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FEASIBILITY STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION

PHASE II

Author: Keith Lawless
Technical Consultant / Sustainable Aviation Fuels

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FOREWORD

In 2022, the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal. Each ICAO Member State will contribute to achieving the goal in a socially, economically and environmentally sustainable manner and in accordance with its national circumstances. The ICAO Assembly also affirmed that specific measures to assist developing States as well as to facilitate access to financial support, technology transfer and capacity building should be initiated as soon as possible.

In support to these Assembly Resolution provisions, ICAO has launched the ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ICAO ACT-SAF), which aims to provide tailored support for States in various stages of SAF development and deployment, facilitate partnerships and cooperation on SAF initiatives under ICAO coordination and serve as a platform to facilitate knowledge sharing and recognition of all SAF initiatives around the globe.

In line with the ICAO ACT-SAF objectives, ICAO has been actively partnering with the European Union (EU) to develop assistance projects that support Member States' initiatives to reduce the climate impacts of international civil aviation. The first phase of the ICAO Assistance Project with the European Union (EU) Funding was launched in 2013 and provided support to 14 participating States in Africa and the Caribbean. Among other results, this project led to development of four feasibility studies on the use of Sustainable Aviation Fuels (SAF) in Burkina Faso, Kenya, Dominican Republic, and Trinidad and Tobago. After completion of the first phase, in 2020 ICAO and the EU decided to add a second phase to the Assistance Project, in order to provide support to 10 African States. This Phase 2 of the project funded three feasibility studies on sustainable aviation fuels in Cote d'Ivoire, Rwanda, and Zimbabwe.

The following feasibility study assesses the potential for production and use of socially acceptable, environmentally friendly, and economically viable drop-in SAF in Cote d'Ivoire. The study follows the general structure and information provided in the "Template for Feasibility Studies on Sustainable Aviation Fuels", developed in the context of the ICAO ACT-SAF programme. Such analysis includes:

- information on the specific circumstances of the State, explaining the unique characteristics and factors that could affect the development and deployment of SAF in the State;
- the identification of priority pathways for SAF production
- information on implementation support and financing needed for the implementation of the priority pathways identified; and
- recommendation of an action plan aligned with the State's governmental policies related to the SAF development, with a focus on the priority pathways identified.

EXECUTIVE SUMMARY

A. Background

The International Civil Aviation Organization is committed to helping states reduce carbon dioxide emissions from international aviation. The 40th Session of the ICAO Assembly in October 2019 requested the Council to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation, for consideration by its 41st session (Resolution A40-18, paragraph 9). The LTAG report, as developed by the ICAO Committee on Aviation Environmental Protection (CAEP), consolidates cumulative efforts of over 280 experts over two years of intensive work. In October 2022, the 41st ICAO Assembly, ICAO Member States adopted a collective long-term global aspirational goal (LTAG) of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal, recognizing that each State's special circumstances and respective capabilities will inform the ability of each State to contribute to the LTAG within its own national timeframe (Resolution A41-21, paragraph 7).

The LTAG report concluded that substantial CO_2 reductions can be achieved using aviation in-sector measures including sustainable fuels, innovative technologies, and improved operations. Technical analysis done at ICAO shows that, of all the measures, SAF has the greatest potential to reduce CO_2 emissions from international aviation. Studies from other international aviation organizations reached the same conclusion. Since SAF will be the main contributor to reducing CO_2 emissions, ICAO has a crucial role in supporting capacity building and mitigation measures. Stakeholders and States have established the need to act now, recognizing that different solutions will be needed to meet local conditions.

In June 2022, the "ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF)" program was officially launched at Stockholm+50. The ICAO ACT-SAF program enables States to advance their full potential in SAF development and deployment. ACT-SAF supports ICAO's No Country Left Behind initiative, the 2050 ICAO Vision for SAF, and the three main pillars, economic, social, and environmental, of United Nations sustainable development.

ICAO ACT-SAF serves as a platform to facilitate knowledge sharing and recognition of all sustainable aviation fuel initiatives around the globe. It provides support for States in various stages of SAF development and deployment by facilitating feasibility studies, holding regular training sessions through the ACT-SAF series, and publishing guides, dashboards, updates, and SAF information. As of August 2023, 85 States and 45 organizations actively participate in ACT-SAF.

The ICAO-EU Assistance Project was put in place to provide capacity building and assistance for ICAO Member states for the development of States' Action Plans to mitigate CO_2 from international aviation, and comprised two phases: **Phase I (2013–2019):** With a budget of 6.5 million Euros, phase 1 of the project successfully supported 14 States from Africa and the Caribbean, meeting and exceeding all targets and expected results. **Phase II (2020–2023);** Building on the success of the first project, a second phase of EUR 1.5 million, fully funded by the European Union was launched to support ten additional States: Benin Cabo Verde, Côte d'Ivoire, Mali, Senegal (WACAF region), Botswana, Madagascar Rwanda, Seychelles and Zimbabwe (ESAF region).

B. Key findings

This study analyzed the potential to develop a viable SAF industry in Côte d'Ivoire based on factors such as feedstock availability and sustainability, government policies and strategies, logistics, economics, available technological pathways, financing requirements, socio-economic factors, and sensitivity to climate change. It looks at the current situation and infrastructure for both fossil and biofuels in the country and outlines how stakeholders can implement key initiatives. The report proposes a short-, medium- and long-term roadmap. Important opportunities and challenges are discussed, as well as recommendations required for successful implementation, such as government policy, strategy, and financing. This roadmap takes into consideration the unique circumstances and issues that Côte d'Ivoire faces.

Suitable feedstocks are the foundation of SAF production. As more processing pathways are approved, the range of potential feedstocks continues to grow. These have the potential to benefit major agricultural producers, small-scale farmers, industries, and society. Feedstocks were evaluated based on availability, transportation, logistics, and socio-economic impact. While access to low-cost abundant feedstock is important, sustainability was a key criterion. The sustainability evaluation was based on ICAO's CORSIA Sustainability Criteria for CORSIA Eligible Fuels[1].

Given its agriculture-based economy, Côte d'Ivoire has an ample supply of biomass feedstock that can be converted into SAF. However, efforts to establish commercial scale operations in neighbouring countries faced challenges due to assorted reasons, with unintended consequences for rural communities. A good case in point is the case of the Jatropha based biodiesel industry which ran into difficulties due to production yields lower than anticipated. Given the risks, identification of suitable biomass sources is a key success factor for any long-term SAF production endeavours and was considered in this report.

The potential impact of feedstock availability was scrutinized since it is having a significant impact on sub-Sahel Africa and Côte d'Ivoire. SAF conversion facilities are built to operate for decades, so long-term feedstock availability is an essential requirement. Climate change must be considered as it can impact volume and quality.

The relationship between SAF deployment and government policies and strategies was also examined to ensure there is a good fit. Costs, financing requirements and mechanisms were identified as an important success factor.

Finally, technological readiness and logistical considerations were considered in the Ivorian context. Sustainable Aviation Fuel processing skill is constantly advancing, but not all are at the same technology readiness levels (TRL). They are constrained by factors such as feedstock, power requirements, logistics, and construction costs. This study evaluated the available pathways that are most suitable for implementation in Côte d'Ivoire.

It is hoped that this report will help Côte d'Ivoire develop and implement a SAF industry that can meet the local, regional, and even international aviation decarbonization requirements. It is anticipated that a SAF industry will provide significant economic, social, and environmental benefits and make Côte d'Ivoire a leading SAF player in Africa. This study also aspires to engage key stakeholders on the potential benefits of producing SAF in Côte d'Ivoire so that the necessary financial and technological support can be attained.

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[1] https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

The results of the study were very positive and concluded that Côte d'Ivoire has everything required to develop a thriving SAF industry and become a West African leader in sustainable aviation fuels. It has abundant agricultural feedstocks, ample renewable energy, a young and growing population, good universities, excellent infrastructure, and a well-developed petroleum refining industry. The development of a SAF industry will help the country to achieve its economic, social and sustainability goals laid out in national plans and strategies. It also creates synergies with other States in the West African region by providing a market for biomass feedstock and as a SAF exporter and technological leader.

C. Policy implications

Côte d'Ivoire has many progressive agricultural, industrial, and environmental policies and strategies but SAF development is not specifically targeted. A solid SAF policy framework is essential for successful implementation, and it is essential that the Ivorian government develop policies that are feasible, effective, and practical. In that regard, it should be noted that the ICAO Committee on Aviation Environmental Protection (CAEP) has developed a Guidance of potential policies and coordinated approaches for the deployment of SAF, and the WEF Clean Skies for Tomorrow SAF has produced a Policy Toolkit.

Several other barriers need to be overcome for the SAF industry to become a reality. The construction of SAF facilities and infrastructure is extremely expensive and Côte d'Ivoire will need financial support for that. The government will need to put in place policies and frameworks that support SAF production and assess the priority over other applications of biomass. In addition, incentives and measures to make SAF more affordable will be needed, as well as encouragement of use by airlines. This will require partnerships and cooperation between key stakeholders from the government, the oil refinery (SIR), the aviation industry, academia, agricultural organizations, technology developers, and financial institutions. Social, sustainability and economic goals will have to be balanced and risks minimized.

D. Opportunities and Challenges

This report proposes a multi-year roadmap with an action plan to develop a national SAF industry in Côte d'Ivoire. It is important to note that it can take 5–10 years to build a SAF facility. Many steps need to be taken:

- Initial feasibility studies.
- Selection of a feedstock and conversion pathway.
- Construction and operation of a pilot plant to demonstrate proof of concept.
- Detailed engineering and techno-economic studies.
- Plant construction and commissioning.

Each step requires substantial financial, policy, and technological resources. For this reason, the roadmap is presented in three phases: It should be noted that a single SAF standalone plant will be more than sufficient to mitigate international and domestic aviation emissions so Côte d'Ivoire's SAF industry can act as an exporter and regional supplier. It also makes co-processing and LCAF production at the SIR refinery a viable option.

Short term (2023–2025): Quick wins and building the foundation for a SAF industry.
Action is urgently required to decarbonize as soon as possible to minimize the negative effects of climate change. For this reason, the first phase of the proposed roadmap focuses on initiatives that can be deployed at the lowest cost with the lowest technological risk. It is recommended that priority be given to cassava residues and wastes feedstock for the following reasons:

- It has already been demonstrated that ethanol and isobutanol can be produced from the starch in the residual cassava liquid waste, and small quantities are already being produced.
- The process is scalable, and the alcohols can be converted to SAF via the ATJ pathway which is less capital intensive than some other SAF technologies.
- Multiple ethanol and isobutanol producing feedstocks, such as sorghum and sugarcane molasses, could be used to feed an Alcohol-to-Jet SAF production facility. This would increase feedstock volume, provide more flexibility, and reduce the risk of over-reliance on a single feedstock.
- Cassava is an abundant crop and production is growing. It can be grown in a wide variety of soil conditions, making it resistant to the effects of climate change.
- Other waste from cassava production can be collected and used as a feedstock, or combined with other agricultural wastes, for gasification via the Fischer-Tropsch pathway.
- Feedstocks that meet ASTM D1655 Annex A1 requirements (FOGs, hydrocarbons and biomass) can be co-processed up to 5% in using the existing SIR refinery infrastructure with a limited investment.
- Using cassava residue to produce SAF will have other social and economic co-benefits. It will create jobs for farmers, women, and disadvantaged groups, and can also bring environmental benefits by reducing cassava processing wastes.

Based on the above, the quickest route towards a SAF industry would be to finance a pilot plant for the conversion of cassava liquid waste containing starch into ethanol and an ATJ production facility. In parallel, SIR should explore the feasibility of co-processing FOG, especially those classified as wastes and residues. In that regard, it is recommended that data be collected, and a request be made to ICAO to assess the life cycle of cassava's wastes and residues for potential inclusion in the CORSIA's positive list of materials classified as co-products, residues, wastes or by-products, from the document CORSIA Methodology for Calculating Actual Life Cycle Emissions Values.

The possibility of using biodiesel (FAME) to replace fossil diesel in ground equipment should also be studied as this would be a low risk and quick way to reduce emissions. The next most promising SAF pathway consists of using low-cost agricultural wastes and municipal solid waste (MSW) to produce SAF via the Fischer-Tropsch synthesized paraffinic kerosene (FT-SPK) process. Cashew nut shells and cocoa pods are Ivorian specialties and provide good candidates for feedstock.

These, along with other agricultural waste, are available in significant quantities and are already concentrated in specific regions. This study has shown that enough feedstock exists, but further in-depth analysis is required to demonstrate economic and logistical feasibility.

The third potential pathway consists of using oil seeds to produce SAF from lipid-based feedstocks such as rubber seeds via the HEFA pathway. As for the case of alcohol producing feedstocks, different oil-based crops, such as oil palm or Jatropha, could be pooled to provide volume and reduce supply chain risk. The environmental, social, and economic effects associated with them need to be further assessed along with logistical matters.

Government policy and financial support will be critical in the first phase. The Ivorian government should consider implementing policies and frameworks that incentivize the nascent SAF industry. Financial support is required at the early stages of the industry, so that it can attain a level of maturity that attracts private investment. Examples of support include the construction of a pilot plant for the proof of concept and additional studies. Ivorian universities and academia can also play an important role in research and technology development.

Medium Term (2026–2030): Planning for Success

Upon selection of the most promising feedstock and technical pathway, the second phase should consist of engineering studies and detailed-techno-economic studies for the production facilities. The main objective is to attract investment by building a business case that demonstrates the economic viability of the process. During this period, it will be essential to get financial commitments from airlines and other fuel end users through mechanisms such as offtake agreements, forward fuel purchases or direct investment. Other key elements that need to be completed include sourcing and selecting technology partners, securing power and energy contracts, and site selection and permitting.

Long term (2030 onwards): Launching the SAF industry

The final phase is the construction and commissioning of the SAF facility. Once the plant is in operation, the onus will be on improving operational and logistical efficiency to reduce costs. At that point in time, the policy framework should be in place to provide a thriving industry. The success of the first plant should provide the incentive for other SAF and biofuel initiatives whether it is an improvement of the current processes or expansion into other technologies. The experience gained will enable Côte d'Ivoire to export and share their expertise in Africa and beyond.

CONTENTS

METHODOLOGY

LITERATURE REVIEW AND SECONDARY DATA

A literature review was conducted to assess national conditions in Côte d'Ivoire as well as global development for the production and use of SAFs and sustainable fuels for ground support equipment (GSE).

Significant advances have been achieved by different ministries in Côte d'Ivoire to address climate change concerns and GHG reductions from the transport sector. However, no specific work has been conducted that evaluates the GHG reduction potential and deployment viability of SAFs and sustainable fuels for GSE. Nonetheless, the decision from the **L'Autorité Nationale de l Aviation Civile** (ANAC) to participate in ICAO Assistance Project with EU Funding, phase II (2020–2023) sends a clear message about the country's commitment to sustainable growth for the aviation sector.

Research material evaluating regional and local potential for deployment of SAFs is limited in Côte d'Ivoire like other regions of the world considering that this is a nascent industry. In this regard, secondary data was also collected on processing technology developments, feedstock generation, advanced conversion processes, and the entire supply chain.

INTERVIEWS AND ELECTRONIC DATA COLLECTION

Data collected during in-person and virtual interviews, as well as via e-mail, helped reach more accurate and comprehensive conclusions for this study. In person meetings were conducted in Abidjan for one week from July 14th through July 22, 2023 (see annex 1).

ANALYTICAL FRAMEWORK: QUALITATIVE AND QUALITATIVE DATA ANALYSIS

The objective of this study is to evaluate the potential for production and use of socially acceptable, environmentally friendly, and economically viable SAF and sustainable fuels for GSE in Côte d'Ivoire.

Data and statistics were collected from publicly available sources. In addition, the Côte d'Ivoire ANAC point of contact supplied critical information used in the study. Published production volumes and the ICAO "Rules of Thumb" were used to make an order of magnitude estimations related to SAF costs, investment needs and production potential.

ABBREVIATIONS AND ACRONYMS

AFD	Agence française de Développement
AFDB	African Development Bank
AES	Aviation Environmental Systems
AFTF	Alternative Fuels Task Force
ANADAR	L’Agence Nationale d’Appui au Développement Rural
ANEREE	Agence Nationale des Énergies Renouvelables et de l’Efficacité Energétique
ANAC	Agence Nationale de l’Aviation civile
ANOC	African National Oil Corporation
APROJER	Association pour la Promotion du Jatropha et des Énergies Renouvelables
AtJ	Alcohol-to-Jet
ATAG	Air Transport Action Group
ASTM	American Society for Testing and Materials
ATM	Air Transport Management
APER	Action Plan for CO_2 Emissions Reduction
AU	African Union
BMZ	German Federal Ministry for Economic Cooperation and Development
Bpd	Barrel per day
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAEP	ICAO Committee on Aviation Environmental Protection
CAAF	First Conference on Aviation and Alternative Fuels
CCO	Coordination and Cooperation Office
CE	Conseil de l’Entente
CEN-SAD	Community of Sahelo-Saharan States
CHP	Combined heat and power plant
CICAFIB	Comité interministériel chargé de la coordination des activités de développement des filières biocarburants
CIF-FIP	Climate Investment Funds’ Forest Investment Program
CIRAD	Centre de coopération Internationale en Recherche Agronomique pour le Développement
CJO	Crude jatropha oil
CNS	Communication, navigation and surveillance
CNSL	Cashew Nutshell Liquid
CNSO	Cashew Nut Oil
CO2	Carbon dioxide
CO2eq	Carbon dioxide equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPP	Programme National de Partenariat pour la Gestion Durable des Terres

Def Stan	UK Defence Standard 91-091, Issue 09 (Turbine Fuel, Aviation Kerosene Type, JET A-1)
DDO	Distillate diesel oil
DLR	German Aerospace Center
DOA	US Department of Agriculture
DOD	US Department of Defense
DOE	US Department of Energy
DSCH	Direct sugars-to-hydrocarbon
ECOWAS	Economic Community of West African States
EE	Energy efficiency
EIF	Environmental Intervention Fund
EFPRA	European Fat Processors and Renderers Association
ETJ	Ethanol to Jet
EU	European Union
EUEI	European Union Energy Initiative
FAME	Fatty acid methyl ester
FAO	Food and Agriculture Organization of the United Nations
FCFA	Franc de la Communauté Financière d'Afrique
FIP	Programme d'Investissement Forestier (Forest Investment Program)
FRL	Fuel Readiness Level
FSRL	Feedstock Readiness Level
FT	Fischer-Tropsch
G.C.F.	Governors' Climate and Forest Task Force
GGGI	Global Green Growth Institute
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Gigajoule
GPC	Cotton producer groups
GWS	Genomic wide selection
H	Hydrogen
Ha	Hectares
HEFA	Hydrogenated Esters and Fatty Acids
HRJ	Hydro-treated renewable jet fuel
HVO	Hydrogenated vegetable oil
IATA	International Air Transport Group
ICAO	The International Civil Aviation Organization
IEO	Project Implementation & Execution Office
ILUC	Indirect land use change
INERA	Institut Nationale de l'Environnement et de Recherches Agricoles
IFSET	ICAO Fuel Savings Estimation Tool
IPS	Industrial Promotion Services

IRAM	Institut de Recherches et d'Applications des Méthodes de Développement
IRSAT	Institut de Recherche en Sciences Appliquées et Technologies
ISFL	BioCarbon Fund Initiative for Sustainable Forest Landscapes
Kg	Kilogram
Km2	Square kilometres
LAE	Laboratory for Aviation and the Environment
LCA	Life cycle assessment
LFO	Light Fuel Oil
LICs	Low-income African countries
MBMs	Market-based measures
MICs	Middle-income African countries
MIT	Massachusetts Institute of Technology
MJ	Megajoule
MT	Metric ton
MTJ	Methanol-to-jet
MW	Megawatts
MRV	Measurement, reporting, and verification
MSW	Municipal solid waste
NSC	National Steering Committee
OECD	Organization for Economic cooperation and Development
PNDES	Plan National de Développement Économique et Sociale
PPM	Parts per million
PPO	Pure Plant Oil
PPP	Public-private partnership
RE	Renewable Energy
REM	REDD Early Movers Program
REDD+	Reducing Emissions from Deforestation and Degradation
REEEP	Renewable Energy and Energy Efficiency Partnership
RTK	Revenue Metric ton Kilometres
SAF	Sustainable aviation fuels
SARPs	Standards and Recommended Practices
SDGs	Sustainable Development Goals (United Nations)
SDR	Rural Development Strategy
SEFA	Sustainable Energy Fund for Africa
SIP	Synthetic iso-paraffin
SIP-HFS	Synthesized iso-paraffin produced from hydro processed fermented sugar's
TRL	Technology readiness level
UEMOA	West African Economic and Monetary Union
UNDP	United Nations Development Program
UNEP	United Nations Environment Program

UNPA	Union National des Producteurs d'Anacardes
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries

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SECTION 1. STATE-SPECIFIC INFORMATION

1.1. GEOGRAPHY AND CLIMATE

The Republic of Côte d'Ivoire is a country located on the south coast of West Africa on the Gulf of Guinea. It is roughly square shaped with approximately 600 kilometres sides and a surface area about 322,462 km^2, which by comparison is slightly smaller than Poland. It has a coastline of 515 km. The Côte d'Ivoire is the 28th biggest country in Africa and in terms of area ranked 69th worldwide. More than half of all residents (53%) live within cities and over 10 percent of residents live in the main city of Abidjan.

It has direct national borders with five countries: Mali (to the northwest), Burkina Faso (to the northeast), Ghana to the east, Liberia (to the southwest) and Guinea (to the west-northwest). It is bordered by the Atlantic Ocean on the south. The population of Côte d'Ivoire in 2021 is estimated at nearly 29 million. The country's political and administrative capital is Yamoussoukro but almost all its institutions are in Abidjan, its main economic centre. Nearly 70 ethnic groups have coexisted peacefully for centuries, making Côte d'Ivoire a model in Africa. It is a multilingual country with an estimated 78 languages currently spoken but the official language is French.

Côte d'Ivoire is comparatively low with an average elevation of 250 metres above sea level and is mostly composed of flat plains that rise from the coast to the northern border. The highest mountain peak is 1,752-meter Mont Richard-Molard, also known as Mount Nimba, located on the border with Guinea.

Four major rivers flow through the country and empty into the Gulf of Guinea-the Bandama, Cavally, Komoe, and Sassandra. Lake Kassau and Lake Baya are large artificial lakes created by dams. They provide a water source and are used to generate hydroelectricity. The country has approximately 30 islands.

Figure 1. Côte d'Ivoire Geography

Côte d'Ivoire is in the intertropical transition zone between two major climate realms. With about 1200 animal and 4700 plant species, it is one of West Africa's most biodiverse countries.

The southern part of the country has a humid equatorial climate which features high rainfall and humidity. The south is covered with forests, which are in decline due to deforestation caused by agriculture and logging. It has two rainy seasons from March to July and from October to November. Annual temperatures are about 30 °C with high humidity and plenty of precipitation.

The northern part of the country has a semi-arid tropical savannah climate. Vegetation consists of grassland and sparse tree cover. It has a single rainy season from March to October that supplies annual precipitation totals from 1100 mm in the northeast/centre to 1500 mm in the northwest. Temperatures range from 28 °C to 37 °C.

Figure 2. Côte d'Ivoire Agricultural Zones

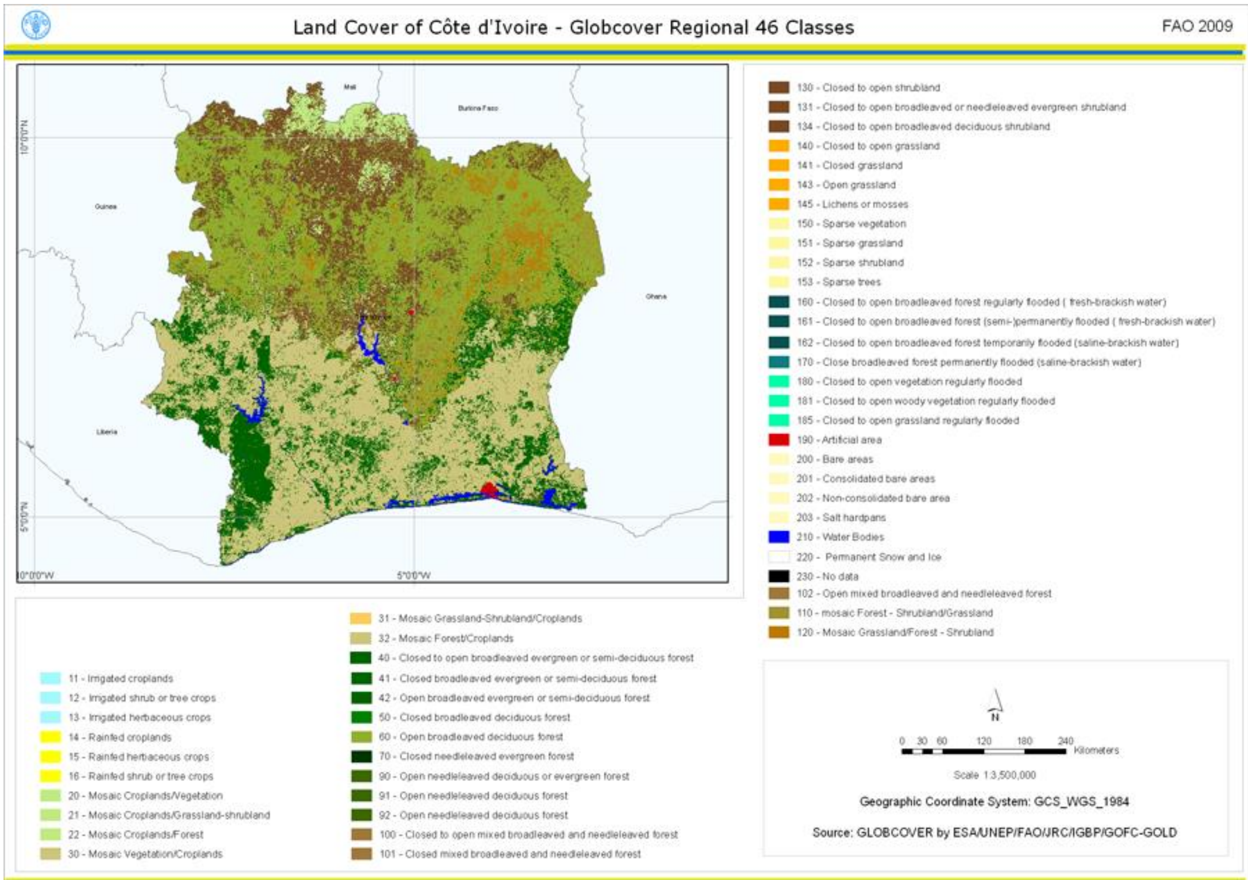


Figure 3. Land Cover of Côte d'Ivoire

Table 1. Feedstock environmental requirements

Potential Feedstock	Key Requirements
Cacao (shells)	Uniform temperatures, high humidity, abundant rain, nitrogen-rich soil, and protection from wind.
Cashew Nuts (shells)	Hot temperatures and not too much wind or rain. It's also very important that cashew trees receive at least six hours of bright sunlight each day and adequate fertilization.
Yam	Fertile, well-drained soil with a high organic matter content. They require plenty of water during the growing season.
Cassava	Humid-warm weather with good soil conditions. Cassava is one of the few plants that grow in any weather conditions.
Maize	Plentiful and steady rainfall are the most important requirements along with warm weather.
Sorghum	Full sun, warm temperatures, and fertile, well-drained soil
Oil palm	Tropical climates with temperatures between 30 and 32° C in areas with plenty of sunlight and high levels of humidity. They require plenty of precipitation.
Rubber	Plenty of sunlight and water
Shea and Kola nuts	Dry savannah environment with annual rainfall between 400 nm and 1800 mm but can survive multi-year droughts as well as the usual 6-to-8-month annual dry season.

Sugarcane	Warm and tropical climate with high rainfall or irrigation
Cotton	Requires about 200 days of sunshine with high average temperatures and alternation between dry and wet seasons. It does well in the dry or humid savannahs of Africa.
Coconut	Warm climate, plenty of sunlight, and good soil evenly distributed and an annual rainfall ranging from 1000 mm to 3000 mm.
Elephant grass	Rainfall range is 200-4000 mm and well-drained soils. It is tolerant to drought but not flooding.
Jatropha	Tropical and subtropical climates. It is well adapted to arid areas and helps to combat soil erosion.
Municipal solid waste	High urban concentration
Used Cooking Oil and animal waste	Sufficient volume and good collection logistics

The geography of Côte d'Ivoire suggests three promising SAF feedstock sources. First, the high urban concentration in Abidjan could provide a large, concentrated supply of municipal solid waste (MSW) and perhaps used cooking oil (UCO). Second, the large amount of agricultural activity in the coastal area could provide crops and agricultural wastes that can be converted into SAF. Finally, the savannah may be able to furnish energy grasses feedstocks. These potential feedstocks will be evaluated in detail in section 2, considering environmental concerns such as deforestation, protection of biodiversity, soil and coastal erosion, conservation of water resources, and food security.

In addition, climatic and geographic conditions in Côte d'Ivoire favour the development of renewable energies such as hydropower, solar, and biomass that can be used in SAF production. Its sea access and location make it ideally suited to transport SAF to regional and international destinations.

1.2. TRADE AND GOVERNANCE

Côte d'Ivoire is one of the largest, most stable, and fastest growing economy in West Africa. It is the world's largest exporter of cocoa, one of the largest producers of cashews, and an important exporter of other agricultural products such as coffee and palm oil. Agriculture and related activities employ about a large percentage of the population, making the economy dependent on international commodity prices and climate variations.

In addition to agriculture, Côte d'Ivoire has growing industrial and service sectors. Oil and gas production are an important part of the economy with substantial exports to Ghana, Togo, Benin, Mali, Burkina Faso, and other countries.

Côte d'Ivoire has excellent infrastructure with a good road and rail network, state-of-the-art telecommunications, modern ports, and scheduled regional and international air service. These factors make it a business and economic hub for international and Economic Community of West African States (ECOWAS) companies and organizations.

Under the 2021–2025 National Development Plan, Côte d'Ivoire and the Plan Stratégique Côte d'Ivoire 2030 the country outlined its ambition to transform and modernize its economy, to develop a large middle class, and to reduce extreme poverty. This will require increasing the value-added of agricultural products, building infrastructure, and improving productivity and human capital. In addition, significant investments will be needed in new sectors that can create well-paid quality jobs and reduce over-reliance on the agricultural sector.

Climate Policy and Finance

In 2016, Côte d'Ivoire ratified the Paris Agreement in 2016 and submitted their first **NDC (National Determined Contribution)** which sought to balance development and GHG emissions reduction. Climate adaptation and resilience were two big priorities. In 2022, Côte d'Ivoire submitted their second NDC report which significantly increased GHG reductions targets. It is committed to reducing its greenhouse gas emissions by 30.41% by 2030 relative to business as usual, or 98.95% with international support. Côte d'Ivoire also pledged to improve resilience and decrease vulnerability to climate change in key sectors such as agriculture, food and land use, water, health and coastal zones while creating green jobs. An investment plan will be created to increase and support climate finance.

Money will be required as there will be a significant climate finance deficit over the next decade and limited potential for private support. The main finance sources are insurance companies and two main pension funds (Caisse Nationale de Prévoyance Sociale and Caisse Générale de Retraite des Agents de l'État). The state does not have a climate fund, a carbon market, or SAF investment tax incentives. A greater knowledge of climate financing is needed, along with increased awareness of existing finance mechanisms and a better legal framework. International and private financing, government support, and public private partnerships will all be essential to meet the ambitious new climate targets.

Aviation Emissions Reduction Policy

As per ICAO resolution A37-9 which deals with policies and practices related to environmental protection and climate change, in 2018 Côte d'Ivoire established the CO_2 Committee to develop an action plan to reduce GHG emissions from international aviation. This committee is the responsibility of **L'Autorité Nationale de l Aviation Civile (ANAC)** under the authority of the Ministry of Transport. The ministries of the Environment and Energy also participate in the committee. ANAC provides a focal point and a coordinator and is responsible for GHG mitigation initiatives such as CORSIA.

In 2021, the CO_2 Committee published the Côte d'Ivoire **Action Plan to Reduce CO_2 Emissions from Internal Aviation**. In this report, 20 GHG reduction initiatives were identified. One of these measures was to produce a feasibility study regarding the deployment of sustainable aviation fuels in Côte d'Ivoire in 2023. The present study, developed under the ICAO ACT-SAF programme, addresses this measure.

Agriculture and Land Use Policy

In addition to the NDC, Côte d'Ivoire has several climate plans and policies in place, such as the **National Strategy for Climate-Smart Agriculture 2018-25, National Strategic Plan for the Development of Livestock, Fisheries and Aquaculture and a National Strategy for Forest Conservation**, and the **Rehabilitation and Extension and Law No. 2015-537 (Agricultural Guidance of Côte d'Ivoire).** These all aim to develop an agriculture industry that stresses food sovereignty and reduces food insecurity while providing good nutrition and good employment. Sustainable land management, climate adaptation and mitigation are core long-term objectives.

Implication for SAF Development Trade and Governance

The development of a SAF industry fits nicely into the Côte d'Ivoire's sustainable development plans and objectives. It will help meet GHG reduction targets, create well-paying green jobs, and contribute towards the move to higher value-added agricultural products. However, careful consideration must be given to ensuring that potential agricultural feedstocks respect agricultural, land use and food security criteria, such as reforestation.

There are several barriers that need to be addressed. Unlike other countries and regions, Côte d'Ivoire does not have a SAF policy framework that includes financial incentives or blending mandates. Given that SAF is more expensive than kerosene, domestic airlines will have little motivation to purchase it aside from meeting voluntary GHG reductions targets. Discussions with Air Côte d'Ivoire indicated that cost is a major consideration given that fuel is their major expense. Given that SAF is much more expensive than fossil jet fuel, they would not be able to purchase it without monetary or regulatory incentives.

International airlines will purchase SAF in other countries that have incentives that decrease cost or mandates that oblige use. Development would be greatly accelerated if the Côte d'Ivoire develops a national SAF strategy that incentivizes airlines to use SAF. If not, SAF exportation should be considered. Dialogues with Ivorian stakeholders have made it clear that the export of raw SAF feedstocks is not an option as it does not fit in with the national strategy to increase the valorization of domestic products and waste. Another barrier is the lack of an established climate and sustainable finance system. Côte d'Ivoire will require assistance from the international community and organizations that have more experience in this area.

It is important to note that implementing a SAF ecosystem consists of several steps, each of which need to be funded. The following table gives an order of magnitude guide to funding requirements. Actual figures vary according to such factors as feedstock, pathways, technology level, location, etc. Multiple funding sources and mechanisms are usually required.

Table 2. SAF funding requirements

SAF Development Stage	Funding Requirements (USD)
Feasibility study/studies	$100,000—$500,000
Pilot plant	$2–10 million
Engineering Studies (Fel-1, Fel-2, Fel-3/FEED)	$20-$80 million
Plant construction and commissioning	Hundreds of millions to over 1 billion

1.3. DEMOGRAPHICS

Population overview

According to the latest UN estimate, the current population of Côte d'Ivoire is nearly 29 million people, ranking it 51st globally placing it between Madagascar and Venezuela in terms of population. It represents 0.38% of the global population. Due to a high fertility rate of approximately 4 children per woman, the population is expected to surpass 50 million by mid-century and to more than triple to nearly 100 million by 2100.

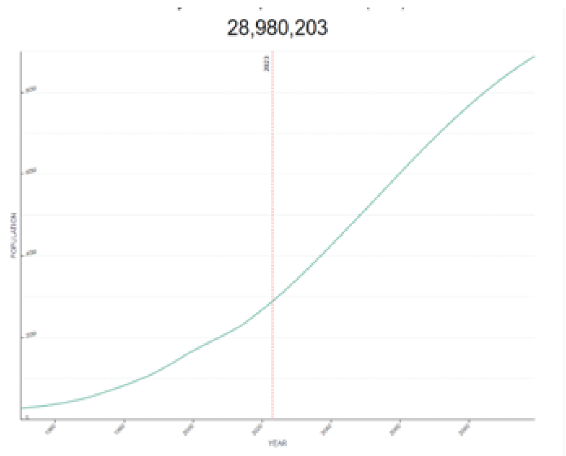


Figure 4 - Côte d’Ivoire Population

Côte d’Ivoire has a population density of 90.8 per square kilometre ranking it 122nd globally. However, much of the population is concentrated in the main cities and there is a high rate of urbanization. The main economic city, Abidjan, has a population of over 3.5 million people.

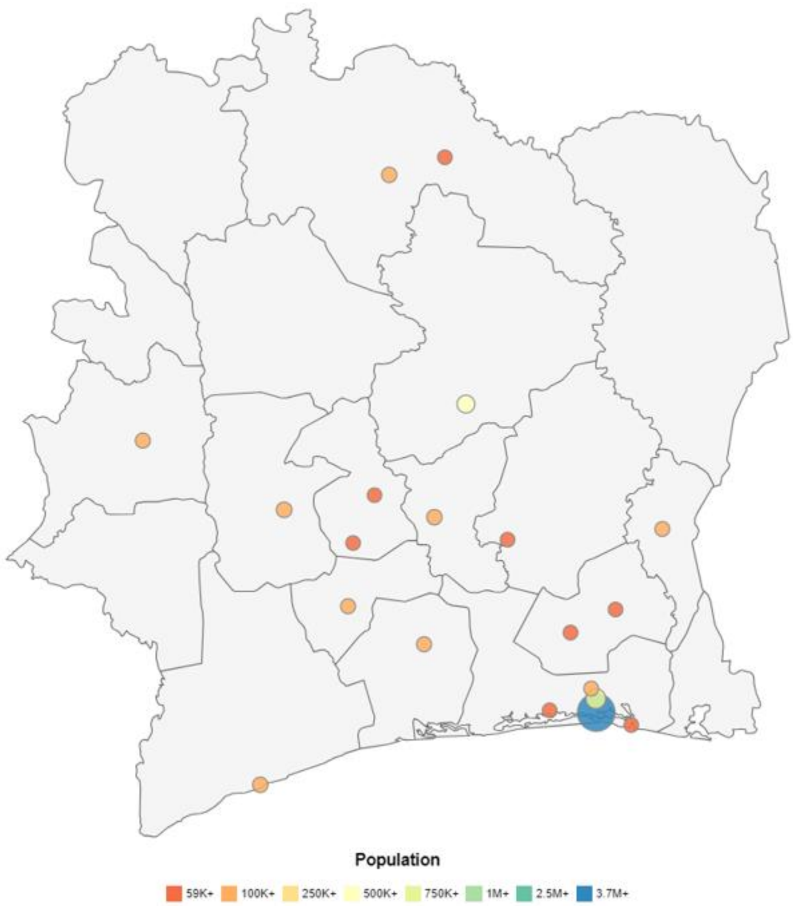


Figure 5. Côte d’Ivoire population density map

With an average GDP growth rate averaging over 8% between 2012 and 2019, Côte d'Ivoire has had one of the fastest growing economies in Africa and in the neighbouring sub-Sahel countries. Despite economic success, there is still a great wealth disparity with nearly half of the population living in poverty. Addressing this inequality is one of the main priorities in the country's **Vision 2030 Plan** which calls for investments in new sectors that offer significant opportunity to create wealth and quality jobs. A special focus is put on including women and underprivileged groups such as rural populations.

Education and Health

Côte d'Ivoire has one of the highest literacy rates in West Africa. According to CIA World Factbook literacy statistics, in 2019 89.9% of the Ivorian population can read and write. Expanding access to education and improving teaching quality are top priorities in the government's **Vision 2030** development program and the current five-year **National Development Plan (Plan National de Développement, PND) 2021-25**. In terms of post-secondary education, the country has universities in Abidjan (Université de Cocody), Bouaké (Université de Bouaké), and Yamoussoukro (Institut National Polytechnique Félix Houphouët-Boigny).

In terms of health care, Côte d'Ivoire is below average worldwide. According to the CIA World Factbook, Côte d'Ivoire's life expectancy at birth is 60.1 years. In the PNDS 2021-25, the government has set ambitious targets to improve general health indicators.

Demographic Implications for Potential SAF Production

The establishment of a SAF industry in Côte d'Ivoire can help meet the need to provide high quality new jobs for a growing young population. SAF facilities will need trained technical personnel to develop and run SAF facilities. These can be provided by the country's universities. Urbanization will provide more feedstock for MSW derived SAF, which can help to reduce landfill waste. Finally, agricultural feedstocks can provide employment in rural areas, provide additional income, and increase inclusivity for marginalized populations.

1.4. VULNERABILITY TO CLIMATE CHANGE

On continental and regional levels, two meta-analyses estimate that climate change will lead to a mean yield reduction of −8% in all Africa by the 2050 s and −11% in West Africa if no adaptation measures are taken. Investments are required in agricultural technology and adaptation to combat climate change.

Due to its geographical position and heavy economic reliance on agriculture, Côte d'Ivoire is especially exposed to climate change risks. In the most recent **2021 ND-GAIN study (Notre Dame Global Adaptation Initiative),** it had a very high vulnerability score which measures a country's exposure, sensitivity, and ability to adapt to the negative impact of climate change. It also has a low readiness score which measures a country's ability to leverage investments and convert them to adaptation actions. This combination of high vulnerability score and low readiness score places Côte d'Ivoire 140 out of 185 countries in the **ND-GAIN Country Index**. The index evaluates a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. Côte d'Ivoire has both a great need for investment and innovations to improve readiness and a great urgency for action. The economic impact of climate change is estimated at a loss of 380–770 billion CFA francs by 2040 (compared to a 2017 baseline).

Although Côte d'Ivoire is only responsible for approximately 0.10% of global emissions and the average individual Ivorian emits 10 times less than the global average, the country is committed to combatting climate change. This is reflected in Côte d'Ivoire's second NDC submitted in May 2022 which noted that agriculture, biodiversity, health, infrastructure, and water are at risk from climate change. Consequently, the country significantly raised its climate ambitions in the areas of adaptation, mitigation, resilience, and GHG reduction.

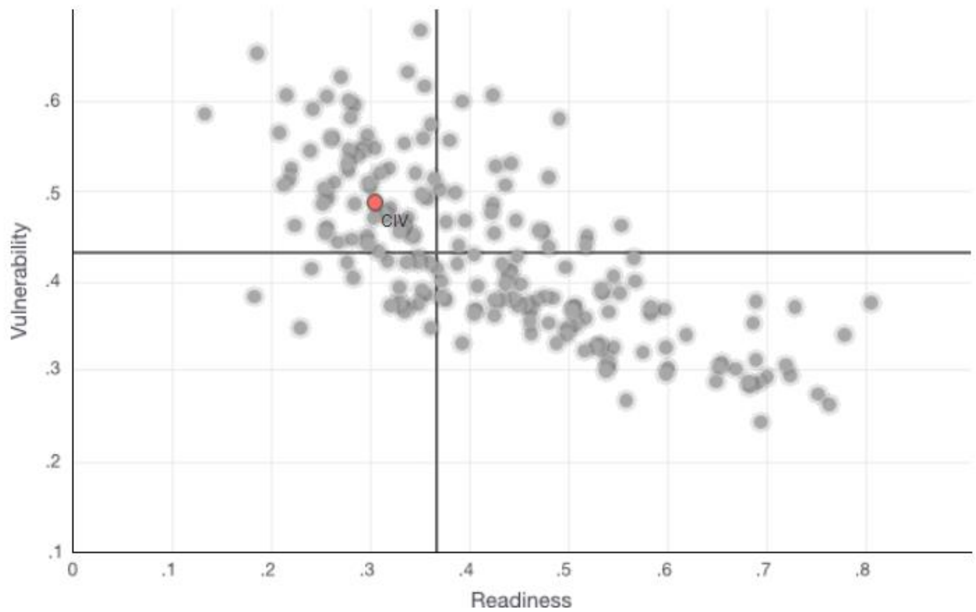


Figure 6. ND-GAIN country index Côte D'Ivoire

Projected Climate Change

Climate models of different climate change scenarios for the Côte d'Ivoire have carried out over the last few years by organizations such as the World Bank and the German Federal Ministry for Economic Cooperation and Development. The models use emissions in line with the Paris Agreement as the best-case scenario and consider medium-high emission projections. This provides a range of possible outcomes for the following parameters.

According to the National Meteorological Directorate, since the 1980s, the country has already seen an average temperature increase of five degrees Celsius as well as changes in rainfall patterns and shorter rainy seasons. Temperatures are anticipated to rise between 1.7 °C and 3.7 °C by 2080, with an average temperature increase of 2° C forecast by 2050 as compared to pre-industrial levels. Northern Côte d'Ivoire will be particularly hard hit with higher temperatures and great extremes. There will be more heatwaves and a lot more very hot days (defined as days over 35 °C).

Sea level is projected to rise by 11 cm in 2030, 20 cm in 2050 and 39 cm in 2080. This will have serious consequences for coastal communities such as infrastructure damage, erosion, and salination of drinking water. Côte d'Ivoire's sea level is rising faster than the global average and over two thirds of the Ivorian coastline is already affected by erosion.

Due to a high natural variability in annual rainfall, climate models of precipitation and soil moisture changes are ambiguous. Some models predict little change while others forecast an increase in precipitation accompanied by a decrease in soil moisture and greater evapotranspiration. Extreme weather events such as heavy rains and droughts are likely to be more common, as is the case in many other parts of the world. Meanwhile, the annual dry season is getting longer. The West African Monsoon appears to be shifting to later in the season with rainfalls more intense and erratic when they do arrive.

Sectors Affected by Climate Change

Climate change impacts all areas of society but in Côte d'Ivoire water, agriculture, infrastructure, land use, and health is especially vulnerable to climate change.

Water availability is projected to decline over the coming decades, although this will be primarily driven by population growth. Nevertheless, climate change will only exacerbate the problem via shifts in the rainy season and changes in precipitation amounts, as well as more frequent, intense, and longer droughts.

Agriculture is a sector that is highly dependent on weather and climate. In Côte d'Ivoire irrigation is primarily from natural precipitation with only a small percentage of crop land using irrigation. Climate change means greater uncertainty and variability in precipitation with higher risks of droughts. This will negatively impact the yields of certain crops such as millet, sorghum, and corn. Other crops, such as rice and cassava, will benefit from higher crop yields. However, there will likely be strong regional variations, so adaptation strategies need to be carefully studied.

Climate change presents significant risk to infrastructure in Côte d'Ivoire from extreme weather events. On the coast, heavy rainfall can lead to flooding of roads and railroads. In 2019 heavy rains in several coastal cities caused major flooding in several cities causing displacement and fatalities. Higher temperatures can cause accelerated degradation of critical infrastructure such as buildings, roads, and bridges. Côte d'Ivoire relies heavily on rail and road transport, especially to Burkina Faso and the sub-Sahel countries to the north, so it is particularly venerable to climate-induced infrastructure damage. Finally, droughts and increased rainfall can potentially disrupt the country's capacity to produce hydropower. This is a big concern since Côte d'Ivoire meets approximately 40% of its electrical energy needs from hydro and has big investments in large-scale projects.

Côte d'Ivoire has one of the highest rates of deforestation in the world. It lost about 80% of its forests in the last 60 years. According to Global Forest Watch, from 2002 to 2022, the total area of humid primary forest in Côte d'Ivoire decreased by 27% (363 kha). In 2022 alone, it lost 172kha of natural forest, equivalent to 111 Mt of CO_2 emissions. Deforestation in Côte d'Ivoire is caused by many factors. Agricultural expansion is a major contributor from both subsistence farmers clearing land to grow food and by agribusiness who cut down forests to increase the production of commercial crops such as cacao and rubber. Other deforestation drivers include logging, mining, and urbanization. Forest clearing releases sequestered carbon into the atmosphere again as carbon dioxide, contributing to climate change. For this reason, Côte d'Ivoire has made forest preservation a major priority and must be considered when considering potential agricultural SAF feedstocks.

Human health and welfare are threatened by climate change. Warmer temperatures and rainfall variability are projected to increase the prevalence of mosquito-borne diseases, such as malaria, while also exacerbating malnutrition and diarrheal diseases. According to the "Climate Risk Profile: Côte d'Ivoire Report by GIZ, heat-related mortality is estimated to increase fivefold by 2080.

Climate Change Vulnerability and Potential SAF Production

Côte d'Ivoire's climate change exposure to the negative effects of climate change presents a couple of challenges for SAF production. Changing climatic conditions can increase the risk for biological feedstocks availability for SAF conversion in the future. For example, droughts and changing rainfall patterns may decrease the availability of specific feedstocks or negatively impact the collection logistics. This is important to keep in mind as long-term supply stability is a critical factor in choosing a suitable biological feedstock. Finally, SAF production requires a stable electricity choice and certain pathways require much more power than others, and this must also be taken into consideration. This is a big barrier to the implementation of power to liquid pathways that are extremely energy intensive.

This following is based on the climate vulnerability of agricultural feedstocks for Côte d'Ivoire: as per the GIZ 'Climate Risk Profile: Côte d'Ivoire' report:

- Feedstocks most immune to climate change: Cassava, rice, elephant grass
- Feedstocks potentially threatened by climate change: maize, millet, sorghum, cacao, coffee, cashews, and plantains/bananas
- Feedstocks with potential land use issues: palm oil, Jatropha, cacao, rubber, maize, millet, sorghum, coffee

1.5. AGRICULTURE

Agricultural Importance and Production

Agriculture is the economic backbone of Côte d'Ivoire, contributing about one fifth of its GDP**,** employing nearly half the working population and responsible for over two thirds of total exports. Over 60% of land in Côte d'Ivoire is used for agricultural purposes. Much of the production is from small-scale family farms but a growing percentage is from large industrial plantations, especially for cash crops such as cocoa and palm oil.

Côte d'Ivoire is composed of two main agricultural zones. The humid and fertile southern area of the country produces most of the country's cash crops such as coffee and cacao. The drier northern savannah mostly grows food crops, cotton, and livestock production.

