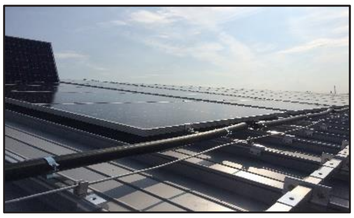
Task Number 63

A Report from the
Advanced Motor Fuels Technology Collaboration Programme

Technology Collaboration Programme on Advanced Motor Fuels




Sustainable Aviation Fuels – Status quo and national assessments

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Summary / Abstract

The aviation industry is responsible for about 2% of global greenhouse gas (GHG) emissions, and with air travel expected to continue to grow in the coming years, it is crucial to find ways to reduce its environmental impact. Sustainable aviation fuels (SAF) are alternative jet fuels made from renewable biomass, waste-based feedstock or renewable electricity, which have lower life-cycle greenhouse gas (GHG) emissions (or carbon intensity) than conventional fossil Jet-A1 and fulfill sustainability criteria beyond carbon intensity. SAF offer a promising solution as they can be used as a drop-in replacement for conventional jet fuel, meaning that they can be used in existing aircraft engines without the need for modifications.

SAF can be produced through various pathways. Currently, nine production pathways have been approved and several more are under review. The main production pathway today is Hydroprocessed Esters and Fatty Acids (HEFA), but Gasification Fischer-Tropsch (FT) and Alcohol-to-Jet (ATJ) are expected to produce significant amounts of SAF by 2030. Power-to-Liquid (PtL) generating e-fuels will take longer to become fully commercial. However, the future demand for SAF is huge and a variety of technology pathways will be needed to achieve sector targets.

The GHG savings from SAF depend on the feedstock and technology used. SAF has the potential to significantly reduce GHG emissions and non-CO_2 effects (e.g. contrails) compared to fossil Jet A-1. Gasification FT has the highest potential for GHG emission reduction but production facilities are very costly to build. The most cost-effective SAF now and in the near future is from HEFA using used cooking oil (UCO), due to its relatively low conversion cost and high fuel yield. However, supply of UCO will be limited and with increasing demand, additional SAF will have to be produced via various other pathways.

SAF production lags behind demand and is estimated at about 0.1% of global aviation fuel consumption by 2022. However, many planned production facilities and offtake agreements have been announced, indicating a sharp increase in production over the next few years. Especially, USA, EU and Brazil have ambitious plans for capacity increases. As of early 2023, worldwide, only a few production facilities are in operation, with Neste as the market leader. In the United States, the production forecast for 2027 is about 60 times higher than in 2022. Several airports worldwide offer SAF either regularly or in individual batches. Scaling up SAF capacities requires huge investments and risk-sharing among stakeholders. Offtake agreements are one way for airlines to support SAF producers while securing their supply. The number of such agreements has increased sharply in recent years and this trend is expected to continue.

The exact demand or future production volume of SAF is hard to assess, but several studies and market outlooks have been published. A publication of SkyNRG foresees a SAF supply of 7 million t by 2026 from EU27 and USA. This would be a sharp increase but still falls short of sector targets. ICAO published its short-term projections on SAF production, where the global production is projected between 7.6 million t and nearly 17 million t by 2030.

Legally binding requirements and incentives for using SAF as well as roadmaps and strategies are being developed. National targets and mandates differ, but efforts are being made to align international and national schemes, since harmonization of regulations and sustainability criteria is desirable to avoid shifting of flight patterns to less regulated markets, leading to higher CO_2 emissions there.

Main barriers for implementing SAF were confirmed within the Task, namely sustainable feedstock availability, comparably high production costs, and a lack of clear (international) regulations. Large scale deployment of SAF requires large investments in new production

facilities and a strong reduction in production costs (over the entire value chain). Currently, SAF is much more expensive than fossil-based fuel, costing generally two to five times more than conventional jet fuel. SAF prices are expected to reduce and the price gap between SAF and fossil-based fuel will narrow over time.

Blending of certified SAF with conventional jet fuel is not a technological issue, even in the case of multi-blending, but an administrative one. There are three modes of SAF delivery: segregated delivery, mass balance, and book and claim. While the book and claim mechanism seems most practical, it does not support reducing regional non-CO_2 effects.

In order to achieve the ambitious decarbonization targets of the aviation sector, the market uptake of SAF must be promoted by identifying and overcoming various uncertainties and challenges and by subsequently improving the framework conditions. Identifying these barriers and showing successful examples of SAF market uptake is an important step to realize the potential of SAF in terms of reducing GHG emissions and achieving International Civil Aviation Organization (ICAO)'s long-term aspirational goal (LTAG) of net-zero carbon dioxide (CO_2) emissions from aviation by 2050.

It is important for governments and the aviation industry to work together to address these challenges and support the development and use of SAF.

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The national assessments and report under Task 63 were carried out and authored by numerous researches from the participating countries as indicated below.

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The Advanced Motor Fuels (AMF) TCP also is an international platform of cooperation working in the framework of the IEA´s Technology Collaboration Programmes. AMF´s vision is that advanced motor fuels, applicable to all modes of transport, significantly contribute to a sustainable society around the globe. AMF brings stakeholders from different continents together for pooling and leveraging of knowledge and research capabilities in the field of advanced and sustainable transport fuels. www.iea-amf.or

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Introduction

The IEA´s Technology Collaboration Programme (TCP) on Advanced Motor Fuels (AMF) aims at putting transport on track to sustainability and reducing environmental impacts from transport by fostering collaborative research, development and deployment and providing unbiased information on clean, energy-efficient and sustainable fuels and related engine and vehicle technology. The topic of the AMF TCP is advanced fuels that are sustainably produced and burn cleanly and energy efficiently. Typically, AMF examines energy efficiency, local emissions, and resulting greenhouse gas (GHG) emissions from the application of advanced fuels in advanced internal combustion engines. The goal is to improve the understanding of the role of advanced fuels for sustainable transportation and to enable knowledge-based decision-making.

The ongoing electrification of the drivetrain means that in the future alternative fuels for operating internal combustion engines will become less important. Especially in inner-city traffic, electric drives are very efficient and are preferable from the point of view of local emissions. For long-distance transport of heavy loads, however, a battery-electric operation is difficult to envisage, which is why alternative fuels will be used mainly to power trucks, large ships and aircraft in the long term. While there are already several AMF projects on trucks and ships, there has not yet been a project on sustainable aviation fuels (SAF).

Sustainable aviation fuels are currently being discussed as an important way to reduce GHG emissions from the aviation industry, which is responsible for about 2% of global GHG emissions[1], 14.4% of EU transport emissions[2] and 11% of US transport emissions[3]. In October 2022, member states of the International Civil Aviation Organization (ICAO) agreed to a long-term aspirational goal (LTAG)[4] of net-zero carbon dioxide (CO_2) emissions from aviation by 2050, with a simultaneous increase in traffic volume of about 3% per year.

In its publication Waypoint 2050[5], the Air Transport Action Group (ATAG), estimates the global development of the demand for aviation fuels up to the year 2050 and beyond and calculates three possible scenarios to achieve the CO_2 reduction target set for 2050. Without measures, this results in a demand of about 570 million tons of aviation fuel per year, causing about 1,800 million tons of CO_2. In Scenario 1, which pushes the development of new propulsion technologies as well as measures in infrastructure and operations, 61% of the emission savings are achieved by using 290-390 million tons of SAF by 2050. This highlights the role of SAF on decarbonizing the aviation sector.

However, this potential remains largely untapped as such fuels currently represent only about 0.1% of global aviation fuel consumption (about 0,27 million t in 2022[6]). The AMF Task 63 on Sustainable Aviation Fuels (AMF-SAF) has started in November 2021 under the lead of Austria. The Task Member Countries within the project are Austria, Brazil, China, Denmark, Germany, Switzerland and the USA.

This report summarizes findings obtained during the project. The chapter on status quo provides a brief overview on the global status of sustainable aviation fuels in terms of technology pathways, production, consumption, GHG emissions, non-CO_2 effects, production

[1] https://www.iea.org/reports/aviation
[2] https://www.consilium.europa.eu/en/infographics/fit-for-55-refueleu-and-fueleu/
[3] https://www.anl.gov/taps/decarbonizing-aviation
[4] https://www.icao.int/environmental-protection/Pages/LTAG.aspx
[5] https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/
[6] https://www.icao.int/environmental-protection/Documents/SAF/ICAO%20SAF%20short-term%20projections%20-%20methodology%20and%20results.pdf

costs and projected development in the energy system. Due to ambitious goals and incentives, the SAF market is developing very fast. For this reason, emphasis has been placed to provide links to interactive maps and websites so that the most up-to-date information can be accessed at any given time.

The chapter on national assessments provides information on the concrete situation of SAF implementation in the respective countries (Austria, Brazil, Denmark, Germany, Switzerland, USA). Each participating task member provides input on national stakeholders, feedstock potential, national strengths and strategies, legal framework as well as challenges and opportunities along the value chain. Afterwards, a summary of the series of three online seminars is provided in the chapter on best practice examples. Finally, concluding remarks summarize challenges of SAF implementation and potential follow-up work on SAF.

Objectives

The objective of AMF is to conduct joint R&D on advanced fuels, to exchange information on R&D, markets and policy, and to support the market introduction of advanced fuels.

The aim of AMF Task 63 on Sustainable Aviation Fuels is to lay the foundation for collaborative RD&D work on SAF within AMF TCP. Thus, the project focused on:

- Identifying stakeholders and experts
- Assessing the national situation of the participants
- Facilitating information exchange

The project scope covered biofuels as well as e-fuels. Task 63 further aims to identify the challenges in bringing SAF to market and to showcase examples of successful deployment and application, to learn from each other, engage with national and international stakeholders and increase the amount of SAF produced. Task 63 shall also provide the basis for further AMF work on the topic.

Methodology and description of activities

Task 63 was structured in the following work packages:

WP 1: Task management	WP 2: Overview of the status quo	WP 3: National assessments	WP 4: Best practice examples	WP 5: International stakeholder

For describing the international status quo on sustainable aviation fuels, relevant information was gathered form literature as well as from websites of relevant organizations, such as ICAO, CAAFI, Clean Aviation Partnership, from conference papers and from personal contacts with stakeholders in respective task participant´s countries and abroad. All participants provided relevant sources of information, including initiatives for the implementation of SAF.

Based on a report outline provided by Austria, each participating Task Member was conducting the national assessment for their own country. The Task Members were asked to contact national or international partners for this purpose (under consideration of GDPR regulations). The topics, as well as methods and data sources for these assessments were discussed in an internal scoping-workshop. A common list of challenges was derived from comparing the national assessments.

To share best practices and facilitate learning among stakeholders in the field (airports, airlines, kerosene providers, etc.), we conducted a series of three online seminars. The thematic focuses of these online seminars were: Feedstock & Conversion, Supply & Operation and Market & Policy. During these online seminars, selected stakeholders described how they have implemented the production or application of Sustainable Aviation Fuels, the challenges they have faced and how they have overcome them. The findings and recordings from these seminars have been made available on the task website.

Throughout the project, international stakeholders were contacted to provide information on status quo and challenges in SAF implementation and to present examples of best practices.

Status quo

This chapter provides a brief overview on the global status quo of sustainable aviation fuels in terms of technology pathways, production status, consumption status, GHG emissions, non-CO_2 effects, production costs and projected development in the energy system. Due to ambitious goals and incentives, the SAF market is developing very fast. For this reason, emphasis has been placed to provide links to interactive maps and websites so that the most up-to-date information can be accessed at any given time.

Overview on technology pathways

The definition of Sustainable Aviation Fuels (SAF) varies and covers a wide range of fuels produced via various pathways. The term SAF includes all non-fossil aviation fuels, which fulfill respective sustainability criteria beyond carbon intensity. SAF can be further divided in biofuels and e-fuels:

- Biofuels cover fuels based on biomass, which can be food/feed crops, energy crops, agricultural residues, forest biomass and residues and other wastes and residues. Feedstocks that are no food or feed crops produce so-called advanced biofuels[7], which have low GHG emissions and a low ILUC impact (e.g. agricultural and forestry residues, short rotation coppice, miscanthus or industrial waste and residues).
- E-fuels, also known as renewable fuels of non-biological origin (RFNBOs), electrofuels or Power-to-Liquid (PtL), are synthetic hydrocarbons from electrical power.
- Besides that, there are also pathways beyond bio-based and electric-based, e.g. Sun-to-Liquid (StL), where H_2O and CO_2 are converted into syngas via a thermochemical redox reaction.

Whereas biofuels and e-fuels can be used as drop-in fuels, the use of hydrogen or electricity requires adapted infrastructure and propulsion technologies. Hydrogen for new drivetrains and diesel substitutes are not considered in this Task.

New aviation fuels must comply with high safety standards, when used in commercial flights. The approval is a long-lasting process. So far, nine SAF production pathways have been approved to meet ASTM D4054 international standards (Table 1). Several additional pathways are currently under review by ASTM[8]. The certification ensures that chemical and performance characteristics of conventional Jet-A1 fuel are met up to a specific blend (drop-in). It does not relate to technology readiness level (TRL) or level of sustainability.

Table 1: ASTM certified technology pathways (ICAO[2])

ASTM reference	Technology pathway	Abbreviation	Feedstocks	Blending ratio	Projects
ASTM D7566 Annex 1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT-SPK	Coal, natural gas, biomass	50%	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
ASTM D7566 Annex 2	Synthesized paraffinic kerosene from	HEFA	Bio-oils, animal fat,	50%	World Energy, Honeywell UOP,

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG
[8] https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx

	hydroprocessed esters and fatty acids		recycled oils		Neste Oil, Dynamic Fuels, EERC
ASTM D7566 Annex 3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%	Amyris, Total
ASTM D7566 Annex 4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%	Sasol
ASTM D7566 Annex 5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Biomass from ethanol or isobutanol production	50%	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy
ASTM D7566 Annex 6	Catalytic hydrothermolysis jet fuel	CHJ	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%	Applied Research Associates (ARA)
ASTM D7566 Annex 7	Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%	IHI Corporation
ASTM reference	**Technology pathway**	**Abbreviation**	**Feedstocks**	**Input feedstock***	**Projects**
ASTM D1655 Annex A1	Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	Co-processed HEFA	Fats, oils, and greases (FOG) co-processed with petroleum	5%	Total, OMV, …
ASTM D1655 Annex A1	Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	Co-processed FT	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%	Fulcrum Bioenergy

** For co-processing pathways, the input of renewable feedstocks of the co-processing units is limited*

Work is ongoing to allow the use of 100% SAF in aircraft, as well as to increase the maximum blending for co-processing from 5% to 30%. There are further conversion processes under evaluation by ASTM (lead developers in brackets)[9]:

- Synthesized aromatic kerosene – SAK (Virent)
- Integrated hydropyrolysis and hydroconversion - IH2 (Shell)
- ATJ derivative utilising biochemical production of isobutene (Global Bioenergies)
- ATJ derivative starting with the mixed alcohols (Swedish Biofuels)
- Single Reactor HEFA (Drop-in Liquid Sustainable Aviation and Automotive Fuels – DILSAAF (Indian CSIR-IIP)
- Pyrolysis of non-recyclable plastics – ReOIL (OMV)
- Co-processing of pyrolysis oil from used tires
- Co-processing of hydroprocessed biomass

HEFA is currently the main production pathway, but until 2030 also Gasification-FT and ATJ have the potential to produce significant amounts. PtL will take longer to be fully commercial. However, production of SAF from a variety of feedstocks and via different technology pathways is needed to achieve the targets of the aviation sector. Following, a brief description of most promising SAF production pathways is given. A more detailed description can be found in e.g. the IEA Bioenergy Task 39 report "Progress in commercialization of biojet/SAF – Technologies, potential and challenges[10]".

HEFA

The HEFA pathway has the highest TRL among SAF pathways and has the potential to provide high volumes of SAF in near-term. HEFA is already on the market and requires comparably low capital expenditures (CAPEX). Triglycerides containing waste oils and fats are hydrogenated and subsequently hydrocracked and hydroisomerized. Isomerization is required to improve the cold flow properties of the aviation fuel. Alkanes, isomers and cracking products are separated and fractionated to propane, gasoline, diesel and drop-in aviation fuel. The simplified process is shown in Figure 1.

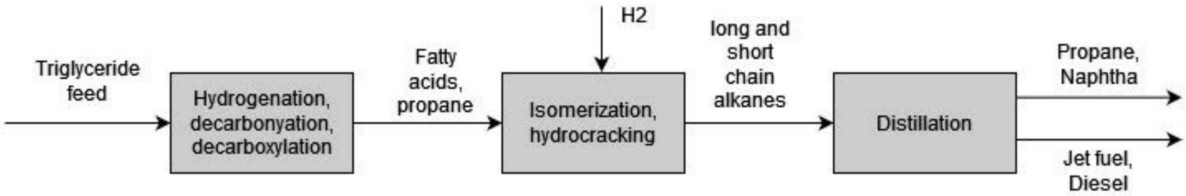

Figure 1: HEFA process[11]

Gasification Fischer-Tropsch

The Fischer-Tropsch pathway is promising regarding CO_2 emissions reduction as well as feedstock flexibility. Additionally, the technology is already developed and the production of liquid transportation fuel from fossil sources is well established. Commercial scale FT-facilities run on fossil fuels, such as coal or natural gas, but also e.g. biogenic residues can be used as

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[9] https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx
[10] https://task39.ieabioenergy.com/wp-content/uploads/sites/37/2023/01/Progress-in-commercialization-of-biojet-Sustainable-Aviation-Fuels-SAF-Technologies-potential-and-challenges.pdf
[11] https://doi.org/10.1016/j.biombioe.2020.105942

fuel. Figure 2 shows a simplified flowsheet of the main process steps when using lignocellulosic biomass. During gasification, biomass reacts with e.g. steam and produces CO and H_2 rich syngas by partial oxidation. Subsequently, the syngas is purged from impurities and other unwanted components. A water-gas shift reaction manages the CO to H_2 ratio and CO_2 is removed before the FT-synthesis. Fischer-Tropsch reactions are exothermic and the stream must be cooled to avoid catalyst deactivation or unwanted methane production. Light hydrocarbons can be oligomerized and heavier hydrocarbons can be hydrocracked in order to obtain the desired SAF characteristics. Finally, the crude products are isomerized and fractionated by distillation.

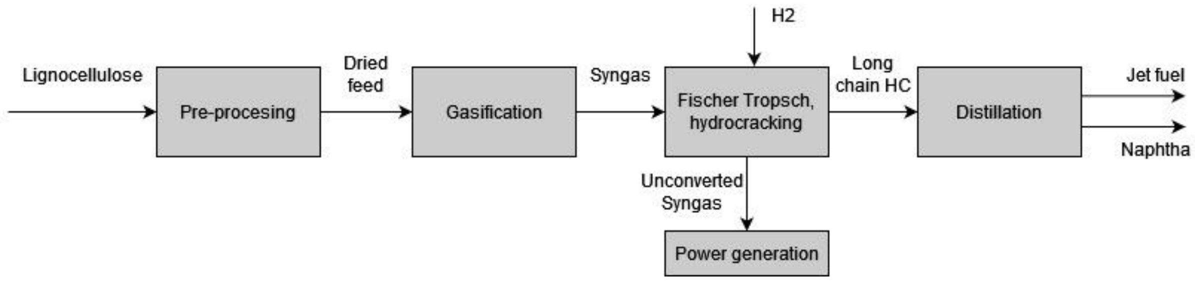

Figure 2: Fischer-Tropsch process[12]

Alcohol-to-Jet

The ATJ process converts ethanol (or isobutanol) to synthethic paraffinic kerosene and diesel. First, the ethanol is dehydrated to ethylene in the dehydration step. The ethylene is then oligomerized into longer carbon chain olefins in the oligomerization step, where the process operating conditions can be tuned to produce a high yield of either aviation fuel or diesel. The hydrogenation step saturates any olefins to paraffins and iso-paraffins. Finally, the product is fractionated in the fractionation step to isolate jet and diesel. The simplified process is shown in Figure 3.

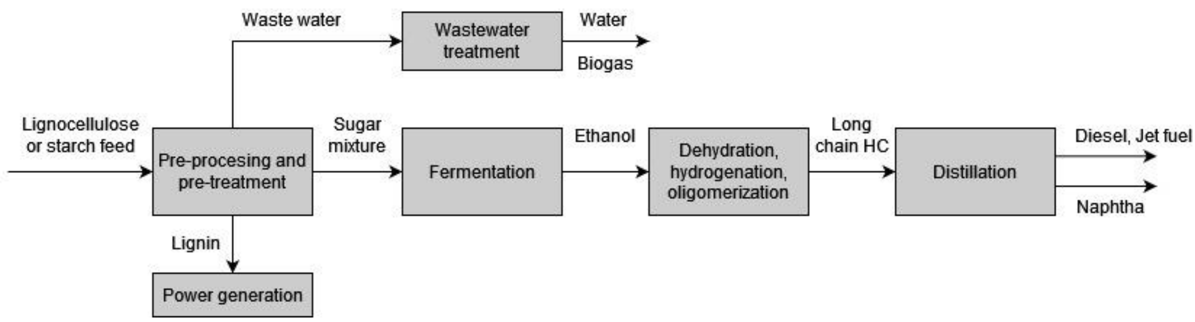

Figure 3: Alcohol-to-Jet Process (using lignocellulosic feedstock)[13]

Power-to-Liquid/E-fuels

E-fuels production comprises three main steps: 1) Hydrogen production from renewable electricity and water through electrolysis; 2) Provision of CO_2; and 3) Synthesis to hydrocarbons with subsequent upgrading/conversion to refined fuels[14]. An overview of production pathways of e-fuels is shown in Figure 4.

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[12] https://doi.org/10.1016/j.biombioe.2020.105942
[13] https://doi.org/10.1016/j.biombioe.2020.105942
[14] https://www.icao.int/Meetings/a40/Documents/WP/wp_526_en.pdf

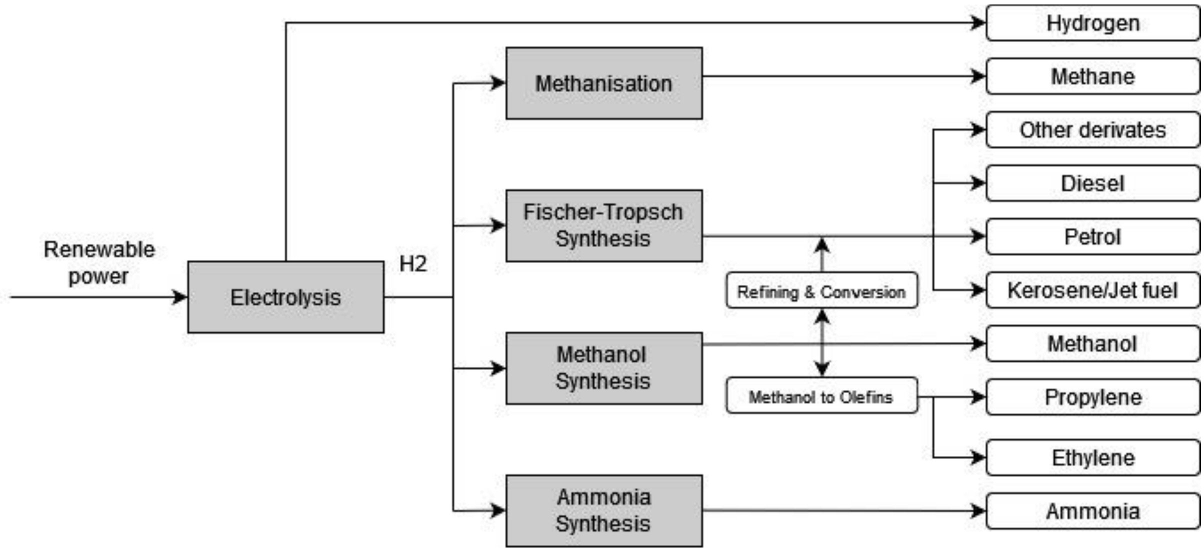

Figure 4: E-fuels production pathways[15]

GHG emissions and non-CO_2 effects

The aviation sector is responsible for about 2% of global greenhouse gas (GHG) emissions[16], 14.4% of EU[17] and 11% of US transportation GHG emissions[18]. In October 2022, member states of the International Civil Aviation Organization (ICAO) agreed to a long-term aspirational goal (LTAG)[19] of net-zero carbon dioxide (CO_2) emissions from aviation by 2050. The LTAG feasibility study[20] is using three main integrated scenarios, SAF is identified as important measure. For creating the scenarios, the marginal abatement cost (costs per ton of abated CO_2) has been established in LTAG. This is an important decision support for investors to choose the most efficient technology. The LTAG does not attribute specific obligations or commitments in the form of emissions reduction goals to individual States. Instead, it recognizes that each State's special circumstances and respective capabilities (e.g., the level of development, maturity of aviation markets, sustainable growth of its international aviation, just transition, and national priorities of air transport development) will inform the ability of each State to contribute to the LTAG within its own national timeframe. Each State will contribute to achieving the goal in a socially, economically and environmentally sustainable manner and in accordance with its national circumstances.

The carbon intensity of conventional Jet-A1 is about 89 g CO_{2e}/MJ[21], which is ICAO´s fossil baseline. The GHG savings through SAF mainly depend on the feedstock used and the technology pathways. Prussi et al. (2021)[22] calculated carbon intensities of SAF for CORSIA.

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15 https://www.eai.enea.it/archivio/pianeta-idrogeno/the-potential-of-e-fuels-as-future-fuels.html
16 https://www.iea.org/reports/aviation
17 https://www.consilium.europa.eu/en/infographics/fit-for-55-refueleu-and-fueleu/
18 https://www.anl.gov/taps/decarbonizing-aviation
19 https://www.icao.int/environmental-protection/Pages/LTAG.aspx
20 https://www.icao.int/environmental-protection/LTAG/Documents/REPORT%20ON%20THE%20FEASIBILITY%20OF%20A%20LONG-TERM%20ASPIRATIONAL%20GOAL_en.pdf
21 https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf
22 https://doi.org/10.1016/j.rser.2021.111398

A relevant reduction of GHG emissions for HEFA can be achieved when using used cooking oil or corn oil. The Fischer-Tropsch (FT) synthesis paths in particular have very low GHG emissions when using residues from agriculture and forestry. Further, ICAO published default life cycle emissions for CORSIA eligible fuels[23].

In its working paper on the sustainability of SAF, the International Council on Clean Transportation (ICCT) assessed the well-to-wake direct and indirect GHG emissions of a number of production paths and feedstocks[24]. As for indirect emissions, induced land use change and indirect displacement emissions (indirect effect of using by-products) must be considered. Several by-products that could be used for SAF production have established markets and – if instead used for SAF - are likely to be substituted by crops or fossil fuels, causing displacement emissions. E-fuels may also cause displacement. Therefore, it is important to ensure that renewable electricity for SAF production is new and additional. The highest displacement emission risks come with oils and animal fats, followed by molasses, industrial flue gases and renewable electricity. In contrast, used cooking oil (UCO), municipal solid waste, agricultural and forestry residues have low displacement emissions risks.

