^n \times \frac{44}{16}$$

Case	Biogenic CO ₂ Emissions (CO ₂ ⁿ)
Case 1	$72,712 \times 44/16 = 199,958 \text{ g CO}_2$
Case 2	$24,540.3 \times 44/16 = 67,485.83 \text{ g CO}_2$
Case 3	$81,914.67 \times 44/16 = 225,265.33 \text{ g CO}_2$

Step 7: Calculate Final Landfill Emissions Credit (LEC)

$$LEC = CH_4^n \times GWP_{CH_4} - CO_2^n$$

Case	LEC (g CO ₂ e)
Case 1	$72,712 \times 28 - 199,958 = 1,835,978 \text{ g CO}_2\text{e}$
Case 2	$24,540.3 \times 28 - 67,485.83 = 619,642.58 \text{ g CO}_2\text{e}$
Case 3	$81,914.67 \times 28 - 225,265.33 = 2,068,345.33 \text{ g CO}_2\text{e}$

Step 8: Calculate LEC per MJ of Fuel

$$LEC_{\text{final}} = \frac{LEC}{20}$$

Case	LEC per MJ (g CO ₂ e/ MJ)
Case 1	$1,835,978/20 = 91,798.9 \text{ g CO}_2\text{e/MJ}$
Case 2	$619,642.58/20 = 30,982.13 \text{ g CO}_2\text{e/ MJ}$
Case 3	$2,068,345.33/20 = 103,417.27 \text{ g CO}_2\text{e/MJ}$



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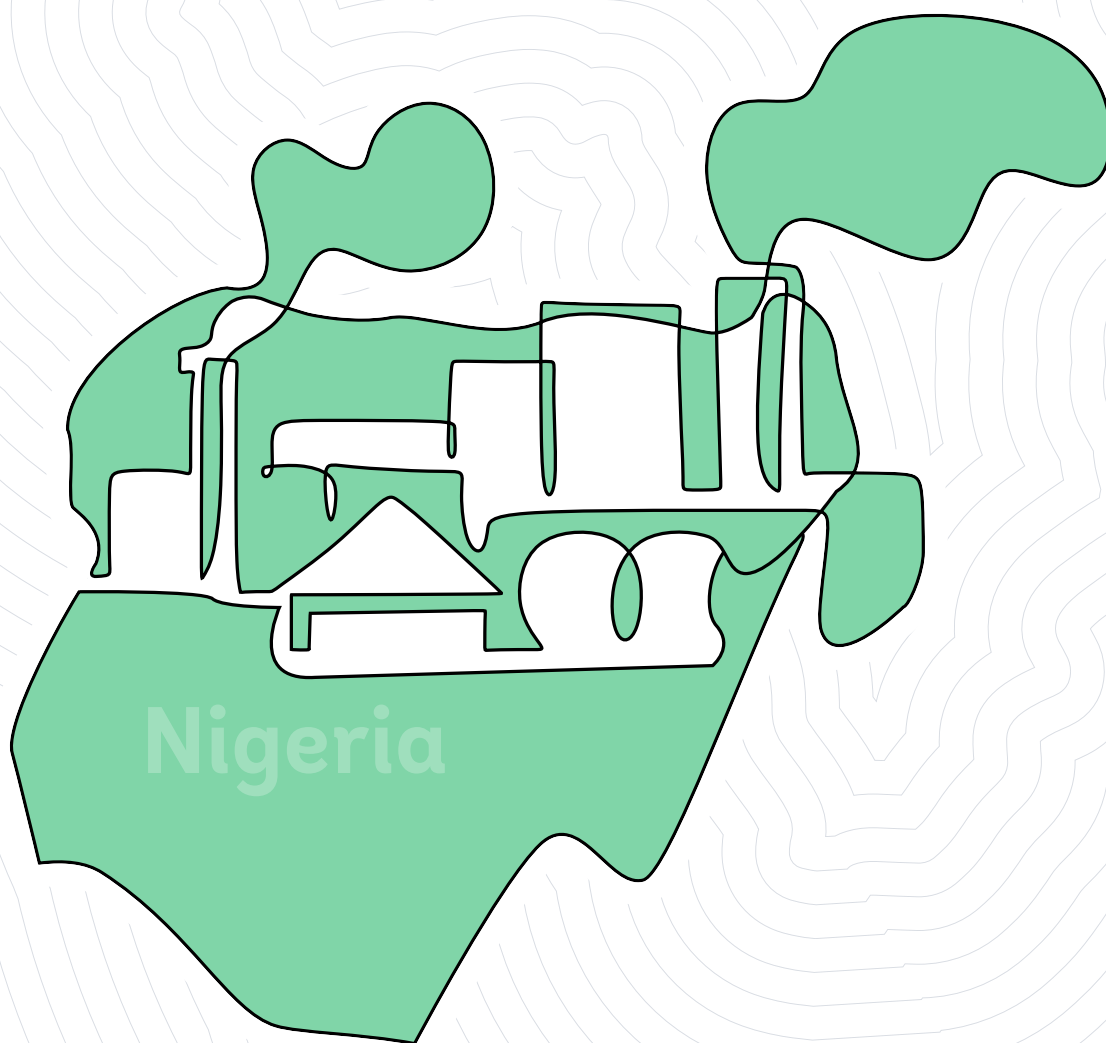
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04

Nigeria Deep Dive

Leveraging its petrochemical industry gives Nigeria a sustainable, cost-effective way to switch to SAF production. This chapter explores the use of co-processing as a flexible solution that can ensure adaptability to market demand.





Overview

This chapter analyzes the potential for producing sustainable aviation fuels (SAF) in Nigeria, with a focus on leveraging the country's petrochemical industry. Co-processing—the transformation of biogenic feedstocks with petroleum-based distillates to produce finished fuels—offers a cost-effective approach to SAF production by leveraging existing refinery infrastructure, eliminating the need for costly standalone biofuel plants. Nigeria's location in the Gulf of Guinea provides it with access to abundant lipid-based feedstocks, including vegetable oils, waste oils, and fats, which are essential for co-processing. The use of waste oils, such as used cooking oil (UCO) and tallow, offers a sustainable alternative that minimizes competition with food production while achieving up to 80 percent greenhouse gas reductions compared with conventional jet fuel. Co-processing enables flexible blending of renewable and fossil fuels, up to the current 5 percent renewable feedstock limit, ensuring adaptability to market demands.

A large refinery such as the Dangote refinery could produce additional SAF and diesel by blending bio-based materials with regular crude oil. This process could add around 3,321–5,950 barrels of SAF per day, depending on the refining method used, along with 5,530–15,714 additional barrels of diesel. The estimated selling price for this blended jet fuel is \$1.02–\$1.06 per liter; fully bio-based SAF costs more, about \$1.90–\$2.34 per liter. Using cheaper sources, such as USO, could lower costs to about \$1.7 per liter, less than the global average SAF price of \$1.83 per liter in 2024.

Nigeria's SAF industry faces challenges that require coordinated efforts from both government and private sector stakeholders. They include managing feedstock supply, creating policy incentives, and securing financing. Success in lipid co-processing hinges on overcoming supply chain barriers such as access to quality feedstock, mechanization, storage infrastructure, logistics, and regulatory hurdles.

A comprehensive feedstock strategy is needed that prioritizes sustainable, cost-effective sources while striving toward minimal environmental impact. Certification schemes and partnerships with local farmers can strengthen supply chains and reduce conflicts between food and fuel. Clear policy frameworks—including financial incentives for refineries, SAF blending mandates for airlines, and increased funding for research and development—are needed to drive industry growth. Establishing a roadmap with defined production targets and monitoring mechanisms will be essential for progress.

The private sector can play a crucial role in scaling SAF production by making long-term commitments through offtake agreements, investing in production infrastructure, and supporting distribution networks. Financial support from multilateral development banks and development financial institutions can help mitigate the investment risks associated with feedstock production and SAF infrastructure.

By prioritizing co-processing, Nigeria can position itself as a regional leader in SAF production. With a collaborative approach by government and industry stakeholders, SAF can contribute significantly to Nigeria's green energy transition and aviation decarbonization goals.



Description of Country Case

Aviation and Economy

Air transport is a vital part of Nigeria's economy, playing a crucial role in its status as the second-largest economy in Sub-Saharan Africa. With a population of more than 220 million, Nigeria provides a consistent supply of passengers for airlines. The aviation sector adds NO 198 billion to the country's GDP (0.6 percent), including the catalytic effects from tourism. It supports around 289,000 jobs, both directly and indirectly. Air transport enhances Nigeria's economic performance by improving connectivity, facilitating easier and more efficient trade and investment. This improved connectivity is crucial for Nigeria's integration into the global market, which is essential for economic diversification and resilience. Aviation also provides substantial consumer benefits, with passengers and shippers valuing services higher than their actual costs, indicating high consumer surplus. The sector also contributes over NO 25.5 billion to public finances, through various taxes (IATA 2023).

Nigeria's aviation sector is considered one of Africa's largest untapped markets. Driven by its large population and GDP, Nigeria is projected to need around 160 new aircraft by 2042 to accommodate growth, particularly from increases in intra-African traffic (Simple Flying 2024).

The domestic airline industry faces significant financial challenges, including numerous bankruptcies, which limit companies' capacity to absorb the cost premium of SAF. The presence of major international carriers in Nigeria, which are financially stronger, offers a promising avenue for SAF adoption. These airlines can afford the additional costs associated with SAF, making them ideal partners for producing it.

Nigeria's largest airports, Murtala Muhammed Airport in Lagos and Nnamdi Azikiwe Airport in Abuja, are hubs for the country's aviation sector. In 2022, Murtala Muhammed Airport handled 6.5 million passengers, and Nnamdi Azikiwe Airport saw 6.0 million passengers (Arise News 2023). These airports are served by 22 international carriers, including major airlines from Europe, the Middle East, and North America (Nigeria Civil Aviation Authority n.d.).

Reliance on international carriers has advantages and disadvantages. International carriers offer vital connectivity, but they also increase imports, affecting Nigeria's trade balance.³⁹ This drawback notwithstanding, the financial strength and extensive networks of these international networks make them suitable partners for SAF adoption.

Air Transport Decarbonizing Policy

Nigeria's Nationally Determined Contribution (NDC) targets a reduction in greenhouse gas emissions of 20 percent unconditionally and 47 percent conditionally by 2030 compared with business-as-usual levels. This ambitious plan focuses on expanding renewable energy, enhancing energy efficiency, and implementing climate adaptation measures across various sectors, including energy, agriculture, transport, and waste management. To meet these targets, Nigeria estimates that it will need annual investment of \$17.7 billion, underscoring the need for significant international support (Federal Ministry of Environment 2021; NDC Partnership n.d.; Premium Times 2023).

³⁹ In the first half of 2023, Ethiopia's trade balance recorded a deficit of 1.7 percent of GDP, up from 1.6 percent in the same period in 2022. The slight increase reflected higher imports of services, particularly in transportation and travel (World Bank 2023).



The Energy Transition Plan (ETP), launched in August 2022, outlines Nigeria's strategy for achieving net-zero greenhouse gas emissions by 2060. It focuses on emissions reduction in the power, transport, oil and gas, cooking, and industry sectors, which together account for about 65 percent of total emissions. In the transport sector, the ETP sets specific biofuel targets, including achieving a 10 percent biofuel blend by 2030 and a 30 percent blend by 2036. It also aims for a 2 percent adoption rate of electric vehicles by 2030 and a 60 percent adoption rate by 2050, along with a reduction in the number of kilometers traveled by passenger cars, which it hopes to achieve through increased use of public transport and electric three-wheelers (Centre for Climate Change & Development n.d.).

Although the ETP includes measures for the broader transport sector, it does not address the unique challenges of aviation. The biofuel targets within the ETP present opportunities for SAF to reduce aviation emissions. As part of the broader biofuel strategy, SAF can help bridge this gap. Current policies and efforts are insufficient to meet the aviation sector's needs, however. Addressing this gap will require targeted strategies, international support, and robust policy frameworks to ensure comprehensive emission reductions across all transport modes.

Jet Fuel Demand and Supply

Nigeria consumed around 12,750 barrels per day (BPD) of jet fuel in 2023, all of which was imported (Olawin 2024). In April 2024, the new Dangote refinery near Lagos began selling finished fuels, including conventional jet fuel (Energy Intelligence Group 2024). When fully operational, the refinery will have a capacity of 650,000 BPD.

Nigeria is a major African aviation hub. Its largest airport, Murtala Muhammed International Airport, is less than 100 km from the only refinery in Nigeria producing jet fuel.

The challenges facing Nigeria's aviation fuel sector are complex. The main one is the lack of local refining capacity, which has forced dependence on imports, leaving the supply chain vulnerable to disruptions from poor planning and financial constraints. Infrastructure deficits, including insufficient storage facilities and underdeveloped transport networks, exacerbate distribution issues. The road network, which is critical for transporting jet fuel from ports to airports, suffers from poor conditions, increasing the risk of accidents and delays.

Financial barriers further complicate the jet fuel landscape in Nigeria. The high costs of importation and distribution prevent smaller companies from entering the market, leaving the supply chain dominated by a few large entities capable of handling the expenses. Regulatory obstacles, like acquiring import licenses and navigating the country's bureaucratic processes, slow operations. These challenges are exacerbated by security issues, including theft and vandalism, especially in areas like the Niger Delta, which disrupt supply lines and inflate costs.

Traffic congestion at critical locations like the Apapa Shore Depot in Lagos, where fuel loading occurs, leads to significant delays and logistical complications. This area is infamous for its long queues of tanker trucks, which disrupt both the supply chain and daily traffic. The absence of modern infrastructure to facilitate efficient aviation fuel logistics, such as dedicated refueler parking spaces and direct apron access, further impedes operational efficiency. Economic pressures, such as high fuel taxes and multiple operational fees, escalate the cost of jet fuel, rendering air travel more costly and less competitive than it is in neighboring countries. Consequently, some international airlines choose to refuel in countries like Ghana and Togo, where fuel prices are lower and supply chains more reliable. These operational, logistical, and economic challenges strain Nigeria's aviation fuel sector and hinder the growth of the country's aviation industry.



The Dangote refinery, strategically located in Nigeria's Lekki Free Trade Zone, has started to alter the dynamics of jet fuel production and supply both within Nigeria and across regional and international markets. As one of the largest single-train refineries in the world, it has begun exporting jet fuel, marking a significant step toward reducing Nigeria's reliance on imported jet fuel. The refinery's first cargo to Europe (Rotterdam) was secured by BP for 120,000 metric tonnes at the end of May 2024. The deal was part of a broader strategy to quickly enhance production and distribution capabilities. In April 2024, the refinery began distributing jet fuel within Africa, meeting European jet A1 standards and demonstrating its capacity to adhere to international quality standards. Exports have reached Senegal, Togo, and Ghana, expanding Nigeria's regional influence.

The Dangote refinery's venture into the jet fuel market coincides with a saturated European market, presenting potential challenges for new entrants. Nevertheless, with a production capacity potentially yielding 45,000 BPD of jet fuel at 80 percent utilization, Nigeria could soon become a net exporter of jet fuel.

The refinery's role extends beyond production; it aims to redefine the supply chains and logistics for jet fuel across Africa and Europe. By integrating production with direct exports, Dangote could significantly influence jet fuel pricing and availability, potentially stabilizing supply fluctuations and reducing costs in the Nigerian and regional aviation sectors. Realizing these benefits depends on overcoming infrastructural and logistical challenges, including enhancing pipeline reliability, expanding storage capacity, and ensuring efficient operations at the Lekki port facilities.

Conversion Technology and Feedstock Potential

Potential for Co-Processing in Nigeria

The International Air Transport Association's 2024 *Finance Net Zero CO₂ Emissions Roadmap* emphasizes the significant global potential of co-processing for SAF production. It shows that maximizing co-processing at existing refineries worldwide could yield substantial cost savings, potentially avoiding up to \$347 billion in capital investments by 2050, because co-processing leverages existing infrastructure, eliminating the need to build new dedicated SAF plants. The study estimates that global SAF production from co-processing could reach 33.6 million tonnes (Mt) a year by 2050, making a significant contribution to meeting the growing demand for SAF. By scaling up co-processing, the industry can accelerate the transition toward sustainable aviation while slashing costs.

Co-processing leverages existing refinery infrastructures, allowing for the integration of renewable and conventional fuels without requiring new capital-intensive facilities. By producing a blend of biogenic and fossil carbon fuels, these refineries could directly supply airports like Murtala Muhammed Airport, streamlining the supply chain and eliminating the need for separate blending operations. This approach simplifies logistics and supports the transition to aviation fuels with a lower carbon footprint.

Co-processing lipids in petroleum refineries presents several operational challenges. Elevated metal levels in lipid feedstocks can cause catalyst deactivation, and the presence of free fatty acids and other contaminants in lipids can cause corrosion of metallurgy in refinery processing units and piping. Careful monitoring and potential upgrades to equipment are needed to mitigate corrosion-related issues (Vincent and others 2024).