Côte d'Ivoire is the world's leading cocoa producer and the top cashew nut exporter. The country is also a key producer and exporter of palm oil, cashews, bananas, coffee, rubber, kola nuts, coconuts, cotton, cassava, yams, pineapples, mangoes, and sugarcane. However, only a small percentage of agricultural products are transformed before being exported. For example, Côte d'Ivoire accounts for 40% of global cocoa beans production, but processes less than one third of its own output locally. Côte d'Ivoire currently processes only 10–12% of its cashews, exporting most of the raw nuts to India and Vietnam. The Ivorian government's objective is to significantly increase domestic processing to 50% by 2025.

Government Agricultural Policy

Climate change is a big preoccupation for the government due to climate vulnerability and risks of over-reliance on agricultural exports. Changing weather, raising temperatures, deforestation, and longer dry seasons threaten the country's agricultural industry. In addition, agriculture contributes to 12 percent of Côte d'Ivoire's total GHG emissions, with 63% of those emissions coming from livestock. Creating jobs, reducing food insecurity, creating employment, and inclusivity are also areas of focus.

To address these issues, the **2nd National Agricultural Investment Plan 2018–2025 (NAIP 2)** and the **Vision 2030** strategy stress the importance on domestic processing of agricultural products in order to maximize the added value of exports and create more local jobs. The Ivorian government's economic goals are to increase production and local processing of key crops, such as cocoa and cashews. The plans also outline initiatives to improve climate adaptation and mitigation, combat deforestation, protect biodiversity, and to modernize and improve productivity.

Promising Agricultural Waste Feedstocks

Several studies, most notably the **Study of the biomass potential in Côte d'Ivoire,** have identified the following agricultural products that can provide waste streams suitable for valorization into SAF:

- Côte d'Ivoire produces nearly 850,000 metric tons of raw **cashew nuts** per year, making it one of the world's leading cashew nut producers, although it only processes a small percentage domestically. Cashew Nutshell Oil (CNSL) can be converted to biodiesel. Nutshells and other waste can also be used to create SAF via gasification into syngas and Fischer—Tropsch (FT) synthesis. Government plans to increase production and local processing will make it a very interesting potential feedstock.

- Côte d'Ivoire is the largest **cocoa** producer in the world. Annual production is estimated a 2.1 million metric tons in 2020. **Cocoa bean shells** can be used to make SAF in the same way as cashew nutshells. It is estimated that 89 MT of waste shells are produced annually. Unfortunately, most cocoa beans grinding is done in Europe, so the shells are not available for biomass upgrading. However, the government strategy to increase local processing will increase local supply. In addition, to increase supply, the ships returning from Europe can be filled with waste shells that can be used domestically.
- **Cassava** production Côte d'Ivoire is expanding rapidly. In 2019, production was estimated at 5.87 million metric tons with approximately 588,000 metric tons (10%) of waste available. Cassava starch and peels can be used to produce bioethanol that can be converted into SAF via the alcohol-to-jet pathway. A local company, Edindia, currently produces 6000 litres per month of bioethanol from cassava waste. This process has great potential to be scaled up to at least 120,000 litres per month and Edindia is very interested in producing SAF from bioethanol.
- Energy plants, such as elephant grass, contain sugars and starches that can be used to produce SAF via the ATJ process.
- Côte d'Ivoire produces nearly 1 million metric tons of **rubber** per year, making it the largest African producer and the fourth largest in the world. Rubber production produces several possible SAF feedstocks. Rubber seeds have a highly energetic oil content and can be used to produce HVO and SAF through the HEFA pathway. Waste and residue can be converted into SAF via gasification the Fischer-Tropsch pathway.
- After Nigeria, Côte d'Ivoire is Africa's second-biggest **palm oil** producer and ranks 11th globally. In 2020, the country produced 515,000 Mt of Palm oil, which can be used to produce SAF via the HEFA pathway, and residues via gasification and FT. However, according to the World Rainforest Movement September 2022 report "Oil Palm Plantations and Water Grabbing: Ivory Coast and Gabon", the use of palm oil for SAF is not a preferred use of this resource due to land-use issues and the fact that the oil already has a developed value-added market.
- In addition to cashew nut oil (CNSL) and rubber seeds, oil from cotton seeds and shea nuts are potential biodiesel feedstocks that can be used in ground service equipment (GSE).
- The relevant stakeholders in the Côte d'Ivoire have expressed concerns over potential feedstocks due to food security and land-use concerns: Jatropha, palm oil, sugarcane, sorghum, and maize. However, these feedstocks were evaluated in this study due to their SAF feedstock potential.

Implications of Ivorian agricultural policy on potential SAF production

Côte d'Ivoire's focus on expanding agricultural production and local processing means that there will be an increasing amount of available agricultural waste. Currently agricultural waste is either burned or left to decompose. Valorizing this biomass will not only provide economic and social benefits but will also reduce pollution and improve soil conditions. However, biomass can also be valorized in other ways than as a feedstock for SAF production. For example, it can be burned for energy, converted into biochar, or used to produce biodiesel. It is important that the Ivorian government puts in place policies and incentives to ensure that enough agricultural residue is available to support SAF production.

1.6. ENERGY

Côte d'Ivoire currently generates approximately 2200 MW annually, of which approximately 60 percent originate from thermal sources and 40 percent from hydroelectric dams. The growing Ivorian economy is putting the power supply network under pressure, so Côte d'Ivoire plans to increase generation capacity to 6000 MW by 2030 and modernize the nationwide transmission and distribution of electricity.

The country has the third-largest electricity system in West Africa and the most stable power supply. It exports electricity and petroleum products to neighbouring countries. Overall, the country aims to expand generation capacity. Principal energy sources are biomass, oil, natural gas, hydropower, and solar power.

The national electricity access rate is 64% which is one of the highest in West Africa although there is a sharp difference urban access (92%) and rural areas (38%). It is a government priority to improve supply to rural regions. The residential sector accounts for nearly 70% of total energy consumption, followed by commercial and public services, transportation, industry, and agriculture.

Energy Policy and Strategy

Because it is so important for the economy, social development, and sustainability, energy is of key strategic importance to the Côte d' Ivoire. Developing sustainable energy through renewable sources is one of the focus areas of the government's **2011–2030 Strategic Development Plan**. Côte d' Ivoire has a vast amount of untapped hydropower and solar generation resources.

In addition to increasing power generation capacity, a key strategic objective in the **Plan d'Actions National des Energies Renouvelables de la Côte d'Ivoire 2014–2030** is to diversify its energy mix to increase the proportion of renewable energy to 42% by 2030 and to reduce consumption by 25%.

Renewable energy will allow Côte d' Ivoire to reach its greenhouse gas emissions reduction target of reducing the GHG emissions by 30.41% by 2030 relative to business as usual from 2022[2], or 98.95% with international support, as stated in its second NDC report. The transition towards renewable energies will require billions of dollars in investments. Côte d'Ivoire has developed and maintained a vigorous regulatory framework for the power sector that has encouraged investor confidence.

[2] https://climatepromise.undp.org/fr/what-we-do/where-we-work/cote-divoire

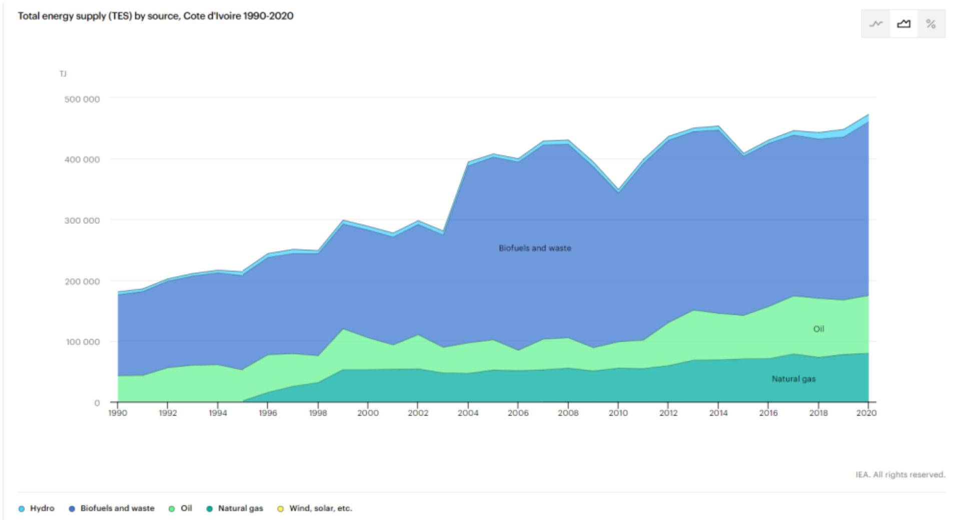


Figure 7. Côte d'Ivoire energy mix

Biomass Energy

More than half of the domestic energy needs are already met by combustible renewable resources and waste, mainly biomass. There is a tremendous opportunity to use agricultural waste to produce bioenergy. It is estimated that there is a biomass potential of approximately 16.7 metric tons per year primarily from cocoa, palm oil, rubber, and cotton equivalent to 1645 MW of energy. The government's objective is to produce 126 MW from agricultural waste by 2030.

Several biomass projects are underway. Côte d' Ivoire is building the largest biomass power plant (46 MW) in West Africa in Aboisso, 100 km east of Abidjan. It will be powered by locally grown palm leaves, most of which will be collected locally. The plant will have many social co-benefits such creating local jobs, increasing farmer revenue, reducing GHG emissions and providing fertilizer from combustion ash. Other projects using cocoa and cotton waste are under discussion.

Figure 8. BIOVEA Biomass Power plant Launch

Hydropower

. As of 2021, Côte d'Ivoire had an installed capacity of 2,269 MW, with roughly 61 percent (1,390 MW) generated by thermal and the remaining 39 percent (879 MW) generated by hydroelectric dams. Given the large potential, the government wants to more than double the hydroelectric capacity by 2030. This will require the construction of many more large-scale and small-scale dams. However, hydropower is highly sensitive to climate changes such as variations in rainfall patterns and droughts. Officials need to ensure that the country does not become over-reliant on hydropower to meet its energy needs.

Figure 9. Singrobo-Ahouaty hydroelectric project

Solar Energy

A recent report by the Oxford Business Group entitled "Côte d'Ivoire develops solar energy, biomass plants and new dams to increase energy capacity," shows how the country is developing its solar energy capacity. Blessed with abundant natural energy sources, solar energy production was not a priority for Côte d'Ivoire, and it has lagged behind other African countries. This situation is changing as the untapped potential of solar power is becoming more evident. In addition, the cost of solar projects has decreased from $0.40 to $0.10 per kWh in the last decade, making them very competitive with other sources of power. The government plans to increase solar energy capacity to 400 MW by 2030. Solar projects are planned in the sunny savannah northern part of the country. This will help to balance power production between the north and the south where most of the power is currently generated. Côte d'Ivoire is commissioning its first solar power plant in the country's northern town of Boundiali. The 37.5 MW installation is the first solar plant by the CIE and it features a 13.8 MWh salt storage system. Other solar power projects are planned in the coming years.

Figure 10. Boundiali solar power plant

Fossil fuels

As per the Dentons "Côte d'Ivoire — Summary of Petroleum Legal and Regulatory Regime" report, Côte d'Ivoire has oil reserves estimated at 100 million barrels and natural reserves estimated at 1.1 trillion cubic feet. However, the country is better known as an oil refiner and exporter than a producer. It has a well developed refining infrastructure which includes a refinery complex and bitumen plant in Abidjan, as well as an oil terminal with two stations for the loading and unloading of petroleum products. The refinery has one of the only hydrocrackers in Africa which enables it maximize diesel and kerosene (jet fuel) production. The refinery receives crude via pipeline from its offshore fields and crude from Nigeria. A major pipeline project from Côte d'Ivoire to Cameroon is being planned.

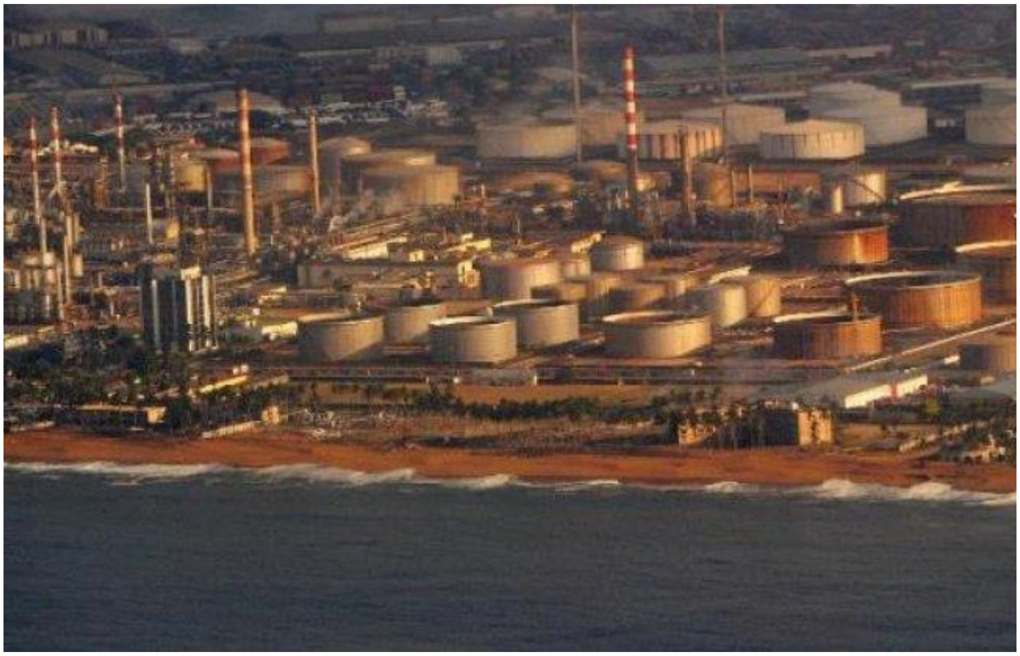


Figure 11. SIR refinery Abidjan

The SIR (Société Ivoirienne de Raffinage) refines 3.8 million metric tons of crude each year into the following products:

- Butane (1%)
- Gasoline (13–20%)
- Jet fuel (18–23%)
- Gasoil (25-29 %)
- Distillate diesel oil (DDO) (5%)
- Other fuel products (10%)

The Côte d'Ivoire is self-sufficient in producing refined petroleum products and is also a major supplier to the West African region. The country is a net exporter of petroleum products and crude oil. Refining is an important part of the economy, and the refinery is a major strategic asset.

The following chart from the Archie initiative shows the petroleum flows to and from Côte d'Ivoire. It is interesting to note that the Jet A fuel produced has a medium jet fuel carbon intensity compared to other countries meaning that the fuel is about average in carbon intensity.

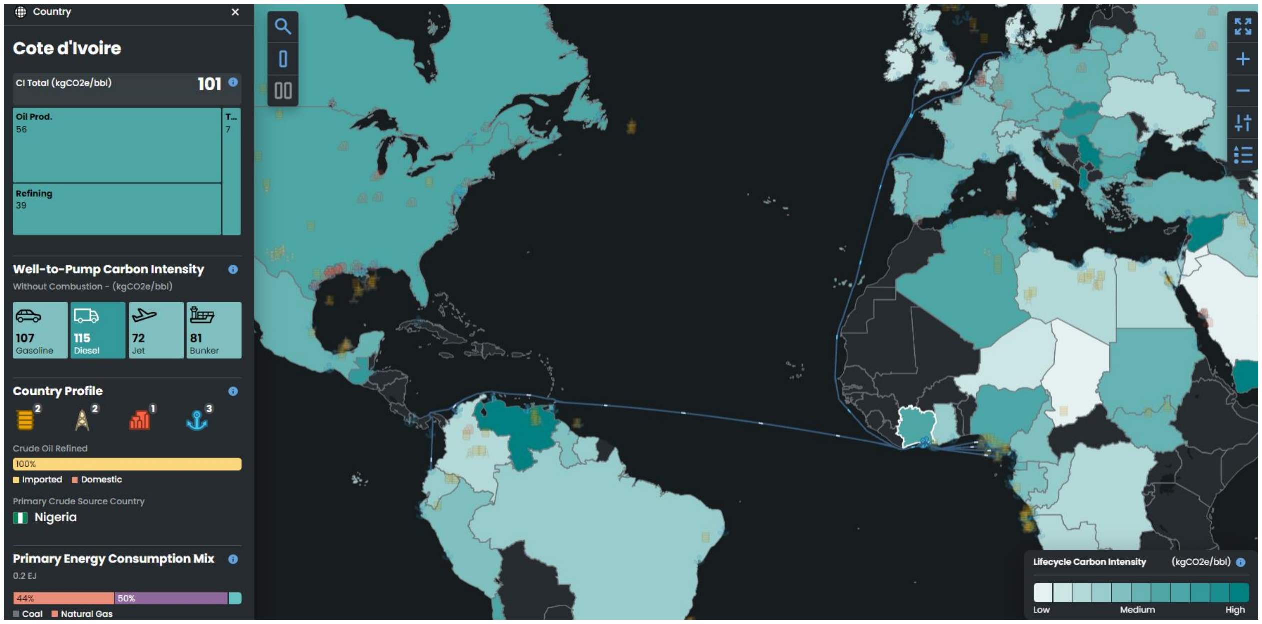


Figure 12. Côte d'Ivoire petroleum profile

Energy implications on potential SAF production

Côte d'Ivoire's energy mix and renewable energy strategy provide both opportunities and challenges for SAF production. The plan to increase renewable energy production and valorize waste biomass are factors that can benefit SAF production. Côte d'Ivoire's biggest advantage over most other African nations is that it has a well-developed and strategic refining industry. This is of immense use in the production, co-processing, blending, logistics and distribution of SAF.

On the other hand, Côte d'Ivoire's energy profile and strategy present some serious barriers to adoption of SAF. Electrical capacity is tightening, and future hydropower is at risk from climate change. Cost, distribution issues and the desire to prioritize electrification of rural areas rule out using Power-to-Liquid technologies. Agricultural waste feedstocks for SAF are in competition with use for power generation. It will take careful coordination between government agencies to ensure that there are enough available for all industry sectors.

1.7. AVIATION FUEL SUPPLY CHAIN

Airports and aerodromes

Côte d'Ivoire has one international airport (Félix Houphouët Boigny) and twenty-seven airfields open to air traffic. Five can accommodate domestic commercial flights domestic flights. These airports are in Bouaké, Korhogo, Man, Odienné and San Pedro.

Félix-Houphouët-Boigny International Airport in Abidjan is one of the most modern and important aviation hubs in West Africa. It is a leader in airport sustainability on the continent, becoming the first Level 3+ Carbon Neutral certified airport in Africa in ACI's Airport Carbon Accreditation program. They have implemented many GHG reduction initiatives and are planning others such as solar power and carbon sequestration (Project Soil.is).

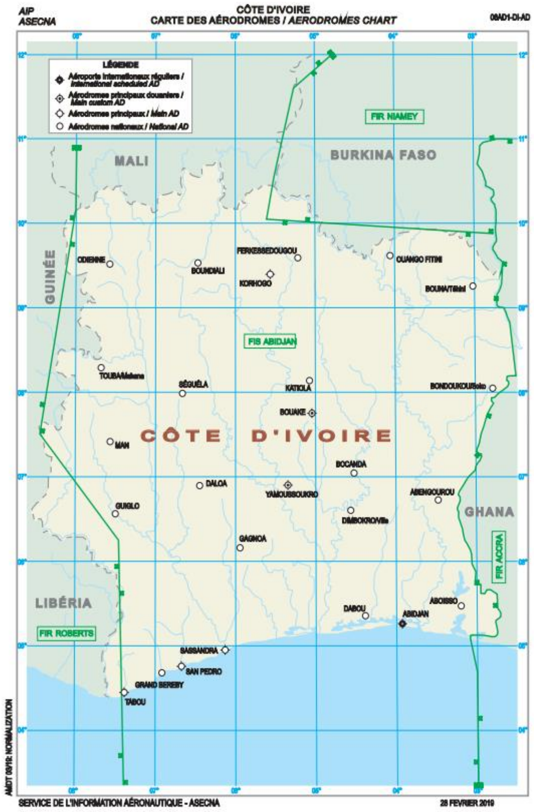


Figure 13. Côte d'Ivoire airports

Air Transporters

Air transport in Côte d'Ivoire is growing steadily. This activity is carried out by air operators certified by ANAC in accordance with the applicable aviation regulations of Côte d'Ivoire (RACI). There are six aircraft operators holding a Permis d'Exploitant Aérien (air operator's permit). Operating international or domestic flights. Amongst aircraft operators, only Air Côte d'Ivoire, Solenta Aviation Côte d'Ivoire and Max'Air operate international flights.

Figure 14. Air Côte d'Ivoire regional air network

Figure 15. Air Côte d'Ivoire domestic air network

Currently 26 foreign airlines operate exclusively flights to and from Côte d'Ivoire. These include Air Burkina, Air France, Air Algérie, Air Sénégal, Asky Airlines, Brussels Airlines, Kenya Airways, Ethiopian Airlines, Emirates Airlines, Corsair International, Royal Air Maroc, Turkish Airlines. Several operators are active in the light aviation sector, mainly for aerial work and flying club activities.

In the **Plan d'action de la Côte d'Ivoire pour la réduction des émissions de CO_2 issues de l'aviation civile internationale,** international aviation emissions were calculated as a baseline for GHG improvements. Domestic emissions were not included but are much smaller because domestic flights represent a small portion of the total aviation activity.

Table 3. Côte d'Ivoire's international aviation emissions

REFERENCE SCENARIO			
Year	International RTK ('000)	Fuel consumed on international flights (t)	International CO_2 emissions (t)
2019	84,057.00	42,425.40	134,064
2020	87,419.28	44,122.42	139,427
2021	90,916.05	45,887.31	145,004
2022	94,552.69	47,722.81	150,804
2023	98,334.80	49,631.72	156,836
2024	102,268.19	51,616.99	163,110
2025	106,358.92	53,681.67	169,634
2026	110,613.28	SS 828.93	176,419
2027	115,037.81	58,062.09	183,476
2028	119,639.32	60,384.57	190,815
2029	124,424.89	62,799.96	198,448
2030	129,401.89	65,311.95	206,386
2031	134,577.97	67,924.43	214,641
2032	139,961.08	70,641.41	223,227
2033	145,559.53	73,467.07	232,156
2034	151,381.91	76,405.75	241,442
2035	157,437.18	79,461.98	251,100
2036	163,734.67	82,640.46	261,144
2037	170,284.06	85,946.08	271,590
2038	177,095.42	89,383.92	282,453
2039	184,179.24	92,959.28	293,751
2040	191,546.41	96,677.65	305,501
2041	199,208.26	100,544.75	317,721
2042	207,176.59	104,566.54	330,430
2043	215,463.66	108,749.20	343,647
2044	224,082.20	113,099.17	357,393
2045	233,045.49	117,623.14	371,689
2046	242,367.31	122,328.07	386,557
2047	252,062.00	127,221.19	402,019
2048	262,144.49	132,310.04	418,100
2049	272,630.26	137,602.44	434,824
2050	283,535.48	143,106.53	452,217

Jet fuel production and logistics

Jet used in Côte d'Ivoire is produced at the SIR refinery in Abidjan (described in section 1.6) or imported into the port of Abidjan by several large petroleum companies. In both cases the fuel is stored in a petroleum pool by the Côte d'Ivoire Oil Stocks Management Company (GESTOCI) which has depots in Abidjan and Yamoussoukro. From there, jet fuel is transported to airports by tanker trucks where it is delivered into planes by several service providers.

Requirements for a SAF supply chain

Before it can be made into SAF, a feedstock must go through several steps, as shown in the following diagram:

- The feedstock must be produced and collected. In the case of agricultural biomass, this means growing and harvesting. Non-biological feedstocks as MSW and captured carbon dioxide have their own logistical processes.

- Once collected, the feedstock must be sorted, treated, processed, and transported to a production facility.

- At the production facility, the feedstock is converted into SAF by one of the approved conversion pathways. The feedstock may undergo transformation into an intermediate product beforehand. For example, sugar-containing feedstock may be processed into ethanol before conversion to SAF. In this way, it may be possible for a SAF facility to use inputs from multiple feedstocks in the same category.

- Once produced the neat (pure) SAF must be blended with fossil jet fuel and distributed to the airports. This process is shown below.

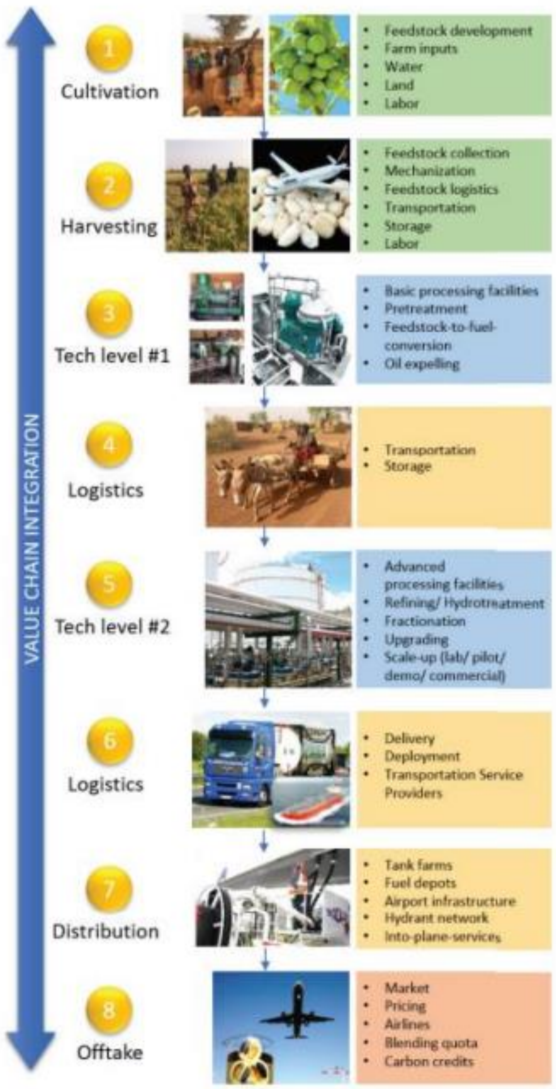


Figure 16. SAF value chain

Blending

Current regulations stipulate that SAF must be blended with jet fuel up to 50% before being uploaded into an aircraft. Therefore, blending is a critical part of the SAF delivery chain. If the SAF feedstock is co-processed at a refinery, the resulting blend is equivalent to jet fuel and the current supply chain would be used. If the SAF is produced at a biofuel or Fischer-Tropsch facility, it must be blended with kerosene. This is expected to be done at existing fuel terminals and then delivered to airports by pipeline, rail, or truck. Since the blending would occur upstream to the airport, no operational changes or investments would be needed at the airports. In addition, due to the space restraints, the need for additional staff and equipment, and quality standards it makes more sense to certify SAF as ASTM D1655 upstream of an airport. Côte d'Ivoire's highly developed petroleum infrastructure that includes the SIR refinery in Abidjan makes it an ideal location to blend SAF feedstocks not only domestically but also for the region.

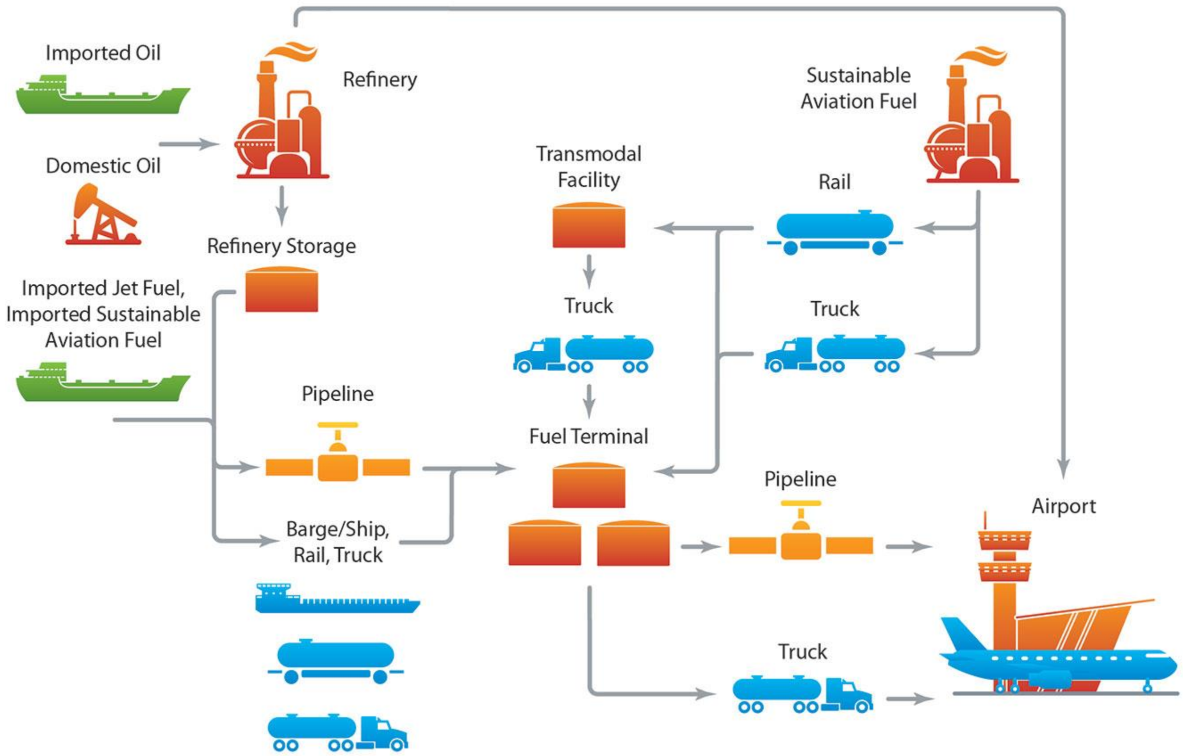


Figure 17. SAF logistics flow

The production of SAF requires that all the members within its value chain work together to reduce costs and maximize benefits, as shown in the following figure.

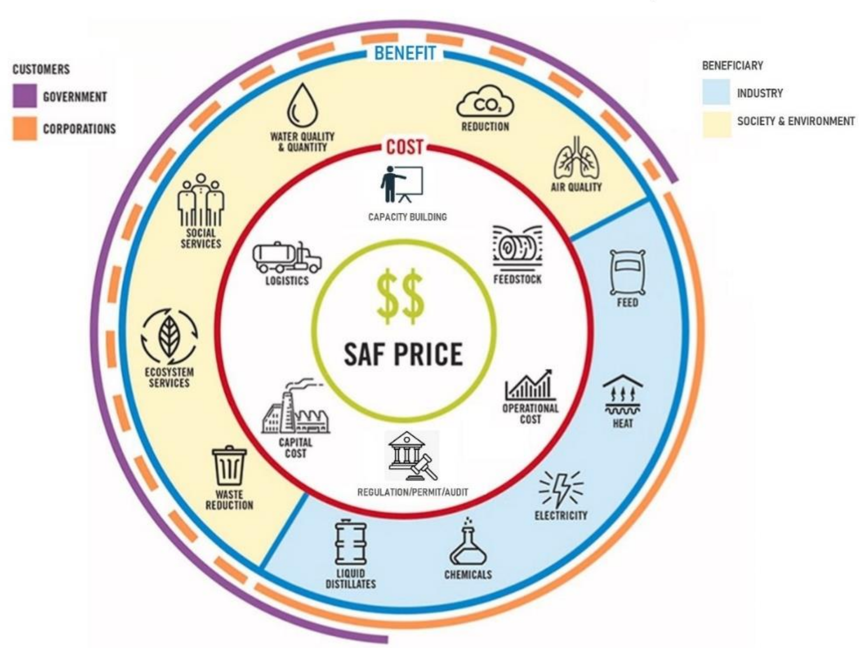


Figure 18. SAF value chain

Implication of the aviation fuel supply chain on SAF

Côte d'Ivoire's aviation fuel supply chain is well positioned to distribute SAF. Discussions with SIR have indicated that it would be relatively easy for them to receive SAF and blend it into fossil jet fuel with little additional capital cost. SIR could also co-process approved sustainable feedstocks at their Abidjan refinery complex. Once the SAF is blended or co-processed it is fungible with jet A, meaning that it can be sent to the petroleum poll and distributed using current equipment and procedures with no additional capital investment. SIR also indicated its capability to store segregated neat or blended SAF at their refinery and to distribute it to the petroleum pool via their current pipeline. The chain of custody tracking would be needed to claim of the environmental benefits. In the case of CORSIA, claims of emissions reductions from the use of CORSIA Eligible Fuels are based on purchasing records as per **ICAO Standards and Recommended Practices—Annex 16 Volume IV**. Since other schemes may not use the same chain of custody standards, it may be necessary to distribute neat (unblended) SAF directly to the airlines, at least until universal standards are developed.

SECTION 2. EVALUATION OF CONVERSION PROCESSES AND FEEDSTOCK ANALYSIS

CONVERSION PATHWAYS

ICAO annex 16 vol IV defines a conversion process as "a type of technology used to convert a feedstock into aviation fuel". SAF conversion processes are evaluated and approved by organizations such as ASTM international. As of July 2023, 11 conversion processes for SAF production have been approved and 7 other conversion processes are currently under evaluation.

Table 4. ASTM certified SAF pathways

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
ASTM D7566 Annex 1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Coal, natural gas, biomass	50%
ASTM D7566 Annex 2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Bio-oils, animal fat, recycled oils	50%
ASTM D7566 Annex 3	Synthesized iso-paraffin from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%
ASTM D7566 Annex 4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%
ASTM D7566 Annex 5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Biomass from ethanol, isobutanol or isobutane	50%
ASTM D7566 Annex 6	Catalytic hydrothermolysis jet fuel	CHJ	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%
ASTM D7566 Annex 7	Synthesized paraffinic kerosene from hydrocarbon—hydroprocessed esters and fatty acids	HC HERE—SPK	Algae	10%
ASTM 07566 Annex 8	ATJ derivative starting with the mixed alcohols	ATJ-SKA		
ASTM 01655 AnnexA 1	co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	co-processed HEFA	Fats, oils, and greases (FOG) co-processed with petroleum	5%
ASTM 01655 Annex A1	co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	co-processed FT	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
ASTM D1655 Annex A1	co-hydroprocessing of biomass	co-processed biomass		5%

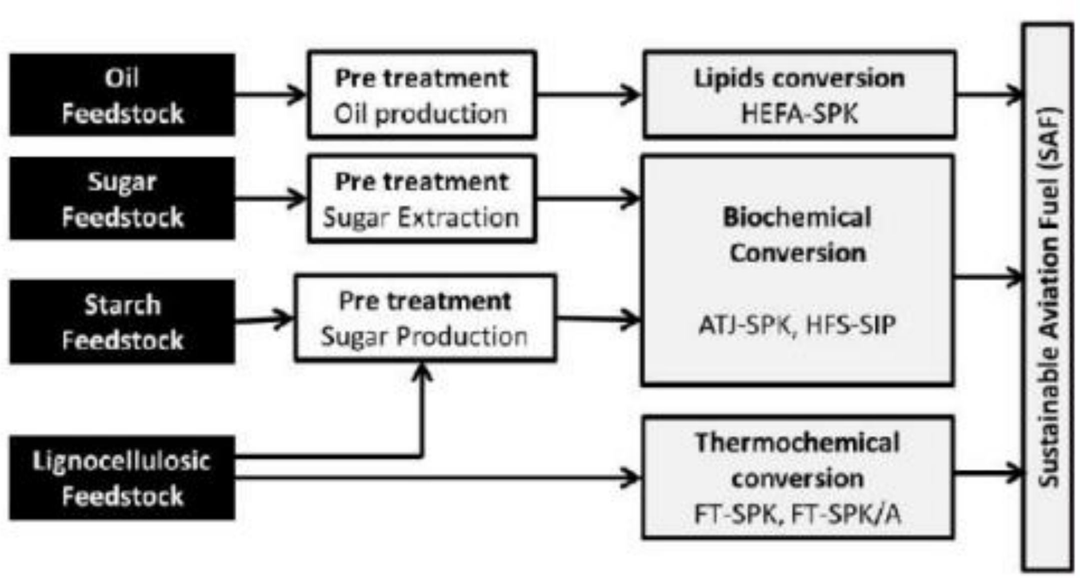


Figure 19. SAF conversion processes

There are two main types of technologies used to make SAF. Thermochemical processes use heat and chemical reactions while biochemical processes use micro-organisms and enzymes to convert feedstocks to energy bearing biofuels or SAF. These processes are at different levels of technical maturity. A brief description of the production pathways and their technological readiness level (TRL) considered in this study are given below.

Table 5. SAF feedstocks and approved pathways

Production pathway	Feedstocks	Certification name (blending limit)	TRL
Biomass Gasification + Fischer-Tropsch (Gas+FT)	Energy crops, lignocellulosic biomass, solid waste	FT-SPK32 (up to 50%)	7–8
Hydroprocessed Esters and Fatty Acids (HEFA)	Vegetable and animal fat	HEFA-SPK (up to 50%)	8–9
Direct Sugars to Hydrocarbons (DSHC)	Conventional sugars, lignocellulosic sugars	HFS-SIP[32] (up to 10%}	7–8
Biomass Gasification + FT with Aromatics	Energy crops, lignocellulosic biomass, solid waste	FT-SPK/A[34] [up to 50%]	6–7
Alcohols to Jet [AtJ]	Sugar, starch crops, lignocellulosic biomass	ATJ-SPK [up to 50%]	7–8
Catalytic Hydrothermolysis Jet [CHJ]	Vegetable and animal fat	CHJ or CH-SK35 [up to 50%]	6
HEFA from algae	Microalgae oils	HC-HEFA-SPK36 [up to 10%]	5
FOG Co-processing	Fats, oils, and greases	FOG [up to 5%]	-
FT Co-processing	Fischer-Tropsch [FT] biocrude	FT [up to 5%]	-

2.1. EVALUATION OF CONVERSION PROCESSES

2.1.1. ALCOHOL TO JET (ATJ)

Sugars and starches from feedstocks are fermented into ethanol or butanol. The alcohol-to-jet (ATJ) pathway then converts these alcohols into renewable fuel by removing oxygen and linking the molecules together through several process steps to get the desired carbon chain length needed to make SAF (Synthetic Paraffinic Kerosene-SPK) or Green Diesel (Synthetic Paraffinic Diesel-SPD). The current maximum SAF blending ratio is 50% as per ASTM D7566-4 Annex 5. Two US-based companies are planning facilities that will produce SAF and renewable diesel and gasoline per this process.

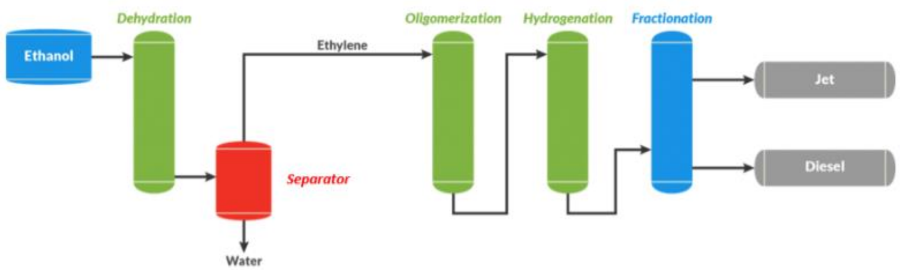


Figure 20. ATJ SAF conversion process from ethanol

2.1.2. SYNTHESIZED ISO-PARAFFIN PRODUCED FROM HYDROPROCESSED FERMENTED SUGARS (SIP-HFS)

SIP, also called Direct Sugar to Hydrocarbon (DSHC), is a biological platform where sugars from feedstocks are biologically converted by aerobic fermentation by yeast micro-organisms into a hydrocarbon molecule called farnesane which, when treated with hydrogen, can produce SAF. The current maximum blending ratio is 10% as per ASTM D7566 Annex 3.

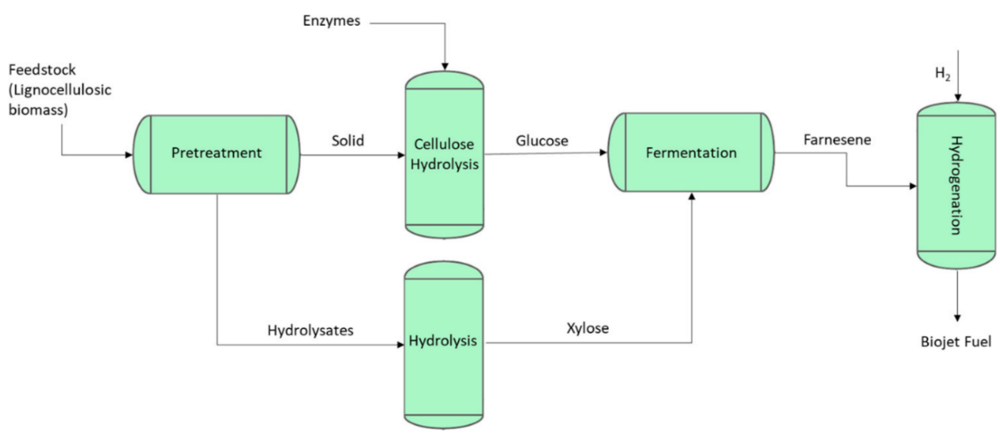


Figure 21. SIP-HFS/DSHC SAF Conversion Process from Biomass

A company was able to produce SAF by the SIP-HFS process using Brazilian sugarcane syrup feedstock and genetically modified yeasts and conducted successful demonstration flights in 2014 using SIP-HFS SAF blended with kerosene. However, there are two limitations related to this process. First, the fuel is very homogenous, having only one carbon chain length, which currently limits the maximum blending ratio to 10 percent. Ongoing efforts at ASTM are looking into blending multiple synthetic components, which could allow SAFs produced under different processes to be mixed. Second, implementing the technology is being more complex, challenging, and costly than other technologies such as ATJ or HEFA. For these reasons, SAF using the SIP-HFS pathway is mentioned here for completeness but not considered to be a viable pathway in the context of this feasibility study.

Figure 22. Test flight using HFS-SIP S, Brazil 2014

2.1.3. HYDROTREATED ESTERS AND FATTY ACIDS (HEFA)

Certified in 2011, the HEFA process is a well-developed and widely used process to produce SAF from vegetable oils, waste oils, or fats through a process that uses hydrogen (hydrogenation). In existing HEFA plants, large amounts of hydrogen are required and usually produced via steam reforming of natural gas or using co-products like naphtha. In the first step of the HEFA process, the oxygen is removed by hydrodeoxygenation. Next, the straight paraffinic molecules are cracked and isomerized to the jet fuel chain length. The HEFA process is like that used for Hydrotreated Renewable Diesel production, only with more severe cracking of the longer chain carbon molecules. The current maximum blend ratio is 50% as per ASTM D7566 Annex 2. HC-HEFA is produced in much the same way as HEFA but uses the fast-growing high oil content Botryococcus braunii species of algae as a feedstock. Max blend ratio is 10%. ASTM spec: D7566 – Annex 7.

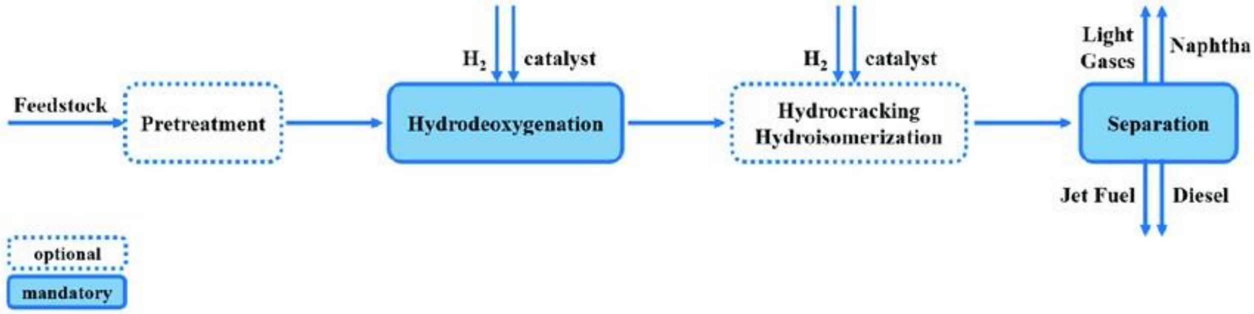


Figure 213. HEFA SAF conversion process

2.1.4. CATALYTIC HYDROTHERMOLYSIS (CHJ)

In 2020, ASTM International approved the new CHJ pathway. It converts fatty acid esters and free fatty acids into SAF via catalytic hydrothemolysis followed by any combination of hydrotreatment, hydrocracking, or hydroisomerization and fractionation. Researchers have demonstrated that the CHJ process can produce jet fuel from vegetable feedstocks containing triglycerides, such as Jatropha, camelina and carinata. Although proven at the laboratory scale, there are currently no production facilities using the CHJ process. The current maximum blending ratio is 50% as per ASTM. D7566 Annex 6.

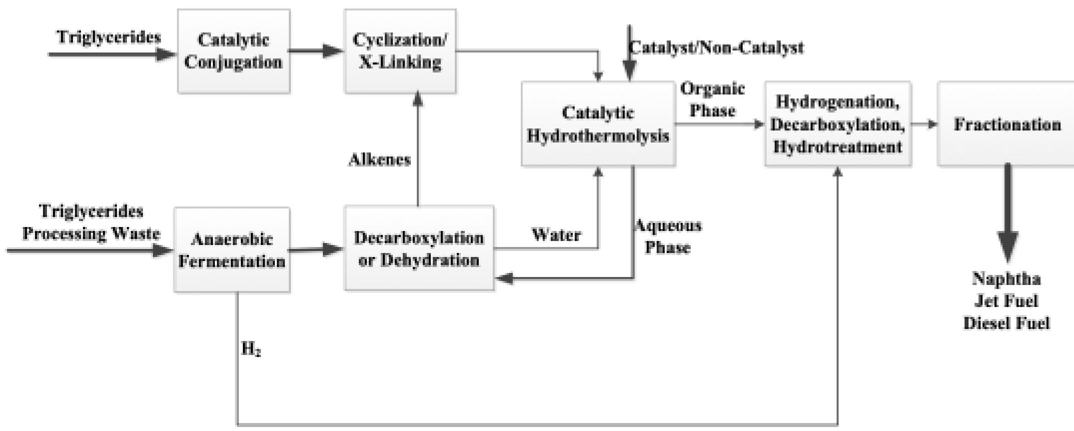


Figure 224. CHJ SAF conversion process from vegetable oils

2.1.5. FISCHER-TROPSCH (FT)

The FT process takes any material containing carbon and converts into a gas form (syngas) that form building blocks that when combined form synthetic fuels such as SAF. Feedstocks can be coal, natural gas, captured CO_2, municipal solid waste, or biomass. Two different FT processes have been certified by ASTM. One that produces a straight paraffinic jet fuel (SPK) and another that produces additional aromatic compounds (SAK). Both processes can use any carbon containing starting material. FT technology was developed in Germany using a coal feedstock about 100 years ago and, 92% of Germany's air fuel and over 50% of its petroleum supply in the 1940s was created using FT technology. Synthetic fuel has been supplied to Johannesburg - OR Tambo International Airport in South Africa since 1999. In these two cases, the coal feedstock does not provide carbon reductions so it is not SAF but it demonstrates the technological maturity of the FT process. Maximum blend ratio for both options is 50%. ASTM spec for SPK D7566 – annex 1 ; ASTM spec for SAK: D7566 – annex 4.

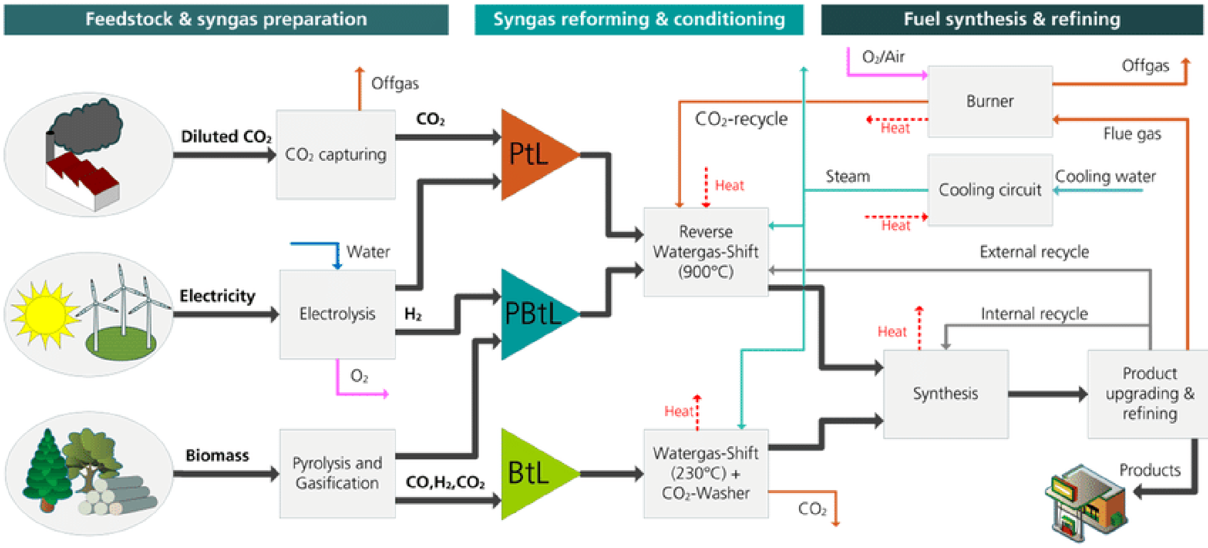


Figure 235. PtL SAF conversion process from carbon dioxide and biomass

2.1.6. FAME AND HVO DIESEL

Lipid feedstocks are not only a SAF feedstock, but can also be used to produce non-fossil diesel for road transport. This makes them a very interesting option to reduce the GHG emissions from ground service equipment (GSE). Two different types of non-fossil diesel, biodiesel, and renewable diesel, can be produced, depending on the feedstock and the conversion technology. These are discussed below.

