THE VIABILITY OF SOUTH AFRICAN SUGARCANE ETHANOL AS FEEDSTOCK FOR SUSTAINABLE AVIATION FUEL PRODUCTION

Part I: Market analysis

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Executive summary

In April 2018, the American Society for Testing and Material (ASTM) revised the ASTM D7566 standards to allow for ethanol, produced from any renewable feedstock, using any technology, to be used to produce sustainable aviation fuel (SAF) via the Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) process. The significance of this revision is that it removes previous restrictions on the ethanol feedstock approved for this process, allowing SAF to be produced anywhere around the world using suitable feedstocks such as sugar cane.

The potential for sugarcane to be used as a feedstock for SAF production presents an opportunity for the South African sugar cane sector. The industry plays an important role in the national economy however is struggling to maintain its profitability amidst ongoing challenges including drought, rising input costs, global overproduction of sugar, and the national sugar tax. Diversification is therefore an imperative to support the economic sustainability of the industry.

The objective of this research is to explore the Alcohol-to-Jet potential for the South African sugarcane industry. The research aims to assist the industry in understanding the market potential for SAF, and feed into the long-term goal of equipping the industry with the necessary knowledge to develop an effective market development strategy.

Aviation is one of the fastest growing transport sectors, and the projected growth for the industry and subsequent fuel demand means that the aviation industry requires effective and sustainable solutions to meet its commitments in the global efforts to combat climate change. SAF is expected to play a critical role in the decarbonization of the industry, as it can deliver significant reductions in greenhouse gas (GHG) emissions while requiring no changes to existing aircraft and infrastructure. The decarbonization of aviation is being driven by various factors, including consumer pressure and an increasingly stringent policy and regulatory environment around GHG emissions. An important policy driver in this regard is the International Civil Aviation Authorities (ICAO) Carbon Offsetting and Reduction Scheme for Aviation (CORSIA). The aim of CORSIA is to address any annual increase in CO_2 emissions from international civil aviation above 2020 levels, hence supporting carbon neutral growth. Under CORSIA, from 2020 onwards, any emissions above the 2019[1] baseline represent the entity's carbon offsetting requirement[2]. An important question facing the success of CORSIA is the identification of SAFs and offsets that will be eligible under the scheme. Eligible SAFs include any alternatives to fossil based liquid fuel that contributes to CO_2 emission reductions and meet addition sustainability criteria.

While the implementation of CORSIA amongst other drivers is expected in increase global demand for SAFs with verified emission saving potential, the SAF market is still at an early stage of development, and the production of SAFs has been relatively constrained. Due to the novelty of certain processing routes, and the specialized nature of aviation fuel, processing and infrastructure requirements to produce it are relatively high. Consequently, financing new refineries is a challenge, given both the high capital investment required and the price uncertainty surrounding the end product. Typically, the market price of SAF ranges between two and seven times more expensive than conventional jet fuels. Due to the cost disparity between conventional jet fuel and SAF, and consumer's unwillingness to pay the perceived "premium" for SAF, the benchmark price for SAF should not be the price of conventional jet, but instead be considered as *conventional jet* ***plus*** *the cost of carbon pricing* (usually in the form of carbon offsetting, or carbon tax, as is the case in South Africa), as a minimum. Currently, the price of offsets is too low to tip this into favour of SAF, but it does go towards reducing the price gap. The remainder should be filled by either voluntary contributions or subsidies.

Sugarcane's use as an alternative to fossil-based feedstocks for jet fuel production has significant emission saving potential and can contribute positively to the development of a sustainable bioeconomy. High level estimates suggest that local demand for sugarcane-based fuel ethanol could be ~ 2.4 billion litres annually, of which 75% (1.8 billion litres) is from aviation, while 25% (600 million litres)

[1] Original baseline of 2019/2020 amended to 2019 only due to the dramatic impact of the Covid-19 pandemic on the aviation sector

[2] Whilst taking into consideration special circumstances and respective capabilities.

comes from the national fuel blending mandate (which is set at 2 – 10% blending on a volumetric basis). Based on current domestic demand trends for sugarcane, approximately 50% of cane that is produced (~ 10 million tonnes) can be diverted from the export market to domestic ethanol production. This could yield ~ 700 million litres of ethanol, representing 30% of the estimated potential fuel ethanol demand.

While both the supply and demand for sugarcane-based ethanol has strong potential in South Africa, current regulatory frameworks supporting alternative fuels in South Africa are not up to standard, and those that exist are best developed for the road transportation sector. While the recently released *South African Biofuels Regulatory Framework* might provide a stimulus for reinvestment, development, and support for alternative fuels in the country, this needs to be followed by explicit policy development and government support alongside clear and accessible funding models and investment strategies.

About the RSB

The Roundtable on Sustainable Biomaterials Association (RSB) is a global, multi-stakeholder organisation that offers advisory, membership and certification services for the bioeconomy on a global scale. Together with our partners, members and certified projects, we represent best practice in sustainability and proactively drive the development of a sustainable bioeconomy.

The RSB Principles and Criteria are the most robust and comprehensive indicators of why a biomaterial is sustainable. They are a one-stop solution for sector pioneers who need guidance in developing innovative products for a new world founded on social, economic and environmental considerations. The RSB certification system includes regulatory standards for compliance with the European Union's Renewable Energy Directive (EU RED) and ICAO's CORSIA.

RSB enjoys wide NGO support and is aligned with the United Nations' Sustainable Development Goals (SDGs). RSB certification is recognised by WWF, IUCN and the Natural Resources Defence Council as the strongest and the most trusted of its kind. It has been endorsed by SAFUG (Sustainable Aviation Fuel Users Group), ATAG (Aviation Transport Action Group), and ICSA (International Coalition for Sustainable Aviation) for its high level of sustainability assurance and is increasingly being requested by airlines as an essential part of their biofuel procurement.

RSB certified Sustainable Aviation Fuels (SAF) have a minimum 50% GHG reduction compared to fossil fuels, do not compete with food security or cause deforestation, and actively promote human rights and healthy ecosystems.

For more information visit www.rsb.org

About SA Canegrowers

The South African Canegrowers Association was established in 1927 to create a common platform to address grower issues. Today, our mission is to play a leading role in growing sugarcane and diverse production opportunities for cane growers through innovation, research, specialised services and products throughout the value chain

For more information visit www.sacanegrowers.co.za/

Abbreviations

ASTM	American Society for Testing and Material
ATJ-SPK	Alcohol-to-Jet Synthetic Paraffinic Kerosene
BFP	Basic Fuel Price
BTT	Biofuels Task Team
CAAFI	Commercial Aviation Alternative Fuels Initiative
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
ETS	Emission Trading Scheme
EU	European Union
EU RED	European Renewable Energy Directive
FAA	Federal Aviation Administration
FT-SPK	Fischer-Tropsch hydro-processed synthesized paraffinic kerosene
GHG	Greenhouse Gas
GRAAF	Global Framework for Aviation Alternative Fuels
H_2	Hydrogen
HEFA-SPK	Synthesized paraffinic kerosene produced from hydro-processed esters and fatty acids
IATA	International Air Transport Association
ICAO	Civil Aviation Organization
IEA	International Energy Agency
L	Litres
MBM	Market Based Measures
MFSP	Minimum Fuel Selling Price
MT	Mega tonne (1 MT = 1 000 000 tonnes)
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
ROA	Return on Investment
RSB	Roundtable on Sustainable Biomaterials
RTFO	Renewable Transport Fuel Obligation
RTK	Revenue Tonne Kilometer
SAA	South African Airways
SAF	SAF
SAFUG	Sustainable Aviation Fuel Users Group

SIP-HFS	Synthesized iso-paraffins produced from hydro-processed fermented sugars
SPK/A	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources
WWF	World Wide Fund for Nature

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1. Introduction

Aviation is one of the fastest growing transport sectors, with the demand for conventional jet fuel increasing alongside it. Currently, the sector is responsible for 2 – 3% of global anthropogenic greenhouse gas (GHG) emissions[3]. The projected growth for the industry and subsequent fuel demand means that the aviation industry requires effective and sustainable solutions to meet its commitments in the global efforts to contribute its fair share in the global efforts to combat climate change. Sustainable aviation fuel (SAF), which can deliver significant reductions in GHG emissions while requiring no changes to existing aircraft and infrastructure, offer the most effective and immediate solution to an industry looking to decarbonise rapidly.

To date, the production of SAFs has been relatively constrained. The high production costs of SAF as compared to convention fossil-based fuel has been an important factor in historic demand trends, with many airlines unwilling, or unable, to pay a premium for fuel. The majority of SAF used by commercial flights has been produced using hydro-processed esters and fatty acids technology, converting oils and fats to hydrocarbons in the jet fuel and diesel range. Although demonstrated on a commercial scale, the high price and limited availability of sustainable oil feedstocks are limiting factors for increasing production volumes. In light of these limitations, there is increasing emphasis and support for the development of conversion pathways that bridge the current price premium of SAFs and enable large scale production whilst utilizing sustainable feedstocks.

One such pathway is the Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) process, recently approved by ASTM International, formally known as the American Society for Testing and Material (ASTM). In April 2018, the ASTM D7566 standards were revised to include ethanol as an approved feedstock for the ATJ-SPK process. As a result of this revision, jet fuel produced by ATJ-SPK can use ethanol produced from any feedstock, using any conversion technology. This means that SAF can be produced anywhere around the world using suitable feedstocks such as sugar cane.

This revision has particular relevance to the South African sugar industry, as it allows for the conversion of ethanol produced from local sugar cane to SAF. Given the current crisis that the industry is facing due to a combination of factors including drought, falling prices, the sugar tax and impact of cheap imports, the production of ethanol as input into the ATJ process, could form part of a much-needed diversification strategy for the industry.

1.1 Research Objectives

The key objective of this research is to explore the Alcohol-to-Jet potential for the South African sugar cane industry. The research aims to assist the industry in understanding the market potential for SAF, and feed into the long-term goal of equipping the industry with the necessary knowledge to develop an effective market development strategy.

The research is structured to address the following topics:

1. Current technology and relevant technology developments
2. SAF markets and demand trends
3. Global policy environment in support of SAF
4. Local policy environment
5. Costing and financial considerations for the development of an ATJ refinery
6. Potential demand estimate

[3] https://www.atag.org/facts-figures.html

2. About Sustainable Aviation Fuels (SAF)

2.1. What is Jet Fuel

Jet fuel or kerosene is a specialist fuel used to power aircrafts. It is a mixture of hydrocarbons (carbon and hydrogen) with chain lengths (number of carbons) of approximately $C_9 – C_{16}$. This overlaps with both the range for petrol ($C_4 – C_{12}$) and diesel ($C_8 – C_{24}$). Jet fuel is generally of a higher quality than regular petrol or diesel and needs to have a low flammability and low freezing point for high altitudes. Therefore, additives[4] are often added to ensure high compressibility, low volatility (high boiling point), and prevent freezing at high altitude.

There are various classes of jet fuel, each fulfilling slightly different requirements[5]:

- **Jet A:** Typically used in the United States and Canada. **Flash point[6] of 38°C and auto-ignition[7] temperature of 210°C. This makes jet fuel safer than traditional gasoline.**
- **Jet A-1: Similar to Jet A, but with a lower freezing point of 47°C. Also includes anti-static additive. Less dense than Jet A.**
- **Jet B: Jet B is designed for use in cold climates. It has a lower auto-ignition temperature, which makes it more dangerous than Jet A fuels as it can ignite at lower temperature, and hence has a higher risk of explosion.**

2.2. There are currently four major jet fuel production technologies:

- Conventional crude oil refining
- Unconventional oil source refining
- Fischer-Tropsch Synthesis (coal to liquid, gas to liquid, biomass to liquid)
- Renewable jet fuel processes

Due to the strict technical requirements for jet fuel, in order to be used commercially, jet fuels (including bio-based fuels) need to be processed according to the rules set out by the American Society for Testing and Material (ASTM)[8].

2.3. What is Sustainable Aviation Fuel (SAF)

Sustainable aviation fuels (SAF) – sometimes known as aviation biofuels or bio jet fuels – are low-carbon alternatives for the aviation industry. These non-petroleum-based drop-in aviation fuels are generally produced from bio-based feedstocks including waste, residues and end-of-life products – as well as fossil waste such as CO or waste plastics and tyres (see Table 1).

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[4] Antioxidants, antistatic agents, corrosion inhibitors, fuel system icing inhibitors, biocides (reduce fungal growth in tanks), metal deactivators (reduce dangerous effects of trace metals in fuel). For more information, refer to : http://www.petroleum.co.uk/refining

[5] For more information, refer to: http://www.petroleum.co.uk/refining

[6] The flash point of a volatile material is the lowest temperature at which vapours of the material in the air near the surface will ignite, when given an ignition source.

[7] The autoignition temperature is the lowest temperature at which a substance spontaneously ignites in normal atmosphere without an external source of ignition.

[8] Founded in 1898, ASTM International is one of the world's largest international standards developing organizations and develops standards for a wide range of materials, systems and services, including fuels. For more information, visit: https://www.astm.org/

The use of SAF, along with other efficiencies in operations and aircraft design, is intended to reduce the industry's growing share of GHG emissions and lower the overall climate impact of aviation.

Table 1 Bio-based and fossil-waste feedstocks for SAF production

Bio-based feedstocks	Fossil-based feedstocks
• Virgin vegetable fats and oils such as canola, castor oil and Solaris tobacco oil. • Waste vegetable fats and oils such as used cooking oil or animal tallow • Starch and sugar crops such as sugar cane, corn, sorghum, etc. • Lignocellulosic[9] materials such as sugarcane bagasse and wood chips • Biogenic content of municipal solid waste	• Carbon off-gases, such as CO and CO_2 [10] • Waste tyres • Waste plastic

2.4. How is SAF Produced?

The production of SAF must be done in specialised biorefineries. A simplified schematic illustrating the different technology pathways for bio-based SAF is shown in Figure 1.

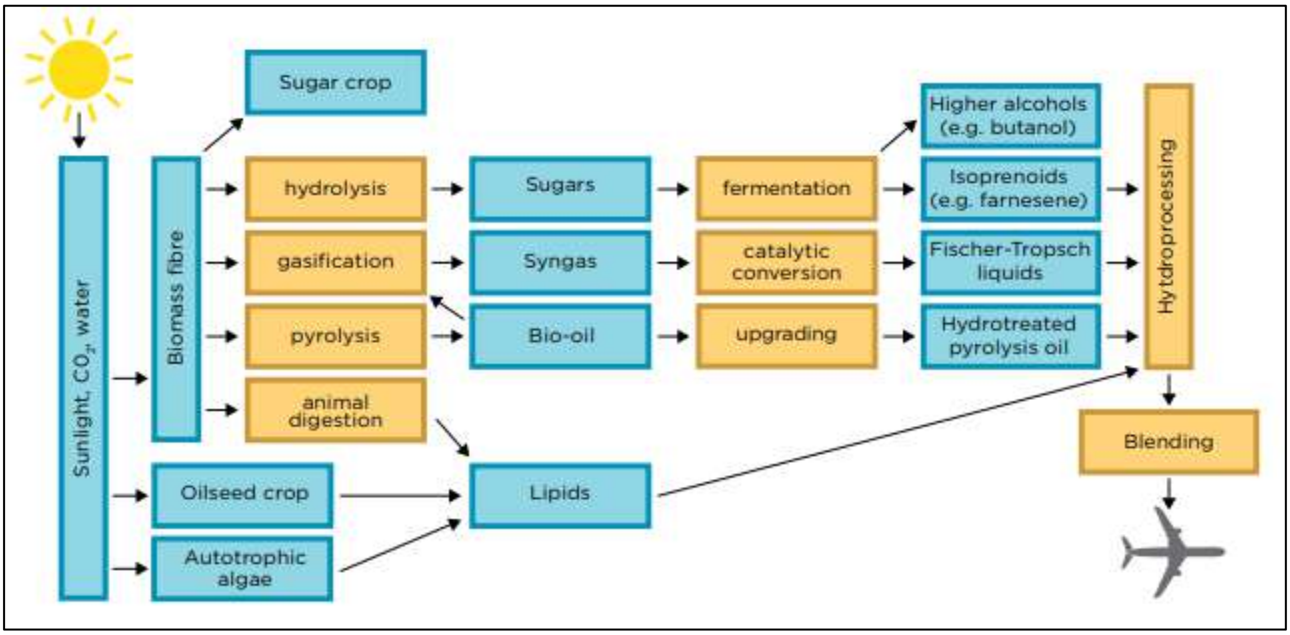

Figure 1 Simplified schematic illustrating the different technology pathways to SAF[11].

[9] Lignocellulosic material, is the stringy fibre of a plant, such as the bark, wood or leaves and includes materials such as agricultural and forestry residues, sugar cane bagasse etc.
[10] CO is the typical feedstock for the LanzaTech process, because it is a by-product of ferroalloy and titania smelting, although CO_2 can be processed in the presence of H_2. In addition, CO_2 can be used for SAF production via electrolysis, but the technology is still under development.
[11] IRENA Biofuels for Aviation Technology Brief. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf

Currently, there are seven SAF pathways and related blending limits that have been approved by the ASTM under the fuel standard ASTM D7566[12]. These are summarised in Table 2. A further four pathways are currently under the ASTM approval process (

Table 3).

Table 2 Conversion processes approved as annexes to ASTM D7566[13].