Co-processing can also alter the yields of various refinery products, potentially affecting the overall refinery economy. Refiners must carefully balance these yield changes to maintain profitability when incorporating renewable feedstocks.



American Society for and Materials (ASTM) certification for lipid co-processing (outlined in ASTM D1655 Annex A1) currently permits the integration of up to 5 percent renewable lipid feedstocks—such as vegetable oils, animal fats, and used cooking oils—into conventional petroleum-refining processes to produce jet fuel. Despite some operational concerns—many of which are easier to address at the low blending limit currently prescribed by ASTM—the co-processing strategy offers significant flexibility, enabling refineries to adjust the ratio of renewable to conventional fuels within the ASTM certification limits to meet market demands. Consequently, as of the end of 2024, a significant share of global SAF capacity came from the co-processing of lipid feedstocks (IATA 2024).

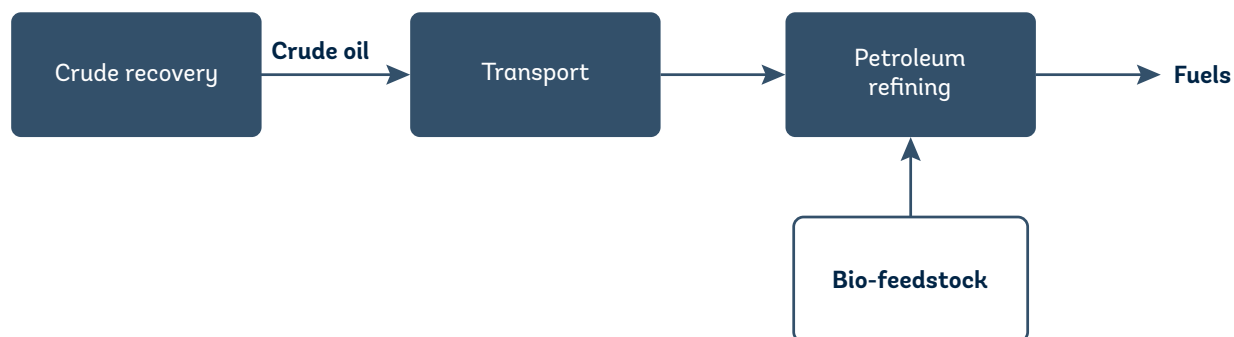
The adaptability of co-processing ensures efficient production management and prevents the under-utilization of assets, a common issue in dedicated biofuel facilities. The variety of lipidic biofeeds available—including virgin vegetable oils, waste oils, and animal fats—broadens the raw material base, enhancing sustainability and resource efficiency.

A report by the World Wide Fund for Nature (Bole-Rental and others 2019) identifies the Gulf of Guinea, where Nigeria is situated, as a prime region for SAF production from lipid feedstocks, given its abundance of vegetable oils. The potential to feed smaller quantities of bio-feedstock than needed in standalone biofuel production facilities offers economic benefits by reducing overall feedstock requirements. This reduction in feedstock needs, coupled with the strategic geographic and resource advantages, positions Nigerian refineries to become players in the global market for SAF.

Plant Design for Co-processing

Co-processing can be performed at existing petroleum refineries, using existing infrastructure. For the production of SAF, biogenic intermediates can be introduced at various points in a refinery (figure 4.1). Process steps can include fluid catalytic cracking (cracking using a catalyst), hydrocracking (cracking using hydrogen), and hydrotreatment.

Figure 4.1. Simplified process flow diagram of production of SAF at a co-processing facility



Source: Original figure for this publication.

Insertion of the bio-feedstock affects the input and output balance and distribution of a refinery (Lee and others 2022); cost changes are therefore highly depending on the refinery used for co-processing.



To provide a general view of the costs of co-processing, we base our analysis on a study by Lee and others (2022) that uses a linear programming model to estimate the inputs and outputs from a refinery with and without co-processed biogenic content. We considered hydrocracker and hydrotreater as points of insertion for the biogenic content. We assumed 10 percent biogenic feedstock in the co-processing unit (not 10 percent of the refinery crude), as this ratio would not require any significant changes in refinery infrastructure (Bezergianni and others 2018). We used soybean oil as the co-processed feedstock, because its fatty acid profile is similar to that of most vegetable oil types. We modeled different feedstock prices to account for price differences between different lipid feedstocks and explore the sensitivity of the selling price of co-processed SAF to feedstock prices in general.

Techno-Economic Model and Results

As existing petroleum refineries in Nigeria could be used for co-processing, we estimate only the additional expenses incurred to upgrade and use a refinery for this pathway, adopting the methodology of Lee and others (2022). Tables A4.1 and A4.2 in the annex to this chapter show the differences in the inputs and outputs in the base case and co-processing. Both the hydrotreater and the hydrocracker were considered for insertion points. Valuable fuel products from co-processing facilities include gasoline, jet fuel, and diesel fuel, as shown in table 4A.2.

Using this product slate, we estimate that a 650,000-BPD facility could produce an additional 3,321 BPD of SAF from the hydrotreater and 5,950 BPD from the hydrocracker. The hydrotreater and hydrocracker could also produce 15,714 and 5,530 BPD, respectively, of diesel. These figures are upper bounds of co-processable SAF for a petroleum refinery of this size. As co-processing of SAF enables flexible bio-feeds to be used, the amount of co-processed SAF can be tailored to the projected or secured uptake of SAF.

Costs of Production Results

We estimated the cost of co-processing at the same facility (using the hydrotreater and hydrocracker as insertion points) using the refinery-level marginal approach, allocating the jet portion of the product slate. Using the cost of jet fuel of \$0.95 per liter, we calculated the minimum selling price (MSP) for co-processing fuels at \$1.02 if the hydrotreater is the insertion point (table 4.1). When the hydrocracker is the insertion point, the MSP of jet fuel is \$1.06 per liter.





Table 4.1. Minimum selling price of co-processed jet fuel produced from soybean oil at a petroleum refinery in Nigeria (naira)

Input	Base cost	Hydrotreater cost	Hydrocracker cost
Crude oil	22.8	22.8	22.8
Biogenic feedstock	0	2.22	1.64
Natural gas	233.5	245.3	244.8
Electricity	0.05	0.05	0.05
Butane	0.24	0.23	0.23
Total	256.61	270.63	269.54
Cost allocated to jet	24.9	26	27.8
Minimum selling price of jet fuel per liter ^a	1,023.0 ^b	1,097.8	1,143.4
Difference in price per liter of jet fuel		74.8	120.4

Notes:

a. Price is for the full jet A1 slate, not just the biogenic portion.

b. Price estimate of kerosene in Nigeria.

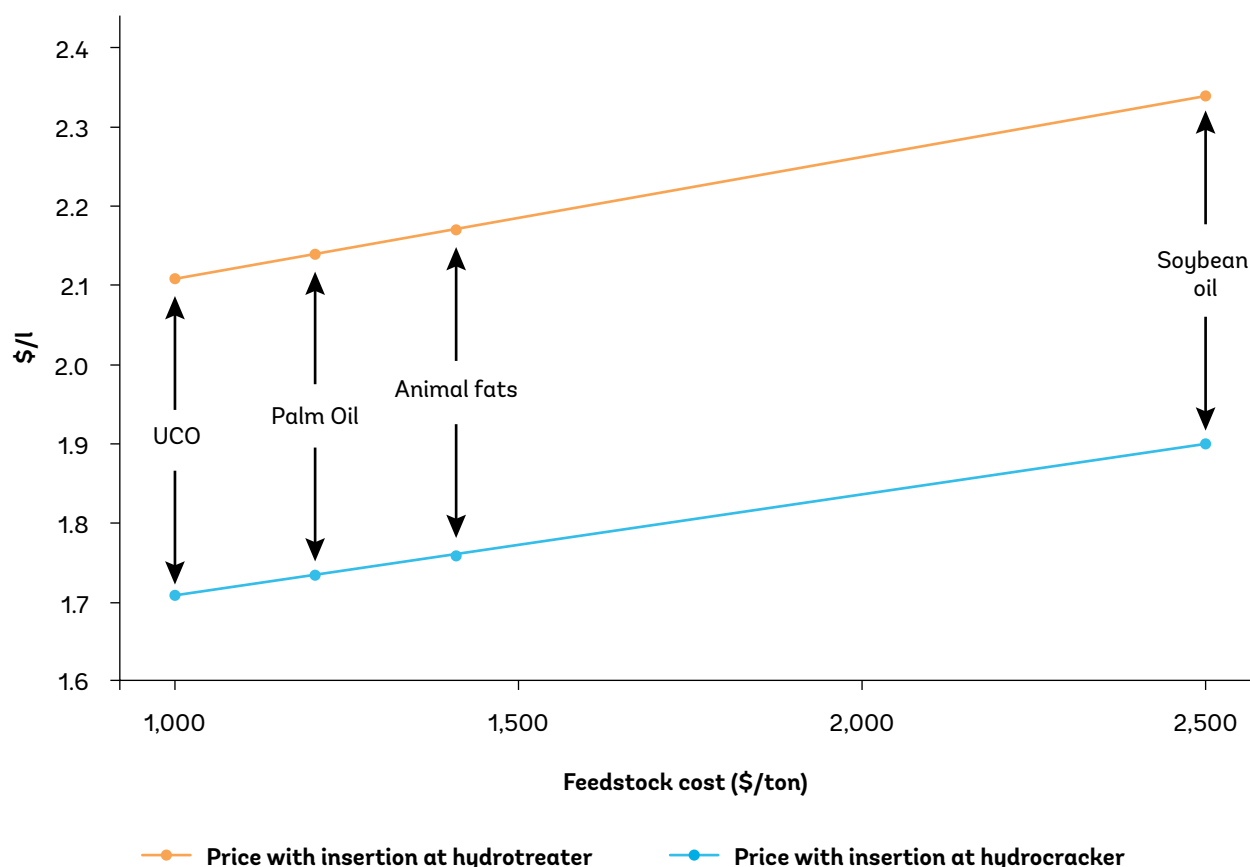
Source: Original table for this publication.

These MSPs are for the full jet A1 product slate, including biogenic and nonbiogenic carbon sources. We can estimate the MSP for the biogenic portion of the total jet volumes produced (the portion that could be sold as “neat” SAF) by apportioning all of the cost for jet fuel production in the refinery to the biogenic jet fuel portion. Doing so yields an MSP for neat SAF of \$2.34 per liter for the hydrotreater and \$1.90 per liter for the hydrocracker when soybean oil is used as the biogenic feedstock at a price of \$2.5 per kg oil. The larger difference in prices between the two inserting points for neat SAF compared with the jet A1 price differences is a function of the higher share of biogenic jet fuel if the biogenic feedstock is inserted at the hydrocracking stage rather than the hydrotreatment stage.

Other oils or fats might have lower costs than assumed here. A detailed modeling of the selling prices for different lipid feedstocks is beyond the scope of this report. We can, however, give indicative selling prices for co-processed SAF from different lipid feedstocks by varying the feedstock price within the model of Lee and others (2022). Doing so yields the results shown in figure 4.2.



Figure 4.2. Minimum selling prices for neat co-processed SAF for hydrocracker and hydrotreater insertion as a function of feedstock prices



Note: Indicative world market prices for used cooking oil, mixed animal fats, and palm oil are as of 2024.

As expected, the feedstock price has a strong effect on the selling price of co-processed SAF. Using low-cost feedstocks such as UCO or animal fats enables production of co-processed SAF at about \$1.7 to \$1.8 per liter, less than the global average SAF price in 2024 of \$1.83 per liter of neat SAF.

In order to start lipid co-processing in Nigeria, barriers with regard to feedstock sourcing need to be overcome. Leveraging Nigeria's feedstock potential will require setting up complex supply chains from the field to the SAF biorefinery that cut across borders and jurisdictions. At the production level, access to good-quality seeds and fertilizer is needed to produce sufficient yields, especially given climate variability and traditional farming practices. Harvesting inefficiencies, driven by a lack of mechanization and skilled labor, could further constrain supply. Post-harvest, adequate storage infrastructure is needed to avoid feedstock degradation, particularly in tropical climates, where lipids are prone to spoilage. Transportation is another bottleneck: Poor road networks, high fuel costs, and logistical inefficiencies increase the cost and risk of moving bulky feedstock to processing facilities, especially in regions with underdeveloped infrastructure. Supply chain fragmentation—in the form of numerous smallholder farmers with limited coordination—complicates the aggregation of feedstock at scale. Regulatory hurdles, including unclear land tenure policies, also create uncertainties that deter investment in robust supply chain systems.



Transborder trade of lipid biomass feedstock introduces additional complexities with regard to tariff and nontariff-related trade barriers, which can disrupt the supply chain from the field to the biorefinery. Lengthy customs procedures, inefficient border controls, and bureaucratic red tape can reduce the reliability of the supply chain. Experience from other African countries with lipid feedstock production and aggregation indicate that these challenges can be overcome. In Kenya, for example, agri-hubs have been built for large-scale extraction and aggregation of lipid biomass that serve as central point in the upstream biofuel supply chain.

Lifecycle Greenhouse Gas Emission Results for Co-processed Sustainable Aviation Fuel

For international aviation, default lifecycle greenhouse gas emission estimates for co-processed SAF currently exist for three feedstocks: tallow, UCO, and soybean oil. They were established using the model used for the costs of production estimates presented in this chapter (Lee and others 2022). Given the small differences between emissions of co-processed SAF inserted at the hydrotreater versus hydrocracker levels, one default value per feedstock was established. The lifecycle greenhouse gas emissions of co-processed SAF are driven by the emissions associated with the bio-feedstock used and the emissions occurring within the refinery from the insertion point onward (table 4.2).

Table 4.2. Default core life-cycle emission values for co-processed SAF under CORSIA (gCO₂e/MJ of co-processed SAF)

Item	Used cooking oil (UCO)		Soybean oil		Tallow	
	HDT	HYK	HDT	HYK	HDT	HYK
Insertion point						
Feedstock production/transportation	3.6	3.6	27.0	26.8	15.9	15.8
Fuel production	11.1	14.4	11.8	15.2	9.4	12.7
Fuel transportation	0.3	0.3	0.3	0.3	0.3	0.3
Total	15	18.3	39.1	42.3	25.6	28.8
Default core LCA value (gCO ₂ e/MJ)	16.7		40.7		27.2	

Note: HDT = hydrotreater; HYK=hydrocracker

Source: Original table for this publication.

The values for co-processed SAF currently within CORSIA represent three different feedstock types: a waste (UCO), a residue or byproduct (tallow), and a traditional vegetable oil requiring dedicated land (soybean oil). For wastes, the relative lifecycle starts with collection. In the case of UCO, limited processing is needed. Tallow needs to be rendered, increasing emissions compared with UCO. For traditional virgin oils such as soybean oil, emissions from soybean farming (fertilizer, diesel, electricity) have to be accounted for, increasing emissions beyond those produced by tallow.



On the refinery side, the type of feedstock has only limited influence on the lifecycle emissions value (about a 6 gram variation between the lowest and the highest value versus about 23 gram for feedstock). Variations in refining emissions are caused partly by different chemical compositions of lipid feedstocks that affect hydrogen needs and the degree of feedstock pretreatment needed.

For virgin oils, emissions associated with direct and indirect land-use change can play an important role in the total lifecycle emissions (Escobar and others 2024). The main drivers of emissions from direct land-use change include the loss of vegetation and soil organic carbon during land conversion, particularly in high-carbon-stock areas like forests and grasslands. The type of land converted (intact forests versus already managed lands) significantly affects emissions, with undisturbed lands contributing more. Spatial variability, driven by factors like location, climate, and land management practices, also affect emissions. Indirect emissions stem from market-mediated responses: The increased demand for vegetable oils drives up prices, which disrupts equilibria on feedstock markets and leads to a reallocation of land use that leads to a change in greenhouse gas emission fluxes.