The Systems Assessment Center at Argonne National Laboratory developed an interactive standalone aviation module for GREET, which is a life-cycle analysis (LCA) tool. The GREET Aviation Module[25] includes details of both biofuel feedstock and conversion. The results show significant emission reduction potential of SAF pathways, depending on pathways and feedstocks. Carbon capture can even lead to negative emissions.

However, non-CO_2 effects, such as the effect of contrails must be considered along with GHG emissions, which account for about two thirds of the climate impact of aviation[26]. Aircraft engines emit soot particles, which act as condensation nuclei for small supercooled water droplets, which immediately freeze into ice crystals and become visible as contrails in the sky. The ice crystals of the condensation trails can persist for several hours in cold and humid conditions at altitudes of about 8 to 12 kilometers and form high clouds, so-called condensation trail cirrus. These clouds can have a warming or cooling effect locally, depending on the position of the sun. Numerous research studies show that globally the warming effect predominates. Occurrence and effects of these clouds are extremely variable in time, location, height and weather conditions, so that a relatively small number of contrails is responsible for a large part of the warming or cooling effect. Further information on non-CO_2 effects is availability in e.g. Appendix S1 of the LTAG report[27] and in a study by Lee et al. (2014)[28].

Nitrogen oxide emissions from aviation lead to additional ozone and a number of other indirect effects on global warming. In addition, emissions such as water vapor, soot, aerosol and sulphate aerosol particles have a climate-relevant contribution. If all non-CO_2 effects are included, the contribution of aviation to global warming to date is calculated to be 3.5%. Research for climate-neutral aviation must take all these factors of the climate impact of flying

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

24 https://theicct.org/wp-content/uploads/2021/06/Alt-aviation-fuel-sustainability-mar2021.pdf

25 https://greet.es.anl.gov/greet_aviation

26 https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixS1.pdf

27 https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixS1.pdf

28 https://doi.org/10.1016/j.atmosenv.2020.117834

into account.[29]

Key results of the DEMO-SPK project[30] include a reduction of particle emissions in ground runs between 30% and 60% and a reduction of GHG emissions by about 35% through the use of multi-blend SAF instead of fossil Jet A-1. In practice, multi-blend of SAF cannot be avoided, but the project results show that this does not cause problems. There were no adjustments of airport infrastructure with regard to fuel storage and delivery needed. The project further shows that multi-blend SAF meet ASTM requirement if the single fuels are doing so. PtL based e-fuels can also meet these requirements. The reduction in particle emissions is expected to significantly lower the non-CO_2 effects of aviation, especially at high blending ratios.

Production costs

SAF production costs and the price gap between SAF and fossil Jet-A1 is the most critical challenge of SAF market uptake. The production costs of SAF are highly dependent on the technology pathway and the feedstock used. In any case, the production costs of SAF are higher compared to conventional fossil jet fuel (Jet A-1), which are about 0.5$/l in 2023[31]. In comparison, the price for HEFA-SPK on the spot market in May 2023 amounted to about 1.8$/l[32]. The production costs of SAF are not known for each technology, since not all technology pathways have reached commercialization. Therefore, information on production costs are based on modelling.

Several price models and scenarios have been published. The long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 by ICAO include robust price modelling[33]. According to LTAG, the minimum selling price (MSP) for SAF lies between 0.52 and about 2.5 $/liter. Lowest minimum selling price was calculated for LTAG-LCAF (Lower carbon petroleum fuels, which are still fossil fuels, but eligible for CORSIA), followed by LTAG-SAF (SAF based on solid or liquid biomass) and LTAG-SAF-waste CO_2 (SAF produced from gaseous waste CO_2). Also, the marginal abatement costs have been calculated, reflecting the amount of money required per kg reduced CO_2-emissions (see Figure 5).

[29] https://www.dlr.de/content/en/articles/dossier/electric-flight/climate-impact-air-transport.html
[30] https://www.dbfz.de/fileadmin/user_upload/Download/Extern/DEMO-SPK_Final_report.pdf
[31] https://jet-a1-fuel.com/
[32] https://www.argusmedia.com/-/media/Files/sample-reports/argus-biofuels.ashx?la=en&hash=722281F6D0DD05BC0145352940C5E57E1A6A020E
[33] https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM5.pdf

F1	MSP [$/L]	F2	Marginal Abatement Cost [$/kgCO2red]	F3	Lifecycle [gCO2e/MJ]
LTAG-LCAF	0.52	LTAG-SAF-biomass/waste	<1	LTAG-SAF-DAC	8-13
LTAG-SAF-biomass/waste	0.9-2	LTAG-LCAF	<1	LTAG-SAF-waste CO2	13-16
LTAG-SAF-waste CO2	~2.5	LTAG-SAF-waste CO2	4.3	LTAG-SAF-biomass/waste	21-24
LTAG-SAF-DAC	N/A	LTAG-SAF-DAC	N/A	LTAG-LCAF	80.1

Figure 5: ICAO LTAG - Fuel order (F) according to selection criteria

According to a study by ICCT[34], SAF are two to five times more expensive compared to conventional Jet-A1. Gasification FT has the highest potential of GHG emission reduction, but CAPEX is comparably high. Production costs are very dependent on pathway and feedstock. Main costs for HEFA and PtL production are feedstock costs, whereas main costs for Gasification FT are capital costs. Capital costs are even higher for SAF production from agricultural residues or energy crops via the ATJ pathway. The most cost-effective SAF in the near-term will be UCO-derived HEFA, since cost of conversion is relatively low and the fuel yield is high compared to technologies based on lignocellulosic feedstocks. However, the supply will be limited and with increasing demand, SAF will have to be produced from a broader range of feedstocks via various pathways.

To estimate order of magnitude of SAF capital costs, minimum selling price, CO_2 abatement costs etc., ICAO published rules of thumb on their website. These SAF "Rules of Thumb"[35] are intended to provide big picture trends for costs and processing technology/feedstock comparisons. An excerpt of the data can be viewed in Table 2, which shows total capital investment (TCI), capital costs, minimum selling price (MSP) for nth and pioneer plants.

Table 2: SAF "Rule of Thumbs" (ICAO)

Pathway	Feedstock	TCI [million $]		Capital Cost [$/l total distillate]		MSP [$/l]	
		nth	pioneer	nth	pioneer	nth	Pioneer
FT	MSW	1428	813	2.9	8.1	0.9	2.1
FT	Forest residues	1618	1088	4.0	10.9	1.7	3.3
FT	Agricultural residues	1509	1267	5.0	12.7	2.0	3.8

[34] https://theicct.org/wp-content/uploads/2021/06/Alternative_jet_fuels_cost_EU_2020_06_v3.pdf
[35] https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

ATJ	Ethanol	328	117	0.3	1.2	0.9	1.1
ATJ	Ethanol, agricultural residues	581	170	0.6	1.7	2.2	2.5
ATJ	Isobutanol-Low	332	94	0.3	0.9	1.3	1.5
ATJ	Isobutanol-High	410	110	0.4	1.1	1.7	1.9
HEFA	FOGs	448	-	0.4	-	0.8	-
HEFA	Vegetable oil	456	-	0.5	-	1.0	-
FT	DAC CO_2 H_2	3366	-	3.4	-	4.4	-
FT	Waste CO_2 H_2	3209	-	3.2	-	3.5	-

SAF Production

Current SAF production continues to lag behind demand. However, there are already many announcements and offtake agreements signed and binding legal requirements are being discussed, which indicate a sharp increase in production in the next few years.

The "Database on facilities for the production of advanced liquid and gaseous biofuels for transport" of IEA Bioenergy Task 39[36] lists more than 200 production facilities for advanced biofuels. Of these, more than 50 production facilities use technologies that could be used for the production of SAF (Hydrotreatment, Gasification/FT, E-fuels Biomass Hybrids, and Alcohol-to-Jet). The plants are located mainly in Europe and the USA. Several plants are planned or under construction, see Figure 6.

[36] https://demoplants.best-research.eu/ (last access: 4 July 2023)

Figure 6: Database on facilities for the production of advanced liquid and gaseous biofuels for transport (Screenshot[37])

Operational hydrotreatment plants are owned by BP (Spain), Eni (Italy), Neste (Netherlands, Finland and Singapore), Pertamina (Indonesia), Preem (Sweden), Repsol (Spain), Total (France) and World Energy (USA). Operational FT plants are owned by Fulcrum (USA) and Total (France). The only known operational ATJ plant is owned by Gevo (USA). There are several e-fuels plants planned and e.g. Haru Oni (e-fuels via e-methanol pathway) is already operational. Announcements include: Norsk e-fuel (kerosene from air, water and green electricity, PtL, 2023), Nordic Electrofuels (FT-liquids, 2024) and GEVO Net-zero 1 (2024).

However, not all of these plants are producing SAF or are planning to do so. One possible way to assess current and future SAF production capacities is to monitor offtake agreements between producers and consumers. These offtake agreements are one solution to support future SAF producers, while securing SAF supply.

The estimated current production of SAF in 2022 was about 0.1% of the current consumption of aviation fuels[38](about 0,27 million t in 2022)[39]. First producers of sustainable aviation fuels worldwide include World Energy in Paramount, USA, Neste in Porvoo, Finland, Gevo in Silsbee, USA, and Total in La Mede, France. The currently largest share of SAF is

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[37] https://demoplants.best-research.eu/ (last access: 4 July 2023)
[38] https://www.iata.org/en/iata-repository/pressroom/presentations/energy-transition-hemant-mistry-gmd2022/
[39] https://www.icao.int/environmental-protection/Documents/SAF/ICAO%20SAF%20short-term%20projections%20-%20methodology%20and%20results.pdf

HEFA-SPK, based on fats and oils.

97 offtake agreements, with a total quantity of about 41,800 million liters, between (some future) producers and (mainly) airlines have so far been announced[40]. The announced offtake volumes in 2022 amounted to 21.715 million liters, as can be seen in Figure 7, volumes increased sharply in the last years and growth is predicted to continue.

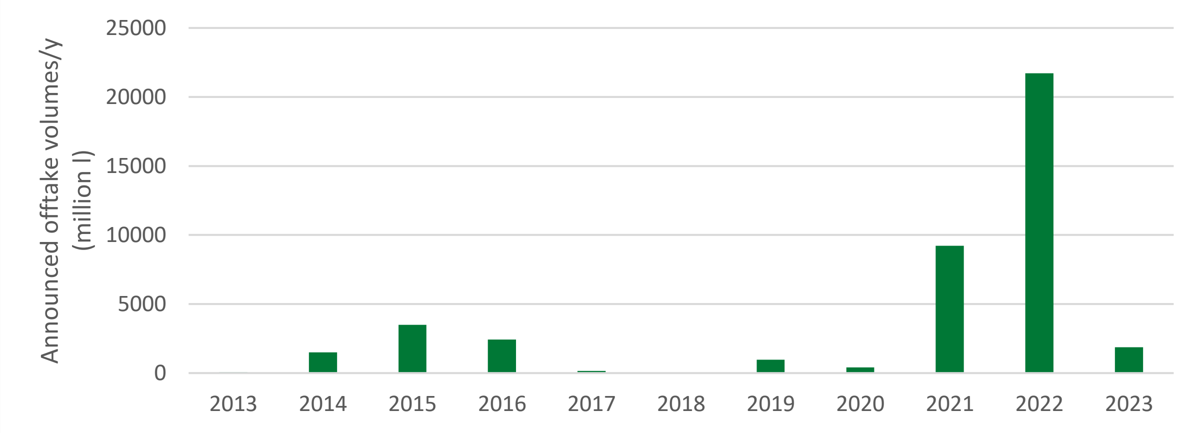

Figure 7: Announced offtake volumes per year (million liters)[41]

Table 3 shows examples of SAF production facilities according to announced offtake agreements[42]. Numbers in brackets refer to the amount of offtake agreements signed.

Table 3: SAF production facilities

Company	Location	Feedstock	Fuel	(Planned) Capacity	Offtake volume in million liters (amount)
Gevo	Luverne and Silsbee, USA	Isobutanol	ATJ-SPK	50kG/a (plan 50 MG/a in 2024, 100 MG/a in 2029)	9,360 (13)
Fulcrum Bioenergy	Sierra Nevada, USA	Landfill waste	FT-SPK, Co-processed FT	10,5 MG/a (plan 300 MG/a)	6,720 (3)
Neste	Finland (Porvoo), Netherlands (Rotterdam), Singapore	UCO	HEFA	100,000 tons/a	2,290 (13)
OMV	Austria, Schwechat	Waste oils, fats, greases	Co-processed HEFA	2,000 tons = 2.3 million liters	1,433 (5)

[40] https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx#InplviewHashef347ce3-9fcc-4b72-be6a-207e60680777=ShowInGrid%3DTrue
[41] https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx#InplviewHashef347ce3-9fcc-4b72-be6a-207e60680777=ShowInGrid%3DTrue
[42] https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx

		and vegetable oils			
Aemetis (Inc.)	California, USA	Orchard waste wood	Gasification, Syngas to hydrogen (hydroprocessing)	Plan 23 MG/a in 2023, 56 MG/a in 2024, 90 MG/a in 2025	1,270 (9)
Dimensional Energy	Tucson, USA	Carbon dioxide, hydrogen	Electrolysis, FT synthesis FT-SPK	Plan 0.1 barrel/day in 2022, 2 in 2023, 100 in 2026, 1,000+ in 2029)	1,140 (1)
Total	La Mede, France		Co-processed HEFA		1,000 (1)
SG Preston BioEnergy	Philadelphia, USA	Waste oils and greases, non-food oilseeds	HEFA	Offtake A. with JetBlue over 33 gallons/a of blended jet fuel with Jet A1 (30/70) over 10 years starting 2023	1,290 (3)
World Energy	Paramount, USA (former AltAir)	UCO, e.g.	HEFA	150 million gallons renewable fuels (diesel, gasoline, SAF)	110 (10)
Lanzajet	Chicago, Georgia	Ethanol, agricultural and industrial waste	ATJ	Technology provider	50 (2)
Air BP	Refinery in Lingen, Germany (first industrial SAF production in Germany) + Castellon (Spain) + …	UCO	Co-processed HEFA	5,000 bpd/200-250 million liters total volume of biofuels incl. SAF in three refineries, plan: triple amount by 2030	30 (1)
Philips 66	UK (Humber refinery, first refinery in UK producing SAF in commercial scale – delivery to British Airways)	Waste oils, fats, greases and vegetable oils	Co-processed HEFA	Renewable fuel (diesel and SAF) through co-processing 3,000 bpd, plan: 5,000 by 2024	10 (3)

The current status of SAF production facilities (existing and announced) can be followed on ICAO´s SAF facility map, see Figure 8.

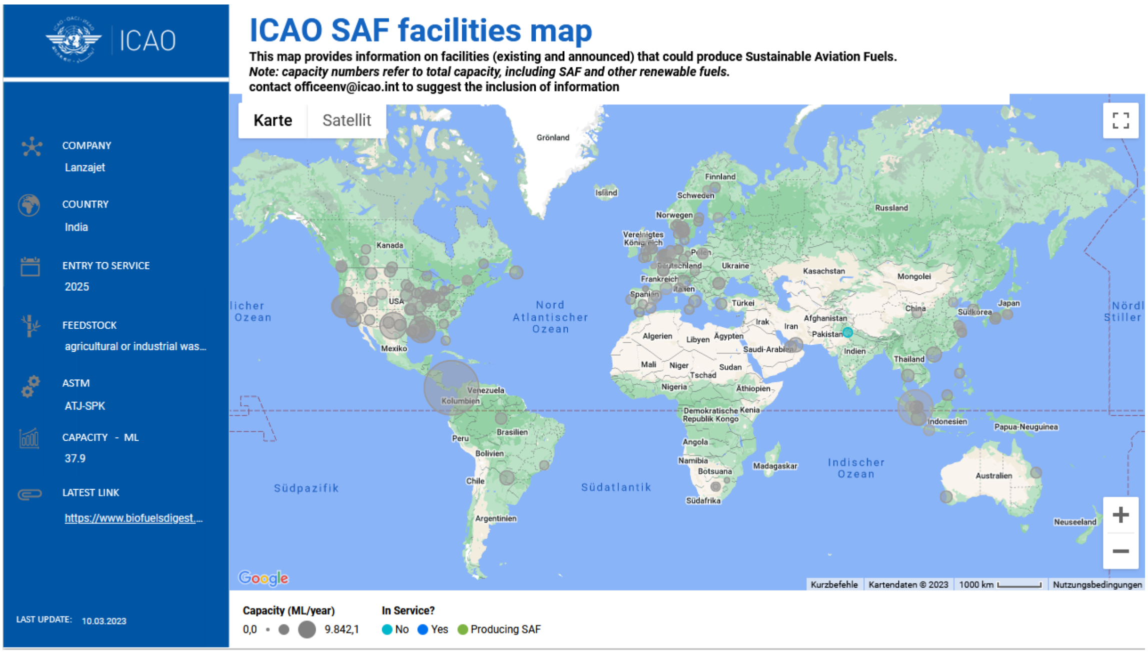

Figure 8: SAF facilities map (Screenshot[43])

SAF Consumption

As of early 2023, 37 airports worldwide offer sustainable aviation fuels on a regular basis, 15 have offered at least individual batches. Most of these airports are located in North America and Europe, as can be seen in Figure 9[44].

[43] https://lookerstudio.google.com/reporting/2532150c-ff4c-4659-9cf3-9e1ea457b8a3/page/p_2sq3qol5nc?s=mGz_sTv1l-c (last access: 4 July 2023)

[44] Airport Use of Sustainable Aviation Fuel – Google My Maps

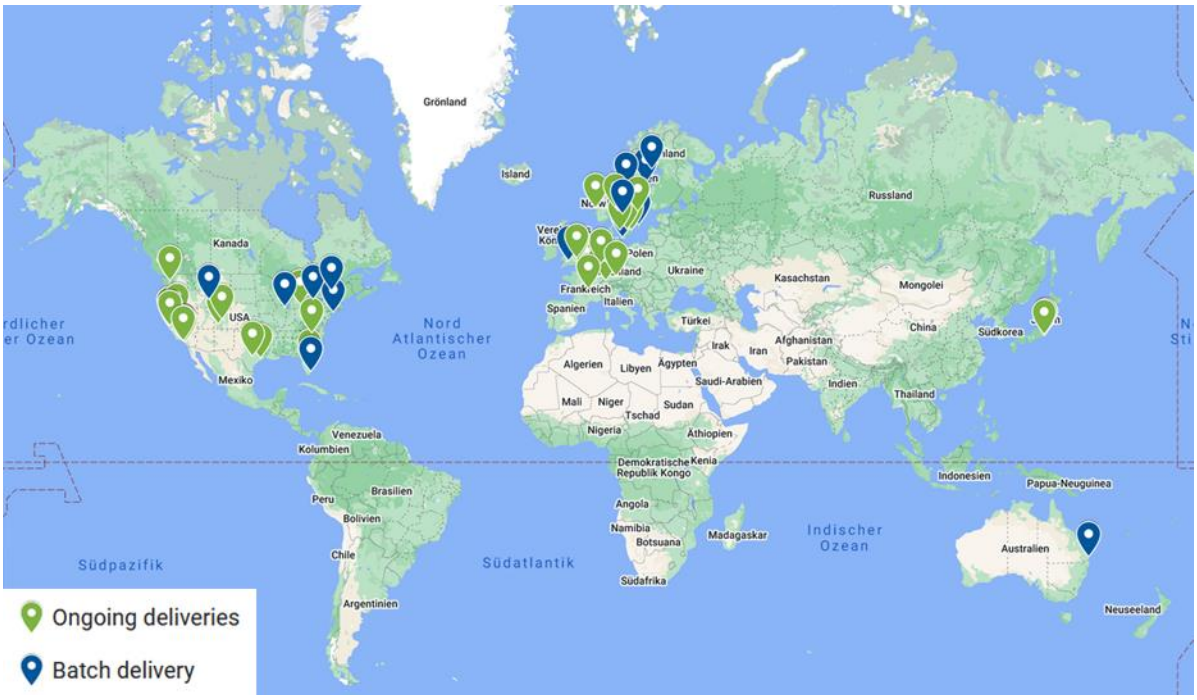

Figure 9: Airport use of SAF (Screenshot[45])

Several airlines announced ambitious decarbonization targets and SAF purchasing plans. Table 4 lists purchasers of SAF according to announced offtake agreements. Most quantities are sold by contract even before they are produced.

Table 4: SAF consumer and purchaser[46]

Company	Offtake volume (number)	Company	Offtake volume (number)
United Airlines	10,510 (6)	Quantas	230 (3)
OneWorld	3,790 (1)	JAL	100 (1)
Delta	2,370 (6)	FedEx	80 (1)
AirBP	2,190 (2)	British Airways	50 (2)
Cathay Pacific	1,420 (1)	oneworld	30 (1)
Jet Blue (2X)	1,140 (3)	Alaska Airlines	20 (2)
KLM	940 (4)	SAS	20 (2)
Southwest Airlines	910 (2)	IAG Cargo	10 (2)

[45] Airport Use of Sustainable Aviation Fuel – Google My Maps

[46] https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx#InplviewHashef347ce3-9fcc-4b72-be6a-207e60680777=ShowInGrid%3DTrue

DHL Express	800 (1)	Amazon Air	7 (1)
Shell	750 (1)	Virgin Atlantic	3 (1)
American Airlines	500 (3)	Boeing	2 (1)
Air Transat	410 (1)	Austrian Airlines	2 (1)
Netjets	380 (1)	Singapore Airlines	1 (1)
IAG	280 (1)	SAS, BRA, Kalmar Municipality	(1)
Finnair	160 (2)	Lufthansa Cargo/Kuehne + Nagel	(1)
Lufthansa	150 (1)	Airbus/Jet Blue	(1)

Legal framework

Sustainable aviation fuels are an important part of decarbonizing the aviation sector and therefore legally binding requirements and incentives are currently being developed. The development and deployment of SAF will mainly be driven by policies. Policies will be critical to bridge the price gap between SAF and fossil Jet-A1 while creating a level-playing field.

Aviation is a global business, and therefore harmonization of regulations and sustainability criteria is desirable to support a level-playing-field and to avoid shifting of flight patterns to less-regulated regions. National targets and mandates can differ, but it will be crucial to agree on sustainability criteria and how the carbon intensity of SAF is calculated. Efforts are being made to achieve alignment of international (e.g. CORSIA) and national schemes.

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA[47]) of the International Civil Aviation Organization (ICAO) is the first internationally adopted approach to calculate and credit lifecycle GHG emissions for aviation fuels. This is important since emissions from international aviation are not included in nationally determined emission reduction contributions. The aviation sector voluntarily committed itself to CO_2-neutral growth from 2020 onwards and to becoming net-zero CO_2 by 2050.

The CORSIA mechanism compares a baseline with the actual CO_2 emissions of the sector. The gap defines the CO_2 offsetting requirement. The baseline is lowered over time to e.g. 85% of CO_2 emissions in 2019 (from 2024 to 2035). This means that the offsetting requirement is increasing. CORSIA eligible Fuels - SAF or LCAF (Lower-Carbon Aviation Fuel) are considered as alternative to the offsetting requirement and are therefore decreasing the requirement for the operator. LCAF are not SAF in the context of this study, but rather fossil fuels with an optimized production process. Eligible fuels must comply with the CORSIA sustainability criteria. These currently cover GHG emissions and carbon stock, but will be expanded by further criteria in 2024. So far, 119 countries voluntarily committed to

[47] https://www.icao.int/environmental-protection/CORSIA/pages/default.aspx

CORSIA[48]. However, this approach will become mandatory for international aviation in 2027.

Major national policies include the Inflation Reduction Act[49] (USA), ReFuelEU Aviation[50] (EU) and RenovaBio[51] (Brazil), which are described in more detail in the respective national assessments. These policies each take a different approach. Whereas the Inflation Reduction Act provides tax credits for SAF producers, the ReFuelEU Aviation Initiative sets binding blending mandates, and RenovaBio introduces decarbonization certificates.

Following, some (potential) differences in national legislation:

- The Renewable Energy Directive[52] (EU) lists feedstocks eligible for advanced biofuels production, and ReFuelEU Aviation only accepts feedstock listed in Parts A and B of Annex IX of the Renewable Energy Directive, as well as synthetic aviation fuels. This list excludes feedstocks in competition with food and feed. USA and Brazil are unlikely to dismiss agricultural crop-based feedstocks for SAF production.
- The US Aviation Climate Action Plan[53] of the transportation department aims for reaching net-zero GHG emissions by 2050. The ReFuelEU Aviation aims for a gradual ramp-up of SAF while maintaining a well-functional aviation market (level playing field in the aviation sector) of 70% SAF by 2050 (under discussion).
- The US Aviation Climate Action Plan includes international as well as domestic flights for US operators. The ReFuelEU Aviation applies to all air operators flying from EU airports that exceed the lower limit on operator activity and airport size.
- In the EU, blending mandates have to be fulfilled by aircraft fuel suppliers, airlines departing from EU airports have to refuel SAF (avoidance of tankering) and EU airports have to guarantee necessary infrastructure[54]. In Brazil, fuel suppliers are the obligated party, aviation fuel suppliers have not been included in the legislation yet. In the USA the obligated party are air transport operators.
- The California Low Carbon Fuel Standard[55] (USA) and RenovaBio are GHG emission reduction schemes, favoring fuels with low carbon intensity. In comparison, the ReFuelEU Aviation introduces volumetric blending mandates, without distinction between fuels. However, minimum GHG emission reduction requirements must be met.
- US policy is focusing on financial incentives for SAF producers, while e.g. the EU sets targets for SAF producers and defines consequences in case of non-compliance.
- There are three ways for SAF delivery - segregated delivery, mass balance and book & claim. Only a physical delivery allows for reducing regional non-CO_2 effects. When there is no physical delivery possible, chain of custody becomes even more important. A SAF registry is required to enable book & claim. This could be on a

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48 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-News.aspx
49 https://www.energy.gov/lpo/inflation-reduction-act-2022
50 https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698900/EPRS_BRI(2022)698900_EN.pdf
51 https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/renovabio-1/renovabio-ingles
52 https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
53 https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf
54 https://www.consilium.europa.eu/en/infographics/fit-for-55-refueleu-and-fueleu/
55 https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

global, national or local level.

- International flights are not taxed in any country. But, in a global comparison, national air travel in the EU is taxed at a much lower rate than in the USA, Canada or large Asian countries. Kerosene is generally exempt from excise duty and in addition, airline tickets for cross-border flights are exempt from VAT[56].

Projected development of SAF in the energy system

The transport sector is responsible for 16.2% of global GHG emissions. Aviation accounts for nearly 2%[57], which is by far lower than road transport, but slightly higher compared to the shipping sector (see Figure 10). Before the COVID pandemic, the aviation sector was continuously growing. Now the sector is still recovering, but the combustion of fuel is expected to further grow in the future by about 3% annually. Main growth is expected in Asia-Pacific, the Middle East, Africa and Latin America, but also in North America and Europe a significant growth remains[58]. In addition to efficiency measures, SAF are an effective short to medium-term measure to decarbonize aviation.