ASTM Approved Process	Date of approval	Feedstock options	Blending Ratio by Volume
FT-SPK Fischer-Tropsch hydro-processed synthesized paraffinic kerosene)=	2009	**Lignocellulosic biomass** *Agricultural and forestry residues (e.g. sugar cane bagasse, sugar cane trash, tree-tops, corn stover and corn stalk) and municipal waste*	Up to 50%
HEFA-SPK Synthesized paraffinic kerosene produced from hydro-processed esters and fatty acids	2011	**Oils and fats** *Camelina, jatropha, castor oil, palm oil, animal fats, used cooking oil*	Up to 50%
HFS-SIP Synthesized iso-paraffins produced from hydro-processed fermented sugars	2014	**Microbial conversion of sugars to hydrocarbon** *Sugarcane, cassava, sorghum, corn*	Up to 10%
FT-SPK/A Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	2015	**Lignocellulosic biomass** *Agricultural and forestry residues (e.g. sugar cane bagasse, sugar cane trash, tree-tops, corn stover and corn stalk) and municipal waste*	Up to 50%
ATJ-SPK [isobutanol] Alcohol-to-Jet Synthetic Paraffinic Kerosene	2016	**Biomass used for sugar production and lignocellulosic biomass** *Sugarcane, cassava, sorghum, corn, ethanol*	Up to 50%
ATJ-SPK [ethanol] Alcohol-to-Jet Synthetic Paraffinic Kerosene	2018	**Biomass used for sugar production and lignocellulosic biomass** *Sugarcane, cassava, sorghum, corn, ethanol*	Up to 50%
CHJ Catalytic hydrothermolysis synthetic jet fuel	2020	**Triglyceride-based feedstocks** *Waste oils, algae, soybean, jatropha, camelina, carinata*	Up to 50%

[12] For more information on this standard, visit https://www.astm.org/Standards/D7566.htm

[13] Adapted from https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel/producing-sustainable-aviation-fuel/

HHC-SPK High Hydrogen Content Synthetic Paraffinic Kerosene	2020	**Biologically derived hydrocarbons** *Algae*	Up to 10%

Table 3 Conversion processes within the ASTM approval process[14]

ASTM Approved Process	ASTM Abbreviation	Possible Feedstocks	Notes
Co-processing bio-oils in existing refineries	Co-processing	• Bio-oils	Co-processing is based on the processing of bio-oil with conventional middle distillates in existing refineries.
Alcohol-to-jet synthetic kerosene with aromatics	ATJ-SKA	• Biomass used for starch and sugar production and cellulosic biomass for alcohol production	Fuel produced with bio-aromatics to allow for higher blend percentages.
HEFA Plus	Green diesel	• Bio-oils • Animal fat • Recycled Oil	First test flight with a 15% HEFA-diesel blend has already taken place.

To date, the majority of SAF that has been used by commercial flights have been produced using HEFA technology. However, the SAF market is still at a relatively early stage of development and consequently, many dedicated refineries are at the development or pilot stage. This means that the financing of such refineries is a challenge, due to the significant capital investment needed, the long-term nature of the required infrastructure, and the price-uncertainty surrounding the final product. Promoting the development of conversion pathways that bridge the current price premium of SAFs and enable large scale production whilst utilizing sustainable feedstocks[15] is critical for stimulating long-term and sustainable growth.

2.5. Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) Process

Of particular relevance to the sugarcane industry is the ASTM Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) process. In April 2018, the ASTM D7566 standards were revised to include ethanol as an approved feedstock for the ATJ-SPK process[16]. The standards were also revised to increase the blending limit to 50% (from the previous 30%). This means that because jet fuel produced by ATJ-SPK can use ethanol produced from any feedstock, using any conversion technology, SAF can be produced anywhere around the world using suitable feedstocks such as sugar cane.

[14] Adapted from ICAO *Facts and Figures.* Available: https://www.icao.int/environmental-protection/GFAAF/Pages/Facts-Figures.aspx

[15] Sustainable feedstocks should be abundantly available, have low economic value, not compete with food production and have negligible environmental impact

[16] Previously, this standard only approved isobutanol as a feedstock for the process. For the press release on this announcement, refer to: http://www.lanzatech.com/jet-fuel-derived-ethanol-now-eligible-commercial-flights/

Although ethanol from all the bio-based feedstocks (i.e. corn, sugar beet, sweet sorghum, sugar cane etc.), is chemically identical, sugar cane is frequently a preferred feedstock for the following reasons[17]:

- Given suitable agro-ecologic and climate conditions, it has a higher biomass output per hectare than other crops
- It is usually the cheapest available crop
- It does not compete as a staple food source[18]
- It does not require pre-treatment prior to fermentation into alcohol
- It can have a relatively low fossil energy input if bagasse is used for co-generation at sugar and ethanol mills, therefore delivering greater GHG emission savings as compared to other feedstocks

Currently, the production of SAF using the ATJ process has not reached the same level of commercialization as other processes (such as HEFA). However, companies currently producing jet fuel using the ATJ process include:

- Lanzatech
- Gevo
- Byogy Renewables
- Vertimass
- Swedish Biofuels

An overview of a typical approach to produce synthetic paraffinic kerosene jet fuel from ethanol is provided in the following sub-sections. While there are various pathways available[19], the recently approved LanzaTech/PNNL Alcohol-to-Jet process first dehydrates the ethanol to ethylene, which is followed by oligomerization, hydrogenation and fractional distillation[20]. An overview of this process is shown in Figure 2. This is followed by a brief explanation of each stage.

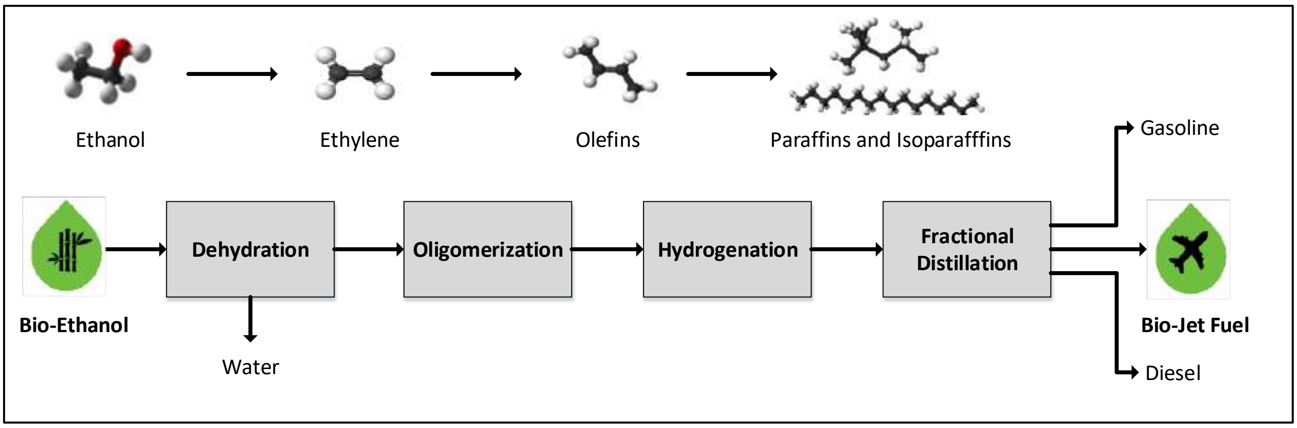

Figure 2 Overview of the Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) process using ethylene as an intermediate.

Dehydration

[17] RSB. *Market Analysis on Sugar-based Biomaterials.* 2017

[18] Although not a staple crop, sugar is consumed globally. Consequently, if this were completely eliminated from our diets, we would most likely require alternative sweeteners.

[19] These pathways are characterized according to the chemistry involved and include production through the following intermediates: ethylene, propylene intermediate, higher alcohol or carbonyl

[20] For more information refer to: http://www.lanzatech.com/jet-fuel-derived-ethanol-now-eligible-commercial-flights/

The first step in the process is the dehydration of ethanol. Ethanol is heated in an excess of concentrated sulphuric acid to form ethylene. Ethanol dehydration is well-developed and widely practiced commercially, and high ethylene yields are achievable. The yield of ethylene is dependent on the conversion of the ethanol, as well as the molar selectivity[21]. These factors are influenced by the specific reaction conditions used (for example, temperature, reactor type and catalyst), but typical ethylene yields can range from 94 – 99%[22].

Given that the dehydration reaction produces water in steam form as the by-product, before the ethylene is processed further, it must be separated from the steam.

Oligomerization

Once the ethylene has been separated from the water, it is fed into the oligomerization reactors. The purpose of oligomerization is to convert the short-chain hydrocarbons, such as ethylene (two-carbon chain) into longer chain hydrocarbon molecules. The products from this process are called *olefins*. This process is necessary as jet-fuel is a mixture of hydrocarbons with chain lengths of approximately C_9 – C_{16}.

However, olefins are molecules that contain one or more double, whereas hydrocarbons used in jet fuel require single bonds. Therefore, the olefins must undergo further processing before they can be used.

Hydrogenation

After the oligomerization reaction, the olefins are fed into a hydrogenation reactor. During hydrogenation, the olefins react with hydrogen. This process breaks the double in the olefins and produces single chain hydrocarbons of various chain lengths.

Given that jet fuel requires hydrocarbons of chain length C_9 – C_{16}, the resulting mixture of hydrocarbons must be processed in order to separate those with the required chain length.

Fractional Distillation

The hydrocarbon mixture produced in the hydrogenation reactor is separated by fractional distillation. In this process, the hydrocarbon mixture is heated and the different hydrocarbons are separated based on their boiling points. This is shown in Figure 3.

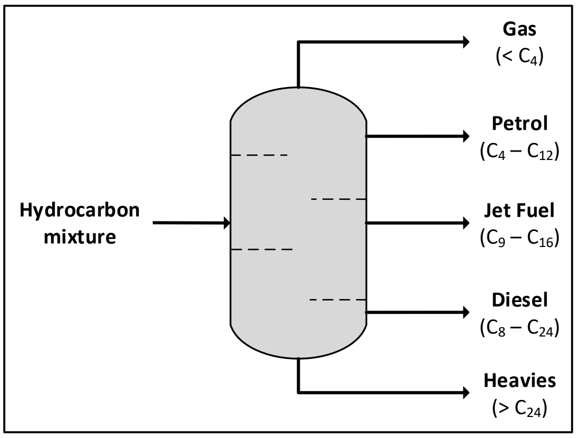

Figure 3 Simplified illustration of the fractional distillation of hydrocarbons

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21 Molar selectivity refers to the extent to which a reactant forms a particualr product when multiple reactions are possible. For more information refer to: MOHSENZADEH, A., ZAMANI, A. & TAHERZADEH, M. J. 2017. Bioethylene Production from Ethanol: A Review and Techno-economical Evaluation. *ChemBioEng Reviews,* 4**,** 75-91.

22 ZHANG, M. & YU, Y. 2013. Dehydration of Ethanol to Ethylene. *Industrial & Engineering Chemistry Research,* 52**,** 9505-9514.

Through this process, the C_9 – C_{16} hydrocarbons can be separated from the shorter and longer chain molecules in the hydrocarbon mixture. The benefit of this process is that various liquid fuels are produced (as these are comprised of hydrocarbons with different chain lengths).

2.6. Sustainability Considerations

An important driver for SAF is the growing need to reduce CO_2 emissions from the aviation industry. Over the last 20 years global GHG emissions from aviation have more than doubled, making this the largest increase in emissions from the transport sector. Currently, sectoral emissions from aviation account for approximately 2%[23] of total anthropogenic GHG emissions and as the sector grows, there will be a corresponding growth in emissions. Although there has been significant technological progress in the aviation sector to date[24], projected annual improvements of 1 – 2% in terms of fuel efficiency, advances in air traffic management and other operational measures will be unable to offset the increased demand for fuel (and hence emissions) consequent of the predicted growth in air traffic[25].

SAF derived from biomass, wastes and other feedstocks are capable of delivering significant GHG savings to the industry, having the potential to reduce the carbon footprint of aviation fuel by up to 94% over its full lifecycle[26]. An important benefit of SAF is that it can be used as a "drop in" to existing fuel supply networks, requiring no changes to existing aircraft and infrastructure. Consequently, SAF offer the most effective and immediate solution to an industry looking to decarbonize rapidly[26].

Currently, for bio-based feedstocks, both EU Directives and the RSB Standard require biofuels to achieve a minimum of 60% GHG emission reduction compared to fossil fuels[27]. However, when considering GHG emissions only, not all feedstocks are suitable for producing jet fuel. The GHG impact of the SAF is largely determined by the type and origin of the feedstock. For example, the lifecycle GHG emissions associated with SAFs are strongly affected by how the feedstock was produced (i.e. the use of fertilizers, land-use change effects etc.) and production and transport energy needs. Consequently, the GHG emissions of SAF may in certain cases be higher than conventional fossil fuels, as shown in Figure 4.

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[23] https://www.atag.org/facts-figures.html

[24] For example, aircraft efficiency has increased by approximately 80% per passenger kilometer since the 1960s

[25] Uniting Aviation: Why Did ICAO Develop A Global MBM Scheme For International Aviation? Available: https://www.unitingaviation.com/strategic-objective/environment/why-did-icao-develop-a-global-mbm-scheme-for-international-aviation/

[26] https://rsb.org/wp-content/uploads/2018/09/RSB-Alternative-Aviation-Fuels-A-Sustainable-Future-is-Taking-Off.pdf

[27] EU Directives 2009/28/EC and EU/2015,1513 Article 7b

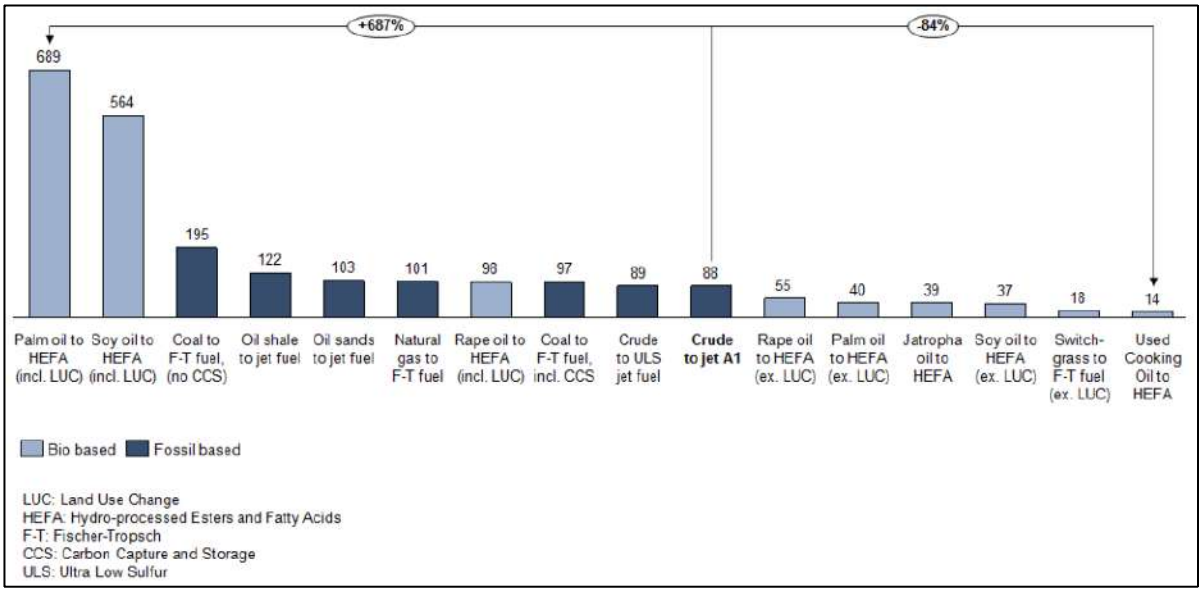

Figure 4 Well-to-wing emissions of different jet fuel production pathways (gCO_2/MJ)[28].

Despite their potential for GHG savings, it is important to note that SAF are not inherently more sustainable that conventional fossil-based fuels. Without sustainable practices in place (verified by reliable certification schemes), some of these fuels risk having negative social and environmental impacts, such as negligible GHG emissions reductions (or even increased emissions), reduced food security through the conversion of food-producing land to feedstock production, environmental degradation from deforestation, biodiversity loss and unsustainable soil and water usage.

According to the IATA[29], for SAF to be considered sustainable, the following must be true:

- The SAF must have a substantially better (>50%) GHG balance than their fossil fuel alternative.
- The SAF production and/or use cannot harm the environment.
- The production/use of SAF does not involve any negative socio-economic impacts.
- The production/use of SAF does not deplete natural resources.

The sustainability standards developed by the Roundtable on Sustainable Biomaterials (RSB) are widely recognised by the industry to be best-in-class, covering every sustainability aspect from food security, rural development and protection of ecosystems (Figure 5). Certification to the RSB Standard covers the production of any bio-based feedstock, biomass-derived material and any advanced fuel, as well as complete supply chains and new technologies. Certification not only contributes towards the development of a sustainable bio-economy, but is beneficial to the business, helping to identify and mitigate risk[30].

[28] FAAIJ, A. & VAN DIJK, M. 2012. White Paper on Sustainable Jet Fuel [Online]. SkyNRG. Available: https://skynrg.com/wp-content/uploads/2019/03/Publications-White-Paper-on-Sustainable-Jet-Fuel.pdf

[29] IATA: SAF Roadmap. Available: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

[30] For more information on RSB Certification refer to the following: https://rsb.org/certification/about-certification/

Figure 5 The 12 RSB Principles

3. MARKET ANALYSIS FOR SUSTAINABLE AVIATION FUELS

3.1. Markets for Sustainable Aviation Fuels

While in many countries, cars have been running on biofuel blends for decades, SAFs have not yet reached “business-as-usual” state, meaning that SAF cannot be sold or purchased by traders on the market or purchased by airlines at airports. Currently, the production and consumption of SAF is driven by supply chain initiatives that depend on close collaboration between various stakeholders including airlines, feedstock producers, fuel processors and distributors, airports, research establishments and governmental agencies[31]. Industry associations represent another important group of stakeholders in promoting the use of these fuels. An overview of key aviation industry associations is shown in Table 4.