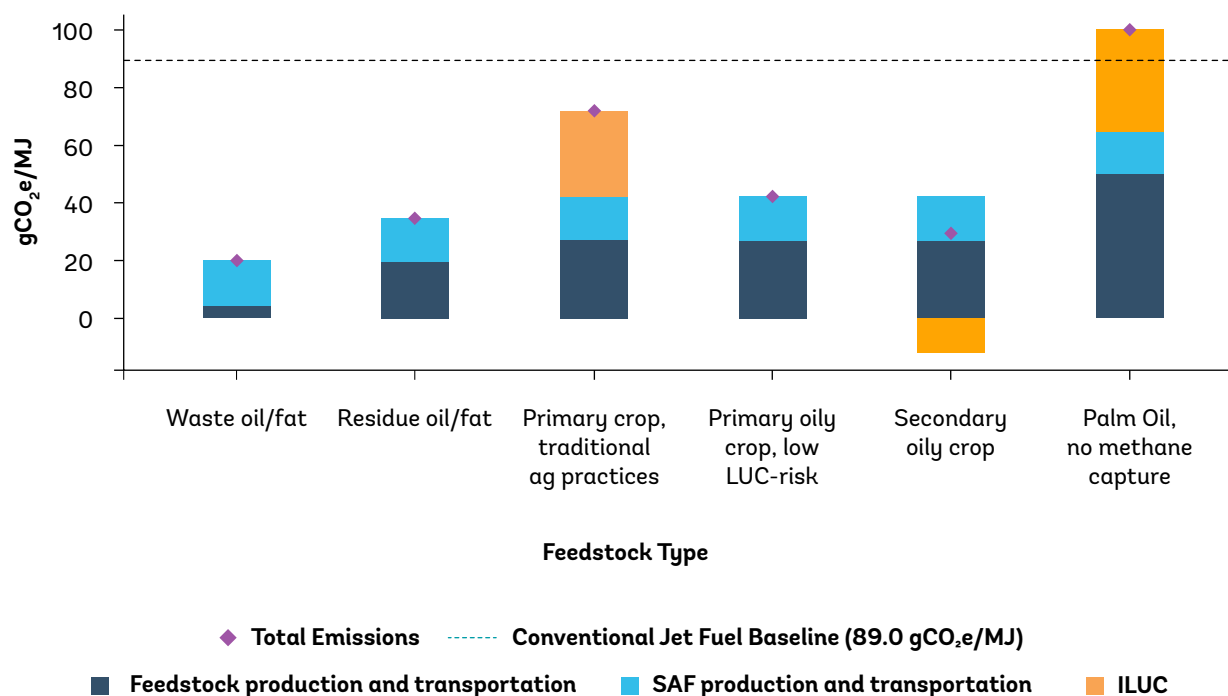
CORSIA quantifies the direct and indirect emissions from land-use change associated with a set of oil-producing biomass. For co-processed soybean oil, the sum of direct and indirect emissions is estimated at 25.8 grams of carbon dioxide equivalent per megajoule of energy ($\text{gCO}_2\text{e/MJ}$) of SAF, yielding total emissions for the full lifecycle of 66.5 $\text{gCO}_2\text{e/MJ}$. The induced land-use change (ILUC) values for primary crops shown here apply in case in which the feedstock is grown on arable land. If primary crops are grown on marginal land or management practices that imply low land-use change risk are applied, ILUC values will be lower; in CORSIA they are set to zero.

For co-processed SAF in Nigeria, the three International Civil Aviation Organization (ICAO) default values for co-processing using UCO, tallow, and soybean oil have global applicability and can therefore be applied to the Nigerian case. Beyond the three cases for which lifecycle emission values with applicability to Nigeria exist, the evidence presented above points suggests that lifecycle greenhouse gas emissions from SAF produced from lipid co-processing are highly dependent on the type of feedstock used and the emissions associated with land-use change.

Figure 4.3. provides indicative values for Nigeria derived from the CORSIA default value data. It shows that waste and residue lipids provide opportunities for greenhouse gas emission reductions per unit of fuel of 70–80 percent compared with conventional jet fuel. The limited availability of these feedstocks limits their scalability, however. The lifecycle greenhouse gas emissions of virgin lipids are strongly affected by the emissions associated with land-use: Co-processed SAF can produce relatively high emissions, potentially exceeding the emissions from conventional jet fuel, if grown on high-carbon-stock land with conventional farming practices. In contrast, emissions can be close to zero—or even negative—when crops are cultivated on degraded or marginal lands with low carbon stocks, avoiding deforestation or conversion of high-carbon ecosystems, when grown as a secondary crop or when implementing sustainable land management practices that enhance soil carbon sequestration.



Figure 4.3. Indicative lifecycle emissions for co-processed SAF produced in Nigeria



Note: Figures are indicative values, derived from CORSIA default values. Refinery and SAF transport emissions are set constant across fuels and feedstock production. Induced land-use change values vary. CORSIA = Carbon Offsetting and Reduction Scheme for International Aviation. ILUC=induced land use change.
 Source: Original figure for this publication.

The Gulf of Guinea region contains significant areas of high-carbon-stock land, including tropical rainforests, mangroves, and peatlands. These ecosystems store large amounts of carbon, making them critical to global climate regulation. Avoiding destroying these areas for biomass production is critical for preserving a lifecycle emission benefit for SAF produced from oils from this region.

Beyond land-use change emissions—especially for palm oil, which is considered a highly suitable oil crop for Gulf of Guinea countries (Bole-Rentel and others 2022)—it is important to avoid methane emissions from palm oil biofuel production, which can account for more than 20gCO₂e/MJ of SAF (Figure 4A.1 in the annex to this chapter). These emissions arise from the anaerobic decomposition of palm oil mill effluent (POME), which can release large amounts of methane (Yacob and others 2006). Mitigation strategies like biogas capture systems and aerobic treatment can significantly reduce these emissions, turning methane into a renewable energy source for palm oil mills.

Conclusions and Recommendations

With a state-of-the-art petroleum refinery already producing jet fuel, Nigeria is well-positioned to become a player in the global SAF market by co-processing lipids (vegetable oils, waste oils and fats, or animal fats). Co-processing offers a commercially attractive pathway for SAF production because it leverages existing refinery assets to produce both biogenic and conventional jet fuel, reducing the need for additional capital expenditures. Doing so is particularly relevant given the financial challenges domestic airlines in Nigeria face.



The cost of producing 1 MJ of energy products from crude oil in Nigeria is estimated at NO 347.4. Using the existing infrastructure for co-processing increases the cost to NO 368.4 using a hydrotreater and to NO 366.5 using a hydrocracker.

Based on these data, the estimated MSP for co-processed jet fuel is NO 1,103.8 per liter for inserting at the hydrotreater and NO 1,148.3 per liter for inserting at the hydrocracker. Using low-cost feedstocks such as UCO, animal fats, or palm oil, could reduce the cost to about \$1.9 per liter. This price is competitive with the 2024 global average SAF price of \$1.83 per liter of neat SAF. This finding underscores the significant cost advantage of co-processing, particularly when using readily available, inexpensive feedstocks.

Nigeria's existing petrochemical industry and jet fuel-refining capabilities offer a cost-effective entry point into SAF production through lipid co-processing. The country's location on the Gulf of Guinea provides access to abundant lipid-based feedstocks, including waste oils. Co-processing leverages existing infrastructure, potentially avoiding substantial capital investments in standalone biofuel plants. However, uncertainties—about quality, mechanization, storage, and logistics—exist regarding the establishment of complex feedstock supply chains from the field to refineries. The scaling of feedstock availability, particularly for waste oils, may be limited. The MSP of co-processed SAF is highly sensitive to feedstock prices, with lower-cost feedstocks like UCO leading to more competitive SAF prices. Policy incentives and a clear regulatory framework are crucial to overcome barriers and drive the adoption of co-processing in Nigeria.

Capital investment for co-processing is limited, but a joint effort by government and private sectors actors is essential to overcome barriers on both the supply and demand sides to facilitate the production and uptake of co-processed SAF in Nigeria.

Government Initiatives

Possible government initiatives include the following:

- **Developing a feedstock strategy:** The Nigerian government could develop a plan to ensure a sustainable, abundant, and cost-effective supply of raw materials for SAF production. The ample vegetable oils in the Gulf of Guinea region give Nigeria a strategic advantage; efforts could prioritize using waste oils and fats like UCO and tallow, which can reduce greenhouse gas reductions and do not compete with food production. The government could promote sustainable sourcing through certification schemes and partnerships with local farmers to prevent deforestation and food crop displacement. It could promote non-food oil crops on marginal lands and use agricultural residues and waste materials as alternative feedstocks, to address concerns about food and fuel competition.
- **Developing efficient logistics and transport infrastructure:** Efficient logistics and transport systems are critical for SAF feedstock collection and fuel distribution. The integration of road, rail, inland waterways, and pipelines is necessary for cost-effective and timely movements. Establishing storage facilities and hubs would streamline the supply chain; prioritizing low-emission transport options would minimize the carbon footprint. Using smart technologies for route optimization and inventory management can enhance efficiency and reduce emissions. This approach would both strengthen Nigeria's SAF industry and support climate and economic goals.



- **Establishing clear policy frameworks:** The government could implement financial and nonfinancial incentives for refineries to engage in co-processing, such as tax breaks, grants, and streamlined permitting processes to encourage investment. SAF blending mandates for airlines operating in Nigeria, similar to those adopted in other regions, would create a guaranteed market for SAF and stimulate further investment in production capacity. To support technological advancements, the government could invest in R&D initiatives aimed at optimizing co-processing technologies and exploring alternative feedstocks. This effort could include funding pilot projects, providing grants to research institutions, and fostering international collaborations to share knowledge and best practices.
- **Drafting a roadmap for SAF development:** A comprehensive roadmap would outline the government's vision for a domestic SAF industry and facilitate collaboration between the private and public stakeholders. It should set clear targets for SAF production and uptake, define roles and responsibilities for different stakeholders, and establish a monitoring and evaluation framework to track progress.

Private Sector Initiatives

Private sector actors are essential drivers of SAF adoption, bringing capital, expertise, and market demand to accelerate the transition toward cleaner aviation. Their participation is crucial in building a robust and sustainable SAF ecosystem in Nigeria.

- International airlines should commit to long-term offtake agreements for co-processed SAF, in order to provide stable demand and reduce investment risk. These agreements ensure producers of a consistent market, which is vital for financing and scaling up production. Airlines could also invest in SAF production facilities through equity investments, joint ventures, or partnerships with local refineries to increase capacity and lower costs. They could educate travelers and stakeholders about SAF's environmental benefits to boost industry support. Collaborating with fuel suppliers to create efficient distribution networks would help ensure reliable delivery and minimize logistical issues.
- International corporations operating in Nigeria can also play a critical role in supporting SAF adoption. Companies with significant carbon footprints could purchase SAF credits to offset their emissions and meet their sustainability targets. Such an approach would allow corporations to directly support the SAF market without requiring immediate changes to their own operations. Corporations could also invest in SAF production facilities, providing capital for infrastructure development and supporting local industry growth. By financing production facilities or engaging in power purchase-style agreements, corporations would help expand SAF supply while demonstrating their commitment to sustainable practices. Such investments not only offset their carbon footprint, they also align with corporate social responsibility goals and environmental, social, and governance standards.

Cross-industry collaboration between airlines, fuel producers, and corporate buyers can amplify the impact of these efforts. For example, corporate commitments to purchase SAF for business travel or cargo shipments can aggregate demand and encourage large-scale production. Companies could also form coalitions to fund research and pilot projects aimed at improving SAF production technologies. These initiatives, combined with transparent reporting on carbon reduction impacts, could drive industry-wide progress and establish Nigeria as a leader in sustainable aviation fuel development.



Initiatives by Multilateral Development Banks

Multilateral development banks and development finance institutions can spur the development of SAF in Nigeria in several ways:

- **Providing targeted financial tools:** Concessional loans, guarantees, and grants are essential to reduce the financial risks associated with feedstock production and SAF infrastructure development. These tools can lower borrowing costs, making SAF projects more attractive to private investors.
- **Linking these financial instruments to sustainability criteria, to ensure that feedstock sources comply with international standards, such as those mandated by CORSIA:** Adherence to these standards would promote sustainable practices in feedstock sourcing, reduce environmental impacts, and enhance the credibility of Nigeria's SAF initiatives. Unlike in many other capital-intensive industries, the greatest financial need in SAF co-processing lies not in large-scale infrastructure investment but in securing access to abundant, affordable, and sustainable feedstocks. Therefore, financial tools should be specifically designed to reduce the cost and risks of developing local feedstock supply chains.
- **Providing technical assistance to strengthen feedstock supply chains:** Technical support can include capacity-building programs for local farmers, training on sustainable agricultural practices, and assistance with certification processes to meet international sustainability standards. Multilateral development banks can also help stakeholders map potential feedstock sources, identify gaps in the supply chain, and design solutions to address these gaps. This assistance is critical for ensuring the availability of sustainable and cost-effective feedstocks.
- **Facilitating knowledge sharing, by connecting Nigerian stakeholders with international experts and successful case studies from other countries developing their SAF industries.**





Annex 4A Key Assumptions and Data for Techno-Economic Analysis of Nigeria

Co-processing is a promising method for producing SAF by integrating biogenic feedstocks like lipids and biocrudes into existing petroleum refining processes, thereby leveraging established infrastructure and supply chains (Lee and others 2022; Van Dyk, S., & Saddler, J. (2024); IATA 2024). This approach allows for the production of lower carbon-intensity fuels and can adapt to market fluctuations. Challenges include feedstock availability, processing complexities, and regulatory constraints. Hydrotreaters, hydrocrackers, and fluid catalytic crackers (FCC) are key units for co-processing, each with unique capabilities and limitations.

Co-processing faces several challenges. ASTM D1655 Annex A1 restricts petroleum refineries to a maximum of 5 percent biogenic feedstock for SAF production, although more can be co-processed if jet fuel is not produced. Feedstock pretreatment is often necessary to remove oxygen, which increases hydrogen requirements. The high oxygen content and complex chemistry of biocrudes pose additional challenges, including thermal instability, acidity, corrosion concerns, and catalyst deactivation.

Tracking the “green molecules” throughout the co-processing procedure and determining the distribution of renewable content in the final fuel fractions is critical for substantiating emission reductions and complying with regulatory standards. Various methods, including C14 testing, mass balance calculations, and soft sensor approaches, are being explored to accurately quantify the biogenic portion of co-processed fuels. Policies such as the Low Carbon Fuel Standard (LCFS) are driving the adoption of co-processing by placing a value on carbon emissions and incentivizing the production of fuels with low carbon intensity (Lee and others 2022).

Tables A4.1 and A4.2 present the assumptions for the techno-economic analysis of SAF production via co-processing in Nigeria. Table 4A.1 lists variable operating expenses for soybean oil, natural gas, and electricity. It compares refinery inputs and outputs for a base case scenario using hydrotreater and hydrocracker units.

Table 4A.1. Variable operating expenses of a co-processing facility in Nigeria

Expense type	Dollars	Naira
Soybean oil (kg)	2.50	2,689
Natural gas (liters)	0.08	90
Power (kwh)	0.02	36.1

Source: Soybean data are from IndexBox (n.d.). Natural gas costs are from Nig LP Gas (n.d.). Power costs are from Statista (n.d.).


Table 4A.2. Refinery-level inputs and outputs for the co-processing pathway in Nigeria (kilojoules)

Item	Base input/ output (MJ)	Change in input/ output (MJ) Hydrotreater	Change in input/ output (MJ) Hydrocracker
<i>Input</i>			
Crude oil	1,017	0	0
Biogenic feedstock	—	30.4	22.4
Natural gas	95	4.8	4.6
Electricity	5	0.6	0.4
Butane	17	-0.3	-0.9
<i>Output</i>			
Gasoline	425	1.6	4.2
Diesel	395	23.3	8.2
Jet fuel	97	4.8	8.6
Liquefied petroleum gas	25	1.7	2.1
Coke	58	0	0
Total	1,000	1,031	1,023

Note: — = Not available.





Figure 4A.1 Default lifecycle emissions within CORSIA for SAF produced from oily feedstocks



Note: Values are hydrotreated esters and fatty acids (HEFA) and global in applicability, unless indicated otherwise. Used cooking oil, tallow, palm fatty acid distillate, and corn oil have caused no induced land-use change, as they are not purposely produced or are, not the main product. Palm values are applicable to Malaysia and Indonesia only. HEFA values are shown for camelina, brassica carinata, palm, rapeseed, corn oil and palm fatty acid distillate. CORSIA = Carbon Offsetting and Reduction Scheme for International Aviation.