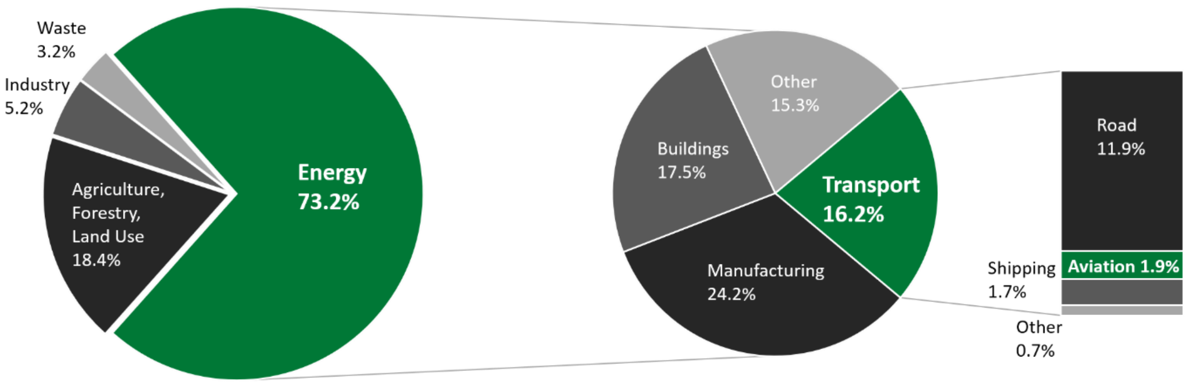

Figure 10: Global GHG emissions by sector[59]

SAF is a policy-driven market. Therefore, future development is highly dependent on decarbonization targets. However, there are different goals among countries and associations:

- The aviation sector accounts for 11% of US transportation GHG emissions. The US Aviation Climate Goal of the transportation department is reaching net-zero GHG emissions by 2050, including international as well as domestic flights for US operators. Another activity is the US Governmental SAF Grand Challenge[60] which foresees a minimum reduction of 50% in life-cycle GHG emissions, a near-term (3 billion gallons in 2030) and a long-term goal (35 billion gallons in 2050, representing

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[56] https://op.europa.eu/o/opportal-service/download-handler?identifier=0b1c6cdd-88d3-11e9-9369-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part
[57] https://www.topsoe.com/sustainable-aviation-fuel/saf-the-big-picture
[58] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jul/IRENA_Reaching_Zero_Biojet_Fuels_2021.pdf?rev=86779f68cc374259b5030f97eee9b0af
[59] https://www.topsoe.com/sustainable-aviation-fuel/saf-the-big-picture
[60] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

100% of US aviation fuels). To achieve these goals, more than 400 biorefineries will be required[61].

- The share of aviation in transport-related emissions in the EU is about 14.4%. There are five initiatives with direct effects on aviation within the Fit-for-55 package, which aims for reducing net GHG emission by at least 55% by 2030. The binding blending mandate of 2% SAF by 2025 would require about 1 million tons of SAF. A share of 20% by 2035 would require about 35 to 40 SAF production plants. And in 2035 there should be SAF at every airport in the EU. By 2050, about 105 SAF production plants will be required, corresponding to about 25.5 million t/a of SAF[62].
- The International Air Transport Association (IATA) plans net-zero aviation by 2050. The estimated volume of SAF needed to achieve this target is above 400 billion liters. This would require construction of between 5,000 and 7,000 new facilities by 2050.

In its publication Waypoint 2050, the Air Transport Action Group (ATAG), estimates the global development of the demand for aviation fuels up to the year 2050 and beyond and calculates three possible scenarios to achieve the CO_2 reduction target set for 2050. Without measures, this results in a demand of about 570 million tons of aviation fuel per year, causing about 1,800 million tons of CO_2. In Scenario 1, which pushes the development of new propulsion technologies as well as measures in infrastructure and operations, 61% of the emission savings are achieved by using 290-390 million tons of sustainable aviation fuels.

ICAO published short-term projections on SAF production until 2030 by LTAG (Long-term Aspirational Goal for international aviation) and FTG (ICAO Fuel Task Group) scenarios[63] (see Figure 11). SAF Production in 2022 amounted to 273 kt. Depending on the scenario the production of SAF could increase to between 7.6 million t and nearly 17 million t by 2030. SAF production will be mainly located in North America, Europe and South America.

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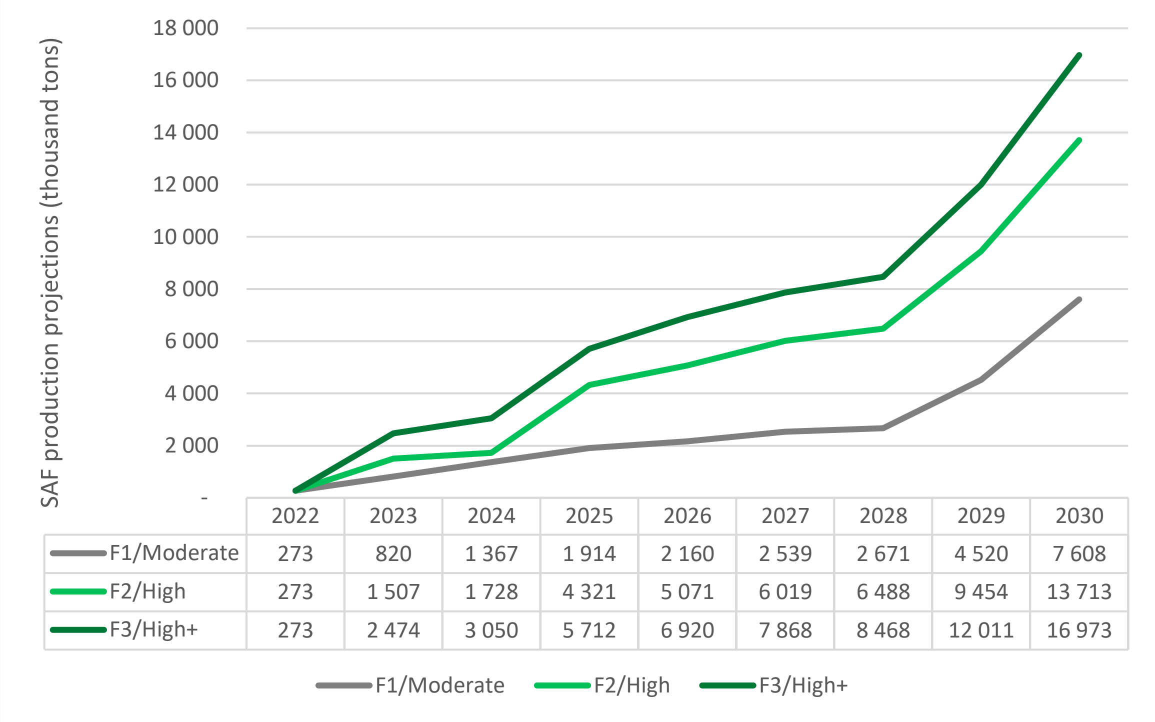
61 https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf
62 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021SC0633&from=EN
63 https://www.icao.int/environmental-protection/Documents/SAF/ICAO%20SAF%20short-term%20projections%20-%20methodology%20and%20results.pdf



	2022	2023	2024	2025	2026	2027	2028	2029	2030
F1/Moderate	273	820	1 367	1 914	2 160	2 539	2 671	4 520	7 608
F2/High	273	1 507	1 728	4 321	5 071	6 019	6 488	9 454	13 713
F3/High+	273	2 474	3 050	5 712	6 920	7 868	8 468	12 011	16 973

Figure 11: ICAO SAF production projections by LTAG and FTG scenarios in thousand tons

Based on mandates and announcements, SkyNRG calculated and published a detailed potential market outlook on SAF by 2030 for the USA and the EU27+UK[64]. Based on realistic announcements only, SkyNRG estimates global SAF supply at 7 million tons by 2030. This amount will be mainly provided by HVO/HEFA, but a significant share of ATJ is expected from 2026 onwards. The values only reflect the current announcements, the SAF supply in 2030 may be considerably higher as additional announcements are expected.

Besides the aviation sector, also other transport and energy-intensive industry sectors announced decarbonization goals. A cross-sectoral analysis is needed to avoid feedstock competition, in case of biomass, renewable electricity as well as green hydrogen.

64 https://skynrg.com/a-market-outlook-on-sustainable-aviation-fuel-may-2022/

National assessments

The respective partners in the task member countries Austria, Brazil, Denmark, Germany, Switzerland and the USA conducted a national assessment to ascertain the concrete situation regarding SAF. The assessment includes the identification of current and potential national actors along the value chain, a qualitative assessment of feedstock potential, analysis of national strengths and strategies, as well as legal framework and challenges along the value chain.

Austria

Authors: Doris Matschegg, Dina Bacovsky

Sustainable Aviation Fuels are seen as an important measure for decarbonizing the aviation sector by both industry and politics. SAF roadmaps and strategies have been developed and published and there is interest in producing and purchasing SAF among national actors. The strategy foresees advanced biofuels as well as e-fuels.

Qualitive supply chain assessment

According to Statista, domestic consumption of Jet A1 in Austria was around 1,190 million liters[65] in 2019. The domestic production volume was around 1,116 million liters[66] in 2019, which shows that most of the demanded kerosene is produced domestically. Import and export volumes were about 63 million liters[67] and 36 million liters[68], respectively, as shown in Table 5. There was no SAF production or consumption in Austria in 2019.

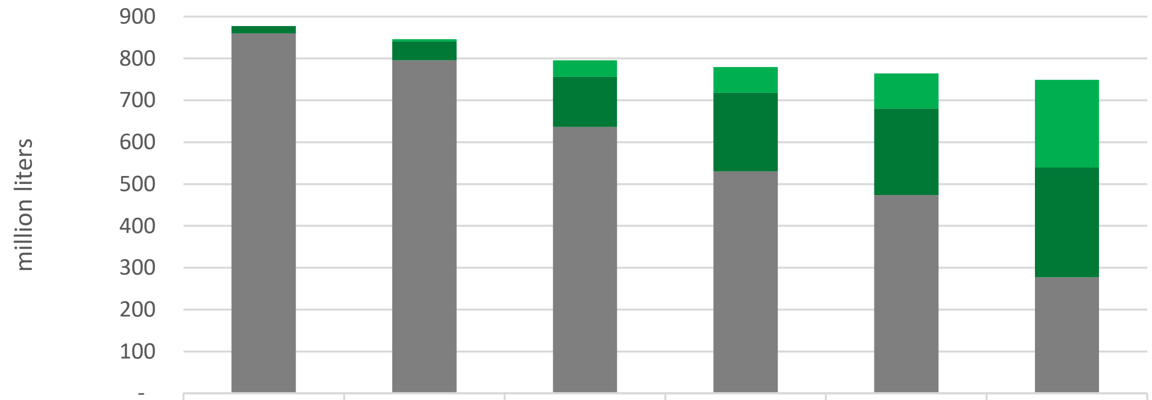
Table 5: Aviation fuel availability in Austria (2019)

Aviation Fuel	Domestic production volume [million l]	Import volume [million l]	Export volume [million l]	Carbon intensity [gCO_{2eq}/MJ]	Production costs [USD/l]
Jet A1	1,116 (893,040 t)	62.6 (50,064 t)	36.1 (28,848 t)	85 to 95 [x]	0.45 0.4 €/l [x]

Considering an increased volume of flights and efficiency developments as well as the targets of the ReFuelEU Aviation (see Table 7), Austrian SAF demand should develop as shown in Figure 12. Following considerations were taken to project Austrian SAF development in line with EU legislation/targets. The share of SAF in total aviation fuel demand has to continuously increase until reaching 63% SAF by 2050, with a sub-target of 28% of synthetic aviation fuels. Until 2050 the volume of flights will increase on average 1.2% per year (0.8% 2020-2035 and 1.6% 2036-2050 (Eurocontrol assumes a slower growth

65 https://de.statista.com/statistik/daten/studie/808627/umfrage/verbrauch-von-erdoelprodukten-in-oesterreich-nach-produkt/
66 https://de.statista.com/statistik/daten/studie/808866/umfrage/produktion-von-erdoelprodukten-in-oesterreich-nach-produkt/
67 https://de.statista.com/statistik/daten/studie/808885/umfrage/importe-von-erdoelprodukten-in-oesterreich-nach-produkt/
68 https://de.statista.com/statistik/daten/studie/809039/umfrage/export-von-erdoelprodukten-aus-oesterreich-nach-produkt/

over the next 15 years catching up from the Covid-19 outbreak, afterwards growth will accelerate because people are expected to fly in increasing numbers)[69]. According to the baseline scenario of EUROCONTROL Forecast Update 2021-2027[70], IFR movements will grow in Austria as follows: 2021 (+22%), 2022 (+70%), 2023 (+6%), 2024 (+6%), 2025 (+2%), 2026 (+2%), 2027 (+2%). Further, ICAO has set a target of 2% annual efficiency improvement by 2050 (fuels, technology, operation)[71]. These scenarios and considerations will lead to a demand of SAF of 18 million liters until 2025 and 51 million liters until 2030, including 6 million liters of synthetic aviation fuels.



	2025	2030	2035	2040	2045	2050
SAF synthetic	0	6	40	62	84	210
SAF biogenic	18	45	119	187	206	262
Jet A1	860	796	637	530	474	277

Jet A1 ■ SAF biogenic ■ SAF synthetic

Figure 12: Projected SAF development in line with EU legislation/targets (in million liters)

According to a study by the Austrian Energy Agency[72] the final energy consumption of the aviation sector will be 9,325 GWh by 2040, divided in 1,025 GWh biogenic SAF and 8,300 GWh e-fuels. This study assumes a share of e-fuels in the aviation sector of 89% by 2040. For the production of 8,300 GWh e-fuels (equal to 750,000 t/a or 940 million l), a demand for green hydrogen of about 12,000 GWh (equal to 360,000 t or 4,000,000 million l) was calculated.

Biogenic SAF

For the evaluation of the theoretical biomass potential for SAF production by 2050, the status quo of relevant feedstock fractions was assessed. In 2019 the biomass potential amounted to about 6 million tons absolute dry. This amount was almost fully utilized. The potential can be theoretically increased to 13 million tons absolute dry[73]. The potential by feedstock is listen in Table 6.

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[69] https://www.eurocontrol.int/publication/eurocontrol-aviation-outlook-2050
[70] https://www.eurocontrol.int/publication/eurocontrol-forecast-update-2021-2027
[71] https://www.icao.int/environmental-protection/pages/climate-change.aspx
[72] https://www.bmk.gv.at/themen/energie/publikationen/erneuerbares-gas-2040.html
[73] https://best-research.eu/files/publications/pdf/Machbarkeitsuntersuchung_Methan%20aus%20Biomasse_V03.docx%20-%20BioEnergy2020.pdf

Table 6: Theoretical biomass potential (in tons absolute dry)

Feedstock	Status 2019	Potential 2050	Useable Share (High Scenario)	Potential 2050 for SAF
Unused wood increment	2,836,371	4,123,039	10%	412,304
Waste wood	641,242	1,289,893	1%	12,899
Sawmill residues	2,378,758	4,394,265	1%	43,943
Short rotation coppice	26,631	1,339,173	40%	535,669
Miscanthus	16,000	1,338,750	25%	334,688
Sewage sludge	238,000	261,800	50%	130,900
Used cooking oil	2,376[74]	4,400	100%	4,400
Greases and fats	133,965[75]	107,172	33%	35,367
Sum	**6,273,343**	**12,858,492**		**1,510,169**

The real biomass potential is dependent on political, economic, technical and ecological developments. Several assumptions were taken in order to calculate the feedstock potential for SAF by 2050. It was assumed that the sawmill industry in Austria continuous to grow, wood construction is expanded, small forest owners are mobilized, fallow land is re-cultivated, soil sealing is reduced, population is growing and meat consumption is decreasing.

The useable share of these biomass fractions for SAF production represent a high scenario, aiming for achieving the EU blending mandates for SAF by 2050. It must be stated that this scenario puts SAF production in direct competition with renewable gas production.

Considering the technology pathways HEFA, FT and ATJ, about 260 million liters of SAF can be produced with this amount of biomass, 26 million liters of which via HEFA. This is highlighting the fact that a high share of SAF will be produced via FT and ATJ.

Synthetic SAF

Austrian total electricity consumption accounted to 70.3 TWh in 2020. Electricity is mainly produced via hydropower (45.4 TWh) and thermal power plants (18.3 TWh). Additionally, 8.9 TWh were produced with renewables, such as wind power, photovoltaics and geothermal power. Electricity imports are slightly higher compared to electricity exports[76]. By 2030, Austria wants to generate 100% of its electricity demand and 100% of its energy demand for transport domestically and from renewable sources. The production of e-fuels for aviation is excluded

74 https://www.ifeu.de/fileadmin/uploads/UCO_ifeu-Studie_final_28-10-20.pdf

75 https://www.statistik.at/fileadmin/publications/Versorgungsbilanzen_fuer_tierische_Produkte_2020.pdf

76 https://www.e-control.at/documents/1785851/1811582/E-Control-Statbro-2021.pdf/83442b63-df8c-a732-7152-8df34986c2c3?t=1636364279845

from this target.

In Austria there is an electrolysis capacity of 1 GW, equal to 5 TWh or 125,000 t/a hydrogen (assuming 5.000 hours of annual operation), planned by 2030[77]. This amount would cover the current demand of hydrogen in Austria. By 2040 the projected demand for hydrogen for Austrian´s industry corresponds to 16 – 25 TWh. So, the planned capacity of hydrogen by 2030 (5TWh) is far below the projected demand for industry by 2040, even when considering the low demand scenario and dedicated hydrogen use only (16TWh)[78].

In order to produce 210 Million liters of synthetic SAF by 2050, about 75.000 t of green hydrogen and 530.000 t of CO_2 would be needed (stoichiometric).

The blending mandates could be achieved with domestic production. However, there is competition for the use of biomass and green hydrogen. SAF production must either be prioritized or import of feedstock and SAF will be necessary. Due to the competition for certain feedstocks technology openness is crucial and a combination of biogenic and synthetic SAF is needed to achieve European and national targets.

Legal framework and strategies

There are five initiatives with direct effects on aviation within the Fit-for-55 package, namely ReFuelEU Aviation Initiative, Renewable Energy Directive (RED), EU Emission Trading System, Energy Taxation Directive and Alternative Fuel Infrastructure Regulation. The ReFuelEU Aviation Initiative[79] aims for a gradual ramp-up of SAF while maintaining a well-functional aviation market (level playing field in the aviation sector). SAF have to be made available for airlines at competitive prices. The aim is a gradual increase of the SAF share, with a sub-target on synthetic fuels, see Table 7. Eligible SAF are biofuels produced from waste oils and fats, advanced biofuels from waste and residues (listed in Annex IX of the Renewable Energy Directive, and synthetic fuels (PtL). An enlargement of base is discussed to recycled-carbon fuels, nuclear-based e-fuels and renewable hydrogen. The targets have to be achieved by fuel suppliers and the operators have to buy the SAF provided. The regulation applies to all air operators flying from EU airports. Supporting measures include intensifying European efforts at ICAO, creation of the Renewable and Low-Carbon Fuels Value Chain Industrial Alliance and regulatory support towards SAF update (CORSIA, EU-ETS, etc.).

Table 7: SAF blending mandates according to the draft of the ReFuelEU Aviation (under discussion)

Year	Blending mandate SAF	Sub-target synthetic SAF
2025	2%	0%
2030	6%	0.7%
2035	20%	5%
2040	32%	8%

[77] https://www.bmk.gv.at/themen/energie/publikationen/wasserstoffstrategie.html
[78] https://www.bmk.gv.at/themen/energie/publikationen/wasserstoffstrategie.html
[79] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0561

2045	38%	11%
2050	63%	28%

The Renewable Energy Directive (RED-II[80]), which is currently being amended, lists feedstocks eligible for advanced biofuels production (Annex IX, Part A and B) and sets targets for their use as a share of final energy consumption in transport. The share of fuels supplied in the aviation sector shall be considered to be 1.2 times their energy content, with the exception of fuels produced from food and feed crops. The European Strategy for Low-Emission Mobility[81] highlights the particular importance in the medium term, of advanced biofuels and renewable liquid and gaseous fuels of non-biological origin for aviation.

Austria as Member State of the EU is transposing these Directives into national law. The Austrian Government set even more ambitious targets. By 2030, net 100% of national electricity consumption is to be covered from renewable sources. The total energy consumption for the transport sector (except for aviation) is to be covered from renewable energy from Austria. Additionally, Austria wants to become climate neutral by 2040.

In Austria, the BMK (Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology)[82] as the supreme civil aviation authority and the Safety Investigation Office (SUB) subordinate to it, Austro Control GmbH, the Austrian Aeroclub, the provincial governors and the district administration deal with aviation matters. Aviation policy is shaped by the government (ministries) and the federal states in coordination with the stakeholders.

Several strategies and reports with relevance for SAF have been published in the last years:

- Aviation Strategy 2040+ (2022) - Luftfahrstrategie 2040+
    - This Aviation Strategy, published by BMK, is focusing on four thematic areas, namely: environmental protection and introduction of SAF, integration into the overall transport system, development of a level-playing field and innovation and technological change.
    - FTI Strategie für Luftfahrt 2040+ (2022) is part of the Aviation Strategy and puts the Federal Government's Research, Technology and Innovation Strategy 2030 into concrete terms for aviation-related topics.
- Hydrogen Strategy for Austria (2022) - Wasserstoffstrategie für Österreich
    - Hydrogen will be one solution for decarbonizing the industry, but only if produced with renewable energy. Austria´s plan foresees 1 GW electrolysis capacity by 2030 and the development of a supportive framework to integrate hydrogen in the energy system. The focus of using hydrogen will be on industries which are hard to decarbonize, e.g. chemical industry, steel industry, maritime and aviation. Gas infrastructure will be transformed to hydrogen infrastructure and incentives, such as investments in research and networking (e.g. Hydrogen platform H2Austria), will be created.

80 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018L2001-20220607
81 https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52016DC0501
82 https://www.bmk.gv.at/themen/verkehr/luftfahrt/behoerden/ozb/l2.html

- Renewable Gas in Austria 2040 (2021) - Erneuerbares Gas in Österreich 2040
    - The assessed gas demand for 2040, in line with the 100% renewable electricity target, is between 89 TWh and 138 TWh, depending on the scenario (25 TWh or 16 TWh respectively can only be covered by hydrogen). The demand for green gas clearly exceeds the potential supply of biogas, which is about 20 TWh. Only those sectors are to be supplied with green gas that have no substitution options. These are primarily industries. The building sector and the mobility sector have substitution possibilities.
- Climate neutrality of Austria by 2040 (2021) - Klimaneutralität Österreichs bis 2040
    - The Austrian target is a complete decarbonization of the energy system and the economy by 2040. Austria´s industry consume about 110 TWh/a of energy, this equals about 27% of gross domestic consumption. Annual GHG emissions account for 27.1 Mt CO2-eq, mainly from the production of steel, cement, paper and chemical products. There are four strategies to achieve this target: electrification, utilization of green gases, carbon capture and circular economy. The transport sector, including aviation, is not mentioned in the document since the focus is on industries.
- Mobility Master Plan 2030 for Austria (2021) - Mobilitätsmasterplan 2030 für Österreich
    - The Austrian mobility master plan foresees a promotion of e-fuels as well as innovative propulsion systems based on hydrogen and battery, an introduction of blending mandates, compliance with international approval criteria, the participation in CORSIA, climate neutral transport by 2040 and a transport sector covered by 100% renewable energy from Austria (except for aviation). Biofuels which are now used exclusively in road transport should, up to a certain extent, also be used for aviation, if there is no other more efficient application
- Integrated nation energy and climate plan for Austria NEKP (2019)
    - CORSIA should be integrated in EU-ETS and certificates should not be given away for free anymore. Blending mandates for SAF should be introduced and long-term research in e-fuels for hard to decarbonize sectors, such as aviation, should be intensified. Unavoidable flights should be compensated. Investments in alternative infrastructure and cost truth for flight tickets should lead to decreased flight movements. Fuel should be saved through free route airspace and optimized descent profile (ODP). The Single European Sky should be finalized and tax exemptions for green gas and green hydrogen should be established. Research in CO_2-free fuels for aviation should be fostered.
- Roadmap Aviation 2020 (2011) - Roadmap Luftfahrt 2020
    - SAF or aviation fuel is not mentioned ones
- Further, a SAF Roadmap is under development by the Federal Environmental Agency.
- Additionally, ZOVI (Zukunftsoffensive Verkehr & Infrastruktur) a non-partisan alliance of leading Austrian infrastructure providers, presented an action plan for the introduction of SAF in Austria.

National strengths and potentials

Table 8: SWOT analysis for Austria

Strengths	Weaknesses
• Know-how, there are several related research institutes and technology providers • Agreement of policy and industry on the importance of SAF • Joint position on SAF of the leading companies from mobility, energy and digitalization • Sustainable forest management and biomass utilization is traditional	• Electricity production is comparably expensive • Currently no domestic green hydrogen production
Opportunities	**Threats**
• Political incentives such as funding and risk-sharing could lead to investments • National actors are interested in producing and purchasing SAF	• Uncertain legal framework • Feedstock availability limited by the small size of the country

Challenges for market uptake

The following bullet points are a collection of challenges for a market uptake of SAF by Austrian stakeholders during a discussion at an AMF-SAF national networking workshop in September 2022[83].

Feedstock & Conversion

- Feedstock availability
  - Competitive market for feedstock suitable for SAF, which influences availability, reliability of supply and quality.
  - Necessity of imports in case of biomass, green hydrogen and electricity
- Technology openness
  - Curse and blessing – diversification, but money is spread across many technologies
- Research
  - Collaboration with researchers needed - Data is often not available for them
  - Global collaborations needed

[83] https://www.iea-amf.org/content/events/web_seminars/workshop_task63

    - Best technology pathways should be evaluated and optimized
    - Diversification of technologies and feedstocks (parallel research on multiple technologies and feedstocks)
    - Upscaling of biogenic SAF pilot plants to large scale and demonstrate synthetic SAF
- Energy demand
    - Expansion of renewable energy sources necessary
    - Energy distribution (grids)
    - No energy self-sufficiency

Supply & Operations

- Infrastructure
    - Necessity for new infrastructure
- Availability of SAF for research
    - It needs enough test quantities of SAF for research trials
- Sustainability
    - Assess sustainability at operation only or over life cycle
    - Appropriate definition of system limits

Markets & Policy

- Costs
    - Future relation between costs for fossil jet fuel and SAF. Do SAF remain that expensive or will there be a shift?
    - Willingness of consumers to bear additional costs (increased ticket price)
    - The production costs for synthetic SAF are highly dependent on the electricity price
    - Production in larger plants could reduce costs, but then the necessary raw material quantities are more difficult to obtain (transport distance).
- Regulatory framework
    - Lack of clear framework is decreasing planning certainty and is hindering investments (RED-III and ReFuelEU Aviation still under discussion)
    - How to avoid carbon leakage? Are international regulations possible?
    - ReFuelEU Aviation foresees that 90% of SAF must be purchased at the physical place of consumption
    - Inhomogeneous regulations should be harmonized
- Planning certainty
    - Investments are calculated for a long lifetime (aircraft development takes about 30 years)
- Financing/Earmarking

- Which option is the most promising: Flighty levy, EU-ETS, Kerosene tax
- Funding and start-up financing for demonstration plants needed

- Political will

The following support requirements from public authorities were identified:

- Funding should be seen as an investment or risk coverage (Innovation Fund)
- Start-up financing for demonstration plants needed
- Support for research (tenders, etc.)