FAME Biodiesel

FAME (Fatty Acid Methyl Ester) or UCOME (Used Cooking Oil Methyl Ester) biodiesel, that is produced by a process known as transesterification. Transesterification converts organic fats and oils into fatty acid alkyl esters by reacting them with alcohols and catalysts.

The main advantages of FAME are that it is relatively easy and cheap to produce. It also has other good qualities such as lubricity. However, it is important to know that FAME is not a hydrocarbon fuel like diesel made from crude oil, which creates some disadvantages. FAME contains oxygen, which lowers the energy content by roughly 7%, limits the time it can be stored, and can cause corrosion and clogging problems in tanks and infrastructure. It also forms ice crystals at a much higher temperature than petroleum-based diesel. This is referred to as the cloud point. For these reasons, FAME biodiesel is blended with petroleum. Pure FAME is called B100, but common blends are B5 (up to 5 percent biodiesel) and B20 (20 percent biodiesel).

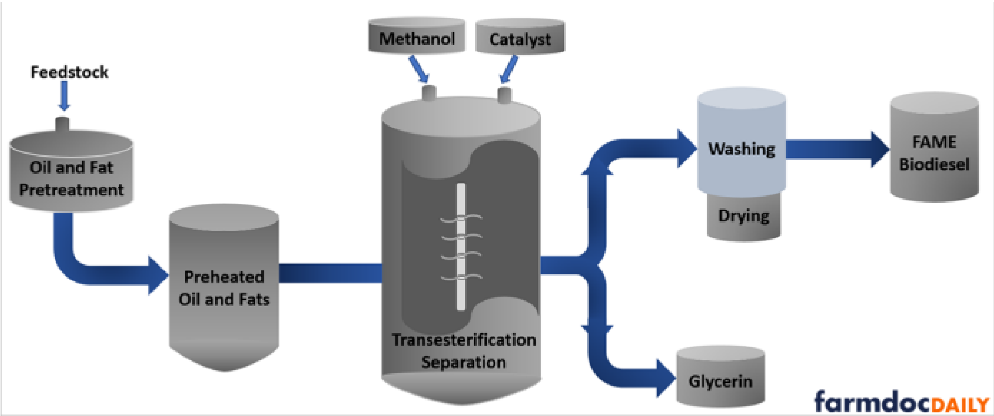


Figure 246. FAME biodiesel production process

HVO Renewable Diesel (RD)

Hydrotreated Vegetable Oil (HVO), also known as renewable diesel, is produced from the same feedstocks as FAME biodiesel. However, HVO is fundamentally different from FAME in that it only contains hydrogen and carbon, making it a hydrocarbon just like petroleum diesel. This means that it does not require blending to be used in a diesel engine. It is created by a thermochemical hydrotreating process that is very different than that for biodiesel. Hydrotreating is similar to the process used to crack crude oil into petroleum products. Therefore, HVO is usually produced in conjunction with SAF in concerted oil refineries.

The advantage that HVO has over FAME is that HVO's chemical composition is so close to fossil fuel that it is regarded as a drop-in fuel and does not need to be blended. The disadvantage of HVO RD is that because crude oil refining is needed the capital costs are much higher than for FAME. Another disadvantage of FAME is that it has a lower energy content than fossil fuel.

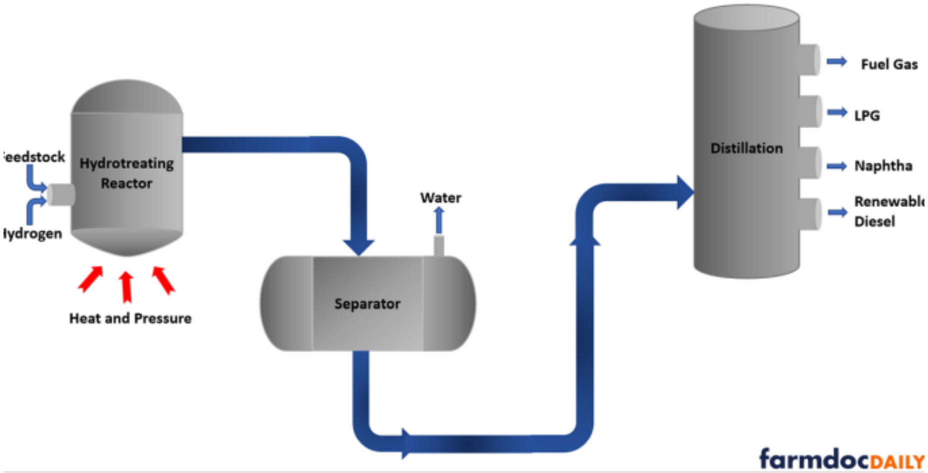


Figure 257. HVO renewable diesel production process

The following diagram explains the differences between FAME, HVO and SAF.

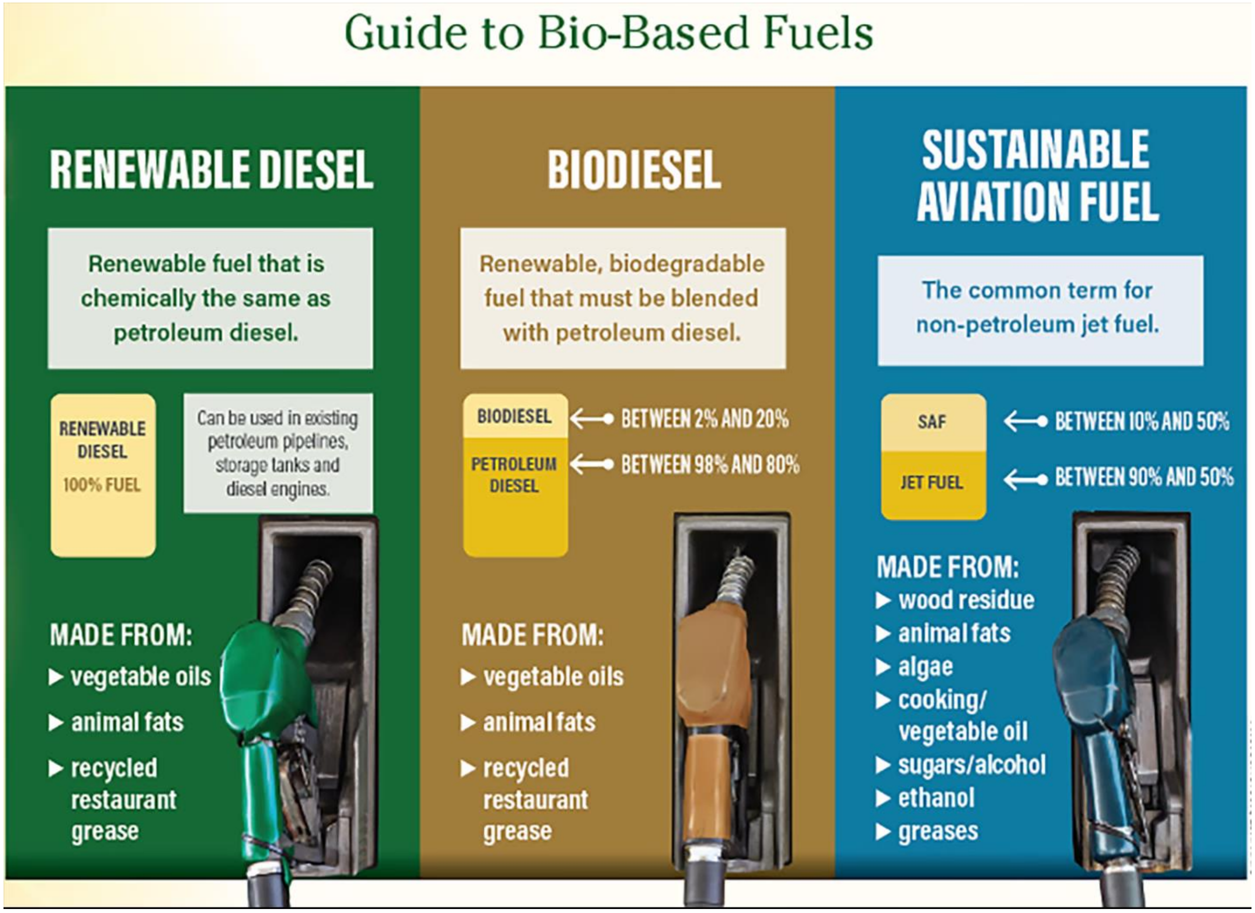


Figure 268. Renewable diesel, biodiesel, and SAF comparison

2.1.7. CO-PROCESSING

Co-processing is the simultaneous processing of approved non-petroleum biogenic feedstocks, with fossil fuel in at existing refineries. The potential volume of SAF that a refinery can produce through co-processing is currently limited by ASTM D1655. The standard only permits co-processing of 5% of total volume with vegetable oils or waste oils and fats, and Fischer-Tropsch synthetic liquids for SAF production. It should be noted that a task force has been set up to look at the possibility of raising the limit from 5% to 30%.

Table 6. ASTM certified co-processing pathways

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
ASTM 07566 Annex 1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Coal, natural gas, biomass	50%
ASTM 07566 Annex 2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Bio-oils, animal fat, recycled oils	50%
ASTM D7566 Annex 3	Synthesized iso-paraffin from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%
ASTM D7566 Annex 4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%
ASTM D7566 Annex 5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Biomass from ethanol, isobutanol or isobutane	50%
ASTM D7566 Annex 6	Catalytic hydrothermolysis jet fue!	CHJ	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%
ASTM D7566 Annex 7	Synthesized paraffinic kerosene from hydrocarbon - hydroprocessed esters and fatty acids	HC HERE- SPK	Algae	10%
ASTM 07566 Annex 8	ATJ derivative starting with the mixed alcohols	ATJ-SKA		
ASTM 01655 AnnexA1	co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	co-processed HEFA	Fats, oils, and greases (FOG) co-processed with petroleum	5%
ASTM 01655 Annex A1	co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	co-processed FT	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
ASTM D1655 Annex A1	co-hydroprocessing of biomass	co-processed biomass		5%

Fuel from dedicated SAF production facilities needs to meet ASTM D7566, the standard for aviation fuel containing synthesized hydrocarbons. The SAF must then be blended up to 50% with fossil jet fuel and the blend is recertified to ASTM D1655. Thus, co-processing eliminated the blending and recertification steps. The following diagram explains these processes.

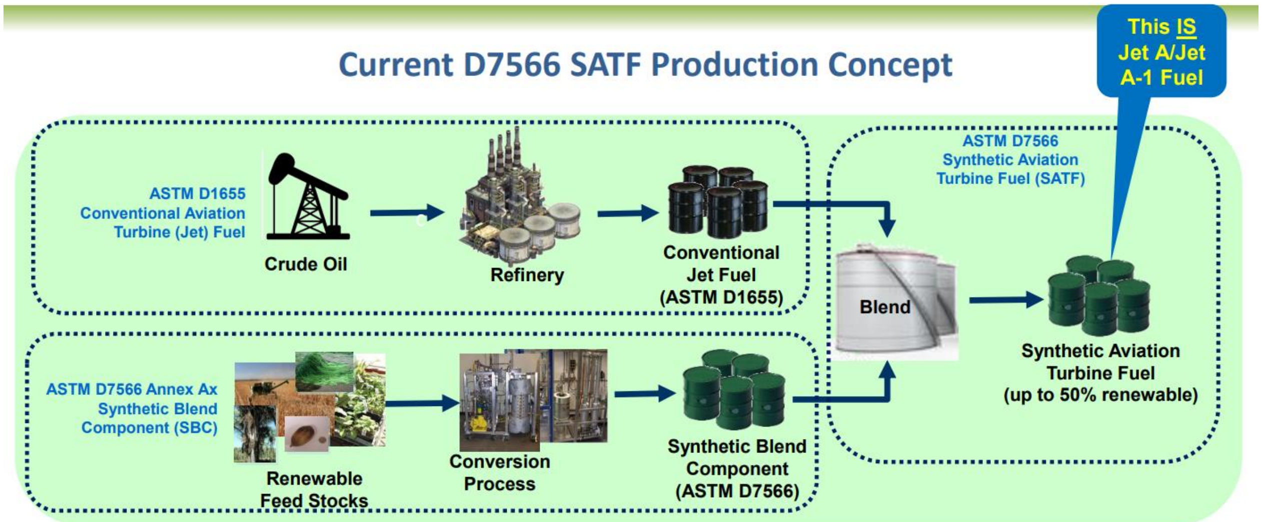


Figure 279. SAF blending process

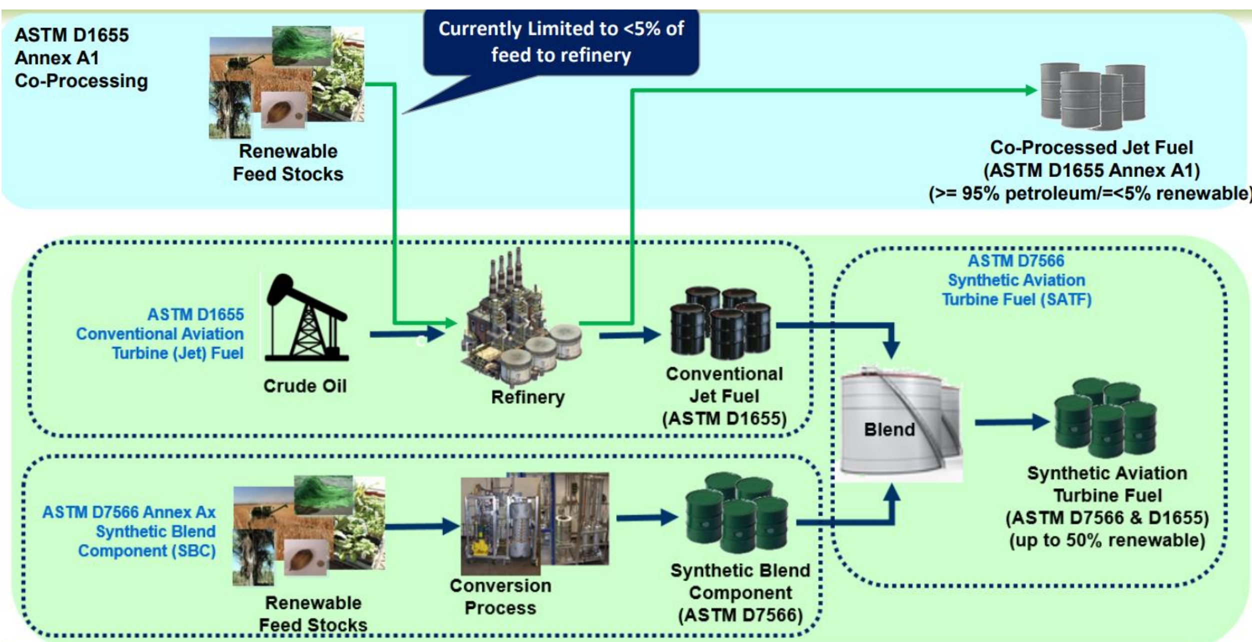


Figure 280. SAF co-processing process

The SIR refinery in Abidjan already produces large volumes of fossil jet fuel. This report, amongst others, has identified abundant available biomass and other potential biofuel feedstocks in Côte d'Ivoire. All the necessary conditions for successful co-processing are present. As calculated in the LCAF section, the SIR refinery produces approximately 874 000 metric tons of jet fuel annually. Coprocessing 5% would displace 43 700 metric tons of fossil fuel which equates to 138 092 metric tons of CO_2.

If all the feedstock co-processed was converted into jet fuel, and the life cycle emissions reduction of the fuel derived from that feedstock was 80%, the resulting CO_2 emissions reductions would be over 110 000 metric tons per year.

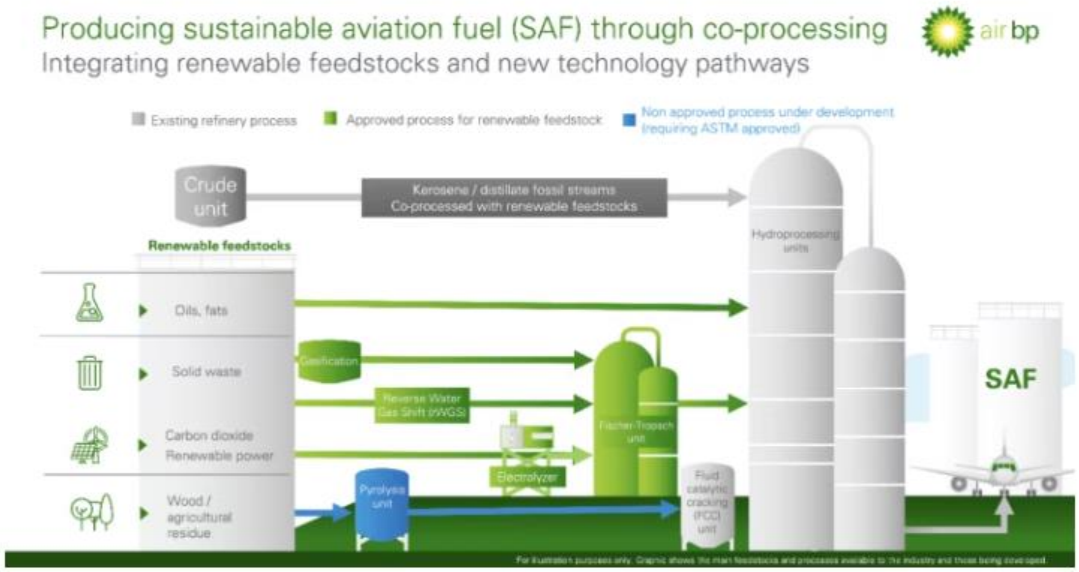


Figure 29. Co-processing pathways using various renewable feedstocks.

Co-processing has several important qualities that make it an interesting option for Côte d'Ivoire. The biggest advantage to co-processing is that it does not require substantial financial investments to plan, build and operate a standalone facility. A refinery only requires minor modifications to be able to co-process renewable feedstock. This not only saves money, but time as well. This is important as aviation needs to start decarbonizing immediately and cannot wait for the years and decades that it will take to build dedicated SAF facilities. Refineries also offer flexibility in that they can switch between co-processing and full fossil fuel refining as conditions dictate. This reduces feedstock availability and demand fluctuation risks. Finally, co-processing will allow a knowledge ramp up about how different renewable feedstocks behave and impact refinery operation.

Logistics are another factor in favour of co-processing. Operating refineries are already set up in areas where they can receive bulk shipments by truck, rail, or boat. They also are well equipped to distribute jet fuel to airports by pipeline, rail, or truck. This increases efficiency over dedicated SAF plants which may lack transportation or infrastructure, such as blending facilities.

Several major oil and gas companies are already co-processing SAF feedstock in various countries:

- **Germany:** A refinery has been co-processing SAF from used cooking oil (UCO) since 2021
- **Spain:** Certified SAF is produced through co-processing of waste fats and used cooking oil. In **the USA** (Washington State) began producing renewable diesel via co-processing in 2018.
- **United Kingdom:** A refinery co-process fuel in northeast England from sustainable waste feedstocks and supplies it to British Airways. The Humber Refinery recently increased renewable fuel produced through co-processing from 1,000 bpd to 3,000 bpd, and the refinery aims to expand renewable fuels capacity to 5,000 bpd by 2024. A major UK-based petroleum company

has as already produced more than 5,000 barrels per day (bpd) of biofuels (approximately 200-250 million litres total volume of biofuels, although SAF is not the only product) at three refineries through co-processing and aims to triple production by 2030 across these sites.

- **France:** A refinery started co-processing SAF from UCO in Normandy with an objective of producing 40 000 metric tons from 2025. They also plan to produce an additional 150 000 metric tons by co-processing hydrotreated vegetable oil (HVO) biodiesel at their refinery near Marseille, pending ASTM certification of this process.
- **Austria:** A refinery co-processes Austrian used cooking oil and use it to supply Austrian Airlines with 1,500 metric tons of SAF per year.
- **USA:** Several major US oil companies in the United States are planning to repurpose refinery facilities start co-processing bio-based feedstocks to make biodiesel and SAF by 2025.

Figure 302. Refinery that produces SAF through co-processing of renewable feedstock

Co-processing does face one challenge. To qualify for financial incentives, such as tax credits and emissions reduction benefits, some regulatory authorities' suppliers must provide verified third-party proof of renewable carbon content in the aviation fuel. For dedicated SAF plants this is not a problem as they can easily provide feedstock traceability since the final SAF product is usually 100% derived from the same feedstock,

Co-processing is one of the most promising SAF pathways for Côte d'Ivoire and is probably the best short-term implementation option. The SIR already produces large quantities of jet fuel and has a dynamic management team that is always looking for improvement opportunities. They are very interested in SAF, and co-processing would be a good way to acquire knowledge that can be used to expand future production. It would provide the time for a domestic SAF to establish itself and sort out issues with feedstock, technology, and logistics. Côte d'Ivoire also has partnerships with big international oil companies that can provide technical and financial support. Perhaps the most important factor is that it is by far the cheapest SAF option, requiring a small capital investment that is essential storage tanks and additional piping. In contrast, a standalone SAF facility can easily cost hundreds of millions to over a billion dollars.

Many types of feedstocks can be used to produce SAF. Under the CORSIA framework, such feedstocks are broadly categorized into five categories:

1. Primary and co-products are the main products of a production process. These products have significant economic value and elastic supply (i.e., there is evidence that there is a causal link between feedstock prices and the quantity of feedstock being produced).
2. By-products are secondary products with inelastic supply and economic value.
3. Wastes are materials with inelastic supply and no economic value. A waste is any substance or object which the holder discards or intends or is required to discard. Raw materials or substances that have been intentionally modified or contaminated to meet this definition are not covered by this definition.
4. Residues are secondary materials with inelastic supply and little economic value.

Under the CORSIA framework, by-products, wastes, and residues are entitled to an ILUC value of zero on the calculation of the life cycle emission value of the SAF. Primary and co-products can also be entitled to zero ILUC value with the use of low LUC risk methodologies defined in Chapter 5 of the ICAO document " CORSIA Methodology for Calculating Actual Life Cycle Emissions Values."

The following table lists the feedstocks in this study that are currently recognized in the ICAO CORSIA framework to produce SAF. In this study, a couple of feedstocks, namely cassava and sorghum, do not have an ICAO assessment. As a result of this study, they should be proposed to ICAO for inclusion in the CORSIA framework.

Table 7. ICAO feedstock LCA references

Feedstock	Classification	Reference
Palm fatty acid distillate	By-product	Table 1, ICAO document "Actual LCA methodology" Table 2, ICAO document "Default LCA values."
Molasses	co-product	Table 1, ICAO document "Actual LCA methodology" Table 3, ICAO document "Default LCA values."
Corn grain	Main product	Table 3, ICAO document "Default LCA values." Table 4, ICAO document "Default LCA values."
Jatropha oil	Main product	Table 2, ICAO document "Default LCA values."
Miscanthus (herbaceous energy crops)	Main product	Table 1, ICAO document "Default LCA values." Table 3, ICAO document "Default LCA values." Table 4, ICAO document "Default LCA values."
Palm oil	Main product	Table 2, ICAO document "Default LCA values."
Sugarcane	Main product	Table 3, ICAO document "Default LCA values." Table 4, ICAO document "Default LCA values." Table 5, ICAO document "Default LCA values."
Agricultural residues: Bagasse	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Cobs	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Husks	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Manure	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Nut shells	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Stalks	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Stover	Residue	Table 1, ICAO document "Actual LCA methodology"
Agricultural residues: Straw	Residue	Table 1, ICAO document "Actual LCA methodology"
Forestry residues: Branches	Residue	Table 1, ICAO document "Actual LCA methodology"

Forestry residues: Leaves	Residue	Table 1, ICAO document "Actual LCA methodology"
Processing residues: Empty palm fruit bunches	Residue	Table 1, ICAO document "Actual LCA methodology"
Processing residues: Forestry processing residues	Residue	Table 1, ICAO document "Actual LCA methodology"
Processing residues: Palm oil mill effluent	Residue	Table 1, ICAO document "Actual LCA methodology"
Municipal solid waste (MSW)	Waste	Table 1, ICAO document "Default LCA values." Table 1, ICAO document "Actual LCA methodology"
Tallow	Waste	Table 1, ICAO document "Actual LCA methodology" Table 2, ICAO document "Default LCA values." Table 6, ICAO document "Default LCA values."
Used cooking oil	Waste	Table 1, ICAO document "Actual LCA methodology" Table 2, ICAO document "Default LCA values." Table 6, ICAO document "Default LCA values."
Waste gases	Waste	Table 1, ICAO document "Actual LCA methodology" Table 4, ICAO document "Default LCA values."

2.2. CARBOHYDRATE FEEDSTOCKS (SUGARS AND STARCHES)

Sugar and starch-bearing plants are the most important global feedstocks for biofuel production. They provide fermentable feedstock which is readily transformed into an intermediate alcohol product such as ethanol or butanol. These alcohols can then be converted into SAF and other renewable fuels.

Fermentable sugars from sugar-bearing plants such as sugarcane and sorghum are directly obtained by mechanically processing the feedstock through processes such as milling. Starch-based feedstocks include grains, such as corn or sorghum, and tubers, such as yams and cassava, that contain long complex chains of sugar molecules. The sugar must be separated from the starch through chemical reactions. The ATJ-SPK and SIP-HFS ASTM approved pathways, described in section 2.0 can be used to produce SAF from sugar and starch feedstock:

2.2.1. SUGARCANE

Sugarcane-Related Information

Sugarcane is an important cash crop in Côte d'Ivoire with a total production of about 2 million tons of cane/annum and 200,000 tons of sugar/annum. It contributes to about 1.2% of total country GDP and 3.3% of agricultural GDP. Sugarcane has many qualities that make it an excellent feedstock for biofuels and SAF. It is photosynthetically efficient, contains up to 20 percent sucrose by weight, and grows well in tropical regions. It has been used to produce ethanol and biofuels for many years in countries such as Brazil and being considered as a potential SAF feedstock in countries such as South Africa and Australia.

A study done in 2014 analyzed the potential for biofuel production in ECOWAS Member States. The report, entitled Étude de Viabilité de la Production de Biocarburants dans l'UEMOA), concluded that sugarcane-based biofuels held the greatest potential out of the 12 crops studied. However, the report also stated that this would require improvements in agricultural practice and production technology as well as integration into a national strategy that incorporates social factors such as food security and energy access. Since 1980, production has steadily increased by 1.8% annually and is expected to reach 2.1 million metric tons by 2026. The country ranks 50th in the world in sugar production.

SUCAF Côte d'Ivoire is the main sugar producer in Côte d'Ivoire. It is part of the SOMDIAA group which has sugarcane operations in 5 African countries including Chad, Cameroon, Congo, Côte d'Ivoire, and Gabon. SUCAF Côte d'Ivoire grows sugarcane through irrigated farming operations and sources neighbouring village crops.

They have two sugar manufacturing plants located in Ferkessédougou in Northern Côte d'Ivoire, near the Burkina Faso and Mali borders. One plant produces white granulated and lump sugar and the other one produces brown granulated sugar. Total production is over 1 million tons of sugarcane yielding 105,000 tons of sugar.

Figure 31. Main Sugarcane Processing Areas in Côte d'Ivoire

SUCRIVOIRE, a subsidiary of SIFCA, is the other major Ivorian sugarcane player. They manage more than 14,000 hectares of industrial plantations spread over two sites in Zuénoula and Borotou-Koro. They have an annual capacity of approximately 1 million metric tons of cane for the production of more than 100,000 metric tons of sugar. In addition, they produce bagasse that is burned for energy, molasses used for alcohol production and stillage used to manufacture liquid fertilizers.

Figure 324. Sugarcane Harvesting in Côte d'Ivoire

The main product of sugarcane is crystallized sugar for human consumption. During the processing, molasses, bagasse, and cane juice are produced and that can be used to make biofuels.

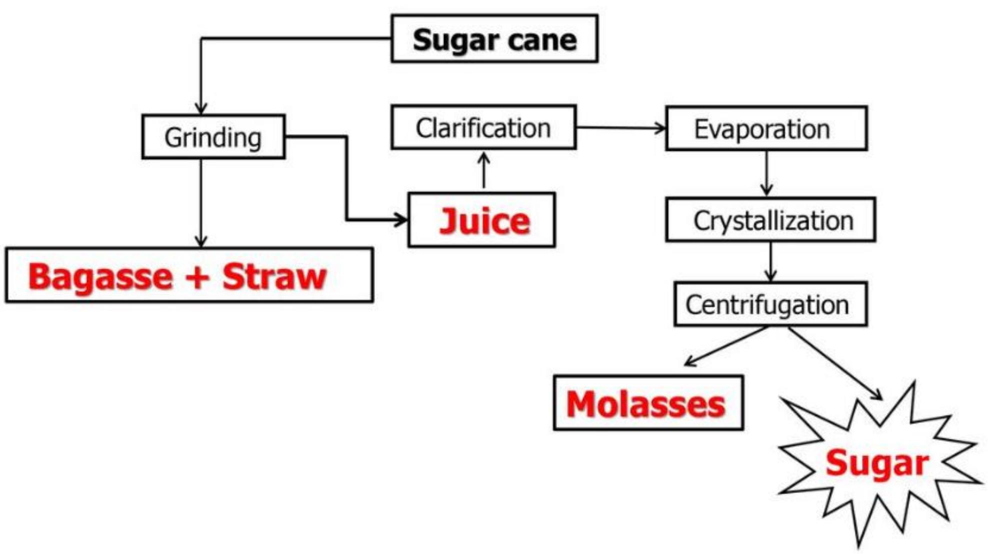


Figure 335. Sugarcane Processing By-products

The yield of molasses from crushed sugarcane is 2 to 4 percent, so the potential for molasses production from 2 million metric tons of sugarcane feedstock is 40 000 to 80 000 metric tons of molasses. For each metric ton of molasses, about 200 litres of ethanol is produced by a fermentation process using yeasts. This gives a production potential of between 8 and 16 million litres of ethanol per year, which can then be further processed into SAF via the ATJ pathway. Using the ICAO rule of thumb of 0.6 to convert ethanol into SAF this would provide a potential SAF output of 4.8 to 9.6 million litres per year. One standard ATJ plant is typically in the 100 million litres per year range so other alcohol-based feedstocks would be required.

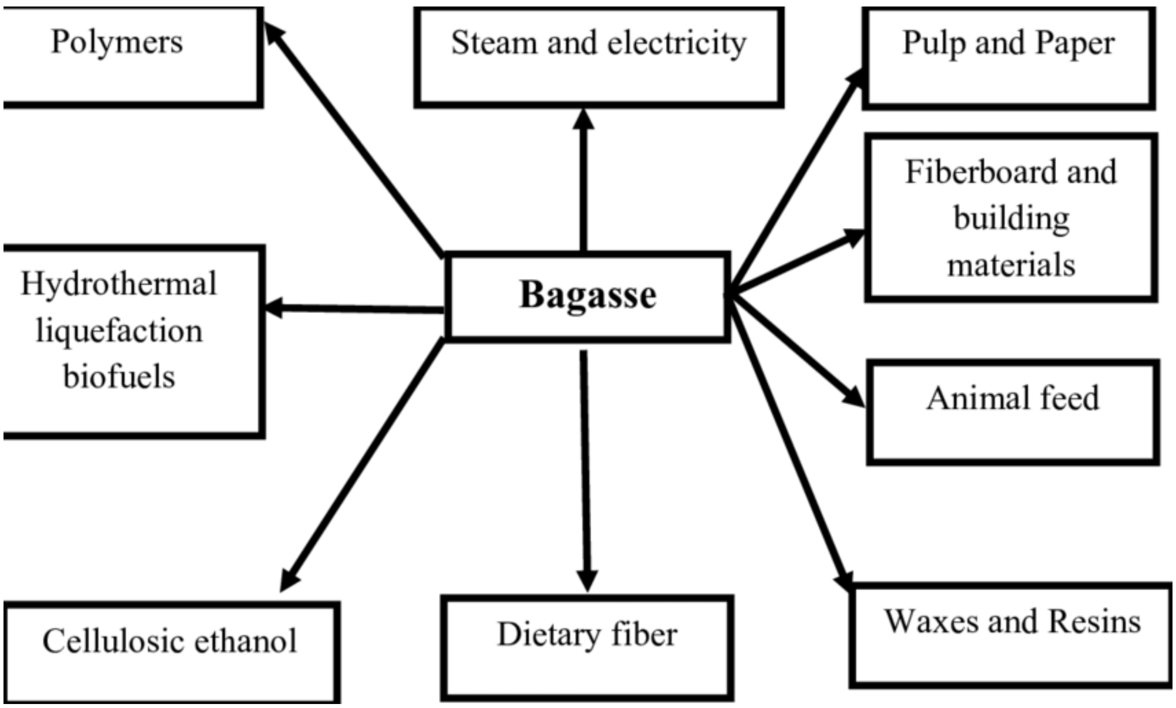


Figure 346. Uses of Bagasse

The second potential SAF feedstock is bagasse, the dry pulpy fibrous material that remains after crushing sugarcane stalks to extract their juice. Approximately three metric tons of bagasse with a moisture content of 40-50% is generated for every 10 metric tons of sugarcane crushed. As shown in the diagram above, bagasse has a multitude of uses. A big advantage of bagasse is that it is easy to collect and store. It can be burned at the mill to provide energy, be used for animal feed, for paper and building materials or converted into second-generation lignocellulosic bioethanol by fermentation and distillation. The resulting bioethanol can then be converted into SAF via the ATJ pathway.

Sugarcane bagasse is an attractive lignocellulose feedstock for biofuel production due to its high organic content and biomass yield. At a production of 2 million metric tons per year in the Côte d'Ivoire would yield 600 000 metric tons of bagasse, or 300 000 metric tons of dry bagasse (at 50% water content). Assuming a yield of 180 litres per dry metric ton of bagasse. Côte d'Ivoire has the potential to produce 54 million litres of bioethanol which could be converted to 32.4 million litres of SAF using the ATJ process (0.6 yield rate). Bagasse therefore has more potential SAF volume than molasses, but it also has many other possible applications.

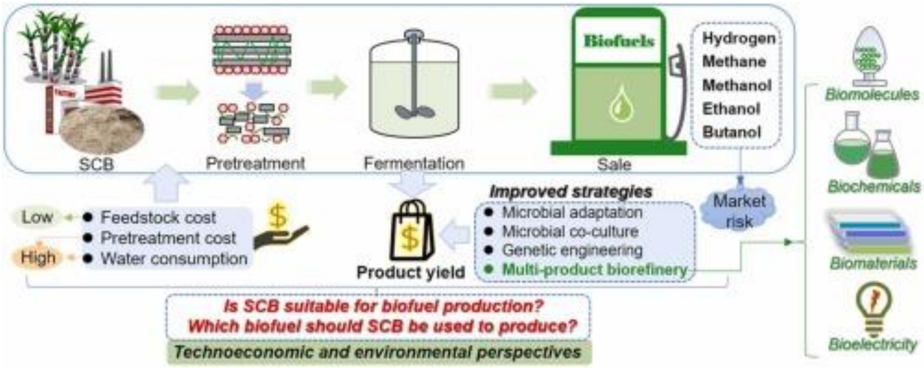


Figure 357. Biofuel production from sugarcane bagasse (SCB)

The third sugarcane production by-product that could be used to produce SAF is sugarcane juice. As with molasses, sugarcane juice can easily be converted into biofuel via fermentation and distillation. However, diverting cane juice from food products and using it to produce biofuels could be potentially challenging. The "Low Land Use Change practices" methodology for CORSIA Eligible Fuels could potentially be explored as a means of producing feedstocks and certifying for sustainability.

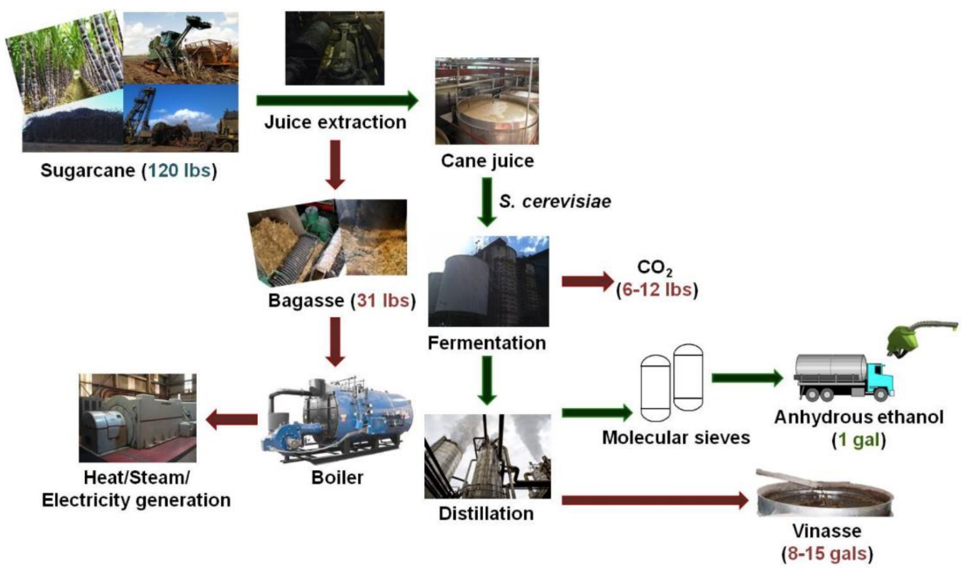


Figure 368. Biofuel production process from sugarcane juice

Sustainability-related issues for sugarcane feedstock

For CORSIA, when produced directly from the cane juice via the Ethanol-to-Jet Fuel Conversion Process, the default life cycle emissions for sugarcane at global level is set at 32.6 gCO_2e/MJ for the integrated conversion design, including an Induced Land Use Change (ILUC) emissions factor of 8.5 g CO_2e/MJ. In comparison to the conventional fossil jet fuel emission factor of 89.0 gCO_2e/MJ, it reduces CO_2e emissions by 63.4% [3].

Molasses is classified as a co-product for CORSIA. The total default life cycle emissions for molasses at global level is set at 36.1 gCO_2e/MJ for the Alcohol (isobuthanol)-to-Jet Fuel Conversion Process in the CORSIA methodology, including an Induced Land Use Change (ILUC) emissions factor of 9.1 gCO_2e/MJ. In comparison to the conventional fossil fuel emission factor of 89.0 gCO_2e/MJ, it reduces CO_2e emissions by 59.4%.

Bagasse is classified as an agricultural residue in the ICAO CORSIA positive list of materials[4] and thus has an Induced Land Use Change (ILUC) emissions factor of zero. For the Fischer-Tropsch Fuel Conversion Process, the default life cycle emissions for agricultural residues at global level is set at 7.7 gCO_2e/MJ which, in comparison to the conventional fossil fuel emission factor of 89.0 gCO_2e/MJ, reduces CO_2e emissions by 91.4%. For the Ethanol-to-Jet Fuel Conversion Process, the default life cycle emissions for agricultural residues at global level is set at 39.7 gCO_2e/MJ for the standalone conversion design and 24.6 gCO_2e/MJ for the integrated conversion design, corresponding to emissions reductions of 55.4% and 72.4% respectively.[5]

The sustainability-related risks from sugarcane farming, especially those related to water use, water pollution, and land use, can be mitigated through the use of sustainable farming and agricultural practices.

[3] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[4] Table 1 - https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[5] For access to updated methodologies, visit https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

Table 7. Sugarcane sustainability evaluation

ICAO SUSTAINABILITY THEMES

SUGARCANE	
CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
13. Water use rights	
14. Food security	

Positive contribution/no issue

Potential issue-need mitigation or control

Major issue-Needs to be resolved before feedstock can be considered

Economic and Market-Sugarcane related Issues

Côte d'Ivoire imports sugar from countries such as Brazil that often passes through neighbouring countries. The Ivorian government has stated that it wants to become self-sufficient within the next 5 years and has recently announced a 150 B CFA (230 million Euro) investment with Sucaf (SOMDIAA) and Sucrivoire (SIFCA). The objective is to increase production and improve agricultural and production methods. Ivorian sugarcane producers have incurred substantial financial losses in recent years. The industry needs to modernize and improve production to become competitive with other countries. To combat surging sugar prices, in 2023 Côte d'Ivoire has suspended sugar exports and has put restrictions on imports.

Expansion of sugarcane production is intended to make the country self-sufficient in terms of food security. Sustainability aspects would need to be assessed in the case where expansion in the sugarcane land area use is considered, especially on conversion of land, water, soil, air, and food security. On the other hand, the potential expansion plans would provide more by-products that could be used to produce biofuels and SAF, such as molasses and bagasse.

Even if there were enough sugarcane bioethanol available, two other challenges remain. First, bioethanol and ATJ plants are very expensive to construct and operate. This would require significant government policy and financial support. However, the government is already investing heavily to support industry to become more productive. Given limited financial resources, it would be difficult to invest in both areas at the same time.

Production self-sufficiency is a more important objective than any potential reductions in GHG obtained by using SAF.

Finally, the ATJ process requires copious amounts of hydrogen to transform hydrocarbon feedstocks into SAF. The refinery in Abidjan could potentially help with this, as hydrogen can be produced from natural gas or ethanol steam reforming, but the sugar processing facilities are in the centre and northern parts of the country. This would present a logistical challenge to moving the bioethanol to an ATJ conversion facility. If the bioethanol and ATJ facilities were co-located near the sugarcane facilities, the hydrogen would have to be transported there and the SAF transported back to Abidjan airport where it is needed. In addition to complicate logistics, the transport of the materials would reduce the environmental benefit of the SAF on a life cycle basis.

Overall Assessment of Sugarcane as a Potential SAF Feedstock

The analysis shows that sugarcane could be a potential source of biofuel and SAF feedstocks in Côte d'Ivoire, as is the case in other countries such as Brazil and Australia. However, several factors make it a low potential option for use in the Ivorian context. There is not enough supply of molasses to warrant construction and operation of a large-scale plant. It would be difficult for Côte d'Ivoire to compete with countries with higher volumes and cheaper feedstocks. Bagasse has more economical uses than for conversion into SAF. Most importantly, social, and economic factors such as food security, self-sufficiency, and climate change risk weigh against the use of sugarcane as a SAF feedstock in Côte d'Ivoire. However, the ethanol derived from bagasse and molasses could be combined with other alcohol producing feedstocks to feed an ATJ facility.

Table 8. Sugarcane SAF feedstock evaluation

Sugarcane		
Feedstock availability	**Technology readiness**	
Qualities	**T1: Biomass processing**	
• Feedstock suitability • Energetic potential • High yield • Well established	• Basic infrastructure in place • Bioethanol already produced at small scale for use in clean cooking stoves with plans to scale up	
Constraints/challenges	**T2: Fuel Conversion pathways(s)**	
• It is water intensive. • Care needs to be taken to avoid water contamination by fertilizers and silt. • Wastewater, emissions and solid waste from sugarcane mills have to be handled appropriately. • Land use planning and selection needed to avoid sustainability concerns • inappropriate agricultural practices, such as burning wastes, have to be avoided. • Care needs to be taken on soil health for farming.	• Alcohol-to-jet (ATJ) pathway has reached the level of commercialization. • Synthesized Iso-Paraffinic bio-jet (SIP).	
Risk mitigation options	**Technology complexity**	
• Sustainable farming techniques can resolve many of the constraints/challenges	• Medium. ATJ technology has advanced significantly is very close to commercial scale.	
Feedstock expansion potential	**Economic viability**	
• Domestic production is planned to increase to meet growing demand	• Medium	
	Biofuel/AAF potential	
	In general:	High
	In Côte d'Ivoire:	Low-medium

2.2.2. CASSAVA

Cassava-related Information

Cassava, also known as manioc, is a nutty-flavoured, starchy root vegetable or tuber. It is the second most important staple food crop in Côte d'Ivoire after yams. It is used to make Attieke, the national dish, amongst other foods.

Figure 379. Small-scale cassava production in Côte d'Ivoire

Cassava Processing

The diagram below lists the steps in cassava processing. Traditional methods for processing cassava are very labour-intensive and use rudimentary equipment. As a result, it only yields about 30 kilograms per hour. Fuelwood and biomass are burned to provide energy during the boiling step. In industrial processes, grinding and grating are mechanized using electric or diesel power, which is also used for boiling. The cassava production produces two key agricultural residues can be used for biofuel and SAF production: peels and starch.

Figure 38. Hydraulic cassava press

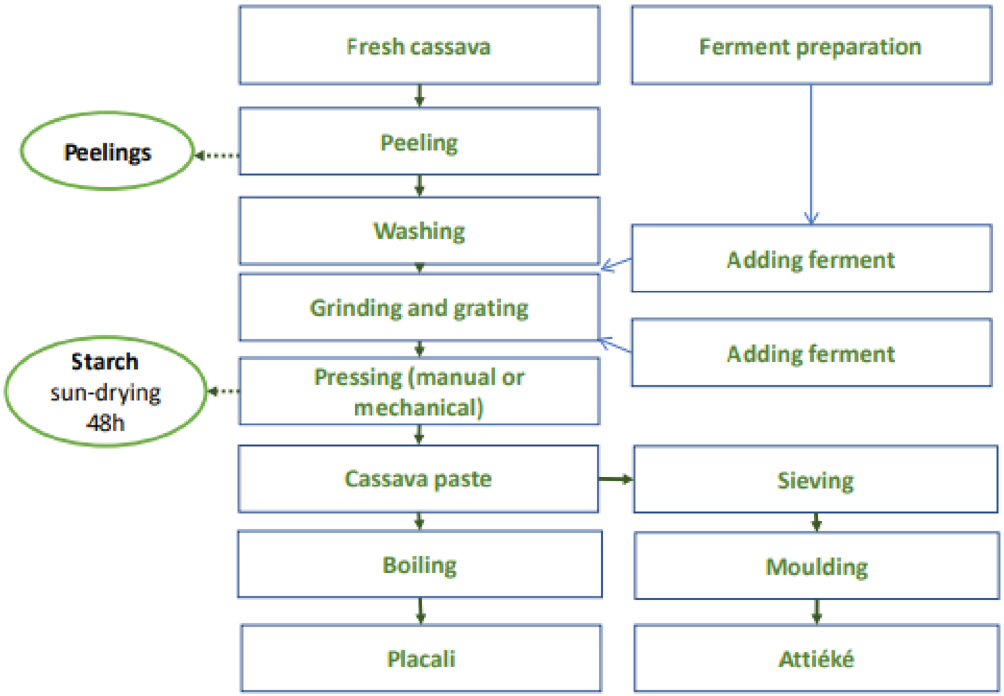


Figure 391. Cassava production process

Cassava Peels

Processing cassava roots into food or starch products leaves behind large numbers of peels containing a high concentration of toxic cyanide. This waste can create significant environmental air and water problems because it is often disposed of by burning or dumping. Several solutions have been developed to valorize this waste and to reduce pollution:

- Cassava peels can be dried and used for animal feed. However, it is therefore important that the peels are properly processed to remove toxic contaminants. In addition, the peels spoil quickly so adequate collection logistics as well as drying and storage facilities are important. Access to facilities and energy sources in rural areas has limited the use of cassava as an animal feed.

Figure 402. Cassava Peel Processing

- Studies have shown that cassava peelings can be processed into biochar from the pyrolysis process, heated in a closed system with restricted oxygen. Biochar is a carbon-rich product obtained when biomass, in this case cassava peels. It resembles charcoal but is more porous and adsorbent. Biochar is used to remove contaminants from waste gases and water and as an excellent fertilizer and soil stabilizer. Biochar also sequesters greenhouse gases from the atmosphere and can help fight climate change. The major impediment to biochar production is economics. It is currently very expensive to produce and has a low selling price.

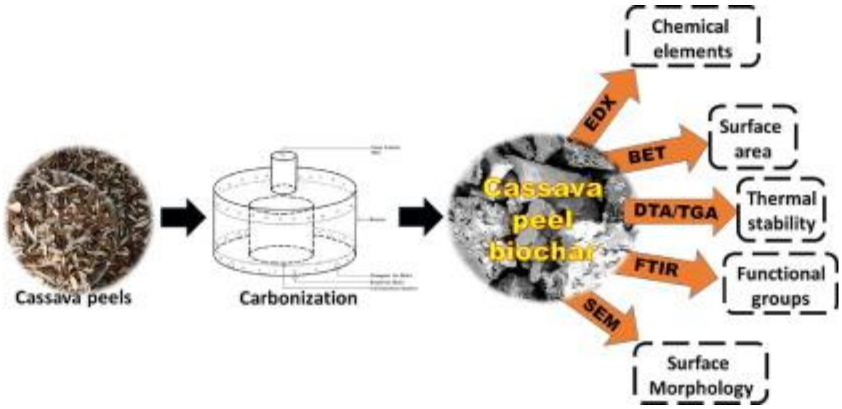


Figure 413. Biochar Production from Cassava Peels

- Another way to valorize cassava peelings and reduce pollution is to transform the peelings into biofuel. Lignocellulose material of cassava peels can be used as raw material for bioethanol. Cassava peels contain 43% cellulose, hemicellulose, and 10.4% lignin. There are two main stages of bioethanol production: first is hydrolysis process that breaks down cellulose into simple sugars with the help of acids or enzyme. The second is a fermentation process that converts sugar into alcohol through anaerobic respiration by microbes. For every metric ton of cassava processed, 10–15% of wet peelings are generated. Since cassava production in Côte d'Ivoire is in the order of 6.9 million metric tons, this represents a potential of 690 000- 1 035 000 metric tons of peels. Biofuel production from cassava is still in the research and development phase, so reported yields vary widely according to the process used. However, an Indonesian study (BIOETHANOL POTENTIAL FROM WHOLE PARTS OF CASSAVA PLANT IN INDONESIA) reported a yield of 160 litres of ethanol per ton of peelings. This would indicate a potential production of 110 -165 million litres per year of ethanol. At the conversion rate of 0.6 to convert ethanol to kerosene via the ATJ pathway, this indicates potential SAF production from cassava peelings at 66-100 million litres per year which is the right size for a commercially viable operation. Several petrochemical companies, including the French company TOTAL and the Italian base ENI, are investigating the possibility of using cassava peels to produce renewable biofuels.