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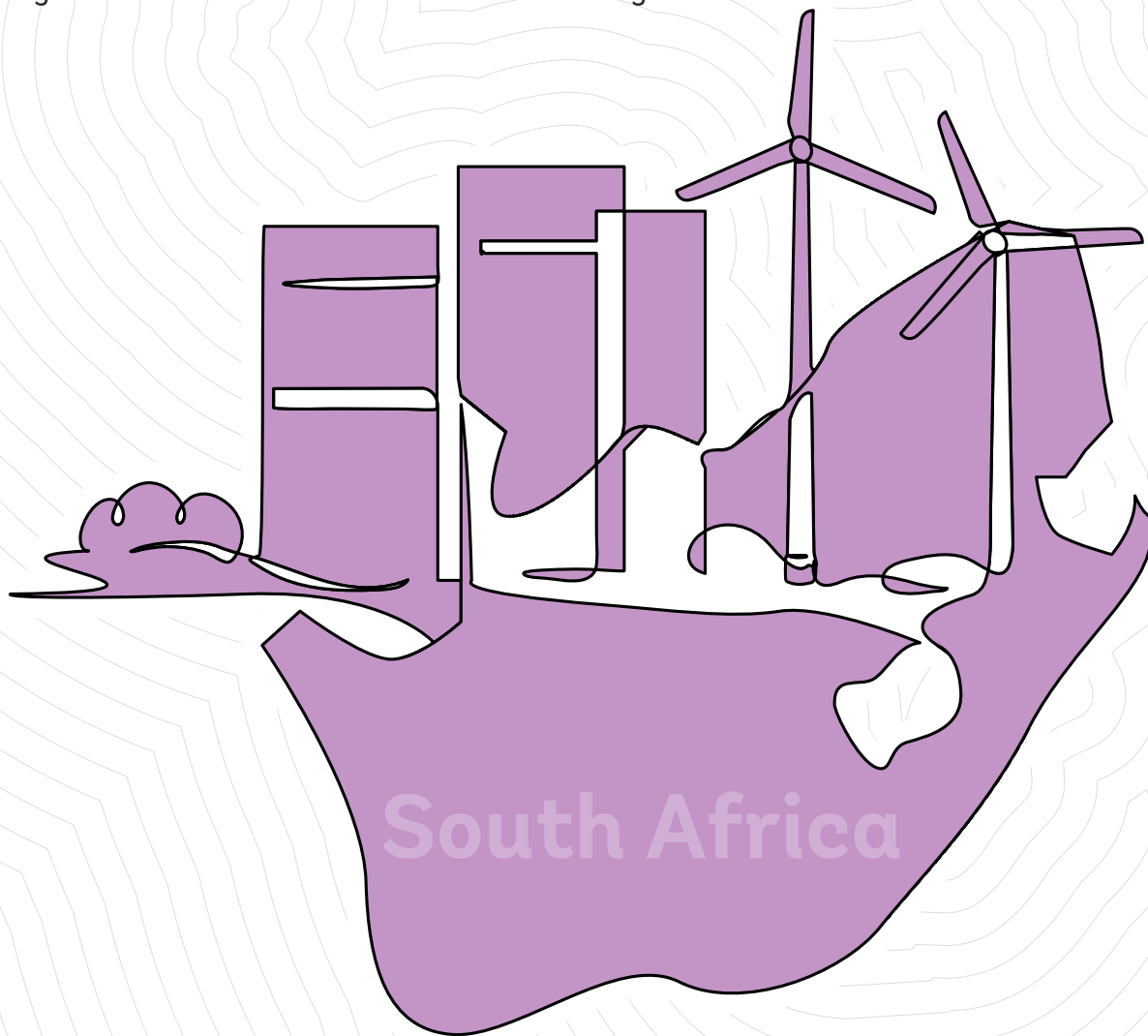
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05

South Africa Deep Dive

South Africa's technical expertise and potential in e-kerosene production present a promising pathway for producing and scaling SAF production. This chapter explores how South Africa can leverage existing resources and knowledge banks while reducing high costs and reliance on coal-fired electricity.





Overview

South Africa has strong potential to lead the sustainable aviation fuel (SAF) market, particularly by producing e-kerosene (synthetic fuel) via the power-to-liquid (PtL) pathway. This potential is supported by the country's expertise in Fischer-Tropsch (FT) technology, its ample sources of industrial waste carbon, and its large-scale green hydrogen projects. Challenges include high production costs and reliance on coal-fired electricity.

The minimum selling price (MSP) for e-kerosene in South Africa is estimated at \$4.6 per liter—more than twice the global SAF average of \$2.2. Green hydrogen, a critical PtL input, accounts for 41 percent of production costs. A 1,000-barrel per day (BPD) PtL facility requires a \$156 million capital investment, with capital costs making up 46 percent of total jet fuel production costs. Expanding green hydrogen production to support five such plants could require a \$2.5 billion investment. Carbon sourcing also influences costs: Industrial point sources are less expensive, and direct air capture substantially raises expenses.

South Africa's heavy reliance on coal-fired power plants for electricity generation raises concerns about the lifecycle emissions associated with e-kerosene production. If e-SAF production relies on electricity from the existing grid mix, lifecycle emissions are projected to reach about 600 grams of carbon dioxide equivalent per megajoule of energy ($\text{gCO}_2\text{e/MJ}$) of SAF—an increase over the emissions from conventional jet fuel, undermining the environmental benefits of SAF. Achieving substantial emissions reductions with PtL SAF requires a paradigm shift in the electricity generation landscape. Ensuring that the electricity used for SAF production comes from newly added renewable energy capacity is paramount, to prevent the depletion of existing renewable energy sources and ensure emissions reductions.

The source of carbon also plays a role in the environmental performance of e-SAF. Using biogenic point-source carbon or direct air capture can offset the emissions from e-SAF combustion. Using fossil carbon from industrial point sources requires meticulous carbon accounting practices, however. Clear rules need to be established to prevent double-counting of emission benefits (ensuring that the emission reduction is credited only once, either at the SAF producer or the airline level).

Overcoming economic and environmental barriers requires a strong policy framework. SAF blending mandates, financial incentives, and loan guarantees can stimulate demand and close the price gap with conventional jet fuel. A robust carbon accounting system can ensure compliance with international sustainability standards. Private sector involvement is crucial: Long-term airline purchase agreements can secure revenue, and corporate investment in SAF production can drive industry growth. Financial institutions, including local commercial banks and development banks, must collaborate to de-risk investments and attract capital. International cooperation can accelerate progress by sharing technical expertise, sustainability certification knowledge, and policy best practices. Capacity-building programs will equip local stakeholders with the necessary skills.



Description of Country Case

Aviation and Economy

Aviation plays a vital role in South Africa's economy, contributing significantly to GDP, employment, and trade facilitation. In 2017, the sector accounted for 3.2 percent of GDP. South Africa earned \$8.8 billion from foreign tourism expenditure and \$150 billion in foreign direct investment (IATA 2018). Supported by robust domestic airlines and major airports (OR Tambo, Cape Town International, and King Shaka), the sector facilitates passenger and cargo transport and drives substantial economic activity through job creation and infrastructure development. These airports serve as economic hubs, enhancing connectivity within the country and supporting local commerce and international trade.

Air travel is essential for bringing international visitors to South Africa's natural and cultural attractions, significantly boosting the economy (Njoya and Nikitas 2020). The importance of sustainable practices in this sector is increasingly recognized, with initiatives shifting toward SAF and more efficient air traffic management systems. These efforts not only support South Africa's commitment to global environmental goals, they also ensure the long-term viability of air transport as a pillar of the economy.

South Africa could position itself strategically to capitalize on the global demand for SAF that is being driven by international mitigation measures and rising carbon-offset costs. With its rich resource base and expertise in SAF technologies, the country is poised to develop a substantial domestic SAF industry. This development is expected to help decarbonize the local aviation sector and increase exports in regulated (that is compliance) and voluntary markets.⁴⁰ The transition toward becoming a self-sufficient producer of aviation fuels aligns with South Africa's plans to participate in international carbon-reduction schemes by 2027, which could transform the country from a net importer to a leading player in the global SAF market.

The path to establishing a thriving SAF sector is fraught with challenges, however, including the need for significant technological and financial investment to scale up production and develop necessary infrastructure. Regulatory stability and market predictability are crucial to attracting and securing investments. Financial difficulties faced by domestic airlines, such as, could dampen demand for SAF, underscoring the need for supportive government policies and incentives (World Bank 2022).

Air Transport Decarbonization Policy

South Africa's transport decarbonization policy is an important component of its broader strategy to drive economic growth through green solutions and a just transition. This comprehensive strategy includes initiatives such as amending the Electricity Regulation Act to facilitate the integration of green hydrogen, updating the Integrated Resource Plan with significant renewable energy projects, and enacting the Climate Change Bill to legally mandate sectoral emission targets (WEF 2024). The Green Transport Strategy aims to significantly reduce emissions from road transport.

⁴⁰ A study by the World Wide Fund (WWF) for Nature in South Africa notes that transitioning to SAF could transform the country from a net importer to a self-sufficient producer of aviation fuels, potentially covering all jet fuel imports and even exporting excess production. This shift could improve South Africa's trade balance by at least R 81.5 billion a year, with the potential to reach to R 170 billion. Exporting SAF could also yield substantial revenues, enhancing the country's economic stability and contributing to its global emissions reduction goals (WWF South Africa 2022).



These initiatives are supported by the Just Energy Transition Investment Plan, which targets substantial investments in low-carbon technologies, all anchored by the revised Nationally Determined Contribution, which commits South Africa to reach net-zero emission by 2050 and to meet a 2030 target that aligns with limiting global warming to less than 2°C (Climate Action Tracker 2023).

The transport sector is the third-largest emitter of greenhouse gases in South Africa. Over 90 percent of these emissions coming from road transport (IEA 2025). Aviation is the second-largest contributor in the sector, emitting about 4 million tonnes (Mt) of CO₂ in 2017, primarily from jet fuel combustion (National Business Initiative 2023).

Decarbonizing aviation in South Africa involves increasing the blending of SAF, despite the higher operational costs associated with green fuels. Without these efforts, the sector's emissions trajectory will not meet national and international climate commitments. The transition to SAF is linked to broader transport strategies, such as shifting road traffic to rail, improving spatial planning, and enhancing the grid's decarbonization, part of an holistic approach for achieving a net-zero emissions target by 2050.

A study by the Roundtable on Sustainable Biomaterials (RSB 2022) identifies several policy gaps that hinder the growth of the SAF industry in South Africa. They include limited policy support for nonfood feedstocks, inadequate capital and financial incentives for new technologies, and a restrictive regulatory framework that excludes co-products like renewable diesel and petrol. Addressing these gaps by expanding policy support to include labor-intensive nonfood feedstocks; providing financial incentives, such as capital subsidies and concessional finance; revising regulations to incorporate SAF co-products; and implementing an SAF blending mandate could secure the necessary demand and enhance financial viability. Integrating SAF production with national just transition plans and focusing on maximizing local content could boost employment and revenue generation in local supply chains, supporting both environmental and socioeconomic objectives.

Jet Fuel Demand and Supply

South Africa consumed about 1.478 billion liters of jet fuel in 2022 (about 25,000 barrels per day [BPD]), accounting for 5.8 percent of the country's total petroleum consumption (table 5.1. and figure 5.1) (South African Petroleum Industry Association 2022). Jet fuel consumption was much higher before the pandemic and the struggles of the national carrier (South African Airways): In 2015, it was 2.4 billion liters (42,000 BPD).

Table 5.1. Consumption of petroleum products in South Africa, by fuel type, 2012–22 (million liters)

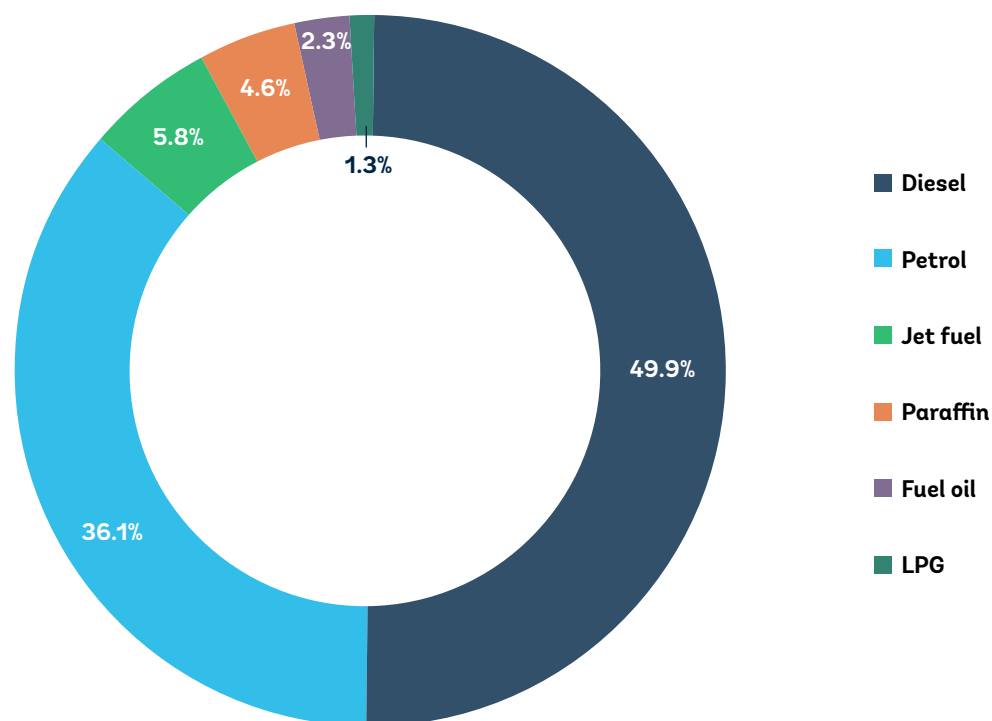
Year	Petrol	Diesel	Jet fuel	Liquefied petroleum gas	Fuel oil	Paraffin
2012	11,714	11,262	2,367	656	568	470
2013	11,153	11,890	2,223	485	523	530
2014	11,344	13,169	2,197	398	487	568



Year	Petrol	Diesel	Jet fuel	Liquefied petroleum gas	Fuel oil	Paraffin
2015	12,072	14,178	2,441	588	591	573
2016	10,160	10,846	2,121	557	562	558
2017	11,174	12,147	2,713	551	523	648
2018	11,142	12,539	2,346	504	552	702
2019	10,773	12,909	2,439	495	410	642
2020	8,761	11,690	1,091	448	486	702
2021	9,302	12,,946	1,048	308	494	1,078
2022	9,185	12717	1,478	323	594	1,178

Source: South African Revenue Service website.

Figure 5.1. Share of petroleum products consumed in South Africa, 2022



Source: South African Revenue Service website.

Note: LPG = liquefied petroleum gas.



South Africa relies on imported jet fuel because it has insufficient local refining capacities. This dependence exposes the country to global oil price fluctuations and supply chain vulnerabilities, as evidenced during the global COVID-19 pandemic.

The infrastructure for jet fuel supply faces significant challenges, particularly from severe weather events such as the flooding in April 2022, which disrupted supply chains and flight operations. Major airports such as OR Tambo International Airport receive jet fuel through a dedicated pipeline from the Natref refinery and by rail from Durban. Limited storage capacity in Durban and frequent rail network security breaches pose ongoing risks to stable fuel supply. These issues underscore the need for enhanced infrastructure resilience and diversified supply sources to mitigate such risks (South African Petroleum Industry Association 2022).

To reduce reliance on volatile imported jet fuel and enhance energy security, South Africa is increasingly focusing on the development of SAF (Chireshe, Bole-Rentel, and Reeler 2022). This shift aims not only to stabilize the supply chain but also to align with global environmental targets by reducing the aviation industry's carbon footprint.

The pursuit of SAF involves both enhancing the technological and processing capabilities of existing refineries and investing in new technologies that can convert biomass and waste into jet fuel. Promoting SAF could also stimulate local industries, create jobs, and position South Africa as a leader in renewable energy within the aviation sector. SAF could serve as a buffer during disruptions to traditional fuel supplies, ensuring more consistent availability and price stability. This strategic emphasis on SAF underscores the importance of innovative, sustainable solutions in securing the future of South Africa's aviation fuel supply while contributing to global environmental goals.

Feedstock Potential and Plant Design

South Africa was selected as a case study for the power-to-liquid (e-SAF) pathway from green hydrogen (which uses industrial waste carbon as a carbon source) because of several factors.⁴¹ It can leverage its expertise in Fischer-Tropsch conversion and cost-effective green hydrogen production to establish itself as a leader in the global e-SAF market. The country's industrial waste carbon provides a low-cost entry point for sustainable fuel investments, supported by governmental and industrial initiatives.

South Africa's ambitious national strategy is detailed in the Hydrogen Society Roadmap, published in 2021. It sets targets for deploying 10 gigawatts (GW) of electrolysis capacity and producing 500 kilotonnes of hydrogen annually by 2030 (Republic of South Africa Department of Science and Innovation 2021).

To support these targets, South Africa is pioneering the development of "hydrogen valleys." This initiative encompasses a geographic corridor that stretches from Mokopane in Limpopo, a notable mining hub, through Johannesburg's industrial heartland to Durban, a major port city. The approach

⁴¹ Previous studies on SAF in South Africa revealed the country's potential, suggesting that it could produce up to 4.5 billion liters of SAF a year, especially when incorporating green hydrogen. Using sugarcane and molasses could yield over 300 million liters a year. FT synthesis from invasive plants and garden waste could contribute up to 3 billion liters. The hydroprocessed esters and fatty acids (HEFA) pathway with Solaris seeds is another viable method, potentially producing 1.1 billion liters and generating approximately 20,000 agricultural jobs. Using biogenic waste feedstocks for ethanol production could supply up to 300 million liters a year of ethanol for SAF production (Chireshe and others 2022).