National actors along the value chain

Austria has six relevant airports, with Vienna International Airport (VIE) being the most important one, followed by airports in Graz, Innsbruck, Salzburg, Linz and Klagenfurt.

The company OMV is running the only fossil refinery in Austria, which is located close to Vienna (Schwechat). The OMV Schwechat refinery can process annually up to 9.6 million tons of crude oil. Since September 2022, OMV is producing HEFA via co-processing of mainly used cooking oil and is supplying Austrian Airlines with SAF[84]. OMV and Lufthansa signed a memorandum of understanding to supply more than 800.000 tons of SAF for the years 2023 to 2030, with cooperation to include new sites and new SAF production technologies[85]. Another memorandum of understanding for the delivery of around 160.000 tons of SAF was signed by OMV and Ryanair. This is to be supplied in Austria, Germany and Romania[86].

The OMV refinery is located close to Vienna International Airport (VIE) and SAF can be transported via existing pipelines. Fuel tanking is handled by FSH (Flughafen Wien Schwechat-Hydranten-Gesellschaft GmbH & Co OG), which is a subsidiary company of OMV and VIE.

Table 9: National actors Austria

National Actor	Type of company/association	Description (including potential role regarding SAF)
Feedstock supply (H_2, CO_2, MeOH)		
Verbund	Energy provider	Planned production of 40,000 t/a green hydrogen by 2025 together with Burgenland Energie.
Energie Steiermark	Energy provider	Planned production of 300 t/a green hydrogen by 2022.

[84] https://www.omv.com/en/news/220412-omv-supplies-austrian-airlines-with-sustainable-aviation-fuel-under-the-partnership-agreement
[85] https://www.roadmap2050.at/omv-und-lufthansa-group-bauen-partnerschaft-zu-nachhaltigen-flugkraftstoffen-aus/
[86] https://aviation.direct/wien-ryanair-bestellt-saf-bei-omv

Wien Energie	Energy provider	Potential feedstock supply
Fuel production		
OMV	Fossil refinery	OMV is the only fossil refinery in Austria, processing mainly crude oil. Since 2022 OMV is producing SAF from HEFA. Currently, production is around 2,000 tons. By 2030, production is expected to increase to more than 700,000 tons per year. OMV is also interested in producing green hydrogen.
Agrana	Biorefinery	Potential producer of SAF
Fuel consumption		
Austrian Airlines	Airline	Offtake agreement with OMV
Avcon Jet	Private Airline	Charter flights and management of business aircraft
DHL Air Austria	Airline (Cargo)	Announced ambitious decarbonization plans
Aviation OEMs		
Combustion Bay One	Technology provider	Mechanical engineering office specialized in combustion technology
Austro Engine	Technology provider	Aircraft engine manufacturer
Zoerkler Gears GmbH & Co KG	Technology provider	Development of propulsion systems for international aviation
Diamond Aircraft Industries	Technology provider	Aircraft manufacturer
Bosch General Aviation Technology GmbH	Aviation engineer	Certified aviation supplier
Brimatech Services GmbH	Markets and technology	Technology transfer, market studies, business development
FACC AG	Technology provider	Aviation supplier
TEST-FUCHS GmbH	Aerospace company	Components and assemblies for aircraft and the aerospace industry
SAF technology providers		

AVL List	Technology provider	High temperature electrolysis (SOEC)
Caphenia	Technology provider	Renewable fuels from CO2
Research institutes/projects		
BEST – Bioenergy and Sustainable Technologies GmbH	Research institute, K1 Competence Center	Current status of SAF, fostering networking between SAF stakeholders and SAF market uptake
H2Future (Voestalpine, VERBUND, Siemens, Austrian Power Grid, K1-MET, TNO)	Horizon project	6 MW PEM electrolysis system for green hydrogen production at the steel plant of Voestalpine Linz
AIT (LKR)	Research institute	Light metals technologies
Joanneum Research	Research institute/University	Aviation master program
TU Graz	University	Thermal turbo machines
TU Wien	University	Automotive engineering, aviation transmissions
HyCenthA	Research institute, K1 Competence Center	Hydrogen research and projects
Other stakeholders (e.g. interest groups, networking)		
AviationIndustry Austria	Interest group	Umbrella organization for aviation (Austrian Aeronautics Industries Group and the Austrian Aviation Association)
VIE	Airport	International Airport of Vienna
ZOVI	Interest group	Cooperation of leading energy, mobilization and digitalization companies
A3PS	Interest group	Austrian Association for Advanced Propulsion Systems
Federal Energy Agency	Governmental organization	Non-profit scientific association
Federal	Governmental	Transformation of the economy and society

Environment Agency	organization	to ensure sustainable living conditions

References

Austria´s 2030 Mobility Master Plan. The new climate action framework for the transport sector: sustainable – resilient – digital , Vienna 2021, URL: https://www.bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html

Erneuerbares Gas in Österreich 2040. Quantitative Abschätzung von Nachfrage und Angebot, Vienna, 2021, URL: https://www.bmk.gv.at/dam/jcr:2486be49-85cd-41d6-b2af-a6538757e5cd/Erneuerbares-Gas-2040.pdf

FTI-Strategie für Luftfahrt. Klimafreundliche Luftfahrtinnovationen. Die Strategie für Forschung, Technologie und Innovation für die österreichische Luftfahrt 2040+, Vienna 2022, URL: https://www.bmk.gv.at/themen/innovation/aktivitaeten/luftfahrttechnologie/FTI-Strategien-Luftfahrt.html

Klimaneutralität Österreichs bis 2040. Beitrag der österreichischen Industrie, Vienna, 2021, URL: https://www.bmk.gv.at/dam/jcr:0ac604d1-7928-492f-991a-4845dce78c27/Begleitstudie_Endbericht.pdf

Luftfahrtstrategie 2040+. Klimafreundliche und zukunftsorientierte Luftfahrt – Eine Umsetzungsstrategie im Rahmen des Mobilitätsplans, Vienna 2022, URL: Luftfahrtstrategie 2040+ (bmk.gv.at)

Machbarkeitsuntersuchung Methan aus Biomasse. Dißauer C., Rehling B., Strasser C., März 2019, URL: https://www.gruenes-gas.at/assets/Uploads/BioEenergy2020+_Machbarkeitsuntersuchung_Methan_aus_Biomasse.pdf

Mission 2030. Die Österreichische Klima- und Energiestrategie, Vienna, 2018, URL: https://www.bundeskanzleramt.gv.at/dam/jcr:903d5cf5-c3ac-47b6-871c-c83eae34b273/20_18_beilagen_nb.pdf

Integrated National Energy and Climate Plan for Austria (NECP), Vienna, 2019, URL: https://energy.ec.europa.eu/system/files/2020-03/at_final_necp_main_en_0.pdf

Wasserstoffstrategie für Österreich, Vienna, 2022, URL: https://www.bmk.gv.at/themen/energie/publikationen/wasserstoffstrategie.html

Brazil

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Brazil has a long history with renewable energy sources and holds today a position that many countries aspire to have in the near future concerning the renewable participation in the energy matrix. Brazil's current actions in the global effort against climate change represent one of the largest undertakings by any single country to date, having reduced its emissions by 43,9% (GWP-100) (IPCC SAR) in 2015 in relation to 2005 levels (MCTIC, 2017). One of the main important routes to reach this target is the use of renewable sources, including biofuels in the transport sector. The country is an important biofuels producer, being the second world sugarcane ethanol producer, with 29.9 billion liters sugarcane and corn ethanol produced in 2021 and a relevant biodiesel producer, with 6.8 billion liters of biodiesel produced last year. It is estimated that BioQAV will enter the Brazilian energy matrix from the year 2027, reaching about 100 thousand m^3 in 2031, according to Ten Years Energy Plan (PDE 2031) from EPE (2022), which corresponds to a market share of approximately 1% of the total demand for aviation fuel, with specific airlines taking routes certified technologies, following CORSIA (EPE, 2022).

Qualitive supply chain assessment

Currently, the country does not have an operational supply chain for SAF. However, to attend CORSIA targets, Brazil must be using SAF from 2027 and beyond, which can be done by domestic production, considering its potential already mentioned above, or acquisition from external market. Therefore, qualitative supply chain assessment is limited, though possible to identify the key players, separated in the three categories: regulator, producers, distributers, consumers.

In Brazil, as far as raw materials are concerned, the production of biofuels can be carried out from different sources: agricultural production, waste agricultural and forestry, cooking oil, municipal waste and, especially sugarcane, soybean, palm, sunflower and tallow in the production of ethanol and biodiesel (CORTEZ *et al.,* 2014). One of the most recent studies was released by RBS (GRASSI *et al.,* 2021) states that the country has the potential to produce 9 billion liters of biokerosene from sugarcane waste, forest and agricultural residues, among other waste sources. Potential conditioned to the consolidation of its production chain and creation of a favorable environment the installation of biorefineries (ProBioQAV, 2022).

The Brazilian experience with biofuels dates back to 1931. More recently, it has achieved a strong development after 2003, with the introduction of flex-fuel cars, which use both ethanol and petrol. Considering the growing of fossil fuel cost, environmental issues and its impact in greenhouse gas (GHG) emissions, biofuels have become more competitive and increasingly demanded by the aviation industry (CORTEZ *et al.,* 2014).

However, biofuels still have challenges to be overcome compared to conventional fuels. For the development of a successful market in this area, biofuels should ensure a high energy density, as well as achieve restricted quality standards, with economic competitiveness and reducing GHG (CORTEZ *et al.,* 2014). In view of the continued rise of the aviation industry and its growing role in GHG emission (idem), technological innovations present solutions for mitigating environmental impacts in relation to such an industry. These various technological trajectories have been developed as solutions to the problems (TELLO-GAMARA *et al.*, 2015b).

Biofuels are produced from renewable raw materials, such as sugarcane and starches, oilseeds and urban and industrial waste, being the most promising in view of the Brazilian reality (TELLO-GAMARA *et al.,* 2015b). In any case, regardless of their origin, in general, biofuels must submit:

> *[...] high energy density, good atomization, rapid evaporation, viscosity suitable, low freezing point, good chemical stability, be non-toxic, in addition to being widely available and able to compete with current fuels in terms of costs and availability (TELLO-GAMARA et al., 2015b, p. 5).*

In addition, the production of aviation biofuels should consider the technological challenges, in order to achieve a product that is economically sustainable and viable, as well as consider the limitations of agricultural production (CORTEZ *et al.,* 2014).

Furthermore, another requirement of industry and economic viability refers to biofuels drop-in. Recognized for their ability to be exchanged with conventional fuels, drop-ins can be aggregated at high proportions (ProBioQAV, 2022).

Comparison of production potential with demand and the possibility to increase production potential

Considering the Brazilian demand for aviation fuels, it can be observed that national production (fossil QAV) is not enough to supply it until the end of 2031, according to the estimates from EPE's Ten Years Energy Plan (PDE 2031) (EPE, 2022). However, analyzing the Brazilian potential, regarding natural resources available, besides the common inputs for biofuels plants, shall be considered the potential of Fischer Tropsch – SAF production using CO_2 from many industrial wastes, including the pulp and paper, cement and iron and steel industries, plus all the agro-industrial wastes[87].

Current application/use and competing markets

A recent development occurred in July 2022, when Embraer[88] (Brazilian largest aircraft manufacturer) and a global reference in bioenergy company[89], signed a letter of intent with the companies' commitment to stimulate the development of the sustainable aviation fuel (SAF) production ecosystem in Brazil. Embraer is committed to develop products, services and technologies for Net-zero carbon emissions by 2050 and is currently producing airplanes compatible to the use of 100% SAF. Furthermore, Embraer is using SAF since 2021 in its airplanes, aligned with its strategy to neutralize the carbon footprint of its operations by 2040, what also consider that SAF uses will achieve up to 25% of its global consumption of jet fuel by the same horizon. Nowadays more than 60% of emissions in the company's operations derive from the use of jet fuel in tests and production flights.

Recently, in July 2022, Embraer has performed a flight test using 100% SAF produced with animal manure. Important to underpin that Brazil has the largest cattle ranch in the world, which produce tons of feedstock for SAF and biogas (EMBRAER, 2022).

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[87] More information about it, can be read in: https://ptx-hub.org/wp-content/uploads/2021/09/Potential-Syngas-Production-Brazilian-Industry-ENG.pdf

[88] Embraer is Brazilian aircraft manufacturer, whose activities began in 1969. Nowadays, it is considered the 3rd largest manufacturer of commercial aircraft in the world, with 18.000 employees and more than 8.000 airplanes delivered. It has established factories, offices, and centers of distribution for parts and services in the Americas, Africa, Asia, and Europe.

[89] Raízen is a biofuels producer and distributer.

In February 2022, the National Industrial Learning Service (SENAI[90]) and the German Technical Cooperation for Sustainable Development (GERMAN GIZ – *Deutsche Gesellschaft für Internationale Zusammenarbeit*) have just closed a partnership to produce SAF at the SENAI Renewable Energy Innovation Institute (ISI-ER) located in Natal, in the Rio Grande do Norte state, in the northeast region of Brazil. In total, more than R$ 4.5 million will be invested by 2023 for adaptation works for existing reactors and equipment to produce the fuel, aiming at reducing GHG in aviation (SENAI, 2022).

Legal framework and strategies

Brazil has historically implemented public policies such as Proálcool (1975) (EPE,2015), the National Program for the Production and Use of Biodiesel - PNPB (2005) (MME, 2016), the National Biofuels Policy (RenovaBio) in 2017 (ANP,2017) and the recent Future Fuels Policy (MME, 2021). These initiatives evidence the country's ability to produce results in the field of biofuels and this same motivation is related to the challenges brought by the so-called energy transition.

Although Brazil still doesn't have a consolidated public policy specifically designed for SAF, it is building the legal framework and also the regulations that will allow the renewable fuel meeting quality and specification standards, to be used in airplanes. It can be considered the first step to the creation of a market for SAF.

RenovaBio is the National Biofuels Policy, implemented through Law No. 13,576/2017. Its key objective is to promote the expansion of production and use of biofuels in Brazil's transport matrix. Its main instruments consist of decarbonization targets, certification of biofuels production and decarbonization certificates, also named as CBIO. Currently, the only certified routes are for road transport sector.

National Petroleum, Natural Gas and Biofuels Agency (ANP) is the national fuels regulator, and its scope includes SAF quality standards and regulation framework. Figure 1 describes the timeline for ANP resolutions (RANP), directive and standards for aviation kerosene (QAV). In Brazil, the developments of directives and standards has followed very closely the international timeline directive development, as per Annex 1.

[90] Created in 1942 at the initiative of entrepreneurs in the industrial sector, SENAI is the largest professional and technological education institution in Latin America. It represents a network of professional non-profit secondary schools, established and maintained by the Brazilian Confederation of Industry.

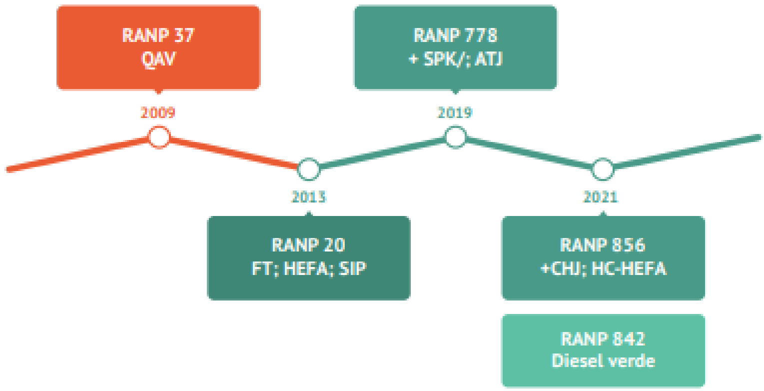

Figure 13: Timeline of ANP Resolutions for Aviation Kerosene (ProQR, 2022)

In terms of directives and standards, ANP has issued the following Resolutions (PROBIOQAV, 2022):

- RANP 37/2009 QAV - The ANP Resolution No. 37/2009 dealt with the specification of kerosene from aviation, intended exclusively for consumption in aircraft turbines, marketed by producers, importers, distributors and resellers throughout the national territory. (ANP, 2009)
- RANP 20/2013 FT; HEFA; SIP – It established the specifications of Alternative Aviation Kerosenes, and their mixtures with Aviation Kerosene (QAV-1), contained in ANP Technical Regulation No. 01/2013, as well as the obligations regarding quality control to be served by the various economic agents that sell these products throughout the national territory. It also set alternative aviation kerosene may be added to aviation kerosene (QAV-1) up to the maximum limit of 50% (fifty percent) by volume for consumption in aircraft turbines. (ANP, 2013)
- RANP 778/2019 – It incorporated the routes of paraffinic kerosene synthesized with aromatics (SPK/A) and paraffinic kerosene synthesized by alcohol (SPK-ATJ) that had been approved by ASTM in 2015 and 2016 respectively. The standard provided that aviation kerosene C (QAV-C) was the mixture of QAV (QAV-1) with the alternative kerosene, obeying mixing percentages of 50% for the SPK-FT, SPK-HEFA, SPK/A and SPK-ATJ routes and 10% for SIP (ANP, 2019)
- RANP 856/2021 - Establishes the specifications of JET A and JET A-1 aviation kerosene, alternative aviation kerosene and aviation kerosene C (JET C), as well as the obligations regarding quality control to be met by economic agents that sell these products on national territory. Based on ASTM D7566, as per Annex Table A.1.(ANP, 2021a)
- Annex to ANP Resolution - RANP 856/2021 - Product quality specification table, as per Annex Table A.2.
- ANP Resolution 842/2021: It establishes the specification of green diesel, as well as the obligations regarding quality control to be met by the economic agents that sell it in the national territory. The green diesel covered by the Resolution is obtained from the hydrotreatment of vegetable oils (in natura or residual), oils from algae, microalgae, and animal fats, fatty acids from biomass, synthesis gases obtained from the gasification of organic waste, such as biomass, oligomerization of ethyl alcohol (ethanol) or isobutyl alcohol (isobutanol) and from catalytic hydro thermolysis of

vegetable oil (in natura or residual) (please see EPE, 2020 (TN – Green Diesel). Green diesel routes (ANP, 2021b)

Besides ANP, some more crucial regulatory developments for SAF in Brazil:

- CT CF – The Fuel of the Future Program (CF) has created several sub-committees to study and develop the different aspects of this policy, among them the ProBioQAV CT-CF, which is dedicated to BioQAV and SAF. Link: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro/subcomites-1/ProBioQAV/documentos-do-subcomite-1 .
- ProBioQAV - National Program for Sustainable Aviation Fuel, Law 14,248/2021. It aims to foster the production and use of SAF in the Brazilian energy matrix and reduce carbon dioxide emissions by air operators. Link: http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2021/Lei/L14248.htm.
- Brasil is a signatory of CORSIA (ICAO) – As per the following link : https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro/subcomites-1/ProBioQAV
- RENOVABIO – it has no target to kerosene distributors yet, due to the lack of production, at the initial phase. Link: https://www.gov.br/anp/pt-br/assuntos/renovabio.
- SAC / ANAC - routes – The ProBioQAV Subcommittee has studied several SAF routes. For more details, please see: https://www.gov.br/mme/pt-br/assuntos/noticias /ApresentacaoMMEnoCRBQAV_RenatoDutra_180522_v01.pdf
- PROQR - MITCI – Project to support the planning, financing, construction and operation of small, decentralized power plants that produce fuel for aviation from renewable electricity in remote locations, integrating various Brazilian ministries, authorities, universities and other public institutions. Link: https://www.giz.de/en/worldwide/68382.html

Announced new regulations

The Project of Law 1873/2021, issued in 24th November 2021, is based on ProBioQAV Project (source: https://www.gov.br/infraestrutura/pt-br/assuntos/transporte-aereo/plano-aeroviario-nacional), and has not yet been sanctioned by the President of Brazil.

National strategy and target

According to EPE (2021) and IEA (2021), Brazil has 42% of renewable content in its energy matrix in 2020 and will reach 49% by 2031. Brazil is a signatory to the Paris Agreement (UNFCCC, 2015) and to the Glasgow Pact (UNFCCC, 2021), when has committed to reducing 50% of GHG by 2030 compared with 2005. As previously mentioned, Brazil has developed a regulatory framework towards decarbonization and biofuels, including signatory of CORSIA / ICAO, and implemented the RenovaBio policy, the Fuel of the Future Program, besides the Program for Biojet Fuel or ProBioQAV (ProBioQAV, 2022).

The National Council for Energy Policy (CNPE), in its 7th Resolution, from 21st April 2021, has instituted the Fuel of the Future Program (CF), created the Technical Committee for Fuel of the Future (CT-CF), among other measures. This Program aimed to increase the use of sustainable and low-carbon fuels, including SAF. In particular, the Program ProBioQAV has the institutional objective of introducing SAF into the Brazilian energy matrix. ProBioQAV identified 2 key issues to be dealt through the following actions:

- Action Plan 1: To increase integration and thematic gap in the availability of studies on economic and technological feasibility and public policy governance to produce SAF in Brazil

- Action Plan 2: To tackle absence of a legal framework and public policy guideline for SAF in Brazil

Analysis related to their impact on national climate targets.

The regulatory agency analyses the proposed routes within CORSIA, starting from the feedstock available in Brazil and according to the technological routes that the country wishes to adopt. This implies to evaluate which route is the best to serve the CORSIA´s emission targets.

Governmental institutions in charge

- MME is the Ministry of Mines and Energy, responsible for all the SAF initiatives. Link: https://www.gov.br/mme/pt-br
- MCTI is the Ministry of Science, Technology, and Innovation. Together with MME, it shares the responsibility of SAF implementation in Brazil. Link: https://www.gov.br/mcti.
- BNDES or National Bank of Economic and Social Development, is the national public bank that finances innovation, energy and SAF projects. Link: https://www.bndes.gov.br/ .
- MAPA or Ministry of Agriculture, Livestock and Supply, is an important governmental entity in the SAF ecosystem deployment. Link: https://www.gov.br/agricultura/pt-br/
- LNBR or the Brazilian Biorenewables National Laboratory, is the scientific arm connected to the MME, holding a crucial role in SAF ecosystem. Link: https://lnbr.cnpem.br/

National strengths and potentials

The table 1 summarizes the SWOT analysis of SAF development in Brazil, showing not only the potential but also what must be done to produce SAF in Brazil.

Table 10: SWOT analysis for Brazil (ProBioQAV, 2022)

Strengths	Weaknesses
• Abundant feedstock • Feedstock of plant and animal origin. • Drop-in fuels (no required changes in the supply infrastructure). • Possibility to adjust to RenovaBio • New BNDES financing lines: R&D ANP • Supply of qualified labor	• Lack of pilot plant of different routes • Production and logistic costs • Tax issues • Risk of limitations in the supply of natural resources • Optimize the logistics of production towards the airports • Obliged parties / compliance • Investments and R&D
Opportunities	**Threats**
• CORSIA Implementation • Net-zero movement adopted by the companies • The new biorefineries will expand the offer of new bioproducts to the market. • The drop-in fuels may replace fossil fuels in the mix. • International technical cooperation	• Non-competitive SAF price • CORSIA certification • Risk of economic competition among routes • It is hard to align the several parts of the biofuels supply chain: engine and accessories manufacturers, distributors, fleet operators and consumers. • The entry of new alternatives in the fuel mix

• International climate agreements	requires aircraft operations to adapt to it. • Lower oil prices can damage any SAF and biofuels policy.

Technological routes in Brazil

Currently, seven routes are approved by ASTM, which were also approved and updated by the ANP, though in different order and with few adjustments to Brazilian reality. Some SAF production initiatives in Brazil deserve to be highlighted, such as, for example, the partnership between the Bevalue projects of CNPEM and the European Becool to "explore synergies between Brazil and the European Union for the production of biomass, diversification of production and logistics chains for the sustainable development and deployment of advanced biofuels". The idea of this partnership is both to advance in autonomous transport routes and in integrated thermochemical and biochemical routes. (LNBR, 2021). In Brazil, the SAF routes are still at a technological readiness level - TRL 3 (maturity level technology).

The key technological routes are described in
Table 11.

Table 11: Overview of available raw materials in relation to main products, SAF (ProBioQAV, 2022)

Raw Materials	Technological route	Main Process	Fuel
Frying oil, animal fat, inedible vegetable oil, tall oil	Chemical conversion	Esterification + HDT	HEFA-SPK
		Esterification + HDT	HC-HEFA-SPK
Municipal solid waste, forest, agricultural and agro-industrial waste	Termochemical	Gasification + reform + Fischer-Tropsch	SPK-FT
		Gasification + Fischer-Tropsch + Alkylation	FT-SPK/A
Starch or lignocellulosic biomass hydrolysates	Biochemical	Biochemical + HDT	ATJ-SPK
Carbohydrates (sucrose)	Biochemical	Biochemical + HDT	SIP
Sewage, manure and waste from food processing, forestry, agricultural and agro-industrial waste	Termochemical	Fast pyrolysis + hydrothermal liquefaction	CHJ

Although we still don't have a SAF plant in Brazilian territory, a Brazilian industrial group is working on the project called "Omega Green" a biodiesel plant based on paraffinic hydrocarbons, in Paraguay, a neighbor country. The works to install the internal infrastructure and access to the industrial complex, which will have a production capacity of approximately 20,000 barrels a day of green diesel, aviation biokerosene and green naphtha, began in July 2022. This plant will produce HVO (in conjunction with renewable aviation kerosene), fuels that will be exported to North America and Europe. This project is based on Honeywell UOP's Ecofining technology and will use recycled soybean oil, animal fat and frying oil as plant inputs EPE (2020a).

It will be the first biofuels biorefinery in Paraguay, scheduled to start operating in three years after its initial construction. Besides, it will be the first southern hemisphere for an advanced diesel project of this type in the HVO hemisphere (Hydrotreated Vegetable Oil), the renewable one for operation (Synthetic Paraffin Kerosene – SPK), Sustainable Aviation Fuel

(SAF) and Green Naphtha (used in the chemical industry to make green plastic, among other products).

According to the decarbonization issues from Petrobras' Strategic Plan 2022-2026, it will be developed the BioRefining Program, focused on the development of modern fuels and sustainable development. Among its projects, there is a dedicated plant to produce between 500 and 1000 kt/year of renewable diesel and BioQAV, made by renewable feedstocks.

Two others different companies from Brazil, Vibra Energia and Brasil BioFuels, made a partnership for the production and commercialization of SAF and HVO, by using palm oil as feedstock. This industrial investment comes over 2 billion reais and include a biorefinery construction in Manaus Free Trade Zone, with an estimated volume of 500 thousand m^3 per year[91].

Challenges for market uptake

SOUZA *et al.* (2018) stated that there are many technological and commercial uncertainties, such as lack of mastery in the production of alternative raw materials with higher energy density, lack of laboratory infrastructure for certification, logistical issues, high cost of raw materials and refining routes and lack of public-private investment for aviation biofuel development in the country.