Table 4 Key aviation industry associations

Industry Association		Overview
	International Air Transport Association (IATA)	• Global trade association representing 290 airlines (82% of total air traffic) • Supports various areas of aviation activity • Assists in the formulation of industry policy on critical aviation issues
	United Nation’s International Civil Aviation Organisation (ICAO)	• UN specialized agency established to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention) • Works with the Convention’s 192 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs)
	Commercial Aviation Alternative Fuels Initiative (CAAFI)	• Coalition of airlines, aircraft and engine manufacturers, airports, energy producers, researchers, international participants and US government agencies • Supports the development and deployment of alternative jet fuels for commercial aviation
	SAF User Group (SAFUG)	• Group comprising of 28 airline members and 4 affiliates • Focused on accelerating the development and commercialization of sustainable aviation biofuels • Commitment to source RSB, or equivalent, sustainably certified aviation fuel

A comprehensive list of SAF initiatives across the world is available on the ICAO’s Global Framework for Aviation Alternative Fuels (GRAAF) database[32]. Currently, there are over 30 initiatives worldwide, with their number continuously increasing. A mapping of global initiatives (as of 2015) is shown in Figure 6.

[31] IATA: Sustainable Aviation Fuel Roadmap. Available: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

[32] The ICAO provides an up-to-date list of aviation biofuel projects. For further information refer to: https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx and https://www.icao.int/environmental protection/GFAAF/Lists/Initiatives%20and%20Projects/Projects.aspx

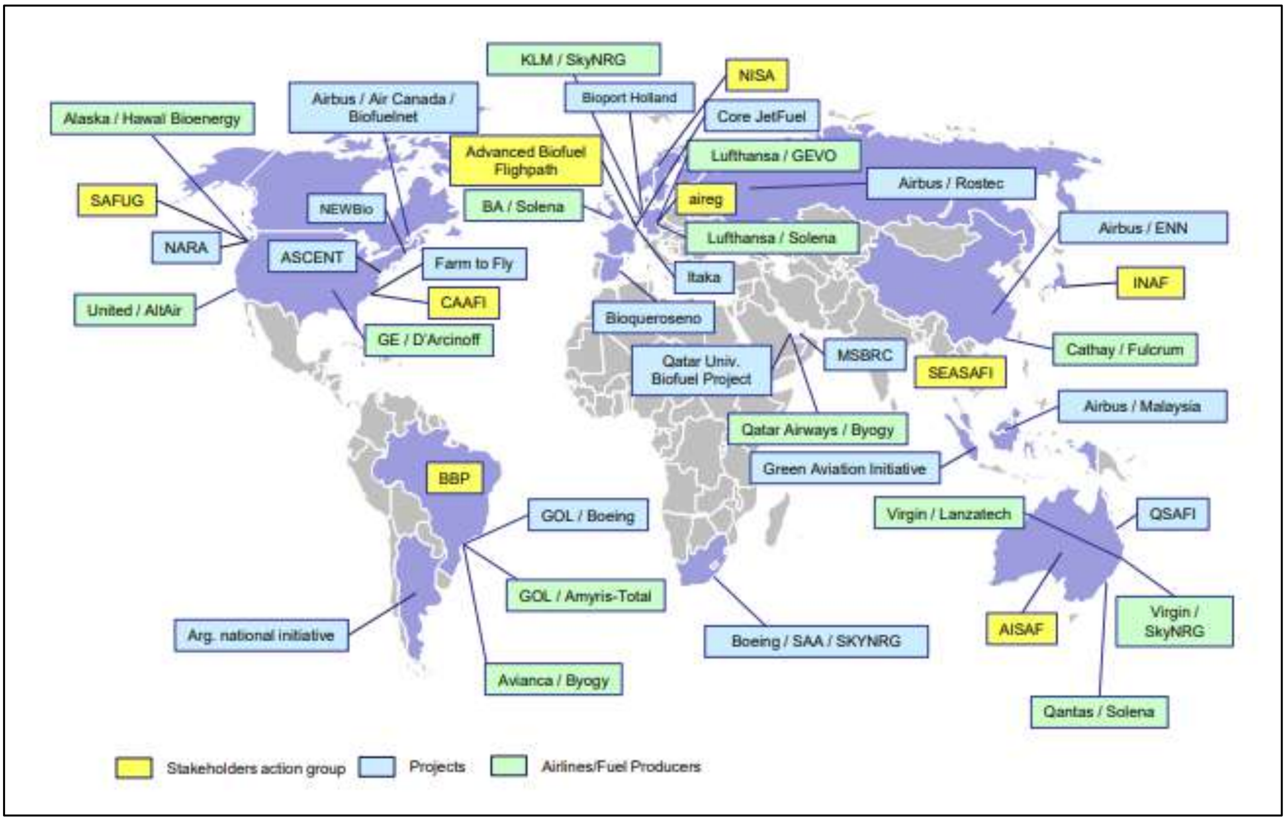

Figure 6 Mapping of aviation biofuel initiatives (based on initiatives recorded in GRAAF in 2015)[33].

The scope of current initiatives ranges from bilateral partnerships for a specific project to multi-stakeholder associations intended for continuous, long-term cooperation. According to the IATA, existing initiatives are typically of the following types[34]:

- Networking/coordination
- Internal cooperation
- Research and development
- Assessment
- Setting of production (for example, off-take agreements)
- Other

The SAF initiative in South Africa shown in Figure 6 is *Project Solaris*[35]. It is a joint venture between Sunchem SA, SkyNRG, Boeing and South African Airways to scale up the cultivation of the energy tobacco crop "Solaris" in South Africa and in so doing, lay the basis for a regional SAF supply chain. The project is supported by Boeing and South African Airways (SAA) and has been certified by the RSB.

Solaris is a nicotine and GMO free crop that yields significant amounts of high quality vegetable oil, as well as press cake (which is suitable for animal feed) and lignocellulosic residues. SAF made from the

[33] Image source: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

[34] IATA SAF Roadmap. Available: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

[35] For more information on this project refer to: http://www.projectsolaris.co.za/

Solaris plant is capable of reducing lifecycle CO_2 emissions by 50 – 75%, and as an inedible plant oil, it is not linked to the food market[36].

The project is operating in Marble Hall, in the Limpopo province, with a launch crop of 50 hectares. The first crop was harvested in 2015/2016, and the fuel (refined in the US by World Energy) was used in Africa's first commercial flight using SAF in a SAA Boeing 737-800 flight from Johannesburg to Cape Town on 15 July 2016[37]. The long-term goal of the project is to cultivate 50 000 hectares of land and produce the jet fuel in a local refinery. If successful, the project will provide a long-term viable domestic fuel supply and meet government's objectives for rural economic development, job creation and local manufacturing.

Figure 7 Project Solaris and its partnerships[38]

Although not shown in Figure 6 (due to the time frame represented by this figure), another notable initiative in South Africa is the Waste to Wing project. This project aims to assess the feasibility of a waste-based jet fuel industry in South Africa. The project is driven by a consortium of the World Wide Fund for Nature-South Africa (WWF-SA), SAF specialists, SkyNRG and enterprise development specialist Fetola. A strong principle of the project is that it should conform to the RSB's sustainability standard. The project has the support of the European Union's Switch Africa Green Program and will look to sharing key results and learnings with other African countries.

Started in January 2018, the project will run until December 2020. Given that biomass is already recognised as a technically feasible feedstock for aviation fuel production, the objective of the project is to prove that SAF produced from biomass can be used economically in South Africa and that is can be an inclusive value chain, providing a new market opportunity to small, medium and microenterprises (SMMEs). The consortium will pilot the development of 25 SMMEs to supply the biomass feedstock. The project will then demonstrate how this feedstock can be pre-treated and converted to SAF[39].

[36] https://www.defenceweb.co.za/aerospace/aerospace-aerospace/first-solaris-aviation-biofuel-crop-ready-for-harvest/?catid=74&Itemid=30

[37] For further infromation on this flight refer to: https://www.greenaironline.com/news.php?viewStory=2259

[38] Images courtesy of SunChem: http://www.projectsolaris.co.za/p/activities_5.html

[39] For further information on this project refer to: https://www.wwf.org.za/food/?24801/Waste-to-Wing-project-first-to-enable-sustainable-aviation-fuel-production-in-South-Africa

Figure 8 The Waste to Wing project consortium

Another recent development not shown in Figure 6, is the collaboration between a local engineering company Swayana and the carbon recycling company Lanzatech, headquartered in the USA. In 2017, the two companies signed a Memorandum of Understanding (MoU) to collaborate on developing projects for the production of ethanol and higher value products from waste gases in the ferroalloy and titania smelting sectors using Lanzatech's proprietary carbon capture and gas fermentation technology[40]. This project also has the support of the South African Department of Trade and Industry (dti) which is working with Swayana to realize the implementation of the project. With the recent approval of the ASTM ATJ pathway, this initiative has strong potential to supply feedstock for SAF in South Africa. LanzaTech is already producing SAF using ATJ technology in China and India, and on 4 October 2018 Virgin Atlantic completed a commercial flight from Orlando to London Gatwick using SAF produced from waste industrial gases[41].

The first commercial ethanol production facility (52 MTA) in the Lanzatech/Swayana collaboration is based on off-gases from an existing smelter site in the Mpumalanga province, with operations planned to commence in 2019. According to a Lanzatech statement on the collaboration[42], the impact of using off-gases from this sector could be considerable: South Africa has the potential to produce more than 400 000 tonnes per annum ethanol from existing ferroalloy and titania smelters. This would sequester over 700 000 tonnes of CO_2 annually (the equivalent to removing 250 000 cars from South Africa's roads). In addition to environmental benefits, the project will also contribute to social upliftment in the area by providing jobs and stimulating the development of a new industry based on ethanol and its chemical derivatives.

Figure 9 Collaborators on the South African ethanol production facility

[40] For further information on this collaboration refer to: http://www.swayana.co.za/lanzatech-collaborating-with-swayana-to-convert-waste-gases-from-ferroalloy-production-to-ethanol/

[41] For more information on this flight refer to: http://www.lanzatech.com/virgin-atlantic-lanzatech-celebrate-revolutionary-sustainable-fuel-project-takes-flight/

[42] For further information on this collaboration refer to: http://www.lanzatech.com/swayana-brings-carbon-recycling-south-africa/

A significant challenge for SAF suppliers intending to supply the aviation market is the risk of demand continuity: due to the relatively high price of SAFs and airlines' low profit margins, most airlines are hesitant to commit to large fuel purchases[43]. However, as capital and production costs are strongly affected by economies of scale, so long as the short-to-medium term outlook for SAF demand remains low, production facilities are likely to remain small, adversely affecting production costs and increasing the price of SAF for the final user.

Improved certainty in demand through off-take agreements between SAF users and suppliers is a mechanism that can help to overcome this challenge and provide benefit to both parties, allowing suppliers to offer more competitive terms and potentially invest in new production facilities to increase output capacity. While there are various ways in which an off-take agreement might be structured, the fundamental objective of such an agreement should be to enable the SAF user to receive a reliable quantity of fuel at an acceptable price (or within an acceptable range), while guaranteeing a market for the supplier (thus reducing production risk and improving financing terms for the supplier)[43].

There have been increasing numbers of offtake agreements between airlines and alternative fuel suppliers. Although the majority of these have reportedly been short-term offtake agreements to use SAF in trial runs[44], this type of agreement is important in developing user/ supplier collaboration. A summary of off-take agreements according to the ICAO's GRAAF database[45] is shown in Table 5 overleaf.

Table 5 Announced off-take agreements (as of May 2018)[46]

<table>
<tr><th rowspan="2">Producer</th><th rowspan="2">Feedstock</th><th rowspan="2">Purchaser</th><th colspan="2">Off-take production/year</th><th rowspan="2">Start /Length of agreement (years)</th></tr>
<tr><th>(Million gallons)</th><th>(Mt)</th></tr>
<tr><td>Air Total</td><td>Vegetable oil and lignocellulosic biomass</td><td>Airbus/China Airlines</td><td colspan="2">5 A350-900 deliveries at 10% blend</td><td>2017 / N/A</td></tr>
<tr><td rowspan="4">World Energy (ex AltAir Fuels)</td><td rowspan="4">Vegetable oils and tallow</td><td>United Airlines</td><td>5</td><td>0.015</td><td>2016 / 3</td></tr>
<tr><td>World Fuel/ Gulfstream</td><td colspan="2">30/70 blend</td><td>N/A / 3</td></tr>
<tr><td>SkyNRG/KLM – Los Angeles International Airport</td><td>N/A</td><td>N/A</td><td>2016 / 3</td></tr>
<tr><td>SkyNRG/KLM – Växjö Småland Airport</td><td>0.032</td><td>0.000</td><td>2018 / N/A</td></tr>
<tr><td>World Energy (ex AltAir Fuels)/Neste</td><td>Vegetable oils and tallow</td><td>KLM/SAS/Lufthansa/AirBP</td><td>0.33</td><td>0.001</td><td>N/A / 3</td></tr>
<tr><td>Amyris/ Total</td><td>Sugar cane</td><td>Cathay Pacific/Airbus</td><td colspan="2">48 A350 deliveries at 10% blend</td><td>2016 / N/A</td></tr>
</table>

43 IATA SAF Roadmap. Available: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

44 As reported in the IRENA Biofuels for Aviation Technology Brief. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf

45 Reported offtake agreements as of May 2018. Available : https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

46 Adapted from ICAO *Facts and Figures.* Available: https://www.icao.int/environmental-protection/GFAAF/Pages/Facts-Figures.aspx

Fulcrum Sierra BioFuels	Municipal Solid Waste	Cathay Pacific	35	0.106	N/A / 10
		United Airlines	90 – 180	0.274 – 0.547	N/A / 10
		Air BP	50	0.152	N/A / 10
Gevo	Corn, corn stover and woody waste	Lufthansa	8	0.024	N/A / 5
Red Rock	Forestry residues	Southwest Airlines	3	0.009	N/A / N/A
		FedEx	3	0.009	N/A / 7
SG Preston	Non-edible plant oils	Jet Blue	10	0.030	2019 / 10
		Qantas	8	0.024	2020 / 10
Lanzatech	Industrial off-gas	Virgin Atlantic	N/A	N/A	2011

3.2. Airport Supply

In addition to developing reliable and economically viable fuel supply chains, an important step in the growth of SAF is to enable the deployment of alternative fuel to the common fuel distribution system of airports, with the possibility for all operators flying into these airports to be refuelled with SAF. Currently, there are three such "bioports" in operation[47]:

- Karlstad Airport, Sweden
- Oslo Airport, Norway
- Amsterdam Schiphol Airport, Netherlands

Several other airports are planning for a similar implementation of regular SAF supply through their common distribution network, namely[47]:

- **Brisbane Airport, Australia** – currently undertaking a study to facilitate the planning and development of infrastructure to deliver SAF to airlines.
- **Helsinki Airport, Finland** – identified by Finnish Government to be well positioned as a future bioport.

Certain off-take agreements between airlines and suppliers are also reliant on distribution facilities at specific airports. For continuous supply agreements (especially those with the long-term objective of increasing volumes), establishing an appropriate distribution network is critical. Key airports currently servicing such off-take agreements include[47]:

- **Los Angeles International Airport, USA**
  - World Energy (ex AltAir) will deliver fuel to United Airlines at this airport
  - Fulcrum will start delivering fuel to Cathay Pacific at this airport and aims to develop distribution facilities at additional airports in future
- **London City Airport, England** – the British Airways/Solena agreement foresees a delivery of 50kt/yr at this airport.

[47] IATA: SAF Roadmap. Available: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

3.3. Future Growth and Drivers

Aviation is one of the fastest growing transport sectors, with the demand for conventional jet fuel increasing alongside it. Annual growth in this sector is expected to average 5% towards 2030, with demand for aviation fuel growing by an estimated 1.5 – 3% per year[48]. Similar growth rates are anticipated for the following decade, and by 2040, the following demand estimates have been proposed:

- The International Energy Agency (IEA) estimates demand to reach 522 billion l/year[49]
- The ICAO estimates demand to be between 496 billion l/year and 691 billion litres/year[50]
- WWF South Africa estimates the demand from South Africa to be 6,9 billion l/year by 2050 (from the current 2,6 billion l/year).

These projections suggest that future demand will be at least 58% from 2014 levels, with the potential for demand to more than double by 2040[51]. While growth is anticipated to be global, significant growth rates are anticipated for China, India and the Middle East (Figure 10).

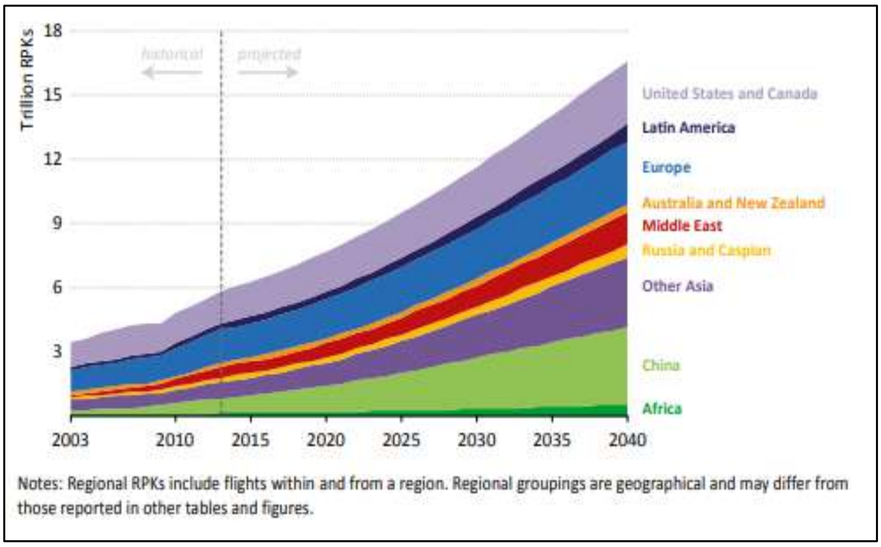

Figure 10 Revenue passenger kilometres in aviation by region (according to the IEA's New Policies Scenario)[52]

The projected growth for the aviation industry and subsequent fuel demand, coupled to the stringent policy environment surrounding GHG emissions, has created a number of important drivers for the development of SAFs. Key drivers for the development of SAFs in the next decades include:

- **Lack of alternative options for fossil-based kerosene:** Gaseous biofuels and electrification are not likely to be viable options for air transport in the short-to-middle term.