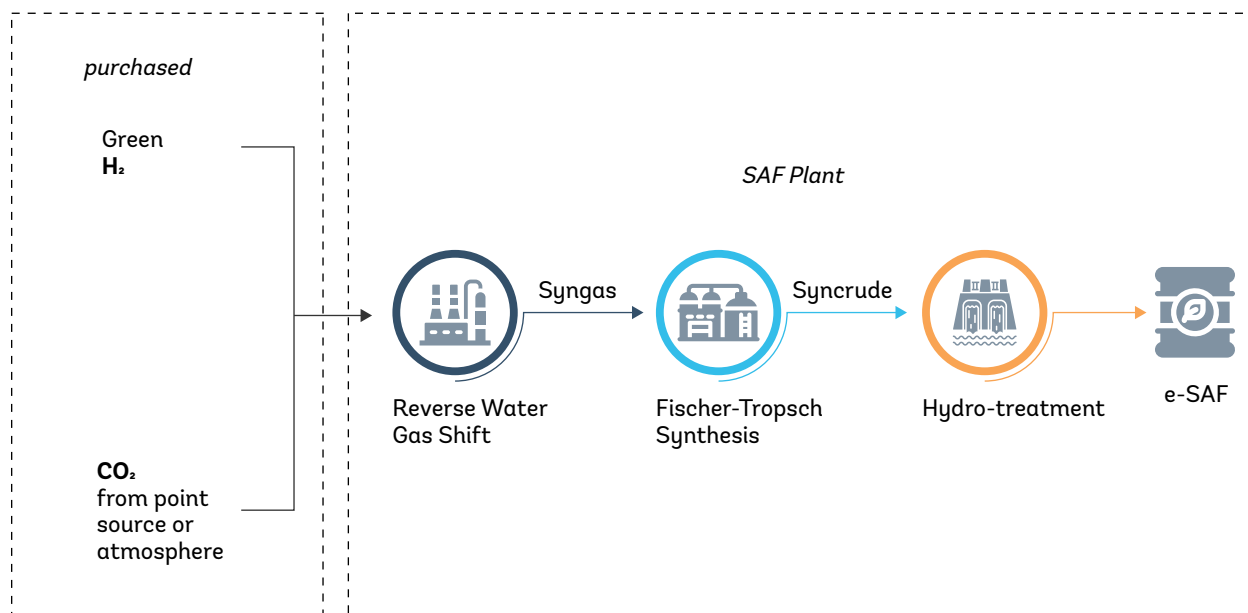


aims to create an interconnected network across this region, linking the production, transportation, storage, and usage of green hydrogen. A recent report (International PtX Hub. 2024) estimates that concentrated and unavoidable industrial carbon emissions in South Africa will amount to 30–40 Mt of CO₂ a year by 2030. For context, a 1,000-BPD PtL plant would require about 0.1 Mt of input CO₂ a year.

Building on its expertise in the coal-to-liquid process (in which coal is gasified and the resulting syngas is converted into liquid fuels using Fischer-Tropsch technology), South Africa continues to innovate. Liquid fuels are currently produced via this pathway at SASOL's Secunda refinery, and there are plans to extend this technological leadership to SAF facilities, including an e-SAF project in Secunda (HyShiFT). Although no specific domestic policies currently support the deployment of SAF, the development of an e-SAF plant is integrated within the aforementioned Hydrogen Roadmap, underscoring South Africa's proactive approach to integrating cutting-edge green technologies into its energy and industrial sectors.

We modeled an SAF plant that uses green hydrogen and concentrated CO₂ to produce syngas (figure 5.2). CO₂ is supplied from industrial waste gas from a concentrated point source, such as iron, steel or cement production; a hydrogen or ethanol plant; or natural gas treatment. We also explore the use of direct air capture as carbon source. Green hydrogen is assumed to be purchased from a supplier. CO₂ has to be converted to carbon monoxide by the reverse water-gas-shift reaction during syngas upgrading. Fuel production in the FT reactor is followed by product separation and upgrading. High-molecular-weight products are hydrocracked to obtain low-molecular-weight hydrocarbons.

Figure 5.2. Simplified process flow diagram of production of SAF using the power-to-liquid pathway



Source: Original figure for this publication.

Table 5.2 shows the slate for the baseline 1,000-BPD facility, which could produce about 39 million liters of SAF per year, satisfying about 3 percent of South African jet fuel demand.



Table 5.2. Product profiles for SAF production using the power-to-liquid pathway for a 1,000-barrel per day facility in South Africa

Product	Annual production (million liters)	Barrels per day	Percent of total
Sustainable aviation fuel	39.2	751	75
Gasoline	13.0	249	25
Total	52.2	1,000	100

Source: Original table for this publication.

Compared with SAF facilities that use other conversion technologies modelled and analyzed in this report, the baseline facility is smaller (1,000 versus 4,000 BPD). The choice of a smaller facility was driven by the high utility needs, especially hydrogen and, by extension, renewable electricity. Operating larger plants would place an excessive burden on the energy systems of developing countries and emerging markets, which are often constrained by a lack of supply. For the 1,000-BPD facility modelled here, annual hydrogen consumption is about 18,900 tonnes, which would require the use of about 0.5 percent of the total electricity production in South Africa in 2023 or 5.0 percent of the renewable electricity production.⁴² We report cost estimates for larger size plants as well but note the heavy burden they would place on the electricity supply in an electricity-constrained country such as South Africa.

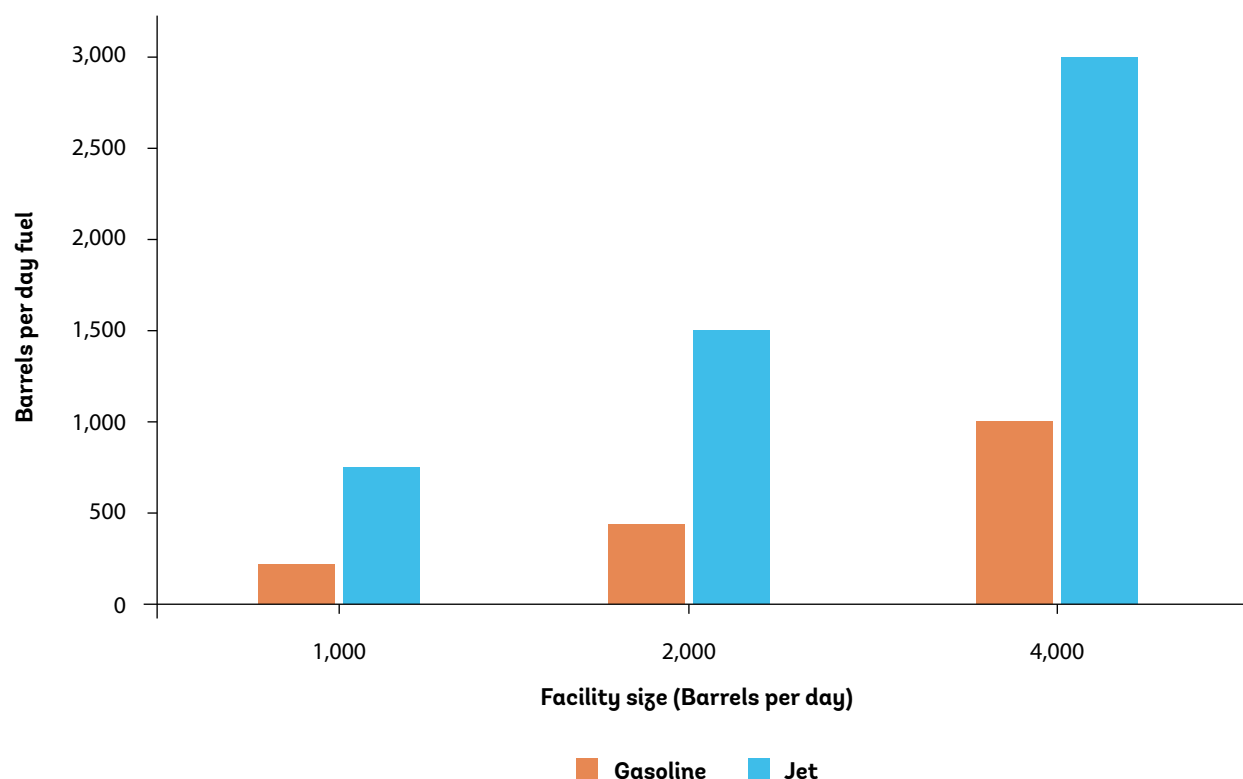
Figure 5.3 shows the volume of fuel products that could be produced from different plant configurations. Based on 2022 jet fuel consumption values, a 1,000-BPD facility could satisfy about 2.6 percent of jet fuel demand and 0.3 percent of gasoline demand; a 4,000-BPD facility would meet 10.6 percent of jet fuel and 1.0 percent of gasoline demand in South Africa.

⁴² These estimates are based on the assumptions that 55kWh per kg H₂ of electricity is needed for electrolysis and that total electricity production in South Africa in 2023 was 226 terawatt hours (TWh), with a renewable share of 9.3 percent (<https://www.crses.sun.ac.za/sa-energy-stats/>).





Figure 5.3. Estimated gasoline and jet fuel production by 1,000-, 2,000, and 4,000-barrels per day power-to-liquid facilities in South Africa



Source: Original figure for this publication.

Techno-Economic Model and Results

The economic feasibility of the PtL pathway was assessed using techno-economic models from Brandt and others (Brandt, Geleynss, and others 2021; Brandt, Tanzil, and others 2021), supplemented by other studies (Albrecht and others 2017; Geleynse and others 2018; Humbird and others 2011; Klaver, Petersen, and Görgens 2023; Petersen and others 2018).⁴³ The analysis assumes the operation of an *n*th plant leveraging conventional petrochemical plant designs and equipment rather than pioneering new facilities. The capital cost was extrapolated from studies by Brandt and co-authors and Humbird and others indexed to 2022 values using the Chemical Engineering Plant Cost Index (CEPCI). A critical assumption was the adjustment of geographical location factors to translate costs from the United States to South Africa, highlighting the importance of accounting for regional economic variations in financial projections.

For accurate project cost translation from the United States to South Africa, the last recorded location factor from 2015 was updated to 2023 based on shifts in the dollar/rand exchange rate—from R 12.8 per dollar in 2015 to R 18.5 in 2023—resulting in a location factor of 0.66. Economic assumptions included a 30 percent discount rate, reflecting South Africa's BB- credit rating, and a

⁴³ For details of the modeling methodology and assumptions, see the annex to this chapter.



15 percent loan interest rate. The projections used a five-year average inflation rate of 4.9 percent (Statista n.d.) and corporate tax rate of 27 percent (South African Revenue Service n.d.). These factors were integrated into a cash flow model to determine the minimum selling price (MSP) for jet fuel that would achieve a break-even net present value. The sensitivity of the MSP to variables such as plant size, equity structure, loan rates, input costs, location factor, and discount rate was also analyzed.

Costs of Production Results

The total plant investment for a 1,000-BPD PtL production facility is \$156 million (see table 5A.1 in the annex to this chapter). As hydrogen is assumed to be purchased from a vendor, the costs of hydrogen production are not included in the total plant investment but are rather part of the operating costs of the SAF production facility. A large-scale green hydrogen production facility can cost several billion dollars.⁴⁴

For the 1,000-BPD PtL facility with hydrogen purchased from a vendor, the total direct capital costs, including processes like syngas upgrading, fuel synthesis, and other necessary installations, sum to \$48.2 million. Indirect costs related to engineering and construction amount to \$34.5 million. A contingency of 20 percent and additional working capital of 5 percent of the fixed capital investment are factored in to cover unforeseen expenses and operational needs, respectively. The costs are adjusted with a location factor to translate the expenses from the United States to South Africa.

Table 5.3 shows the estimated capital expenses (CAPEX) for PtL facilities with capacities of 1,000, 2,000, and 4,000 BPD. Economies of scale are evident as the facility size increases: Increasing the size of a plant from 1,000 to 2,000 BPD reduces the CAPEX per BPD by 18 percent; increasing the size from 2,000 to 4,000 BPD cuts CAPEX by an additional 11 percent per BPD. Expanding from 1,000 to 4,000 BPD results in a 27 percent reduction in CAPEX per BPD. These reductions underscore how cost efficiencies achieved through larger-scale operations make higher-capacity facilities more economically viable.

Table 5.3. Estimated fixed capital investment required to build a power-to-liquid SAF facility in South Africa, by plant size

Plant size	Millions of dollars	Billions of rand
1,000	156	2.9
2,000	257	4.7
4,000	458	8.5

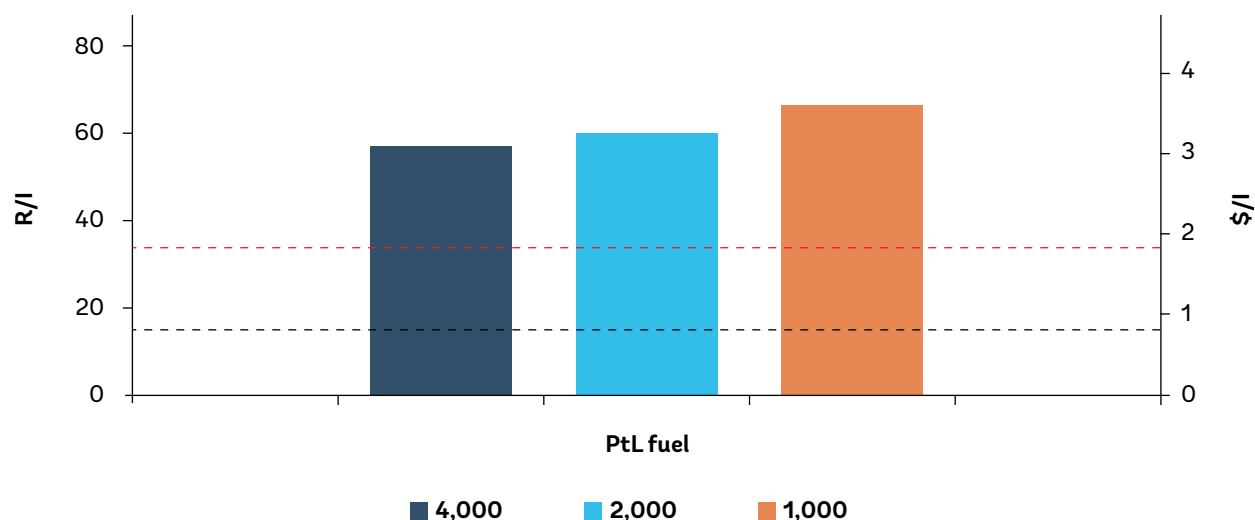
Source: Original table for this publication.

⁴⁴ For example, the Saldanha Bay project in the Western Cape province, which aims to produce 85,000 tons of hydrogen per year (roughly five times the hydrogen needed for a 1,000-BPD PtL production facility) is projected to cost \$2.5 billion to build (GBA 2023).



The MSPs are estimated at \$3.6, \$3.2, and \$3.1 per liter for facilities with capacities of 1,000, 2,000, and 4,000 BPD, respectively (figure 5.4). The average market price for conventional jet fuel in South Africa was \$0.8 per liter in 2023. For comparison purposes, the average global market price paid for neat SAF was \$1.83 per liter in 2024 (IATA, 2024). In line with other techno-economic studies, we assume that other liquid fuels (here gasoline) also take up part of the green premium, based on their share of the product slate. If the full green premium is allocated to jet fuel, the MSP for e-kerosene would increase to \$4.6 per liter.

Figure 5.4. Minimum selling prices for e-kerosene in South Africa as a function of facility size (1,000, 2,000, 4,000 Barrels per day)



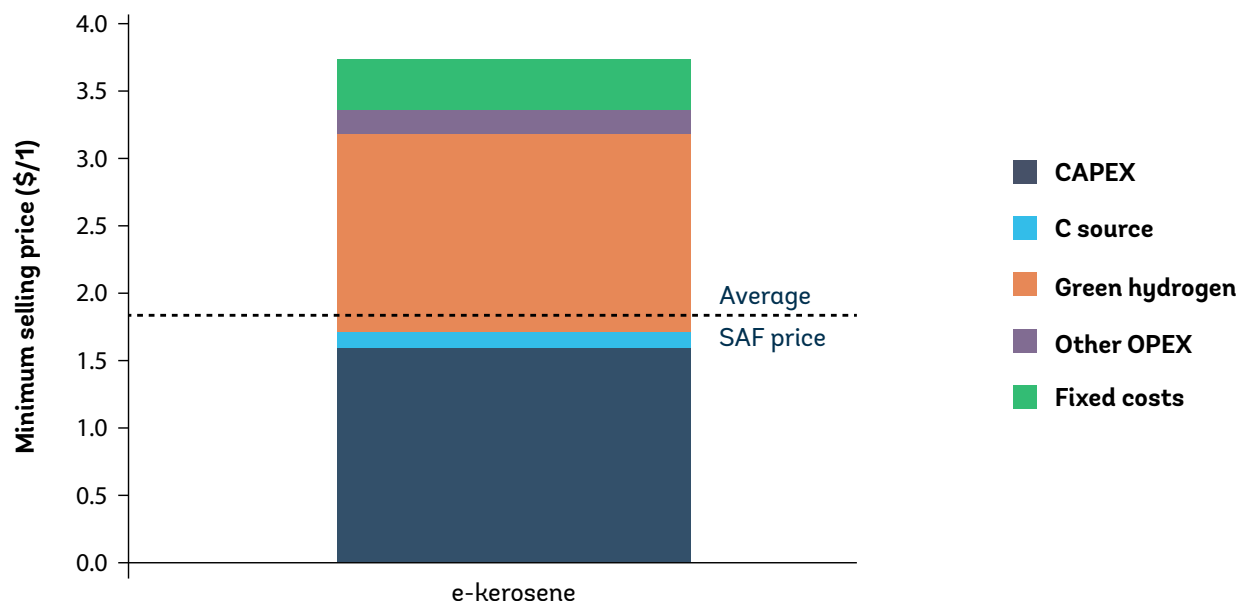
Note: The black dashed line shows the average conventional kerosene price in South Africa (\$0.8 per liter). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).