Figure 424. Process to produce bioethanol from cassava peels

Cassava Starch

Cassava starch is considered as a potential source for the commercial production of bioethanol because of its widespread availability and low market price. A single-step ethanol production is the combination of raw cassava starch hydrolysis and fermentation. The yield of anhydrous ethanol varies with the starch content in fresh cassava roots and in the range of 185 to 200 litres per metric ton. Using this figure, an annual production of 6.9 million metric tons of cassava would theoretically yield 1.277-1.380 million litres of bioethanol per year. Conversion into SAF via the ATJ pathway using a conversion factor of 0.6 would indicate a potential production of 766-828 million litres of SAF.

Sustainability-Related Issues for Cassava Feedstock

If proper agricultural and land management practices are maintained, cassava is one of the most sustainable food crops. It is a "triple win" crop, providing economic, environmental, and social benefits. Cassava produces the highest number of calories per hectare in most tropical countries, can withstand increasing temperatures, is drought resistant, and thrives in poor soils. These qualities make it resilient to climate change. Cassava can be harvested at any time of the year and has been called 'the drought, war and famine crop' (Burns et al., 2010) and the" Rambo Root" for its rugged appearance and resilient qualities. Cassava can break the soil preventing erosion and degradation. This could allow the land to be cultivated where other cash crops (for example, soybean and corn) cannot thrive due to poor soil conditions. Rotating or intercropping cassava with cash crops, including legumes that can fix nitrogen from the atmosphere, can further mitigate soil degradation.

Production of cassava has several socio-economic co-benefits. It provides employment to women at all the process steps including decision making and trading. Cassava farming also provides income to rural communities and offers the potential to provide additional revenue if by-products and residues, such as peels and starch, can be valorized, and care needs to be taken in relation to human and labour rights.

Cassava processing creates a large amount of waste that can lead to environmental issues if not properly handled. Industrial cassava processing produces large volumes of a waste sludge that needs to be treated or processed. Unfortunately, this sludge is not currently valorized due to the significant cost associated to it.

Cassava farming and production have limited environmental impact and the use of waste by-products as a potential SAF feedstock does not cause any food security or land use issues. However, further study is required to determine whether it is better from an economic and social point of view to use the waste products to produce SAF or for some other application such as animal feed or biochar (peelings) or food products (starch).

Currently, cassava peels are not contained in the positive list of materials classified as co-products, residues, wastes or by-products of ICAO CORSIA Eligible Fuels. The evaluation can be requested to ICAO at any time, and the process is described in the ICAO document CORSIA Methodology for Calculating Actual Life Cycle Emissions Values, session 4[6].

[6] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

Table 9. Cassava sustainability evaluation

ICAO SUSTAINABILITY THEMES
CASSAVA

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue	
Potential issue-need mitigation or control	
Major issue-Needs to be resolved before feedstock can be considered	

Economic and market-cassava-related issues

Cassava production has been increasing rapidly, at an average annual rate of 5.90%. and reaching a record 6.9 million metric tons in 2021. Côte d'Ivoire ranks 10th out of 78 countries with cassava production.

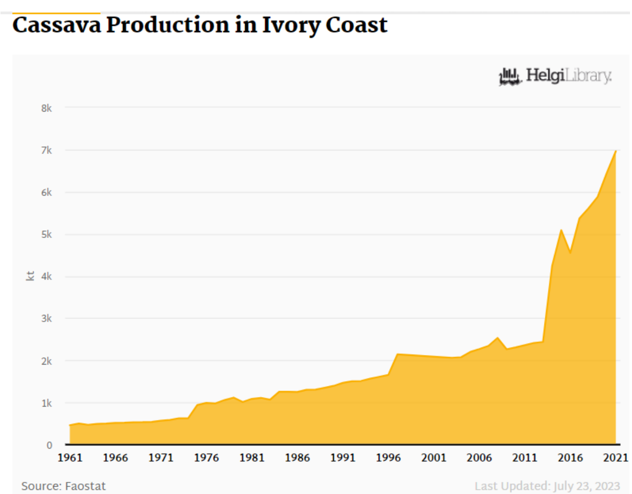


Figure 435. Cassava Production Statistics Côte d'Ivoire

Cassava growing, production, and retail employs over 450 000 people, mostly in small-scale operations with a very small percentage of industrial processing. Women traditionally handle most of the production. Cassava can be grown in 80% of the country with the main production areas being located in the Sud-Comoé region, which is by far the largest producer of cassava.

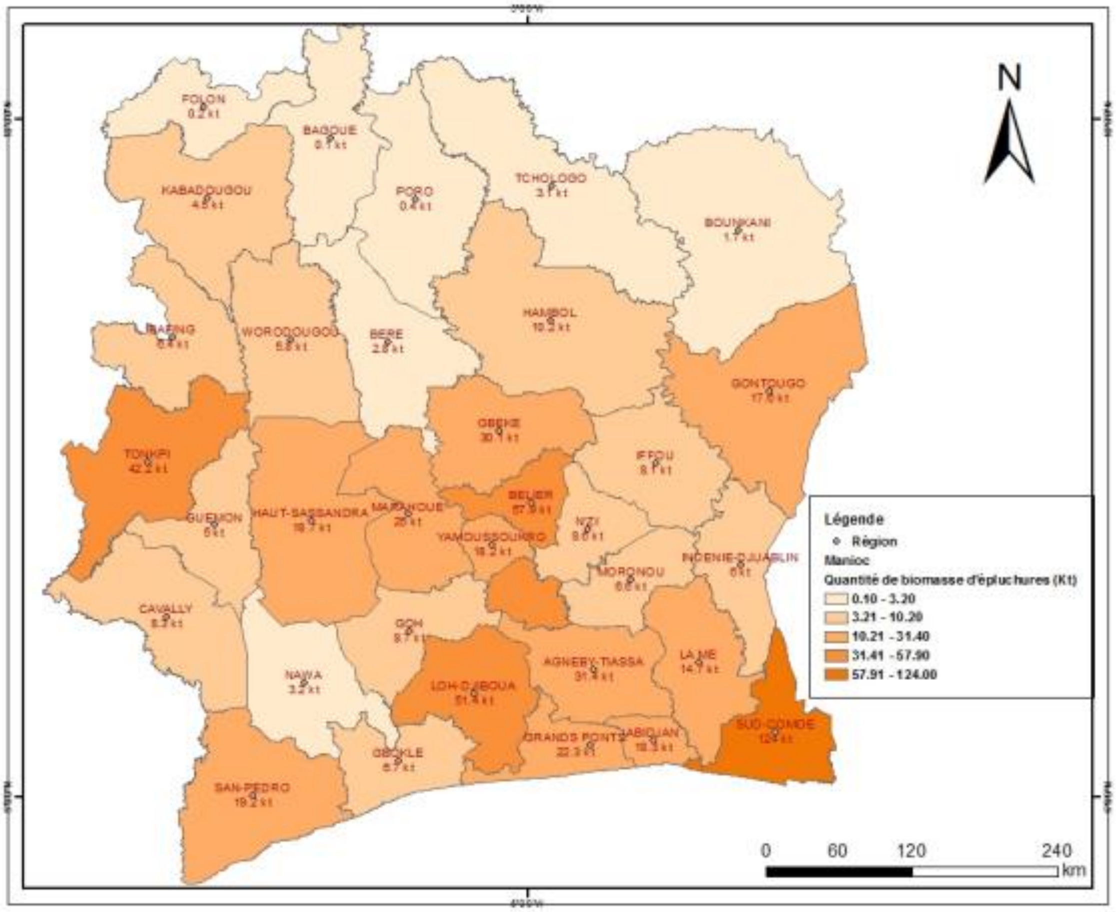


Figure 446. Cassava Production Areas in Côte d'Ivoire

In 2020, the Ministry of Environment and Sustainable Development of Côte d'Ivoire launched a project entitled "La production industrielle durable de manioc et d'autres secteurs agroalimentaires grâce à l'utilisation d'énergies renouvelables et de technologies à faibles émissions de carbone." The project had a budget of 385 million FCFA funded by the Fonds pour l'Environnement Mondial (FEM) under the direction of UNIDO (Unite Nations Industrial Development Organization). The objective of the initiative is to investigate how agricultural waste streams, including cassava residues and wastes, can be used to produce renewable energy and reduce greenhouse gas emissions in the agro-food industry.

Turning cassava waste and residues into biofuel fits into the objectives of this program and a couple of Ivorian companies are actively exploring this possibility:

- Edindia Industry produces small quantities - 6,000 litres per month - of bioethanol from cassava starch. It is used as a clean cooking fuel. They would like to build a biorefinery with a capacity of 30,000 litres per day in Toumodi, the centre of cassava production in Côte d'Ivoire. The bioethanol could be converted to SAF via the ATJ pathway and Edindia has indicated that they would be very interested in exploring this option.

- Several companies, including the TOTAL and ENI, are investigating the possibility of using cassava peels to produce biofuel.
- LONO is installing a digester to convert the waste from the transformation process into compost and cooking gas.

Overall assessment of cassava as a potential SAF feedstock

Cassava starch and peels have great potential for SAF production in Côte d'Ivoire. It is grown widely, is resistant to climate change and has many environmental and social co-benefits. The technology to use waste products, starch, and peelings to produce biofuels have already been tested and proven at the laboratory and pilot plant scales. The next steps would be to scale up biofuel production and to build a pilot plant to turn the bioethanol into SAF via the ATJ pathways. As cassava production is dispersed throughout the country, logistical studies on how to best collect and process the waste need to be done.

Table 10. Cassava waste SAF feedstock evaluation

<table>
<tr><th colspan="3">Cassava starch and peels</th></tr>
<tr><td>Feedstock availability</td><td colspan="2">Technology readiness</td></tr>
<tr><td>Qualities</td><td colspan="2">T1: Biomass processing</td></tr>
<tr><td>• Feedstock suitability
• Energetic potential
• High yield
• Socio-economic benefits
• Proven transformation technologies
• No land use or food security issues</td><td colspan="2">• Basic infrastructure in place
• Bioethanol produced at small scale for use in clean cooking stoves
• Conversion to bioethanol proven</td></tr>
<tr><td>Constraints/challenges</td><td colspan="2">T2: Fuel Conversion pathways(s)</td></tr>
<tr><td>• Potential for air and water pollution in processing
• Dispersed production
• Lack of established logistics system (collection, storage, transportation)</td><td colspan="2">• Alcohol-to-jet (ATJ) is a technologically mature conversion process
• Synthesized Iso-Paraffinic bio-jet (SIP)</td></tr>
<tr><td>Risk mitigation options</td><td colspan="2">Technology complexity</td></tr>
<tr><td>• Proper agricultural and land management practices
• Establishment of logistics systems</td><td colspan="2">• Medium</td></tr>
<tr><td>Future biomass potential</td><td colspan="2">Economic viability</td></tr>
<tr><td rowspan="4">• Excellent. Production is expected to expand in the coming years</td><td colspan="2">• .High</td></tr>
<tr><td colspan="2">Biofuel/AAF potential</td></tr>
<tr><td>In general</td><td>High</td></tr>
<tr><td>In Côte d'Ivoire</td><td>High</td></tr>
</table>

2.2.3. SORGHUM

Sorghum-related Information

Sorghum is the fifth most produced cereal crop in the world. Its whole grain is commonly used in baking, while its syrup is used as a sweetener. Sorghum is the fifth most important crop in Côte d'Ivoire, just ahead of millet. The production of sorghum of Côte d'Ivoire increased from 14,000 metric tons in 1972 to 70,000 metric tons in 2021 growing at an average annual rate of 2.2% year-on-year since 1966. Côte d'Ivoire is not an especially big sorghum producer, ranking about 45th place in terms of country production.

Most of the sorghum (94%) is produced in the Northern Savannah area of the country where it is suited to the tough climatic conditions of high temperatures, low and irregular rainfall, and poor soils. Sorghum is called "the camel of crops" because of its ability to grow in arid soils and withstand prolonged droughts and grow where other crops cannot. For this reason, it is widely grown in sub-Saharan Africa and constitutes a large part of the staple diet, along with millet, in rural communities in countries such as Mauritania, Gambia, Mali, Burkina Faso, Ghana, Niger, Somalia and Yemen.

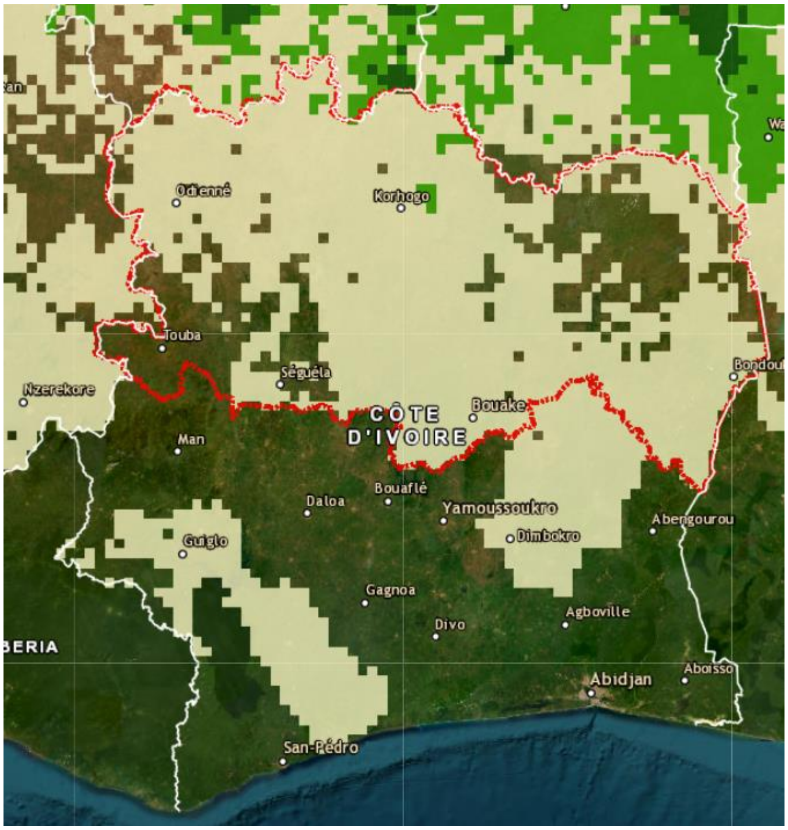


Figure 457. Sorghum Producing Areas in Côte d'Ivoire

Sorghum is a very versatile and useful plant. It provides nutritious grains for human consumption while its leaves and stocks can be used to feed livestock. In addition, the stalks are high in sugar, and, like sugarcane and corn, sorghum has been considered as a potential source of bioethanol feedstock given its highly efficient conversion of atmospheric carbon dioxide into sugar that can be fermented into fuel.

The process to convert sorghum into ethanol is shown in the following diagram.

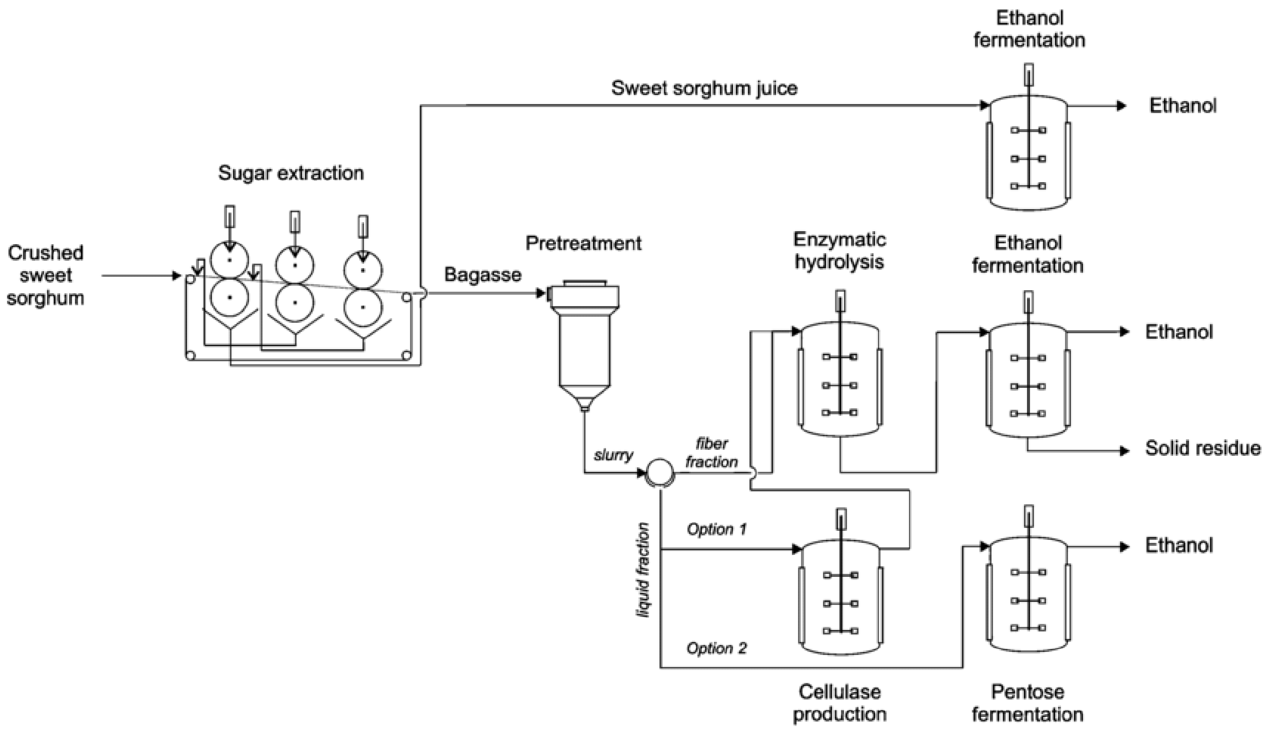


Figure 468. Process to make bioethanol from sorghum feedstock

Suitability for use as a feedstock

Sorghum is not just a versatile food crop. It is also a starch source, sugar source and cellulose source all in a single plant. Sorghum can be used to produce ethanol using a multitude of technologies:

- The **grains** contain starches that can be converted to bioethanol, as is the case with cassava.
- The inedible **stalks** are the reason that sorghum is such a promising biofuel candidate. The juice extracted from crushing the stalk contains 16-18% sugars which can be easily fermented into alcohol. In some sweet sorghum varieties, juice yields can attain 78% of the total with most of the sugars concentrated in the stalk.
- After juice extracted from the stalk, about 50-60% bagasse, the pulpy fibrous material that remains after crushing, can be obtained. This can be converted into bioethanol or biobutanol by fermentation. These alcohols can then be upgraded to SAF through conversion to high-grade, long-chain kerosene via the ATJ or SIP processes.
- Leftover waste lignocellulosic biomass (stover) can be converted to SAF via gasification via the Fischer-Tropsch pathway.

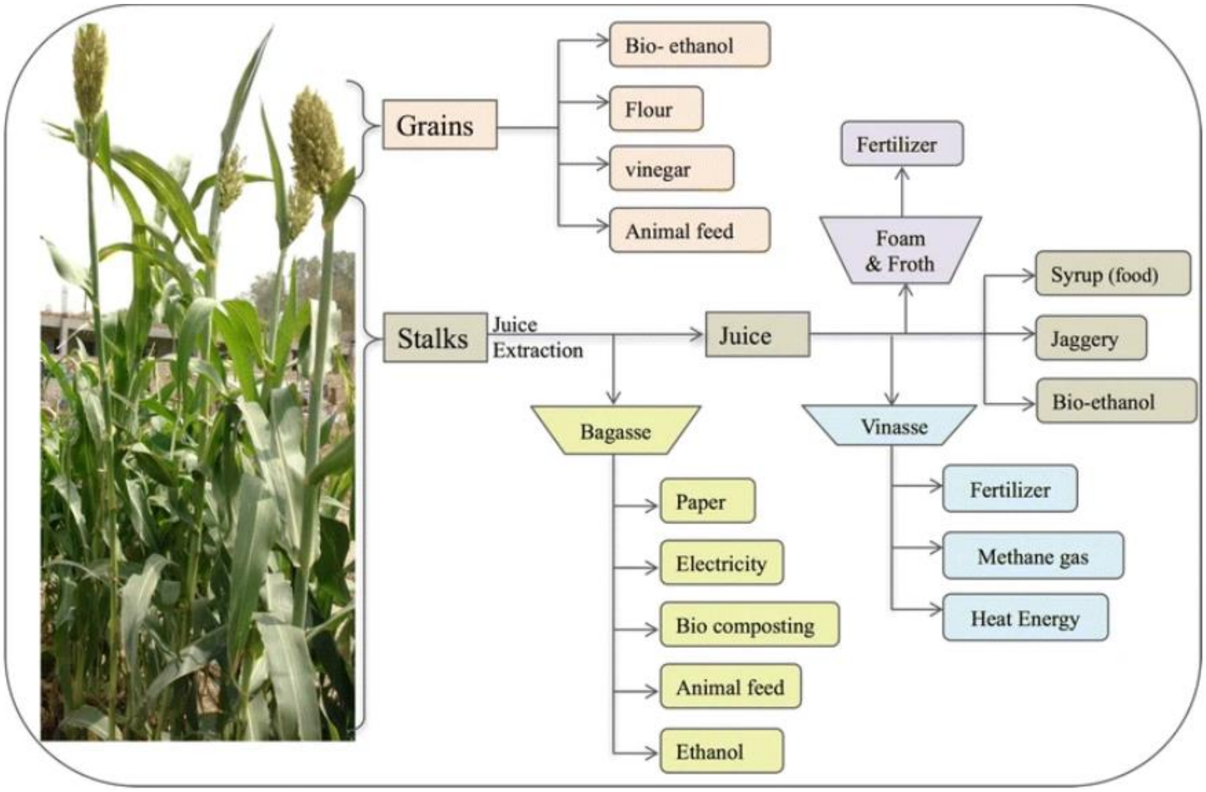


Figure 479. Uses of sorghum

Estimated potential volume of sorghum feedstock

Sorghum grain is not a big food source in Côte d'Ivoire. Therefore, additional grain production for the conversion to bioethanol and SAF could be explored. Studies on the theoretical yield of sorghum give widely varying amounts of the amount of ethanol that can be produced from a metric ton of sorghum. A study from "Energy in Agriculture" estimated a yield between 387 and 447 litres of ethanol per metric ton of sorghum . Another study estimated the average ethanol productivity was approximately 220 g ethanol per kg of original dry stem which would translate to approximately 280 litres of ethanol per metric ton of sorghum using an ethanol density of 0.8 kg/l.

There are several reasons for the wide variation in theoretical yields. First, there are about 250 different types of sorghum cultivated such as grain sorghum, forage sorghum, and sweet sorghum. These all have very different sugar, starch, and biomass profiles that impact biofuel yield. Second, growing conditions and geography affect yields, even for the same variety of sorghum. Finally, conversion technology and plant size play a very important role in determining yield. The conversion technology is only in the developmental stage and there is no large commercial sorghum to biofuel plants operating. Most of the research is dedicated to finding the optimal agricultural and technological techniques.

If we use a widely optimistic value of 400 litres of biofuel per metric ton of sorghum, a production of 70 000 metric tons of sorghum in Côte d'Ivoire would yield 28 million litres of bioethanol which would produce 16.8 million litres of SAF using the ICAO 0.6 conversion factor. It should also be noted that production figures used in this study did not specify the type of sorghum produced so this study assumed that it was all high sugar yielding sweet sorghum. Given that there is probably a mix of sorghum varieties produced and that even the sweet variety may not have the highest yield, a production of half the high estimate, 14 million litres of biofuels and 8.4 million per year, is more realistic but still probably on the optimistic side. Although this volume is too low by itself to support a SAF industry, the output could be combined with ethanol produced from the other feedstocks in this study to feed an ATJ SAF refinery.

Sustainability-related issues for sorghum feedstock

ICAO GHG Sustainability evaluation

While there is no default life cycle emissions value calculated for sorghum in CORSIA, there is a high probability that emissions savings from a SAF produced from it can bring significant emissions reductions. One estimation indicates that sweet sorghum-based ethanol can reduce Core Life Cycle Emissions (not considering Induced Land Use Change emissions factors) by 71% when converted into ethanol using sugar juice to produce ethanol, which does not include the upgrading emissions from the ATJ process. It is usually grown on land with low rainfall and usually not on land with a high carbon stock.

ICAO Environmental Sustainability Evaluation

Sorghum is a very sustainable crop. It requires low input requirements, so it is more economical to produce than other crops such as corn and sugarcane. It efficiently absorbs nitrogen and minerals from the soil, so it does not require much fertilization. In addition, it leaves very little post-harvest residue, thus contributing to lower nitrate losses in water. Sorghum is very resistant to diseases and pests and produces more grain per unit of water than corn or soybeans. Compared to other sugar crops, such as sugarcane, is much more water efficient. It yields more ethanol per unit area of land than other crops, especially in a harsh environment. Unlike many other crops, sorghum is climate resilient and thrives in arid areas where other crops struggle and is a good rotational crop.

Table 11. Sorghum sustainability evaluation

ICAO SUSTAINABILITY THEMES
SORGHUM

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue
Potential issue-need mitigation or control
Major issue-Needs to be resolved before feedstock can be considered

ICAO Socio-economic evaluation

Growing sorghum does not displace crops or populations, so it does not cause any human food security or land-use issues. Using sorghum to produce biofuels could create jobs and provide additional income to farmers. This is especially important in rural areas. Although selling sorghum bagasse and stover for biofuel production will generate revenue for farmers, it may create a fodder scarcity issue because the farmers currently use the waste as a nutritious animal feed.

In conclusion, from a sustainability point of view, sorghum is a very good potential SAF feedstock candidate. The grains can be used for food or biofuels while the rest of the plant can be valorized into fuel so there are no food tradeoffs. Increased and additional production could also be considered for the production of biofuels as long as the sustainability criteria are met – for example, it should promote food security in food insecure regions. Compared to other carbohydrate feedstocks such as sugarcane and maize it is more efficient and cheaper to grow. Finally, it only offers benefits to the local community without any negative socio-economic impacts.

Economic and Market-Sorghum Waste-Related Issues

Sorghum offers 30% more ethanol yield potential than sugarcane, and 30% more than corn. It can help farmers make extra income and provides a rotational crop. Another economic benefit is that it can be used in ethanol production facilities when sugarcane is not available, thus increasing its utilization and productivity.

In terms of logistics, sorghum feedstock presents some challenges. The grain is grown in the north of the country while the SAF facilities will most likely be located closer to the main airport in Abidjan. Sorghum is a bulky low-value product that will require large volumes to make biofuel transformation economically viable. Aside from logistical challenges, there is need for additional infrastructure such as mechanized harvesting, processing, and storage facilities. Another problem is the limited access to electricity in the rural areas.

If sorghum is to be used as a SAF feedstock, it will be critical to maximize yield and production, maximize drought resistance, and increase pest and disease resistance. It will be critical to find the best sorghum varieties and growing conditions to optimize sugar yield. This will require improvements in agricultural practices and research. Universities and agricultural experts will need to be involved.

Conversion of sorghum into biofuels is well developed. Approximately one third of the US grain sorghum crop is used for ethanol production, and sorghum and corn are interchangeable in starch-based ethanol production. It therefore is at TRL 9. However, the ATJ conversion process is just starting to be done using corn, with a TRL on the 8-9 level.

Overall Assessment of Sorghum Waste as a Potential SAF Feedstock

Sorghum has numerous qualities that make it an intriguing potential SAF feedstock. It is a highly sustainable crop with low fertilizer and water needs and does not displace other agricultural crops. It is climate change resistant, and the production area will increase as the plant grows well in warmer and more arid land. Its naturally high sugar content in the inedible parts of the plant is ideal for economic conversion to biofuels and does not create a food security issue. The establishment of a biofuel industry would provide income and jobs in rural areas and reduce waste.

Despite these positive traits, there are challenges for sorghum to be considered as a SAF feedstock by itself in Côte d'Ivoire. However, bioethanol produced from sorghum could be pooled with other sources to augment the input into a SAF ATJ facility. Aside from increasing the overall potential volume, it can smooth out variations in the availability of other feedstocks, such as sugarcane.

Table 12. Sorghum SAF feedstock evaluation

<table>
<tr><th colspan="3">Sorghum</th></tr>
<tr><td>Feedstock availability</td><td colspan="2">Technology readiness</td></tr>
<tr><td>Qualities</td><td colspan="2">T1: Biomass processing</td></tr>
<tr><td>• Highly sustainable
• Low water usage
• Climate change resistant
• High sugar content
• No food security issues
• Can use other parts of the plant</td><td colspan="2">• Not currently used for bioenergy</td></tr>
<tr><td>Constraints/challenges</td><td colspan="2">T2: Fuel Conversion pathways(s)</td></tr>
<tr><td>• Insufficient volume for a standalone plant
• Lack of domestic experience in biofuel production from sorghum</td><td colspan="2">• Alcohol-to-jet (ATJ)
• Synthesized Iso-Paraffinic bio-jet (SIP)</td></tr>
<tr><td>Risk mitigation options</td><td colspan="2">Technology complexity</td></tr>
<tr><td>• Combine with other alcohol feedstocks.
• Develop logistics processes and infrastructure
• More research and initiatives to make bioethanol form sorghum</td><td colspan="2">• Medium</td></tr>
<tr><td>Future biomass potential</td><td colspan="2">Economic viability</td></tr>
<tr><td rowspan="4">• Good. Production volumes are expected to rise as climate change creates more favourable conditions for the crop</td><td colspan="2">• Low to moderate.</td></tr>
<tr><td colspan="2">Biofuel/AAF potential</td></tr>
<tr><td>In general</td><td>Medium</td></tr>
<tr><td>In Côte d'Ivoire</td><td>Low</td></tr>
</table>

2.2.4. CASHEW APPLES

Cashew-related Information

Cashews are a very interesting potential feedstock as its by-products have multiple applications for renewable fuels, Cashew apples are a sugar crop that can be used to produce SAF via the ATJ pathway. Cashew oil can be made into biodiesel. The agricultural residues from cashew processing contain lignocellulosic material that can make SAF using the ATJ or FT processes. These are covered in different sections of this report.

Côte d'Ivoire is the largest cashew nut producer in the work. Output rose from 400,000 metric tons in 2011 to 1 million metric tons in 2022 and is expected to be at the same level in 2023. Côte d'Ivoire currently processes only 10% of its cashew harvest but the government aims to increase domestic processing to 40 to 50% by 2025. The Ivorian has implemented policy measures, such as tax and export incentives, to attain this objective. They are supported by investments from the World Bank and International Monetary Fund (IMF). Unfortunately, a recent slump in cashew prices and a supply glut have hit Côte d'Ivoire's cashew value chain and threatens some producers and growers with bankruptcy.

Figure 48. Cashew Value Chain in Côte d'Ivoire

The government cashew processing strategy will require more production facilities and ten are planned that will add nearly 250 000 metric tons of capacity. This rapid growth will generate many more cashew by-products, residues and wastes that will need to be treated or disposed of. This presents an economic opportunity and an environmental challenge. As shown in the following figure, Cashews are grown in northern, northwestern, and northeastern part of the country and employ about 330 000- 450 000 people.

The following figure shows the steps involved in cashew processing and the main by-products.

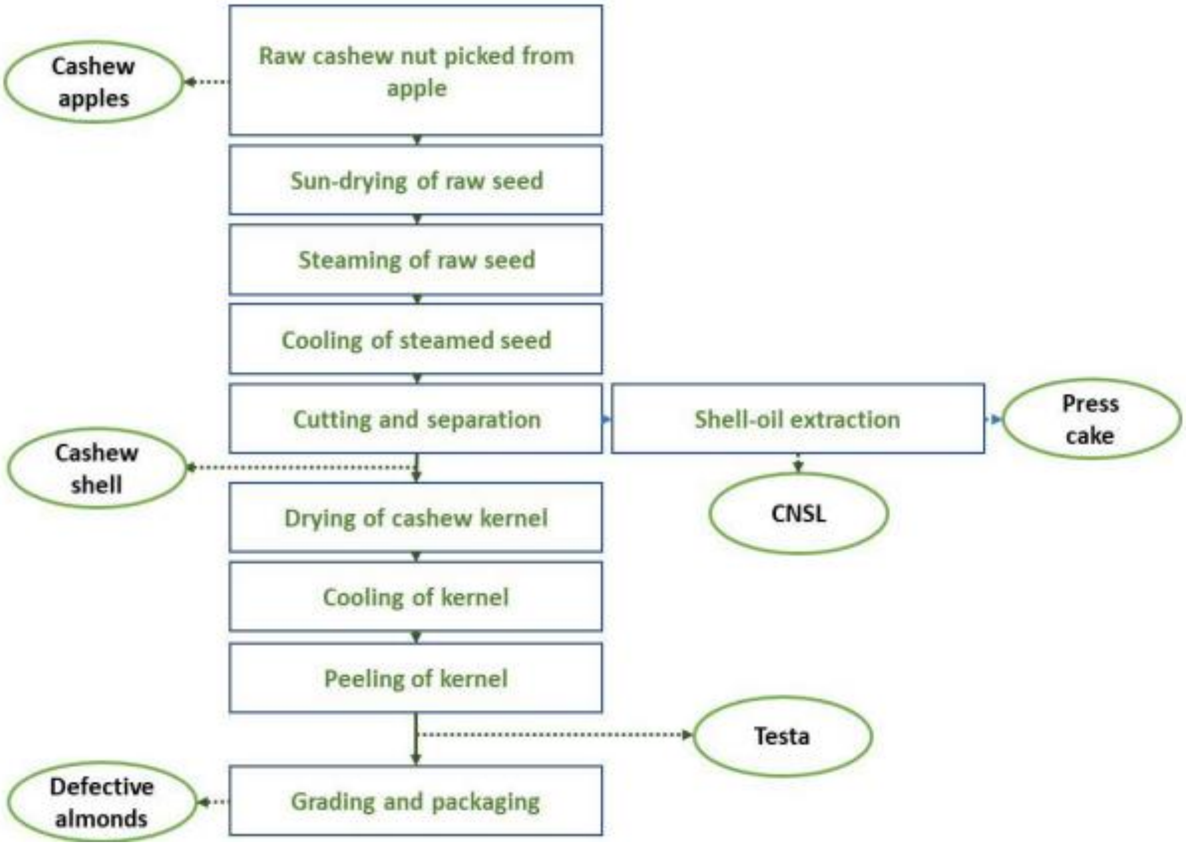


Figure 491. Cashew processing

Figure 502. Cashew production areas in Côte d'Ivoire

The cashew fruit is composed of the nut and the apple, which is the largest part accounting for approximately 80% of the total fruit weight. The apple can be made into many value-added products, including juice, syrup, wine, alcohol, dietary fibre extracts, and animal feed. As a recent Ivorian study demonstrated that apples contain sugars that can be used to produce ethanol and butanol via fermentation making it a potential SAF feedstock via the ATJ pathway. Unfortunately, the potential of cashew apple valorization is untapped as an estimated 99% of the apples are discarded in the field after the raw nut is removed. Of the recovered fruits, 0,9% is consumed directly and 0,1% is processed into juice. In addition to the lost economic potential, the rotting apple produces a significant quantity of greenhouse gases.

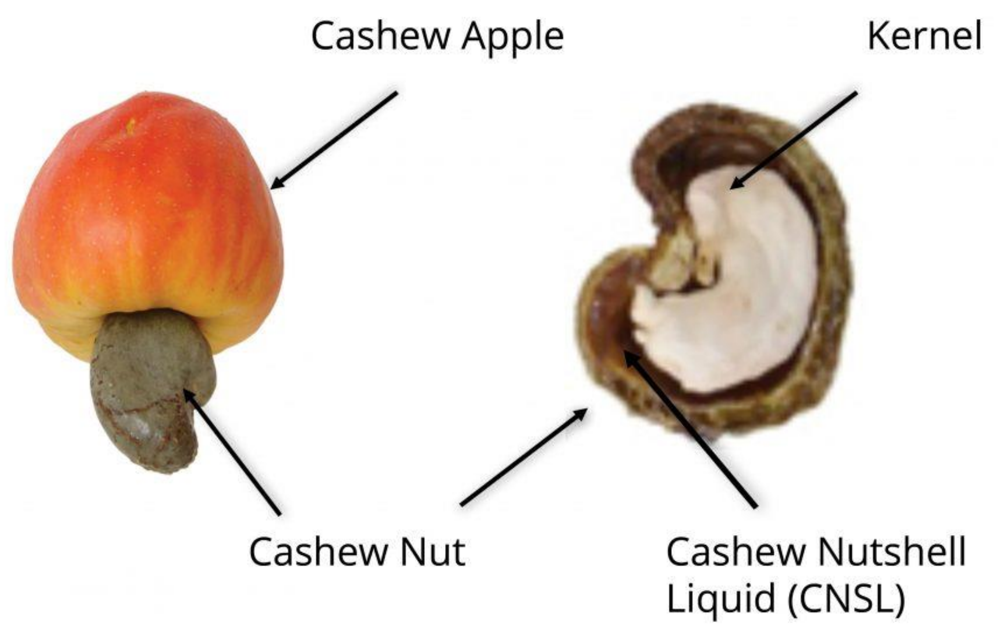


Figure 513. Components of a cashew fruit

Estimated potential volume of cashew apple feedstock

About 33 kg of cashew apples are required to produce 1 litre of ethanol. Using the estimate of 5 million metric tons of cashew apple waste, there is a potential of 151 500 litres of ethanol. Using the ATJ conversion rate of 0.6, this leads to 90,900 litres of SAF which is a factor of 7 lower than a typical ATJ plant[7]. However, the current recuperation rate of cashew apples in Côte d'Ivoire is about 1%, and that the best recovery rates in countries like Brazil are in the order of 12%. Despite the overall potential described previously, the current potential is reduced, and improved agricultural practices to significantly increase the volume of cashew apples collected would be needed to provide enough feedstock for a small-scale ethanol production facility, which could further feed a larger ATJ SAF.

[7] https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

Economic and market-cashew-related issues.

Many projects have been initiated in Côte d'Ivoire to increase value all along the cashew value change, including valorizing cashew by-products. Here are a few recent initiatives:

- The Cashew Value Chain Competitiveness Project, the World Bank is supporting Côte d'Ivoire aim to move from primarily exporting raw cashew nuts to exporting value-added domestically processed products that will generate more value and income for the country.
- In 2022, the Netherland's Centre for the Promotion of Imports from developing countries (CBI) initiated a 4-year project aimed to increase the export of processed cashew nuts from Côte d'Ivoire and Benin to Europe. CBI offers technical and marketing expertise to remove export barriers and increase competitiveness.
- The CBI project CARDOIL - Feasibility study of local sales of CNSL for fuel to boost competitiveness of cashew processors (2020-2023) researched the technical and economic feasibility of producing CNSO for use as a diesel fuel in Côte d'Ivoire and Benin.
- The Germain international sustainable service organization GIZ (Gesellschaft für Internationale Zusammenarbeit) has done several projects, such as the Competitive Cashew Initiative (ComCashew), in African countries with the goal of increasing the effectiveness of the cashew value chain, including valorizing by-products.
- The AFD (Agence France Développement) ran a 4-year project in northern Côte d'Ivoire, called ELECTRI investigated the possibility of burning nutshell waste to produce electricity.
- The AFD AGROVALOR - Energy valorization of agro-industrial waste in Côte d'Ivoire project (2017-2021) studied how to recovery energy from a cashew nut, cassava and shea sectors via the development of a pyrolysis reactor known as the "H2CP" (High Calorific Cashew Pyrolyser). The system permits waste generated by cashew nut shelling to be transformed into two types of fuel: pyrolysis gases to power a boiler and biochar. The biochar blocks were distributed locally to replace wood charcoal made from forests threatened by deforestation.

Initiatives to turn cashew nut waste to produce SAF would fit in with the government strategy these types of projects. However, there are severe challenges and hurdles to overcome.

Cashew apples start to rot soon after falling from the tree. This makes collection, storage, and transportation logistics very difficult. This is probably a major reason that they are not currently being valorized despite their qualities and potential.

Sustainability-Related Issues for Cashew Apple Feedstock

Cashew growing has many positive sustainable qualities. The tree is hardy, grows fast and can grow in many climatic conditions and soil types. Cashew trees can rehabilitate degraded soils and sequester carbon, thus mitigating climate change. They are drought resistant and require less water than other nuts such as almonds, Cashew growing and production provides income and jobs to rural communities and women.

An environmental concern related to cashews is waste. It is estimated that annually over 5 million metric tons of cashew apples are left in the fields. The rotting fruit emits a large amount of methane, which has more than 80 times the warming power of carbon dioxide. In addition, both methane and CO_2 are released when shells and other cashew processing waste are dumped and decompose. It is estimated that these produce up to 0.10 tCO_2eq per metric ton of cashew processed. Other environmental challenges include soil depletion, low productivity, and climate change vulnerability. Valorizing cashew apples and other wastes will help to alleviate these environmental issues.

ICAO GHG Evaluation

Currently, there is no default life cycle emissions value calculated for cashew apples in CORSIA, and it is not contained in the positive list of materials classified as co-products, residues, wastes or by-products. Considering the situation of the cashew apples described herein – remaining in the field – it would be important to collect data and submit a request for ICAO's classification and assessment of the potential emissions reductions.

Table 13. Cashew sustainability evaluation

ICAO SUSTAINABILITY THEMES
CASHEW

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue	
Potential issue-need mitigation or control	
Major issue-Needs to be resolved before feedstock can be considered	

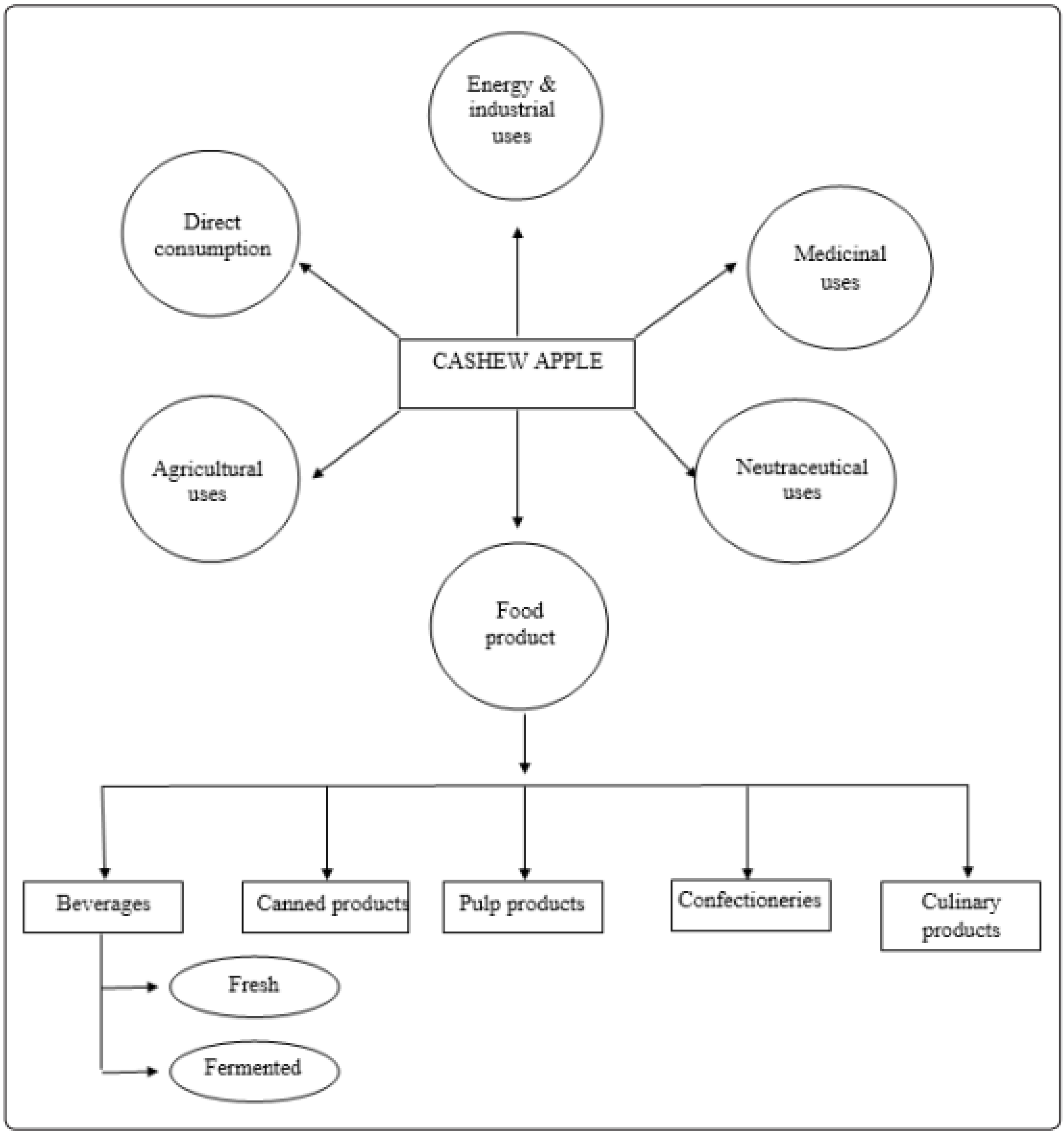


Figure 524. Cashew apple uses

Making cashew apples a SAF feedstock option for Côte d'Ivoire would require a radical increase in the collection rates, a well as the establishment of new logistics and processing infrastructure, so that the ethanol produced from the cashew apples could feed a larger SAF upgrading facility via the ATJ technology.

It is recommended that research be undertaken on harvesting and processing the cashew apple. Partnerships with other States, such as Brazil and India that are making a concerted effort to recuperate the apples and have a much higher recovery rate than the current 1% in Côte d'Ivoire could assist. Given the Ivorian government's strategic support of this industry, it makes sense to optimize the valorization of all the products in the cashew value chain. This would create new economic opportunities and increase profitability for growers and processors.

Table 14. Cashew apple SAF feedstock evaluation

Cashew Apples	
Feedstock availability	**Technology readiness**
Qualities	**T1: Biomass processing**
• Highly sustainable • Important socio-economic benefits • Very important crop • Processing can reduce pollution	• Not currently used for bioenergy
Constraints/challenges	**T2: Fuel Conversion pathways(s)**
• No system to collect, store and transport apples • Technology not well developed	• Alcohol-to-jet (ATJ) • Synthesized Iso-Paraffinic bio-jet (SIP) •
Risk mitigation options	**Technology complexity**
• Combine with other alcohol feedstocks. • Develop logistics processes and infrastructure • More research and initiatives to make bioethanol form apples	• Medium
Future biomass potential	**Economic viability**
• Excellent. The strategy is to significantly increase production in the coming years	• Low to moderate. **Biofuel/AAF potential** In general: Low In Côte d'Ivoire: Low

2.2.5. MAIZE (CORN)

Maize-related Information

Corn is by far the most widely grown cereal crop in the world, followed by wheat and rice. In 2023 Côte d'Ivoire produced 1.2 million metric tons of corn ranking ahead of rice and palm oil as the largest crop. Most of the production is by smallholder farmers and consumed domestically, being used in many Ivorian dishes, such as a corn paste called aitiu.

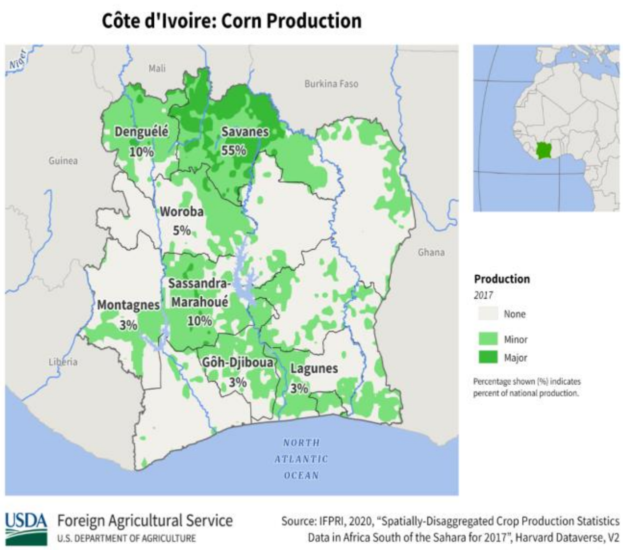


Figure 535. Corn producing areas in Côte d'Ivoire

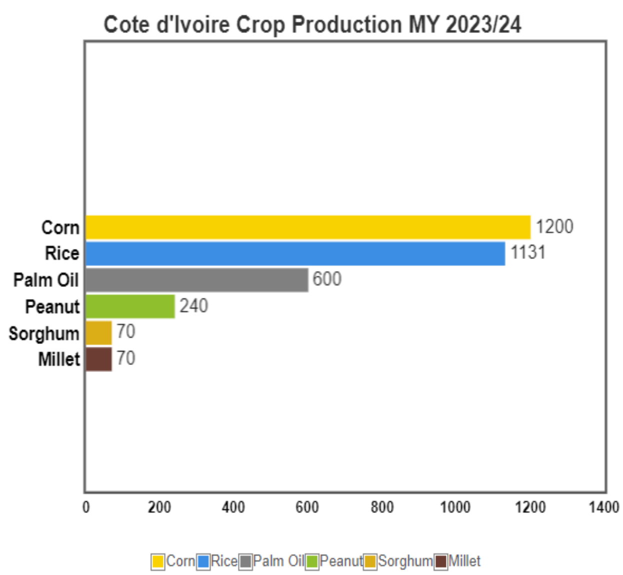


Figure 546. Major food crops in Côte d'Ivoire

Corn is used in a multitude of food and industrial products including starch, sweeteners, corn oil, animal feed, and beverage and industrial alcohols. Corn grain makes a good biofuel feedstock due to its starch content and relatively easy conversion to ethanol. It is the main source of ethanol fuel in the United States. Unlike sugarcane where the juice can be directly fermented, corn starch must be cooked with enzymes to break the starch to simple sugars or fuel ethanol. In the process, two more steps are included: using a molecular sieve to remove the residual water and denaturing to make the ethanol undrinkable.