[48] RSB: SAFs: A Sustainable Future is Taking Off. Available: https://rsb.org/wp-content/uploads/2018/09/RSB-Alternative-Aviation-Fuels-A-Sustainable-Future-is-Taking-Off.pdf

[49] IEA: World Energy Outlook 2015. Available: https://www.iea.org/publications/freepublications/publication/WEO2015.pdf

[50] ICAO: 2016 Environmental Report. Available: https://www.icao.int/environmental-protection/pages/env2016.aspx

[51] IRENA: Biofuels for Aviation: Technology Brief. Available: https://www.irena.org/publications/2017/Feb/Biofuels-for-aviation-Technology-brief

[52] IEA: World Energy Outlook 2015. Available: https://www.iea.org/publications/freepublications/publication/WEO2015.pdf

- **Domestic energy security:** Alternative sources of aviation fuel can reduce country's foreign spending and dependence on imported fossil-based fuels.
- **Less exchange rate volatility:** A domestic supply of SAF would reduce the risk of exchange rate volatility linked to imported petroleum products.
- **Policy and regulatory environment:** Policy measures such as carbon pricing and other market mechanisms aimed to incentivise the use of alternative, low carbon fuels and the transition towards a low carbon economy.
- **Market and consumer demand:** Increasing consumer demand for commercial airlines to curb GHG emissions, particularly given the projected growth trends for the industry.
- **Business-to-Business marketing (B2B):** B2B Initiatives such as the Fly Green Fund[53] and Below50[54] bring together commercial stakeholders and investors with the aim to rapidly increase the demand for SAF, thus increasing volumes traded while decreasing costs.
- **Increasing investment in biorefineries:** Building and scaling up of biorefineries reduces costs and increases availability of SAF supplies.
- **ASTM certification of more pathways:** Addition of more SAF pathways provides more feedstock and processing opportunities.
- **Desires of aviation brands to be pioneers and leaders in the industry:** Investments and partnerships help to bridge the financial gap and promote SAF production.

SAFs with certified GHG savings and other sustainability benefits therefore provide a means for the industry to reduce emissions and improve energy security over the medium to long term. In 2016, the global alternative fuels market was valued at $168.18 billion and is expected to reach $246.52 billion by 2024 (Figure 11).

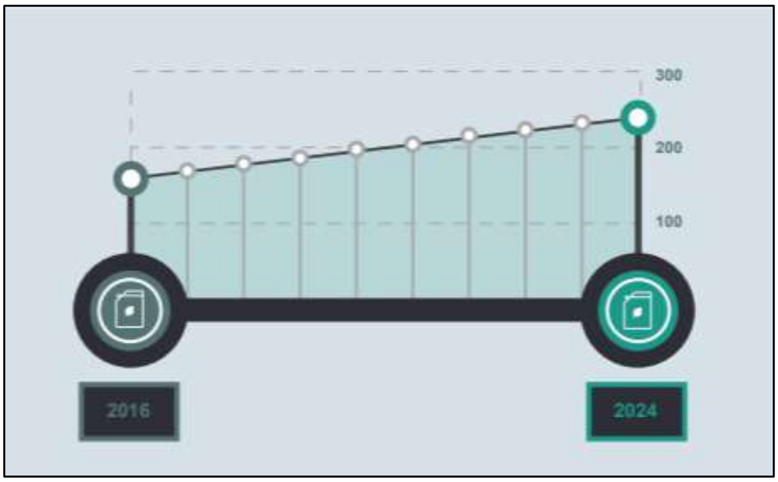

Figure 11 Global alternative fuels market and projected growth (all figures are in $ billions)[55]

Whilst the majority of existing initiatives and partnerships/associations for SAFs are concentrated in Europe, North America and Asia Pacific, there has been interest in creating similar initiatives in other countries. According to the IATA[56], this interest can be summarised by two main trends:

1. Countries where aviation plays an increasingly key role, which are developing their aeronautical technology and industry e.g. Japan, Israel, Singapore etc.

[53] http://www.flygreenfund.se/en/
[54] http://below50.org/, RSB is the sustainability partner of Below50
[55] RSB: SAFs: A Sustainable Future is Taking Off. Available: https://rsb.org/wp-content/uploads/2018/09/RSB-Alternative-Aviation-Fuels-A-Sustainable-Future-is-Taking-Off.pdf
[56] IATA: SAF Roadmap. Available: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

2. Countries with favourable conditions for biofuel feedstock production, often in tropical regions, interested in creating new opportunities for the local (often rural) economy e.g. Indonesia, Malaysia, South Africa, India, etc.

3.4. Overview of Policy Support Mechanisms

Renewable energy policies and targets generally vary between both nations and regions. These policies tend to be influenced by the prevailing policy environment, particularly around issues concerning climate, energy security, agriculture and economics. Given the relative cost of producing alternative fuels, government intervention and support schemes can be critical in facilitating the development and long-term feasibility of the industry. An overview of typical support schemes relevant to renewable energies is shown in Table 6.

Table 6 Overview of support schemes for renewable energies[57]

Instrument	Principle	Cost Burden for…
General Instruments for Climate Policy		
European Emission Trading Scheme	Certificates must be possessed/bought for the emission of GHGs	Supplier/end user
Carbon taxation	Higher tax rates imposed on products with higher GHG emissions	Supplier/end user
Dedicated Instruments for Renewable Energy Implementation		
Feed-in tariffs	Producer gets a guaranteed price for the provision of renewable energy	End user
Investment support programs	Investment support given to the producer for the conversion plant and/or infrastructure provided	Government
Taxation	Lower tax rates imposed on renewable products (i.e. tax credit, tax exemption)	Government
Quotas/blending mandates	Suppliers have to provide a certain share of renewables in their product portfolio	Supplier/end user

To date, the implementation of quotas and blending mandates for the blending of bioethanol and biodiesel with gasoline and diesel has proved very successful, most notably in Brazil[58]. Although mandated blending can be implemented separately, in practice, a combination of different instruments is generally used. This improves the cost-competitiveness of alternative fuels, which in turn helps these mandates to be met.

[57] Adapted from: THRAN, D. & PONITKA, J. 2016. Government Policy on Delivering Biofuels for the Aviation Sector. *In:* CHUCK, C. (ed.) *Biofuels for Aviation. Feedstocks, Technology and Implementation.* London, United Kingdom: Elsevier.
[58] Brazilian blending mandates and targets are as follows: Bioethanol: 25%, Biodiesel: 5%. For more information on mandated blending targets refer to: http://globalrfa.org/biofuels-map/

3.5. Support Mechanisms for Sustainable Aviation Fuels

Currently, the majority of government interventions in support of alternative fuels (e.g. mandated blending targets and related financial incentives, tax exemptions and other subsidies) are directed towards the production of bioethanol and biodiesel for the road transport sector. Given the challenge that the cost-competitiveness of SAFs as compared to conventional, fossil-based fuels presents to the growth of the industry, the relative lack of directed policy support for this sector is a concern. According to the IATA SAF Roadmap, the main reasons for this are as follows[59]:

1. The road transport sector is ahead of the aviation sector in terms of biofuel development and hence has benefitted from early policy formulation.
2. Road transport fuel generally has higher direct taxes applied to it relative to aviation fuel.
3. There are less stringent technical standards for road transport fuel compared to aviation fuel.

In addition to the above, the international nature of aviation means that the regulation of emissions is typically handled by the ICAO instead of at a national level. Given that there is no globally agreed upon target regarding the share of SAFs that must be used, there is a strong case for the development of novel and internationally relevant policy approaches that favour aviation. In general, the development of such policies should take the following into account[59]:

- SAF is more expensive to produce than bioethanol or biodiesel due to its strict technical requirements. This means that so long as policy favours the road sector, an alternative fuel producer will continue to produce the product that is most profitable i.e. bioethanol or biodiesel.
- Volume is lost during the refining of fuel to aviation grade fuel, thus policy incentives for alternative fuels should be applicable to aviation on an energy basis.
- There are no alternatives to liquid fuel for the aviation industry. Although the road transport sector has alternatives such as electricity, this option is not available for aviation, and is unlikely to become available over the medium term.

As in the case of bio-based fuels for the road transport sector, there are various policy instruments that can be used to incentivize the production of SAFs[59]:

- **Economic instruments.** Economic instruments use market, price and other economic variables to provide incentives for the production and use of bio-based aviation fuel. These instruments try to address the market failure of externalities by incorporating the external cost of production and consumption activities. Examples of such instruments include:
  - Direct incentives e.g. premiums for energy crops, support to use waste land
  - Subsidies
  - Taxes or charges on processes or products
  - Trading rights mechanisms e.g. emissions-trading mechanisms
- **Command and control instruments.** Command and control instruments are the regulatory conditions that define what is permitted and what is not permitted in a specific industry or activity. This not only establishes the conditions that must be complied with, but also the consequences of non-compliance. For example, the ‘command’ element might set a standard or consumption mandate (such as a blending mandate) and the ‘control’ element would monitor and enforce this standard.
- **Co-regulation instruments**. Co-regulation refers to the recognition of industry voluntary initiatives and programs as part of the public regulation. This instrument is particularly valid when regulating economic activities performed across geographic boarders. Examples of co-regulation instruments include:
  - Governmental recognition of industry agreements setting own “targets”

[59] Available: https://www.iata.org/whatwedo/environment/documents/safr-1-2015.pdf

- Governmental recognition of rules for compliance of such obligations and targets e.g. trading mechanisms at national or international level
- Negotiated support and/or penalties for the compliance of recognized obligations and agreements

- **Voluntary initiatives and collaborative instruments.** The adoption of standards, codes of conduct and self-regulation by the industry, is a form of voluntary instrument. When sufficiently articulated and extended among industry players, voluntary and collaborative instruments can become effective private policy instruments.

3.6. Examples of Policy Support for Sustainable Aviation Fuels

As mentioned above, policy instruments and market mechanisms play an important role in driving a commercially viable SAF industry. The following sections provide an overview of key policy mechanisms currently influencing the SAF market.

ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

In recognition of the need for low-carbon growth, in October 2013 the 38th Session of the International Civil Aviation Organization (ICAO) adopted Resolution A38-18. This resolution committed the ICAO and its Member States, with relevant organisations, towards a collective aspirational goal of achieving carbon neutral growth from 2020[60]. To meet this target, the assembly defined a "basket of measures" including the following[61]:

- Improvements in aircraft technologies and efficiencies
- Operational improvements
- Market based measures (MBMs)
- Scaling up the use of alternative low-carbon fuels

An illustration of the projected emissions under various scenarios — including the successful realization of this goal — is shown in Figure 12.

[60] Carbon neutral growth requires that global net CO_2 emissions from the aviation industry from 2020 onwards will be kept at the same level

[61] Uniting Aviation: Why Did ICAO Develop a Global MBM Scheme for International Aviation? Available: https://www.unitingaviation.com/strategic-objective/environment/why-did-icao-develop-a-global-mbm-scheme-for-international-aviation/

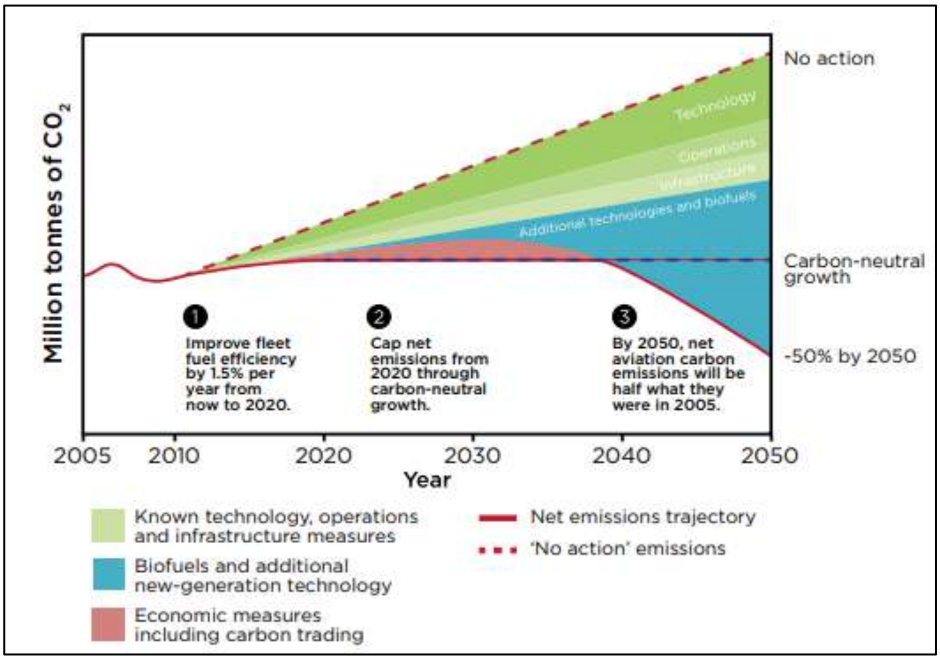

Figure 12 Emissions projections for aviation showing scenarios for no action and emissions reduction goals set by the industry[62].

An important MBM scheme implemented under this resolution is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)[63]. Globally, it is the only international market mechanism aimed to offset carbon emissions in aviation. The main aim of CORSIA is to address any annual increase in CO_2 emissions from international civil aviation above 2020 levels, whilst taking into consideration special circumstances and respective capabilities. The scheme has been developed to use the average CO_2 emissions from international aviation between 2019 and 2020 as the baseline for carbon neutral growth beyond 2020 (see Figure 12). However, given the dramatic impact of the Covid-19 pandemic on the aviation sector, ICAO determined that the value of 2019 emissions shall be used for 2020 emissions for the CORSIA implementation during the pilot phase from 2021 to 2023, in order to avoid inappropriate economic burden on the aviation industry[64]. From 2021, international aviation CO_2 emissions covered by the scheme will be compared to the 2019 baseline, with any differences representing the sector's offsetting requirement[65].

Although the majority of the 191 countries represented by the ICAO are in favour of the introduction of CORSIA, the implementation of a mandatory global scheme is not feasible due to the differing circumstances and capabilities of the member countries. Therefore, as a compromise, it was agreed that CORSIA will be implemented through a phased approach, incorporating both voluntary and required participation[66], as shown by Figure 13.

[62] Image adapted from ATAG: http://www.flygreenfund.se/wp-content/uploads/2015/05/A-Sustainable-Flightpath-Towards-Reducing-Emissions-ATAG-2012.pdf

[63] Implemented under ICAO Assembly Resolution A39-3, paragraph 5

[64] https://www.icao.int/Newsroom/Pages/ICAO-Council-agrees-to-the-safeguard-adjustment-for-CORSIA-in-light-of-COVID19-pandemic.aspx

[65] ICAO: *What is CORSIA and how does it work?* Available: https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ2.aspx

[66] A list of voluntary and mandated participating states can be found on the following link: https://www.verifavia.com/greenhouse-gas-verification/fq-which-states-are-participating-in-corsia-250.php

Figure 13 CORSIA implementation approach[67]

Based on the current commitment from member countries, over 80% of CO_2 emissions growth beyond 2020 will be covered by the scheme. Although South Africa has not volunteered to participate in the Pilot or First Stage of the scheme, it will have to mandatorily participate in the Second Phase, based on its contribution towards international Revenue Tonne Kilometers (RTKs)[68].

An important question facing the success of CORSIA is the identification of SAFs and offsets that will be eligible under the scheme. SAFs include any alternatives to fossil based liquid fuel that contributes to CO_2 emission reductions and meet addition sustainability criteria besides GHG emissions. Offsets (which can also be referred to as carbon units, or credits) typically come from projects that reduce CO_2 emissions. Carbon offsets can be generated from a range of projects, typically occurring in developing nations, including renewable energy projects (including biofuels), energy efficiency initiatives and forestry conservation projects[69]. A key requirement in the identification of sustainable alternative fuels and eligible offsets is that the scheme delivers real and "additional" environmental benefits. To ensure real environmental benefit is achieved, it is necessary to establish standards that ensure the following[70]:

- CO_2 reduction created by the offset unit can be fully attributed to the purchaser and is not counted towards any other climate goal or is something that would have happened regardless.
- Emission reductions cannot be reversed.
- Offset projects do not lead to an increase in emissions elsewhere.

As of June 2018, the ICAO Council formally adopted the Standards and Recommended Practices (SARPs) for the CORSIA. Given the global nature of CORSIA, an objective of these standards was that that they provide a harmonized view of sustainability criteria through the definition of a globally recognized sustainability framework. There are already a number of existing sustainability standards and frameworks — such as the RSB — that provide well-proven compliance mechanisms. Therefore, the ICAO approach is to build upon existing standards, adopting a framework or "umbrella" standard,

[67] Image source: https://aviationbenefits.org/media/136900/atag_carbon_offset_infographic.pdf

[68] Revenue tonne kilometers (RTKs) are the standard industry metric used to quantify the amount of revenue generating payload carried, taking into account the distance flown. RTKs comprise the passengers, freight and mail carried multiplied by the great circle distance (standard distance between two airports).

[69] Air Transport Action Group. *How a global carbon offsetting scheme for aviation would work*. Available: https://aviationbenefits.org/media/136900/atag_carbon_offset_infographic.pdf

[70] Air Transport Action Group. *CORSIA Explained*. Available: https://aviationbenefits.org/environmental-efficiency/our-climate-plan/corsia-explained/

which allows existing (current or future) mandatory or voluntary standards to be recognised as suitable to demonstrate sustainability under CORSIA. This approach is illustrated in Figure 14.