Regarding the financing conditions, the following sources are aligned (GIZ, ProBioQAV, 2022):

a) The budgets of the federal direct administration, with emphasis on the areas of Defense, Science and Technology, Education and Agriculture and Livestock;

b) Resources from federal funding agencies, coming from their own endowments, transfers from the direct administration or even in composition with private sources;

c) Budgets of the federation units, highlighting the resources provided to the State Research Support Foundations;

d) Resources managed by regulatory agencies, which, by virtue of regulation in the electricity and oil sectors, are concentrated in ANEEL and ANP;

e) Resource funds integrated into the National Science, Technology and Innovation System - SNCTI, such as the National Scientific and Technological Development Fund - FNDCT, the Technological Fund - FUNTEC and the Amazon Fund;

f) Sectoral funds, with emphasis on Energy (CT-ENERG), Oil and Natural Gas (CT-PETRO), Mineral Resources (CT-MINERAL), Agribusiness (CT-AGRO), Biotechnology (CT-BIO) and Transport (CT-TRANSPORTES);

g) Resources allocated by state or regional development banks, such as BRDE, BDMG, BNB;

h) Resources from international funding agencies, organizations and programs and international cooperation agreements, such as Horizon 2025 and the Sectoral Dialogues (European Union), Newton Fund and Prosperity Fund (United Kingdom), Global Environment Facility - GEF (several countries), CLIENT - International

[91] According to Vibra, the production of this new installation is equivalent to 2% of its demand for QAV+DIESEL in the country, corresponding to 24% from the North region.

Partnership for Sustainable Innovations (BMBF, Germany), International Climate Initiative - IKI (GIZ, Germany) and others.

The main sources of funding for the science, technology and innovation structure in Brazil are the National Treasury and the National Fund for Scientific and Technological Development - FNDCT.

FINEP - Financier of Studies and Research, a public company linked to the Ministry of Science, Technology and Innovation (MCTI), plays the role of executive secretary of the FNDCT. The FINEP Programs have as their main objective to finance projects and studies that promote the development of companies and the Brazilian market in various sectors, including energy.

In summary, it is up to FINEP to execute the lines of finance, that is, those shorter-term operations, whether repayable or not, and to BNDES the so-called funding lines, redeemable and oriented towards long-term financing.

An alternative to increase the availability of raw materials is to exempt from taxation the income obtained with sustainable crops used as raw material SAF. Example: as in the PNPB, guarantee tax incentives for biodiesel producers who buy raw material from family farmers. Minimum purchase percentages for eligibility range from 20% to 40% according to regional socioeconomic status (ProBioQAV, 2022).

The CT-CF Program is discussing under a Law Project, the establishment of a the SAF mandate from 2027 to 2037, consisting of positive carbon dioxide reduction imposed on airflight operators.

The RenovaBio Program provides a crucial financial incentive with the so-called Decarbonization Credits (CBIO), whose concession is conditional on obtaining the Efficient Biofuel Production Certificates. To obtain current update of this carbon market, please see B3 (2022).

To estimate the necessary investments, it was adopted as a premise the introduction of, at least, one mixed unit with intercropped production of BioQAV, HVO (hydrotreated vegetable oil), bionaphtha and LPG, with a world average profile of about 400 million liters per year (320 thousand tons of HVO) and a production ratio of 35% for BioQAV and 52% for HVO. The projected necessary investment would be in the order of 100 million dollars or 700 million reais (92% utilization factor). Operating costs related to the production of these biofuels at this plant are not listed here (EPE, 2022). It is important to clarify that this unit, singly, is not enough to market needs to comply with CORSIA.

National actors along the value chain

Below it is presented some players of the SAF market, considering its description and the main role in this market.

Table 12: National stakeholders Brazil

National Actor	Type of company/association	Description (including potential role regarding SAF)
Feedstock supply		
Petrobras	Fossil refinery	Petrobras is the major and dominant fossil refineries holder in Brazil, processing mainly crude oil, gasoline (petrol) and diesel and, until today, the unique aviation kerosene producer in Brazil. Until 2022, there is neither a forecast of

		how much SAF liters Petrobras will produce nor when. Eventhough, they already produce a fuel resulted from a coprocessed fossil/biofuel in-put.
Brazilian Association of Vegetable Oil Industries - ABIOVE	The Brazilian Association of Vegetable Oil Industries (ABIOVE) represents 15 companies producing bran, vegetable oils and biodiesel, cooperates in the implementation of sector policies, promotes sustainability programs and generates statistics used in sectoral studies.	Among the main commodities in its area of activity are soy, sunflower, castor bean and corn, crops from which oils and fats used in the food sector are extracted and which are the basis for a multitude of products that can be used as feedstock for SAF.
Brazilian Association of Animal Protein - ABPA	ABPA is the Brazilian Association of Animal Protein and it is mainly dedicated to beef, swine and poultry meat, including the use of beef tallow, swine grease and poultry oil to other destinations, such as the biodiesel production. Obs.: Note that the largest beef producer in Brazil – JBS, with its biodiesel arm – JBS Biodiesel - is also the largest biodiesel producer from organic waste from cattle processing and used cooking oil	• Animal fat (and beef tallow) is already the second most used raw material in mills, with a 15% share, second only to soy in the biodiesel production, according to EMBRAPA (2022). • Bellaver (2005) estimates that the volumes of beef tallow, swine grease and poultry oil generated at slaughter are 1,560,000, 355,000 and 218,000 ton/year, respectively. • Animal fat can be employed through chemical conversion to SAF production.
UNICA - Brazilian Sugarcane Industry and Bioenergy Association	Unica is the representative body of a wide group of companies that produce sugar, ethanol and bioelectricity in the Center-South region of Brazil.	The association aims to promote and defend the interests of sugar, ethanol and bioelectricity producers, not only in Brazil but at a global scale.
Fuel production / distribution		
Petrobras	Oil Derivatives and fossil fuels provider in Brazil.	Petrobras is a major fuel producer in the Brazilian market.
Raízen	Biofuels producer/distributer	Recently (July 2022), Raízen signed a letter of intent with Embraer (the largest aircraft manufacturer in Brazil) to develop the Brazilian ecosystem for SAF production. Raízen commitment to both innovation and bioenergy enables it to become a key SAF trailblazer in Brazil.
Vibra	Biofuels distributer	Originally, a Brazilian government-controlled company, Nowadays, after changing its name from BR to Vibra, they became a private Corporation. After launched the new brand, Vibra, they can be considered as an energy company, concerned for the energy transition and the ESG agenda.
Ipiranga	Biofuels distributer	With more than 80 years, Ipiranga is one of the largest fuel distribution networks in Brazil. They have more than 7,000 service stations and more than 6,000 large customers, who use their products for industrial and collective transport and cargo activities.
Fuel consumption		
LATAM	It is the leading airline group in Latin America, with a presence in five domestic markets in the region: Brazil, Chile, Colombia, Ecuador and Peru, in addition to international operations in Latin America, Europe, the United States and the Caribbean. It currently operates nearly 970 daily flights to 117 destinations in 16 countries.	In its Sustainability Strategy, LATAM plans the following 3 steps: • Be carbon neutral by 2050. • Offset 50% of domestic emissions by 2030. • Use SAF in a Sustainable Alternative Fuels program until 2030.
Gol - Linhas Aéreas	Gol is a Brazilian airline based in Rio de	GOL is a pioneer in encouraging R&D of biofuel technology

Inteligentes	Janeiro, founded in 2001. It is the largest airline in Brazil in terms of number of passengers, with 36% share of the domestic market, operating in 60 airports in Brazil	and was the first Brazilian airline to disclose its greenhouse gas inventory based on the Greenhouse Gas Protocol and has been qualified with the Gold Standard since 2011. GOL is a member of entities national and international organizations such as the Brazilian GHG Protocol Program, the Brazilian Union of Biofuels and Biokerosene (Ubrabio), the IATA Environmental Committee.
Azul - Linhas Aéreas Brasileiras	Azul is a Brazilian airline founded in 2008. In 2014, it was considered the third largest airline in Brazil in terms of number of passengers, the second largest in terms of aircraft fleet and the largest in number of destinations offered, operating in 98 airports in the Brazilian territory and in 8 international airports. In 2016, Azul had a market share of 17.19% of the total seats offered on domestic flights.	Flight with Bio QAV in 2012, at Rio + 20 • Attempt to use BioQAV with Amyris and, 2017, unsuccessful, due to: • There is no tax classification code for the product. i. There were doubts and different interpretations of how to tax the product: if the blend was taxed as a whole, fossil and bio separately or proportionally from the mixture. ii. There were no laboratories able to certify the blend in Brazil, and it was necessary to send abroad, raising costs and deadlines. The company made a petition to Brazil Tax Authorities requesting the tax reduction of the Blend; however, this request was not conceded.
Aviation OEMs		
Embraer	Aerospace manufacturer in Brazil. Brazilian multinational aerospace manufacturer that produces commercial, military, executive and agricultural aircraft, and provides aeronautical services.	It is committed to carbon neutral growth from 2022, as well as the use of SAF in processes from 2021, in addition to the neutrality in carbon by 2040. It also focuses on the development of products, services, and technologies for aviation net-zero carbon 2050 and on 100% SAF compliant aircraft. Finally, it seeks engagement with suppliers and partners to expand the global production of SAF.
Airbus	Aircraft manufacturer in Brazil.	Airbus aims to pioneer sustainable aerospace for a safe and united world. They also have the objective of offering 100% SAF capacity on commercial aircraft up to 2030, as well as becoming the largest manufacturer to offer a neutral aircraft by 2035. Airbus has the ambition to become net-zero by 2050. To achieve this goal, they have a reduction route of CO_2, which includes next-generation aircraft, disruptive technology, operations and infrastructure, sustainable fuels and offsetting.
Boeing	Aerospace manufacturer in Brazil. Boeing operates in Brazil since 1993 and has delivered 230 airplanes to 8 different airliners.	Boeing works with Brazilian partners on several key collaborative projects, including sustainable aviation fuels (SAF), investing in effective SAF production, fleet and operational capabilities. Boeing has made a commitment that its commercial aircraft will be able to be certified to fly 100% with sustainable aviation fuels by 2030. Previously, the company had already flights using SAF. (BOEING, 2021)
SAF technology providers		
Amyris	As the world's leading manufacturer of sustainable ingredients made with synthetic biology, using sugarcane fermentation.	Provides HFS SIP, 2014, sugar fermentation. Operates in Brazil.
Research institutes		
RBQAv	RBQAv - Brazilian Network of Sustainable Bioquerosene and Hydrocarbons for Aviation	Aims to support Research, Development and Innovation (R&D&I) in the sector through partnerships between research institutions, private companies and government institutions.

UFMG	Federal University of Minas Gerais	The university develops SAF research in its laboratory and took part in the certification of BIOQAV in Brazil.
UFRN	Federal University of Rio Grande do Norte	Develops sustainable fuels research and development, including SAF.
FUNPEC	Norte-Rio-Grandense Research and Culture Foundation	Develops sustainable fuels research and development, including SAF.

ANNEX

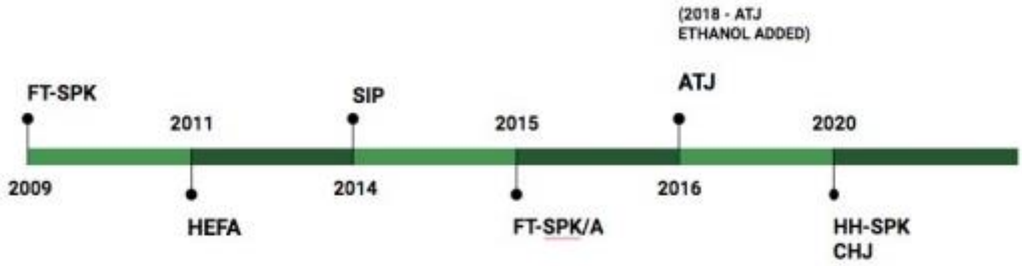

Figure 14: Timeline of ASTM Approvals of SAF Routes (ProQR, 2022, based in IATA s.d.)

Table 13: Comparative Table (ANP (2021b) X ASTM D7566) – Fossil kerosene and alternative kerosene.

		Querosene		Querosene alternativo									
Especificação		JET A / JET A-1		SPK-HEFA / SPK- FT		SIP/ SPK/A		ATJ		CHJ		SPK-HC-HEFA	
Referência		ANP 856	D7566	ANP 856	D7566	ANP 856	D7566	ANP 856	D7566	ANP 856	D7566	ANP 856	ASTM
Acidez total, máx.	mgKOH/g	0,015	0,1	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015
Aromáticos, máx. (3)	% volume (fóssil e SPK/A)												
	% massa (alt.)	25% vol.	25% vol.	0,5	0,5	0,015	0,015	0,5	0,5	8,4-21,2	8,4-21,2	0,5	0,5
Enxofre total, máx.	% massa	0,3	0,3	15	15	0,5(SIP) 20% vol. (SPK/A)	0,5 (SIP) 20% vol. (SPK/A)	15	15	15	15	15	15
Ponto Inicial de Ebulição (PIE)	°C					2 (SIP) 15 (SPK/A)	2 (SIP) 15 (SPK/A)						
10% vol. recuperados (T10), máx.	°C	205	205	205	205	205	205	205	205	205	205	205	205
50% vol. recuperados (T50)	°C	-	-	-	-	-	-	-	-	-	-	-	-
90% vol. recuperados (T90)	°C	-	-	-	-	-	-	-	-	-	-	-	-
Ponto Final de Ebulição (PFE), máx.	°C	300	300	300	300	255 (SIP) 300 (SPK/A)	255 (SIP) 300 (SPK/A)	300	300	300	300	300	300
Ponto de fulgor, mín. (10)	°C	38	38	38	38	100 (SIP) 38 (SPK/A)	100 (SIP) 38 (SPK/A)	38	38	38	38	38	38
Ponto de congelamento, máx. (11)	°C	– 47 (JET A-1) – 40 (JET A)	– 47 (JET A-1) – 40 (JET A)	-40	-40	– 60 (SIP) -40 (SPK/A)	– 60 (SIP) -40 (SPK/A)	-40	-40	-40	-40	-40	-40
Massa específica a 20°C (ANP) / Densidade a 15 °C (D7556)	kg/m³	771,3-836,6	775-840	725,9–796,5	730-770 (HEFA) 730– 772 (FT)	761,2-776,3 (SIP) 751,1-796,5 (SPK/A)	765–780 (SIP) 755-800 (SPK/A	725,9–766,2	730–770	771,3-836,6	775-840	725,9-796,5	730-800
Viscosidade a 20°C negativos, máx.	mm²/s	8	8	-	-	-	-	-	-	-	-	-	-
Poder calorífico inferior, mín.	MJ/kg	42,8	42,8	-	-	-	-	-	-	-	-	-	-

Source: ProQR (2022). Selected criteria based on *Ng et al.* (2021).

Table 14: ASTM Approved Technology Routes (2009-2020)

ASTM Anexo D7566	Rota tecnológica	Matérias-primas possíveis	Limite de Mistura (%)	Data	Desenvolvedor	Comercializador	TRL	% redução Emissões*
A1	FT-SPK	Carvão, gás natural e biomassa	50	2009	Sasol, Shell, Velocys, Johson, Mathey, BP	Sasol, Shell, Fulcrum, Red Rock, Velocys, Loring, Clean Planet Energy	7-8	86-91
A2	HEFA-SPK	Bio-óleo, gordura animal e óleo reciclado	50	2011	UOP/ENI, Axens, IFP, Neste, Haldor-Topsoe, UPM, Shell, REG	World Energy, Neste, Total, SkyNRG, SGPreston, Preem, muitas que usam pro diesel verde	8-9	33-77
A3	HFS-SIP	Biomassa	10	2014	Amyris	Amyris / Total	5-7	63-64
A4	FT-SKP/A	Carvão, gás natural e biomassa	50	2015	Sasol, Rentech	nenhum anúncio	5-6	86-91
A5	ATJ-SPK	Etanol e isobutanol	50	2016	Gevo, Lanzatech (pedente Swedish Biofuels, Byogy)	Gevo, Lanzatech	6-7	73-26
A6	CH-SK ou CHJ	Óleo vegetal	50	2020	ARA / CLG	ARA, Wellington, UrbanX, Euglena	6	n.d.
A7	HHC-SPK ou HC-HEFA	Algas	10	2020	IHI Corporation	IHI	5	n.d.

*% emissions savings compared to fossil-kerosene baseline of 89 g CO_2eq/MJ

Source: ProQR (2022).Data from Csonka (2021); Soares *et al.* (2021); IRENA (2019); Bauen *et al.* (2020); Destination 2050 (2021); Humphris-Bach *et al.* (2020).

References

AMYRIS (2022). "Make Good. No Compromise". Available at: https://amyris.com/. Access on 01 Jun 2022.

AZUL (2021). "PROBIOQAV Combustíveis do Futuro".

BASF (2022). "LanzaTech Inc.". Available at: https://www.basf.com/global/en/who-we-are/organization/group-companies/BASF_Venture-Capital/portfolio/LanzaTech-Inc.html. Access on 01 Jun 2022.

Bauen, Ausilio; Bitossi, Niccolò; German, Lizzie; Harris, Anisha; Leow, Khangzhen. "Sustainable Aviation Fuels: Status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation". Johnson Matthey Technology Review, Volume 64, Number 3, 1 July 2020, pp. 263-278(16). DOI: https://doi.org/10.1595/205651320X15816756012040.

Biomass Magazine (2021). "CLG, ARA to supply technology to Iowa renewable diesel, SAF plant". Published 08 Jun 2021. Available in: https://biomassmagazine.com/articles/18056/clg-ara-to-supply-technology-to-iowa-renewable-diesel-saf-plant. Access on 01 Jun 2022.

BOEING (2022). "Boeing no Brasil". Available at: https://www.boeing.com.br/a-boeing-no-brasil.page. Access on 01 Jun 2022.

BRAZIL, 2017. Law number 13,576, of 26 December 2017. Deals with the National Biofuels Policy (RenovaBio) and other measures. Official Diary of the Union, Brasília. Source: www.planalto.gov.br

BRAZIL, 2018a. Brazilian Nationally Determined Contribution (NDC), Accessed on 30 august 2018: http://www.itamaraty.gov.br/images/ed_desenvsust/BRAZIL-iNDC-english.pdf or http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf

BRAZIL, 2018b. Law number 13,755 of 10 December 2018. Establishes Rota 2030 Program and other measures. Official Diary of the Union, Brasília. Source: www.planalto.gov.br

CIVIL HOUSE. (2021). Approved the creation of the Fuel of the Future Program. Civil House. Access on: March 2023, available on:

https://www.gov.br/casacivil/pt-br/assuntos/noticias/2021/abril/aprovada-a-criacao-do-programacombustivel-dofuturo#:~:text=O%20Programa%20Combust%C3%ADvel%20do%20Futuro%2C%20que%20tem%20como,um%20passo%20na%20lideran%C3%A7a%20da%20transi%C3%A7%C3%A3o%20

CORTEZ, Luís Augusto Barbosa et al. Roadmap for sustainable aviation biofuels for Brazil. São Paulo: Blucher, 2014.

CSONKA (2020) "Targeted Aviation Advanced Biofuels - Demonstration Competition – Feasibility Study - Final report - Report for Department for Transport, UK. September, 2020. Available at: Downloads/final-report-aviation-abdc-feasibility-study-issue-v1-0.pdf

DESTINATION 2050 (2021). "Destination 2050 – A route to net zero European aviation". Airlines for Europe (A4E), CANSO (Civil Air Navigation Services Organisation), ERA (European Regions Airline Association), Airports Council International-EUROPE (ACI), Aerospace & Defence Industries Association of Europe (ASD). Available at: https://canso.org/eu-aviation-maps-a-sustainable-post-crisis-future-in-round-table-report/

EMBRAER – Empresa Brasileira de Aviação (2022). "Voo teste do Embraer E195-E2 usando 100% SAF - combustível sustentável de aviação". Available in: https://www.youtube.com/watch?v=0zGDHH3sgiM&vl=pt. Access on 26 Jul 2022.

EPE – Empresa de Pesquisa Energética (2022). Ten Year National Energy Plan – 2022-2031. Published 2021. Available at: http://www.epe.gov.br, accessed 30 May 2022.

EPE (2020). Combustíveis renováveis para uso em motores do ciclo Diesel. Published 2020. Available at: http://www.epe.gov.br, accessed 26 July 2022.

EPE. Comitê técnico – combustível para o futuro. Apresentação Subcomitê ProBioQAV do Programa Combustível do Futuro do Ministério de Minas e Energia. 2021. Available at: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro/subcomites-1/probioqav/participacao-social/ap-epe-dpg-sdb-2021-43-probioqav_26-08-2021.pdf, accessed 30 May 2022.

GRASSI, Carolina et al. Feedstock availability for sustainable aviation fuels in Brazil: challenges and opportunities. [S. l.: s. n.], 2021. Available at: https://rsb.org/wp-content/uploads/2021/04/RSB-Brazil-SAF-Feedstock-Factsheet-2021.pdf. Access on 01Jun 2022.

LNBR. BioValue. 2021. Available at: https://lnbr.cnpem.br/biovalue/ . Access on: 01 Jun 2022.

MCTIC. "Estimativas anuais de emissões de gases de efeito estufa no Brasil". Fourth edition (2017). Available at http://sirene.mcti.gov.br/publicacoes, accessed on 30 August 2018.

MENDES DE SOUZA, L., MENDES, P. A. S., ARANDA, D. A. G. (2018). "Assessing the current scenario of the Brazilian biojet market". Renewable and Sustainable Energy Reviews, Volume 98, December 2018, Pages 426-438. https://doi.org/10.1016/j.rser.2018.09.039.

PROBIOQAv (2022). "Participação Social". Available at: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro/subcomites-1/probioqav/participacao-social. Access on 01 Jun 2022.

ProQR – Combustíveis Alternativos sem Impactos Climáticos. Estudo sobre Governança e Políticas Públicas de Incentivo à Produção de Combustíveis Sustentáveis de Aviação. Ministério da Ciência, Tecnologia e Inovações – MCTI. Publicado em Janeiro 2022. Brasília.

RBQAV (2022). "Rede Brasileira de Bioquerosene e Hidrocarbonetos Sustentáveis para Aviação". Available in: https://rbqav.com.br/. Access in 01 Jun 2022.

SENAI (2022). "SENAI produzirá combustível sustentável de aviação no RN com apoio da Cooperação Alemã". Available in: https://www.rn.senai.br/44582-2/. Access on 27 Jul 2022.

TELLO-GAMARRA, Jorge; MÔNICA, Ana; DE OLIVEIRA, Fitz. Trajetórias tecnológicas dos

biocombustíveis para aviação: o caso das algas. In: XVI Congresso Latino-Iberoamericano de Gestão de Tecnologia. Porto Alegre, 2015.

Denmark

Authors: Jesper Schramm, Kim Winther

Qualitive supply chain assessment

Denmark's long-term supply of future SAF fuels is closely coupled to the planning of so called "energy islands". Also, biofuels play a major role on the way as these fuels are available already. The offshore wind turbines around the energy islands can supply green power to at least five million households with the possibility to expand to more than 10 million households. The islands will play a major role in the phasing out of fossil energy sources in both Denmark and Europe.

In the North Sea, an artificial island will be established, which will be a hub for 3 GW offshore wind farms and with the possibility of 10 GW in the long term. The island will thus be able to cover the consumption of 10 million households. The wind turbines that will supply power to the island are expected to be larger than they are today, and will go further out to sea than before. The technical equipment for energy distribution will be located on the island. It will not be possible to see the turbines from land. The energy islands are part of the development of the energy systems of the future, and it is part of the political agreements that electricity from the energy islands should be converted into new forms of energy. These fuels are the so-called e-fuels, including marine fuels and aviation fuels (SAF). This means that the green power will contribute to the phasing out of fossil fuels in both Denmark and Europe.

In the Baltic Sea, the technical equipment for energy distribution will be located on Bornholm, where electricity from offshore wind farms will be transported to the electricity grid on Zealand and neighboring countries. The offshore wind farms will stand approx. 20 km south-southwest of the coast and will be visible but not dominant on the horizon. The parks at Bornholm must have a capacity of 2 GW corresponding to the electricity consumption of two million households. Like the island in the North Sea, the ambition is for electricity from the offshore wind farms to be able to be converted into other forms of energy like SAF.

Legal framework and strategies

EU initiatives:

The EU's ambition is to be carbon dioxide neutral in 2050. This requires a huge expansion of sustainable electricity production and the electricity network. As an important step four countries has agreed to collaborate on expanding the off-shore production of electricity from The North Sea and the associated expansion of the electricity grid. These countries are: Germany, The Netherlands, Belgium and Denmark. The plan is to produce 150 GW by 2050.

National initiatives:
The Prime Minister presented in her latest New Year's speech the government's ambition for aviation – Denmark must have one green domestic flight route in 2025, and all domestic aviation must be green by 2030. The government expects to launch an aviation plan in autumn 2022, after which the outcome must be negotiated.

Private initiatives:
Some airlines also contribute to the green restructuring with own goals, for example SAS has a SAF goal of 17% in 2025, Norwegian has a target of up to 28% in 2030, Ryanair has a target of 12.5% in 2030, and British Airways has a target of 10% in 2030.

National strengths and potentials

Two major initiatives are ongoing in order to support the progress towards implementation of

SAF in Denmark. These are the ALIGHT project and the GreenLab project.

ALIGHT:

With Copenhagen Airport (CPH) as the lighthouse, an example of the sustainable airport of the future will be created. The project will both focus upon infrastructure for sustainable aviation fuel and renewable energy sources for ground activities.

Copenhagen Airport has a heating and power supply from large combined heat and power plants (CHP) based on biomass and waste. In nearby Øresund and the Baltic Sea, new large-scale offshore wind parks provide access to a low-cost renewable power supply. There is also a growing interest among stakeholders to establish a production of synthetic SAF close to CPH

Implementing sustainable aviation fuels (SAF) is the key to obtain zero carbon operation in Copenhagen Airport. Two barriers are at stake: the supply of sustainable aviation fuels and the operation and logistics of handling such fuels in a major airport.

A wide range of delivery aspects will be handled in ALIGHT leading to a continuous supply to the airport. The goal is to create solutions that will meet the demands of the airport and end users in terms of climate, economy and supply. ALIGHT will demonstrate an innovative concept for fuelling infrastructure, logistics and blending operations.

Fuel supply chain:

The goal is to improve the logistics chain and make the use of SAF more efficient and cost-effective. Complete fuel chain certification will be obtained. A best practise guide for SAF handling and logistics will be developed.

Usage of SAF:

SAF uptake processes and smart use of SAF should be improved. A digital platform will assess the performance of new SAF candidates (DLR SimFuel). A digital twin will be developed to be a digital record of the whole value chain of the specific fuel for tracing eg. fuel properties.

Economics of SAF:

Economic models will demonstrate the cost benefit of SAF. Furthermore, a novel methodology for reporting and accounting of SAF will be developed.

Sustainability:

Best practice sustainability principles and targets are applied to the development. The full SAF supply chain will be assessed using the RSB certification and requirements of the EC Renewable Energy Directive II (RED II) and ICAO CORSIA. Environmental benefits will be quantified.