Source: Original figure for this publication.

Figure 5.5 shows the MSP distributions for e-kerosene. CAPEX per liter (capital depreciation and return on capital) accounts for 46 percent of the total jet production cost. Green hydrogen accounts for 41 percent of the MSP, and CO₂ contributes about 2 percent. If the carbon source is direct air capture instead of a point source, the cost of the carbon source would increase significantly.



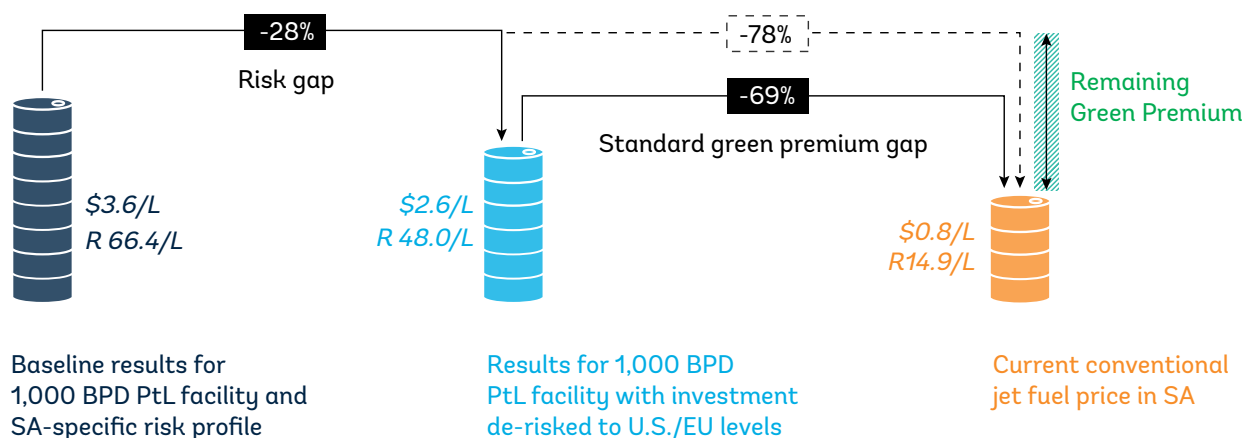
Figure 5.5. Contribution of different cost categories to the minimum selling price of e-kerosene in South Africa



Source: Original figure for this publication.

The higher selling prices of e-kerosene produced in South Africa can be broken down into two main cost components: (a) higher risk premiums than in the United States and the European Union and (b) a residual green premium that also exists in those regions (figure 5.6). The risk premium for e-kerosene contributes about \$1.0 per liter (28 percent) to the costs; the green premium adds \$1.8 per liter (an additional 69 percent over the current conventional jet fuel price).

Figure 5.6. Risk and green premium gap for e-kerosene in South Africa



Note: PtL = Power-to-liquid, BPD = barrels per day; SA = South Africa

Source: Original figure for this publication.



Lifecycle Greenhouse Gas Emission Results

The lifecycle greenhouse gas emissions of e-kerosene are highly heterogeneous, driven by the large variation in greenhouse gas emissions associated with different electricity sources. Consequently, no default emission values for PtL SAF currently exist in major policy schemes pertaining to SAF that could be leveraged for the South African case.

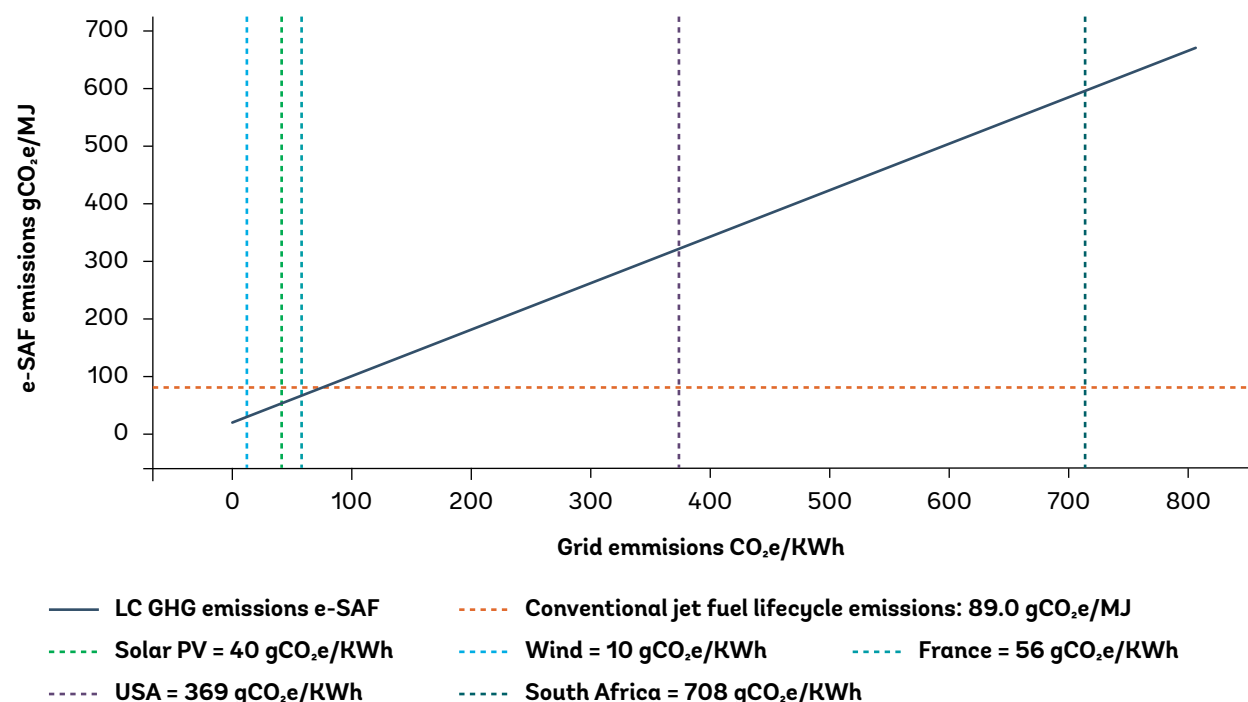
PtL SAF has the potential to be a near-zero fossil fuel with the use of renewable electricity for the production of hydrogen and, where applicable, direct air capture. One report estimates lifecycle emission savings of around 95 percent for e-fuels if renewable electricity is used along the supply chain (Concawe 2024). Partial use of renewable electricity—relying on the grid mix within an energy market that is usually partly fossil and partly renewable—is usually not sufficient for achieving large greenhouse gas emission savings. We use the relationship established in Isaacs and others (2021) of 3.0 MJ of electricity input per MJ SAF output for the classic electrolysis plus reverse water gas shift hydrogen production to estimate electrolysis-related greenhouse gas emissions as a function of electricity emission intensity.

The contribution to SAF emissions of point capture, transportation, fuel synthesis, and distribution is relatively low. For distribution, we use values derived from the Concawe study and the CORSIA assumptions. Figure 5.7 shows the relationship between the intensity of grid electricity emissions and the intensity of lifecycle greenhouse gas emissions of PtL SAF. It shows that the use of low-carbon electricity can significantly reduce lifecycle greenhouse gas emissions compared with conventional jet fuel. The emission effects of PtL produced from electricity grid mixes is highly contingent on the emission intensity of the grid. PtL produced in low-emission grids exhibit emission savings (about 50 percent compared with conventional jet fuel in France); in higher-emission grids, emissions are above the fossil jet fuel baseline. In South Africa, where coal-fired electricity plants are the main source of electricity, e-SAF produced from the grid mix would lead to e-SAF emissions of about 600 gCO₂e/MJ of SAF.





Figure 5.7. Lifecycle greenhouse emissions of power-to-liquid SAF as a function of the emission intensity of electricity production in France, South Africa, and the United States



Note: Emission values of photovoltaic (PV) and wind energy are from Allroggen and others (2024). These values include embodied emissions of electricity generation. Emission values for France, South Africa and the United States taken from Our World in Data (Ritchie and Roser 2020). For point CO₂ and fuel synthesis and conversion, derived from Concawe (2024), we use conservative estimates of 4 2gCO₂e/MJ and 2gCO₂e/MJ, respectively. For transportation and distribution, we assume a value of 2gCO₂e/MJ, based on domestic production of hydrogen and domestic use SAF. LC= life cycle, PV= photovoltaic. Source: Original figure for this publication.

The source of carbon can also have a large impact on the lifecycle greenhouse gas emissions. Capture of biogenic point-source carbon (at an bioethanol production facility, for example) or direct air capture of CO₂ can offset the combustion emissions of e-SAF. Capturing fossil carbon from an industrial point source should be considered as offsetting e-SAF combustion emissions only if the burden of the fossil emission stays with the original emitter (otherwise, the lifecycle greenhouse gas benefit of the e-SAF would be counted twice).

An issue of concern with regard to the use of electricity for e-SAF kerosene is the sourcing of renewable electricity. In the absence of a direct physical connection between the hydrogen/e-SAF production facility, power purchasing agreements must be used. These agreements should include supply and demand matching requirements to credibly document the use of renewable electricity. Given the high electricity needs of this pathway, it could adversely affect the electricity market.

Concerns about emissions from direct or indirect land-use change play a smaller role for PtL SAF than they do for SAF that relies on feedstock grown on arable land. However, there is some evidence of potential land use change-related emission impacts of PV installations when constructed on high-carbon-containing land and without appropriate land-management practices (van de Ven and others 2021). Existing sustainability certification systems for liquid fuels, including SAF, are starting to include provisions on the protection of high-carbon (and biodiverse) lands not only in the case of feedstock production but also for electricity production (RSB 2023).

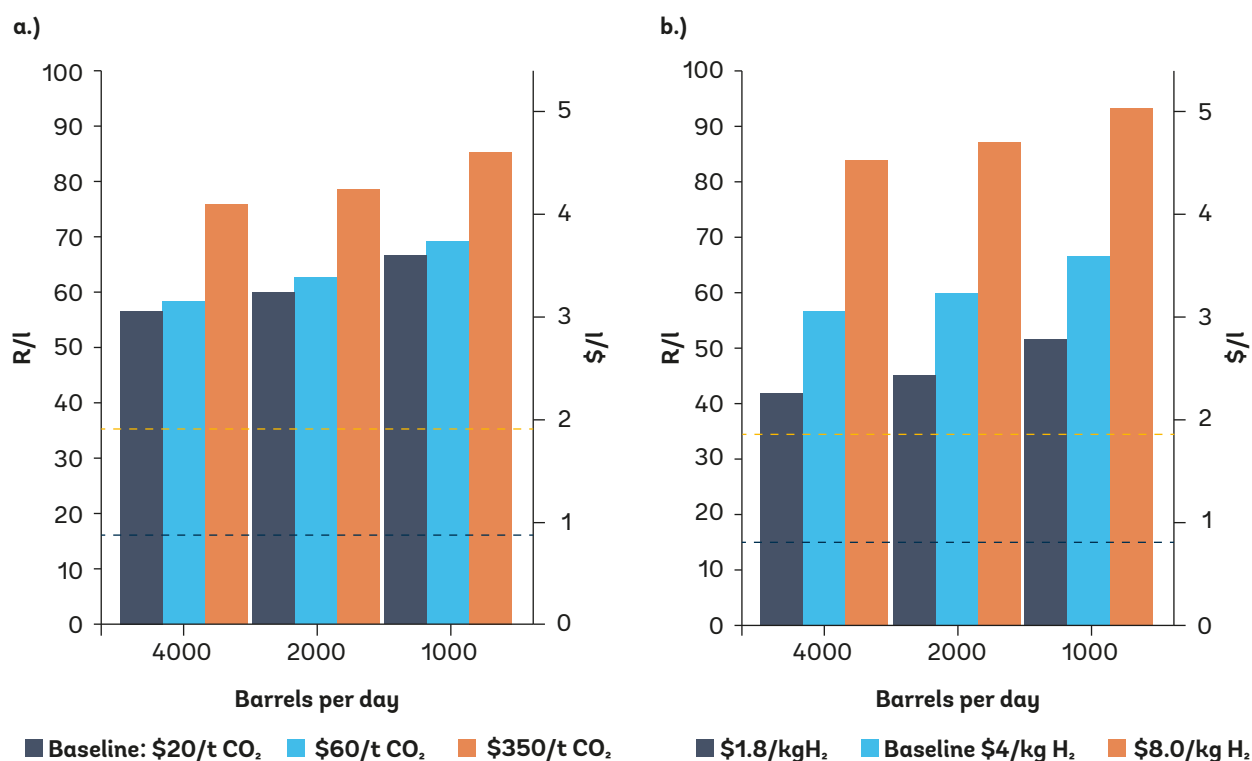


Applying this evidence to South Africa, e-SAF produced domestically could lead to a significant additional emission reduction (on the order of 90 percent or more per unit fuel) if several conditions are met:

- credible use of renewable electricity for hydrogen production, sourced from additional renewable electricity generation capacity
- establishment of credible matching requirements between renewable electricity production and its use for e-SAF production, given the high greenhouse gas emission intensity of the electricity grid in South Africa
- where industrial waste carbon is used, establishment of provisions that guarantee that the emission benefit of the carbon recycling is claimed and counted only once, at the level of the SAF producer or airline
- where solar PV electricity is used, avoidance of usage of high-carbon land for PV construction.

Sensitivity analysis reveals that green hydrogen costs significantly affect the MSP of PtL SAF (figure 5.8).

Figure 5.8. Sensitivity of minimum selling price of SAF produced in South Africa using the power-to-liquid pathway to the cost of carbon dioxide and hydrogen



Note: The black dashed line shows the average conventional kerosene price in South Africa (\$0.8 per liter). The red dashed line shows the average SAF world market price 1.83 per liter, IATA (2024).

Source: Original figure for this publication.

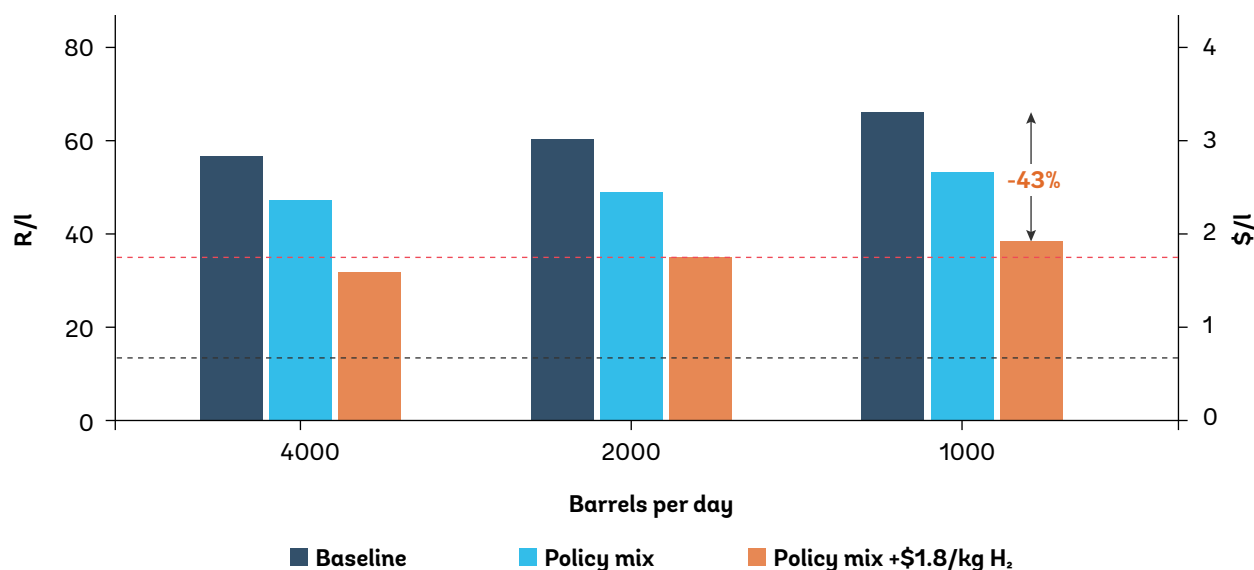


The baseline scenario for CO₂ is set at \$20 a ton, a typical price for waste carbon sources. It was adjusted to \$60 a ton to reflect potentially higher waste carbon costs. A scenario using direct air capture priced CO₂ at \$350 a ton was also examined. For green hydrogen, the baseline cost was \$4/kg. The analysis also assessed the effect of green hydrogen prices of \$1.8/kg and \$8/kg.