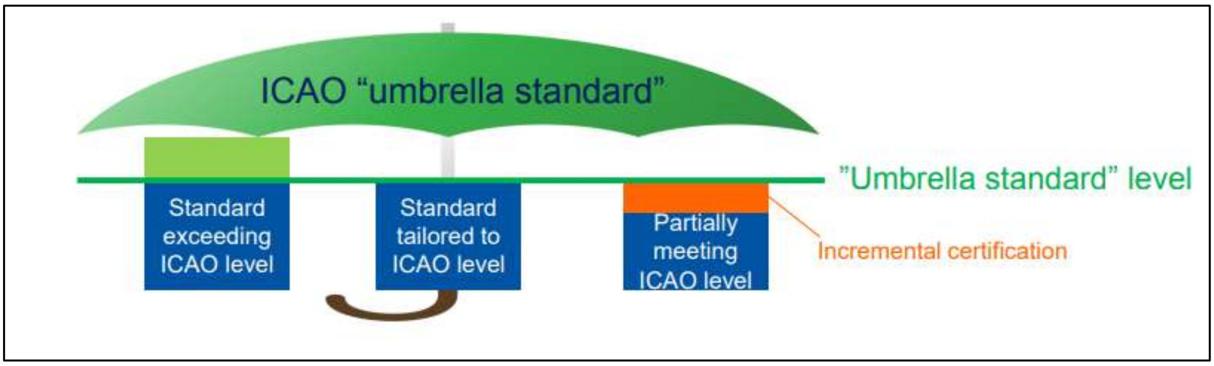

Figure 14 ICAO framework standard for demonstrating sustainability under CORSIA[71]

European Renewable Energy Directive (EU RED)

The European Renewable Energy Directive (EU RED)[72] establishes an overall policy for the production and promotion of energy from renewable sources in the European Union (EU). It requires the EU to fulfil at least 20% of its total energy needs (including aviation fuels) with renewables by 2020 – to be achieved through the attainment of individual national targets. All EU countries must also ensure that at least 10% of their transport fuels come from renewable sources by 2020. This share is expected to increase to 32% with the publication of the revised directive (EU RED II) in 2021, which is also expected to decrease the share of crop-based biofuels in favour of wastes and crop-based fuels with a proven low indirect land use change risk[73].

EU RED also sets out biofuels sustainability criteria for all biofuels produced or consumed in the EU to ensure that they are produced in a sustainable and environmentally friendly manner. Companies can show they comply with the sustainability criteria through national systems or so-called voluntary schemes recognised by the European Commission – such as the RSB.

European Union Emission Trading Scheme (ETS)

The European Union's Emission Trading Scheme (ETS) is a cornerstone of the EU's policy to mitigate climate change and reduce GHG emissions in a cost-effective manner. Established in 2005, the EU ETS is the world's first international emissions trading system and remains the biggest one, accounting for over three quarters of international carbon trading[74].

The EU ETS works on a 'cap and trade' principle. A cap is set on the total amount of certain GHGs that can be emitted by participating installations covered by the system. If the installation exceeds the emissions allowed by the scheme, the installation must purchase credits from others. Conversely, if the installation has performed well and produced less emissions than the cap, it can sell its leftover credits. As of 2012, all internal European flights are included in the scheme. It is the long-term target to extend this scheme to cover all external European flights in the future.

[71] Image source : Available: https://www.icao.int/Meetings/altfuels17/Documents/Thomas%20Roetger%20-%20CAEP%20AFTF.pdf

[72] https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

[73] http://biomassmagazine.com/articles/15371/eu-reaches-deal-on-redii-sets-new-goals-for-renewables

[74] For more information, refer to: https://ec.europa.eu/clima/policies/ets_en

European Advanced Biofuels Flightpath

The European Advanced Biofuels Flightpath was launched in 2011 by the European Commission in partnership with Airbus, and in cooperation with leading European Airlines (Lufthansa, Air France/KLM, and British Airways) and biofuel producers (Choren Industries, Neste Oils, Biomass Technology Group and UOP)[75].

The aims of the European Advanced Biofuels Flightpath are as follows:

- Facilitate the production and deployment of sustainably produced biofuels through the construction of advanced biofuel production plants in Europe.
- Get the aviation industry to use 2 million tonnes of sustainably produced biofuels by 2020.

To achieve this, there is an agreed roadmap of short, medium and long-term actions that are primarily focused on financing these goals, such as the establishment of an Aviation Biofuel Fund and the facilitation of biofuel off-take agreements between the aviation sector and biofuel producers.

National blending mandates and consumption targets

Although national blending mandates are generally exclusive to road transportation, there is growing interest to enforce blending targets for aviation, too. The majority of targets for alterative aviation fuel production are aspirational, with shorter-term targets in particular unlikely to be met owing to slower than anticipated expansion of production capacity[76]. Existing targets include the following:

- **Norway**: 0.5% blending target as of 2020, with a preference for fuels made out of wastes and residues instead of crops. The Norwegian government's goal is that by 2030, 30% of national airline fuel will be sustainable and with climate benefits[77].
- **Indonesia**: 2% penetration target in aviation biofuels by 2018, increasing to 5% by 2025.
- **United States**: 1 billion gallons (3.8 billion litres) production and blending of alternative jet fuels annually from 2018 onwards.
- **European Union**: 2.5 billion litres of SAFs used in the Eurozone by 2020.
- **Australia**: 50% penetration of SAFs by 2050.
- **Germany**: 10% penetration of SAFs by 2025.
- **Israel**: 20% penetration of SAFs by 2025.

US Renewable Fuels Standard

The United States' Renewable Fuels Standard (RFS) program was created under the Energy Policy Act of 2005 as an amendment to the Clean Air Act. The RFS is a federal program that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuels, heating oils or jet fuels produced by, or exported into, the US. The mandated minimum volume of renewable fuel increases annually with the long-term goal of reaching 36 billion gallons by 2022 (Figure 15). Under the RFS, compliance is demonstrated with Renewable Identification Numbers (RINs). RINs are generated per gallon of renewable fuel produced and are tradable credits. Obligated parties are required to obtain sufficient RINs to demonstrate compliance[78].

[75] For more information, refer to: https://ec.europa.eu/energy/node/76
[76] https://www.irena.org/publications/2017/Feb/Biofuels-for-aviation-Technology-brief
[77] https://www.ofimagazine.com/news/norway-to-introduce-0.5-biofuels-blending-mandate-for-aviation-fuel
[78] For more information on RINs, refer to: https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

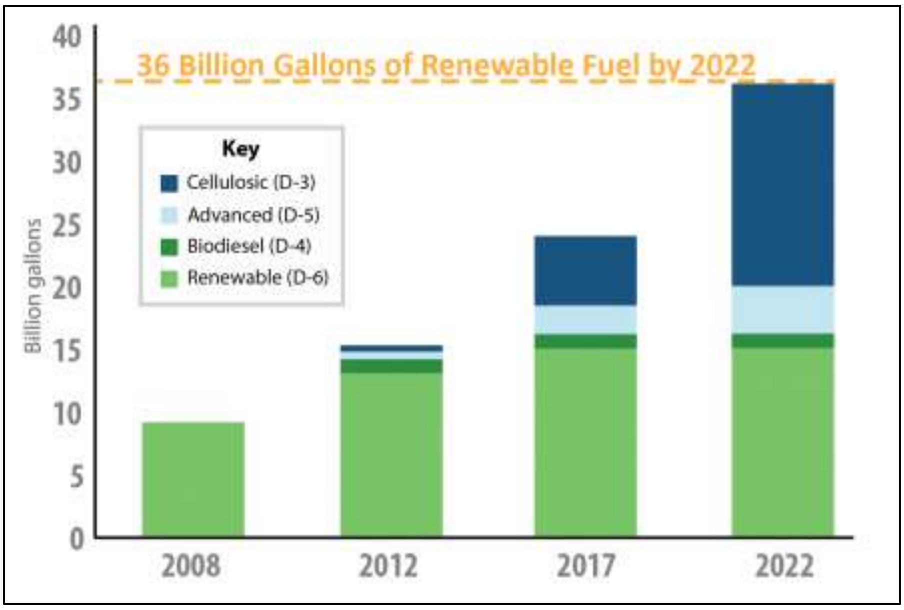

Figure 15 Volume targets for renewable fuel under the US Renewable Fuel Standard[79]

The RFS divides the total renewable fuel requirement into four categories, each of which having specified environmental and/or feedstock criteria:

- **Conventional (renewable) biofuel:** Ethanol derived from corn starch with a life-cycle GHG emissions threshold of ≥ 20% reduction in emissions compared to a 2005 fossil fuel baseline.
- **Cellulosic biofuel:** Biofuels derived from cellulose, hemicellulose, or lignin with a life-cycle GHG emissions threshold of ≥ 60% reduction in emissions compared to a 2005 fossil fuel baseline.
- **Advanced biofuels:** Biofuels produced from any qualifying renewable biomass (other than corn starch) with a life-cycle GHG emissions threshold of ≥ 50% reduction in emissions compared to a 2005 fossil fuel baseline[80].
- **Biodiesel:** Biomass based diesel with a life-cycle GHG emissions threshold of ≥ 50% reduction in emissions compared to a 2005 fossil fuel baseline.

Fuel pathways for all four categories of renewable fuel have already been approved, including (amongst others) ethanol made from sugar cane, jet-fuel made from camelina, cellulosic ethanol produced from corn stover, and biomethane produced by anaerobic digestion of municipal wastewater.

Since 2007 when the statutory volume obligations for the RFS were set, meeting these obligations has become increasingly problematic. Important factors affecting the volume obligations include declining gasoline consumption, blend walls[81], lack of blender pumps and the on-going food vs fuel debate[82]. To reach mandated targets, SAF therefore plays a significant role. Although there are various approved pathways for aviation fuel production that qualify for RINs (thus providing an incentive for production), this is generally considered insufficient to support the growth of the industry[83]. The main problem with

[79] Image source: https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

[80] Under the RFS, the Advanced Biofuel category can include cellulosic biofuel and biomass-based diesel

[81] The "blend wall" refers to the point where RFS volume mandates cannot be met by blending renewable fuels into gasoline used by the road transportation sector.

[82] http://www.biofuelsdigest.com/bdigest/2014/09/17/up-in-the-air-can-aviation-help-preserve-the-renewable-fuel-standard/ (Accessed, 26 April 2019)

[83] IRENA Biofuels for Aviation Technology Brief. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf

the current system, is that the RIN value for aviation fuels is the same as for other advanced fuels in the category (such as biomass derived diesel). SAF is a high specification fuel, thus requiring additional processing which in turn increases production costs. This means that SAFs are unlikely to compete with other advanced biofuels in the US without specific incentives directed towards SAF[83].

UK Renewable Transport Fuel Obligation

The UK Renewable Transport Fuel Obligation (RTFO) regulates biofuels used for transport and non-mobile machinery. The RTFO is aimed at supporting government policy around GHG emission reductions by encouraging the production of sustainable biofuels. Under the RTFO, fuel suppliers who provide in excess of 450 000 litres of fuel a year must be able to show that a proportion of the fuel that they provide comes from a sustainable renewable source[84].

Biofuels – including SAF –must comply with the stipulated sustainability criteria to be recognized under the program. Currently, suppliers of SAF are eligible to apply for Renewable Transport Fuel Credits (RTFCs), but fossil aviation fuel is not obligated under the current RTFO Order.

[84] https://www.gov.uk/guidance/renewable-transport-fuels-obligation

4. COSTING AND FINANCIAL CONSIDERATIONS

Despite its potential to deliver multiple benefits, the SAF market is still at an early stage of development. Currently, the relatively high cost of SAF is the foremost barrier holding back the growth of the industry. Given the specialized nature of aviation fuel, processing and infrastructure requirements to produce it are relatively high. Consequently, financing new refineries is a challenge, given both the high capital investment required and the price uncertainty surrounding the end product.

Reported costs of the ASTM approved pathways can be greater than $10/gallon (R40/l), which limits their marketability despite the operability and environmental benefits they provide[85]. It is generally argued that the broader commercial production and consumption of SAF requires the production of renewable fuels to be near, or at cost parity with fossil derived fuels. However, the market price of SAF ranges between two and seven times more expensive than conventional fossil based jet fuels. This is a major challenge, as fuel usage typically accounts for around 30% of the total expense of operating an airline, and given the relatively low profit margins reported by airlines, they are generally unwilling – or unable – to pay a premium for fuel[86].

However, the argument that price parity for SAF must be met before commercial production and uptake can be widespread is somewhat flawed. The benchmark price for SAF cannot be considered to be the price of conventional jet, it has to instead be considered *conventional jet* ***plus*** *the cost of carbon pricing* (usually in the form of carbon offseting, or carbon tax, as is the case in South Africa), as a minimum. Currently, the price of offsets is too low to tip this into favour of SAF, but it does go towards reducing the price gap. The remainder should be filled by either voluntary contributions or by subsidies.

The following sections provide further detail on the major factors influencing bio-jet fuel production costs and provides an estimate of processing and capital cost requirements.

4.1. Sustainable Aviation Fuel Cost Overview

The cost of SAF is difficult to determine due to two main factors[86]:

1. SAF is not a readily available commodity
2. Contracts for purchase of volumes of SAF do not usually disclose the price

Consequently, costing SAF requires various estimations or modelling approaches, which lead to high variations in the reported cost range. These variations are highly dependent on the assumptions that are made around the production process, feedstock, plant scale, and performance[85]. These factors are also typically location specific, meaning that the resulting costs and cost models reflect a strong geographical dependence. Despite efforts to improve the transparency of the basis of these economic assumptions, the lack of consistency and the range of assumptions continue to limit understanding of the current cost of producing SAFs[85].

An overview of the key cost drivers for SAF production is shown in Table 7 overleaf.

[85] EERE. SAFs. *Overview of Challenges, Opportunities and Next Steps*. Available : https://www.energy.gov/sites/prod/files/2017/03/f34/alternative_aviation_fuels_report.pdf

[86] IRENA. *Biofuels for Aviation Technology Brief*. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf

Table 7 SAF cost drivers[87]

Cost Driver	Description
Feedstock cost and composition	Feedstock costs are strongly dependent on region and/or type and can contribute up to 70 – 80% of the processing costs.
Capital cost	Capital costs are affected by economies of scale; larger facilities will be more economically viable, but short-to-medium term facilities are expected to be small, which will increase production costs.
Overall yield (conversion)	Feedstock efficiency (converting as much as possible of the feedstock into fuel) is critical, whilst meeting fuel specification and achieving the desired blending ability of the fuel.
Product quality and composition	Ability to meet the stringent requirements of product specification for jet fuel is critical.
Operating expenses	These are variable and will be affected by process performance and the need to replace and replenish raw materials like catalysts.
Financial requirements	Debt-to-equity ratios, potential loan rates and terms, and return on investments required to attract investors are all significant costs, particularly for first-of-a-kind facilities.
Logistics	Handling and transport of feedstock to a biorefinery and transport of fuel to a blending facility and filling stations at the airport contribute to overall costs.
Initial resources	Additional resources are required for fuels certification and qualification.

The typical range resulting from the estimation of SAF production costs is illustrated in Table 8[88]. This table is based on the results of a techno-economic analysis undertaken by de Jong et al. (2015)[89] and provides the minimum fuel selling price (MFSP)[90] for SAF produced via different conversion routes. In line with the aviation industry's commitment to prioritize non-food feedstocks, wheat straw and forestry residues were modelled as feedstocks for Fischer-Tropsch (FT) pyrolysis, Alcohol-to-Jet (ATJ) and Direct Sugars to Hydrocarbons (DSHC)*, and used cooking oil was modelled for Hydroprocessed Esters and Fatty Acids (HEFA). Residues produced in the beet sugar industry and pulp and paper industry were also included as feedstocks for conversion pathways involving co-production (FT, ATJ and DSHC). These values are compared to literature estimates for similar production processes, but covering a range of feedstocks.

Given that these results are presented in Euros based on 2013 costing, an estimate for an equivalent South African 2018 rand value has been provided. This value was obtained by inflating the 2013 estimates using the national average annual inflation rates over the period. However, it should be noted that this value is intended as an estimate only, with the geographical and time variation in feedstock pricing, infrastructure and processing costs likely to introduce a significant margin of error to this value.

[87] Adapted from: EERE. SAFs. *Overview of Challenges, Opportunities and Next Steps*. Available : https://www.energy.gov/sites/prod/files/2017/03/f34/alternative_aviation_fuels_report.pdf
[88] This table present the results obtained from an independent study and should be interpreted alongside the details of the study, including context information model approach and all underlying assumptions.
[89] DE JONG, S., HOEFNAGELS, R., FAAIJ, A., SLADE, R., MAWHOOD, R. & JUNGINGER, M. 2015. The feasibility of short-term production strategies for renewable jet fuels – a comprehensive techno-economic comparison. *Biofuels, Bioproducts and Biorefining,* 9, 778-800.
[90] The minimum fuel selling price is the cost price at which products need to be sold to achieve a zero equity net present value.

Table 8 Comparison of bio-jet fuel Minimum Fuel Selling Price[91]

Processing Pathway	Production Cost Range EUR$_{2013}$/litre**		Extrapolated Production Cost Range ZAR$_{2018}$/litre
	Modelled estimates	**Range of feedstocks, reported estimates**	**Range of feedstocks, extrapolated estimates**
Hydroprocessed Esters and Fatty Acids (HEFA)	0.98	0.68 – 0.95	15.2 – 22.3
Fischer-Tropsch (FT)	1.3 – 1.9	0.61 – 1.4	13.9 – 40.7
Alcohol-to-Jet (ATJ)	1.8 – 2.6	0.81 – 0.91	18.3 – 61.0
Hydrothermal Liquification (HTL)*	0.71 – 0.98	0.51 – 0.54	11.5 – 22.3
Pyrolysis*	1.0 – 1.34	0.44 – 0.68	9.83 – 31.5
Direct Sugars to Hydrocarbons (DSHC)*	3.5 – 4.7	3.2	74.6 - 108

*Not currently certified but under ASTM review
** Production cost range was converted from EUR/GJ to EUR/litre using approximate energy density values reported in literature[92].

Comparison of the estimated 2018 SAF rand values (Table 8) to the current A-1 jet fuel market price in South Africa of R207/GJ[93] (approximately R7.22/l, using an energy density basis of 34.9MJ/l) shows that these projections mostly fall within the predicted range for SAF production costs of between two and seven times more expensive than conventional fossil based jet fuels.

The cost breakdown of the production cost range is illustrated in Figure 16[94].