The involve stakeholders can be divided into three groups:

1. Airports:

- Copenhagen Airport
- Rome Airport
- Vilnius Airport
- Warsaw Airport

2. Technology providers:

- Scandinavian Airlines (SAS) SAS is the largest airline in Scandinavia and its main hub is CPH. SAS conducted more than 800 scheduled flights daily in 2018. In addition, SAS offers ground handling services, technical maintenance and air cargo. SAS wants to reduce CO2 emissions by 25 % by 2030 and is pushing for large scale production of SAF in Scandinavia. As a participating airline, SAS will host demonstrations and give input to day-to-day operation of SAF.
- Air BP Air BP is one of the world's largest suppliers of both aviation fuels, including AVGAS and kerosene jet fuels and lubricants. AirBP is to be found in over 1000 airport locations in 70 countries. Air BP will among others supply sustainable aviation fuel.
- Hybrid Greentech Hybrid Greentech is developing software service solutions to facilitate electrical energy storage (e.g. battery, fuel cells). They promote energy storage to obtain 100 % renewables in the energy and transport sector. Hybrid Greentech will implement and demonstrate smart charging of electric vehicles. They will provide guidelines for energy storage at the pilot site and implement smart energy management.
- Brændstoflageret Københavns Lufthavn (BKL) BKL takes care of pumping jet-fuel to the airport, storage of jet-fuel and subsequent pumping of the fuel through the hydrant system, which is an underground piping system to the individual aircraft stand. BKL will be responsible for supply of SAF through existing pipelines or alternative routes. Necessary procedures will be described for both small and large-scale airports.
- BMGI Consulting BMGI is a consulting company working primarily with exploitation and dissemination in EU projects and business development within energy and transport. BMGI will be responsible for an exploitation plan and describing a bold vision for future airports in 2050.

3. Knowledge institutions:

- Danish Technological Institute
- German Aerospace Center
- International Air Transport Association (IATA)
- Hamburg University of Technology
- University of Parma
- Roundtable on Sustainable Biomaterials (RSB)
- Nordic Initiative for Sustainable Aviation (NISA)

Information about this project is found at www.alight-aviation.eu.

GreenLab:

GreenLab is a green and circular energy park, a technology enabler and a national research facility. GreenLab is specialized in accelerating research and technology to scale, and our concept transforms the way green energy is produced, converted, stored and applied. GreenLab test theories in practice and look for viable green solutions to the world’s biggest challenges.

GreenLab will be home to one of the world’s first and largest commercial Power-to-X facilities in 2021 and we will reach 24MW by 2022. Another 100MW will begin construction the following year – it’s a one-of-its-kind endeavour made possible by great partnerships.

GreenLab collaborate with the Denmark’s finest technical universities and together, we turn theory into practice. The technologies developed and scaled up on our platform are a proof of concept for an integrated energy system that has the potential to create a market pull and be the start of an export adventure. **GreenLab Academy**: GreenLab collaborates with institutions of higher education as well as commercial partners in the GreenLab Academy. Here, professionals come to upgrade their skillset in some of the most complex areas of expertise within green energy and hybrid solutions.

National actors along the value chain

National actors are mentioned in the previous section. A recent report has been published by the Danish organisation of a business community, “Green Power Denmark” with interest in aviation fuels among other energy related matters (https://greenpowerdenmark.dk/nyheder/groent-flybraendstof-kan-vaere-klar-om-faa-aar). From this society the following actors have been identified:

<u>Manufacturers of SAF:</u>
Arcadia eFuels
CIP, Copenhagen Infrastructure Partners
European Energy
Oersted

<u>Fuel suppliers:</u>
Crossbridge, Energy Fredericia
DCC & Shell Aviation Denmark A/S
Topsoe

<u>Consumers:</u>
Alsie express
Norwegian
SAS
Sunclass Airlines

<u>Infra structure:</u>
Aalborg Airport
Billund Airport
CPH,Copenhagen Airports

<u>Others:</u>
Green Power Denmark
NISA, Nordic Institute for Sustainable Aviation

Challenges and opportunities for market uptake

Sustainable Aviation Fuels are supported by government and business environment as well as by the public opinion. The willingness is there, but the timing might be an issue. there are plans but the challenges lie mainly in the needed time for technological development of airplanes and fuel. As always there are the issues with economy, since the fuels obviously are more expensive to produce.

Germany

Authors: Franziska Müller-Langer, Stephanie Hauschild[92]

In 2019, all departing flights in Germany counted to about 16% of the total final energy demand in transport (438 PJ of 2,739 PJ) and roughly about 16% (15% international and 1% national flights) of the related total CO_2-equivalent emissions (31 million metric tons of 196 million metric tons) [1]. The need to reduce and prevent emissions in the German aviation industry has been addressed by the German government's Mobility and Fuels Strategy [2]. In addition to technical and operational measures to reduce emissions, the focus is on substituting conventional fossil-based jet fuel with sustainable aviation fuel (SAF). Many R&D&D projects were undertaken in the past years with different key issues. The focus shifted from biobased SAF (like HEFA hydrotreated esters and fatty acids, ATJ alcohol to jet and BTL biomass to liquids via Fischer-Tropsch) to PtL (power-to-liquids or e-fuels) based SAF.

Following a short insight in the current and upcoming activities in regards to SAF production and use in Germany is given.

Qualitive supply chain assessment

SAF is to be produced as neat fuel or synthetic paraffinic kerosene (SPK) and used as drop-in fuel. Once qualified and approved according to ASTM D7566, SPK can be blended to conventional jet fuel in a proportion of up to 50%(v/v) (maximum permitted blending rates depending on the conversion route, referred to version ASTM D7566-22). Furthermore, renewable feedstocks (e.g. lipids and Fischer-Tropsch-based crudes) can be co-processed with crude petroleum-based oils in a proportion of up to 5%(v/v) (referred to version ASTM D1655-18a, Annex A1).

In case of SPK, blending of jet fuel have not been foreseen in larger quantities few years ago. Hence, equipment, procedures and infrastructure have to be established for the synthetic components. Even though SPK shall be "handled and transported in the same manner as finished jet fuel" according EI/JIG 1530 standard, safety issues, the risk of mismatching and purity requirements of the customer may require a dedicated infrastructure. The blending procedure can be performed in tank farms, but is not allowed in tank farms of airports (DEF STAN 91-091). Once the blend is certified in accordance with ASTM D7566 it is approved as jet A/A-1 in accordance with ASTM D1655 or DEF STAN 91-091.

From a technical viewpoint, the supply chain of the final blend jet A/A-1 to the airports is similar to petroleum-based jet fuel and can be performed e.g. via tank truck, barge, tank wagons or pipeline.

A short overview on fuels that have been used for aviation in Germany is summarized in Table 15. Currently, there are no production capacities for renewable SAF in Germany, except coprocessing at the Lingen refinery. All amounts of renewable SAF used in demonstration projects have been imported and being part of about 200,000 metric tons SAF available on the global market in 2019 [3]. As exemplary, values for HEFA-SPK and ATJ-SPK were calculated within the model project DEMO-SPK[93] on the use of multiblend Jet A-1 in practice [4]-[6]; an additional overview on possible SAF production costs is given in [1]. However, it has

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[93] DEMO-SPK | Research and demonstration project on the use of renewable kerosene at Leipzig / Halle airport

to be noted that current market prices that have to paid by the consumers/airlines for e.g. HEFA-SPK are much higher than production costs (in 2022 about 3,000 to 4,000 USD/t, [7]).

Table 15: Aviation fuel availability in Germany (2019, unless stated otherwise)

Aviation Fuel	Domestic production volume [million l]	Import volume [million l]	Export volume [million l]	Carbon intensity [gCO_{2eq}/MJ]	Production costs [EUR/t]
Jet A-1[94]	6,346 (5.08 million metric tons)	8,484 (6.78 million metric tons)	1,748 (1.40 million metric tons)	90	
HEFA-SPK	-	< 1 (in specific projects)	-	3.1	806 EUR/t[95]
ATJ-SPK	-	< 1 (in specific projects)	-	35.8	989 EUR/t[96]

Legal framework and strategies

The general framework to regulate the German aviation sector is set on European level or by international agreements, such as CORSIA. In terms of the achievement of relevant climate goals and GHG reductions in this sector, the Renewable Energy Directive (RED II) as well as the ReFuelEU Aviation initiative is of special interest. Specifying options to fulfil the respective targets, the following have been implemented in Germany. A clear focus is set on PtL SAF in Germany.

- BDL master plan from 12/2020. This master plan was jointly pursued by industry and government, represented by the German Aviation Association, and considers different measures incl. replacing conventional jet fuel with SAF and implementing carbon-neutral airport operation. [8]
- PtL roadmap from 05/2021. The German government and industry representatives have agreed on a plan for the development and use of PtL SAF (cf. Figure 15). The aim is to allow enough capacity and market ramp-up for Germany to produce at least 200,000 metric tons per year PtL-SAF by 2030. [9]-[11] This is linked to Germany‘s National Hydrogen Strategy, as well [12].
- RED II by means of the German GHG quota with the compliance option PtL in aviation from 09/2021: 0.5% by 2026 (about 50,000 metric tons), 1% by 2028 (about 100,000 metric tons), 2% by 2030 (about 200,000 metric tons); amounts can be double-counted [1]

94 Calculated values from official mineral oil data for the Federal Republic of Germany provided by the Federal Office for Economic Affairs and Export Control, $\rho_{Jet\ A\text{-}1}$=800 kg/m³
95 Value from 2018 (incl. revenues from side products), $\rho_{HEFA\text{-}SPK}$=750 kg/m³ → 0,61 EUR/l (2018)
96 Value from 2018 (incl. revenues from side products), $\rho_{ATJ\text{-}SPK}$=760 kg/m³ → 0,75 EUR/l (2018)

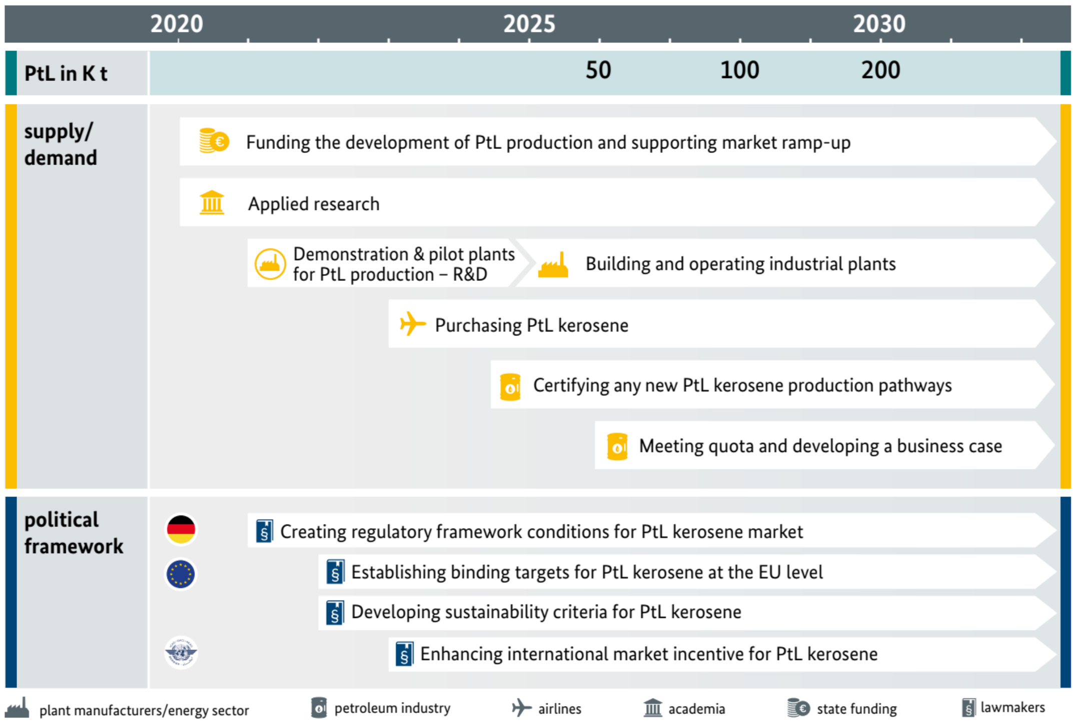

Figure 15: Implementation of PtL SAF roadmap for aviation (figure from the German PtL roadmap, page 7 [11])

National strengths and potentials

Starting from previous studies on SAF in the frame of the former "mobility and fuels strategy" which analyses also the status quo and perspectives of SAF that time (2014/2015) as well as possible value chains and relevant actors in Germany, the focus shifted to PtL technologies for SAF [13][14]. An indicative analysis of strengths, weaknesses, opportunities and threats (SWOT) for Germany is provided in Table 16. The results also consider all renewable SAF as addressed in the ReFuelEU Aviation Initiative.

Table 16: SWOT analysis for Germany (without claiming completeness), based on own observations and [13]-[17]

Strengths	Weaknesses
Well-developed fuel infrastructure, especially advantageous with regard to the import of SAF or JET A-1 blends Leading technology provider and user as well as R&D institutions along the overall value chain in principle and first use cases in practice (cf. national actors) Best practice examples (e.g. DHL, DLH) for import and use of SAF National hydrogen strategy and PtL roadmap and accompanying funding for PtL project for SAF	About 2/3 of the German primary energy demand is currently covered by imports; similar situation is expected for SAF > especially with regard to PtL/electricity from renewable sources, due to limited potentials in Germany High competition on resources (esp. carbon sources as biomass and CO_2, renewable electricity, water for electrolysis) SAF production costs for plants in Germany are expected to be higher compared to so called preferred regions with high availability of resources and lower prices Uncertainty of clear and long-term planning regulatory framework conditions Focus on PtL in Germany, that not allow accounting

	of advanced biofuel SAF to the GHG quota Missing public acceptance of renewable energy solutions and possible sites.
Opportunities	**Threats**
CO_2 equivalent and local pollutant emission reduction through cleaner combustion of synthetic SAF Investment opportunities in the field of innovative renewable electricity production, electrolysis and synthesis technologies relevant for all SPK > export potential for German technologies, value creation for the economy and job creation For a SAF registry more formalized documentation and tracking methods for transparency and trust in the process	Enormous resource demand (esp. on renewable electricity in case of PtL SAF) >> challenge on required technology roll-out of additional renewable generation capacity Shift from fossil-based import dependency to renewable-based import dependency (especially for PtL SAF) Delayed market entry for technologies due to lengthy approval procedures for production plants for synthetic SAF

Challenges for market uptake

General regulatory challenges for the production of SAF, blending with conventional Jet A/A-1, transport and distribution as well as the storage, aircraft refueling, certification and accounting can be found in a recommendation report elaborated within the DEMO-SPK project [18]. Furthermore, various challenges are discussed with regard to the different categories [13]-[17]:

Feedstock & conversion

- Despite Germany's overall focus on PtL, advanced biofuels could also be used to produce SAF (cf. Amelia example) and therefore competition with regard to sustainable feedstock according REDII, Annex IX A
- Focus on advanced feedstocks and fuels that likely show high GHG mitigation provided strict adoption of sustainability criteria
- Technology readiness level of technology routes >> SAF is to be blended and used in commercial flights when qualified and approved in accordance with ASTM D7566 >> only a few qualified process routes are currently ready for the market

Supply & operation

- Supply-side instruments (e.g. tendering models) >> build up production capacities / foster technology development
- Demand-side instruments (e.g. mandates / quota obligations) >> generate a reliable demand for SAF and their usage in the market
- Interaction between producer and customer (e.g. via book and claim models) >> establish a uniform and comprehensible reporting and accounting strategy for the claim of sustainability attributes
- Fuel qualification procedure according to the evaluation process of ASTM D4054 in order to be used for commercial flights >> associated with large personnel, time and financial expenditures; fast track provision has been established in ASTM D4054, Annex A4 with a maximum blending rate of 10% (v/v)

Markets & policy

- Already several best practice offtake-agreements and announcements as well as industry own targets in place beyond R&D&D projects; cf. examples (such as DLH, DHL) mentioned above, but lack of risk sharing among key players in the industry (e.g. airlines, fuel service suppliers)
- Complementary policies that also help to reduce investor risk and costs of SAF for market implementation along the overall value chain
- Revision of RED II, Annex IX awaited
- ReFuelEU Aviation considers both – advanced biofuels and PtL SAF; however, Germany sets a quota on PtL SAF only

National actors along the value chain

Renewable SAF is addressed in many projects and funding programs (e.g. BMWK Energy transition in transport [19], BMDV R&D renewable fuels [20] or R&D platform for PtL [21]), some examples of representative ongoing projects and actors are listed as follows (without claiming completeness).

Since February 2022, BP uses its existing facilities in the refinery Lingen to co-process used cooking oils together with crude petroleum oil. To date, it's the only industrial production facility in Germany of this kind. [22][23]

SAF as e-fuel is going to be produced from autumn 2022 in Germany´s first PtL plant with a capacity of about 360 metric tons per year in Werlte/Emsland. Fischer-Tropsch SPK/PtL is produced by using water electrolysis for H_2 production and CO_2 from a biogas plant and from the atmosphere. The project is operated by atmosfair (a non-profit organisation aiming to reduce GHG emissions) with support from among others SIEMENS and the local energy provider EWE. As supporters cargo companies such as Lufthansa Cargo and Kühne+Nagel have made a joint purchasing commitment of about 20 metric tons per year. [24]

HCS Group announced "project Amelia", a renewable hydrocarbon facility at their Speyer manufacturing center, strategically located near Frankfurt airport, and operated by the Haltermann Carless brand. Starting in 2025, it is estimated to produce 60,000 metric tons of SAF and other renewable hydrocarbons utilizing waste biomass based ATJ-SPK technology. [25]

A consortium of Airbus, Uniper, Siemens Energy and Sasol ecoFT and the research partner Technical University Hamburg announced the "Green Fuels Hamburg" project. The project includes the construction of a plant in Hamburg that will produce at least 10,000 metric tons of SAF annually based on the Fischer-Tropsch PtL route. [26]

Beginning of 2023 DLR was chosen by the German Federal Ministry for Digital and Transport (BMDV) to implement the Technology Platform PtL (TPP) through a competitive selection process. The TPP (with focus on SAF) will have a capacity of 10,000 metric tons a year. [36][37]

As part of the "HyKero project", EDL Anlagenbau Gesellschaft mbH (Pörner Group) is planning the construction of a PtL SAF demonstration plant at the industrial site Böhlen-Lippendorf to produce up to 50'000 metric tons PtL SAF per year. Furthermore, naphtha and hydrogen shall be produced. The production is planned to be start in early 2026. [27]

"KEROSyN100" is a research project intending to make PtL SAF based on synthetic methanol market-ready and to demonstrate the process at Refinery Heide in the North of Germany. The first project phase ended in 2022. In addition to extensive system analysis work, several liters of synthetic kerosene were produced as part of the technology development and promising physicochemical properties have been demonstrated. Another important result is the basic engineering for the construction of a methanol-to-jet demonstration plant at the refinery. [28][34]

Further started projects funded with link to SAF by BMDV are for instance: REPOSE (Real-time Power Supply for e-fuels, [29]), REF4FU (Refineries for Future, [30]), SynergyFuels ([31]), M2SAF (Methanol to SAF, [32]). A BMBF funded project is called CARE-O-SENE (Catalyst Research for Sustainable Kerosene) is a German-South African research project for the new and further development of catalysts in the Fischer-Tropsch (FT) process. [33]

The Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V. is part of the Horizon 2020 project TULIPS, which aims to develop and demonstrate sustainability strategies in aviation. As lighthouse airport Amsterdam Airport Schiphol is the scene for different activities in order to reduce aviation-related emissions in ground and flight operations, hotel infrastructure, airport waste management and other, crosscutting fields. Fellow airports are Avinor in Oslo, Hermes at Cyprus and SAGAT in Torino. [35]

Whilst not a project in Germany: The PtX-Hub Germany is promoting SAF production from glycerin as byproduct of the biodiesel/FAME production in Brazil. The R&D project focuses on glycerol reforming to syngas and subsequent Fischer-Tropsch synthesis for SPK. PtX-Hub and PtX-Lab activities with focus on SAF are also part of the PtX centers in Berlin and the Lausitz region. [38]-[40] Moreover, German partners are involved in different EU projects, among others focusing on SAFs, like HyFlexFuel and ALIGHT. [41][42]

Independent of SAF production projects in Germany a prominent example for off-take agreements is DHL Express, a delivery unit of Germany’s Deutsche Post Group. They made an agreement with BP and Neste for about 640,000 metric tons[97] of SAF from waste oils until 2026 [3]. Together with the previously announced SAF off take agreements in the DHL airport network in San Francisco, East Midlands, the UK, and Amsterdam, this will exceed 50% of DHL Express’s target to reach 10% SAF by 2026. Under its sustainability targets DHL Group has committed to use 30% of SAF blending for all air transport by 2030. [43]

Another example is the Lufthansa Group (DLH) as one of the world’s leading airline. By 2030 the company aims to reduce its CO_2 intensity by -30,6% in comparison to 2019. Biobased and PtL-based SAF will significantly contribute to the target achievement. In order to ramp up the sourcing, DLH has committed to purchase SAF for 260 million USD between 2022 and 2024. In addition, DLH has agreed on several offtakes with major fuel suppliers (e.g. Shell, OMV and Varo Energy) in a volume of more than 2.6 million tons until the year 2030. Moreover, DLH contributes to a project with the swiss Synhelion on solar based SAF [48]. SAF is integrated into the sustainable product portfolio, both for B2C and B2B customers. Corporates can opt for SAF use on their individual flights and may claim the associated emission reduction through proprietary and third-party audited mitigation certificates.

Measurements of emission and performance of aircrafts when using SAF have been done e.g. by DLR in the German projects BurnFAIR (with binary SAF blends) and DEMO-SPK (with multiblend jet A-1) as well as in the ECLIF3 study with 100% SAF. All of them show that SAFs and their blends have the potential to reduce soot emissions and the climate impact of the resulting condensation trails. [44]-[50]

Despite the mentioned project activities there are many national actors being part of the SAF

[97] 800 million liters, $\rho_{HEFA\text{-}SPK}$=750 kg/m^3

supply chain with different value contribution, such as:

- Governmental institutions in charge: several ministries also leading the hydrogen strategy like BMDV, BMWK, BMUV, BMBF, BMZ as well as some federal state governments
- aireg e.V.[98] which is a strong association founded in 2011 with more than 40 national and international members from industry and science.
- Airports as infrastructures like FRA, HAM, MUC, STR, LEJ/DHL Hub
- Airlines like Star Alliance, Lufthansa (DLH), DHL Express
- Aviation OEMs like Airbus [51], who offer options of delivering new aircrafts (until now > 90) powered by blends of SAF since 2016, and Deutsche Aircraft GmbH [52], who developed the technologies with D328eco as flagship pre-equipped for the use of SAF.
- Refineries like BP in Lingen, Heide Refinery near Hamburg, Bayern Oil
- Engineering and manufactures are for instance EDL, HSC Group, Griesemann Gruppe, CAC
- Research institutions working on SAF are for instance DLR, Bauhaus Luftfahrt, TUHH, DBFZ, KIT, University of Bremen

References

[1] Schröder, J.; Naumann, K. (Ed.) (2023): Monitoring renewable energies in transport. (DBFZ-Report No.44) Leipzig: DBFZ. 314 p. ISBN: 978-3-946629-83-2. DOI: 10.48480/da50-sz04.