If green hydrogen costs were halved, the MSP would decrease by 20 percent. It would still be 155 percent above current jet fuel prices in South Africa, however. A doubling of hydrogen prices could result in the MSP exceeding current fossil fuel prices by a factor of more than five. Although MSP changes with the cost of carbon, it is less sensitive to carbon price fluctuations than to hydrogen costs. These variations underscore how the economic viability of PtL SAF production is linked to the costs of hydrogen production and carbon sourcing.

The analysis also assessed the sensitivity of the MSP to changes in policy (figure 5.9). It assumed policies similar to those adopted in Kenya (see chapter 2), where conditions favor investment in the production of SAF. We assumed a discount rate of 21 percent and a loan rate of 10 percent, reduced the percentage of equity to 20 percent, and assumed an income tax 13.5 percent rather than the current rate of 27 percent. The results indicate that a favorable policy environment along with lower cost of hydrogen could reduce the cost of PtL by up to 43 percent for a 1,000-BPD facility, in line with current average prices paid for SAF on the world market.

Figure 5.9. Sensitivity of the minimum selling price of SAF produced in South Africa using the power-to-liquid pathway to policy changes and the cost of hydrogen



Note: The black dashed line shows the average conventional kerosene price in South Africa (\$0.8 per liter). The red dashed line shows the average SAF world market price (\$1.83 per liter, IATA 2024).
Source: Original figure for this publication.



Conclusion and Recommendations

South Africa's expertise in FT technology, wealth of industrial carbon sources, and growing number of green hydrogen projects position it to become a frontrunner in the SAF market by leveraging the PtL (e-SAF) pathway. However, the MSP for e-kerosene is currently high, significantly above the global average, primarily because of the high cost of green hydrogen and capital. Reliance on the current coal-dependent electricity grid could affect the lifecycle emissions benefits of PtL SAF in South Africa, unless renewable energy sources are prioritized for green hydrogen production. The MSP is sensitive to the cost of hydrogen and carbon dioxide, as well as the discount rate, which is influenced by South Africa's economic landscape.

Overcoming these hurdles and unlocking South Africa's SAF potential requires a collaborative, multifaceted approach; decisive action and strategic coordination among governmental bodies, private sector entities, and international development institutions are needed.

A phased strategy would allow South Africa to achieve SAF viability while leveraging the country's strengths in technology, carbon resources, and economic centers.

Phase 1: Establish the Foundation

In the short term (one to three years), the following measures are recommended:

- **Make policy commitments.** The government should issue a clear policy statement outlining its commitment to SAF development and set ambitious yet achievable targets for SAF production and blending, including an SAF mandate tailored to local economic constraints and supported by limited fiscal privileges for SAF facilities within special economic zones.
- **Develop a feedstock strategy.** A comprehensive feedstock strategy should prioritize sustainable sources such as industrial waste carbon, which is eligible under CORSIA, and explore the possibility of using biogenic carbon from invasive plant species, to align with EU SAF mandates.⁴⁵ Biogenic carbon from invasive plant species presents a viable alternative that public and private actors should explore to meet both domestic and export market requirements.
- **Conduct feasibility studies.** Initiate detailed feasibility studies for e-SAF projects, focusing on co-locating production with existing refinery infrastructure, in order to leverage economies of scale and reduce costs. These studies should encompass assessments of environmental impacts, electricity requirements, and potential social benefits. Renewable energy needs for green hydrogen production should be a priority, as access to cheap, renewable electricity is essential for both the economic and environmental feasibility of e-SAF production.

Phase 2: Jumpstart Production

In the medium term (three to seven years), the following measures are recommended:

- **Issue an SAF blending mandate.** Implement a progressive SAF blending mandate, starting at a low percentage (such as 2 percent), gradually increasing it over time (to, say, 10 percent by 2035). This mandate would create a predictable market signal, incentivize investment in SAF production, and drive demand.

⁴⁵ CORSIA allows for the use of industrial waste carbon for e-kerosene production, but EU regulations do not allow SAF produced from waste carbon to qualify for its SAF mandate or support mechanisms.



- **Finance pilot projects.** Secure financing for pilot e-SAF projects through a combination of public and private funding sources. Targeted financial incentives, such as tax credits or production subsidies tied to lifecycle greenhouse gas emission reductions, could be complemented by concessional loans and loan guarantees from multilateral development banks to mitigate investment risks. Multilateral development banks could also provide innovative financing mechanisms, such as blended finance and insurance instruments, to address South Africa's credit rating and volatile energy markets.
- **Expand renewable energy.** Prioritize the expansion of renewable energy capacity, to ensure a sufficient supply of low-carbon electricity for green hydrogen production. Policy makers must ensure that the electricity used for e-SAF production is sourced from new renewable sources, in order to maintain environmental integrity and achieve meaningful reductions in lifecycle greenhouse gas.

Phase 3: Scale Up and Mainstream Sustainable Aviation Fuel

In the long term (more than seven years), the following measures are recommended:

- **Scale up e-SAF production.** Gradually scale up e-SAF production to meet the growing demand spurred by the blending mandate. The goal should be self-sufficiency in meeting domestic jet fuel demand while positioning South Africa as a regional exporter.
- **Create a robust SAF certification system.** Develop a robust SAF certification system that aligns with international best practices and ensures the sustainability of feedstock sources, production processes, and emission reduction claims. Such a system would build trust and facilitate market acceptance.
- **Integrate SAF into broader decarbonization efforts within the aviation and transport sectors.** Efforts should include synergistic strategies, such as modal shifts to rail, improvement of fuel efficiency, and optimization of flight operations. Economic centers such as Johannesburg and Cape Town, with their concentration of corporations committed to emission reduction goals, can play an important role by procuring SAF credits to offset Scope 3 emissions.

Success in this ambitious endeavor will require active participation by and collaboration among stakeholders:

- **Government:** Policy makers need to create a supportive regulatory environment, provide targeted financial incentives, de-risk investments, and prioritize renewable energy expansion. Loan guarantees and policy frameworks must align with South Africa's fiscal constraints while leveraging multilateral development banks for support in areas such as public infrastructure or de-risking instruments for private investment.
- **Private sector:** Airlines should commit to purchasing domestically produced SAF through long-term offtake agreements. Corporations, especially those headquartered in Johannesburg and Cape Town, should invest in e-SAF production facilities or purchase SAF credits to meet sustainability targets. Local banks could collaborate with multilateral development banks to create tailored financial packages for SAF facilities.
- **Financial institutions:** Local commercial banks and multilateral development banks need to develop innovative financing models, including concessional loans, blended finance mechanisms, and risk-sharing instruments, to attract private capital and reduce investment risks. Multilateral development banks could provide concessional financing to reduce capital costs for SAF facilities and mitigate risks associated with South Africa's energy markets.



- **International development organizations:** International development organizations could provide technical expertise, capacity building, and knowledge sharing to support South Africa in developing a thriving SAF sector, drawing on best practices and lessons learned from other countries.

By embracing this collaborative and phased approach, South Africa can overcome its challenges, capitalize on its unique advantages, and establish itself as a player in the global SAF market. Doing so would drive economic growth, create jobs, enhance energy security, and help South Africa achieve its climate goals.

Annex 5A. Key Assumptions and Data for Techno-Economic Analysis of South Africa

Table 5A.1. Capital expenses for a 1,000-barrel per day power-to-liquid facility

Category	Description	Millions of dollars	Billions of rand
Total direct cost (TDC)			
Inside Battery Limit Costs (ISBL)			
Syngas upgrading	Calculated	12.8	0.2
Fuel synthesis	Calculated	11.4	0.2
Hydroprocessing	Calculated	5.4	0.1
Air separation	Calculated	4.9	0.1
Purchased equipment cost (PEC)	Calculated	34.5	0.6
Installation cost	40 percent PEC	13.8	0.3
ISBL Total		48.2	0.9
Other direct costs			
Buildings	45 percent PEC	15.5	0.3
Yard Improvement	15 percent PEC	5.2	0.1
Auxiliary Facilities	40 percent PEC	13.8	0.3
OSBL Total		34.5	0.6



TDC		82.7	1.5
Total indirect cost (TIC)			
Engineering and supervision	30 percent of TDC	24.8	0.5
Construction and expenses	30 percent of TDC	24.8	0.5
TIC		49.6	0.9
	TDC + TIC	132.3	2.4
Contingency	20 percent	16.5	0.3
Fixed capital investment (FCI)	TDC + TIC+ Contingency	148.9	2.8
Working capital (WC)	5 percent of FCI	7.4	0.1
Total plant investment	FCI + WC	156.3	2.9



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06

Conclusion and Recommendations

Advocating for diverse, locally-tailored SAF production pathways can position Africa as an important player in sustainable aviation. This chapter offers recommendations for the common challenges noted in the four case studies, such as infrastructure readiness, feedstock feasibility, and high capital costs and risks premiums.





This study explores the potential for sustainable aviation fuel (SAF) production in Ethiopia, Kenya, Nigeria, and South Africa. It is not a full feasibility analysis but an analysis of cost-reduction strategies and risk management that examines feedstock availability, production technologies, and policy frameworks to identify country-specific opportunities for narrowing the cost gap with conventional jet fuel. By advocating for diverse, locally tailored SAF pathways, this study aims to position Africa as an important player in sustainable aviation while driving significant carbon emission reductions.

Common themes emerge across the four countries studied, in terms of both opportunities and barriers. Abundant feedstock availability—ranging from used cooking oil (UCO) in Kenya to sugarcane in Ethiopia and industrial waste carbon in South Africa—creates a strong foundation for SAF production. Feedstock scalability remains a challenge, however, particularly in Kenya and Nigeria, where supply constraints could limit expansion. Infrastructure readiness also varies, with South Africa and Kenya benefiting from relatively advanced industrial and logistical networks and Ethiopia and Nigeria facing infrastructure deficits that could slow SAF deployment. All four countries also face high capital costs and elevated risk premiums, driven by macroeconomic factors such as currency volatility, limited financing access, and high borrowing rates compared with markets in high-income countries.

Kenya and South Africa are better positioned in terms of infrastructure and policy readiness than Ethiopia and Nigeria, with clear government commitments to SAF development and decarbonization. Ethiopia stands out for its strong aviation sector and feedstock diversity. Nigeria's existing jet fuel production infrastructure gives it a strategic advantage. These differences underscore the need for tailored SAF development strategies that leverage each country's strengths while addressing their specific challenges.

In all countries, transport and logistics infrastructure play a critical role in SAF production by enabling efficient feedstock collection, cost-effective processing, and seamless fuel distribution to airports and export markets. Well-developed road, rail, and pipeline networks are essential for transporting raw materials such as UCO, sugarcane, and municipal solid waste to SAF production facilities, minimizing supply chain inefficiencies. Modernizing aviation fuel infrastructure at key airports and integrating SAF into existing fuel distribution systems will accelerate adoption and reduce operational costs. Strengthening regional connectivity and export logistics will position African countries as key players in the global SAF market, enhancing energy security and fostering economic growth.

All four African countries possess significant feedstock potential for SAF production. But feedstock scalability and consistent availability pose critical challenges. Establishing a thriving SAF industry necessitates a strong emphasis on developing robust and efficient local supply chains for diverse feedstocks, ranging from USO and agricultural residues to municipal solid waste and industrial waste carbon. The development of these supply chains often requires significant time and investment, including infrastructure for collection, pre-processing, and transportation, and must address potential competition with existing uses and ensure sustainable sourcing practices. Addressing these feedstock availability and supply chain complexities is paramount for de-risking SAF projects and ensuring their long-term economic viability in the African context.



SAF production in Africa is expensive because of risk and green premiums, resulting from higher capital costs, financing constraints and low level of technology readiness. Without targeted interventions, these factors make SAF produced in Africa less competitive than traditional jet fuel and less competitive than SAF produced in regions with lower risk premium. To establish a thriving SAF industry in Africa, the study outlines policy and private sector recommendations over the short, medium, and long term that can significantly increase the competitiveness of SAF produced in Africa, compared with both conventional jet fuel, and SAF produced in other regions of the world.

Short-Term Recommendations (One to Three Years)

- **Prioritize sustainable feedstock management.** Countries could quickly establish efficient collection systems for readily available waste-based feedstocks like UCO and animal fats. They could conduct resource assessments to understand feedstock availability and address potential competition between food and fuel by exploring non-food sources such as castor and croton crops grown on marginal lands. Developing local supply chains for these feedstocks is also vital, in order to generate employment and improve economic resilience.
- **Implement targeted financial incentives.** To attract investment, governments could introduce financial incentives such as production tax credits, capital grants, and loan guarantees. These measures would help de-risk projects and make SAF production more attractive. Simultaneously, governments could explore co-processing at existing petroleum refineries and repurposing idle refinery assets to lower costs.
- **Establish supportive policy frameworks.** Clear policy statements are essential, along with the establishment of gradual SAF blending mandates for airlines to create a stable market and reduce reliance on imports. Streamlined regulatory approvals are also necessary. Public-private partnerships should be formed and pilot projects launched to validate assumptions and test technologies.
- **Drive early demand.** Book-and-claim mechanisms could be implemented to allow international stakeholders to support SAF production by purchasing SAF credits. Airlines and corporations could be encouraged to enter offtake agreements and invest in SAF production.





Medium-Term Recommendations (Three to Seven Years)

- **Develop a comprehensive continental SAF roadmap.** A detailed roadmap with clear production targets, defined roles for stakeholders, and a monitoring framework is crucial for the coordinated development of the industry. The roadmap should align with just transition plans to boost local employment and economic benefits.
- **Invest in research and development (R&D).** Governments could invest in R&D hubs to optimize SAF production technologies, reduce costs, and explore a wider range of diverse feedstocks. They could also promote pilot projects and international partnerships to foster innovation.
- **Address the green premium.** Carbon pricing mechanisms could be established to address the green premium associated with SAF and incentivize low-carbon production. De-risking instruments like loan guarantees and political risk insurance can enhance project bankability and help reduce this premium.
- **Expand renewable energy capacity.** Significant investments in renewable energy infrastructure are needed to support the production of e-SAF and ensure that the lifecycle emissions benefits of SAF are fully realized. The electricity for green hydrogen production must come from new renewable sources.

Long-Term Recommendations (More Than Seven Years)

- **Establish robust certification systems.** Robust certification systems, aligned with international best practices, are essential to ensure the sustainability of feedstock sourcing, production processes, and emission reduction claims, building confidence and facilitating market acceptance of SAF.
- **Integrate SAF into broader decarbonization efforts.** SAF should be integrated into broader decarbonization efforts that include the promotion of multimodal transportation strategies and the optimization of flight operations to achieve the deep decarbonization of the aviation sector.
- **Promote public-private partnerships.** Strengthening public-private partnerships and leveraging international collaboration are key for scaling SAF production.
- **Utilize innovative financing.** Multilateral development banks and development finance institutions can de-risk projects through concessional loans, grants, and innovative financing models such as blended finance and risk-sharing instruments.



Appendix A Sustainable Aviation Fuel Pathways, Market Trends, and Regional Opportunities

This technical appendix provides an overview of sustainable aviation fuel (SAF) production pathways, feedstock potential, and market trends, emphasizing their role in aviation decarbonization. It reviews standard SAF production processes, highlights sustainability criteria under CORSIA, and examines challenges such as feedstock limitations and high production costs. The appendix also explores global and regional production trends, with a focus on Africa's potential for sustainable feedstocks, and underscores the importance of policies, incentives, and investments in scaling SAF production and advancing the aviation sector's transition to net-zero emissions.

Sustainable aviation fuel (SAF) is produced through a variety of conversion processes approved by organizations such as the American Society for Testing and Materials (ASTM) International, which had certified 11 processes as of July 2023 and was evaluating another 11 (table A.1). These processes, outlined in ASTM D7566 and D1655 standards, use diverse feedstocks and offer different blending ratios with conventional jet fuel.