[91] Adapted from: DE JONG, S., HOEFNAGELS, R., FAAIJ, A., SLADE, R., MAWHOOD, R. & JUNGINGER, M. 2015. The feasibility of short-term production strategies for renewable jet fuels – a comprehensive techno-economic comparison. *Biofuels, Bioproducts and Biorefining,* 9**,** 778-800.
[92] Approximate energy density values used were as follows: Jet A/Jet A-1 – 34.9 MJ/l, biodiesel – 33.9MJ/l, FT Synfuel 33.6MJ/l. Source: https://www.cgabusinessdesk.com/document/5719_Aviation_Addendum._webpdf.pdf
[93] Based on the reported rand value for May 2018
[94] This figure present the results obtained from an independent study and should be interpreted alongside the details of the study, including context information model approach and all underlying assumptions.

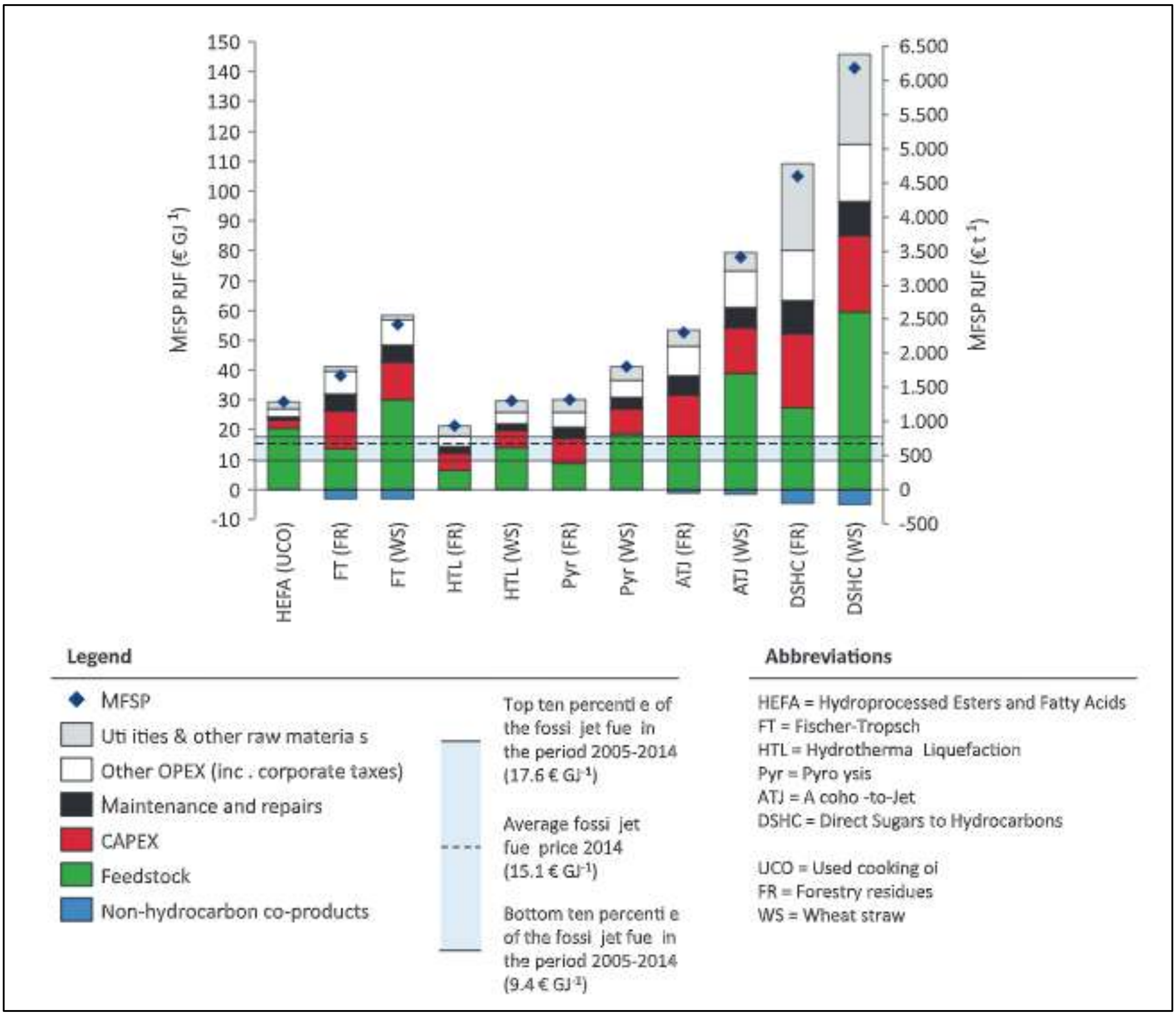

Figure 16 Cost breakdown of the minimum fuel selling price for greenfield (nth plant) production[95]

As noted in Table 7 and illustrated by Figure 16, an important factor influencing the production costs of SAF is the feedstock cost. Feedstock prices are highly dependent on the region were they are sourced and will play an important role in price setting once production plants have reached maturity. As noted by the authors of the study, feedstock prices can have a significant impact on the MFSP, however, future pricing estimates are optimistic, as it is anticipated that lower-cost sustainable feedstocks might become available, due to cost decreases resulting from large-scale cultivation, learning effects, yield increases and optimisation of logistics.

A similar techno-economic analysis to that shown in Table 8 and Figure 16 was undertaken by Diederichs et al (2016)[96]. This study, undertook a techno-economic comparison on three processes (thermochemical, biochemical and hybrid) for production of jet fuel from second generation

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[95] DE JONG, S., HOEFNAGELS, R., FAAIJ, A., SLADE, R., MAWHOOD, R. & JUNGINGER, M. 2015. The feasibility of short-term production strategies for renewable jet fuels – a comprehensive techno-economic comparison. *Biofuels, Bioproducts and Biorefining,* 9**,** 778-800.

[96] DIEDERICHS, G.W., MANDEGARI, M.A., FARZAD, S. AND GÖRGENS, J. 2016. Techno-economic comparison of biojet fuel production from lignocellulose, vegetable oil and sugar cane juice. *Bioresource Technology.* 216. 331–339

lignocellulosic biomass versus two processes from first generation feedstocks, including vegetable oil and sugar cane juice. Key economic results including the estimated MFSP for a range of SAFs is shown in Table 9.

Table 9 Summary of economic results for investigated processes (Adapted from Diederichs et al (2016)[97].

Parameter	Process				
	Lignocellulose biochemical conversion to ethanol with upgrading to jet fuel	Gasification, syngas fermentation to ethanol with upgrading to jet fuel	Gasification and FT synthesis to jet fuel	Hydro-processed esters and fatty acids	Sugar cane juice to ethanol by sucrose fermentation with upgrading to jet fuel
Variable Operating Costs: Raw materials and waste disposal (million US$ per year)	120.23	69.75	62.51	112.60	85.36
Variable Operating Costs: By-product credits (million US$ per year)	24.77	13.03	38.16	25.44	38.28
Fixed Operating Costs (million US$ per year)	24.78	22.09	27.85	10.52	18.92
Total Installed Costs (million US$)	274.2	232.8	321.3	91.7	184.1
Fixed Capital Investment (million US$)	482.6	409.7	565.5	161.4	324
Fixed Capital Investment /Annual Jet Fuel Kilogram ($/kg)	7.90	6.54	9.05	2.87	5.30
Total Capital Investment (million US$)	532.7	452.5	623.9	179.4	358.3
MJSP ($ per kg jet fuel)	3.43	2.49	2.44	2.22	2.54

[97] DIEDERICHS, G.W., MANDEGARI, M.A., FARZAD, S. AND GÖRGENS, J. 2016. Techno-economic comparison of biojet fuel production from lignocellulose, vegetable oil and sugar cane juice. *Bioresource Technology.* 216. 331–339

4.2. Alcohol-to-Jet Capital Costs

The production of SAF is still a relatively new technology and consequently, the capital costs associated with building SAF refineries are high compared to mature technologies such as fossil fuel refineries. As discussed in Table 7, the capital costs of refineries are strongly influenced by economies of scale. Given the short-to-medium term outlook for bio-jet fuel which predicts refineries to be relatively small, the capital expenditure requirements pose a significant challenge. Furthermore, the production of SAF is typically more complex, requiring longer and more sophisticated processing, more specialised equipment and a highly skilled labour force. This further increases the relative cost of production compared to fossil fuels.

An estimate of the capital costs associated with the production of SAF via different processing pathways is shown in Table 10 overleaf. The 2013 dollar estimates are based on normalised reported values from literature for a production output of 500 tonnes of fuel per day. To obtain a 2018 rand estimate for the cost of an equivalent plant in South Africa, the 2013 dollar price was adjusted taking into account the 2013 and 2018 CEPCI indices[98] and a suitable plant location cost factor[99].

It is important to note that the costs shown in Table 10 are not directly comparable, as the feedstock that is used for each process varies in terms of the level of upstream processing. For example, the ATJ process upgrades ethanol (which has already been processed from its raw material feedstock), while the FT process includes raw material processing. However, when comparing available technologies, the general rule concerning capital costs is applicable, with technologies most strongly affected by complexity, number of unit operations required and scaling. For example, the complexity of the FT process makes it capital efficient only at very large scale, whereas the ATJ and HEFA processes use refinery operations but with reduced complexity, making them cost effective at small scale with the additional advantage of being easily scalable.

Given that ATJ processes are scalable, an important consideration is balancing the availability of feedstock with production costs. Expansion of facilities is strongly influenced by the logistics of procuring sufficient feedstock. It has been suggested that these logistical requirements can have a stronger influence on proposed expansion than the base cost of the feedstock. For example, while the co-location of an ATJ refinery with an ethanol processing facility would have shared benefits from a process optimization perspective, and also reduce transport costs, there are risks associated with relying on one source of feedstock. One the other hand, a centralised ATJ facility with diversified feed sources reduces supply risks but increases transport costs, logistical requirements and associated carbon emissions.

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[98] The Chemical Engineering Plant Cost Index (CEPCI) accounts for escalation in costs between historic and present years. The 2013 and 2018 CEPCI indices used were 567.3 and 591.3 respectively https://www.chemengonline.com/cepci-updates-january-2018-prelim-and-december-2017-final/?printmode=1 .

[99] The location factor accounts for varying costs of plants built in different parts of the world. For this estimate a value of 1.32 was used to compare construction costs in the USA with South Africa https://www.intratec.us/indexes-and-pricing-data/plant-cost-index/south-africa.

Table 10 Capital costs associated with the production of bio-jet fuel via different processing pathways[100]

Processing Pathway	Capital Costs US$$_{2013}$ (Millions)	Estimated Capital Costs ZAR$_{2018}$ (Millions)
Hydroprocessed Esters and Fatty Acids (HEFA)	265 – 855	5540 – 17 900
Fischer-Tropsch (FT)	434 – 1575	9070 – 32 900
Pyrolysis* and upgrading	207 – 640	4330 – 13 400
Hydrothermal Liquefaction (HTL)* and upgrading	362 – 681	7570 – 14 200
Alcohol-to-Jet (ATJ) (from ethanol, excludes ethanol production)	90 – 96	1880 - 2000
Direct Sugars to Hydrocarbons (DSHC)* (Farnesene)	388	8100
Ethanol production from agricultural residues (includes pre-treatment, enzymatic hydrolysis and fermentation)	285 – 566	5960 – 11 800
Sugar extraction from agricultural residues (includes pre-treatment and enzymatic hydrolysis)	274	5730

*Not currently certified but under ASTM review

4.3. Ethanol Feedstock Considerations

Regardless of the exact specifics of an ATJ refinery – namely whether it is co-located with an ethanol processing facility or centralized and fed by various independent ethanol suppliers – the cost at which ethanol can be produced and supplied to the facility has an important bearing on the feasibility of the process.

It is generally accepted that the diversification of the South African sugar industry into products including fuel ethanol is essential to ensuring the long-term viability of the industry. According to the results of a 2016 economic assessment of bioethanol production from sugar cane in South Africa[101], ethanol production provides a significant opportunity for value addition given the current positioning of the industry. Sugar cane cultivation and processing is one of the country's key agro-industrial activities and as such, the South African sugar industry is well established and has significant investments within the local economy and the Southern African Development Community (SADC) region. Consequently, the industry has the ability to raise capital, which provides sugarcane with an important advantage relative to other potential ethanol feedstocks, as the lack of access to investment capital is a major constraint in the development of commercial biofuel production facilities. Further advantage lies in capital cost projections, which suggest that ethanol produced from sugar cane has lower capital cost requirements than various fossil-based alternatives (see Table 11).

[100] Adapted from: DE JONG, S., HOEFNAGELS, R., FAAIJ, A., SLADE, R., MAWHOOD, R. & JUNGINGER, M. 2015. The feasibility of short-term production strategies for renewable jet fuels – a comprehensive techno-economic comparison. *Biofuels, Bioproducts and Biorefining,* 9**,** 778-800 and IRENA. *Biofuels for Aviation Technology Brief.* Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf
[101] An Economic Assessment of Bioethanol Production from Sugar Cane : The Case of South Africa. Available: https://econrsa.org/system/files/publications/working_papers/working_paper_630.pdf

Table 11 Capital cost competitiveness of ethanol with other conventional fossil fuels[101]

	Oil refinery	Gas to Liquids	Ethanol (sugar)
	US$/litre fuel		
Plant & Equipment	1.19	3.16	0.79
Infrastructure	0.32	0.32	0.40
Exploration	1.19	0.79	-
Agricultural	-	-	0.40
Total Costs	**2.69**	**4.27**	**1.58**

Despite advantages in capital costs, similarly to other bio-based fuels, processing costs associated with bioethanol are typically higher than fossil based alternatives. An important factor in this trend is linked to production capacity, with current bio-based facilities unable to take advantage of economies of scale. However, production costs are difficult to estimate, due to their dependence on a variety of factors including the commodity price of the feedstock crop, the fuel processing method, and country specific variations in feedstock crop yields.

According to the results of the aforementioned 2016 economic assessment of bioethanol production from sugar cane in South Africa[102], the processing costs of ethanol production can be roughly distributed as follows:

- Feedstock costs: 60 – 65% of overall production costs
- Operating and Maintenance: 20 – 25% of overall production costs
- Capital: 15% of overall production costs

Taking an average world sugar price of 29 US cents per kilogram for the period 2005 to 2015 and an average South African yield of 80 litres of ethanol per ton of sugar cane, this assessment estimates the average feedstock cost incurred by bioethanol producers is 42 US cents per litre. Using this estimate and the above distribution, average bioethanol production costs in South Africa (in 2015) were estimated at 70 US cents (R10.3) per litre[102].

The profitability of ethanol production and commensurate return on investment (ROA) for the development of new facilities is strongly affected by the selling price of bioethanol and the level of subsidy or incentive that is imposed on the price. In South Africa, the price of fuel is regulated by the national Department of Energy (DoE). Each month, the DoE sets a Basic Fuel Price (BFP) based on import costs for crude oil and establishes a notional import parity pricing guideline for the country's petroleum industry in the sale of its products. Therefore, in the case of fuel ethanol, to compete with imported petrol on a cost-basis, bioethanol would need to be cheaper than the BFP. The national Biofuels Task Team established under the National Biofuel Strategy has suggested that the recommended transfer price of bioethanol from producers to the South African petroleum industry be regulated at 95% of the BFP[103].

However, this approach is not without challenges. For one, an ethanol price set on the BFP means that the price paid to bioethanol manufacturers will be subject to the same volatilities as the international crude oil price. Furthermore, the disparity in energy density between petrol and ethanol is approximately 34%. When considering ethanol for transportation, this disparity means that approximately one and a half times more ethanol (on a volumetric basis) would be required than petrol

[102] An Economic Assessment of Bioethanol Production from Sugar Cane : The Case of South Africa. Available: https://econrsa.org/system/files/publications/working_papers/working_paper_630.pdf
[103] http://www.mabelefuels.com/wp-content/uploads/2011/12/National-Biofuels-Study.pdf

to travel an equivalent distance. When considering fuel ethanol pricing from an energy equivalence basis, the cost of production would need to decrease to reflect the energy disparity. This price gap is likely to be further widened by a disparity in the level of subsidy and support provided to the industry. The pricing of South Africa's liquid fuels is subject to a range of domestic and international levies that collectively comprise close to 60% of the retail price[104]. The latest position of the South African Cabinet with respect to the country's biofuels regulatory framework suggests that government is only willing to waive fuel taxes, which compromises ~16% of the retail price of fuels without stipulating a price at which bioethanol ought to be sold, as had been suggested by the Biofuels Task Team.

It has been suggested that these factors amongst others such as reduced biofuel targets and limited fiscal support are likely to see most commercial bioethanol production activities in South Africa operate outside the domain of a state regulated market[102]. Alternative markets to road transportation for fuel grade ethanol therefore provides an opportunity for ethanol producers in this regard.

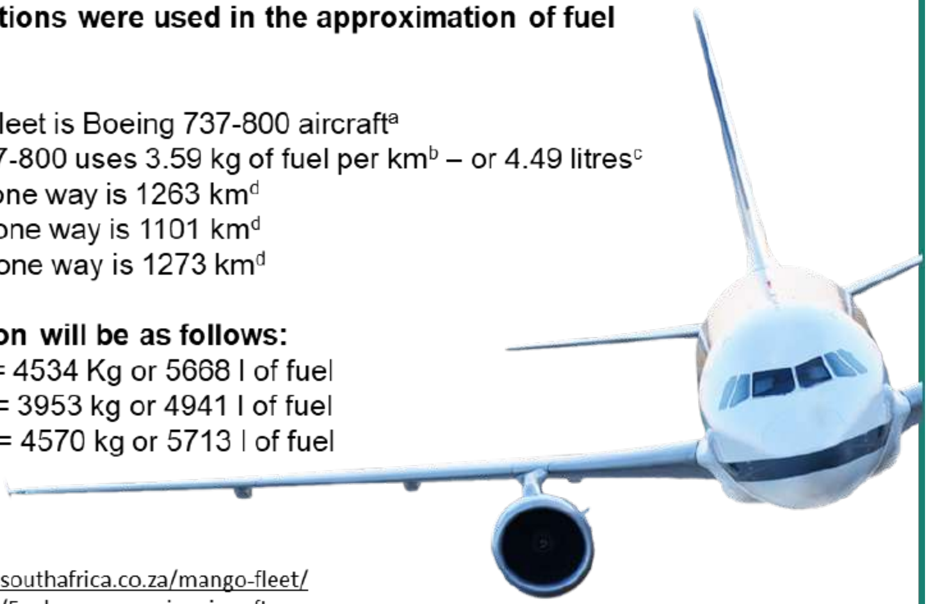
For the purposes of illustration, Figure 17 shows the approximate fuel demand for major domestic routes.