Suitability for Use as a Feedstock

- The grains contain starches that can be converted to bioethanol or biobutanol by milling and fermentation. However, using the grains to produce SAF is not a preferred option since they are used for human and animal food.
- Corn stover refers to stalks, leaves, and cobs that remain in fields after the corn harvest. Corn stover is composed of about 70 percent cellulose and hemicellulose, and 15 to 20 percent lignin. Cellulose and hemicellulose can be converted to ethanol, and lignin burned as a boiler fuel for steam/electricity generation. Corn lignocellulosic biomass (stover) can be converted to SAF by two processes. The biochemical process involves a pretreatment to release hemicellulose sugars followed by hydrolysis to break cellulose into sugars. Sugars are fermented into ethanol and lignin is recovered and used to produce energy to provide power. The thermochemical conversion process involves adding heat and chemicals to a biomass feedstock to produce syngas, which is a mixture of carbon monoxide and hydrogen. Syngas is mixed with a catalyst and reformed into ethanol and other liquid co-products.

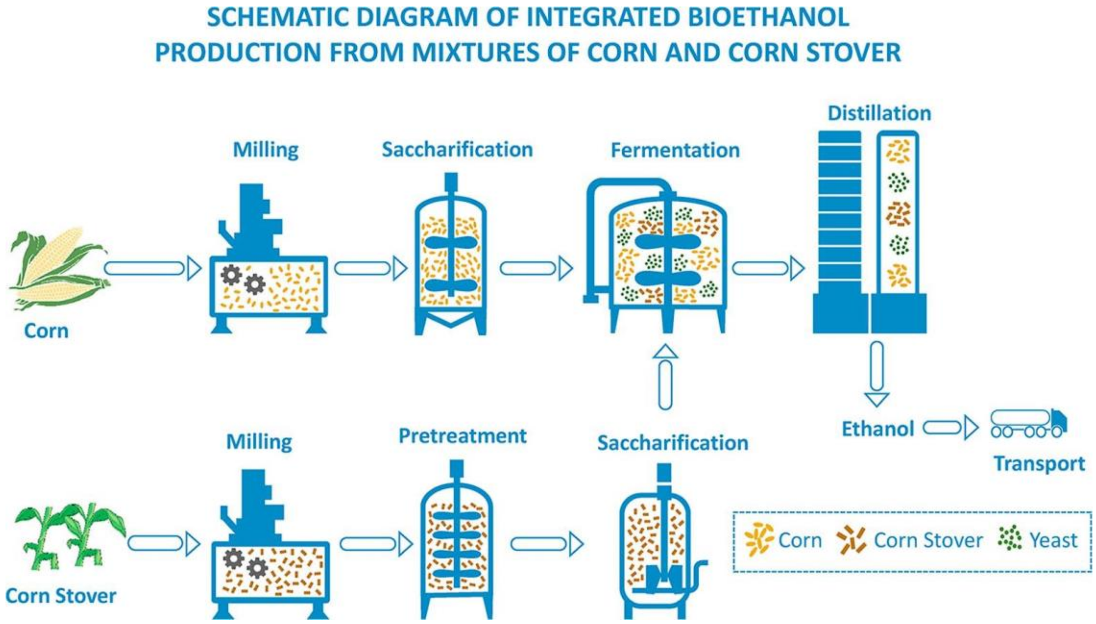


Figure 557. Bioethanol production process from corn grain and stover

The ethanol or isobutanol derived from the corn can then be converted to SAF using the following three steps: dehydration, oligomerization, and hydrogenation.

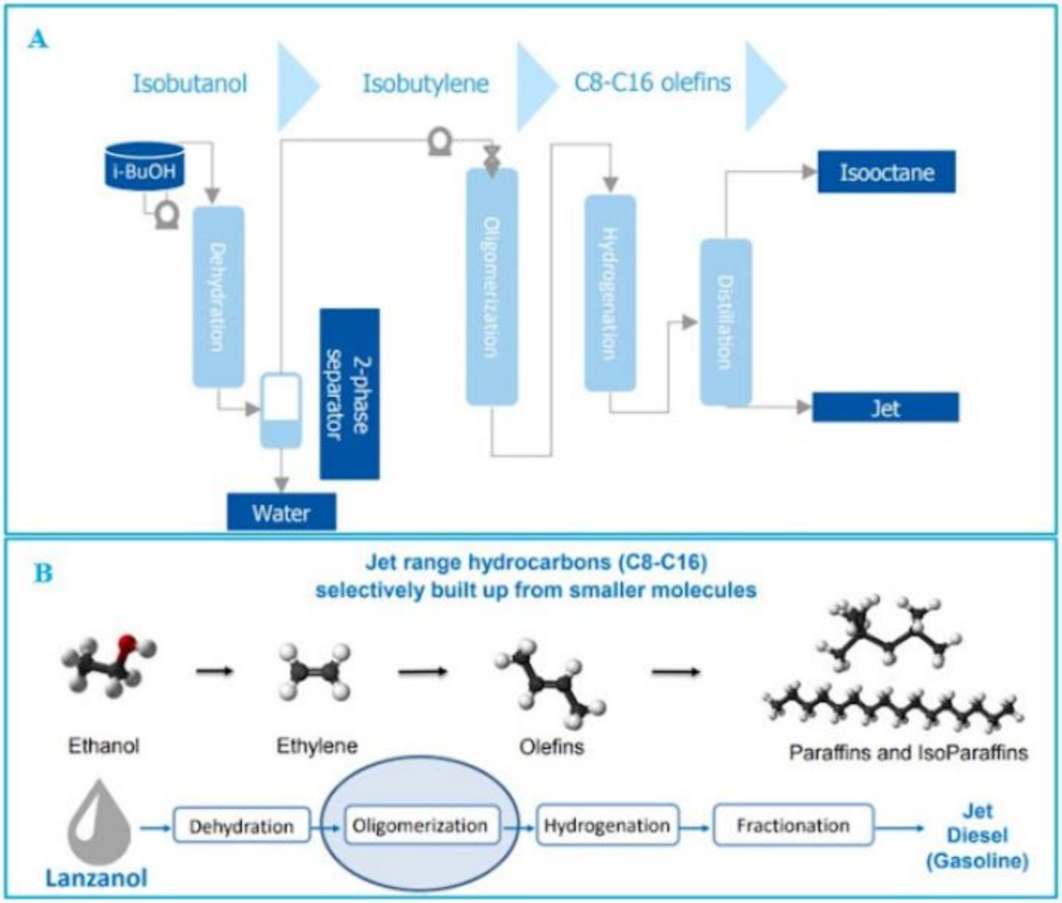


Figure 568. Process to convert bioethanol into SAF

Estimated potential volume of corn feedstock

Various sources estimate a yield of 360-420 L of ethanol to be obtained from a metric ton of corn. However, producing biofuels from edible feedstocks is likely not an option in a developing country. Therefore, we need to look at the potential of corn stover. It is estimated that around 130 gallons (about 500 litres) of ethanol could be produced per ton of corn stover the ratio of grain to stover in corn is close to 1:1 collection efficiency of about 70% have been reported. Given a production of 1.2 million metric tons of corn, this would yield 840 000 metric tons of stover with a potential production of around 420 million litres of ethanol which could theoretically be converted to 252 million litres of SAF. Even though actual yields and collection efficiencies will probably be much lower it demonstrates that corn stover has the potential to provide a significant amount of ethanol feedstock for an ETJ facility.

Sustainability-related issues for corn feedstock

ICAO GHG Sustainability evaluation

Because of a high ILUC value, SAF produced by corn grain via the Ethanol to Jet fuel conversion process has a global default life cycle emissions value of 100.6 gCO_2/MJ, which is actually higher than that for jet fuel (89 gCO_2/MJ), and of 85.5 gCO_2/MJ when produced via the Alcohol (isobuthanol) to Jet fuel conversion process. Corn stover is an agricultural residue and has a much lower value (24.6-39.7 gCO_2/MJ). Producing corn – or any other crop – according to CORSIA's low LUC risk methodology reduces the ILUC value of the resulting SAF to zero, making this a much more suitable approach.

Collecting corn stove has some advantages. Large amounts of stover can interfere with no-till planting, causing corn growers to perform one or more tillage operations to bury part of the residue. It also keeps the soil cool and wet in the spring and can harbour insect and disease organisms, resulting in a need for more pesticides. However, removing corn stover also has several potential disadvantages such as potential impacts on soil organic matter, increased potential for soil erosion, and nutrient removal that need to be addressed before it can be utilized on a widespread basis. Careful agricultural practices need to be used to maximize the benefit of corn stover.

ICAO Socio-economic Evaluation

Drought-tolerant varieties of maize are helping beat harsh conditions in sub-Saharan Africa, and research by the International Food Policy Research Institute shows that maize cultivation can help empower women, while also increasing maize yields. Using corn waste could also generate additional revenue for rural farmers.

Economic and Market-Corn-Related Issues

Conversion of corn into biofuels is well developed. Approximately 45% of the US corn crop is used for ethanol production so the process is well understood and technologically mature. However, conversion into jet fuel ATJ is just starting to be done by companies using corn. The process is there 8-9 on the TRL scale. In terms of cellulosic corn stover, several plants in the United States are producing bioethanol form corn stover.

Overall Assessment of Maize as a Potential SAF Feedstock

Under CORSIA, significant life cycle emissions reductions from corn are achievable only in the situation where there is no Induced Land Use Change, meaning under the use of the low LUC risk methodology. Apart from being produced under this methodology, all CORSIA Eligible Fuels have to meet the sustainability criteria, which requires CORSIA SAF production will, in food insecure regions, strive to enhance the local food security of directly affected stakeholders a. However, corn stover could provide an interesting feedstock.

2.2.6. ELEPHANT GRASS

Elephant grass (*Miscanthus*), also called Napier grass or Ugandan grass, is originated from sub-Saharan tropical Africa. It is one of the highest-yielding tropical grasses and is a very versatile species that can be grown under a wide range of conditions and systems in dry or wet conditions, by smallholders, or industrial agriculture producers. It is an important crop that provides good fodder for farm animals and since it is an important food item for African elephants, a symbol of Côte d'Ivoire, it named 'Elephant grass.'

One of the main qualities of elephant grass is its ability to produce biomass, growing up to four metres in just 100 days and produced several crops to harvest each year. It also has a long lifespan and does not need pesticides or fertilizers. It can be used to manufacture paper, consumer goods, charcoal, and biofuels. It is often cultivated to create boundaries due to its denseness. Given its length, it is a popular hiding place for small animals.

Figure 579. Elephant grass researchers from the University of Hohenheim in Stuttgart, Germany

Elephant grass has been investigated as a promising potential bioethanol feedstock in many parts of the world including the USA, Europe, Asia, and Africa because of the high yields of biomass per unit of planted area. As shown in the figure below, the bioethanol production process of saccharification (breaking a complex carbohydrate such as starch into simple sugars), and fermentation is very similar to that used for other sugar-bearing crops. Once bioethanol is produced, it can be converted into SAF via the ETJ process.

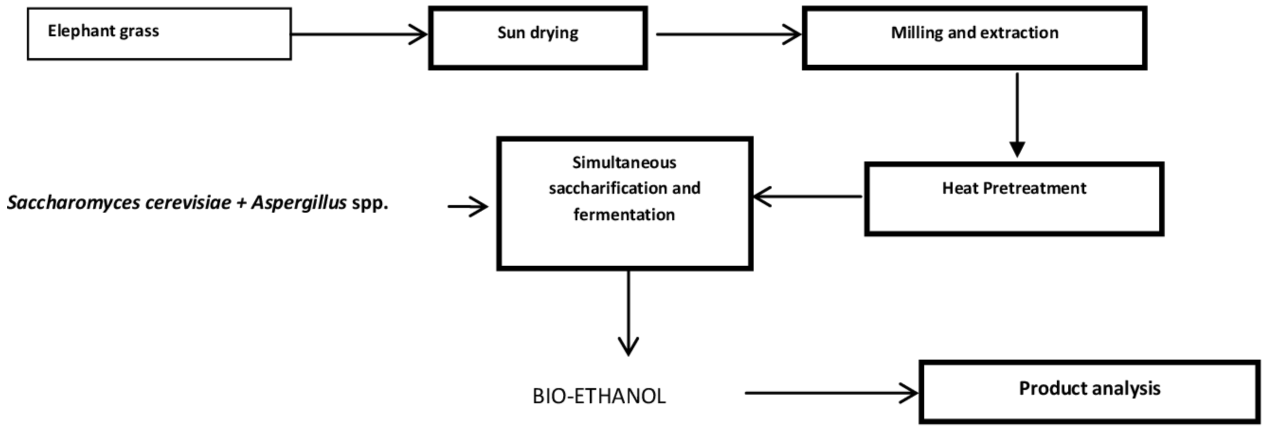


Figure 58. Process to make bioethanol from elephant grass

Elephant grass resembles sugarcane but produces 40 tons of biomass per hectare of crop, while sugarcane produces roughly between 15 and 20 tons, yet they have similar ethanol yield. It also has a higher yield than other energy crops such as sorghum.

It is a very sustainable crop. It can grow on marginal land that is unsuitable for food production and has low input requirements. Elephant grass also stores a large percentage of the carbon it absorbs from the atmosphere in its roots. For these reasons, it has a very low global default life cycle emissions of 9.3 gCO_2/MJ for the Ethanol-to-Jet fuel conversion process under CORSIA. The only potential sustainability issue is that using elephant grass for SAF would reduce the amount available for animal feed or other uses if the production is not expanded.

There is no evidence that using elephant grass for biofuels in Côte d'Ivoire has been explored. There are no data or information regarding production quantities, cultivation, logistics, storage, or harvesting. The conversion pathways elsewhere in the world have a low level of technological maturity. Therefore, elephant grass and energy grasses are not a potential SAF feedstock in the short and medium terms. However, the economic and sustainability advantages merit further investigation and research into using them as a source of bioethanol that could be converted to SAF. The bioethanol volume produced by the energy grasses could be a complement to those produced by other carbohydrate bearing feedstocks such as sorghum and bagasse.

2.3. LIPID FEEDSTOCKS FOGS (FATS, OILS AND GREASES) FEEDSTOCK

FOGS are the feedstock for two SAF pathways; Hydroprocessed Esters and Fatty Acids (HEFA) and Catalytic Hydrothermolysis Jet (CHJ). They are also the feedstock for two types of diesel fuels (FAME and HVO). These processes are described in section 2.0.

2.3.1. CASHEW NUT OIL

The cashew nutshell is composed of a protective shell, liquid in a soft honeycomb structure, and the edible kernel. When mechanically broken to release the shell, a reddish-brown viscous toxic liquid known as Cashew Nutshell Liquid (CNSL) is released, which corresponds to 20% of the cashew nutshell weight. CNSL can be decarboxylated and distilled to yield high purity cardanol, a highly desirable compound in the chemical industry that can be used to make resins, curing agents, coatings, frictional materials, and curing agents for the durable epoxy coatings used on concrete floors. It can also be used to produce Fatty Acid Methyl Ester (FAME, biodiesel).

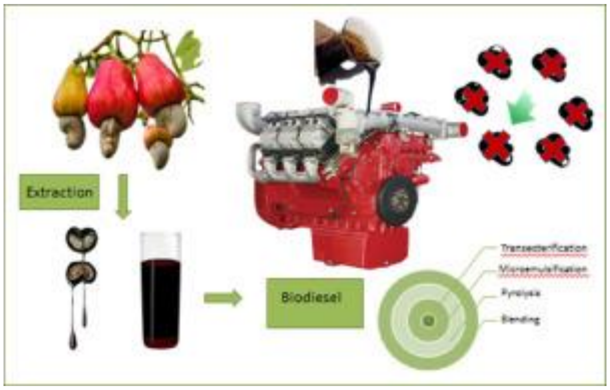


Figure 591. Cashew nut oil biodiesel

Other by-products

- **Testa** is the thin, membranous outer layer of the cashew nut. It is light in colour and has a rough texture. It is high in tannins and can be used as animal feed, insulation, and as a fuel source for cooking or heating. Testa can also be used as a substitute for animal skins in some clothing applications, such as in gloves and shoes.
- **Defective almonds** are the damaged nuts that are rejected during processing. They are used as animal fodder or can be made into cashew paste or oil for human consumption.
- **Cashew Press cake** is the de-oiled residue left after CNSL extraction. It can be used as a combustion fuel for cookstoves or boilers or as a fertilizer.

Sustainability-Related Issues for Cashew Oil Feedstock

A potential environmental issue is that cashew oil produces toxic fumes when burned, so if the waste is disposed of in this manner it can cause health problems for the workers and local community. The oil is also caustic, so workers need to have protective equipment in the deshelling operation. The toxic nature of the oil, as well as other chemicals used, also can create pollution problems if not properly disposed.

Economic and Market-CNSO-Related Issues

In terms of socio-economic sustainability, valorization of cashew by-products, wastes and residues presents important economic benefits for farmers, producers, women, and rural communities. Paradoxically introduced to prevent deforestation, expansion of cashew cultivation can displace food crops as discussed in the World Agroforestry report, “Call to rethink cashew as a restoration crop in the Ivory Coast.”

CSNL production trials have been conducted by several large Ivorian cashew processors but proved uneconomical due to low prices for the finished product. However, several studies have shown that using CSNO to displace fossil fuel can be economical if the right technologies are used. Valorizing the leftover press cake would also help to increase its economic viability.

Overall Assessment of CNSO as a Potential Biodiesel Feedstock

Although CNSO is unsuitable for conversion into SAF, it can be processed into FAME biodiesel. High density and viscosity prevent it from being directly used, but CNSO blends have been successfully tested in diesel engines with an optimum blend ratio of 75% Diesel/25% CNSO biofuel. The blended fuel can directly substitute fossil diesel without equipment modifications. It is therefore a promising potential low-cost biodiesel for ground handling equipment in Abidjan and other airports. It can therefore be another way of valorizing the cashew value chain and warrants further study.

Table 15. Cashew Nutshell Oil (CNSO) feedstock evaluation

<table>
<tr><th colspan="3">CNSO</th></tr>
<tr><td>Feedstock availability</td><td colspan="2">Technology readiness</td></tr>
<tr><td>Qualities</td><td colspan="2">T1: Biomass processing</td></tr>
<tr><td>• Highly sustainable
• Important socio-economic benefits
• Very important crop
• Processing can reduce pollution
• Can be blended into diesel for use in GSE</td><td colspan="2">• Not currently done</td></tr>
<tr><td>Constraints/challenges</td><td colspan="2">T2: Fuel Conversion pathways(s)</td></tr>
<tr><td>• Lack of systems to collect and store shells</td><td colspan="2">• FAME Biodiesel</td></tr>
<tr><td>Risk mitigation options</td><td colspan="2">Technology complexity</td></tr>
<tr><td>• Develop logistics</td><td colspan="2">• Low</td></tr>
<tr><td>Future biomass potential</td><td colspan="2">Economic viability</td></tr>
<tr><td rowspan="4">• Excellent. The strategy is to significantly increase production in the coming years.</td><td colspan="2">• High</td></tr>
<tr><td colspan="2">Biofuel/AAF potential</td></tr>
<tr><td>In general</td><td>High</td></tr>
<tr><td>In Côte d'Ivoire</td><td>High</td></tr>
</table>

2.3.2. RUBBER SEED OIL

Rubber waste-related Information

Rubber trees are grown plantations in the tropics and subtropics, especially in Southeast Asia and western Africa. They are cultivated to produce latex which is obtained by cutting into the bark. The latex is then processed into rubber products, of which about 70 percent is used to manufacture tires and the rest for numerous other products. Côte d'Ivoire is ranked the fourth-largest rubber producer in the world next to Thailand and Indonesia. Production has been expanding at an average of 2.1% year-on-year and the country is close to becoming the world's third-largest natural rubber producer by volume, moving ahead of Vietnam. Côte d'Ivoire produced nearly one million metric tons of natural rubber in 2020 which represents 80% of the continent's latex and plans to double production to two million metric tons.

In recent years, new plantations have proliferated as farmers switch from cocoa to rubber in search of more stable incomes. The majority (approximately 89%) of rubber plantations are operated by over 170 000 smallholder farmers. Large industrial plantations are operated by companies such as SAPH (Société africaine de plantations d'hévéas). Rubber production is concentrated in the south of Côte d'Ivoire in the tropical rainforest belt.

Rubber processing

Apart from the primary output of rubber processing, there are two products that have potential as SAF feedstocks:

Rubber Seeds

The valuable part of a rubber tree is its bark that produces latex. However, the tree also produces seeds that are currently treated as waste in the monocultural plantation system. Rubber seeds have an oil content of 40–60%. The oil is non-edible but can be used to produce FAME or HVO biodiesel or SAF via the HEFA process. Once the oil is extracted, the remaining solids can be made into a cake that can be used for animal feed.

Each rubber tree produces between 700 and 800 seeds yielding around 1.5 kg seeds per year, or about 150 kg/hectare. In Côte d'Ivoire, rubber plantations cover 600,000 hectares indicating a theoretical potential of 90 thousand metric tons of seeds. At a yield of 40%-60%, this would provide 36-54 thousand metric tons of oil, which makes it a very good potential source of SAF feedstock although not enough to feed a refinery by itself. However, it could be a good addition to other oil-bearing feedstocks or for co-processing at the SIR refinery.

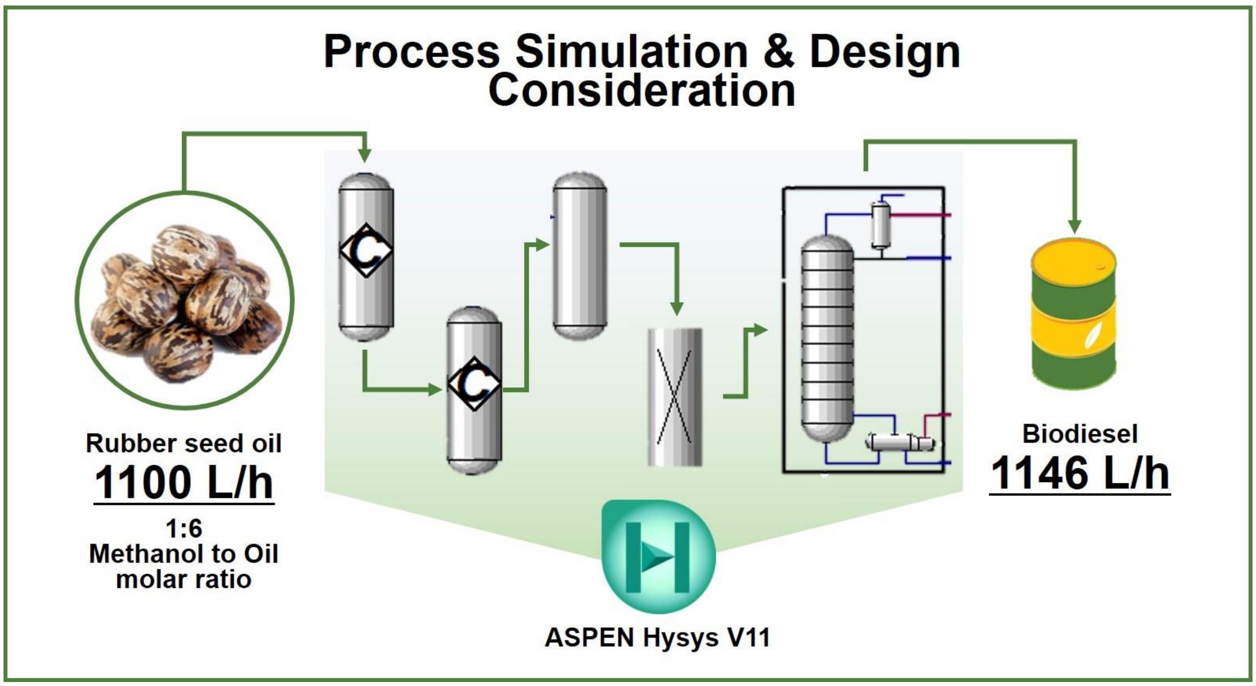


Figure 602. Biodiesel yield from rubber seed oil

Forestry residues

Rubber operations produce a lot of residues spread around the plantation that can be turned into fuel via gasification and the FT process. Leaves fall from the trees and form a biomass of approximately 6 metric tons per hectare per year. Currently the leaves are left to fertilize the soil. Another biomass source is trees that have fallen, died, or been removed. Plantations are usually replaced every 30-40 years, which leads to a percentage of trees being removed every year to be replaced by new ones. Biomass from renewals is estimated at 175 to 250 metric tons per hectare. Most of the removed trees are burned for fuel by villagers for cooking or used to make charcoal. A small amount is used to provide energy for industrial operations. For example, SAPH turns rubber tree wood into wood shavings and sells them to be used as fuel for electricity in boilers. This type of electricity depends on the quantity of wood chips used. Rubber wood is of high quality and plantations in other countries can sell the fallen trees, but this is not an option in Côte d'Ivoire due to the age of the fallen trees and the lack of a domestic timber industry. The final source of feedstock is branches that fall off the trees or are removed for maintenance. In summary, leaves, trees, and branches could represent an interesting source of biomass for SAF production if they are collected and processed. This is further explored in the section on agricultural residues.

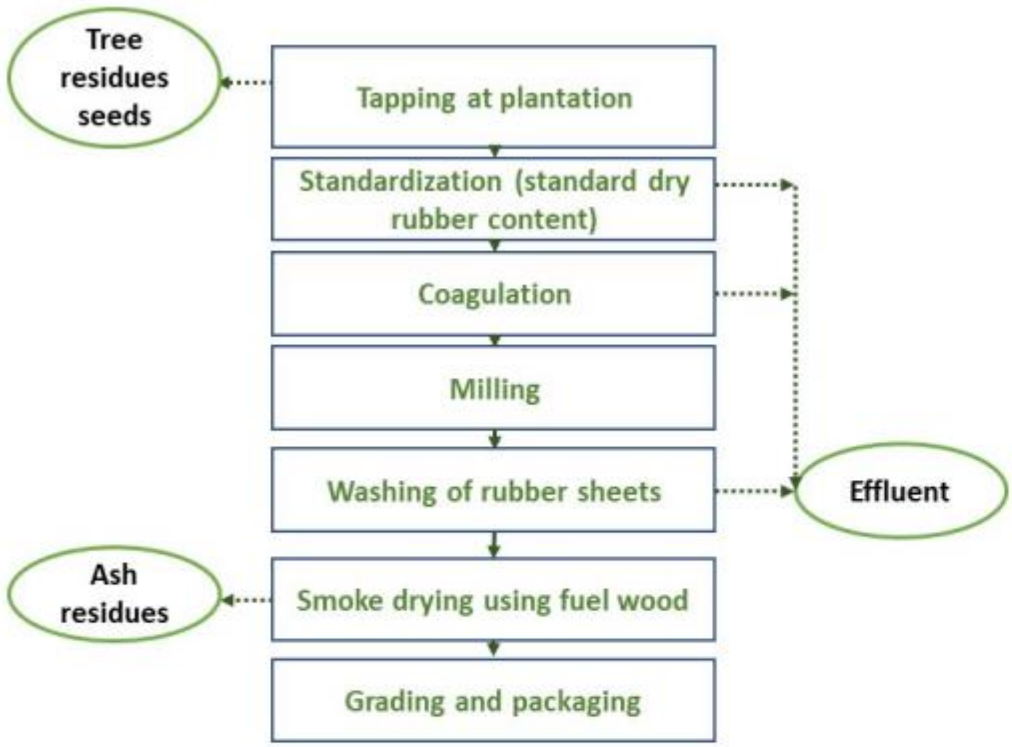


Figure 613. Rubber production process

Sustainability-related issues for rubber feedstock

Although rubber is a very important commodity, its cultivation can lead to sustainability concerns if not managed properly. Rubber plantations can contribute to deforestation and biodiversity loss when forests are cleared to make way for growing trees. This can also result in the displacement of local populations. Finally, rubber production also produces wastewater effluent with high organic matter content that cause can cause water pollution if not properly treated.

Climate change is already impacting rubber production as latex flow after tapping depends on temperature and precipitation patterns. In addition, most pests and diseases associated with rubber are influenced by climatic conditions. Adaptation measures will need to be taken to meet industry growth targets and to ensure future supply of rubber and potential SAF feedstocks.

Côte d'Ivoire is making great efforts to make its rubber industry more environmentally friendly by adopting sustainable agricultural and production practices. Companies, such as SAPH, have strong environmental policies and strategies, but most rubber producers are small-scale farmers which makes standardization of best practices difficult to enforce. In addition, Côte d'Ivoire has an ambitious plan to increase rubber production. This will require the implementation of a strategy that prevents deforestation, land use, and food security issues. If rubber tree seeds or agricultural residues are used as a SAF feedstock, care needs to be taken that they are sustainably sourced according to ICAO CORSIA criteria.

Rubber Seeds

A very important sustainability benefit of using rubber seeds to produce biofuels is the life cycle reduction of CO_2. In addition to the environmental advantage of using RBO to produce SAF, there are also considerable socio-economic benefits. Valorizing the seeds will require the creation of a new infrastructure in areas such as collection, logistics, processing, marketing, and trading. This will lead to the creation of many new full-time and seasonal jobs. For example, ANADER estimates a permanent creation of 420 new jobs as well as work for an estimated 10.000 season workers collecting the seeds.

Currently, rubber (or other) seeds are not contained in the positive list of materials classified as co-products, residues, wastes or by-products of ICAO CORSIA Eligible Fuels. No default life cycle emissions are available either for this feedstock. These evaluations can be requested to ICAO at any time, and the process is described in the ICAO document CORSIA Methodology for Calculating Actual Life Cycle Emissions Values, session 4[8].

Tree Residues

Forestry residues from rubber are currently burned since there are not many available valorization options, which creates air pollution. Using this biomass to produce biofuels would therefore improve air quality . As for the case of rubber seeds, processing these residues into fuel would require a new value chain of activities that would create many jobs.

Tree branches and leaves are classified as forestry residue in the ICAO CORSIA positive list of materials[9] and thus has an Induced Land Use Change (ILUC) emissions factor of zero. For the Fischer-Tropsch Fuel Conversion Process, the default life cycle emissions for agricultural residues at global level is set at 8.3 gCO_2e/MJ which, in comparison to the conventional fossil fuel emission factor of 89.0 gCO_2e/MJ, reduces CO_2e emissions by 90.7%. For the Ethanol-to-Jet Fuel Conversion Process, the default life cycle emissions for forestry residues at global level is set at 40.0 gCO_2e/MJ for the standalone conversion design and 24.9 gCO_2e/MJ for the integrated conversion design, corresponding to emissions reductions of 55.0% and 72.0% respectively.[10]

[8] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[9] Table 1 - https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[10] For access to updated methodologies, visit https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

Table 16. Rubber seed oil sustainability evaluation

ICAO SUSTAINABILITY THEMES RUBBER SEED OIL	
CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue
Potential issue-need mitigation or control
Major issue-Needs to be resolved before feedstock can be considered

Economic and market-rubber waste-related issues

Valorizing rubber plantation residues and waste can provide additional agricultural income. The current price of rubber seeds is 87 CFA per metric tonne, so collecting the seeds would provide much-needed income. This is especially important for the Ivorian rubber industry as most of the producers are small-scale farmers. In addition, it can provide many new jobs in collections, storage, and logistics.

The government of Côte d’Ivoire has recently announced a first project targeting the valorization of rubber. As part of the project, a production unit will be developed to transform rubber tree seeds into biodiesel in the region of the Grands Ponts and more specifically in the locality of Dabou. This project, in which the government of Côte d'Ivoire (through its rural development agency ANADER) cooperates with the Swedish development agency Swedfund and the company Scania. Additionally, the Ivorian companies LONO and SOGB are exploring opportunities for the valorization of waste from rubber plantations.

The Italian energy company ENI has committed to purchasing 15 000 to 20 000 metric tons per year of rubber seeds. The seeds will be exported to Italy for conversion to renewable diesel (HVO) that will be used on road transport. This is part of ENI’s strategy to secure supply of biofuel feedstocks that don't compete with food supply. The positive aspects of this agreement are that it will provide additional income for rubber farmers and provide a new export stream to the EU. It also gives credibility to the technological and economic feasibility of using rubber seeds. However, the local processing of rubber seeds would provide more opportunities for Côte d’Ivoire than exporting the raw materials.

Overall Assessment of Rubber Seeds as a Potential SAF Feedstock

Rubber tree oil (RBO) has many qualities that make it a promising SAF feedstock. It exists in sufficient quantities to supplement other oil-based feedstocks and will increase along with rubber production, RBO can be transformed into SAF through a low-cost, technically mature pathway (HEFA) and arouse the interest of several industrial stakeholders. Since it is a non-edible oil, it does not compete with food crops. It also can provide economic benefits by providing additional revenue for farmers. Finally, it will reduce pollution by valorizing wastes and residues. Challenges include the lack of a logistics system to collect and process the seeds as well as potential sustainability issues associated with rubber farming and processing. Another challenge is feedstock competition for use as a biofuel for road transportation

SAF feedstock from tree plantation wastes and residues also holds promise but is a longer-term option that requires more study to quantify volumes and collection logistics. Processing using the FT SAF pathway is more expensive and this feedstock/pathway has not been studied as much as RBO/HEFA. It also suffers from the same potential sustainability issues as the RBO. It is best to consider rubber plantation waste in the wider scope of using agricultural waste as a SAF feedstock.

Table 17. Rubber seed oil feedstock sustainability evaluation

Rubber seeds		
Feedstock availability	**Technology readiness**	
Qualities	**T1: Biomass processing**	
• Large volumes • Great opportunity to valorize waste • Low-cost transformation process (HEFA) • Additional revenues for farmers	• Rubber seeds are not presently collected	
Constraints/challenges	**T2: Fuel Conversion pathways(s)**	
• Potential land use issues • Susceptibility to climate change • Feedstock competition for biofuel • Lack of collection systems	• HEFA • Co-processing	
Risk mitigation options	**Technology complexity**	
• Sustainable farming practices • Development of logistics systems	• Medium	
Future biomass potential	**Economic viability**	
• Excellent. Production has been increasing and will continue to do so in the coming years.	• Medium	
	Biofuel/AAF potential	
	In general	Medium
	In Côte d'Ivoire	medium

2.3.3. PALM OIL FEEDSTOCK

The fruit of oil palm trees, which originate from West Africa, produces an edible vegetable oil. It grows successfully in any humid tropical climate and today is grown throughout the world, especially in Malaysia and Indonesia. It is the most widely produced oil in the world and accounts for 35% of the world's vegetable oil production. Palm oil trees produce two types of oil; palm oil is obtained from pressing the flesh of the fruit, and palm kernel oil is produced by extracting oil from the stone in the middle of the fruit (kernel).

Palm oil has many qualities. It is high yielding, low cost, needs minimal processing and can be grown year around. It is shelf stable because it is resistant to oxidation, useful in spreads because it is semi-solid at room temperature, good for cooking because it is stable at high temperatures and is odourless and has health advantages over some other oils because it does not contain trans-fat. For these reasons it is used in nearly half of the products consumers purchase such as food, cosmetics, cleaning products, shampoos, soaps, and toothpaste. More importantly in the context of this study, palm oil can be used to make biodiesel and SAF.

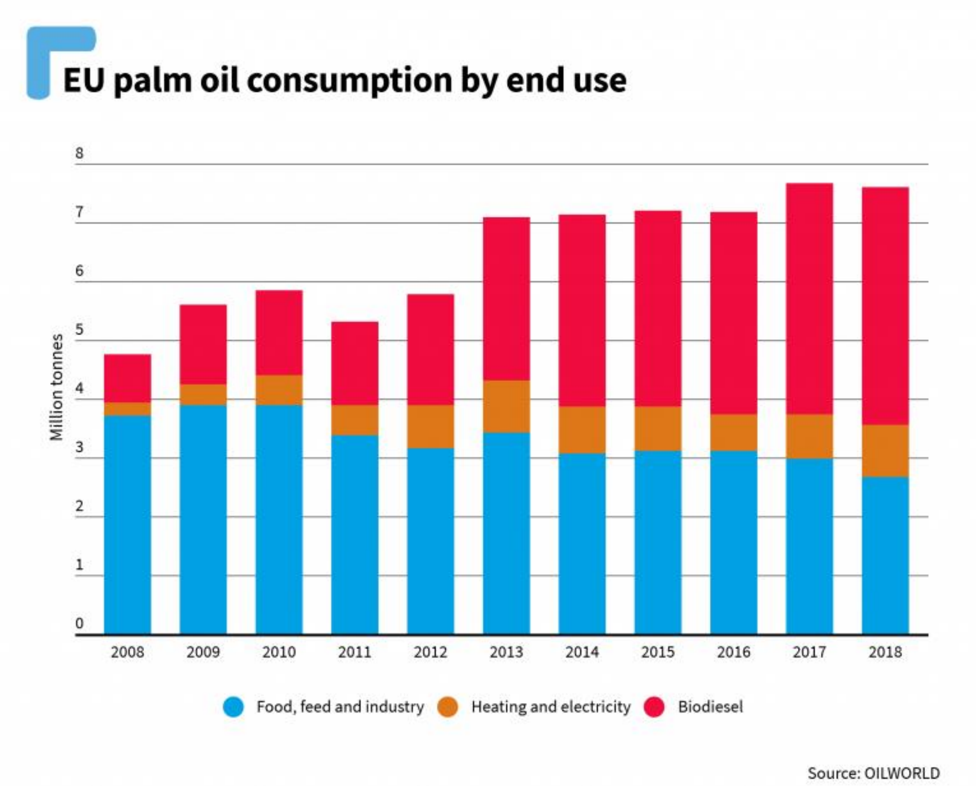


Figure 624. Palm oil uses in the EU

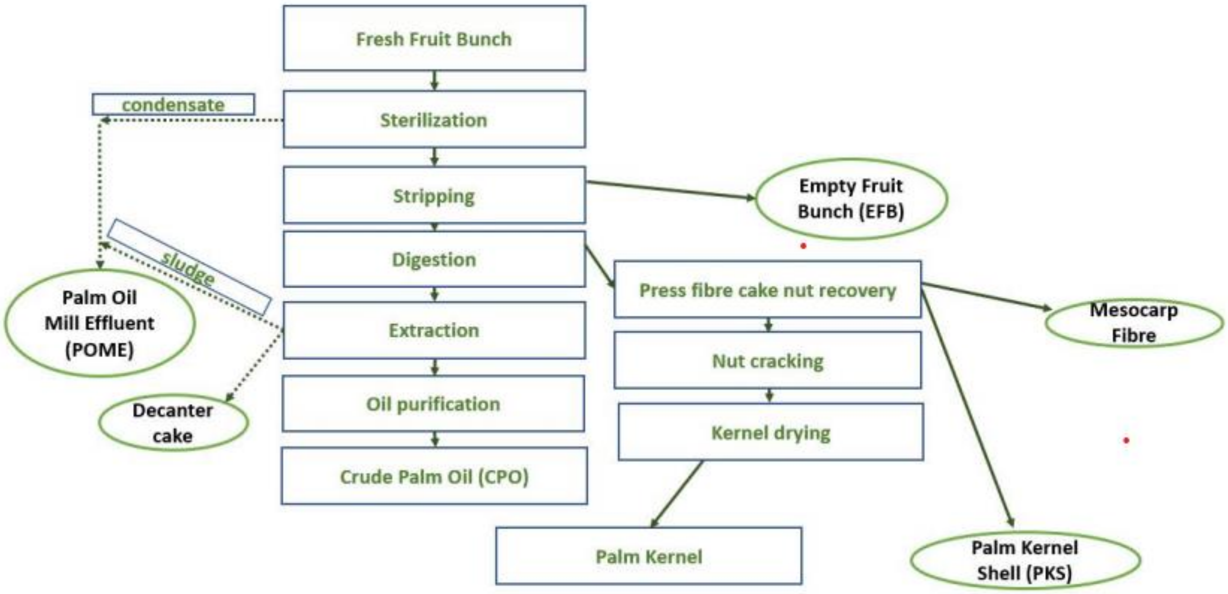


Figure 635. Oil palm processing

As shown in the above diagram, oil palm produces multiple by-products, of which four can be used to make SAF:

1. Agricultural residues such as palm kernel shells, empty fruit bunches, leaves, etc. can be collected and their lignocellulosic content used to produce SAF

2. Used cooking oil (UCO). Palm oil is widely used for cooking in Africa, the used oil can be collected as a SAF feedstock.

3. Palm Fatty Acid Distillate (PFAD) is a waste from the conversion of crude palm oil into cooking oil. During harvesting and transportation to the mills, the fats in the oil palm fruit start to break down in free fatty acids (FFA). These must be removed by distilling to meet cooking oil standards for taste, odour, and shelf life. Approximately 3.5-5% of the raw oil is removed as PFAD which can be used to produce SAF and HVO biofuels amongst other products. At 600 000 metric tons of palm oil production per year, this would provide a potential of between 21 000 and 30 000 metric tons of SAF feedstock. At a HEFA conversion rate of approximately 0.83. this would yield about 17 000-25 000 metric tons of SAF.

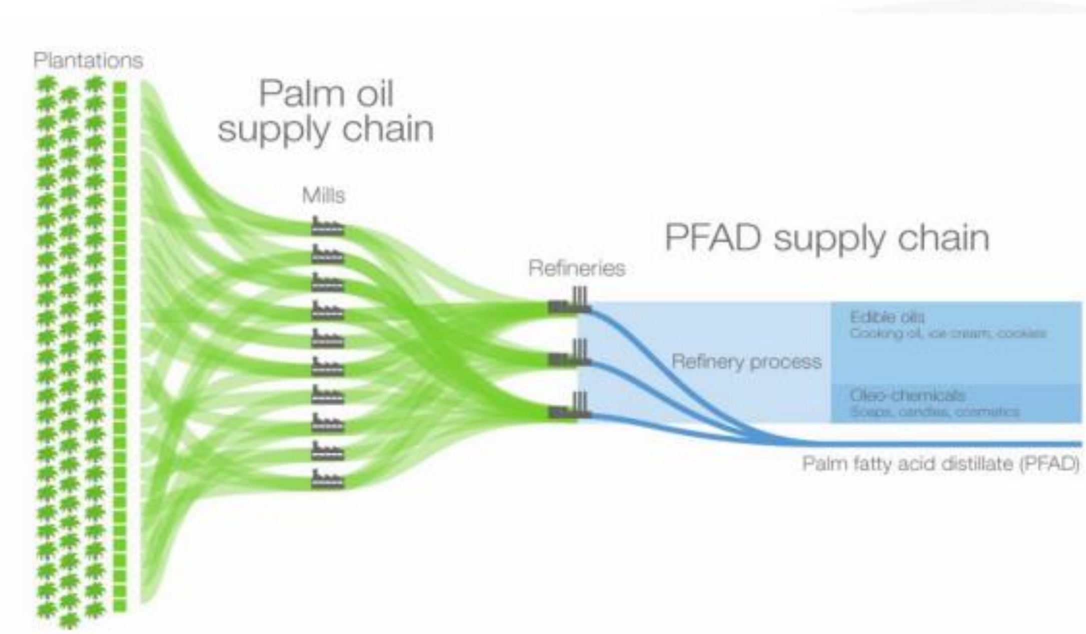


Figure 646. Palm Oil and PFAD Supply Chains

4. Palm Oil Mill Effluent (POME) Palm Oil Mill Effluent is an oily wastewater/sludge generated from palm oil milling during the palm oil production process. The oil contained in the wastewater is called POME oil and settles on top of the wastewater treatment pond. It can be skimmed off and used as feedstock for biofuel production. About 900–1500 L of POME is generated during the production of 1000 kg of palm oil.

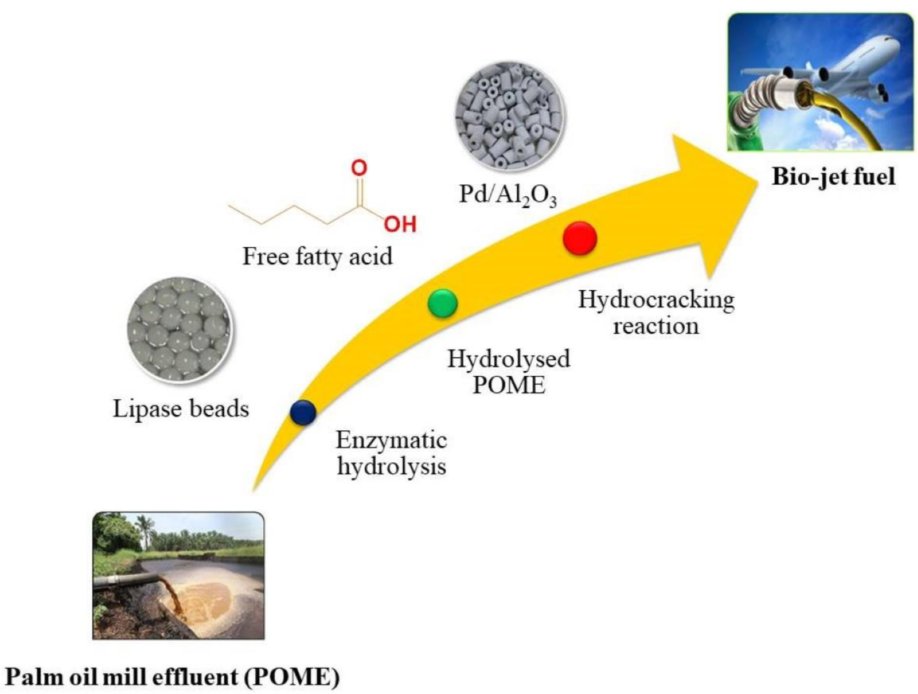


Figure 657. SAF production process from POME

Sustainability-related issues for oil palm feedstock

Palm oil is a controversial topic. The crop spurs economic development, help lift smallholder farmers out of poverty, makes efficient use of land, and is a plentiful source of low-cost biofuels and SAF. Some people cite deforestation, biodiversity loss, water and air pollution, greenhouse gas emissions, soil degradation, and negative social impacts as reasons to limit its use.

The Roundtable on Sustainable Palm Oil (RSPO) defines a set of environmental and social standards that companies must comply with to produce RSPO Certified Sustainable Palm Oil (CSPO). These measures help minimize the negative impact of palm oil production on the local environment, wildlife, and communities. The criteria used by the RSPO are very similar to ICAO's sustainability criteria for the default life cycle emissions for palm oil and its wastes and residues, except for food security. Therefore, palm oil from Côte d'Ivoire that is certified RSPO can potentially meet ICAO's sustainability requirements, and the calculation of Induced Land Use Change values for it should be requested to ICAO, as currently there is no such a value in the CORSIA default life cycle emissions document. The challenge is that most of the production is from smallholders which makes the sustainability verification more time consuming.

Table 18. Feedstock sustainability evaluation systems

EXISTING APPROACHES TO SUSTAINABILITY										
CORSIA Sustainability Theme	**UN FAO SAFA**	**GBEP**	**ISO**	**EU RED**	**ISPO**	**RFS2**	**Bonsucro**	**ISCC**	**RSB**	**RSPO**
Water	X	X	X	X	X	X	X	X	X	X
Soil	X	X	X	X	X	X	X	X	X	X
Air	X	X	X	X	X	X	X	X	X	X
Conservation	X	X	X	X	X	X	X	X	X	X
Waste and Chemicals	X	X	X	X	X	X	X	X	X	X
Human and labour rights	X	X	X	X	X		X	X	X	X
Land use rights and land use	X	X	X	X	X		X	X	X	X
Water use rights	X		X				X	X	X	X
Local and social development	X	X		X	X	X	X	X	X	X
Food security	X	X	X	X		X		X	X	
Total of Themes Covered	**10**	**9**	**9**	**9**	**8**	**7**	**9**	**10**	**10**	**9**

Table 19. Oil Palm sustainability evaluation

ICAO SUSTAINABILITY THEMES
OIL PALM

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue	
Potential issue-need mitigation or control	
Major issue-Needs to be resolved before feedstock can be considered	

Economic and market-oil palm-related issues

Côte d’Ivoire is the second-largest palm oil producer in West Africa, after Nigeria, and produced a record 600 000 metric tons in 2023. As per the Programme National d’Investissement Agricole - PNIA (National Agricultural Investment Plan), increasing palm oil production is a priority for the Ivorian government. More than 70% of oil palm producers in Côte d’Ivoire are small-scale producers who farm according to traditional methods. The balance of the producers are industrial plantations who use best practice agricultural practices, such as fertilization and cover cropping. Palm oil production represents about 3% of Ivorian GDP. It occupies the 5th place in the Ivorian economy and employs more than one million people and contributes to the reduction of poverty in rural areas.