Table A.1. Processes for producing SAF

ASTM reference	Conversion process	Abbreviation	Possible feedstocks	Maximum blend ratio (percent)
ASTM D7566 Annex A1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Coal, natural gas, biomass	50
ASTM D7566 Annex A2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA)	HEFA	Vegetable oils, animal fats, used cooking oil	50
ASTM D7566 Annex A3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10
ASTM D7566 Annex A4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from nonpetroleum sources	FT-SKA	Coal, natural gas, biomass	50
ASTM D7566 Annex A5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Ethanol, isobutanol, isobutene from biomass	50



ASTM reference	Conversion process	Abbreviation	Possible feedstocks	Maximum blend ratio (percent)
ASTM D7566 Annex A6	Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oils, animal fats, used cooking oil	50
ASTM D7566 Annex A7	Synthesized paraffinic kerosene from HEFA	HC-HEFA-SPK	Algae	10
ASTM D7566 Annex A8	Synthetic paraffinic kerosene with aromatics	ATJ-SKA	C2-C5 alcohols from biomass	
ASTM D1655 Annex A1	Co-hydroprocessing of HEFA in a conventional petroleum refinery		Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum	5
ASTM D1655 Annex A1	Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery		Fischer-Tropsch hydrocarbons co-processed with petroleum	5
ASTM D1655 Annex A1	Co-Processing of HEFA		Hydroprocessed esters/fatty acids from biomass	10

Source : ICAO (n.d.).

For SAF to qualify under the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), it must meet specific sustainability criteria. Life cycle emission values for Fischer-Tropsch (FT), hydroprocessed esters and fatty acids (HEFA), synthetic iso-paraffinic (SIP), and alcohol-to-jet (ATJ) processes are available under CORSIA. Advanced processes such as synthesized aromatic kerosene (SAK) and integrated hydrolysis and hydroconversion (IH2) are under evaluation, with the goal of enabling 100 percent SAF utilization and increasing co-processing blending ratios from 5 percent to 30 percent in the near future.

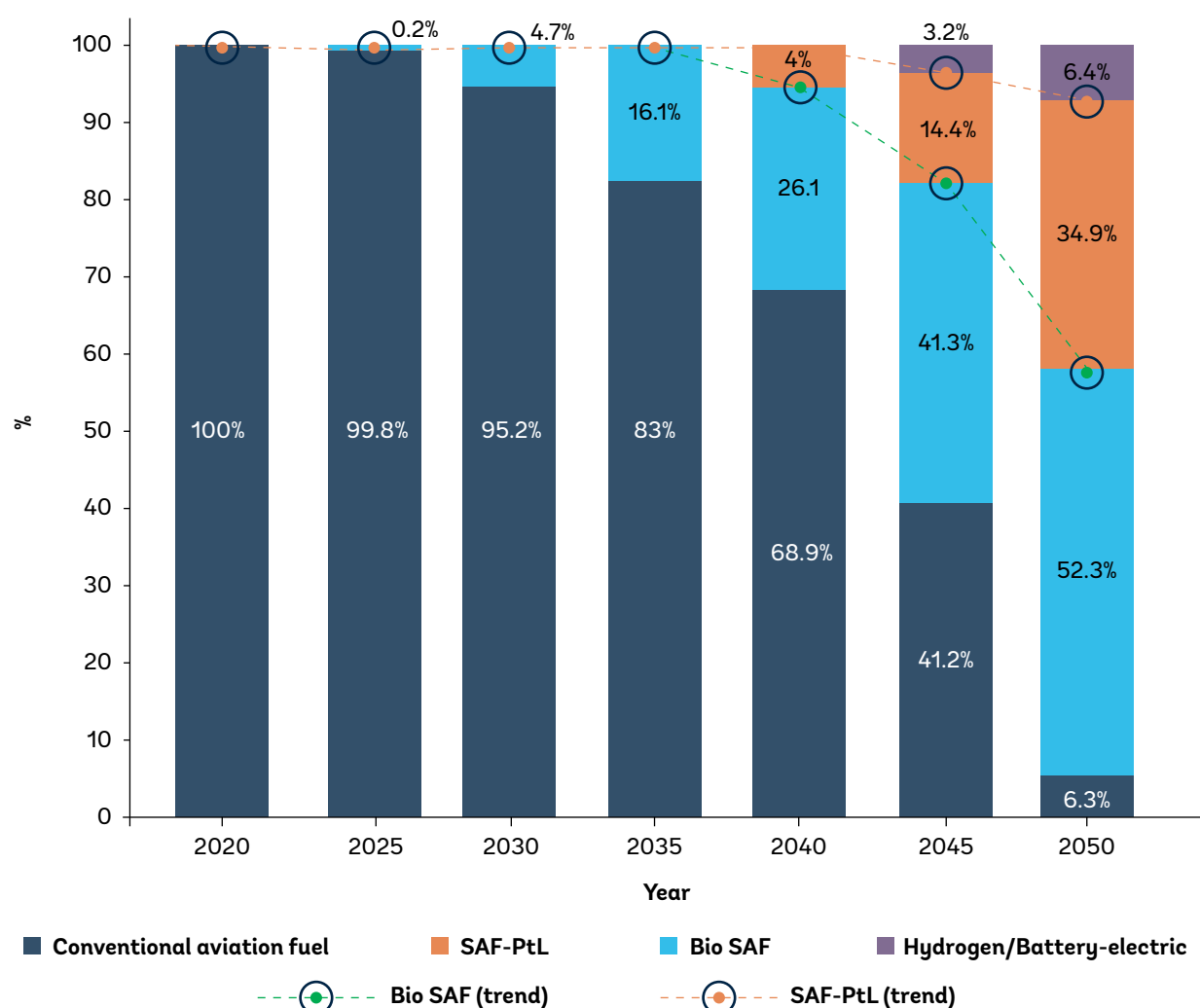
Production of SAF relies on both biogenic and synthetic feedstocks. HEFA technology, which processes oils and fats, is the currently most mature and commercially viable SAF pathway, but its scalability is constrained by feedstock limitations. Other feedstocks, such as municipal solid waste and agricultural residues, offer sustainable alternatives but require advanced technologies like FT or pyrolysis, which are less established and face logistical and cost-related barriers. Synthetic pathways using renewable energy and carbon show immense potential because of their abundance but are hindered by high production costs and technological immaturity.



As SAF production scales, balancing cost, feedstock availability, and environmental sustainability remains critical. Mature technologies like HEFA pave the way for near-term adoption; ongoing investments in research are essential for advancing less developed pathways. Expanding the range of approved processes and increasing blending limits are key to diversifying SAF production and transitioning to a fully sustainable aviation industry.

Despite the potential of global feedstock, conventional jet fuel dominates flight energy sources. Figure A.1 shows the projected transition from conventional fuels to sustainable alternatives, with conventional aviation fuel dominating until 2035 but steadily declining thereafter. Bio-SAF begins to play a small role by 2025 and becomes the leading energy source by 2050, accounting for 52.3 percent of in-flight energy demand. SAF-PtL (synthetic fuel from renewable energy) emerges after 2040, reaching 34.9 percent by 2050. Hydrogen and battery-electric technologies start contributing modestly around 2045, reaching 6.4 percent by 2050. Together, sustainable energy sources are projected to supply nearly half of aviation's energy needs by 2050, reflecting a shift toward decarbonization driven by advancements in SAF and emerging technologies.

Figure A.1 Actual and projected shares of aviation fuel, by energy source, 2020–50



Source: Data from IATA (2024a).



SAF production accounted for only 0.53 percent of aviation fuel consumption in 2024. It faces significant challenges because it costs more to produce than conventional jet fuel (IATA 2024). Advanced SAF technologies, such as PtL, are projected to cost two to four times more than the more mature HEFA production method.

To achieve net-zero emissions by 2050, the SAF market needs to scale significantly, something that requires massive global investment. A 2004 study by the International Air Transport Association (IATA) estimates that capital investments for new SAF production facilities could range from \$3.9 trillion to \$8.1 trillion. In the United States, achieving a domestic SAF production capacity of 77 Mt would require about 250 SAF refineries by 2050 and cumulative capital expenditure of \$400 billion. Existing sources of project financing include grants, venture capital, and offtake agreements. The scale of investment required necessitates increased public and private sector participation.

Governments worldwide are implementing policies and incentive schemes to support SAF adoption, striving to mitigate price risk and attract investment (GFI 2024a; GFI 2024b; IATA 2024c). These initiatives include the following:

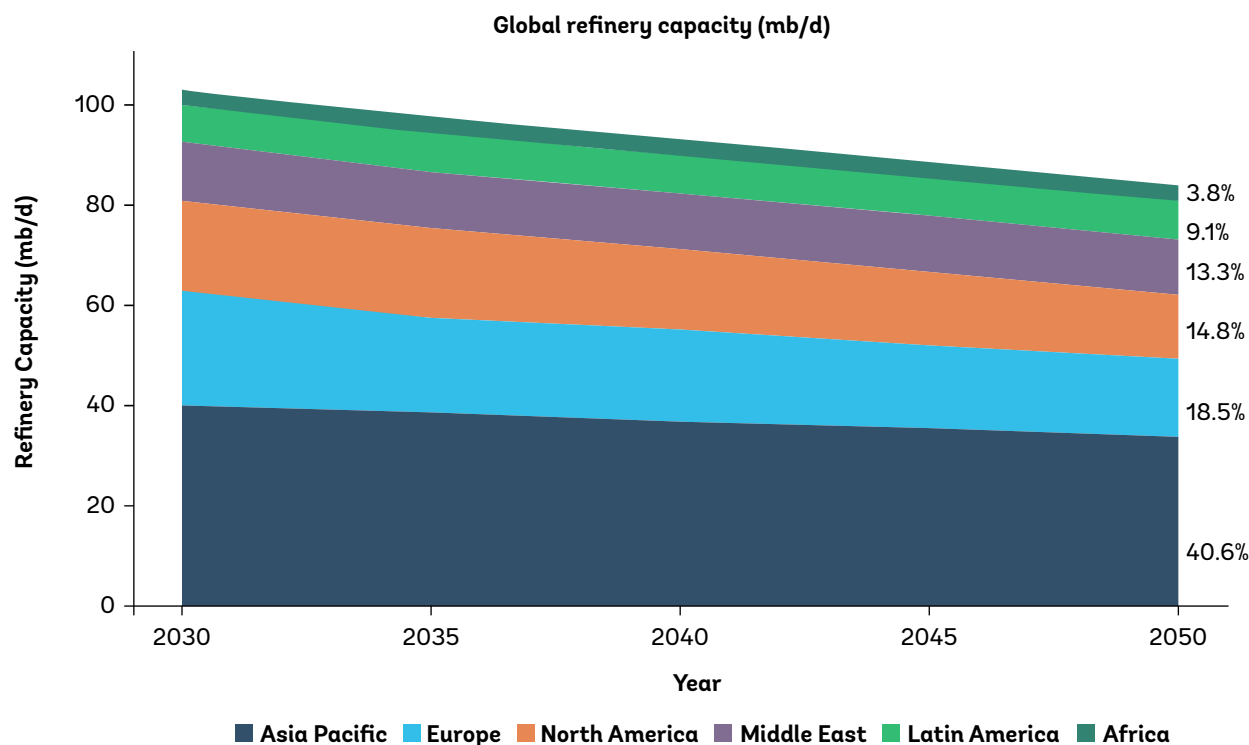
- SAF mandates, which establish minimum blending requirements, providing a clear demand signal for producers. For example, the United Kingdom aims for a 10 percent SAF blend by 2030, supported by a \$165 million Advanced Fuel Fund.
- Financial incentives, such as blender/production tax credits and grants, aim to bridge the price gap between SAF and conventional jet fuel. The United States offers tax credits of up to \$1.75 per gallon for SAF production, aiming to achieve 3 billion gallons of SAF production by 2030.
- Revenue certainty mechanisms (RCMs), such as the one proposed in the United Kingdom, provide price stability for producers, reducing the investment risks associated with fluctuating market prices. The United Kingdom's RCM is not expected to be operational before late 2026, underscoring the need for interim solutions to spur near-term project development and prevent capital flight to regions with more attractive incentives.

Developing countries in Africa are underrepresented in SAF production.



Africa's refinery capacity also remains highly limited (figure A2). Africa is projected to have just 3.8 percent of world capacity in 2050, little more than in 2030. This limited capacity means that it will continue to rely heavily on imported refined petroleum products. Without substantial improvements or policy shifts, this scenario is unlikely to change, reinforcing the continent's dependence on external sources for refined fuel needs.

Figure A.2. Projected refinery capacity, by world region, 2030–50



Source: Data from IATA (2024a).

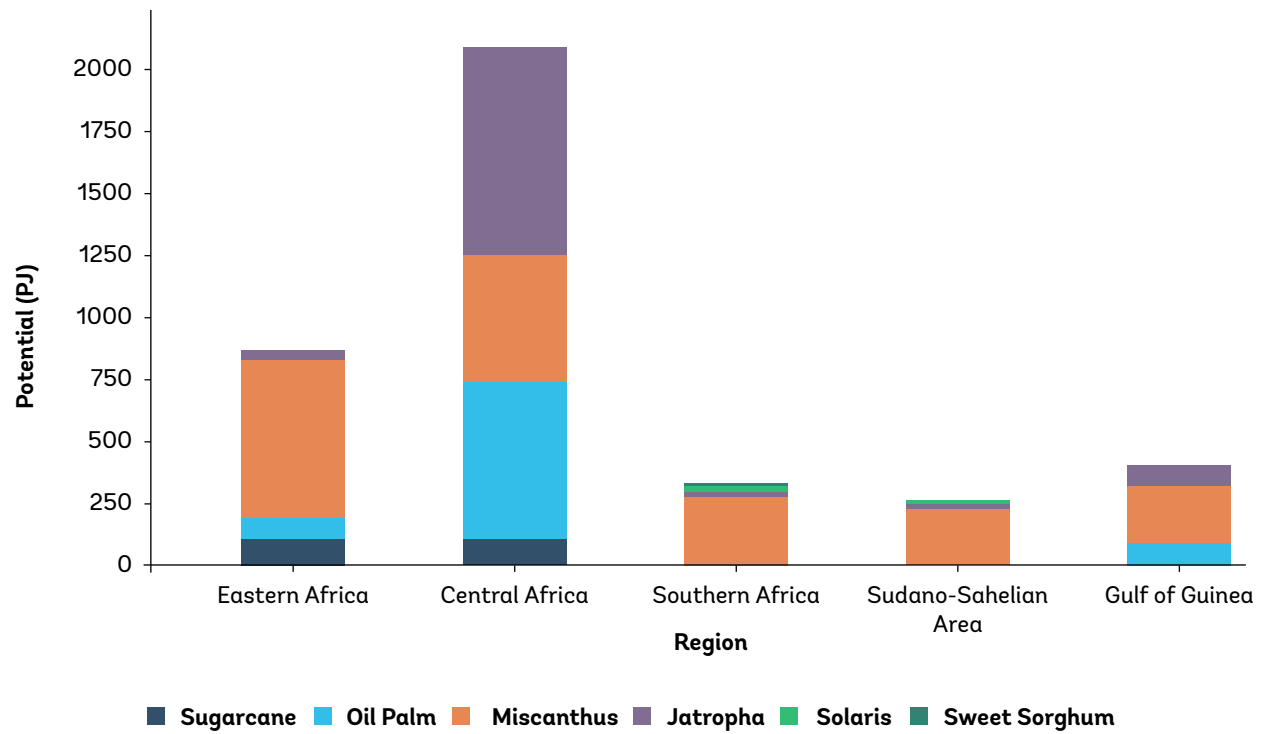
Note: mb/d stands for million of barrels per day.

Non-OECD countries have significant potential to provide feedstock for SAF production, with 68 percent of this feedstock coming from nonfood sources (World Bank 2022). Regions such as Asia and Eastern Europe, Latin America and the Caribbean, and the Middle East and Africa have substantial volumes of available feedstock, particularly from nonfood crops, suggesting that these regions could play an important role in SAF production, supporting decarbonization goals without affecting global food security.

Africa holds immense potential for sustainable feedstock production for biofuels, with significant opportunities for both bioethanol and biodiesel (figure A.3). By 2050, it could achieve total technical energy potential of 3,962 petajoules (PJ) from crops with maximum energy yields, preventing at least 60 percent of the continent's greenhouse gas emissions. Central Africa leads (2,099 PJ), driven by crops such as *Jatropha* (838 PJ), oil palm (646 PJ), and *Miscanthus* (514 PJ). Eastern Africa follows (872 PJ), with a diverse crop portfolio that includes *Miscanthus* (639 PJ) and sugarcane (113 PJ). Southern Africa, while more limited in capacity (329 PJ), can make substantial contributions through *Miscanthus* (273 PJ) and Solaris (27 PJ). The Gulf of Guinea (400 PJ) and the Sudano-Saharan region (262 PJ) also show promise.



Figure A.3. Technical potential of feedstock crops in Africa



Source: Data from WWF South Africa (2019).

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