The following assumptions were used in the approximation of fuel consumption:

- The Mango fleet is Boeing 737-800 aircraft[a]
- A Boeing 737-800 uses 3.59 kg of fuel per km[b] – or 4.49 litres[c]
- CPT – JHB one way is 1263 km[d]
- JHB – DBN one way is 1101 km[d]
- CPT – DBN one way is 1273 km[d]

Hence fuel consumption will be as follows:

- CPT – JNB = 4534 Kg or 5668 l of fuel
- JHB – DBN = 3953 kg or 4941 l of fuel
- CPT – DBN = 4570 kg or 5713 l of fuel



Sources:

[a] https://www.domesticflights-southafrica.co.za/mango-fleet/
[b] https://en.wikipedia.org/wiki/Fuel_economy_in_aircraft
[c] https://aviationdirect.co.za/conversion-table/
[d] https://www.distance.to/Durban/Johannesburg,Gauteng,ZAF/-31.466153715024284,26.696777343750004

Figure 17 Projected SAF consumption for major domestic routes

4.4. Future Cost Projections

To promote the long-term viability of SAF, it is essential that SAF prices become attainable to users, either through market parity with conventional fossil-based fuels or supported by carbon pricing (i.e. the price of SAF is considered *conventional jet* ***plus*** *the cost of carbon pricing* as a minimum). Industry partnerships and collaboration within the bioenergy and aviation industries, as well as with traditional energy and chemical industries, can serve to bridge this financial gap and assist companies working to develop and deploy bio-jet fuel[105]. Currently, the majority of investments into bio-jet fuel production have been made possible by multi-billion-dollar partnerships between airlines and manufacturers.

[104] https://www.businessinsider.co.za/south-africa-petrol-price-fuel-levy-taxes-distribution-costs-20190305
[105] https://www.energy.gov/eere/bioenergy/downloads/alternative-aviation-fuels-overview-challenges-opportunities-and-next-steps

However, partnerships with petrochemical refineries to develop strategies for co-processing or blending renewable derived intermediates with crude oil fractions in existing infrastructure introduces a valuable opportunity to reduce capital expenditures and production costs[105].

Ultimately, the price differential between SAF and conventional jet fuel is expected to improve in the next decade due to the following factors:

- The scaling up of refineries (economies of scale)
- Regulatory pressure to curb CO_2 emissions (development of policy instruments)
- Increasing number of commercial airlines committing to sourcing bio-jet fuels (increased demand/offtake agreements)
- Increase in the oil price

Although the current low oil price and low price of carbon offsets is likely to delay the feasibility of bio-jet projects, ultimately, this might be less of a problem for aviation biofuels than for other sectors, as regulatory pressure, consumer pressure (#flightshame) and energy security concerns mean it is in the best interest of the industry to find long-term solutions. However, for oil prices < $0.36/l, the cost of producing bio-jet fuel will be significantly higher making this price gap difficult to close, with the resulting premiums on bio-jet fuel unattractive to airlines[106].

The relative stabilisation of the oil price and projections for the short-term suggest that it will be difficult for the aviation industry to reach industry targets for carbon neutral growth from 2020. Consequently, policy measures, consumer pressures and regulatory pressure could become critical to facilitate the growth of the SAF industry.

[106] https://www.irena.org/publications/2017/Feb/Biofuels-for-aviation-Technology-brief

5. POLICY AND LEGISLATIVE FRAMEWORKS TO SUPPORT SUSTAINABLE AVIATION FUEL

This section provides an overview of how government interventions and policies can be used to support alternative fuel production, with a focus on SAF. It also provides an overview of South Africa's current legislative environment and to what extent this supports the national alternative fuels industry.

5.1. South African Regulatory Environment: Biofuels and SAFs

Current regulatory frameworks supporting alternative fuels in South Africa, are best developed for the road transportation sector, there is currently no explicit legislative support for SAFs. This is liable to change, as although South Africa has not volunteered to participate in the Pilot or First Stage of the ICAO's CORSIA scheme, it will have to mandatorily participate in the Second Phase. This provides an impetus for the development of a regulatory framework to address the CORSIA requirements, in which SAFs could play an important role.

The lack of explicit support for SAFs aside, national policy and legislative frameworks already in place provide a basis to re-stimulate interest and support for alternative fuels in South Africa. An overview of the current national policy and legislative environment supporting alternative fuels is provided in the following sub-sections.

General Renewable Energy Policy Framework

South Africa's overarching energy policy is detailed in the *White Paper on Energy Policy of the Republic of South Africa*[107] (hereafter, the *Energy Policy*). The purpose of the Energy Policy is to ensure that national energy sources are adequately utilised and delivered while ensuring that the production and distribution of energy is sustainable and contributes towards the ongoing growth and development of the country. In this policy, the importance of a diversified energy supply that includes renewable energy is emphasised, and it is stipulated that the government will provide focused support for the development, demonstration and implementation of renewable energy sources (including biomass) for both small and large-scale applications.

In the Energy Policy, transportation is identified as a key demand sector, accounting for 24% of total energy consumption. According to the policy, over 90% of this energy is derived from liquid fuels. Given South Africa's dependence on crude oil imports to satisfy the liquid fuel demand, pricing is heavily influenced by international supply and demand trends. Thus, this policy acknowledges the importance of increasing fuel diversity in the transport sector, and the potential for government taxation and subsidy schemes to support this objective.

In recognition of the medium and long-term potential of renewable energy, and to further the objectives of the Energy Policy, the *White Paper on Renewable Energy*[108] was published. This Paper sets the vision, policy principles, strategic goals and objectives for promoting and implementing renewable energy in South Africa. An important target laid out in this paper was for 10 000 GWh of final energy production from renewable energy sources – mainly biomass, wind, solar and small-scale hydro – to be achieved 2013[109]. The paper further specified that this renewable energy contribution be utilized for both power generation and non-electric technologies such as biofuels. Although this White Paper was never put through the legislative procedures required to become a Parliamentary Act, it non-the-less serves as an important basis for renewable energy policy development.

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[107] White Paper on the Energy Policy of the Republic of South Africa. Available: http://www.energy.gov.za/files/policies/whitepaper_energypolicy_1998.pdf

[108] White Paper on Renewable Energy. Available: https://unfccc.int/files/meetings/seminar/application/pdf/sem_sup1_south_africa.pdf

[109] Although the 10 000 GWh target was not achieved by the end of 2013, there is ongoing progress towards renewable energy, driven by the Renewable Energy Independent Power Producer Procurement programme (REIPPP).

The commitment towards energy diversification and renewable energy outlined in the Energy Policy and the White Paper on Renewable Energy is to some extent formalized by the *National Energy Act (Act No. 34 of 2008*[110]*.* In the preamble to this Act, the provision for increased generation and consumption of renewable energies is clearly stated. Furthermore, the Act (Article 19(1)(d – f)) allows for the development of various national regulations including the following:

- minimum contributions to national energy supply from renewable energy sources;
- the nature of the sources that may be used for renewable energy contributions to the national energy supply; and
- measures and incentives designed to promote the production, consumption, investment, research and development of renewable energy.

National Biofuel Policies and Regulatory Frameworks

Following the identification of biofuels as an important renewable energy source in the White Paper on Renewable Energy, in order to strengthen and support industry viability, in 2005 Cabinet directed the then Department of Minerals and Energy (DME) to lead and co-ordinate the development of the *Biofuels Industrial Strategy of the Republic of South Africa* (hereafter, the *Biofuels Industrial Strategy*)[111]. This strategy was developed by an inter-departmental Biofuels Task Team (BTT) and approved by Cabinet in December 2007. The key objectives of the strategy were to address issues of poverty and economic development, particularly in rural areas, and contribute towards meeting national renewable energy goals.

The Biofuels Industrial Strategy followed the promulgation of various regulations developed as part of South Africa's clean fuel initiative, under the Clean Fuels 1 (CF1) Program[112]. Important regulations in this regard include the following:

- Regulations Regarding Petroleum Products Specifications and Standards[113]
- Regulations Regarding Petroleum Products Manufacturing Licenses[114]

These regulations revised the South African National Standards (SANS) specification for petrol and diesel, as well as the licensing requirements for manufacturing facilities. This was an important step in establishing a regulatory environment conducive to the commercial production of biofuel. The new regulations allowed for the blending of biodiesel into convention diesel from 5% (B5) to 100% (B100), and the blending of bioethanol into petrol from 2% - 10% on a volumetric basis.

Supported by the new regulatory environment, the Biofuels Industrial Strategy adopted a short-term focus (5-year pilot) with the aim of achieving a 2% (or 400 million litres per annum) penetration level of

[110] National Energy Act (Act No. 34 of 2008). Available:
http://www.energy.gov.za/files/policies/NationalEnergyAct_34of2008.pdf

[111] Biofuels Industrial Strategy of the Republic of South Africa. (2007) Available:
http://www.energy.gov.za/files/esources/renewables/biofuels_indus_strat.pdf(2).pdf

[112] Both of these regulations were issued under the *Petroleum Products Act (Act 120 of 1977)*

[113] Petroleum Products Act, 1997 (Act No. 120 of 1977). Regulations regarding petroleum products specifications and standards. *Government Gazette. Government Notice No. 627 of 23 June 2006.*
http://www.energy.gov.za/files/policies/regulations_petroleumproducts_specifications_2006.pdf

[114] Petroleum Products Act, 1977 (Act No. 120 of 1977). Regulations regarding petroleum products manufacturing licenses. *Government Gazette 28665. Government Regulation 288 of 27 March 2006.*
http://www.energy.gov.za/files/policies/regulations_petroleumproducts_manufacturing_2006.pdf

biofuels in the national liquid fuel supply by 2013[115]. Following careful consideration of environmental and food security concerns, the following crops were identified as viable for biofuel production[116]:

- **Bioethanol**: sugar cane and sugar beet
- **Biodiesel:** sunflower, canola and soya beans

In order to further strengthen the regulatory environment to support the effective implementation of the Biofuels Industrial Strategy, the Department of Energy (DoE) promulgated the *Regulations Regarding the Mandatory Blending of Biofuels with Petrol and Diesel*[117] on 23 August 2012. The mandatory blending regulations – specified by Government Notice No. R. 719 of 30 September 2013[118] as coming into effect on 1 October 2015 – stipulated that all licensed petroleum manufacturers must purchase all biofuels from licensed biofuel manufacturers, provided that the volume of biofuel can be blended with the petroleum manufacturers petroleum within the regulated concentrations. The regulated concentrations were as follows (v/v):

- **Bioethanol blending with petrol:** minimum concentration ranges from 2% to 10%
- **Biodiesel blending with diesel**: minimum allowable concentration is 5% (v/v).

It was intended that the mandatory blending regulations would guarantee the uptake of all biofuels supplied by local manufacturers, hence supporting the biofuel industry. The effective date for the mandatory blending requirements (1 October 2015) was set with the understanding that all outstanding issues, including the installation of the requisite infrastructure to allow blending, would be resolved before this date.

However, despite the efforts of the BTT, the initial impetus achieved by the Biofuels Industrial Strategy was short-lived, due primarily to the prevailing high feedstock and low crude oil/liquid fuel prices, which rendered biofuel projects as financially unattractive. To fill the need for an effective biofuels implementation strategy, and in so doing, address the stagnation of the biofuels industry (and encroaching deadline for the introduction of the mandatory blending targets), the *Draft Position Paper on the South African Biofuels Regulatory Framework*[119,120] (hereafter, the *Draft Position Paper*) was gazetted on 15 January 2015 for public comment.

The Draft Position Paper was aimed at supporting the full and proper implementation of the Biofuels Industrial Strategy by:

1. Promoting the development of a regulatory environment conducive to the commercial production of biofuels, and
2. Developing a pricing and subsidy framework to provide financial support to the industry.

The proposed pricing framework provided for, amongst else, efficient investments in biofuel manufacturing facilities, commensurate returns on investments made, operating costs and the levels at which manufacturing entities will be subsidised. An important mechanism under this framework was the General Fuel Levy, which was to be imposed on all petrol and diesel sold for commercial consumption.

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[115] This target was revised down from an initial target of 4.5% initially proposed in the draft strategy document in light of the challenges facing the development of the biofuels industry.

[116] Other possible crops include maize (the national staple, thus presenting a food concern) and jatropha (an alien species with a high calorific value of seed oil but toxic processing remnants, thus threatening environmental safety).

[117] Regulations Regarding the Mandatory Blending of Biofuels with Petrol and Diesel. Available: http://www.sapia.org.za/pdf/legislation/Final%20mandatory%20blending%20fuel%20regulations%20GG_35623_20120823.pdf

[118] Available : http://www.energy.gov.za/files/policies/petroleum/Annexure-C-Gazetted-Notice-of-the-Effective-Date-of-Mandatory-Blending-Regulations.pdf

[119] This position paper was published in terms of Section 17 of the *National Energy Act (Act. No. 24 of 2008)*

[120] Draft Position Paper on the South African Biofuels Regulatory Framework. Available: http://pmg-assets.s3-website-eu-west-1.amazonaws.com/140127draftpositionpapersabiofuelsregulatoryframework.pdf

The levy was proposed to lie between 4.5 – 6.5 cents/litre and would be applicable for a 20 year period, commencing alongside the mandated blending regulations.

In September 2018, the Minister of Energy indicated government plans to finalise the proposed biofuel framework and have it approved by cabinet by the end of March 2019. It was however only approved on 13 December 2019. The final position paper, *the South African Biofuels Regulatory Framework*, (hereafter, the *Regulatory Framework*) was made publicly available on 7 February 2020[121]. The Regulatory Framework provided five areas to be regulated namely:

1. The mandatory blending regulations so as to create certainty of biofuels demand.
2. The cost recovery mechanism for blending of biofuels.
3. The feedstock protocol, which mitigates the risk of the biofuels program towards food security.
4. The biofuels subsidy mechanism for farmer support and biofuel manufacturers support.
5. The selection criteria for biofuel projects requiring a subsidy.

The Regulatory Framework was meant to provide a policy framework for the implementation of the Biofuels Industrial Strategy of 2007. Together with the regulations regarding the Mandatory Blending of Biofuels with Petrol and Diesel of 2012, it aims to achieve a targeted biofuels penetration of 4.5% v/v of the national fuel pool with 2% expected to come from first generation biofuels technologies. In terms of the Mandatory Blending Regulations, there is a minimum 2% mandatory blending of bioethanol into petrol and a minimum of 5% mandatory blending of biodiesel into mineral diesel (subject to availability of locally produced biofuels). While the long-awaited Regulatory Framework is a step in the right direction to introduce renewable resources at scale into the national transport fuel mix, in its current form, it does not provide adequate regulations. The Regulatory Framework rightly identifies poverty alleviation and economic development as its primary objectives and acknowledges the role of biofuels in contributing towards the achievement of the country's renewable energy goals, energy security and the reduction of GHG emissions. However, regulations to ensure the potential benefits are maximised while the risks are minimised, have not been incorporated.

The Feedstock Protocol, a key component of the Regulatory Framework, excludes staple crops and alien crops as potential biofuel feedstocks. It also prioritises multi-purpose crops, rain-fed crops and crops grown on fallow land. While this is sensible, it is not sufficient to ensure biofuel production does not affect for example maize prices, as competition for land where maize could be grown remains. It is also not sufficient to ensure the preservation of biodiversity, as the conversion of virgin land for the production of biofuel feedstock with local crops can be just as damaging to biodiversity.

In addition, biofuels do not automatically lead to a reduction in GHG emissions. The opposite can in fact be true where land holding high carbon stocks such as forests, or soils with a high concentration of carbon content is converted to agricultural land for the production of biofuel feedstock, or intensive agricultural management is required, which relies on fossil-based fertilisers and coal-based electricity to power irrigation pumps. It is thus critical for any biofuel manufacturer wishing to apply for government support to prove that their fuel does, in fact, reduce GHG emissions on a life-cycle basis. The Regulatory Framework could have addressed this by adding a minimum GHG reduction threshold to the selection criteria for biofuel projects.

The Feedstock Protocol also restricts existing farms entering the biofuel sector unless the biofuel feedstock production is part of a plant rotation regime that augments the financial viability of the farm. If this is strictly adhered to, it will be problematic for the main bio-ethanol production feedstock - sugar cane. It is also in direct conflict with the Feedstock Protocol's stated goal of helping the sugar industry redirect sugar exports from world markets towards a domestic biofuel market.

[121] South African Biofuels Regulatory Framework. Available : https://www.gov.za/sites/default/files/gcis_document/202002/43003gon116.pdf

Furthermore, no timeframe has been given in the Regulatory Framework for the amendment of the Mandatory Blending Regulations to mandate the regulated biofuel transfer price as the Basic Fuel Price, and to resolve the operational aspects of blending biofuels with conventional petrol and diesel. A determination must also still be issued of the blending infrastructure required, the acceptable capital costs that will be incurred by the blender as well as the operating costs of blending.

The Biofuels Farmers Support and the Biofuels Manufacturers Support schemes, as well as the selection criteria for the biofuels manufacturing projects that will be eligible for the subsidy must also still be elaborated on in much more detail. Without those, it will remain difficult for most project developers to determine financial feasibility for their projects and the sector is likely to see a slow and uncertain start.

Due to the lack of a coherent and viable financial framework supported by government, the construction of commercial biofuel plants has stalled. Given that there is an approximate 18 – 24 month construction period required for commercial-scale biofuel plants[122], following the release of the final Regulatory Framework, there will be at least a two year delay before the mandatory blending regulations can come into effect.