[2] BMVBS. The Mobility and Fuels Strategy of the German Government (MFS). New pathways for energy; 2013

[3] Link O. DHL Express ordert Rekordmenge an SAF; 2022

[4] Bullerdiek N, Buse J, Dögnitz N, Feige A, Halling A-M, Hauschild S, Hawighorst P, Kaltschmitt M, Kuchling T, Kureti S, Majer S, Marquardt C, Müller-Langer F, Neuling U, Oehmichen K, Pechstein J, Posselt D, Scheuermann S, Schripp T, Stein H, Zschocke A. Use of multiblend JET A-1 in practice. Summary of the results from the model project of the Mobility and Fuel Strategy. Leipzig; 2019

[5] Müller-Langer F, Dögnitz N, Marquardt C et al. Multiblend JET A-1 in Practice. Results of an R&D Project on Synthetic Paraffinic Kerosenes. Chem. Eng. Technol. 2020; 43: 1514–1521. doi:10.1002/ceat.202000024

[6] Oehmichen K, Majer S, Müller-Langer F et al. Comprehensive LCA of Biobased Sustainable Aviation Fuels and JET A-1 Multiblend. Applied Sciences 2022; 12: 3372. doi:10.3390/app12073372

[7] Ahlstrom J, Pricing of a fuels market in transition, Agrus media, ABC conference Stockholm, September 2022

[8] BDL. Master Plan - Climate Protection in Aviation. Measures for carbon neutral air transport; 2020

[9] Baker McKenzie. Sustainable Aviation Fuel (SAF) and the German PtL Roadmap -

[98] aireg e.V. | https://aireg.de/en/politics/members/ (last access: 03/2023)

Another Area of Application for Hydrogen Technologies; 2021

[10] Barthel S. German government, industry agree SAF development plan; 2021

[11] The Federal Government. PtL roadmap. Sustainable aviation fuel from renewable energy sources for aviation in Germany; 2021

[12] The Federal Government. The National Hydrogen Strategy; 2020

[13] Zech K, Naumann K, Müller-Langer F, Ponitka J, Majer S, Schmidt P, Weindorf W, Altmann M, Michalski J, Niklaß M, Meyer H, Lischke A, Fehrenbach H, Jöhrends J, Markwardt S. Biokerosin und EE-Kerosin für die Luftfahrt der Zukunft – von der Theorie zu Pilotvorhaben. Studie im Rahmen des Auftrags Wissenschaftliche Begleitung, Unterstützung und Beratung des BMVI in den Bereichen Verkehr und Mobilität mit besonderem Fokus auf Kraftstoffe und Antriebstechnologien sowie Energie und Klima für das Bundesministerium für Verkehr und digitale Infrastruktur (BMVI). Leipzig, München, Berlin, Heidelberg; 2016

[14] Zech K, Naumann K, Müller-Langer F, Schmidt P, Weindorf W, Mátra Z, Grimme W, Hepting M, Heidt C. Drop-In-Kraftstoffe für die Luftfahrt. Studie im Rahmen des Auftrags Wissenschaftliche Begleitung, Unterstützung und Beratung des BMVI in den Bereichen Verkehr und Mobilität mit besonderem Fokus auf Kraftstoffe und Antriebstechnologien sowie Energie und Klima für das Bundesministerium für Verkehr und digitale Infrastruktur (BMVI). Leipzig, München, Berlin, Heidelberg; 2014

[15] Batteiger V, Ebner K, Habersetzer A, Moser L. Power-to-Liquids - A scalable and sustainable fuel supply perspective for aviation; 2022

[16] Perner J, Bothe D, Lövenich A, Schaefer T, Fritsch M. Synthetische Energieträger - Perspektiven für die deutsche Wirtschaft und den internationalen Handel. Eine Untersuchung der Marktpotentiale, Investitions- und Beschäftigungseffekte; 2018

[17] Fuelling Flight initiative. Consensus Statement on Fuelling Flight: Response to the ReFuelEU Proposal. Im Internet: https://europeanclimate.org/wp-content/uploads/2022/01/consensus-statement-on-fuelling-flight-feb2022.pdf; Stand: 05.10.2022

[18] Bullerdiek N(T), Buse J(A), Kaltschmitt M(T), Pechstein J(T). Regulatory Requirements for Production, Blending, Logistics, Storage, Aircraft Refuelling, Sustainability Certification and Accounting of Sustainable Aviation Fuels (SAF). Operational requirements derived from the DEMO-SPK project conducted by DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, on behalf of the Federal Ministry of Transport and Digital Infrastructure of Germany; 2019

[19] BMWK. Initiative „Energiewende im Verkehr". Fossile Energieträger durch erneuerbare Alternativen ersetzen; 2022

[20] BMDV. Renewable Fuels (29.09.2022). Im Internet: https://www.now-gmbh.de/en/funding/funding-programmes/renewable-fuels/

[21] Dinh S. Power-to-Liquid Fuels. Development Platform (08/2021); 2021

[22] tagesschau. Speisefett-Kerosin aus dem Emsland; 2022

[23] Air BP. bp refinery in Lingen starts production of sustainable aviation fuel from used cooking oil; 2022

[24] Eickhold F, Ellmann B, Erdmann N, Goihl M, Möller K, Müller-Karpe Z, Posselt T, Pschera P, Richter A, Werner U, Zavisic A, Zeller H. Jahresbericht 2021; 2021

[25] personal communication with HCS group; 2022 (09.2022)

[26] Uniper SE. Green Fuels Hamburg - Das Projekt. Im Internet: https://www.green-fuels-hamburg.de/; last access 04.10.2022

[27] Schwarz R. Das HyKero-Projekt: Weltweit erste industrielle PTX-Anlage zur Herstellung von 50.000 t/a eSAF. Inspiring Technology; 2022

[28] KEROSyN100. Project website. Im Internet: https://www.kerosyn100.de/; last access 04.10.2022

[29] RePoSe, URL: https://erneuerbarekraftstoffe.de/wp-content/uploads/2023/02/RePoSe.pdf; last access 06.04.2023

[30] REF4FU, URL: https://erneuerbarekraftstoffe.de/wp-content/uploads/2023/03/Projektsteckbrief_REF4FU.pdf; last access 06.04.2023

[31] SynergyFuels, URL: https://erneuerbarekraftstoffe.de/wp-content/uploads/2023/03/Projektsteckbrief_SynergyFuels.pdf, last access 06.04.2023

[32] M2SAF, URL: https://erneuerbarekraftstoffe.de/wp-content/uploads/2022/11/M2SAF.pdf, last access 06.04.2023

[33] CARE-O-SENE (Catalyst Research for Sustainable Kerosene) is a German-South African research project for the new and further development of catalysts in the Fischer-Tropsch (FT) process. https://care-o-sene.com/en/

[34] personal communication with coordinator; 2022 (07.2022)

[35] TULIPS. Project website. About TULIPS. Im Internet: https://tulips-greenairports.eu/about/; last access 05.10.2022

[36] Aigner M. Konzeptionelle und technische Ausgestaltung einer Entwicklungs-Plattform für PtL-Kraftstoffe; 2021, URL: https://www.now-gmbh.de/wp-content/uploads/2021/08/EPP_Abschlussworkshop_Praesentationsfolien.pdf, last access 06.04.2023

[37] DLR, PtL technology platform – DLR research addresses the industrial production of electricity-based fuels, URL: https://www.dlr.de/content/en/articles/news/2023/01/20230315_ptl-technology-platform-dlr-research-addresses-industrial-production.html, last access 06.04.2023

[38] International PtX Hub. International Power-to-X Hub Berlin - Flyer. Im Internet: https://ptx-hub.org/wp-content/uploads/2021/06/International-Power-to-X-Hub-Berlin_Flyer.pdf; last access 04.10.2022

[39] International PtX Hub. German Cooperation promotes SAF production in the Northeast of Brazil. SENAI intensifies research on glycerin as feedstock for Sustainable Aviation Fuel. Im Internet: https://ptx-hub.org/german-cooperation-promotes-saf-production-in-the-northeast-of-brazil/; last access 04.10.2022

[40] PtX Lab Lausitz. Bundesminister Habeck nimmt Standort-Landkarte auf der ILA entgegen; 2022

[41] HyFlexFuel project. Project website. Im Internet: https://www.hyflexfuel.eu/; last access 04.10.2022

[42] ALIGHT project. Project website. Im Internet: https://alight-aviation.eu/; last access 04.10.2022

[43] Buyck C. Several New SAF Production Projects Emerge across Europe; 2022

[44] Zschocke A. Abschlussbericht zu dem Vorhaben Projekt BurnFAIR - Arbeitspakete 1.1 bis 1.4; 2014

[45] DLH, Lufthansa und Shell schließen zukunftsweisende Kooperation für nachhaltige Flugkraftstoffe, 08/2022 URL: https://www.lufthansagroup.com/de/newsroom/meldungen/lufthansa-und-shell-schliessen-zukunftsweisende-kooperation-fuer-nachhaltige-flugkraftstoffe.html (last access 05.04.2023)

[46] DLH, Lufthansa Group und OMV bauen Partnerschaft zu nachhaltigen Flugkraftstoffen aus, 09/2022, URL: https://www.lufthansagroup.com/de/newsroom/meldungen/lufthansa-group-und-omv-bauen-partnerschaft-zu-nachhaltigen-flugkraftstoffen-aus.html, last access 05.04.2023

[47] DLH, Airliners, Lufthansa investiert Rekordsumme in nachhaltiges Kerosin, 11/2021 URL: https://www.airliners.de/lufthansa-sichert-nachhaltiges-kerosin-viertelmilliarde-us-dollar/62816, last access 05.04.2023

[48] DLH, SWISS to be the world’s first airline to use Synhelion solar fuel, URL: https://cleantechhub.lufthansagroup.com/en/news/2022/swiss-to-be-the-worlds-first-airline-to-use-synhelion-solar-fuel.html, last access 05.04.2023

[49] Schripp T, Grein T, Zinsmeister J et al. Technical application of a ternary alternative jet fuel blend – Chemical characterization and impact on jet engine particle emission. Fuel 2021; 288: 119606. doi:10.1016/j.fuel.2020.119606

[50] Green Car Congress. Early results from ECLIF3 study on in-flight use of 100% sustainable aviation fuel in passenger jet show promise; 2021

[51] AIRBUS. Company website. Sustainable Aviation Fuel - A proven alternative fuel for immediate CO2 reduction. Im Internet: https://www.airbus.com/en/sustainability/environment/climate-change/decarbonisation/sustainable-aviation-fuel; Stand: 04.10.2022

[52] Deutsche Aircraft GmbH. Company website. The D328eco™. Im Internet: https://www.deutscheaircraft.com/products; Stand: 04.10.2022

Switzerland

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Sustainable aviation fuels are to play an important role for Switzerland in achieving its climate goals, but have not yet been rolled out on a large scale. References appear in the long-term climate strategy[99], the energy strategy (energy perspectives, respectively)[100] as well as the strategy for sustainable development 2030[101]. The latter foresees the creation of a national SAF strategy within its action plan 2021-2023[101]. This strategy was published in late 2022 and outlines the potential and action in developing SAF capacity[102]. Additionally, there are many stakeholders interested in the development and scale-up of SAF production, both in national projects and by participation in international projects.

Qualitative supply chain assessment

Currently, there is no local SAF production capacity in Switzerland. Actors mostly agree to the view, that most SAF demand in Switzerland will need to be covered by imports. Most cited reason for this is the lack of readily available, sustainable and economic feedstock and energy.

In the area of biogenic feedstock, the potential is (depending on the implemented technology) limited to existing local supply of used cooking oils and animal fat unsuited for human consumption, forestry and agricultural residues and MSW. Due to sustainability concerns, Switzerland does not support the dedicated local cultivation of biogenic resources for the purpose of SAF production.

In the area of synthetic fuels, local potential for solar fuels is severely limited by the comparatively low solar irradiation especially during winter. The potential for Power-to-Jet is somewhat contested and depends on renewable electricity production. Physically, there is potential for notable additional generation capacity, from hydropower, wind as well as solar. The challenges lie in the economics of production, especially regarding low load hours and the correspondingly high demand for intra-day as well as seasonal energy storage. For all sources, projects have historically faced delays due to lacking political or civic support. The recently intensified concern for the robustness of the Swiss electricity supply presents an additional hurdle for projects.

Nevertheless, there are actors interested in building SAF production capacity locally. Multiple projects, both for biogenic as well as synthetic SAF production, are currently in the concept phase, but have not yet been publicly announced. A notable actor in this area is the military, which faces an ambitions decarbonisation goal. To reach it, the Federal Department for Defense, Civil Protection and Sport plans to utilize sustainable fuels[103]. Decreasing the dependence on fuel imports is of interest as well. Therefore, demonstration plants for the development and possibly production of sustainable fuels are investigated as well.
and is furthermore interested in achieving a partial autonomy in terms of fuel supply.

Beyond the local production of SAF, a number of actors are heavily involved in the

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99 https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/emission-reduction/reduction-targets/2050-target/climate-strategy-2050.html
100 https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html/
101 https://www.are.admin.ch/are/en/home/sustainable-development/strategy/sds.html
102 https://www.bazl.admin.ch/bazl/en/home/themen/bazl_vorstellung/medien/Medienmitteilungen.msg-id-92234.html
103 https://www.vbs.admin.ch/de/umwelt/umweltschutz/energie-und-klima.html

development of technologies related to the production of SAF. These are discussed in the section "National strengths and potentials".

In terms of import, a lack of administrative procedures has hampered the import of considerable quantities up to 2020 (see section "Legal framework and strategies" below). In 2021, a total of 591 tons (740'000 l) has been imported. The first batch of HEFA-SAF was ordered by Swiss International Airlines, produced by Neste and supplied (in pre-mixed form) to the Zurich Airport, where it was fed into the main kerosene fuel system.

Table 17: Aviation fuel availability in Switzerland (2019)

Aviation Fuel	Domestic production volume [million l]	Import volume [million l]	Export volume [million l]	Carbon intensity [gCO_{2eq}/MJ]	Production costs [USD/l]
Jet A1	-	~2'200	-	-	-
HEFA-SPK	-	-	-	-	-

Production of both biogenic and synthetic SAF is currently zero and thus lower than the theoretical potential. Therefore, projects could tackle that difference. The main challenge in this regard is the business case. Costs for raw materials as well as labour is comparatively high in Switzerland. Success in this regard hinges on offtake agreements, ideally by actors willing to pay a premium for local production. However, commitment in this regard is so far scarce, as the investment risk is perceived as being too high.

Additionally, there is a significant competition around raw materials that can be used for (other) energy applications. This applies to oils that can also be used to produce road fuels, but methane, hydrogen and electricity as well.

Legal framework and strategies

Currently, biogenic fuels including SAF are fostered by the Mineralölsteuergesetz (MinöStG, law on taxation of mineral oil)[104]. This taxation on fuels only applies to aviation fuels, it they are used on flights within Switzerland. For such fuels, it is set at 739.5 CHF per 1000 liters. SAF are exempted, if they comply with a set of sustainability criteria[105]. These criteria however were not coordinated with existing international standards. What turned out to be a hindrance was the requirement that SAF needs to be imported as a segregated liquid (i.e. segregated from non-fossil, non-sustainable feedstock over the whole production and transport chain).

Furthermore, the Swiss emission trading system (ETS), which is linked to the EU ETS, allows crediting of SAF use within Switzerland[106].

[104] https://www.fedlex.admin.ch/eli/cc/1996/3371_3371_3371/de
[105] https://www.bazg.admin.ch/bazg/en/home/information-companies/taxes-and-duties/importation-into-switzerland/petroleum-tax/biofuels.html
[106] https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-

The Federal Council has proposed an update to the currently active law on CO_2 emissions[107]. This legislation proposal includes quota for SAF, following the example of the ReFuelEU Aviation proposal by the European Commission. The goal is to support the creation of the European SAF market, without any notable differences either in the height of the quota or the applying sustainability criteria.

Additionally, the proposed law includes an article for funding of the development of synthetic aviation fuels, yearly providing funds in the amount of 30M CHF[107]. This proposal is planned to be discussed in Parliament in 2023.

Further links apply to the “Klimaschutzgesetz”, a proposed law that includes goals for defossilization of the aviation sector as well as possibly additional funds for promising technologies in this area[108].

The Federal Office of Civil Aviation (FOCA) has published a national strategic report on how to foster the development and use of SAF[101]. It includes three main goals and measures to work towards them: Achieving the full potential of SAF (at least 60% of reduction of CO_2-emissions in aviation), supporting the upscaling of SAF production (especially by providing funds for development), and facilitating framework conditions. Furthermore, synthetic SAF have been recognized in the long-term national climate strategy[99] as featuring the highest potential to lower the climate impact of civil aviation.

On behalf of FOCA and the Federal Office for the Environment (FOEN), the Swiss Road Map for Sustainable Aviation (RMSA) was elaborated[109], analyzing the potential of different measures to lower the climate impact of civil aviation. A share of around 70% of the total potential was attributed to SAF.

So far, no explicit target has been set into law.

Responsibility for SAF is distributed among many governmental institutions:

- FOCA is responsible for aviation aspects, including ICAO/CAEP topics such as CORSIA and relating standards.
- FOEN is responsible for environmental aspects, including sustainability criteria and crediting SAF use for the Swiss emission trading system.
- SFOE (Swiss Federal Office of Energy) is responsible for energy aspects, including the energy strategy and perspective up to the year 2050 and beyond.
- FOCA, FOEN and SFOE each oversee some funding opportunities for projects in this domain. At FOCA, the “Spezialfinanzierung Luftverkehr” (Air traffic special funding)[110] can provide funds for projects which lower or generally investigate the impact of aviation on the environment. SAF corresponds to a focal point within this funding instrument. At SFOE, there are two funding instruments which are relevant in this context: SWEET (Swiss Energy Research for the Energy Transition)[111] and the Pilot and Demonstration programme[112].

measures/ets/aviation.html
107 https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-86492.html
108 https://www.bafu.admin.ch/bafu/de/home/themen/klima/dossiers/klimaschutzgesetz.html
109 https://www.arcs.aero/de/node/250
110 https://www.bazl.admin.ch/bazl/de/home/themen/finanzhilfen-luftverkehr/spezialfinanzierung.html
111 https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/funding-program-sweet.html
112 https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/pilot-and-demonstration-

- FOCBS, the Federal Office for Customs and Border Security is responsible for taxation as well as import and export of SAF and other fuels.
- Armasuisse, the Federal Office for Defence Procurement, is responsible for military aspects.
- Other stakeholders include the Federal Office for National Economic Supply (FONES), as well as the Swiss Innovation Agency Innosuisse and the Secretariat for Education, Research and Innovation (SERI) for some funding instruments in this topic.
- Furthermore, national universities are active in research in this area, especially ETH Zürich, Empa, PSI as well as EPFL.

National strengths and potentials

- **Knowledge and capability, technological expertise**

Switzerland features an excellent network of universities and universities of applied sciences, many world-renowned. These have led to significant discoveries in the field of SAF technologies, such as direct air capture or solar fuels. See the list below for the most important actors in this field. Furthermore, notable technology providers in this field are based in Switzerland or feature local representative offices.

- **Supply chain and conversion technologies**

In the areas of biogenic supply chains as well as related technologies, there are so far only limited contributions from Switzerland. Studies regarding the potential of biogenic sources for the energy system exist, but have not yet allocated a potential specifically to SAF. However, many crucial building blocks for SAF of non-biogenic origin are being developed in Switzerland: Climeworks offers world-leading technology in the area of CO_2 capture, Synhelion has demonstrated the production of SAF with direct use of solar energy. Currently, Metafuels is working on the conversion of methanol to jet fuel.

- **Partnership and networks, stakeholder relations**

Within the academic domain, as well as between academia and industry, there is a network of collaboration, fostered by previous and current projects and funding instruments such as SCCER, SWEET, Innosuisse and others. This allows the coverage of multidisciplinary topics by experts in each respective sub-topic. Nevertheless, some synergies are yet unused and feature further potential for thus the pooling of Switzerland’s capacity for innovation.

- **Market creation (standards, investment support, blending mandates, etc.) and willingness to implement (drivers, policy tool kit…)**

In the last few years, the topic of SAF has significantly increased its importance in Switzerland. Many actors are highly motivated to contribute to a quick upscaling of SAF capacity. However, there are currently lacking incentives for the market to develop. This could be tackled by the introduction of blending mandates by the Federal Council following its draft for the revision of the CO_2 law. This is expected to significantly help to kick-off the necessary investments. Questions remain with regard to the actual implementation including the values of the quota.

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programme.html

- **Roadmaps, strategies**

The abovementioned strategies (climate, energy, sustainable development, SAF) include clear messages regarding the potential of SAF. The same applies to the Swiss Roadmap for Sustainable Aviation (RMSA)[109]. One unknown that influences all strategies and roadmaps is the development of demand for air traffic over time.

- **Summary national strengths ("powerhouse")**

Switzerland has established itself as a powerhouse of technological expertise in the field of synthetic SAF. In terms of market development, hopes are placed on blending mandates which are harmonized throughout Europe. Actors expect that the largest share of SAF will need to be imported.

Challenges for market uptake

- **Feedstock & Conversion**

As stated above, feedstock availability is limited in Switzerland. The challenge lies in the combination of suitable feedstock that is available at scale, with low environmental impact and for reasonable prices.

- **Supply & Operations**

The challenges of SAF supply in Switzerland are similar to the global ones. Unlike kerosene (and AVGAS) which is readily available and traded as a commodity, SAF requires deeper stakeholder engagement. Airlines need to work together with fuel suppliers, technology providers, feedstock providers as well as the financial sector to enable the foreseen scaling up of SAF capacity.

For actors in technology development, of which many are located in Switzerland, timely certification of their product is crucial. This again requires close collaboration between developers, the administration, certification bodies on international level such as ASTM. The same applies for standards by ICAO/CAEP and by the EU. All schemes where SAF is to be credited need to be considered.

- **Markets & Policy**

According to information from stakeholders, the announcement of draft legislation with SAF quotas has thus far not resulted in a tangible impact on the market. As soon as these legislations – i.e. in the EU and Switzerland – are passed, this is expected to change. So far, markets are held back by insufficient demand signals and high technological uncertainty.

An often cited challenge is to avoid market distortion. Due to the internationality of aviation, measures generally have to take into account the effects of passengers evading national measures by choosing to fly from airports just beyond the border. With respect to the outlined SAF quota, this means that any kind of deviation from EU quota are prone to miss their target. This applies both to the respective values of quotas, but especially to sustainability criteria as well. As has been shown in the context of the "Mineralölsteuer", diverging Swiss specifications can seriously hamper the import of SAF (i.e. raise costs) or outright make it impossible. Thus, the legislative proposals at hand aim to avoid any such "Swiss Finishes".

Even with a European harmonization, some aviation stakeholders fear the effect of carbon leakage by long distance flights with a layover just beyond the European area where quotas do not apply for the continuation of the flight. This is feared to create a disadvantage for local operators that are obliged to use SAF on an entire long distance trip without any layover. So far, no countermeasures have appeared in the political discussion. This issue would be resolved by a global harmonization, which Switzerland strives for at ICAO level.

The support requirements for funding by public authorities vary with the respective funding requirement. Owing to the large number of relevant funding instruments, the requirements are not listed in this assessment. Rather they are readily available on the official webpages, if not always in English. Further support schemes have yet to materialize, subject to laws in the legislative process.

National actors along the value chain

Table 18: National actors Switzerland

National Actor	Type of company/association	Description (including potential role regarding SAF)
Feedstock supply		
H_2 providers		There are multiple Swiss projects in the hydrogen domain. Most notably, the availability of hydrogen is pushed for use in mobility by actors such as the H2 Mobility Switzerland Association (Förderverein H2 Mobilität Schweiz), H2 Energy Holding and Hydrospider.
CO_2 providers		There are a number of CO_2 point sources, most notably cement manufacturing plants and waste incineration plants. The latter have signed an agreement with the federal administration to install an annual CO_2 capture capacity of 100'000 tons up to 2030.
MeOH providers		Methanol as a possible feedstock for the production of SAF is brought into discussion due to technologies studied by companies such as Metafuels. In this regard, a number of Swiss companies are developing capacity for the renewable production of methanol, most notably including Methanol Casale and Methanology. Swiss Liquid Future has also performed pioneering work in this regard.
Fuel production		
VARO	Corporation	VARO is the owner of the only active refinery for fossil fuels in Switzerland, processing mainly crude oil so far. It has announced a strategy committing itself to reach Net Zero in 2040, including Scope 1, 2 and 3 emissions. To this end, it is investing over

		$2bn in renewable energies up to 2026. This includes investments in biofuels and specifically SAF.
Helvoil	Corporation	Helvoil is planning to set up a plant in the canton Wallis for the production of sustainable fuels from used cooking oil, both for the road and aviation sector. They foresee a yearly production of 80’000 tons, starting in 2024.
Fuel consumption		
Swiss International Air Lines	Corporation	SWISS is the airline with the highest share of available seat kilometers departing from Switzerland and thus the highest fuel demand. As a subsidiary of the Lufthansa Group, it has set itself a net-zero goal for 2050 and wants to half its specific emissions until 2030.
Federal Depart-ment of Defense, Civil Protection and Sport DDPS	Administration	The DDPS features the highest demand for aviation fuel within Switzerland (excluding intl. flights). With its action plan energy & climate, it has outlined steps to reach net-zero in 2050 and before that lower its emissions by 40% until 2030.
SR Technics	Maintenance, Repair and Overhaul	SR Technics is an MRO service provider located at the Zurich airport. Due to its engine testing activities, it features a comparatively high demand for jet fuel. SR Technics works together with FOCA on measuring pollutant emissions from engines, including the impact of SAF on pollutant emissions.
Aviation OEMs		
Pilatus Aircraft	Corporation	Pilatus is an aircraft manufacturer located in Switzerland, mainly producing trainer and transport planes as well as business jets.
RUAG Holding	Corporation	RUAG is a company owned by the Swiss Confederation. With its Aviation division, it performs maintenance and overhaul for aircraft. Its Aerostructures division manufactures components for civil and military aircraft.
SAF technology providers		
Climeworks		Climeworks is one of the leading providers of CO_2-Capture technology, especially for direct air capture. Their technology is applied both for CCS and CCU projects.

Synhelion		Synhelion is pioneering Sun-to-Liquid technology, producing drop-in fuels with direct utilization of solar heat. They are pursuing an ambitious roadmap with their plants increasing in size every generation. There is an offtake agreement in place with SWISS for all SAF from the current as well as next generation plant.
Metafuels		Metafuels is developing a technology to convert methanol to jet fuel, providing a much sought-after component for Power-to-Liquid fuels. This allows avoiding the use of the inefficient Fischer-Tropsch synthesis.
Research institutes		
General		There is a number of renowned universities and universities of applied sciences in Switzerland. Many of them are active in areas with interfaces to jet fuel production.
ETH Domain		Most prominently, the ETH domain is fostering research in this area, which has already led to the establishment of its spin-offs Climeworks and Synhelion. The ETH domain includes ETH Zürich, EPFL, Empa, WSL and the Paul Scherrer Institute.

References

1. Federal Council (2021): Long-term climate strategy to 2050. Bern.
2. Prognos / TEP Energy / Infras / Ecoplan (2020): Energieperspektiven 2050+ Kurzbericht, im Auftrag des Bundesamts für Energie. Bern.
3. Federal Office for Spatial Development ARE (2021): 2030 Sustainable Development Strategy. Bern.
4. Federal Office of Civil Aviation FOCA (2022): Report by FOCA on fostering the development and uptake of sustainable aviation fuels. Bern.
5. Federal Department of Defense, Civil Protection and Sport DDPS (2021): Aktionsplan Energie und Klima VBS. Bern.
6. Law on taxation of mineral oil, version from 01.01.2022
7. Sustainability criteria of the law on taxation of mineral oil
8. Agreement between the EU and Switzerland on the greenhouse gas emissions trading system (ETS), version from 15.12.2021
9. Draft for CO_2-Law, version at publication by the Federal Council from 16.09.2022
10. Climate protection law, version for public vote at 18.06.2023
11. Ecoplan (2021): Swiss «Road Map Sustainable Aviation». Bern.

12. Air traffic special financing (Spezialfinanzierung Luftverkehr)
13. Swiss Energy Research for the Energy Transition
14. Pilot and Demonstration programme

USA

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Sustainable aviation fuels (SAFs) will be a critical part to achieve the greenhouse gas (GHG) emission reduction goal in the United States for the expected expansion in the U.S. aviation sector. In 2020, The White House has launched the SAF Grand Challenge[113] aiming to produce 3 billion gallons per year (BGY) of SAFs by 2030 and 35 BGY by 2050 meeting 100% U.S. jet fuel demand. In addition, the Inflation Reduction Act (IRA) signed into law in August 2022 includes provisions regarding SAF tax credits, which start at $1.25/gallon for SAF that achieves at least 50% life-cycle GHG reduction when compared to the fossil baseline and offer incremental incentives for additional reduction up to $1.75/gallon. Along with other existing programs in the United States such as California's Low Carbon Fuel Standard (LCFS) and Environmental Protection Agency (EPA)'s Renewable Fuel Standard (RFS), it is expected that U.S. SAF production will be increased.

To achieve the ambitious 2050 production volume target, a diversified SAF production pathway portfolio is required. Also, to quantify emission reduction benefits, the life cycle GHG emissions of particular SAF pathways need to be evaluated through comprehensive life-cycle analyses (LCAs). In this report, we present the current status of U.S. SAFs.

Qualitative supply chain assessment

SAF production technologies in the U.S. context can be classified into the following categories – oil-to-jet, gas-to-jet, sugar-to-jet, and ethanol-to-jet pathways.[114]

Oil-to-jet (OTJ)

The oil-to-jet (OTJ) technology converts various oil-based feedstocks, including vegetable oils, waste oils, and pyrolysis oil to SAFs. Vegetable oils are derived from oilseed crops, including soybean, canola, jatropha, camelina, and carinata. The waste oils include used cooking oil and animal grease. Pyrolysis oil feedstocks are produced from various types of biomass through pyrolysis processes.

The hydroprocessed renewable jet (HRJ), or also called hydroprocessed esters and fatty acids (HEFA) process, is of high maturity and is commercially available in the United States. The HEFA technology includes the following steps. The oil feedstock goes through the hydrotreating step to saturate the unsaturated fatty acids or glycerides. Then, free fatty acids (FFAs) are produced by the propane cleavage of glycerides. FFAs go through the deoxygenation step to produce paraffin, which is then isomerized and hydrocracked to jet-fuel alkane.

The catalytic hydrothermolysis (CH) technology is a novel process that has been developed by Applied Research Associates, Inc. The feedstocks employed by the CH technology are similar to the HEFA technology including oil from crops (e.g., soy oil and carinata oil) and waste oil (e.g., used cooking oil, brown grease, and yellow grease). The CH technology operates at a higher temperature and pressure, as compared to HEFA. Also, in CH

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113 Sustainable Aviation Fuel Grand Challenge. https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/09/fact-sheet-biden-administration-advances-the-future-of-sustainable-fuels-in-american-aviation

114 https://www.osti.gov/biblio/1278318

technology, FFAs are produced by thermal hydrolysis, instead of propane cleavage.