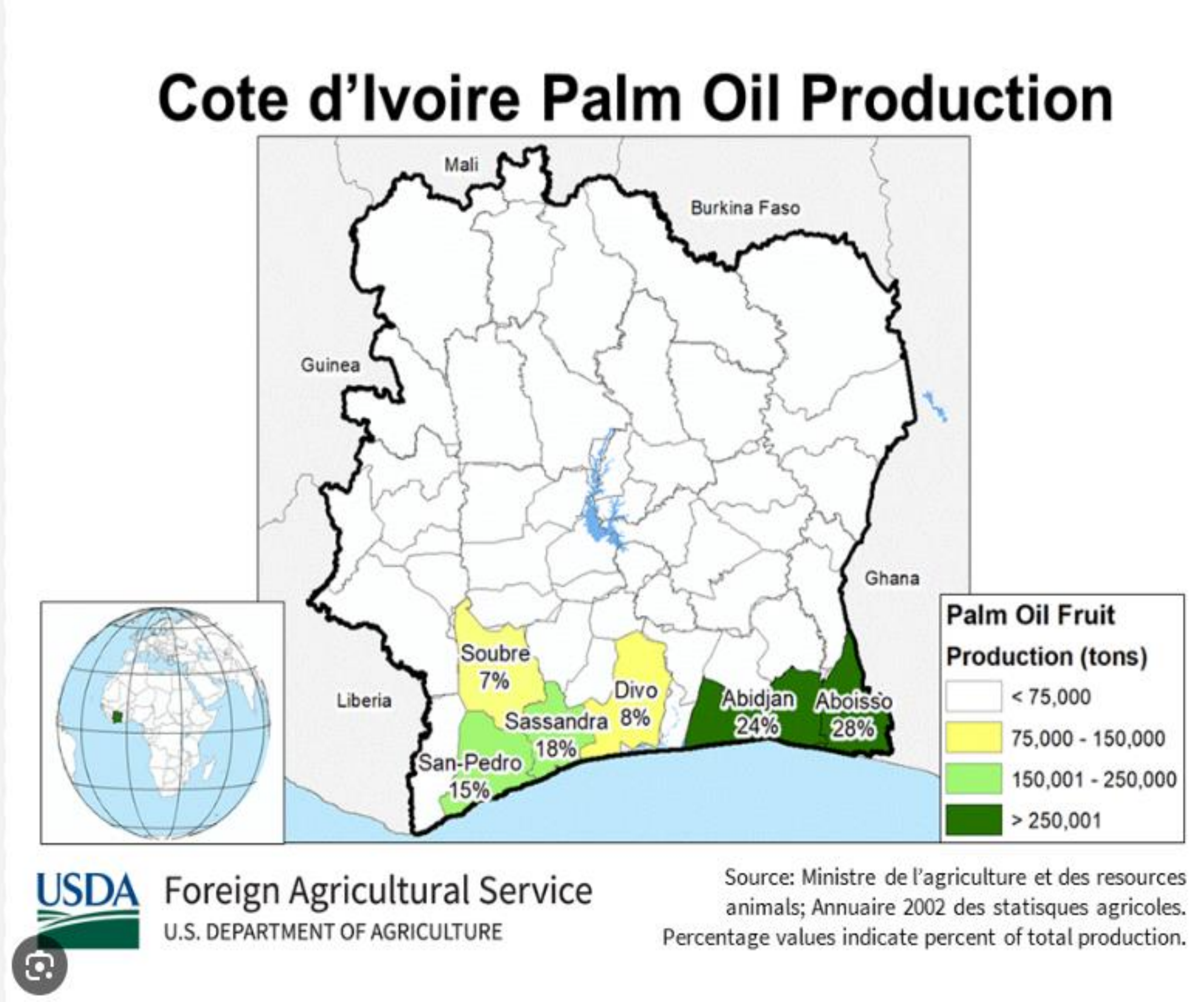


Figure 668. Palm oil production areas in Côte d'Ivoire

Overall assessment of oil palm as a potential SAF feedstock

Palm oil feedstock for SAF has many advantages for Côte d'Ivoire. It is cheap, fits in with the Ivorian agricultural strategy, and has a well-developed technological pathway (HEFA). One challenge is that there is not enough volume for a standalone HEFA plant, but it can be pooled with other lipid-based feedstocks. The world's largest producer of SAF has POME and PFAD amongst one of over 10 different renewable raw materials. The other hurdle to overcome is the perception from some regions in the world that oil palm cultivation is not sustainable, which brings in an associated risk.

Table 20. Palm oil SAF feedstock evaluation

<table>
<tr><td colspan="3">PALM OIL</td></tr>
<tr><td>Feedstock availability</td><td colspan="2">Technology readiness</td></tr>
<tr><td>Qualities</td><td colspan="2">T1: Biomass processing</td></tr>
<tr><td>Very low-cost feedstock
Use as SAF would reduce pollution associated with palm oil wastes.
HEFA process has low capital costs and is well understood.
Eligible for co-processing
Can be pooled with other oil crops</td><td colspan="2">Neither PFAD nor POME is currently used for biofuel production</td></tr>
<tr><td>Constraints/challenges</td><td colspan="2">T2: Fuel Conversion pathways(s)</td></tr>
<tr><td>Sustainability concerns in some jurisdictions such as the EU
Many small farmers make sustainability traceability difficult
Need to change/upgrade palm oil mill processing technologies</td><td colspan="2">HEFA
Co-processing</td></tr>
<tr><td>Risk mitigation options</td><td colspan="2">Technology complexity</td></tr>
<tr><td>Sustainable farming practices
Certified Sustainable Palm Oil (CSPO) certification</td><td colspan="2">Low</td></tr>
<tr><td>Future biomass potential</td><td colspan="2">Economic viability</td></tr>
<tr><td rowspan="4">Good. Increased oil palm production is a priority of the Ivorian government.</td><td colspan="2">High</td></tr>
<tr><td colspan="2">Biofuel/AAF potential</td></tr>
<tr><td>In general</td><td>High</td></tr>
<tr><td>In Côte d'Ivoire</td><td>High</td></tr>
</table>

2.3.4. USED COOKING OIL (UCO) AND ANIMAL FATS

UCO and Animal fat-related Information

The cheapest and easiest method to produce SAF with current technology is by using waste oils such as used cooking oil, animal fats, and other fatty acids. They are a part of the feedstocks often known by their acronym FOGs, which stands stand for Fats, Oils and Greases. Producing SAF from FOGs is mainly done by the HEFA process, the most technically mature SAF conversion pathway. It can also provide feedstock to the CHJ process. Most of the SAF produced and supplied currently is from FOGS derived feedstocks using the HEFA pathway. HEFA SAF produced from UCO and animal fats have the following advantages:

- Waste oils are widely available and have energy density close to the one of the fossil fuels.
- The lower capital costs to build and operate a HEFA refinery (compared to a Fischer-Tropsch, for example) mean that these fuels are likely to be the cheapest source of SAF in the near term.
- Infrastructure is already in place to support large production volumes. HEFA can, and is, produced in refineries that use waste oils for HVO production.
- FOGS feedstocks can be certified under ASTM7566 and co-processed in the SIR refinery, without the need to be a standalone facility.
- These feedstocks avoid sustainability issues associated with using edible crops, such as land use and food security.

Used cooking Oil (UCO)

Used cooking oil is leftover vegetable oil after it is used for frying. It is usually collected from restaurants and other commercial operations but can also be amassed from households.

Animal Fats

Animal fats, such as chicken fat, pork lard, and beef tallow, are obtained during the rendering of wastes and residues generated from carcass cleaning, such as bone, guts, and grease. They can be used to make biofuels but have many other uses such as shortening, other food products, animal and pet food, soap, and heat and power production.

SAF Conversion Pathways

Animal fat and UCO are transported to the HEFA plant, where the oleaginous feedstock undergoes hydrotreatment with hydrogen in the presence of a catalyst. Unsaturated carbon bonds are saturated, and oxygen is removed. Subsequently, the hydrocarbon chains are hydrocracked in different ranges, isomerized and, finally, fractioned, producing SAF and other products, such as diesel, naphtha, and propane.

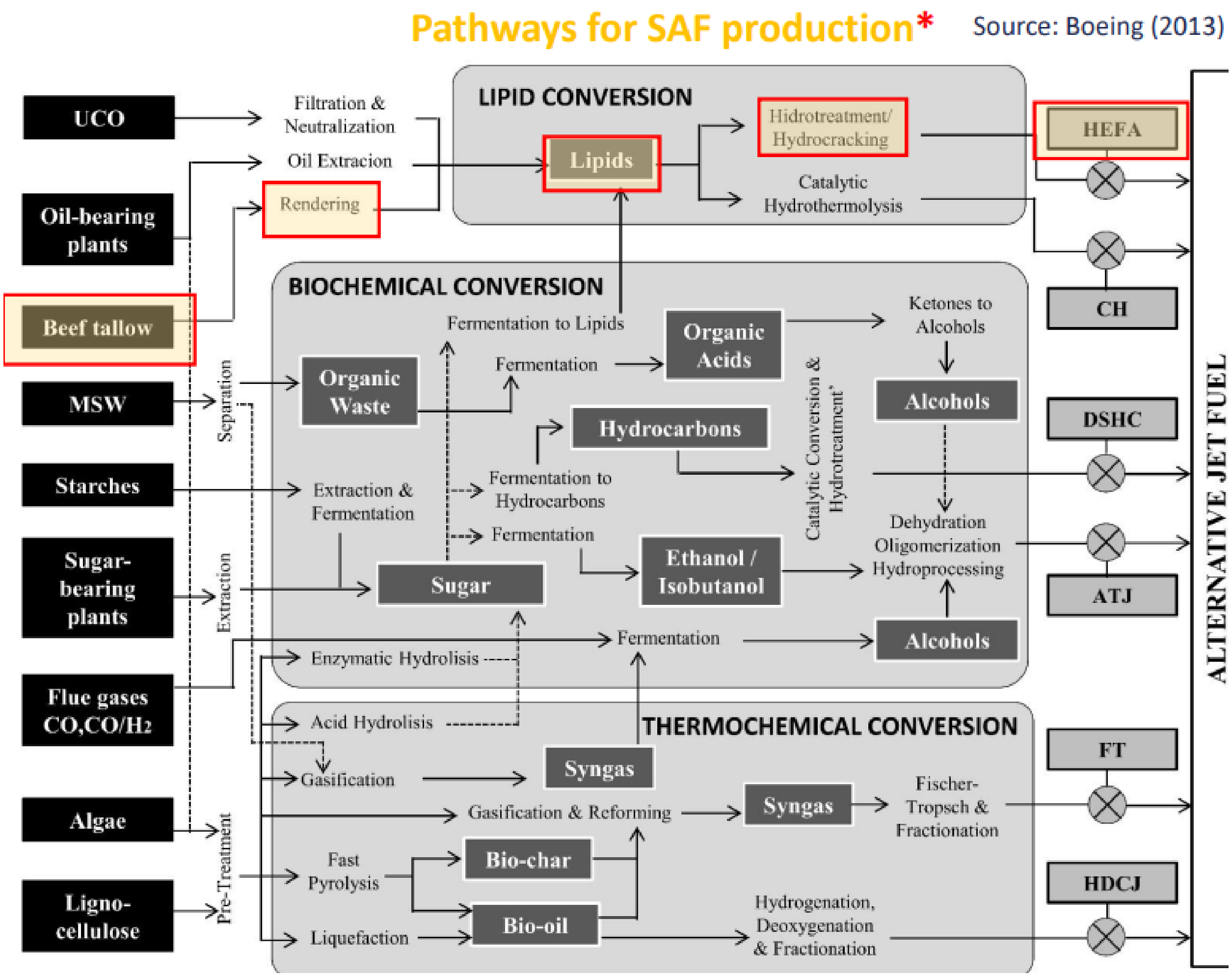


Figure 679. SAF conversion pathways featuring UCO and lipids

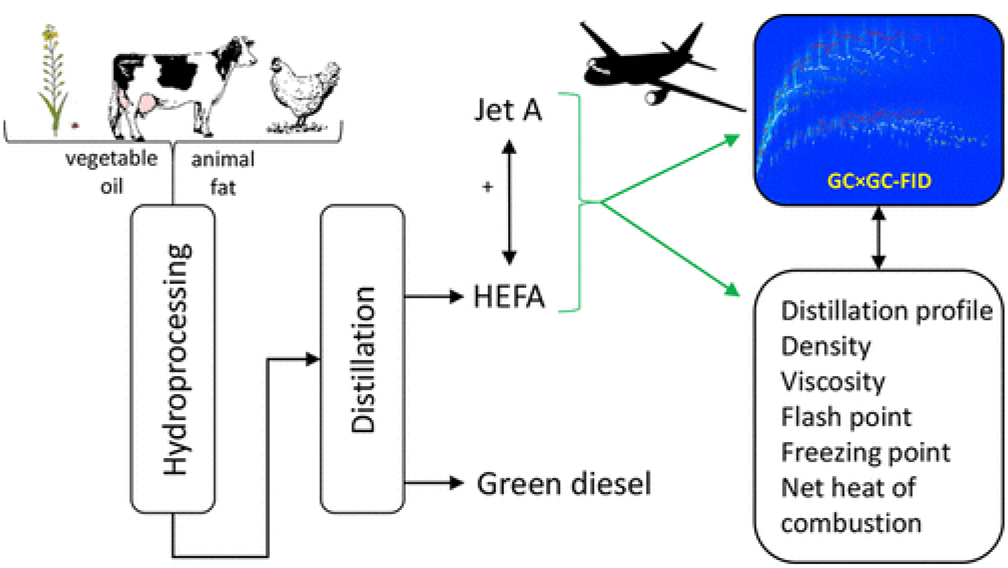


Figure 68. HEFA production from vegetable oils and animal fat

Suitability for use as a feedstock

FOGs can be used to produce SAF and other co-products via the HEFA process or FAME biodiesel that can be blended with petroleum diesel and used in ground equipment.

Estimated potential volume of FOGS feedstock

The following figures show the expected yield of UCO and animal fat feedstocks:

- 525 litres of SAF per metric ton of UCO feedstock
- 672 litres of SAF per metric ton of tallow feedstock

However, unlike for agricultural products, it was not possible to calculate the SAF total potential in Côte d'Ivoire due to the lack of publicly available information regarding production volumes.

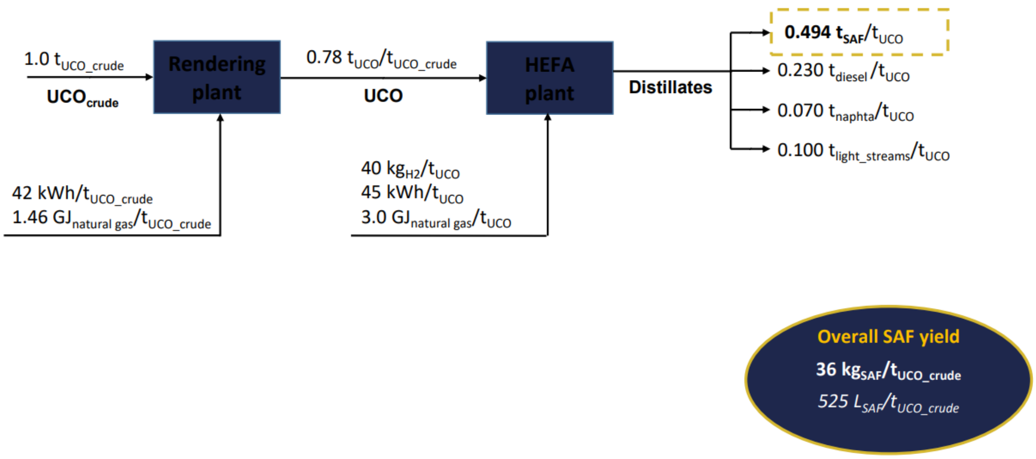


Figure 691. SAF yield from UCO

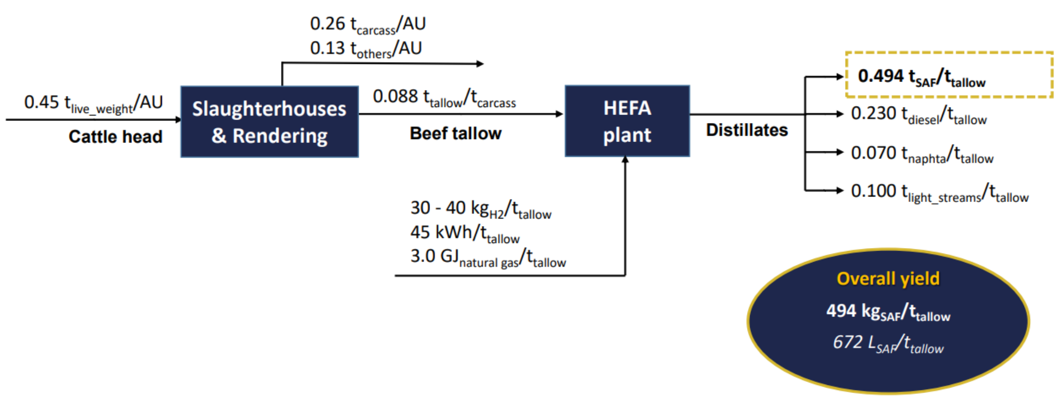


Figure 702. SAF yield from beef tallow

Sustainability-related issues for UCO and Animal Fat

Used Cooking Oil (UCO) is classified as a waste in the ICAO CORSIA positive list of materials[11] and thus has an Induced Land Use Change (ILUC) emissions factor of zero. For the HEFA Fuel Conversion Process, the default life cycle emissions for UCO at global level is set at 13.9 gCO_2e/MJ which, in comparison to the conventional fossil fuel emission factor of 89.0 gCO_2e/MJ, reduces CO_2e emissions by 84.3%.[12]

Tallow is classified as a by-product for CORSIA and has an Induced Land Use Change (ILUC) emissions factor of zero. For the HEFA Fuel Conversion Process, the default life cycle emissions for tallow at global level is set at 22.5 gCO_2e/MJ which, in comparison to the conventional fossil fuel emission factor of 89.0 gCO_2e/MJ, reduces CO_2e emissions by 74.7%. A big sustainability benefit is that using waste FOGs to produce biofuels will help to reduce water and land contamination. If disposed inappropriately - used cooking oils dumped on house sewage or by businesses or landfilled - result in pollution.

Rendering plants also generate a fair amount of fats, oils, and greases (FOGs) for disposal, and their wastewater, if not properly treated before being released downstream, contains a significant number of FOGs. High numbers of these substances in water sources may harm water quality and the environment. Due to these facts, the reuse and recycling of UCO, as well as its valorization such as that for SAF or biodiesel production has environmental and social benefits.

Table 21. FOGS sustainability evaluation

ICAO SUSTAINABILITY THEMES
FOGS

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue
Potential issue-need mitigation or control
Major issue-Needs to be resolved before feedstock can be considered

[11] Table 1 - https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf
[12] For access to updated methodologies, visit https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

Economic and market-UCO and Animal Fat related issues

HEFA synthetic paraffinic kerosene (SPK) produced from used cooking oils and animal fats is currently the most widely used commercial pathway being used at scale to produce SAF.

- SAF production began in 2016 in a converted refinery in Paramount, California and supplies fuel to Los Angeles International Airport and Ontario International Airport. It was the first dedicated SAF refinery in the world and plans to produce 250 million gallons (950 million litres) of SAF annually by 2024 and is building a similar sized refinery in Houston that will double capacity by 2025.
- The world's leading manufacturer of SAF currently operates two refineries in Singapore and Rotterdam that can process approximately 1 million metric tons of waste oils per year with plans to expand its Singapore plant to more than double its current capacity by 2023 (Jaganathan & Samanta, 2019). SAF is available to airlines at a growing number of airports globally and in the Americas, including San Francisco International Airport and Los Angeles International Airport.
- A large petroleum company is planning to convert its San Francisco Refinery in Rodeo, California, into one of the world's largest renewable fuels facilities. The converted facility will no longer process fossil crude oil and instead use waste oils, fats, grease, and vegetable oils to produce an approximately 800 million USG (3 billion litres) per year of renewable transportation fuels, including renewable diesel, renewable gasoline and sustainable aviation fuel. The project is expected to cost USD 850 million and is expected to start production in 2024 pending approval from local and state governments.
- The North America FOG Market size is projected to grow from USD 9.5 billion in 2022 to USD 25.6 billion by 2044, at a CAGR of 4.6% during the forecast period with most of that going into biofuels.

UCO and Animal Fat Initiatives Côte d'Ivoire

In 2014, Florida Biodiesel Inc sold a B-500 biodiesel plant to the Lorymat Corporation in Côte d'Ivoire, Africa with a capacity to 9000 USG (34,200 litres) of biodiesel per day. The process used cooking oil collected locally and from sustainably grown palm oil as a feedstock. The diesel plant also acted as a hands-on educational tool to show students and government agencies how to make renewable energy. Although this initiative never appears to have expanded, it does show the potential of FOGS feedstock in Côte d'Ivoire. An important economic benefit of FOGS feedstocks is that they can help to reduce costs and provide extra income. For example, restaurants traditionally must pay to dispose of UCO. When used for biofuels, they can avoid the cost and be paid for it. Selling animal fat will provide extra income to slaughterhouses and rendering plants.

Challenges and Constraints for UCO and Animal Fat

To use UCO as a SAF feedstock the major challenge is the collection logistics. In certain countries, large fast-food chains such as MacDonalds have set up systems to collect and transport the waste oils to biofuel conversion plants. In certain European countries, programs have been developed to encourage households to recycle their cooking oils. These systems will have to be implemented in Côte d'Ivoire. The biggest challenge for the use of animal fats as a SAF feedstock in Côte d'Ivoire is a lack of rendering capacity. There are only a couple of domestic slaughterhouses and the country imports more than half of its beef consumption. However, initiatives such as a five-year beef cattle production project 9.7 billion CFA francs (US$16.2 million), plans for more chicken production, and other projects aimed at increasing meat self-sufficiency will help to improve animal oil availability in the future.

In both cases, there is a lack of data regarding available quantities and projected future volumes.

Overall assessment of UCO and Animal Fat as a potential SAF feedstock

Although SAF derived from UCO and Animal Fat has many important benefits such as sustainability, cost, and technological readiness, it is difficult to recommend them as a high potential short-term feedstock. There is a lack of data regarding the quantity of used cooking oil available and no collection currently. Given the lower costs, UCO is an option worth exploring in the medium-long term. The opportunity for animal fats should also be considered.

Table 22. UCO and animal fat feedstock evaluation

UCO and Animal Fats		
Feedstock availability	**Technology readiness**	
Qualities	**T1: Biomass processing**	
• Use as SAF would solve pollution problems • Low-cost feedstock • HEFA process has low capital costs and is well understood • Eligible for co-processing	• Neither UCO nor animal fats are currently collected and valorized	
Constraints/challenges	**T2: Fuel Conversion pathways(s)**	
• Lack of collection and logistics processes • Need more animal processing infrastructure • Competition for other uses	• HEFA • Co-processing	
Risk mitigation options	**Technology complexity**	
• Develop UCO collection capabilities • Increase animal processing • Government support for SAF	• Low	
Future biomass potential	**Economic viability**	
• Good. UCO will grow with Abidjan population and animal fats supply will increase with greater domestic processing.	• Medium	
	Biofuel/AAF potential	
	In general	High
	In Côte d'Ivoire	High

2.3.5. OTHER POTENTIAL OIL-BEARING FEEDSTOCKS

The following potential feedstocks were analyzed during the study, but a full quantitative analysis and feasibility determination was not possible due to various reasons such as a lack of production data. Nevertheless, they were evaluated as potential supplemental oil-bearing feedstock for SAF (Jatropha) or biodiesel for GES (cottonseed, shea nuts (karite) and kola nuts). They are briefly described below.

2.3.5.1. JATROPHA

Jatropha is a flowering shrub that grows widely across West Africa in arid areas. Throughout the world, more than 1,000,000 ha of Jatropha has been planted, mostly in Asia and India. It has many qualities that have made it a promising crop for biofuels and SAF. These include rapid growth, drought, and pest resistance. Most importantly for SAF, the inedible seed has a 40-60% oil content, and is second only to oil palm in yield per hectare. The crude jatropha oil (CJO) is used in oil lamps, soaps, and lubricants. However, it is chemically like diesel and can easily be transformed into biofuel and SAF.

Jatropha has many sustainability advantages. Unlike other lipid feedstocks, the crop does not compete with food sources because the seed contains a toxic poisonous substance called curcasin which makes it unfit for human or animal consumption. This reduces the potential for land use conflicts. It grows on marginal land, which brings less land-use issues associated with it, and requires low agricultural inputs. Jatropha plantations can play an important role in rehabilitating degraded lands and supporting reforestation efforts. The seed cake, which is high in nitrogen, can be used to improve soil. Jatropha can grow where other crops cannot in production-insecure regions so it can provide economic benefits for rural and poor areas.

On the downside, in some countries Jatropha plantations have displaced food crops and contributed to deforestation. In addition, the trees take five to seven years to reach maturity, the fruit is difficult to mechanically harvest and is an invasive species in some parts of the world.

Figure 713. Jatropha Plant in Côte d'Ivoire

For many years jatropha oil has identified a high potential SAF feedstock because of its sustainability characteristics, low cost, chemical composition, and operational properties. In 2008, Air New Zealand flew the world's first test flight powered by a 50/50 mix of Jatropha biofuels and fossil jet fuel. The following diagram shows the process of processing CJO into SAF via the HEFA process. As with other oil-bearing feedstocks, the wastes can be used for energy, animal feed and the residues made into SAF via gasification FT process.

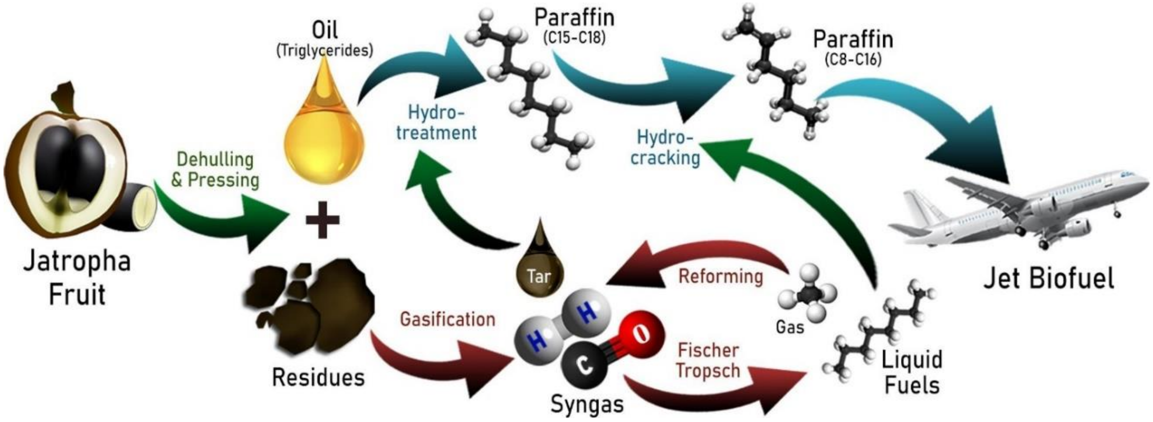


Figure 724. Process to Produce SAF From Jatropha Fruit

Despite the initial promise SAF derived from Jatropha never developed as expected due to various reasons, such as variable yields. Even though Jatropha can grow in marginal conditions it yields more fruit when receiving water and fertilization like other agricultural crops. There is a large Jatropha plantation in Ghana and several small initiatives were undertaken in Côte d'Ivoire. During consultations with key stakeholders, they indicated that they did not consider Jatropha as a high potential SAF feedstock. However, recent improvements agricultural practices have increased yields so it should be kept in mind for the future. In addition, CJO from neighbouring countries such as Burkina Faso and Ghana could be used to supplement domestic oil feedstock or be used for co-processing. For more detailed information on Jatropha feedstock please refer the ICAO SAF feasibility studies for Burkina Faso and Zimbabwe.

2.3.5.2. COTTONSEEDS

Côte d'Ivoire is one of the leading cotton exporters in Africa with production hitting a record 510 000 tonnes in 2022. Unfortunately, a parasite known as "jasside" has infested cotton crops and slashed output forecasts across West Africa for the 2022/23 season slashing Côte d'Ivoire's cotton output by 50% to 269,000 metric tons. Nevertheless, cotton is an important Ivorian agricultural product, and the seeds can be processed into cottonseed oil (CSO). The oil cannot be consumed by humans or animals because it contains a toxic substance called gossypol that must be removed. In addition, it contains trans fats that limits its uses in food products. For example, in 2018, the US FDA (Food and Drug Administration) banned additives containing trans fats, including partially hydrogenated cottonseed oil, from all processed foods. For these reasons, cotton seed is an ideal source for biodiesel production using transesterification, where long and branched chain triglyceride molecules are transformed to monoesters and glycerine biodiesel, known as fatty acid methyl ester (FAME). This is its primary use, but it has also been shown theoretically that cotton seeds and stalks can produce bioethanol (HVO). To-date cottonseed oil has not been used to produce SAF, but it could produce a very interesting biodiesel feedstock for GSE. There is already a cottonseed and soybean cleaning and cottonseed plant with a capacity of 300 metric tons per day. The same company has manufacturing plants in other countries that process other oil nuts.

Figure 735. Cottonseed processing plant

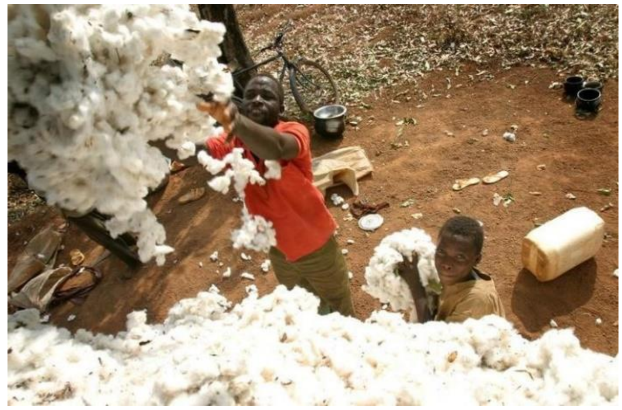


Figure 746. Cotton harvest

2.3.5.3. SHEA NUTS

Shea nuts are primarily grown it the "Shea Belt" in West and Central Africa in the semi-arid Sahel, Shea nut products, the solid fat (butter or stearin) and the liquid oil (olein), are ideal for use in cooking oil, margarine, cosmetics, soap, detergents. Côte d'Ivoire is the fifth-largest producer of shea nuts in the world, harvesting around 40,000 metric tons a year, but the government wants to more than triple that to 150,000 metric tons, it is grown in the northern part of the country, especially in the Korhogo region. Shea butter (karite) is known as "women's gold" because so many women earn money making and selling it and it is a very important source of income for them. Programs such as the UN Women-Government of Cote d'Ivoire have trained from various cooperatives in better manufacturing practices and has improved the equipment in shea butter production facilities so that the products meet international quality standards. The program has provided a climate-smart solution to reducing deforestation, while bolstering rural women's economic empowerment.

Figure 757. Shea nuts

Figure 768. The "Shea Belt" in West Africa

During stakeholder meetings it was suggested that shea nuts could be a potential SAF feedstock. However, the oil from the nut is only suitable for producing biodiesel (FAME) that could be used in GSE. Using the nuts to produce biofuel instead of shea butter would have a very serious negative economic impact on women in rural areas. Coupled with small production volumes, low technological readiness, a lack of logistics, and the difficulty in cultivating the nuts (they only grow wild and produce nuts once every three years), shea nuts should be excluded as a potential SAF or even GSE biofuel feedstock.

2.3.5.4. KOLA NUTS

Kola nuts are indigenous to West Africa and have been traded for centuries. In many parts of the region, they play an in important role in traditional ceremonies like weddings, festivals, coronations, and funerals. They were once one of the key ingredients in Coca Cola. The international profile of kola nuts as a superfood has been on the rise in recent years. Rich in caffeine, the stimulant theobromine, and disease-fighting antioxidants, it is used in energy drinks and numerous medicines. Côte d'Ivoire produces 100,000 metric tons of kola nut annually making the world's largest producers just ahead of Nigeria and Cameroon. Like shea nuts, kola nuts can be made into biodiesel (FAME) suitable for use in GSE equipment. However, like shea nuts, kola nuts have a higher economic and social value as a food item than for transformation into biofuels.

Figure 779. Kola nuts

2.4. RESIDUES AND WASTE

2.4.1. AGRICULTURAL RESIDUES

The lignocellulosic content in agricultural waste and wood residues can be used to produce biofuel and SAF. This feedstock is creating a lot of interest due to abundance and low cost and ability to provide high-value products like ethanol, biofuels, and renewable electricity, Biomass is one of the most abundant renewable sources on earth.

Crop residues are the parts of a plant leftover once the edible part, such as grain or nuts, have been removed. The biomass material can consist of shells, straw, stover, stalks, or leaves that are usually left in the fields as a fertilizer and for other reasons such as pest control. Excess waste can be collected for biofuel protection while leaving enough in the field for fertilization. Collection may not always be feasible due to seasonal availability, quality, transportation logistics and the need for storage facilities. Biomass waste is also produced during processing. Residues contain energy bearing substances such as cellulose and lignin, along with small amounts of sugars, starches, and lignin. Higher lignin levels lower the conversion efficiency.

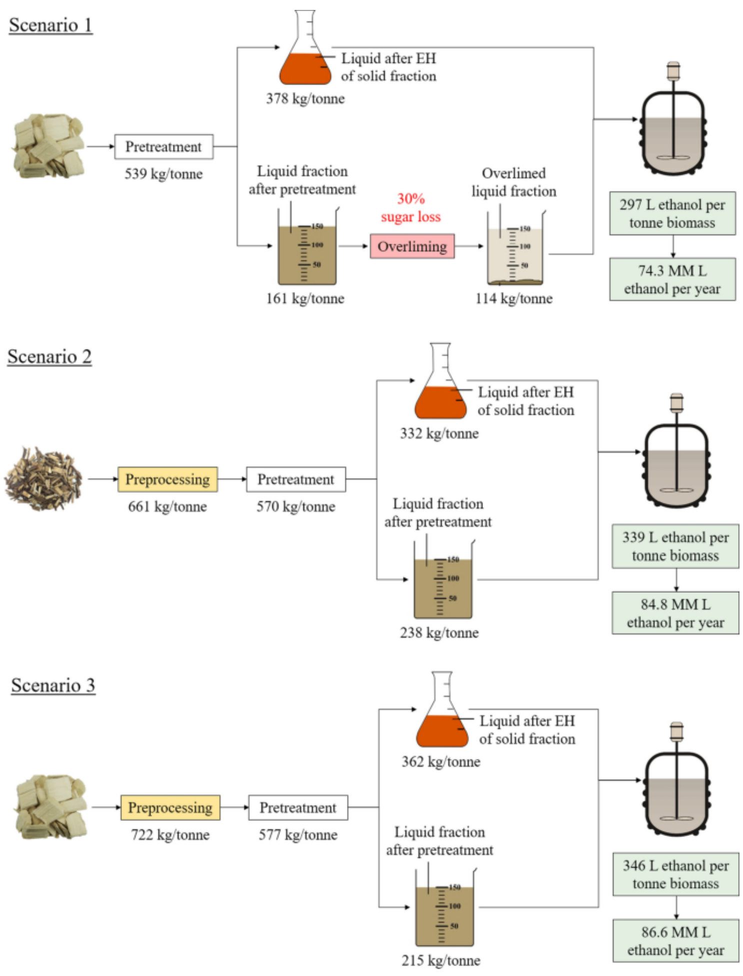


Figure 78. Biofuel yields from biomass waste feedstock

SAF Conversion Pathways

As with MSW, agricultural biomass residue can be made into SAF using two pathways:

1. Gasification and the Fischer-Tropsch process (see the MSW section)
2. Conversion into ethanol and then to SAF via the ATJ process (see diagram below)

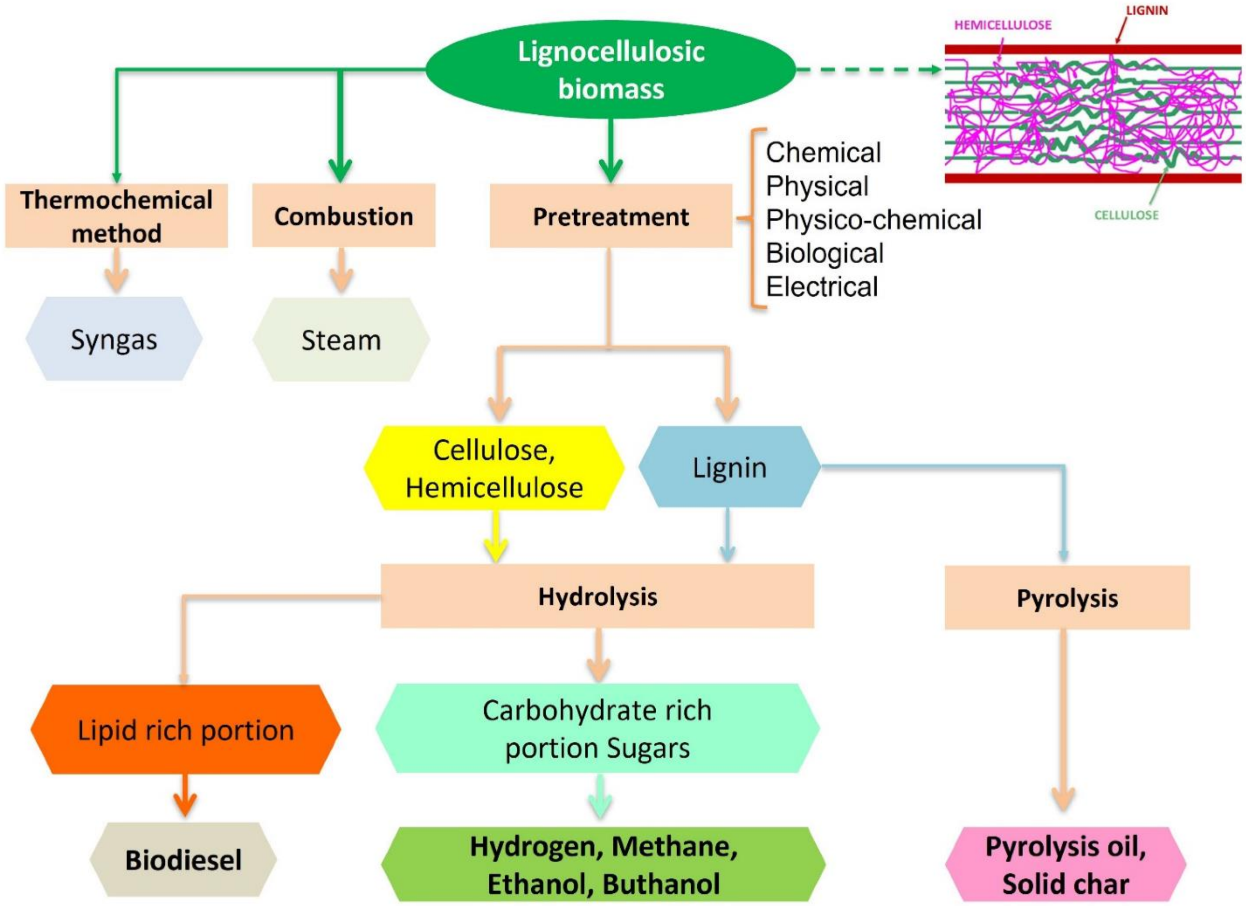


Figure 791. Agricultural waste valorization

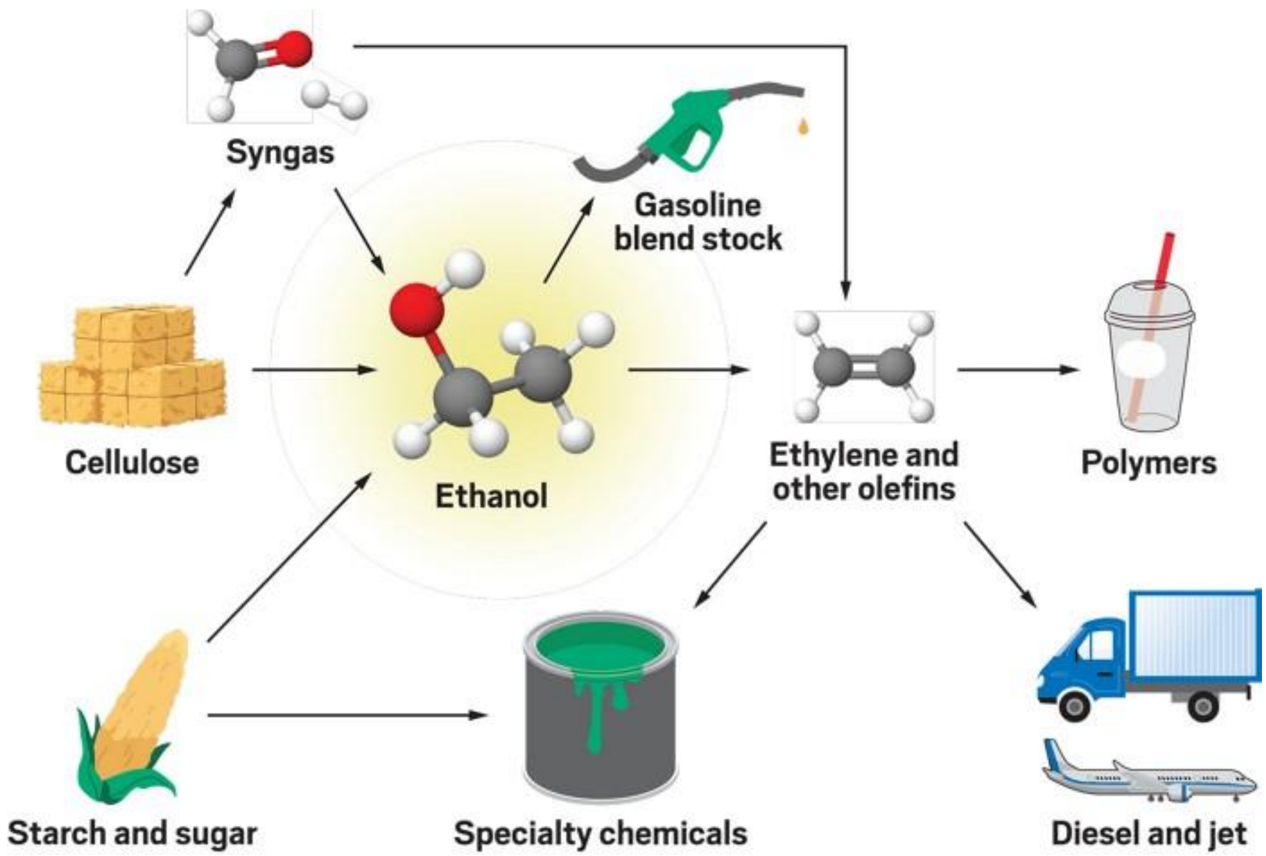


Figure 802. Ethanol as an intermediate to make fuels and chemicals from biomass

Four primary process steps are used to convert the ethanol into SAF:

1. Dehydration - Ethanol is first dehydrated to ethylene/
2. Oligomerization - Ethylene is then **oligomerized** into longer carbon chain olefins.
3. **Hydrogenation** saturates any olefins to paraffin and iso-paraffin.
4. Fractionation - the product is **fractionated** to isolate the SPK jet blend stock as a stable, wide boiling, paraffinic kerosene. The remaining fraction is SPD with superior properties to conventional diesel.

In the report "Study of the Biomass Potential in Côte d'Ivoire," published in June 2022, the Netherlands Enterprise Agency (RVO) indicates that the country's biomass potential is estimated at almost 12,000,000 metric tons per year from these five feedstocks alone:

- Cashews
- Cacao
- Oil palm
- Rubber
- Cassava

In addition, significant additional agricultural waste comes from corn stover, rice husks, forestry residues, coconut shells and husks, maize stover, banana leaves, shea nutshells, kola nutshells and many other agricultural residues.

Bioethanol yield varies widely depending on processing technology as well as such factors as crop yield, amount of residue generated, energy content of the crop and composition. It has been estimated that with proper management, researchers estimate an average of 2.45 billion metric tons of cellulosic biomass could be available in the United States each year for fuel conversion—providing ap potential ethanol yield of 1.02 trillion litres.

A potential of 12 million metric tons of biomass Côte d'Ivoire could potentially yield billions of litres of ethanol and hundreds of millions of litres of SAF. If only a fraction of the potential is realized; it would be more than enough to meet the country's domestic needs and provide export opportunities.

Sustainability-Related Issues for Agricultural Waste

Agriculture and wood biomass waste feedstock have an inherent sustainability in that they do not compete with food crops. Using agricultural waste to produce SAF helps to fight climate change and air pollution by reducing GHG emissions caused by their decomposition or burning to clear fields for planting. Another way in which agricultural waste harms the environment is through the release of heavy metals and other toxic substances. These materials can leach into the soil and groundwater, contaminating the food chain and posing a threat to human and animal health. In terms of socio-economic benefits, agriculture and woody biomass l waste can provide extra income for farmers, reduce disposal costs, and create jobs in collection, transport, and transformation.

The ATJ process produces CO_2 emissions can be sequestered or used in another process in order to maximize the life cycle carbon reduction benefits. That is the reasoning for the consideration of co-locating ATJ and FT plants. The CO_2 emission from the ATJ can provide a feed for the FT process. Agricultural residues are contained in the ICAO CORSIA positive list of materials[13] and thus has an Induced Land Use Change (ILUC) emissions factor of zero. For the Fischer-Tropsch Fuel Conversion Process, the default life cycle emissions for agricultural residues at global level is set at 7.7 gCO_2e/MJ which, in comparison to the conventional fossil fuel emission factor of 89.0 gCO_2e/MJ, reduces CO_2e emissions by 91.4%.

For the Ethanol-to-Jet Fuel Conversion Process, the default life cycle emissions for agricultural residues at global level is set at 39.7 gCO_2e/MJ for the standalone conversion design and 24.6 gCO_2e/MJ for the integrated conversion design, corresponding to emissions reductions of 55.4% and 72.4% respectively.[14]

[13] Table 1 - https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[14] For access to updated methodologies, visit https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

Table 23. Agricultural residues sustainability evaluation

ICAO SUSTAINABILITY THEMES
AGRICULTURAL RESIDUES

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	
10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue	
Potential issue-need mitigation or control	
Major issue-Needs to be resolved before feedstock can be considered	

Economic and market-related issues

Given the limited availability of other SAF feedstocks, such as FOGS for the HEFA pathway, the utilization of biomass waste materials as feedstocks for SAF production is crucial for future demand, cost minimization, and environmental protection. There are several biomass to SAF projects in the rest of the world. A brief description of some of the major ones is given below:

- **2021: A Canadian company** demonstrated the feasibility of producing SAF from woody biomass using a proprietary thermochemical process which won Canada's "Sky is the Limit" organized by Natural Resources Canada. A date for full commercialization has not yet been announced.
- **2023**: **An American company** is constructing the world's first alcohol-to-jet sustainable aviation fuel (SAF) production plant in Freedom Pines, Georgia, USA that will produce 38m litres (10 million USG) of SAF and renewable diesel from ethanol using agricultural residue feedstock.
- **2026:** Project Speedbird, will produce 100m litres of SAF from agriculture residues and wood waste in Northeast England.
- An **American** company is planning a wood waste gasification and Fischer-Tropsch refinery in Bon Weir, Texas, that will make about 100 m litres jet fuel, diesel, and naphtha from 1 million metric tons of wood waste. It is claimed that by capturing and sequestering CO_2 from fermentation and heat generation, the plant will yield negative CI scores. No production date was announced but the project is expected to cost $ 1.7 billion.
- A US-based company makes pyrolysis oil from forestry waste and other woody biomass and then upgrades it into jet fuel. It has pilot and demonstration plants in the Netherlands and is eyeing

commercial facilities in Europe and North America. The company is working with Boeing to test its fuels in commercial airliners, but no date has been announced for refinery construction.

Waste to Energy Initiatives From Agricultural Waste in Côte d'Ivoire

The Biovea power project is a 46 MW capacity biomass power plant under construction in the Aboisso region of the Côte d'Ivoire. It is the largest biomass power plant in West Africa and will be fuelled by oil palm residue. Its operation will create 1,000 full-time local jobs. It will be powered by approximately 450,000 metric tons per year of locally grown palm leaves, 70% of which will be collected from 12,000 community growers. This will increase the annual income of local farmers by up to 20% and they will be able to use the combustion ash as a natural fertilizer.

The plant is under construction and will enter operations in 2025, generating 336 GWh per year, meeting the electricity needs of 1.7 million people per year. The project was developed in the context of the "Plan d'Actions Nationales des Énergies Renouvelables de la Côte d'Ivoire 2014-2030" to increase the share of renewables in the energy mix to 42% by 2030. Its purpose is to support the agro-industrial sector and contribute to the objectives set by the country in the Paris climate agreement. It will also enable the country to reduce its greenhouse gas emissions by 4.5 million metric tons of CO_2 over 25 years.

The estimated cost is €232m ($276m) which will be financed by Agence Française de Développement's (AFD) subsidiary Proparco and Emerging Africa Infrastructure Fund (EAIF). The funding includes a loan amount of €165m ($196m) and a grant of €13m ($15m) corresponding to 70% of the project cost. The remaining financing will be provided by the Biovéa Energie shareholders.

A tri-party agreement was signed between l'Agence nationale d'appui au développement rural (ANADER), Total Energie Marketing Côte d'Ivoire and the Swedish company Scania to make biofuels in Côte d'Ivoire from the following wastes:

- Rubber seeds
- Cassava peels
- Banana waste
- Poultry droppings

The project's objectives are to reduce GHG emissions and provide supplementary income for farmers.

Figure 813. Biovea biomass plant under construction in Aboisso region

Challenges and Constraints

Despite the tremendous potential of agricultural residues and woody biomass feedstocks in terms of volume, availability and cost, several serious challenges need to be overcome in order to establish a viable industry in Côte d'Ivoire and elsewhere.

The biggest challenge is that the feedstock is very attractive to other industries than aviation resulting in feedstock competition. Alcohol products from feedstock processing can be worth a lot more in other applications. For example, isobutanol can earn more when it is sold as a chemical and ethanol are widely used in road transport without the need for costly upgrading to SAF. Biomass can also be burned to provide energy as demonstrated by the BIOVEA project in Aboisso region. The objective to increased electrical production can therefore be in direct conflict with SAF production. Another challenge is the high capital cost of the ATJ facilities. Finally, climate change can create uncertainty and risk for agricultural and woody biomass future supply. For example, in Canada wildfires caused by climate change have burned huge swathes of forest that was a potential supply of woody biomass.

An additional challenge is that the conversion pathway for agricultural waste and woody biomass is not as technically advanced as for other technologies such as sugar and starch-based ATJ, HEFA and FT. It is often said in the industry that cellulosic ethanol has been 5 years away for decades. In the past millions of dollars have been spent on failed cellulosic conversion plants. The projects failed for several reasons. First, there was a lack of adequate collection, distribution and storage systems may supply to plants unreliable. Second, the feedstock was often dirty and abrasive which damaged plant equipment. Third, cellulosic biomass is also a diverse category of materials with different characteristics that not all equipment could handle. Finally, the technology to separate cellulose and hemicellulose from lignin was not advanced enough. Today these issues are much better understood but these factors must be taken into consideration when panning a new plant.