A summary of the policy and legislative environment supporting biofuel development in South Africa is shown in Figure 18.

[122] Available: https://www.engineeringnews.co.za/article/doe-goes-to-ground-over-mandatory-blending-of-biofuels-policy-deadline-2015-03-06/rep_id:4136

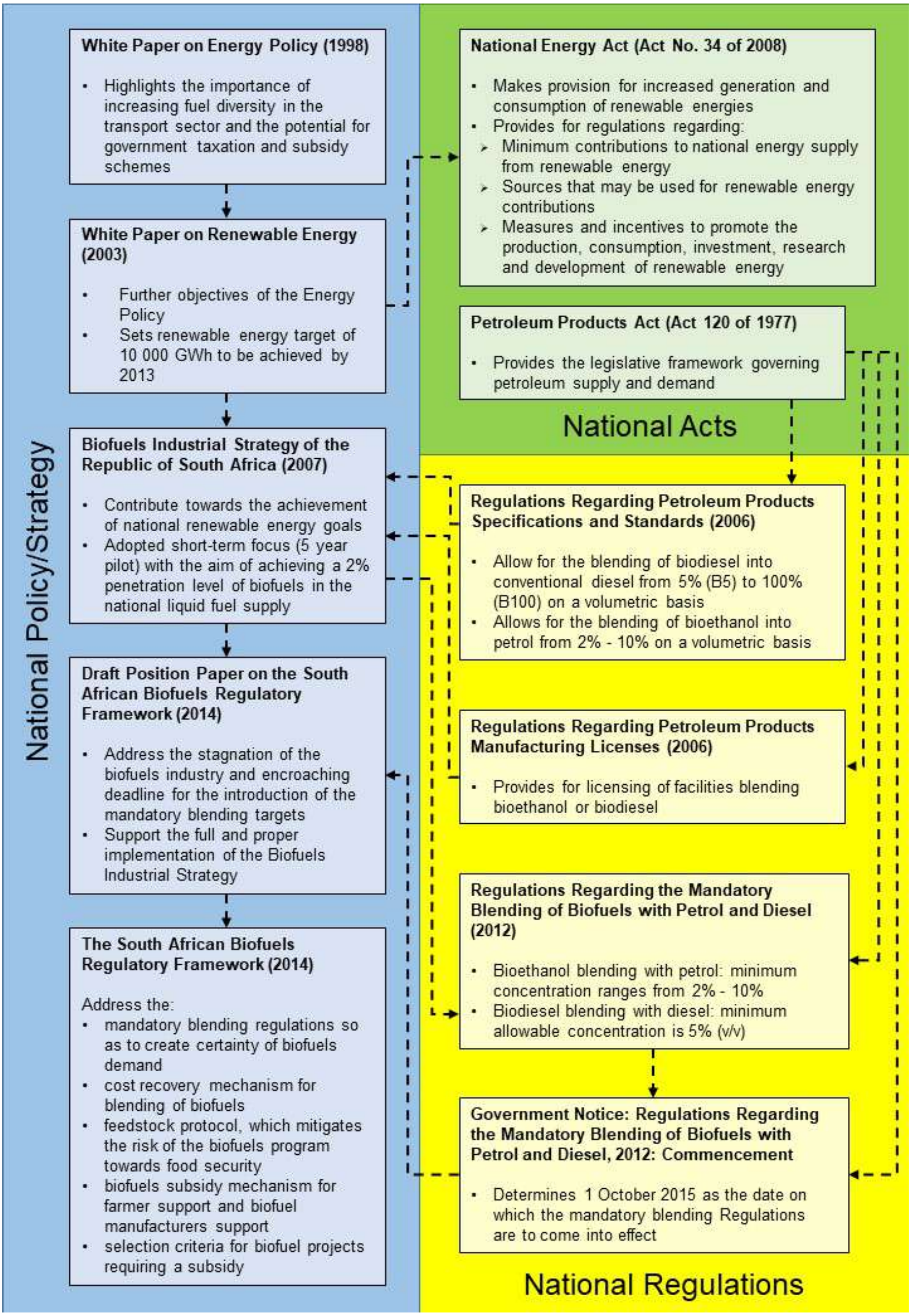

Figure 18 Overview of South African regulatory framework relevant to biofuels

Implications of Other National Policies and Strategies

In addition to the polices and strategies with a specific focus on biofuels (see Section 0), at a national level biofuel production is supported by various other policies and strategies. It has been emphasized that these policies do not in themselves create an enabling environment for biofuels programme development and implementation; this requires a balanced mix of professional, technical, financial and legal service providers, innovative funding, interdepartmental leadership and championing projects for success[123].

Key overarching policies and strategies supporting development of the biofuels industry in South Africa include the following[123]:

- **New Growth Path:** The New Growth Path framework has set a target for the creation of five million jobs by 2020. The "green" industry sector (including renewables) is expected to contribute to this overall target, with a sector-specific target for 33% of power generation to come from renewable energy sources by 2020.
- **Industrial Policy Action Plan (IPAP)** and the **South African Renewables Initiative (SARi):** Whilst there are various IPAP versions, IPAP2 (published in 2011) highlights specific plans for the renewable energy sector. The focus of these plans is directed towards developing competitive local manufacturing for renewable energy technologies, including biofuels. This plan supports the South African Renewables Initiative (SARi)[124], which was launched in 2011 at the United Nations Climate Change Conference (COP17). The SARi is an intergovernmental initiative (driven by the Department of Trade and Industry, Department of Energy and the Department of Public Enterprises) with the aim of catalysing South Africa towards a green growth pathway, through the design and facilitation of financing arrangements that enable the development of a critical mass of renewables without incurring incremental cost burdens on the country. The initiative looks to unlock public, private, domestic and international funding in order to scale up renewables in the country.
- **National Development Plan (NDP):** The principle aim of the NDP is to eliminate poverty and reduce inequality by 2030. As part of this overarching aim, the plan also highlights the need for South Africa to transition towards a low-carbon, climate-resilient economy. To this end, the plan includes proposals to support a "carbon-budgeting" approach through the introduction of emissions reduction targets, introduce programmes and initiatives to promote energy efficiency, and simplify the regulatory framework to encourage renewable energy development.
- **National Climate Change Response Policy:** The National Climate Change Response Policy[125] was developed in response to climate change while achieving the stabilisation of GHG emissions. The policy outlines mitigation and adaptation responses, while also reflecting a strategic approach to support "climate resilient development". This strategy provides three time bound planning horizons to achieve its objectives: short-term (1 – 5 years), medium terms (twenty years from publication of the strategy), long-term (a planning horizon that extends to 2050).

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[123] Brent, A. 2014. The agricultural sector as a biofuels producer in South Africa. *Understanding the Food Energy Water Nexus.* WWF-SA, South Africa.

[124] For more information on the SARi refer to : https://www.dbsa.org/EN/About-Us/Publications/Documents/SARi%20-%20South%20African%20Renewables%20Initiative.pdf

[125] National Climate Change Response Policy: https://www.environment.gov.za/sites/default/files/legislations/national_climatechange_response_whitepaper.pdf

Carbon Tax Act

Following a consultative process lasting close to a decade, the Carbon Tax Act and the Customs and Excise Amendment Act were both officially gazetted on 23 May 2019 and came into effect on 1 June 2019[126]. While the Customs and Excise Amendment Act are focused on administrative issues, the Carbon Tax Act sets out the technical and financial aspects of the act. The Carbon Tax Act is a fiscal instrument that puts a price on the GHGs emitted by various sectors. The tax base comprises emissions from fossil fuel combustion, emissions from industrial process and product use and fugitive emissions. The tax is based on a "polluter-pays principle", meaning that entities liable for this tax include any entity conducting an activity that emits GHG emissions above the threshold for the activity listed in Schedule 2 of the bill[127].

In order to allow businesses to adapt and transition to low carbon alternatives, the carbon tax will be implemented in a phased approach. The first phase of the tax is from June 2019 – December 2022, with a tax rate of R120/tonne CO_2e emitted. However, allowable tax breaks will reduce the effective rate to R6 – R48/tonne CO_2e. During the first phase, all carbon tax liable entities will receive a basic tax-free allowance of 60%. Due to the complexity of emission measurement in the waste and land use sectors (including agriculture), these sectors have been excluded from the tax base for phase 1. The second phase of the tax is scheduled to run from 2023 – 2030. The second phase will be informed by the impact of the first phase in reducing South Africa's GHG emissions in line with the National Determined Contribution.

Although the bill has been met with criticism and resistance from a number of sectors directly affected by the proposed threshold, its role in transitioning South Africa to a low-carbon economy presents long-term investors with new market opportunities, including renewable energy[128].

Within the transport sector, the proposed carbon tax on domestic aviation has sparked strong opposition. As it currently stands, the Carbon Tax Bill stipulates that any airline consuming more than 100 000 l/year of fuel for domestic aviation, falls into the carbon tax net, with a transitional basic tax-free allowance for fossil fuel combustion emissions of 75%. There is also a 5% performance allowance, 5% carbon budget allowance and a 10% offset allowance. Given that the tax only applies to economic activities that emit GHGs within South Africa, international flights will be exempt[129].

It is currently uncertain as to how parliament will respond to these submissions, but should they be rejected, the domestic aviation sector will be liable for the tax. The current fuel combustion emission factors as listed in the Carbon Tax Bill relevant to domestic aviation are shown in Table 12. Whilst the relative price of SAFs will still be an important factor, the potential of SAFs to provide a low carbon fuel alternative to the industry could contribute to the development of a business case. Switching from conventional jet to SAF would reduce the carbon liability of airlines for domestic flights. This reiterates that the relevant price comparison is not between conventional jet and SAF, but conventional jet + carbon tax.

[126] Carbon Tax Bill. Available: http://www.treasury.gov.za/comm_media/press/2018/2018112101%20Carbon%20Tax%20Bill%202018-B46-2018.pdf

[127] For further explanation of the Carbon Tax bill, please refer to the following: http://www.treasury.gov.za/comm_media/press/2018/2018112101%20Explanatory%20Memorandum%20to%20the%202018%20Carbon%20Tax%20Bill%20-%2020%20Nov%202018.pdf

[128] https://www.businesslive.co.za/bd/opinion/2019-03-07-sas-carbon-tax-is-a-step-in-the-right-direction/

[129] Note, this exception refers to international routes, international carriers flying domestic routes will be liable for this tax.

Table 12 Fuel combustion emission factors for stationary and non-stationary source categories as per the Carbon Tax Bill[126]

Fuel Type	CO_2 (kg CO_2/TJ)	CH_4 (kg CH_4/TJ)	N_2O (kg N_2O/TJ)	Default calorific value (TJ/Tonne)
Stationary Source Category				
Aviation Gasoline	70 000	3	0.6	0.0443
Jet Gasoline	70 000	3	0.6	0.0443
Jet Kerosene	71 500	3	0.6	0.0441
Non-Stationary/Mobile Source Category				
Aviation Gasoline	70 000	0.5	2	0.0443
Jet Kerosene	71 500	0.5	2	0.0441

6. Potential Ethanol Demand from Local Fuel Sector

In addition to the market drivers discussed in the previous section, viable production of SAF from sugarcane using the ATJ process in South Africa is also dependent on market demand and attainable supply volumes. South Africa has three major international airports (OR Tambo (JHB), Cape Town International (CPT) and King Shaka International (DUR)). Although South Africa is only obligated to participate in CORSIA from 2027 onwards, from 2020 the scheme will be operational and international airlines already participating, servicing routes to and from these airports, will be looking for refuelling options that help to meet their emission reduction obligations.

In addition to CORSIA, other drivers such as international oil price volatility and consumer pressures are pushing up the market for sustainable alternatives to fossil-based jet fuel, increasing the demand from domestic as well as international airlines operating in the country. SAA for example, has made a public commitment to moving towards SAF, and besides from their partnership with Project Solaris, and publicised test flight using SAF produced from locally produced, RSB-certified Solaris (see Section **Error! Reference source not found.**, pg. **Error! Bookmark not defined.**), has committed to 50% of the fleet using SAF by 2023[130].

While there is a clear market for SAF produced in South Africa, SAF production from sugarcane requires infrastructure investments into both ethanol production capacity and upstream processing capacity, thus increasing the level of investment required. Although the sugar industry is already producing some ethanol, the majority of this is food or pharmaceutical grade, and thus cannot be used as an intermediate in SAF production. Currently, there is limited local demand for fuel ethanol, however, as discussed in Section 5, South Africa does have a national biofuel blending mandate in place for road transportation fuels (i.e. petrol and diesel)[131]. These regulations allow for the blending of biodiesel into convention diesel from 5% (B5) to 100% (B100), and the blending of bioethanol into petrol from 2% - 10% on a volumetric basis. Although the effective date for the mandatory blending requirements was set for 1 October 2015, support for the uptake and implementation thereof has been minimal. With the publication of the *South African Biofuels Regulatory Framework*[132] there is anticipation that this could re-stimulate interest in the bioeconomy and create a direct demand for fuel ethanol.

Considering both aviation and road transportation, high level estimates suggest that local demand for fuel ethanol could be ~ 2.4 billion litres annually, of which 75% (1.8 billion litres) is from aviation, while 25% (600 million litres) comes from the national fuel blending mandate (see Figure 19). Assuming that 50% of cane that is produced can be diverted from the export market to domestic ethanol production, based on current yields, South Africa can produce ~ 700 million litres of ethanol from sugar cane[133]. This represents about 30% of the estimated potential fuel ethanol demand.

While the production of sugarcane ethanol has strong potential in South Africa, the current regulatory frameworks in place is not sufficient for the growth of the bioeconomy. The development of clear policy and government support mechanisms for alternative fuels are critical. This should occur alongside the development of funding models that provide, amongst else, support for feasibility studies and project development, loan guarantees, and encourage private investment.

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130 The draft position paper was gazetted on 15 January 2015 for public comment.

131 See Section 5 for detailed discussion.

132 This position paper was published in terms of Section 17 of the *National Energy Act (Act. No. 24 of 2008)*

133 Assuming annual cane production = 20 MT cane and 1 MT cane yields 700 million litres ethanol. For further information, see Figure 19.

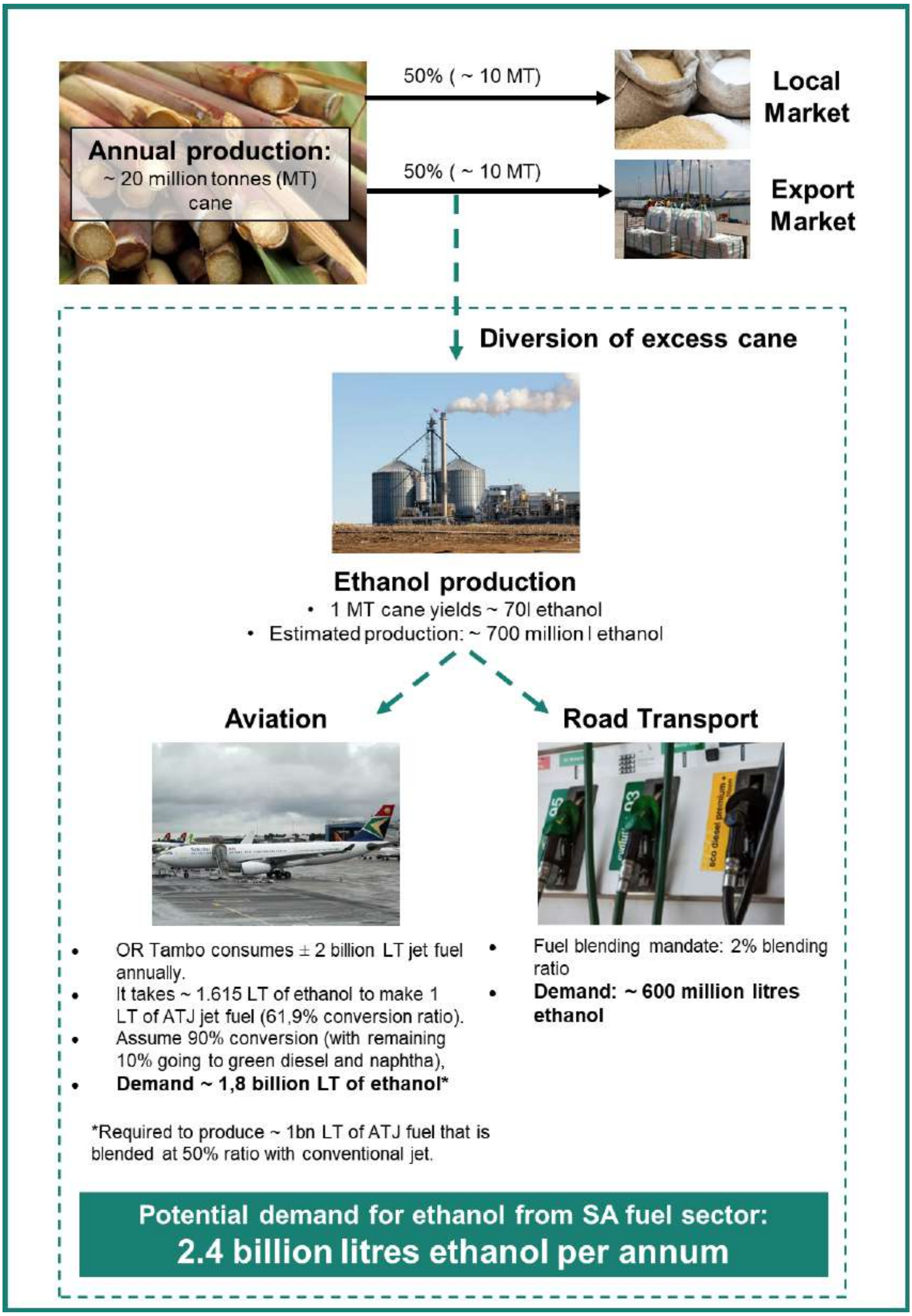

Figure 19 Ethanol production potential and potential demand estimate for fuel ethanol in South Africa