The final hurdle is the capital costs of the projects. As we have seen elsewhere, a cellulosic biofuel plant can cost upward of a billion dollars. Before construction can begin millions needs to be spent on engineering studies. Government and private funding will be essential. For example, LanzaJet's Freedom Pines Fuels SAF plant in Georgia was only made possible by a $US50 million grant from the Bill Gates Breakthrough Energy fund, as well as financial support from the US Department of Energy , the Microsoft Climate Innovation Fund and investments from Suncor, Mitsui & Co and LanzaTech ,British Airways and Shell. The Biovea waste-to-energy plant in Aboisso provides a template for how a waste-to SAF plant could be financed in Côte d'Ivoire and fit into the Ivorian government's climate action and socio-economic improvement.

Overall assessment of agricultural and forestry residues as a potential SAF feedstock

Given the large potential volume, low cost, energy potential and sustainability benefits, agricultural and woody biomass is a very seductive potential SAF feedstock. However, much work remains to be done to realize the potential. The government needs to decide whether the feedstock priority is for biofuel or energy production or both. If so, policy needs to be developed that includes incentives to attract investors. More study needs to be done to choose the optimum feedstock answering questions such as whether it is better to use a single source or mixed waste. Studies need to be carried out on logistics and storage requirements. Ivorian universities and specialized international agencies will play a critical role. In conclusion, agricultural and woody biomass has potential as a SAF feedstock but is more of a medium to long-term solution.

Table 24. Agricultural and forestry residues SAF feedstock evaluation

Agricultural and Forestry Residues	
Feedstock availability	**Technology readiness**
Qualities	**T1: Biomass processing**
• Massive volumes available • Low-cost feedstock • Great opportunity to valorize waste • Additional revenues source for farmers • Pollution reduction (air, water, soil) • Technologically mature conversion pathways	• A small amount of biomass is currently being collected and valorized (ex. plant residues)
Constraints/challenges	**T2: Fuel Conversion pathways(s)**
• No established collection system for many types of waste (collection, storage, transportation) • Geographically dispersed feedstock • FT conversion is expensive • ATJ from woody biomass not as advance as for other ATJ feedstocks • Competition for biomass from other industries (ex. Power generation)	• FT • ATJ

• Renewable biofuels (ethanol, isobutanol, etc.) can command higher prices from other industries		
Risk mitigation options	**Technology complexity**	
• Development of logistics systems • International financing • Government policies that prioritize SAF over other biomass uses	• Medium-high	
Future biomass potential	**Economic viability**	
• Excellent. As agricultural production increases, the amount of associated waste will increase as well.	• Medium	
	Biofuel/AAF potential	
	In general	High
	In Côte d'Ivoire	High

2.4.2. MUNICIPAL SOLID WASTE (MSW)

MSW-related Information

Municipal Solid Waste, more commonly known as garbage, trash or rubbish, are used and discarded nonhazardous items from households, businesses, organizations, and factories. MSW is a mixture of energy-rich materials such as paper, plastics, yard waste, food and products made from wood. It is called municipal because it is usually the responsibility of local governments and municipalities who collect and deliver it to landfills.

MSW contains a large percentage of organic materials rich in carbon and hydrogen. For this reason, MSW was identified as a potential non-fossil fuel feedstock many years ago. In the United Stated first-generation research was followed by construction of refuse-derived fuel systems and pyrolysis units in the late 1970s.

SAF Conversion Pathways

SAF from MSW can be produced by two pathways;

1. Biochemical conversion to ethanol and then into SAF via the **ATJ pathway**. In the process, MSW is sorted and then shredded into small particles. These are then pretreated (pre-hydrolysis) with chemicals and heated to improve sugar formation. After pretreatment the mixture undergoes hydrolysis with enzymes to produce sugars. The sugars are then fermented into ethanol which can then be made into SAF via the ATJ process. Higher food waste contents in the MSW produce better yields since they are more easily broken down than wood, paper, and cardboard.

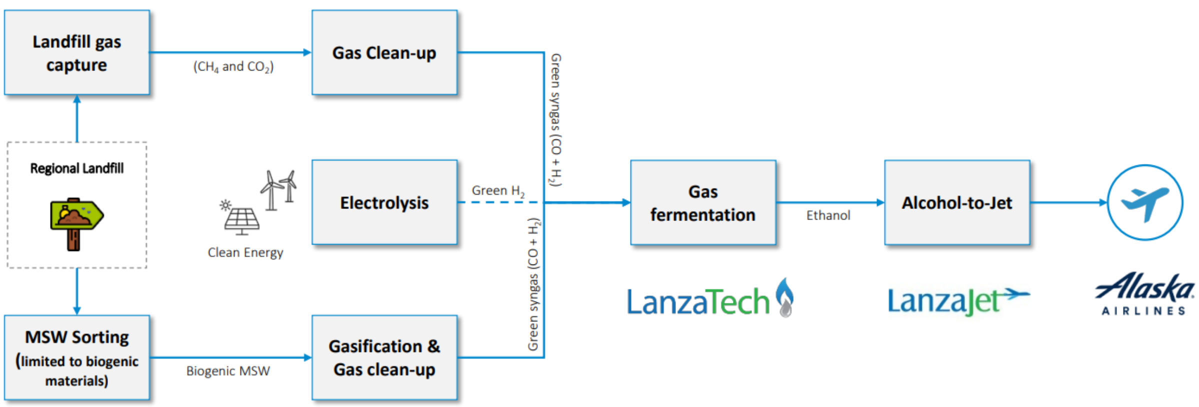


Figure 824. ATJ SAF Process From MSW Feedstock

2. **Thermochemical conversion via gasification and the Fischer-Tropsch Pathway.** The MSW is sorted, shredded to a small size, and dried to reduce gasification energy,

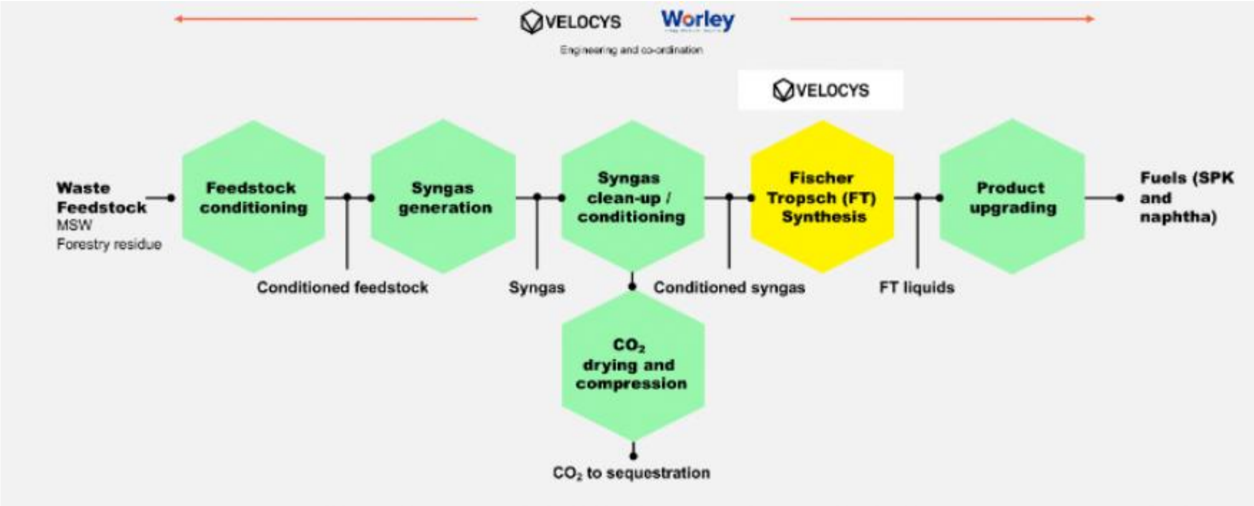


Figure 835. FT SAF process from MSW and forestry waste

After cleaning to remove impurities, the hydrogen and carbon monoxide present in the syngas can be converted into synthetic crude oil via Fischer–Tropsch (FT) synthesis which creates long-chain hydrocarbons by using a catalyst. The synthetic crude oil from FT synthesis is then upgraded and refined to fuel products. It should be noted that production of synthetic aviation fuel via FT synthesis has been done in South Africa since 1999 and is commercially used at Johannesburg International Airport. The fuel is synthetic but not sustainable according to the definition of SAF because coal is used as feed for syngas production. Nevertheless, it highlights the technology readiness level of synthetic aviation fuel production for the FT process. In addition, by using carbon capture and green electricity very high life cycle emission reductions are possible. Some companies even claim negative CI values.

Suitability for Use as a SAF Feedstock

According to the World Bank, the world generates more than 2 billion metric tons of MSW annually; a figure that's expected to grow to 3.4 billion metric tons by 2050. In places with collection systems, there are two traditional paths for un-diverted MSW: landfill and incinerator. Neither solution is ideal, creating environmental pollution and land space problems. This is why using MSW to produce alternative fuels such as SAF is so attractive, especially in developing countries where governments and municipalities are challenged with how to properly manage continuously growing quantities of municipal and industrial waste streams. Urban areas in developing countries often lack collection systems so waste is often indiscriminately dumped in public places and upon areas where it degrades or is burned to get rid of it.

A large percentage of Côte d'Ivoire's population and industry is concentrated in Abidjan and the city will continue to grow. The high urban concentration produces a lot of waste. Using MSW to produce SAF would reduce aviation life cycle emissions while alleviating the environmental problems caused by current landfill and disposal practices.

Putrescible	45.42
paper-cardboard	14
Leaf	2
Wood	4
Bone and straw	3.42
Textiles	2.75
Glass	2.5
Metals	1.75
Plastics	8.5
Stone	1
Battery	1.41
Sand, dust	13.25

Annual average of the waste composition in Abidjan [6].

Figure 846. MSW composition in Abidjan

Estimated potential volume of MSW feedstock

According to the 2018 study, "From Municipal Solid Waste to Energy: Possibilities in Abidjan" (Côte d'Ivoire and The International Organization for the sustainable management and valorization of waste and mineral raw materials "Gevalor") the average daily per capita production of waste in Côte d'Ivoire is between 0.2 kg and 0.8 kg/capita/day with a forecast annual increase in per capita waste production of 7%/year. Collected waste is 75-85% of total generated waste and the rest are recycled and illegally disposed. It is estimated that the city of Abidjan currently generates between 1.5-2 million metric tons of waste a year.

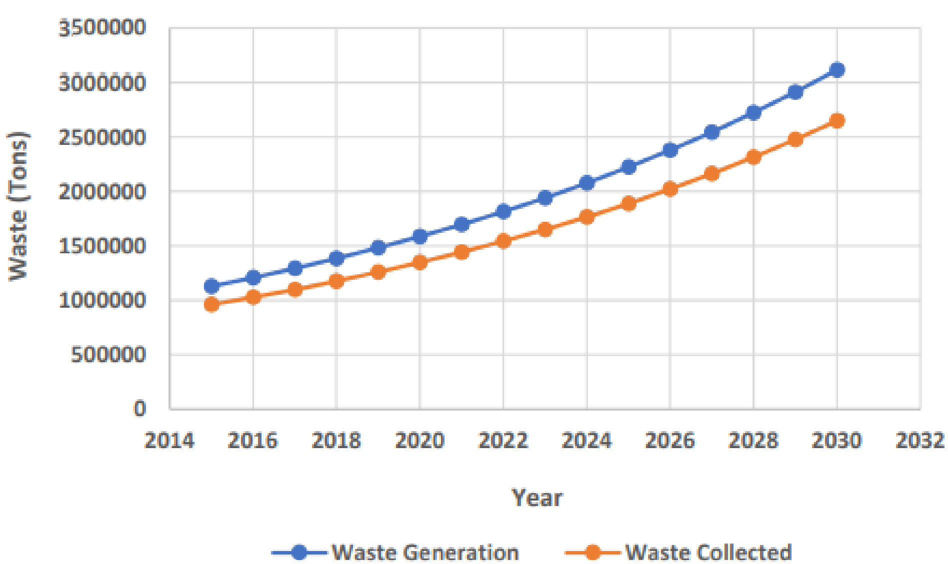


Figure 857. Project MSW volumes in Abidjan

Sustainability-related issues for MSW

MSW derived SAF has several advantages as a potential SAF feedstock over agriculture feedstocks. It is plentiful and cheap. Often it is free, and some places even pay to have it processed. Municipalities typically carry out part of the feedstock collection process. MSW does not compete with food crop base fuels, thus avoiding food security and land-use issues. It reduces landfill requirements which is important as there is progressively less space available and recovers energy stored in waste items. In addition to the GHG reduction benefits of displacing petroleum fossil fuel, it prevents the methane and CO_2 emissions that are produced from landfills.

Despite all the benefits, producing SAF from MSW can have challenges. Sorting is important because mixed waste is very diverse, and MSW can contain contaminants. FT is a well-established process, but the feedstock needs to be free of contaminants. It also requires a high level of input energy. Finally, there might be competition for MSW feedstock if it is used in waste-to-energy facilities where it is burned to created electricity.

An issue that has been brought up in using MSW for SAF is the composition of the MSW. If it is mostly biomass, such as food waste, paper, cardboard and wood, then the CO_2 it contains was originally drawn from the atmosphere and there are life cycle carbon emissions. However, if the MSW contains plastic from fossil sources, and other fossil-based products, then there are no life cycle emissions reductions, and the resulting fuels are essentially equivalent to any other fossil fuel and emit greenhouse gas emissions. CORSIA methodology for MSW defines that only the biogenic proportion of the MSW can be accounted for emissions reductions.

Table 25. MSW sustainability evaluation

ICAO SUSTAINABILITY THEMES
MUNICIPAL SOLID WASTE

CO_2 reduction themes	
1. Greenhouse gases	Green
2. Carbon stock	Green
3. Greenhouse gas emissions reduction permanence	Green
Environmental themes	
4. Water	Green
5. Soil	Green
6. Air	Green
7. Conservation	Green
8. Waste and chemicals	Green
9. Seismic and vibrational impacts	Green
Socio-economic themes	
10. Human and labour rights	Green
11. Land use rights and land use	Green
12. Local and social development	Green
12. Water use rights	Green
14. Food security	Green

Positive contribution/no issue	Green
Potential issue-need mitigation or control	Yellow
Major issue-Needs to be resolved before feedstock can be considered	Red

Economic and market-MSW-related issues

While HEFA synthetic paraffinic kerosene (SPK) using used cooking oils and animal fats is currently the most widely used commercial pathway being used at scale to produce SAF, several projects using MSW feedstock are in service or in development. In the UK, a Royal Society study involving numerous UK scientists and experts looked at four alternatives to traditional kerosene-based aviation fuels – biofuels, hydrogen, ammonia, and synthetic e-fuels. They analyzed feedstock availability, life cycle analysis, cost implications, technology readiness, safety concerns, non-CO_2 impacts and operational considerations. MSW was identified as one of the most promising and is the preferred pathway of three out of eight current SAF projects ongoing in the UK. There are many other MSW derived SAF projects in the rest of the world. A brief description of some of the major ones is given below:

- **2022:** A company **based** in Reno, Nevada, USA, operates the world's first commercial-scale waste-to-fuel SAF plant with a production of over 40 million litres per year. It started operations in May 2022 and produced the first ever synthetic crude oil from landfill in December 2022. The company has contracts with waste management companies to supply the MSW is separated and sized in small pieces, then trucked to the biorefinery. About half of the delivered MSW isn't usable and gets either landfilled or trucked to a recycling centre.
- **2025:** A California is building a plant in California and will initially deliver 50,000 metric tons of SAF made from MSW via FT in 2025 with annual incremental increases over ten years, leading to 200,000 metric tons being delivered in 2034.
- **2026:** A Canadian company**,** in collaboration with a major petroleum company is planning a waste-fuel SAF plant in Rotterdam, the Netherlands. The project would process up to 360,000 metric tons per annum of recycling rejects and produce up to 80,000 metric tons of renewable products, of which around 75% could be SAF and the remainder used for road fuels or to feed circular chemical production. Planned production start is 2026. The same Canadian company opened waste-to-fuel biorefinery in Edmonton, Canada was in 2014 that is operational today.
- **2027**: A British company in collaboration with a major airline is expected to produce 60m litres per year of SAF from municipal waste in Immingham England. The plant will take over 500,000 metric tons per year of household and office waste including non-recyclable plastics.
- **2027:** A company is building a 83.7kt/y plant in Ellesmere Port, Cheshire, the UK to make SAF MSW using the FT process
- **2028:** The Alfanar Energy Project Lighthouse in Teeside the UK is building an 86.6 kt/year plant using MSW and FT. The plant is expected to cost over $US1 billion.

Figure 868. Fulcrum SAF plant in Reno, Nevada that uses MSW feedstock

Waste to Energy Initiatives Côte d'Ivoire

In addition to the studies listed above, in 2009 the Abidjan Municipal Solid Waste-to-Energy Project, a UN CDM initiative was carried out. The study analyzed the feasibility of using anaerobic fermentation of 200 000 metric tons per year of MSW to produce 25 GWh of electricity. After the anaerobic fermentation, residual waste was to be transformed into compost through aerobic treatment and sold to local farmers. This initiative shows that MSW can be converted into value-added products, but also that there are other potential uses for this feedstock,

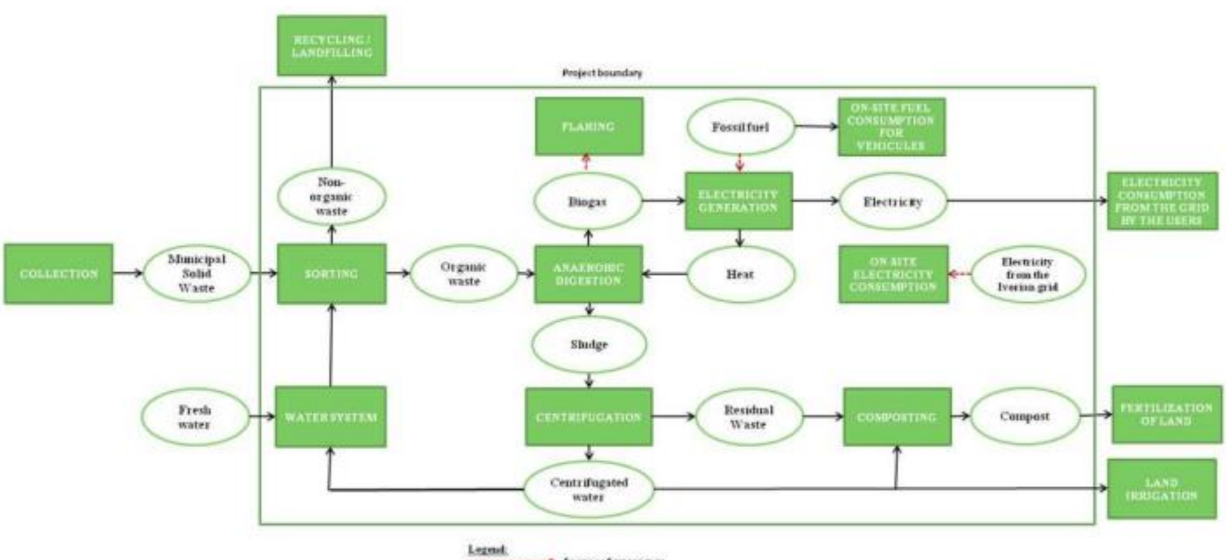


Figure 879. MSW valorization

In 2019, the Akouédo landfill was closed and will be rehabilitated into a park and environmental centre.

Challenges and Constraints for MSW

Although MSW is one of the preferred SAF feedstocks in many areas of the world, will face some special implement challenges. The first is logistics. The countries that are building MSW SAF plants have well-developed MSW sorting and collection systems that have been operating for years. As mentioned, the efficiency of the gasification and FT conversion process is highly dependent on the homogeneity of the feedstock. This will require separation at the source by residents, businesses, and organizations. This typically takes a lot of education and promotion before it becomes effective. In addition, it will require new or upgraded infrastructure, such as sorting facilities, and collection systems.

The second challenge is financial. A SAF MSW FT facility is very capital-intensive, costing upward of 1 billion dollars. Government funding in the UK and North America was a critical success factor in launching similar projects. Construction and operation of the plant will require significant private and public financing.

The final hurdle is to ensure that the MSW feedstock will produce SAF that meets sustainability criteria so that the full environmental GHG benefits can be realized. This will take more thorough study and analysis.

Overall Assessment of MSW as a Potential SAF Feedstock

MSW is a promising potential SAF feedstock for Côte d'Ivoire. There are ample quantities, the FT and ATJ conversion technologies are well established, and it would provide significant environmental and social benefits. However, much additional study needs to be undertaken before it can be implemented. Although several studies have been done, further characterization of the MSW must be undertaken to determine the composition including the percentages of organic, non-organic, and fossil oil (ex. plastic) material. Comparison studies need to be done to compare whether it is better to use MSF for SAF or if it could be better employed for other purposes, such as waste-to-electricity generation. Once this is done, a sustainability assessment needs to be done to evaluate feedstock conformance to standards set by ICAO.

The next step would be to do a techno-economic study to compare and choose the best conversion pathway (FT vs. ATJ). These are interesting projects for Ivorian and international universities and can be done in parallel. Once the conversion process has been chosen, detailed costing and engineering studies need to be undertaken. The high capital cost of the facilities will require international and private financing.

These activities will all take time, and it is recommended that they start as soon as possible. For these reasons, SAF production from MSW is a medium to long-range alternative needing at least 5-10 years before it can be fully implemented.

Table 26. MSW SAF feedstock evaluation

MSW (Municipal Solid Waste)		
Feedstock availability	**Technology readiness**	
Qualities	**T1: Biomass processing**	
• Lots of feedstock available and growing • Conversion to SAF will reduce pollution • No land or food use issues	• There is no current process to treat municipal waste	
Constraints/challenges	**T2: Fuel Conversion pathways(s)**	
• Lack of waste collection systems • Need better characterization of waste • Competition from waste-to-energy	• FT	
Risk mitigation options	**Technology complexity**	
• Collection and logistics development • Characterization studies • FT technology development • Government polices to promote SAF production from MSW	• Low	
Future biomass potential	**Economic viability**	
• Excellent. As Abidjan's population continues to grow, the amount of waste generated will increase.	• Medium	
	Biofuel/AAF potential	
	In general	High
	In Côte d'Ivoire	High

2.4.3. CAPTURED CARBON DIOXIDE

CO_2 feedstock -related Information

There are 3 key inputs needed to produce power-to-liquid synthetic aviation fuel, also known as e-SAF:

1. Carbon dioxide (CO_2) captured from an industrial emitter such as a steel mill or cement factor. This is called point capture. It can also be removed directly from the atmosphere by a process called direct air capture (DAC), although this results in a much lower CO_2 concentration than for point capture.
2. Renewable electricity from sources such as solar, wind or hydroelectricity.
3. Hydrogen produced by water electrolysis,

Renewable energy is used to power electrolyzers to produce renewable (green) hydrogen. Captured CO_2 is converted to carbon monoxide and mixed with green hydrogen and turned into liquid hydrocarbons via the Fischer-Tropsch process. The output is then refined into a synthetic equivalent to kerosene. The synthetic SAF is blended with fossil jet fuel up to 50%. The blended fuel is fungible to kerosene and can be used as a drop in fuel or added to the general fuel supply.

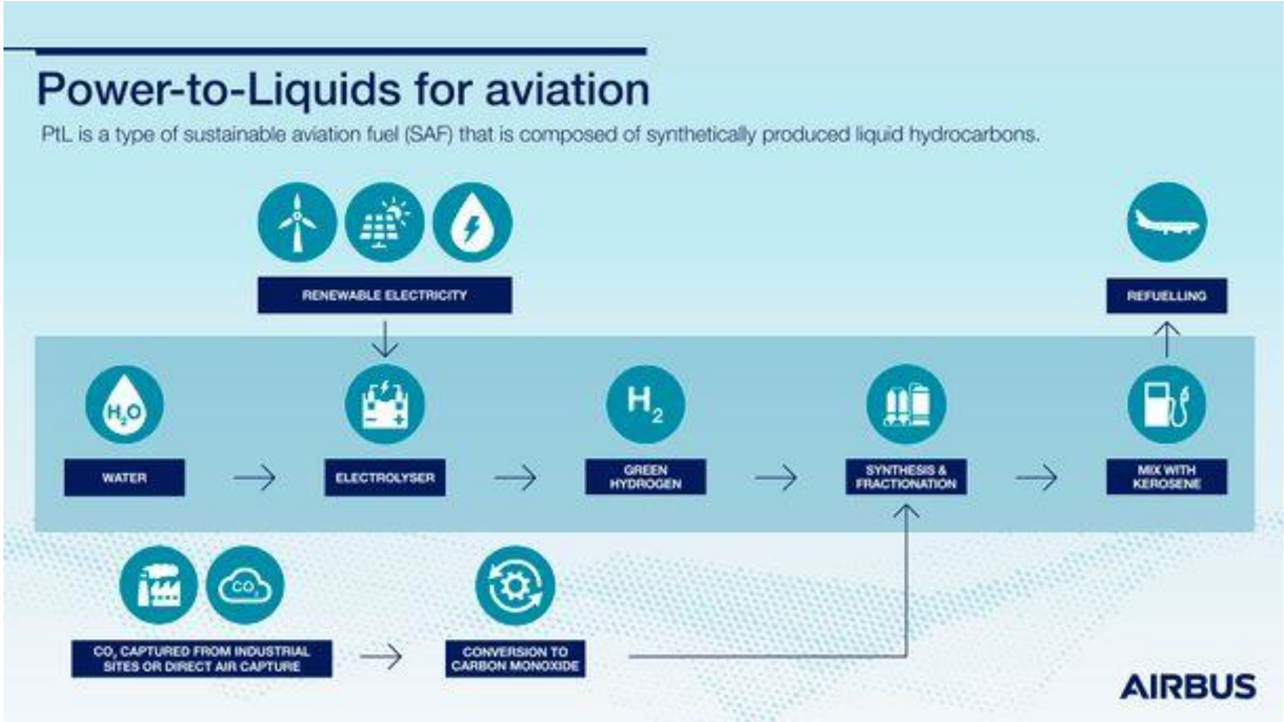


Figure 880. PtL SAF production process

Sustainability-related issues for CO_2 feedstock

Because the feedstock is captured from the air, it is a very sustainable feedstock. The main sustainability issues are the requirement for large amount of energy needed to be produced by the hydrogen. This energy needs to come from renewable sources such as hydroelectricity, solar or wind. If it comes from hydrogen produced from natural gas, it has lower life cycle carbon dioxide benefits. In Côte d'Ivoire the emphasis is on providing enough electricity so that everyone has access, especially in rural areas. Thus, using electricity to produce SAF may conflict with social goals. In addition, hydroelectric power might have risks associated with climate change, as discussed in section 1.4,

Table 27. Captured carbon dioxide sustainability evaluation

ICAO SUSTAINABILITY THEMES
CAPTURED CARBON DIOXIDE

CO_2 reduction themes	
1. Greenhouse gases	
2. Carbon stock	
3. Greenhouse gas emissions reduction permanence	
Environmental themes	
4. Water	
5. Soil	
6. Air	
7. Conservation	
8. Waste and chemicals	
9. Seismic and vibrational impacts	
Socio-economic themes	

10. Human and labour rights	
11. Land use rights and land use	
12. Local and social development	
12. Water use rights	
14. Food security	

Positive contribution/no issue	
Potential issue-need mitigation or control	
Major issue-Needs to be resolved before feedstock can be considered	

Economic and market-related issue for CO_2 feedstock

The main issue for SAF produced from carbon dioxide emissions is the cost. Although the CO_2 is free, or even generates income for its removal, a PtL plant is very capital intensive. Electrolyzers are very expensive (over US 1 billion dollars) and electricity is approximately 80% of the operating cost. Nevertheless, the sustainability advantages and abundant supply make it a very promising feedstock for the future. Several projects are in development:

- A one hundred million litres per year e-fuel plant will be built in Denmark and will enter operation by 2026.
- A 90-million-litre per year plant is planned for the Montreal area in 2028.
- A company in Washington State, USA is building a commercial scale plant capable of producing about 150 000 litres of SAF per year and has plans to scale up quickly. Production is planned to start in 2024.
- European blending mandates require a certain percentage of e-fuels.

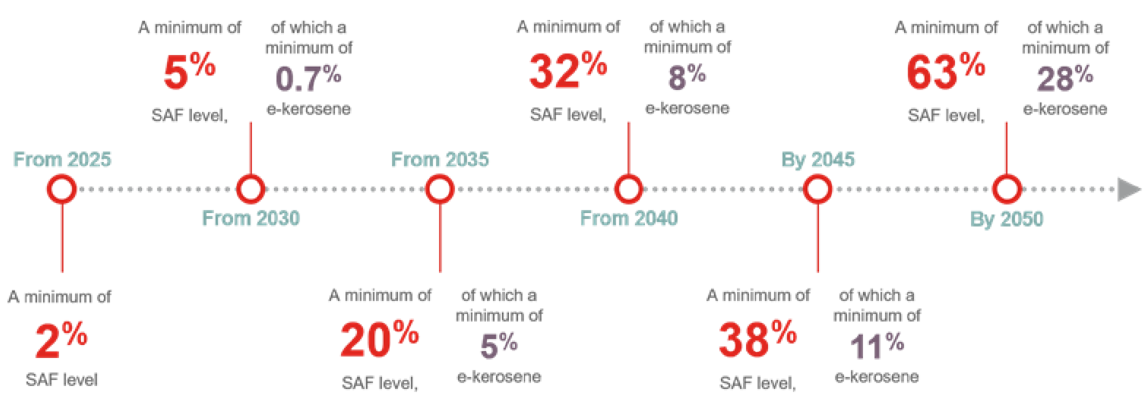


Figure 89. SAF blending mandates in Europe

A big requirement to establish a PtL plant is proximity to large industrial emitters. It takes a production facility that has annual emissions of over 300 0000 metric tons of CO_2 in order to produce enough CO_2 to be economically viable. These are usually cement plants, steel mills, pulp & paper factories, and other big industrial complexes. Industries that produce biogenic carbon dioxide, such as cement plants, are preferred. As with a lot of agriculture-based countries, Côte d'Ivoire lacks the industrial base to provide adequate feedstocks.

Overall Assessment of CO_2 Feedstock

Although making e-SAF from captured CO_2 is attractive is some areas of the world, it is not a good fit for Côte d'Ivoire. The technology is very costly, there are not enough industrial polluters, and there is not enough renewable energy to simultaneously meet SAF production and social goals.

Table 28. Captured carbon dioxide SAF feedstock evaluation

<table>
<tr><th colspan="3">Capture CO₂</th></tr>
<tr><td>Feedstock availability</td><td colspan="2">Technology readiness</td></tr>
<tr><td>Qualities</td><td colspan="2">T1: Biomass processing</td></tr>
<tr><td>• Reduces industrial emissions
• No land or food use issues</td><td colspan="2">• CO₂ is not currently captured, nor are there plans to do so in the future</td></tr>
<tr><td>Constraints/challenges</td><td colspan="2">T2: Fuel Conversion pathways(s)</td></tr>
<tr><td>• Large renewable energy requirements
• Need large industrial emitters
• Very expensive capital costs
• Need very cheap electricity</td><td colspan="2">• FT</td></tr>
<tr><td>Risk mitigation options</td><td colspan="2">Technology complexity</td></tr>
<tr><td>• FT technology development
• Government support for renewable electricity (production and cost)</td><td colspan="2">• Medium</td></tr>
<tr><td>Future biomass potential</td><td colspan="2">Economic viability</td></tr>
<tr><td rowspan="4">• Poor.</td><td colspan="2">• Medium</td></tr>
<tr><td colspan="2">Biofuel/AAF potential</td></tr>
<tr><td>In general</td><td>Low-High (depends on the region)</td></tr>
<tr><td>In Côte d'Ivoire</td><td>Low</td></tr>
</table>

2.5. LOWER CARBON AVIATION FUELS (LCAF)

LCAF-related Information

Lower Carbon Aviation Fuel (LCAF) is defined in Annex 16 Vol. IV as an "A fossil-based aviation fuel that meets the CORSIA Sustainability Criteria under this Annex 16 Vol. IV. An LCAF may be certified as a CORSIA eligible fuel if it meets the CORSIA Sustainability Criteria, including a 10% reduction in life cycle emissions compared to the aviation fuel baseline of 89 gCO_2e/MJ. Studies have shown that crude oil production, transportation, refining, and jet fuel distribution are responsible for about 17% of the life cycle well-to-wake emissions.

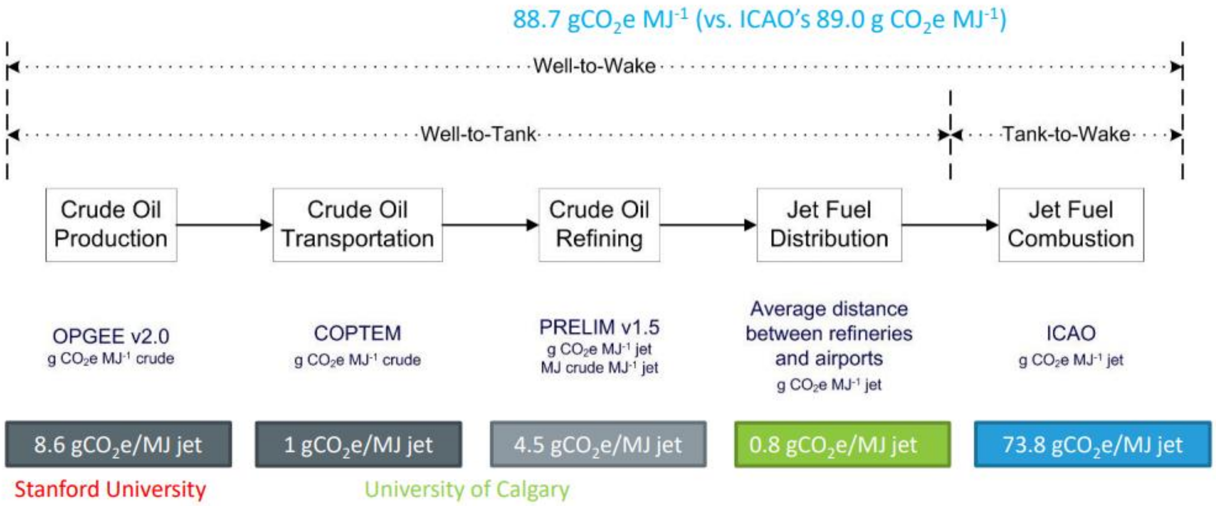


Figure 902. Carbon intensity during the stages of jet fuel production

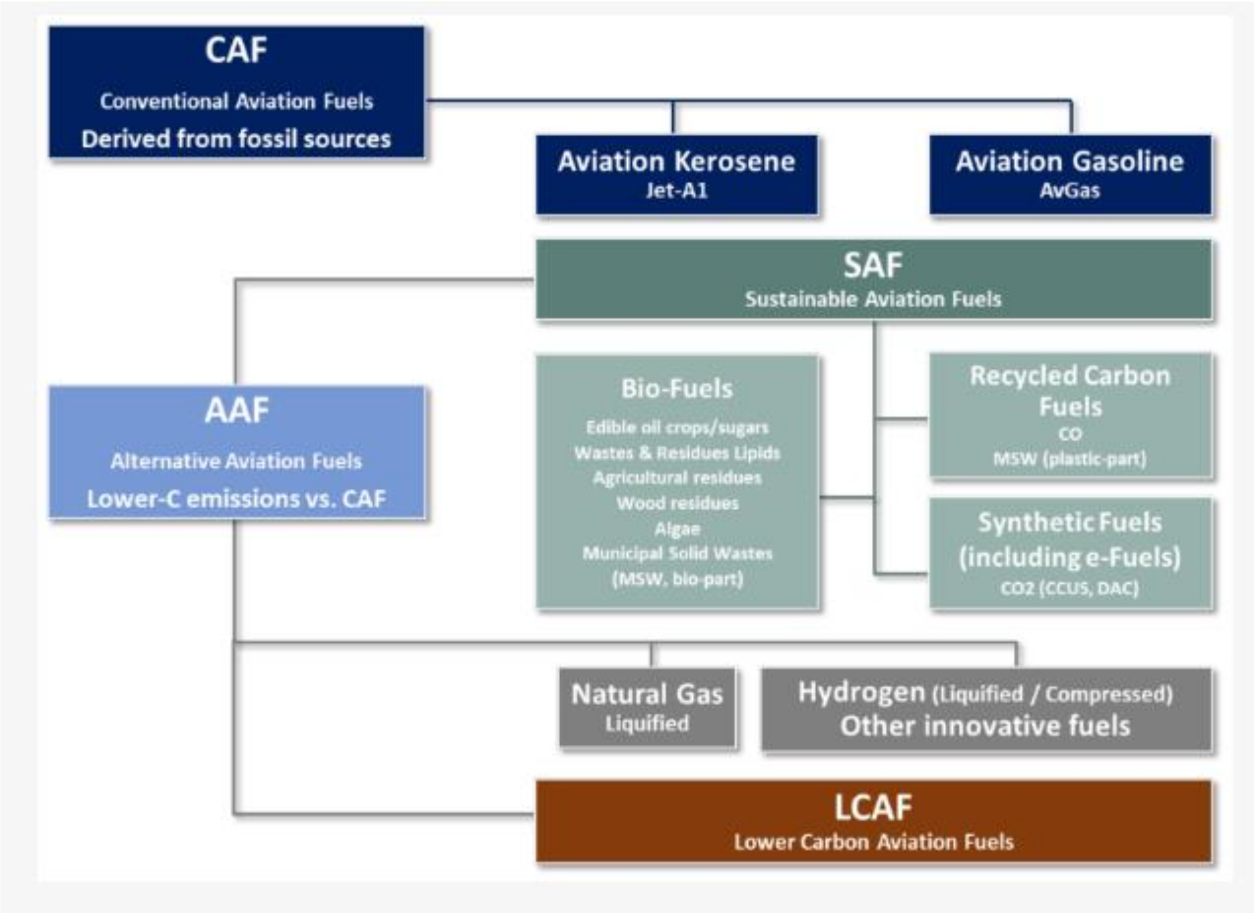


Figure 913. Types of alternative aviation fuels

Although they do not produce the same life cycle emissions reductions as SAF technologies such as HEFA, ATJ and FT, LCAF have several qualities that make them an interesting short-term solution while SAF production ramps up. As we have seen in previous sections, SAF facilities are very capital intensive, costing hundreds of millions to billions of dollars. LCAF leverages existing petrochemical infrastructure at lower costs. In addition, GHG reductions are needed as soon as possible to fight climate change and meet goals set out by the Paris agreement. Since LCAF reduces life cycle emissions during production, they can quickly provide reductions. For example, five billion litres of LCAF at 80 gCO_2/MJ could provide the equivalent GHG emissions reduction of about one billion litres of SAF at 45 gCO_2/MJ.

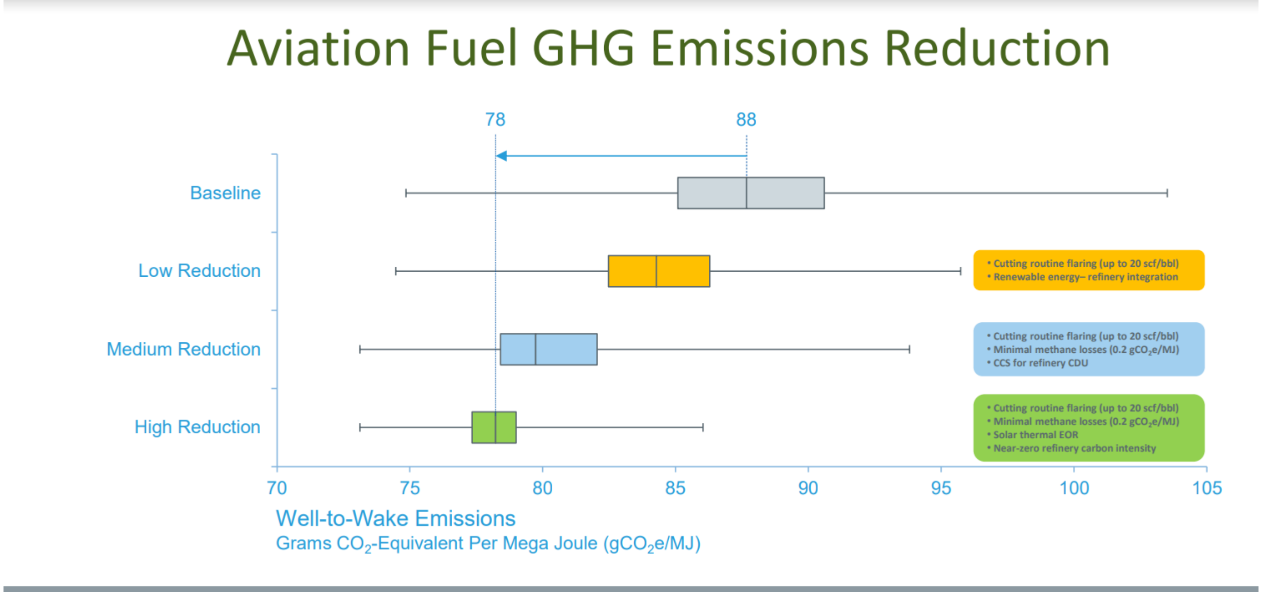


Figure 924. Jet fuel well-to-wake emissions reductions

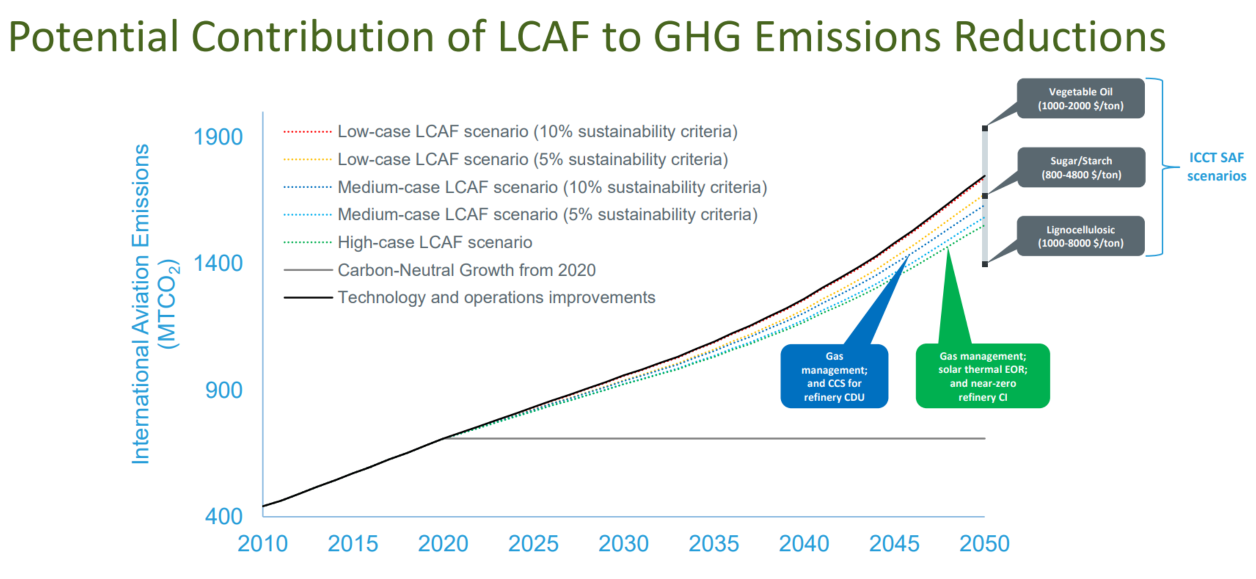


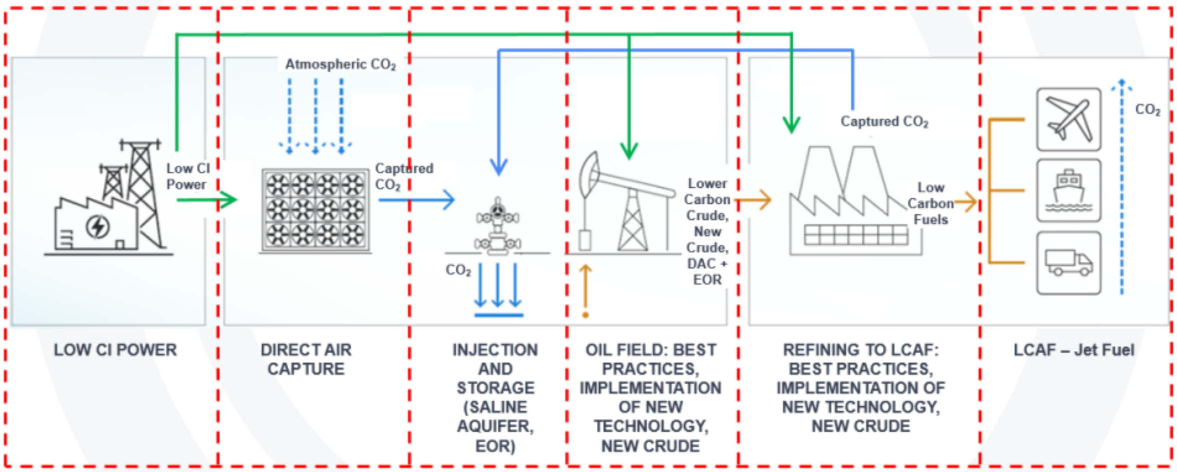
Figure 935. Potential LCAF GHG reductions

Jet fuel in Côte d'Ivoire has a medium carbon intensity, comparable to Spain (72). France (72) and the United States.

Figure 946. Jet fuel carbon intensity comparison

LCAF pathways

LCAF provides incentives to petroleum and refiners to improve operations. As shown in the figure, many technologies, referred to as Carbon Intensity Reduction Technology (CIRT), measures can be used to produce LCAF.



Note : this is a representation of existing and future technologies that could be implemented. Not all technology measures have yet been assessed by ICAO for inclusion i CORSIA.

Figure 957. Methods to lower jet fuel carbon intensity during the production of jet fuel

Energy conservation. One of the easiest and economical means of reducing carbon intensity is to improve energy efficiency. Petrochemical companies can invest in new technologies to improve energy-efficient design of plants, improve plant and production efficiency.

Venting Control and GHG reductions can be attained by better controlling gas release during processes such storage, loading/unloading of oil in ships, shuttles, storage tanks and terminals. Technologies like Vapour Recovery Units and improved sampling and measuring can help.

Fugitive Emissions Detection. Leaks can occur from a myriad of places in a refinery such as pipes, flanges, pumps, seals, and compressors. Individual leaks are usually minor but over a large refinery complex can add up to substantial GHG emissions. Leaks are typically in the parts-per-million (ppm) range and are difficult to detect this requires refineries to invest in technology such as sniffers, optical gas imaging equipment and satellite imaging.

Flaring minimization. Flaring occurs when oil field operators opt to burn the "associated" gas that accompanies oil production, or simply release it to the atmosphere. It is done for safety, economic, technical, or regulatory reasons. It is a big environmental problem as the methane emissions resulting from the inefficiency of the flare combustion contributes significantly to global warming. Methane is the second most abundant anthropogenic GHG after carbon dioxide (CO_2), accounting for about 20 percent of global emissions and is more than 25 times as potent as carbon dioxide at trapping heat in the atmosphere. Petrochemical can reduce GHG emissions from flaring through better operational management and policies or by using technology such as gas recovery systems.

Carbon Capture and Storage (CCS). Carbon capture and storage involves capturing and compressing waste CO_2, then permanently stored at depths beyond one kilometre below the earth's surface, within geological formations suitable for permanent storage. Refineries can capture CO_2 from processes such as catalytic cracking and hydrogen. There are a few CCS technologies in development at different Technology Readiness Level (TRL) levels. CCS is particularly effective when combined with enhance oil recovery.

Renewable Energy Using renewable power sources such as solar, wind, or hydroelectric to generate electricity can help all businesses reduce GHG emissions. Since petrochemical complex use so much electricity to power operations, renewable power could offer significant GHG reduction opportunities. If it is too difficult or expensive to produce onsite renewable power, a company can use power purchase agreements to buy green electricity for the state utility. Another way to renewable energy on the oilfield is solar-thermal installations to produce heat or stream for Enhanced Oil Recovery (EOR) processes. In solar EOR, instead of burning natural gas to produce steam, Concentrating Solar Power (CSP) technology is used.

Low Carbon Hydrogen. Refineries use large quantities of hydrogen during processing for such things as sulphur removal. This hydrogen is produced by using steam to break down natural gas into hydrogen and carbon dioxide, resulting in large emissions. Lower intensity hydrogen can be obtained by capturing and storing these emissions. This is referred to as “blue hydrogen” Extremely low CI hydrogen can be produced by using renewable electricity to generate hydrogen via electrolysis. This is called “green hydrogen” A refinery can lower its carbon intensity by using green or blue hydrogen in its processes.

Table 29. Carbon intensity LCAF abatement costs

LCAF Technologies and Practices	Reductions in CI [gCO2eq/MJ]	Changes in Cost [USD/toe]	Abatement Cost [USD/tCO2eq]
Renewable energy use at oilfield (solar electricity)	0.35-0.36	1.91-4.13	132-290
Moderate flaring reduction policy	1.5	2.32×10^{-4}	3.23
Extreme flaring reduction policy	1.9	2.93×10^{-4}	4.1
Minimal fugitives and venting emissions	2.3	0.57	15.91

Côte d'Ivoire has a large refinery in Abidjan as well as several oil and gas fields. In August 2023, the Italian oil company ENI began oil and gas production at the giant Baleine field using an offshore production facility. In addition, the country has other infrastructure such as pipelines, loading docks and storage facilities, the well-developed petroleum sector makes it an excellent candidate for LCAF.

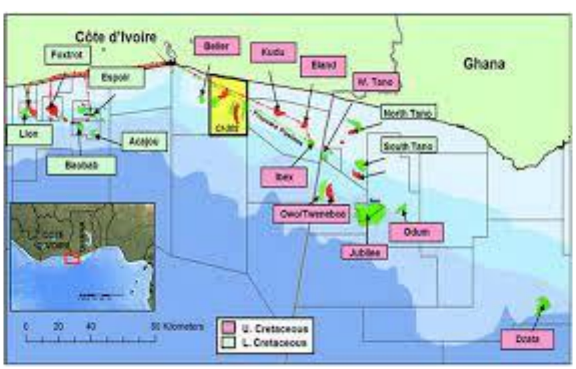


Figure 968. Oil fields in Côte d'Ivoire

Figure 979. Baleine Field, Cote d’Ivoire

Potential Volume

The SIR refinery in Abidjan produces 3.8 million metric tons per year of petroleum products of which 23% is jet fuel (874 000 metric tons). When combusted the fuel will produce 2.76 million metric tons of CO_2. Since 1 metric ton of jet fuel produces 3,16 metric tons of CO_2 therefore a 10% reduction in CI would produce savings in the order of 276 000 metric tons of CO_2 per year. This is more than enough to offset the current GHG emissions from international aviation calculated as 156 836 metric tons in 2023.

Sustainability-Related Issues for LCAF

LCAF sustainability criteria are defined in the ICAO document "CORSIA Sustainability Criteria for CORSIA Eligible Fuels." Chapter 3 defines sustainability criteria applicable to batches of CORSIA LCAF produced on or after 1 January 2024 (e.g., after the CORSIA Pilot Phase). These LCAF sustainability criteria cover carbon emissions, environmental and socio-economical aspects. Under CORSIA, the life cycle emissions of LCAF need to be obtained with the use of the methodologies defined in Chapter 7 of the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values."

Economic and Market-Related Issues

People are becoming aware that SAF production capacity is falling beyond the supply needed to reach industry decarbonization and climate goals. This realization has sparked interest in the development of other innovative fuels such as LCAF and hydrogen. At the ICAO 2019 Stocktaking Seminar LCAF technologies and strategies were discussed and new initiatives are being studied. There is a lot of activity in this new area. For example, an American company is developing a multi-billion-dollar facility in Texas to produce SAF and LCAF from renewable natural gas (RNG) sourced from dairy farms and landfills, as well as from flare gas obtained in the Permian Basin. They will use a new methanol-to-jet (MTJ) pathway which is currently being certified.

An economic study determined that LCAF is a cost-effective CI reduction initiative, raising costs between 39 USD/MT and 46.8 USD/MT depending on the CIRT used. More than two thirds of the total additional costs are accounted to the refinery-level CIRT, and especially for CCS technology.

Overall Assessment of LCAF

Although not a SAF feedstock, LCAF is a high potential decarbonization option for Côte d'Ivoire and can leverage the country’s oil and gas infrastructure and expertise. CIRT technologies can be implemented quickly at relatively low cost. These should be explored and implemented as quickly as possible using external partnerships with international oil and gas companies that have expertise in this area. CIRT technologies can be integrated in SIR’s capital improvement program budget.

SECTION 3. IMPLEMENTATION SUPPORT AND FINANCING

3.1. IMPLEMENTATION SUPPORT

In section 2, LCAF and co-processing were identified as the quickest routes to introducing low carbon aviation fuels in Côte d'Ivoire. The most promising potential SAF feedstocks identified are cassava, agricultural biomass, MSW. and rubber oil seeds. Aside from financing, the following support mechanisms are needed to implement a SAF industry:

- **LCAF and Co-Processing**: SIR would benefit from technical assistance and knowledge transfer from partner oil and gas companies such as TotalEnergies and Eni. As discussed in section, TotalEnergies is already co-processing at their Normandy refinery and planning to do so in their Marseille facility. Knowledge gained from these initiatives would help immeasurably. TotalEnergies is a shareholder in SIR so this would be a mutually beneficial partnership. ENI started reprocessing SAF at their oil refinery in Taranto, Italy in 2021 so they also could provide useful advice.
- **Cassava** starch transformation into biofuels has already been demonstrated. The next step is to scale up the biofuel production and select the optimal ATJ pathway to convert it to SAF. This will require academic research from Ivorian and international universities and technical assistance from companies experienced in plant construction.
- **MSW and agricultural residues** will require further studies on feed characterization and logistics. This could be done by Ivorian universities and specialized agencies. Knowledge gained from the 2009 UN CDM Abidjan Solid-Waste -Energy project can be leveraged. A detailed study will need to be done comparing the economic and technological characteristics of the FT Gasification and the ATJ technologies.
- **Rubber oilseeds** will require further research and studies in conversion technology as well as collection and storage.

Another area in which Côte d'Ivoire will need help is in certification of the SAF through the ASTM process. As shown in the following diagrams, certifying a feedstock using an approved pathway is a lengthy and costly process. It can take over two years and involves many steps.

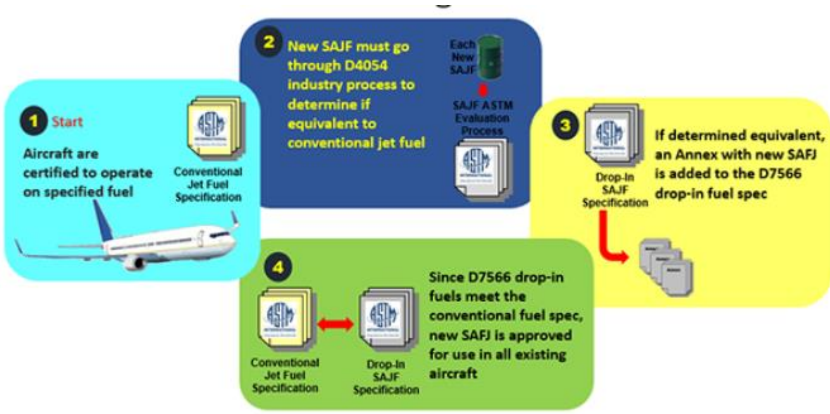


Figure 98. SAF Certification Process

- Phase 1 is an initial examination of the fuel. It takes about 6 months, costs around USD 50K and requires 200 litres of neat SAF
- Phase 2 is testing with aviation partners. It takes another 6 months and costs about USD 350 000.
- Phase 3 requires more testing with at least 100 000 litres of neat SAF, costs millions of dollars, and can take 2-3 years of testing. The fuel must then be approved by the FAA and an ASTM panel of experts.

A fuel produced with a pathway already in a D7566 annex is eligible for fast-track approval. This saves time but not necessarily money as the standards are as stringent. Moreover, a fast-tracked can only be blended to a maximum of 10%, against 50% for the normal process.

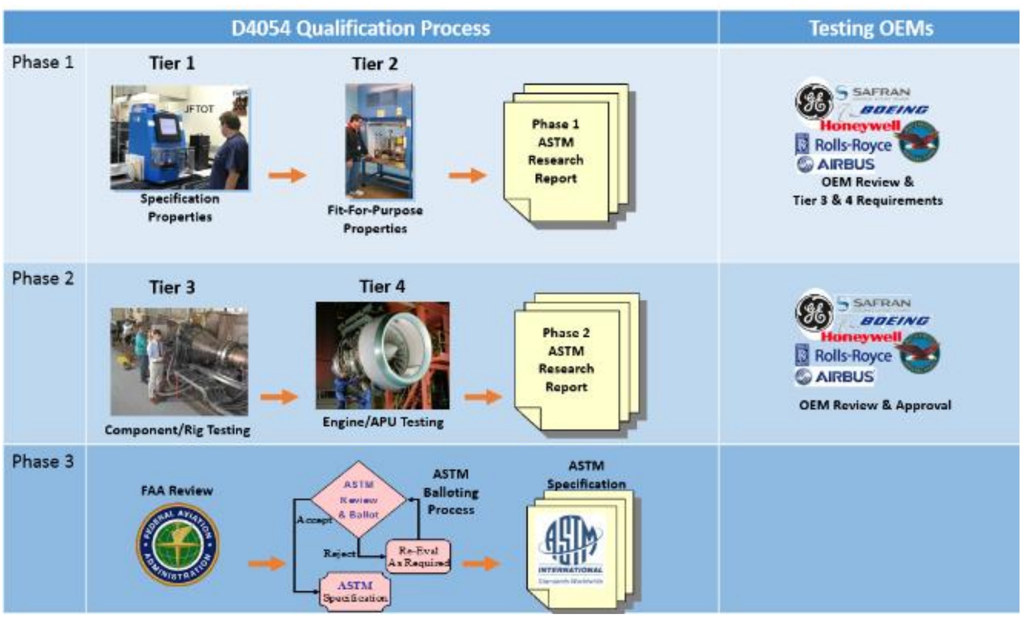


Figure 991. Steps to certify new SAF

3.2. FINANCING

SAF Cost Premium

Despite all its environmental and social benefits, the largest barrier to producing and selling SAF is price. In 2021, on average SAF was 3.6 times more expensive than kerosene. In 2022 this dropped to 2.5 times and is about 2.3 more expensive in 2023 according to S&P Platts . It should be noted that this is an average and cost is highly dependent on feedstock and processing pathway and on the raw materials and manufacturing process being used. SAF costs more than fossil fuel because it involves new technologies, lacks scale, and requires massive capital investments. It is also competing against an entrenched fossil fuel industry that already has infrastructure, has had a hundred years to perfect their operations, and benefits from government subsidies in some countries. Some studies predict that the price gap will persist until 2030-2035 while more pessimistic estimates say 2050.

Figure 1002. SAF price premium

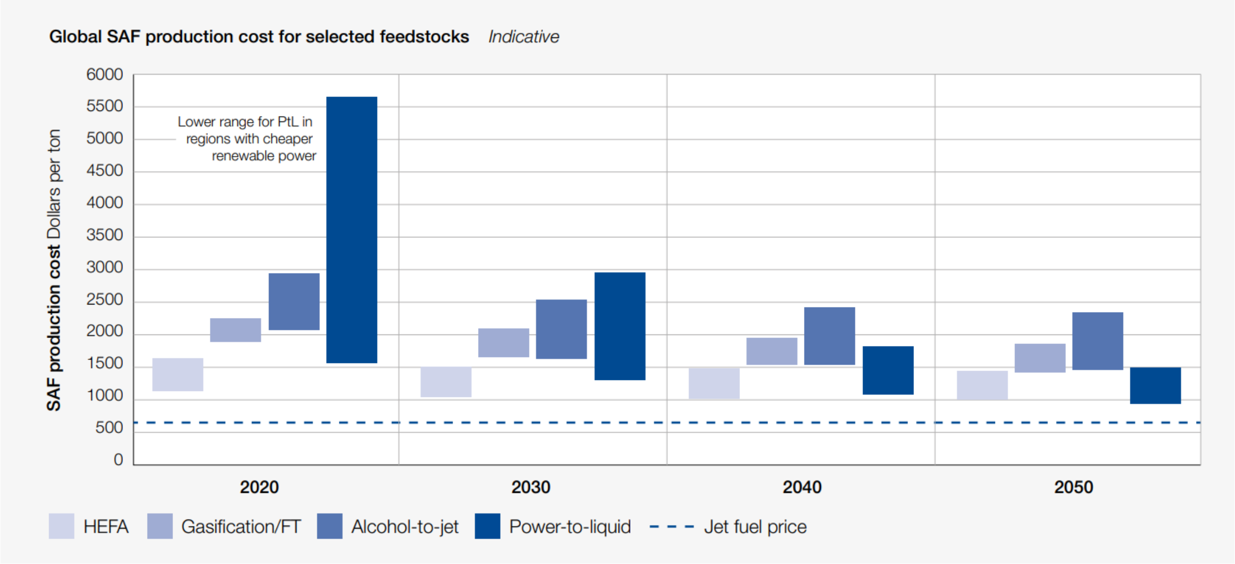


Figure 1013. SAF production costs for different feedstocks and technologies

Recognizing that SAF is essential for sustainable development of the aviation, a t least 30 airlines have promised to use more SAF, usually for 10% of their fuel consumption by 2030. This is significant as less than 1% of today's flights use SAF. The high "green premium" for SAF is a big problem for airlines who would gladly purchase SAF but struggle to afford it. Fuel is their largest expensive and the industry has very thin profit margins. Large purchases of SAF would wipe out any profits and total replacement of kerosene would lead to financial ruin. This creates a scenario whereby airlines cannot buy SAF because it is too expensive and it is too expensive because airlines cannot buy it. Financial support for the SAF industry is essential to break this conundrum and drive down the cost of SAF so that it approaches cost parity with fossil jet fuel. Some of the most common financial mechanism for SAF is described below.

Direct Investment

Planning and building a SAF facility is an extremely expensive proposition. Most people focus on the high capital costs of building a production facility, but it is important to remember that financing is required at every step in the development process. Innovative SAF projects often encountered difficulty accessing low-cost capital because they have "high-risk premiums" and face unexpected challenges and costs, particularly in the current high inflation environment. This makes it critical to secure financing from various sources.

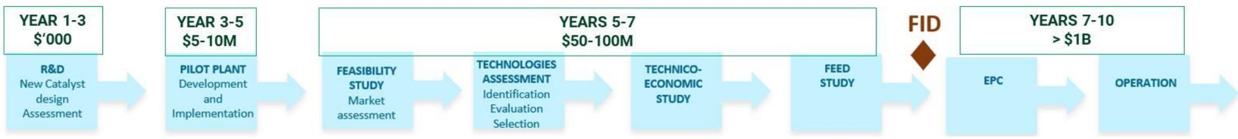


Figure 1024. SAF Investment Costs

- The first step on the road to producing SAF is to do feasibility studies to identify the most promising feedstocks and pathways. These generally cost in the hundreds of thousands of dollars. Due to the exploratory nature of these studies, they are usually funded by government organizations or university research grants. For example, this study was funded under the Second Phase of the ICAO Assistance Project with the EU Funding: "Capacity Building for CO_2 Mitigation from International Aviation."
- Once a feedstock and pathway are selected, it is necessary to build and operate a pilot plant to demonstrate that SAF can be produced to ASTM7566 specifications. This step can easily cost from $5-$10 million or more. At this point, it is too speculative and risky to attract private investment so financing is backed by governments.
- Once the pilot plant demonstrates the technological feasibility to produce SAF, detailed engineering and techno-economic studies need to be done. This process is known as Front End Loading (FEL) or Front-End Planning. It includes the development of strategic information and key documentation necessary to estimate costs and to identify potential project risks. The objective is to decide whether to move forward with the project and commit financial and human resources. This is called the Final Investment Decision (FID) FEL consists of three distinct phases:

    - FEL 1: Opportunity Identification and Assessment
    - FEL 2: Scope Development and Conceptual Engineering
    - FEL 3/Front-End Engineering Design (FEED): Execution Planning and Basic Engineering

  These studies are very expensive and can cost from $50-$10 million. Although the project is still risky, it starts to attract interest from provide investors especially at the FEED stage. However, a lot of the funding still comes from climate action funds.

- The results of the FEED study will determine if the proposed SAF production facility is economically viable. Assuming a positive outcome, a large sum of money will be required for construction. A full-scale standalone facility can easily cost over $1 billion. Since the FEED has shown that the facility can be profitable, it will attract private investment. Nevertheless, the high capital investment will require multiple funding sources. Private sector investment and government support are crucial to enabling the scale-up of new technologies to curb carbon emissions. For example, to support the construction of its first alcohol-to-jet (ATJ) sustainable aviation fuel production plant in Georgia, United States LanzJet received financial support from multiple sources. This includes a $50 million investment from the Microsoft Climate Innovation Fund as well as investments from LanzaTech, Suncor Energy, Mitsui & Co, Shell, British Airways and All Nippon Airways, and the US Department of Energy.

Financing is especially required in the period between the starting feasibility studies and the start of commercial operations. In investment terms this is called the "valley of death." During this window, it can be difficult for firms to raise additional financing since their business model has not yet been proven. Many promising SAF projects have failed at this point because they have run out of money.

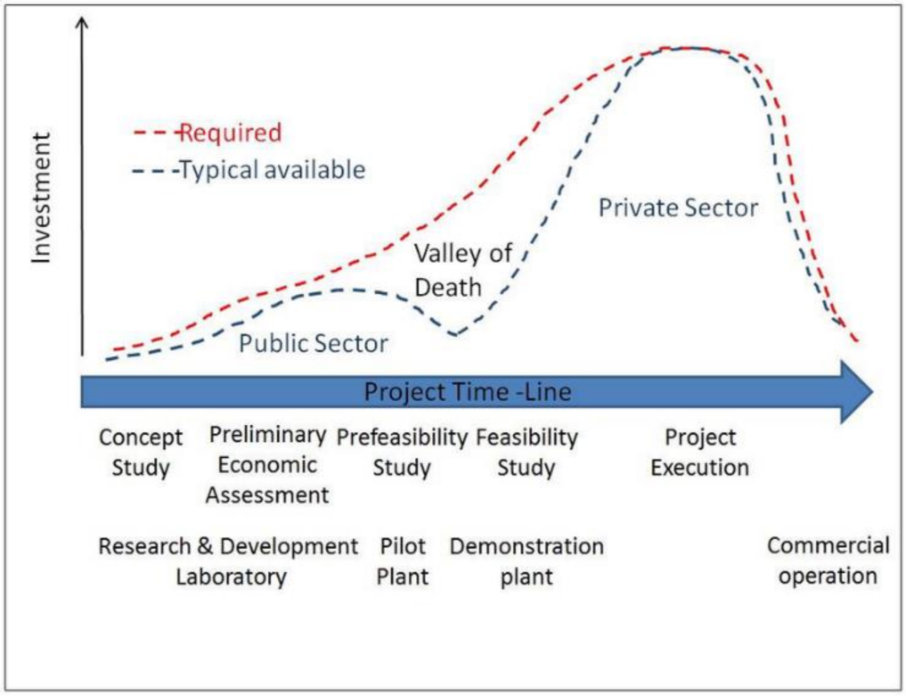


Figure 1035. Investment requirements for big capital projects

Offtake Financing

A SAF offtake is an agreement between a SAF developer or producer and a buyer (usually an airline) to buy a future volume of fuel over a period of years. These agreements help finance SAF projects in two ways. The agreements attract investors by guaranteeing that there is an end customer for the plant's production. In addition, many offtake agreements provide project funding through advance prepayments to guarantee a specify volume one the plant is in operation. For example, an airline may pay several cents per litre for the annual volume that they want. These payments are made annually from the signature of the contract until the plant becomes operational and the payments are deducted from the SAF price once deliveries begin. Certain offtake agreements also require a non-refundable downpayment deposit to reserve a certain volume. This is done when future demand outstrips supply and prioritization is needed for production slots. In both cases the money is usually used to fund the FEED study and help get the developer through the "valley of death." ICAO provides a dashboard with publicly available information on sustainable aviation fuel (SAF) offtake agreements on their website.

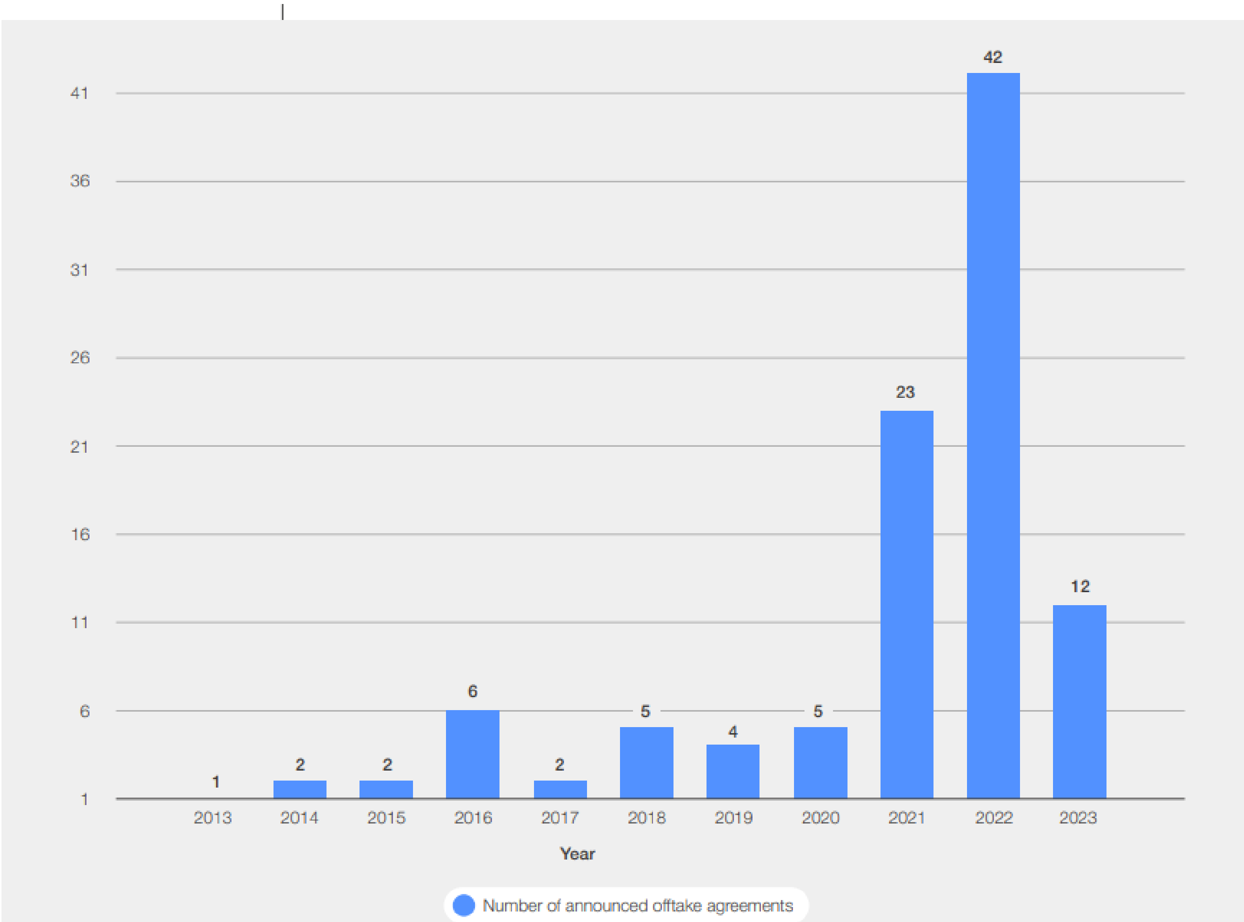


Figure 1046. Number of publicly announced offtake agreements as of 2023

Public Private Partnerships

Public-private partnerships (PPP) involve collaboration between the government private-sector companies, NGOs, and academia that can be used to finance, build, and operate projects Financing a project through a public-private partnership can make a project viable or allow it to be completed sooner. Public-private partnerships will be essential to establish a SAF industry in Côte d'Ivoire.

PPPs are classified as the preferred method of financing infrastructure in Côte d'Ivoire, Côte d'Ivoire has a strong track record of successful PPPs has an attractive environment for PPP investment. PPP legislation is clear and concise, with all relevant laws outlined in two decrees: Decree 2012-1151 defines contracting, monitoring and dispute resolution issues; and Decree 2012-1152 establishes the institutional environment. Responsibility for PPPs is shared between three bodies, all of which report to the presidency, but with staff drawn from different ministries and agencies. The Comité National de Pilotage des PPP (CNP-PPP), or national steering committee, is responsible for strategic oversight of the sector and approving new PPP projects. The Secrétariat Exécutif des PPP provides administrative and technical support, outreach and training. The Cellule d'Appui des PPP, or support unit, assists with project preparation and monitors implementation.

In March 2023, Côte d'Ivoire validated its diagnostic study and action plan on Public-Private Partnership for Infrastructure Financing. Which is part of the UN ECA's "PPP for Infrastructure Financing" project. The study emphasized the importance of private sector investments in financing the national development effort and wants to increase in the number of PPPs that are inclusive, provide local and sustainable employment, promote gender equality and allow better access to basic social services.

The development of a SAF industry is coherent with these objectives. The financing of the BIOVEA waste-to-energy plant Uwas a PPP with funding from various sources such as Emerging Africa Infrastructure Fund (EAIF), Biovea Energies and Proparco. These types of financing initiatives could serve as a good model for future SAF projects.

SECTION 4. ROADMAP AND ACTION PLAN

4.1. POLICY AND REGULATORY FRAMEWORK

Government policy has an instrumental role to play to make SAF more widely avoidable and affordable. Incentives for wind and solar helped to drive costs down and make renewable energy cheap and widely available. Similar policies are needed for SAF. The ICAO Guidance on Potential Policies and Coordinated Approaches for the Deployment of SF guide lists 28 types of Policy Options, divided into 3 impact areas and 8 categories that can achieve this goal.

Table 30. ICAO SAF policy guidance

Impact area: Stimulating Growth of SAF Supply			
1 • Government funding for RDD	2 • Targeted incentives and tax relief to expand SAF supply infrastructure	3 • Targeted incentives and tax relief to assist SAF facility operation	4 • Recognition and valorization of SAF environmental benefits
1.1 - Government R&O	2.1 - Capital grants	3.1 Blending incentives: Blender's Tax Credit	4.1- Recognize SAF benefits under carbon taxation
1.2 - Government demonstration and deployment	2.2 - Loan guarantee programs	3.2-Production incentives: Producer's Tax Credit	4.2 - Recognize SAF benefits under cap and-trade systems
	2.3 - Eligibility of SAF projects for tax-advantaged business status	3.3 - Excise tax credit for SAF	4.3 - Recognize non-carbon SAF benefits improvements to air quality
	2.4 - Accelerated depreciation/'bonus depreciation	3.4 - Support for feedstock supply establishment and production	4.4 - Recognize non-carbon SAF benefits reduction ln contrails
	2.5 - Business investment Tax Credit (ITC) for SAF investments		
	2.6 - Performance-based tax credit		
	2.7 - Bonds/Green Bonds		
Impact area: Creating Demand for SAF			**Impact area: Enabling SAF Markets**
5 • Creation of SAF mandates	6 • Update existing policies to incorporate SAF	7 • Demonstrate government leadership	8 • Market enabling activities
5.1 - Mandate, renewable energy volume requirements in the fuel supply	6.1: incorporating SAF into existing national policies	7.1 Policy statement to establish direction	8.1- Adopt clear and recognized sustainability standards and life cycle GHG emissions methods for certification of feedstock supply and fuel production
5.2 - Mandate reduction in carbon intensity of the fuel supply	6.2 - incorporating SAF into existing subnational, regional or local policies	7.2 - Government commitment to SAF use, carbon neutral air travel	8.2 - Support development/recognition of systems for environmental attribute ownership and transfer
			8.3 - Support SAF stakeholder initiatives

It is no accident that countries with well-developed policies with financial incentives have seen the greatest growth in SAF projects.

- The **USA** has implemented many policies to spur growth of their domestic SAF industry:
  - The US Grand Challenge targets 3 billion gallons of domestic SAF production in 2030 and 35 billion gallons per year by 2050. This sends a demand signal to potential investors.
  - The US government's SAF incentive program that was included in last fall's Inflation Reduction Act credits of between $1.25 and $1.75 per gallon for SAF purchases, depending upon how much the fuel improves upon life cycle greenhouse gas emissions compared to standard kerosene-based jet fuel. Such credits help reduce the cost gap between SAF and standard jet fuel.
  - The IRA also includes a blenders tax credit (BTC) that makes SAF producers eligible for a $1.25 per gallon credit for each gallon of SAF sold as part of a qualified fuel mixture with a demonstrated life cycle greenhouse gas (GHG) reduction of at least 50% compared to conventional jet fuel. The standalone SAF tax credit increases by one cent for each percentage point by which the life cycle GHG emissions reduction of such fuel exceeds 50%, up to $1.75 per gallon for a 100% reduction.
  - The IRA SAF and Clean Technology initiative offers $245 million competitive grant program.
  - The California Low Carbon Fuel Standard (LCFS) provides tradeable compliance credits for producers of low CI fuel. This helped World Energy in Paramount, California, become the world's first commercial SAF producer. World Energy also received grants from the state to support their clean energy projects,

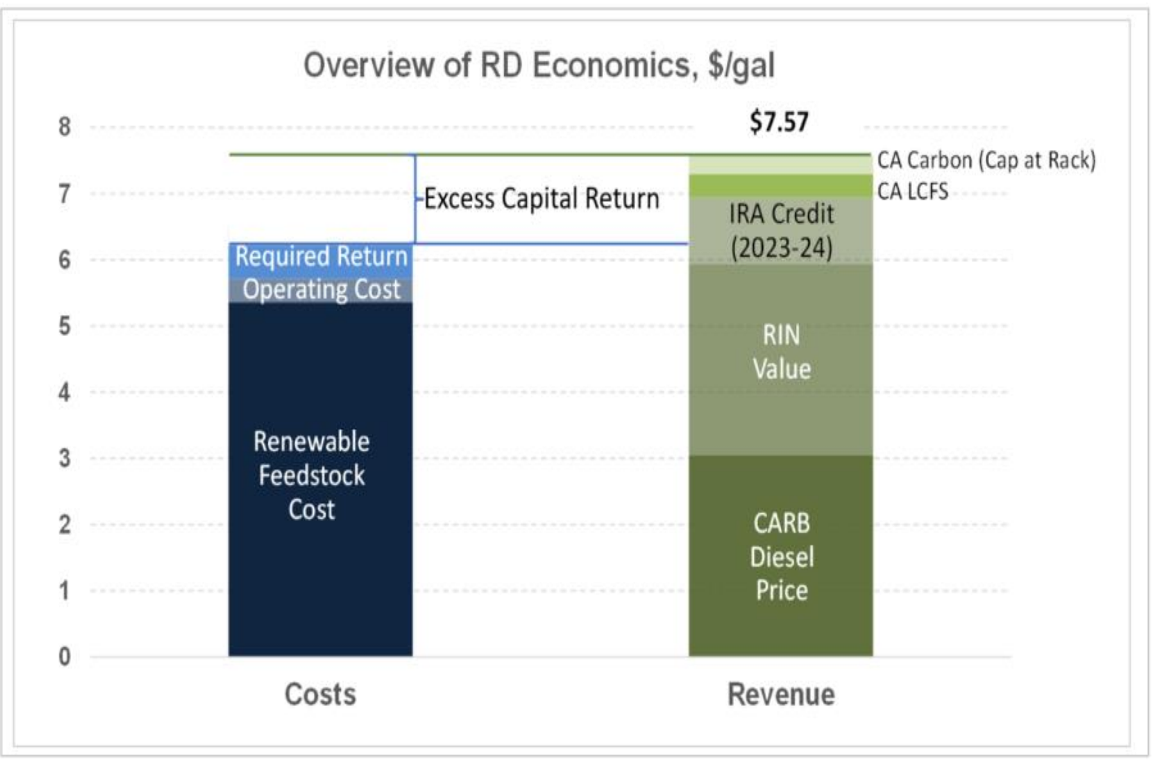


Figure 1057. Renewable fuel economy

- As part of the EU's European Green Deal policy framework, the ReFuelEU Aviation initiative specifies a minimum SAF blending quantity, increasing to 2050. This sends a strong demand signal to the market. In addition, they have put in place a number of SAF financing mechanisms:

- EU Financial programs : Horizon Europe, Innovation Fund, InvestEU
- Revised state aid guideline
- EU taxonomy to facilitate access to finance
- SAF Allowances under EU ETS to reduce the price gap between fossil and SAF (up to €2 bn)
- Strengthen price signal: proposals for a revision of EU Emissions Trading System (carbon price) and Energy Taxation Directive (removal of jet tax exemption.

Table 31. EU SAF and e-SAF blending targets

Total shares in the fuel mix (in %)	2025	2030	2035	2040	2045	2050
Sustainable Aviation Fuels (SAF) target	2	5	20	32	38	63
Synthetic aviation fuels *sub-targets*	-	0.7	5	8	11	28

- The UK Jet Zero plan commits to have at least five UK SAF plants under construction by 2025 and a SAF mandate in place with a target of at least 10% SAF by 2030. To support this objective the UK government is providing financing incentives to produce SAF via price support from tradable certificates with a monetary value, a£165 million Advanced Fuel Fund and blending mandates from 2025.
- Brazil, Japan, Singapore, France, Germany, and the UAE are amongst other countries that have implemented strong SAF support policies.

Côte d'Ivoire should strongly consider implementing similar policy initiatives to encourage SAF production.

4.2. CRITICAL SUCCESS FACTORS

The biggest factor for the successful implementation of SAF in Côte d'Ivoire will be the implementation of a policy framework that supports production, reduces cost, and prioritizes feedstock for SAF production over such options as waste-to-energy; otherwise potential SAF feedstocks may be used by other industries due to of economics or technological readiness. Integration of SAF into the national climate plan and GHG reduction plans is recommended. SAF needs to be a government priority. As with any large-scale industrial initiative, organization is essential. Someone needs to have the responsibility for the program, establishing monitoring plans, timelines and budgets.

Another key success factor is access to funding. This will require public private partnerships involving international companies and agencies. Offtake agreements will also be critical as they raise money and send a strong market signal to investors.

Co-processing at 5%, combined with LCAF, has the potential to assist in reducing international aviation emissions. Industry efforts to increase co-processing to 30% will allow additional reductions at marginal cost. Help with the SAF certification process will require the cooperation of aviation stakeholders such as certification agencies, engine manufacturers, airframers, and other OEMs.

Establishment of a standalone SAF facility would enable Côte d'Ivoire to meet and exceed its aviation climate objectives. It would also provide the possibility of low-carbon fuel exports, and an international accounting system for SAF (e.g., book-and-claim system) would increase the access to the SAF produced in Cote d’Ivoire by allowing international airlines to access the environmental benefits of Ivorian SAF without taking physical delivery, which can also assist in the economic viability of the project. Since the number of international airlines flying in and out of Côte d'Ivoire is limited, this would greatly expand market potential.

SAF conversion technology is essential as the industry is in its infancy and there is a dearth of expertise. It is important to choose a technology that has a high technological readiness level (TRL). Technology providers will play a key role in establishing a SAF industry. Access to key inputs such as electricity and water are also important for waste biomass and MSW.

TECHNOLOGICAL READINESS LEVEL

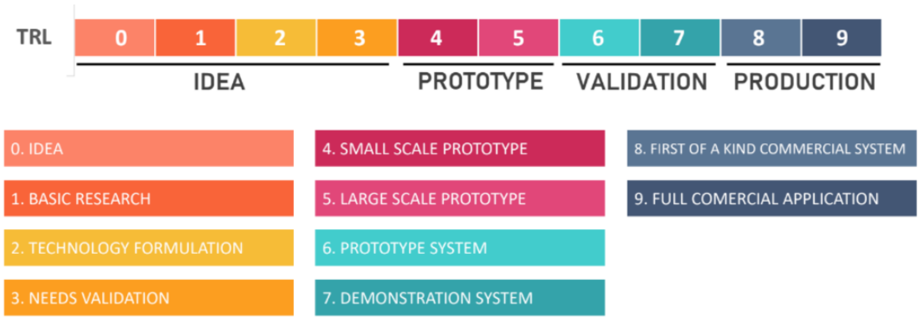
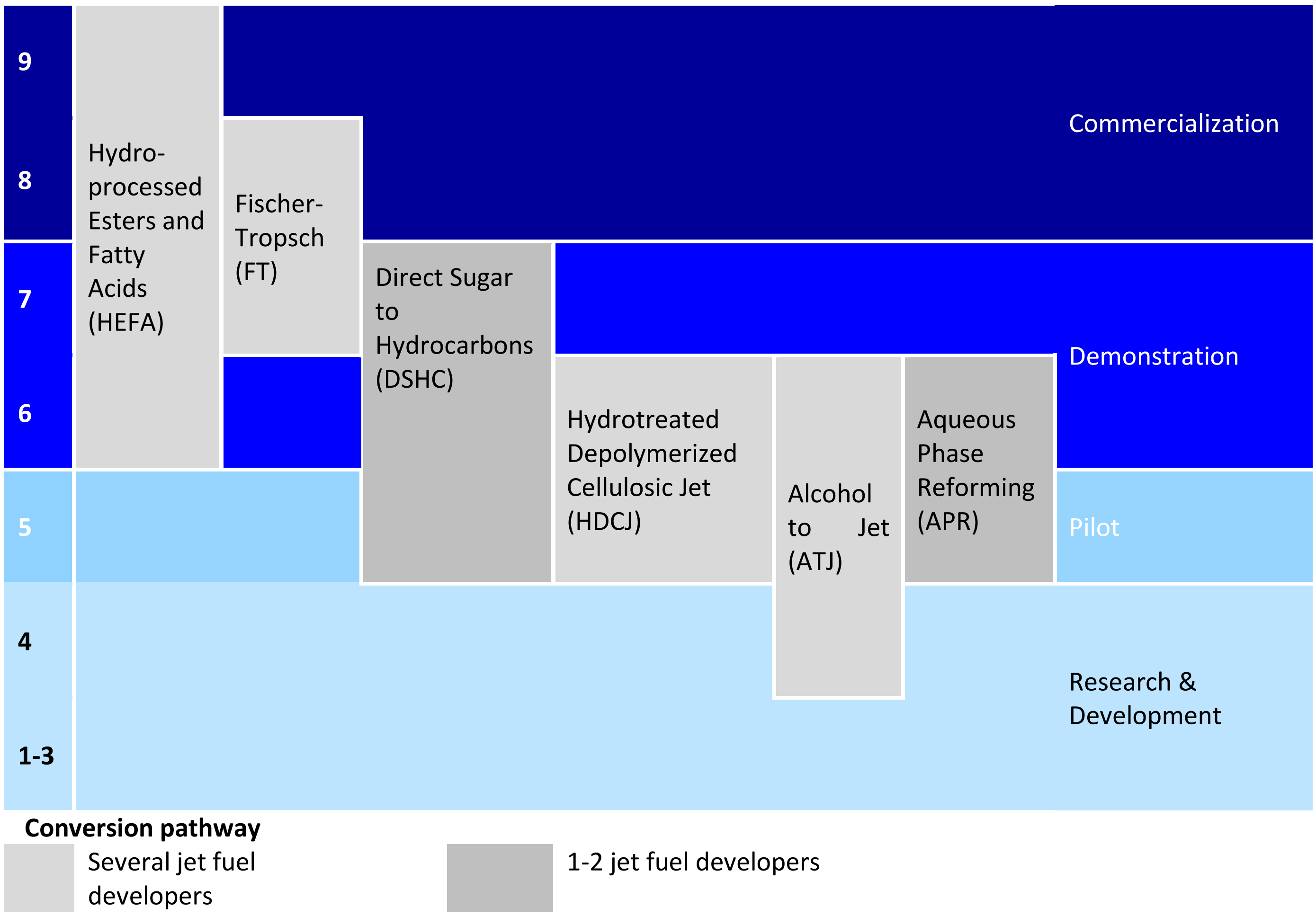


Figure 1068. TRL stages

Table 32. TRL description

	Level	FRL Description	FRL 'Toll Gate'
Technological R&D	1	Basic principles	▪ Feedstock & process basic principles identified
	2	Technology concept formulated	▪ Feedstock & complete process identified
	3	Proof of concept	▪ Lab-scale fuel sample produced from realistic feedstock ▪ Energy balance analysis conducted for initial environmental assessment ▪ Basic fuel properties validated
	4	Preliminary technical evaluation	▪ System performance and integration studies ▪ Specification properties evaluated
	5	Process validation	▪ Scaling from laboratory to pilot plant
Certification processes	6	Full-scale technical evaluation	▪ ASTM certification tests conducted fit-for-purpose properties evaluated, turbine hot section testing, components and testing.
	7	Certification/fuel approval	▪ Fuel listed in international standards
Commercial deployment	8	Commercialization	▪ Business model validated for production ▪ Airline purchase agreements secured ▪ Plant-specific independent greenhouse gas assessment conducted in line with internationally accepted methodology
	9	Production capability established	▪ Full-scale plant operational

Table 33. TRL levels for various SAF technology pathways



Feedstock's logistics support will be important as there is currently a lack of well-developed processes for collection, transport, and storage. Access to biomass feedstock will also depend on the cooperation with the producers and farmers who regard the waste as an unwanted secondary product.

4.3. ACTION PLAN

VISION:

To establish a domestic SAF industry that can help Côte d'Ivoire reduce emissions from international aviation and ensure the future prosperity of the Ivorian oil & gas industry through the transition to sustainable fuels.

OPPORTUNITIES:

- Solid government commitment to decarbonization and renewable energy.
- Strong track record of successful public private partnership projects.
- Well established and well-run jet fuel refinery and oil & gas sector.
- Large volumes of agricultural and municipal solid wastes.
- Biofuel (ethanol) production from cassava feedstock (peelings and starch) technology proven and ready to be scaled up.

- Experience in collecting and valorizing agricultural waste
- Socie-economic co-benefits of SAF production such as increased farmer revenue, reduced pollution, and more inclusion of marginalized populations such as rural populations and women.

CHALLENGES:

- Insufficient domestic volume of international and domestic air traffic to support an average sized SAF facility.
- Lack of established collection systems for collection for rubber seed feedstock.
- No government policy framework to support SAF.
- High capital costs of SAF production facilities.
- Competition for biomass feedstock for waste-to energy applications.
- Food security, land-use and deforestation concerns may reduce the availability of crops for SAF production.
- Need to get ICAO life cycle emissions analysis for cassava and sorghum for inclusion in the CORSIA documents.

Short term (2023-2025): Quick wins and building the foundation for a SAF industry.

- Implement a policy framework to promote the development of SAF (possibilities include, but are not limited to, targets, incentives, or blending mandates).
- Set up a focal point to coordinate and advance the project. Ideally, this would be ANAC who was the lead on the Action Plan to Reduce Carbon Emission from International Aviation
- Identify key stakeholders from government, the aviation industry, academia, technological experts, the oil and gas industry and other relevant parties.
- Set up a steering committee with representatives from each group of relevant stakeholders, assigning roles and responsibilities.
- Begin capacity building:
    - SAF and aviation decarbonization training.
    - Identify research and technology requirements.
    - Seek out funding sources from government, NGOs and private companies.
    - Negotiate offtake agreements with international airlines.
- Leverage cooperation with international organizations specialized in biomass valorization and biofuel production.
- Engage international partners to study how SIR can implement LCAF and co-processing. This includes technical and economic analysis.
- Include LCAF and co-processing upgrades in SIR improvement plan and develop an implementation schedule.
- Finance and build pilot plant to validate production of SAF from cassava starch ethanol
- Commence trials on ground equipment using FAME biodiesel
- Start preliminary economic, technical, and logistics study for rubber seed and MSW feedstocks.

Medium term (2026-2030): Building the foundation for a SAF industry

- Start implementing LCAF and co-processing improvements at SIR and oil and gas installations.
- For cassava feedstock, conduct engineering and techno-economic studies (FEL-1, FEL-2, FEL-3/FEED) up to a final investment decision (FID)

- Source and select technology partners.
- Secure project financing
    - Finalize contributions from aid agencies, climate funds, and technology providers.
    - Maximize offset agreements so that most of the production is attributable to end customers.
    - Prepare a pitch deck presentation to attract private and venture capital.
- Secure long-term energy and power contracts
- Identify SAF location and perform necessary permitting including environmental and social impact studies.
- If additional SAF capacity is required, complete studies for MSW and rubber seed SAF production and make a final decision on whether to proceed.
- Maximize FAME biodiesel use in Abidjan airport and expand its use to other Ivorian airports.

Long term (2030 onwards): Competing the transition to low-carbon aviation fuels

- If not already completed in stage 2, fully implement LCAF and co-processing technologies at the SIR refinery.
- Complete construction of the SAF plant using cassava-biofuel-ATJ pathway and start production.
- Should additional SAF be required, perform engineering and techno-economic studies for Rubber seed and MSW feedstocks (FEL-1, Fel-2, FED)

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ANNEX 1

Table—In-Person/Virtual Meetings Participants

LIST OF SAF STAKEHOLDERS			
ORGANIZATION		**PARTICIPANTS**	
SECTOR	**DEPARTMENT**	**Family name/Surname**	**Positions**
AVIATION	ANAC	Sinaly SILUE	DG
		Konan KOFFI	Directeur de la Sécurité des Vols
		TRAORE Waogninlin	Point focal
		Philippe LEGBEDJI	Point focal suppléant
		Yves-Aimé GNEBEHI	Chargé de la navigabilité
PRIVATE INDUSTRY	Association Ivoirienne des Énergies Renouvelables et de l'Efficacité Énergétique (AIENR)	BORAUD Edi	Président
	Fédération Ivoirienne des Associations en Efficacité Énergétique et Énergies Renouvelables (FIACER)	Camara K Moussa	Directeur Exécutif
	LONO-CI	Youssouf TOURE	Sourcing Biomasse, Valorisation coproduite des biocarburants

PRODUCERS	Total Énergies (1)	Douglas N'ZO	Directeur — Direction Exploitation
	Edindia Industry	EDIAbé Valère	Co-Fondateur
		N'da Ya mira	Chef de production-usine
REFINERS + MÉLANGEURS	Société Ivoirienne de Raffinage (SIR)	YAO Yao Ernest	Directeur Adjoint/Resp. Pilotage économique
		BROU Simplice Roger	Directeur adjoint, chef de projets cogénération et transition énergétique
STORAGE	Petroci	LAUBOUET Viviane	Chef du Service Environnement
DISTRIBUTION	Ola Energy	Monthomon Fabrice BLESSON	Terminal Operation Coordinator
	Corlay Côte d'Ivoire	KOFFI Christophe	Superviseur Unité produit
	Pool Pétrolier	Eric BIZIE	Responsable QHSSE
		ENONHANLOU Ange	Manager
	Vivo Energy	Djekourboyom Mekoulom	Ingénieur produit et Services
AIRLINES AND AVIATION	Air Côte d'Ivoire	KOUELY Julien	Directeur du Suivi de la Conformité
	Solenta Aviation	AFFRE Assouan	Responsable Qualité/Sécurité
		ZOUZOU Kouassi Jordan	RDOS
	Max'Air	AUSSET Jerome	Responsable Qualité

	IAS	AUSSET Jerome	Responsable Qualité/SGS
	IH	AHOUTOU Béatrice Epse ZOUZOU	Responsable Qualité
		Marc KOSKA	Directeur Général Adjoint
	NHV	ESSOH Guy Louis	Responsable Qualité/SGS
	Endeavour	MAISSA Zadi	Responsable Qualité/SGS
		BEDA Yves Didier	Responsable CAMO
	AERIA	El-Hadj Aly OUATTARA	Chef du Département Conformité Gestion des Risques
	Unité Circulation aérienne	ALLOU Kouassi Eugène	Chef Unité Circulation aérienne
	SODEXAM	Téba Jean-Fiacre	
	Menzies	YAO Marie Claudine Epse EKOLAN	Directrice QHSE & SÛRETÉ
GOVERNMENT	Ministère des Mines du Pétrole et de l'Énergie (MMPE)	DOSSO Moussa	Directeur Général de l'Énergie Direction Gle de l'Énergie (DGE)
		YAO Philippe-Tanguy K.	Sous-Directeur de la Valorisation de Bioénergie et de la Cuisson Propre Direction Gle de l'Énergie (DGE)
		Mireille AKA NIANGO	Directeur de l'Approvisionnement, du Raffinage et de la Distribution Direction Gle des Hydrocarbures (DGH)
	Ministère des Transports	COULIBALY Ahmed	DG Transport Aérien
	Ministère du Budget et du Portefeuille de l'État (MBPE)	NONVIDE A. Fidèle	Chef du Service Transport Aérien Direction Générale du Portefeuille de l'État

		Fabrice TAHI	Conseiller technique du MBPE Direction Générale du Portefeuille de l'État
	Ministère de l'Environnement et du Développement Durable (MINEDD)	Dr Eric ASSAMOI	Directeur de la DLCC Direction de la lutte contre les Changements Climatiques (DLCC)
		Santoni AKOSSI	S/ D Direction de la lutte contre les Changements Climatiques (DLCC)
		TANON Kangah Myriam	Chef du Service Finance Climatique Direction de la lutte contre les Changements Climatiques (DLCC)
		ONAMOUN Djédji Benjamin	S/ D des Technologies Environnementales Direction des déchets industriels et substances chimiques (DDISC)
		N'DRI Konan Aimé	Expert IGES Agriculture Programme National du Changement Climatique (PNCC)
		YAO N'Da N'Guessan Eric	Assistant technique Programme National du Changement Climatique (PNCC)
		KASSI Jean-Baptiste	Conseiller technique du Ministre de l'Envir. Et du Dév. Dur. Responsable de la stratégie et Politique côtière, Marine et Dév. Dur.

	Ministère d'État, Ministère de l'Agriculture et du Développement Rural (MEMINADER)	Mme GBO Amin Dzamla	Chef de la Division Changement Climatique ANADER (Agence Nationale d'Appui au Dévelopement Rural)
		Olivier Jacques Arnaud YAO	ANADER (Agence Nationale d'Appui au Dévelopement Rural)
		Dadi Richard	Chef de Service, chargé des Questions énergétiques Direction Générale du Développement Rural
		Rodrigue Koffi N'GUESSAN	Directeur Général du Développement Rural Direction Générale du Développement Rural
	IREN/UNA	Pr AKA Boko	Directeur IREN
		KOUADIO Marc Cyril	Responsable Labo Biomasse Énergie (IREN)
		DJOHORE Ange Christine Epse KOUAME	Chercheur Responsable du laboratoire des études énergétiques et environnementales de l'IREN
	Ministère de l'Enseignement Supérieur et de la Recherche Scientifique (MESRS)	N'DAHOULE Yao Rémi	Géographe — environnementaliste — chercheur Université FHB-IGT
		ZAHUI Franck Michaël	Enseignant Chercheur — Membre de l'Unité Biotech Université de Man
	Ministère de l'Assainissement et de la Salubrité (MINASS)	Sita OUATTARA	Sous-Directeur des Opérations et de la Coordination technique (SDOCT) Agence nationale de gestion des déchets (ANAGED)
	Ministère du Commerce, de l'Industrie et de la promotion des PME	MAWA KONE	Maître de Conférences LANEMA

		Dr MONGBE Medy	Enseignant chercheur Directeur des Essais et Analyses LANEMA
		Pr ALI Eugène	Enseignant chercheur LANEMA
INVESTMENT FUNDS	PASRES	N'Guessan Evrad	Contrôleur de Gestion