For pyrolysis oil-based jet fuel production, biomass is heated without oxygen to produce pyrolysis gas, biochar, and pyrolysis oil. Pyrolysis oil can then be refined to jet fuel, as with HEFA technology.

Gas-to-jet (GTJ)

Gas-to-jet (GTJ) uses syngas (carbon monoxide [CO] and hydrogen [H_2]) to generate SAFs through a Fischer-Tropsch (FT) process. Although fossil feedstocks such as coal and natural gas also can be used to produce syngas, they are excluded in the context of SAF production for their high GHG emissions. For biomass feedstocks, a wide range of woody biomass and agriculture waste feedstocks are used. Biomass is dried and milled, which is then sent to a gasifier to produce syngas containing CO and H_2, which is then processed by FT synthesis to produce liquid fuels, including jet, renewable diesel, and naphtha. Note that the water-gas-shift process can be applied to adjust the CO/H_2 ratio. In addition, biogas produced from the anaerobic digestion of organic matter can be used to meet the heat demand with low GHG impacts for the GTJ process.

Sugar-to-jet (STJ)

The sugar-to-jet (STJ) technologies use sugars obtained directly from crops such as sugarcane or sugar beet or indirectly from biomass through biochemical conversion involving pretreatment and enzymatic hydrolysis steps. Two different STJ conversion technologies are available. The biological route ferments sugar to produce hydrocarbons, [115] which is then separated, oligomerized, and hydrotreated to produce SAFs. The catalytic upgrading of STJ[116] includes steps such as hydrogenation, deoxygenation, and acid condensation to produce SAFs.

Alcohol-to-jet (ATJ)

The alcohol-to-jet (ATJ) technology converts alcohols (e.g., ethanol or butanol) from various biomass feedstocks into SAFs typically via three-step processes including dehydration, oligomerization, and hydrogenation. In the dehydration step, ethanol is dehydrated to ethylene, which then undergoes a catalytic oligomerization process to linear α-olefins. In the hydrogenation step, the linear α-olefins are hydrotreated, isomerized, and fractionated to jet-range alkanes. Ethanol can be produced from starch and lignocellulosic biomass, through both fermentative and thermochemical processes, while butanol is produced from fermentative processes.

Legal framework and strategies

There are extensive programs at the state and federal levels in the United States to reduce GHG emissions. These have promoted the biofuel production industry for the last two decades.

At the federal level, US Environmental Protection Agency (EPA) has Renewable Fuel

[115] https://www.nrel.gov/docs/fy14osti/60223.pdf
[116] https://www.osti.gov/servlets/purl/1346572

Standard (RFS), a program requiring certain amount of biofuels for use in the U.S.[117] RFS requires a certain volume of renewable fuels with several categories based on GHG emissions to be used for transportation fuels, which includes biodiesel, cellulosic biofuels, advanced biofuels, and renewable diesel. SAFs can be also approved under the current RFS program. However, RFS is designed for biofuels in general not specifically for SAFs. The program uses renewable fuel categories; fuels nested in the same category will get the same credit.

In 2022, the US government included additional SAF subsidies in the Inflation Reduction Act (IRA) facilitating SAF production.[118] SAFs with a minimum 50% GHG emission reduction compared to petroleum-based jet fuels qualify for $1.25/gallon SAF, which can go up to $1.75/gallon SAF with additional $0.01/gallon tax credit for each GHG emission reduction percentage through 2024. Then, clean-fuel production credits designed for biofuels will be applicable from 2025 to 2027. It is expected this incentive would promote SAF production in the United States.

California Air Resources Board (CARB) developed Low Carbon Fuel Standard (LCFS),[119] which is another venue where SAFs can get incentives. The LCFS program aims to reduce GHG emissions from California's transportation sector mainly by using low-carbon fuels. Unlike the EPA's RFS which uses renewable fuel categories (D-code), LCFS uses the carbon intensity values (gCO_2e/MJ) for the renewable fuel production pathway to calculate GHG emission reductions. Thus, fuels with more emission reductions will get more credits. Like other biofuels certified under LCFS, life-cycle GHG emission values (carbon intensities) of SAF production pathways are calculated through comprehensive life-cycle analyses. And the emission reductions will bring credits that could be traded at the market. Other states such as Oregon and Washington also have similar programs (Oregon Clean Fuel Program[120] and Washington Clean Fuel Standard[121])

The US federal strategies are well presented in its SAF roadmap document.[122]

National strengths and potentials

- **Large US aviation market for SAF**

The United States has had the largest jet fuel consumption globally. Based on the Annual Energy Outlook (AEO) by the US Energy Information Administration (EIA),[123] the US aviation sector is expected to keep increasing, 32% increase by 2050 compared to the 2019 level. Since the US government promotes replacing the entire petroleum jet with SAFs by 2050, the SAF market in the United States will increase accordingly.

- **Clear SAF goals and R&D activities to support SAF production**

With the ambitious SAF production goal of 35 BGY by 2050 by the federal government, there

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117 https://www.epa.gov/renewable-fuel-standard-program/approved-pathways-renewable-fuel
118 https://www.congress.gov/bill/117th-congress/house-bill/5376/text
119 https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard
120 https://www.oregon.gov/deq/ghgp/cfp/Pages/default.aspx
121 https://ecology.wa.gov/Air-Climate/Climate-change/Reducing-greenhouse-gases/Clean-Fuel-Standard
122 https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf
123 https://www.eia.gov/outlooks/aeo/pdf/AEO2022_Narrative.pdf

are significant research and development (R&D) activities supported by the Department of Energy (DOE). DOE's Bioenergy Technologies Office (BETO) has supported many SAF R&D projects to help produce and deploy SAFs. National laboratories supported by the US DOE have worked to produce SAFs from various feedstocks (e.g., biomass, waste feedstocks, and CO_2 emissions) through many conversion technologies (e.g., biochemical and thermochemical processes).[124]

University research teams and SAF producers have been also supported by the DOE's funding opportunities, which enabled bringing low technology readiness level (TRL) technologies to commercial-scale SAFs. For example, LanzaJet (and LanzaTech) has been supported from the stage of concept work to scale up with additional support. Similarly, SAF companies such as Alder Energy, Gas Technology Institute, SkyNRG, T2C-Energy have been supported by DOE to overcome the key technology barriers for the development of SAFs.[125]

U.S. Federal Aviation Administration (FAA) also supported R&D and deployment activities. The Aviation Sustainability Center (ASCENT) was established in 2013 under the authority of the FAA to support sustainable aviation projects.[126] ASCENT is an active research organization led by Washington State University (WSU) and Massachusetts Institute of Technology (MIT) with an overall goal to promote sustainability in aviation. Participating ASCENT organizations include universities and research organizations. Other federal agencies such as DOE, U.S. Department of Agriculture (USDA), FAA, and the National Aeronautics and Space Administration (NASA) have been advising the ASCENT. Funded research under ASCENT covers a wide variety of topics including SAF production technologies.[127] Through ASCENT, there are six SAF pathway candidates currently in the ASTM D4054 approval pipeline; three of which are U.S.-based (Shell IH^2's wood pyrolysis, Virent's synthesized aromatic kerosene [SAK], and ARA's catalytic hydrothermolysis jet [CHJ]). As of 2022, new candidates for ASTM D4054 include additional six SAF pathways, among which three pathways are U.S.-based: Prometheus Fuels' electrochemical CO_2-to-alcohol pathway, Alder Energy's Fast Track pyrolysis conversion, and Vertimass's ethanol-to-cycloalkanes pathway.[128]

- **SAF promotion programs**

It is expected that the US incentive programs will substantially boost investment in SAF production. The Inflation Reduction Act will promote SAFs compared to other biofuels (e.g., renewable diesel or renewable gasoline) in the near future due to more favorable subsidies. In addition, many states in the United States consider building energy programs that include SAF to reduce GHG emissions.

- **Substantial amount of biomass/waste feedstocks for SAF production**

[124] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuels
[125] https://www.energy.gov/eere/bioenergy/articles/us-department-energy-announces-more-64-million-biofuels-research-reduce
[126] https://s3.wp.wsu.edu/uploads/sites/192/2017/04/FINAL-ASCENT-2015-Annual-Report-05-2017.pdf
[127] https://ascent.aero/projects-by-topic/
[128] https://s3.wp.wsu.edu/uploads/sites/2479/2022/03/1500-4-5-Ascent_31-presentation-for-April-2022-v2.pdf

The 2016 Billion Ton report[129] indicated that the U.S. holds great potential for biomass feedstock production, including those from agricultural residues, forest resources, energy crops, and municipal wastes, summing up to 1.0–1.5 billion tons of biomass annually. The 2030 SAF production goal of 3 BGY requires 50 million tons of biomass; while the 2050 SAF production goal of 35 BGY requires 600 million tons of biomass. Therefore, the U.S. biomass production potential may be able to fully supply the future SAF need although it would compete with other sectors using biomass.

- **Active SAF producers**

New SAF pathways must be submitted to an ASTM D4054 voting process, which is the common production standard for alternative aviation fuels and fuel additives. It includes two testing phases, reviews by original equipment manufacturers (OEMs) and the FAA, and a ballot.[130]

The Commercial Aviation Alternative Fuels Initiative (CAAFI) has released a forecast of new U.S. SAF production endeavors up to 2027. By the end of 2022, the forecast estimates 20 million gallons per year (MGY) of SAF from ASTM D4054-approved fuel producers including Gevo, Fulcrum Bioenergy, World Energy, and Neste. Other contributing organizations in the 2027 timeframe include Red Rock Biofuels, LanzaJet, Phillips 66, Aemetis, USA BioEnergy, Velocys Bayou, and SkyNRG Americas. Together, SAF production is estimated to grow to 1.2 BGY by the end of 2027.[131]

Challenges for market uptake

- **High SAF production cost and uncertain future incentive programs**

Typical SAF prices are higher than that of petroleum jet fuels. Therefore, without strong incentives, SAFs are not currently cost-competitive compared to petroleum jet fuels. Although the current SAF incentive programs such as Inflation Reduction Act (IRA) 40B can help facilitate SAF production in the near future, fuel producers would need more stable revenue streams for longer-term investments.

- **Long SAF approval processes**

New SAF pathways must be submitted to the ASTM approval process to meet production standards. Feedstocks, conversion technologies, and product specifications must be specified. Typically, a new submission requires 2–5 years of ASTM review and approval. The testing process is time-consuming and costly; Phase 1 typically costs $300–$400K and Phase 2 can cost $3–5M. A Fast Track (Annex A4) approval requires only one phase of testing – as opposed to the full two phases – but this option is reserved for new pathways with minor modifications from existing ones. Fast Track pathways are limited to a 10% blend wall.[132]

[129] https://www.energy.gov/eere/bioenergy/2016-billion-ton-report
[130] https://www.astm.org/d4054-22.html
[131] https://www.caafi.org/focus_areas/docs/CAAFI_US_SAF_Production_Forecast_August2022.pdf
[132] https://s3.wp.wsu.edu/uploads/sites/192/2018/03/clearinhouse.pdf

- **Logistic challenges**

Due to regional mismatch among SAF feedstock production (e.g., farms), fuel production, and final applications (e.g., airports), there are logistic challenges to move feedstocks and SAFs.

National actors along the value chain

Table 19: National actors in the United States

National Actor	Type of company/association	Description (including potential role regarding SAF)
Fuel production*		
ARA[133]	Corporation	Catalytic hydrothermolysis (CH) / ReadiJet formation process. On track for first 100% ASTM approved CH jet fuel pathway.
Gevo[134]	Corporation	Alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK) producer. Meets ASTM D4054.
Virent[135]	Corporation	Synthesized aromatic kerosene (SAK) using BioForming sugar/biomass to jet process. Currently undergoing ASTM D4054 approval Phase 2 testing.
Fulcrum[136]	Corporation	Waste gasification to Fischer-Tropsch producer. Sierra Biofuels Plant in Reno, NV opened in May 2022 and is projected to convert 175,000 tons of landfill waste into 11 Mgal of SAF per year.
LanzaJet[137]	Corporation	Ethanol-to-jet synthetic paraffinic kerosene (ETJ-SPK) producer. Drop-in fuel meets ASTM D7566 Annex. In 2022, LanzaJet partnered with Marquis to commit 120 Mgal of SAF per year at the Marquis plant in Hennepin, IL.
Neste[138]	Corporation	Processes waste fats, oils, and greases (FOGs) through hydrodeoxygenation, a HEFA-like process. Trademarked as MY SAF. Currently produces 125,000 gal of SAF per year and plans to increase production to 1.875 Mgal per year.

133 https://www.ara.com/products/readijet/
134 https://gevo.com/products/sustainable-aviation-fuel/
135 https://www.virent.com/technology/bioforming/
136 https://www.fulcrum-bioenergy.com/our-fuel-process
137 https://www.lanzajet.com/what-we-do/
138 https://www.neste.com/products/all-products/saf#0cd83b98

Fuel consumption		
United Airlines	Corporation	The company committed to reducing GHG emissions 100% by 2050 mainly by using SAF and direct air capture.[139]
American Airlines	Corporation	The company announced a target of carbon neutrality by 2050. By 2030, it aims to achieve 10% SAF use across the member airlines.[140]
Delta Airlines	Corporation	The company targets to replace 10% of its jet fuel using SAF by 2030.[141]
Southwest Airlines	Corporation	The company plans to replace 10% of total jet fuel with SAF by 2030 and to achieve carbon neutrality by 2050.[142]
Aviation OEMs		
Boeing	Corporation	Boeing targets to deliver commercial airplanes that can fly using 100% SAF by 2030.[143]

*Estimates were obtained from fuel producers and may not match CAAFI forecasts

139 https://www.united.com/ual/en/us/fly/company/global-citizenship/environment/100-percent-green.html
140 https://news.aa.com/news/news-details/2022/American-Furthers-its-Commitment-to-Sustainable-Aviation-Fuel-CORP-OTH-07/
141 https://www.delta.com/us/en/about-delta/sustainability
142 https://www.southwest.com/citizenship/planet/sustainable-aviation-fuels/
143 https://boeing.mediaroom.com/2022-02-07-Boeing-Buys-Two-Million-Gallons-of-Sustainable-Aviation-Fuel-for-its-Commercial-Operations

Best practice examples

A series of three online seminars has been organized between 3rd November and 1st December, 2022. The aim of these seminars was to highlight best practice examples for the market uptake of SAF so that other stakeholders can learn from them. The seminars focused on the following topics: Supply & Operation, Feedstock & Conversion and Market & Policy. This chapter provides a brief summary of the seminars; recordings (incl. Q&A) and presentations are available on the task website[144].

Supply & Operation

After opening words and an introduction by the moderator **Dina Bacovsky (BEST)** the seminar started with a presentation by **Alexander Bjørn Hansen (NISA)** on results of the ALIGHT project. Aim of the project is to showcase a way to the sustainable airport of the future with e.g. Copenhagen Airport as a case study. So far there is no indication that there are any issues with blending SAF except for administrative ones. There are three ways for SAF delivery - segregated delivery, mass balance and book & claim. However, only a physical delivery of SAF allows for reducing regional non-CO_2 effects. SAF demand will increase in future and as a result sustainable feedstock availability will decrease, since waste feedstocks are limited. Therefore, e-fuels are expected to become a game changer. So far SAF is not available in Denmark. When there is no physical delivery possible, chain of custody becomes even more important.

Henrik von Storch (DHL Group) presented the role of SAF in decarbonizing logistics. DHL Group aims for becoming a leader in sustainable aviation since currently about 70% of their GHG emissions are related to aviation. In 2020 they started to buy low volumes of SAF. In 2022 these volumes increased to about 28.000 tons (plus additional volumes via 3rd party carrier airlines), which is still a small share but already relevant in total. A steady increase is planned. Main issues for SAF introduction are increasing price premiums (tight market due to increasing demand but stable production facilities), low investment security (there are companies willing to produce, but uncertain regulations hinder them) and sustainability requirements (differences across the globe lead to uncertainties, chain of custody). DHL Group is highly in favor of book & claim, which is needed when a costumer/passenger wants to purchase SAF in a specific plane. Additionally, small SAF suppliers can only deliver SAF to specific airports. A central SAF registry is required to enable book & claim. DHL Group has an own sustainable fuel policy to cover different frameworks around the world (CORSIA, US, EU, etc.).

Subsequently, **Franziska Müller-Langer (DBFZ)** presented results of the DEMO-SPK project, which was investigating behavior of multi-blend SAF in practice. Key results include a reduction of particle emissions in ground runs between 30% and 60% and a reduction of GHG emissions by about 35% through the use of multi-blend SAF instead of fossil Jet A-1. In practice, multi-blend of SAF cannot be avoided, but the results show that this does not lead to any problems. There were no adjustments of airport infrastructure with regard to fuel storage and delivery needed. The project further shows that multi-blend SAF meet ASTM requirement if the single fuels are doing so. E-fuel based PtL can also meet these requirements.

The final presentation of this seminar was covering the U.S. perspective and was held by **Steve Csonka (CAAFI)**. SAF are not really new, they are pure hydrocarbons in the jet fuel range (C7 to C17). This is why they don´t need to be necessarily handled in a different way.

[144] https://www.iea-amf.org/content/events/web_seminars/webinars_task63

Worldwide there are six production facilities in operation, with Neste as market leader in 2021.In the U.S. there are two production facilities in operation and several others are in commissioning, under construction or announced. The production forecast for 2027 is about 60 times higher compared to 2022, which indicates a significant ramp-up. Currently, renewable diesel is favored in terms of policies. A lot of offtake agreements have been already signed between future producers and airlines. U.S is unlikely to dismiss agricultural crop-based feedstocks for SAF production. There is no single feedstock targeted, nor sufficient. The biggest challenge remains the cost delta between SAF and fossil Jet A-1. However, there is increasing engagement from buyers, regulators, policy-makers, producers, etc. in the U.S., but also worldwide. The governmental program “SAF Grand Challenge” aims for 10% SAF by 2030 and 100% SAF by 2050.

Feedstock & Conversion

The moderator **Paula Isabel da Costa Barbosa (EPE)** opened the seminar with an introduction of IEA AMF and the speakers. The first presentation on SAF opportunities in Brazil was given by **Donato Aranda (Federal University of Rio de Janeiro)**. Brazil has a long history with biofuels production, especially with bioethanol production, but also biodiesel. The regulatory framework is supportive. Besides HEFA, the Alcohol-to-Jet pathway is very promising for Brazil. The average production cost for SAF is estimated with 0.50€/l, which is competitive to fossil Jet-A1. The biggest share (> 85%) of costs is due to feedstock costs. With an input of about 165,000 t/a of hydrous ethanol (and hydrogen), about 100,000 t/a SAF can be produced, with water as a by-product. Hydrogen can be produced from biogas, which has a huge potential in Brazil.

Subsequently, **Susan van Dyk (University of British Columbia)** presented potential and challenges of technologies for SAF production and commercialization status. The presentation covers a report published by IEA Bioenergy Task 39. SAF is essential to reduce emissions from aviation. Currently, production is low, but many new facilities are planned or under construction. IATA plans net-zero aviation by 2050, the estimated volume of SAF needed to achieve this target are > 400 billion liters. This would require construction of 5,000 to 7,000 new facilities by 2050. Main challenges for market uptake are slow technology scale-up, high costs, low availability of sustainable feedstock and SAF and lack of adequate policy support. HEFA is currently the main pathway, but until 2030 also Gasification-FT and ATJ will produce significant amounts. PtL will take longer to be fully commercial. However, all SAF technology pathways are needed to achieve the targets of the sector. The development of SAF is driven by policies. Major policies are the ReFuelEU Aviation (EU) and the Inflation Reduction Act (USA). Policies will be critical to bridge the price gap between SAF and fossil Jet-A1.

The final presentation addressed vertical integration for SAF and HVO production in Brazil and was held by **Andréia Almeida (Brasil Biofuels)**. The operations of Brasil Biofuels include the generation of renewable energy and biofuels originated from oil palm cultivation in degraded areas in the Amazon region. Energy is produced and distributed in isolated systems, with no access to the national power grid. An agricultural zoning initiative mapped all areas which are suitable for sustainable oil palm cultivation, considering only areas which have been deforested before 2007 (31 million hectares). Brasil Biofuels are reforesting these degraded areas and cultivate oil palm. Brazil consumes about 7 billion liters of aviation fuel per year. The transition to SAF is relevant, since Brazil committed to CORSIA. There is a production of about 500,000 t/a of vegetable oil on 100,000 hectares planned. The project is also positively contributing to socio-economic development through e.g. cooperation with the Family Farming Program. The investment for the biorefinery (not including e.g. soil preparation) is about 400 million USD. The biorefinery is planned to start production in 2025.

Market & Policy

The final online seminar started with opening words by the moderator **Michael Wang (Argonne National Laboratory)**. **Robert Malina (Uhasselt)** held the first presentation on CORSIA, the first international adopted approach to calculate and credit lifecycle GHG emissions for aviation fuels. This approach by ICAO is important since emissions from international aviation are not included in nationally determined emission reduction contributions. The aviation sector voluntarily committed itself to CO_2-neutral growth from 2020 onwards and to becoming net-zero CO_2 by 2050. The CORSIA mechanism compares a baseline with the actual CO_2 emissions of the sector. The gap defines the CO_2 offsetting requirement of the sector. The baseline is lowered over time to e.g. 85% of CO_2 emissions in 2019 (from 2024 to 2035). This means that the offsetting requirement is increasing. CORSIA eligible Fuels (Sustainable Aviation Fuel = SAF or Lower-Carbon Aviation Fuel = LCAF) are considered as alternative to the offsetting requirement and are therefore decreasing the requirement for the operator. The aviation fuels must comply with the CORSIA sustainability criteria. These currently cover GHG emissions and carbon stock, but will be expanded by further criteria in 2024. Countries voluntarily committed to CORSIA. However, this approach will become mandatory for international aviation.

The second presentation about the expected role of SAF in decarbonizing international civil aviation was given by **Matteo Prussi (Denerg Politecnico Di Torino)**. Before the COVID pandemic, the aviation sector was continuously growing. Now the sector is still recovering. The combustion of fuel is expected to further grow in the future. SAF are an effective short to medium-term measure to decarbonize aviation (by over 90% as defined in CORSIA). ICAO published its long-term global aspirational goal (LTAG) feasibility study. The study is assessing the net-zero carbon emissions by 2050 goal using 3 main integrated scenarios. The relevance of SAF can be clearly seen. For creating the scenarios, the marginal abatement cost (costs per ton of abated CO_2) has been established in LTAG. This is an important decision support tool for investors for choosing the most efficient technology. At European level a volumetric SAF share is being discussed. A share of 5% SAF would be around 3 Mtoe/a of SAF, which represents 17.5% of current EU27 biofuel consumption in the whole transport sector. To reach the targeted share, a huge amount of feedstock is required and it has to be ensured that the required feedstock is sourced sustainably. One strategy to ensure sustainable feedstock availability (also though competition with e.g. the maritime sector) is increasing the potential feedstock pool. However, an analysis confirmed that feedstock availability will not be the major barrier in the short term, but feedstock costs, price volatilities and the effective sustainable feedstock mobilization.

The seminar continued with **Andrei Mungui (DG Move)**, presenting SAF in the context of the Fit-for-55 package (EU policies and proposals). Aviation and resulting emissions become more important for the society. There are five initiatives with direct effects on aviation within the Fit-for-55 package, namely ReFuelEU Aviation Initiative, Renewable Energy Directive, EU Emission Trading System, Energy Taxation Directive and Alternative Fuel Infrastructure Regulation. The ReFuelEU Aviation aims for a gradual ramp-up of SAF while maintaining a well-functional aviation market (level playing field in the aviation sector). SAF have to be made available for airlines at competitive prices. The aim is a gradual increase of the SAF share, with a sub-target on synthetic fuels. Eligible SAF are biofuels produced from waste oils and fats, advanced biofuels from waste and residues (listed in Annex IX of the Renewable Energy directive) and synthetic fuels (PtL). An enlargement of base is discussed to recycled-carbon fuels, nuclear-based e-fuels and renewable hydrogen. The targets have to be achieved by fuel suppliers. The operators have to buy the SAF provided. The regulation applies to all air operators flying from EU airports. Supporting/flanking measures include intensifying European efforts at ICAO, creation of the Renewable and Low-Carbon

Fuels Value Chain Industrial Alliance (tinder for fuels) and regulatory support towards SAF update (CORSIA, EU-ETS, etc.).

The final presentation was held by **Michael Wang (Argonne National Laboratory)**, speaking about US policies and programs for decarbonizing the aviation sector. The aviation sector accounts for 11% of US transportation GHG emissions. The US Aviation Climate Goal of the transportation department is reaching net-zero GHG emissions by 2050, including international as well as domestic flights for US operators. Another activity is the US Governmental SAF Grand Challenge which foresees a minimum reduction of 50% in life-cycle GHG emissions, a near-term (3 billion gallons in 2030) and a long-term goal (35 billion gallons in 2050, representing 100% of US aviation fuels) as well as detailed roadmap document. To achieve these goals, about 400-500 refineries will be required. A sharp ramp-up of SAF production facilities is expected, but the goal is still ambitious. The 2022 Inflation Reduction Act (IRA) provides incentives (tax credit for fuel producers) for SAF sold or used from 2023. There are also incentives for clean transportation fuels and clean hydrogen. There are specific grant opportunities from the Federal Aviation Administration ($297 million). Argonne generated LCA values of SAF pathways using GREET, which includes details of both biofuel feedstock and conversion. SAF LCA results show significant emission reduction potential, depending on pathways and feedstocks. Carbon capture can even lead to negative emissions.

Conclusions and Outlook

Global aviation currently causes about 2% of global GHG emissions. The aviation industry supports the Paris accord and has committed to achieving net-zero CO_2 emissions by 2050. Next to efficiency measures and technology development, Sustainable Aviation Fuels will have to deliver an important contribution to this target.

Production of SAF can be based on biomass or renewable electricity, and nine pathways have been certified by ASTM so far. As of early 2023, almost all SAF on the market is produced through hydrotreatment of lipids, producing HEFA-SPK. Other promising pathways are gasification and FT-synthesis and the Alcohol-to-Jet pathway. Since the availability of lipids will be lower than required to substitute for fossil jet fuels, it is necessary to broaden the feedstock base and develop technologies to convert more abundant feedstocks into SAF.

Globally there are only a few production facilities for SAF in operation, and the volume produced covers less than 0.1% of jet fuel demand. Interest in the sector, however, is large, and 97 offtake agreements, with a total quantity of about 41,800 million liters, have been signed. SAF production capacity in the US for example is foreseen to be 60 times higher by 2027, compared to 2022. The impact assessment of the ReFuelEU Aviation initiative foresees the need for around 105 SAF production facilities in Europe by 2050.

The main challenges to the quick market deployment of SAF are:

- High production costs of SAF compared to conventional jet fuel
- Limited availability of sustainable feedstock (biomass, electricity)
- Lack of clear international regulations and alignment between them

Although SAF production technologies other than through hydrotreatment still have to be further developed and deployed, neither production technology nor technical issues when operating aircrafts on SAF are seen as challenging. The implementation of SAF is, first and foremost, an economic problem, not a technical one. Policies are needed to create market demand and help off-set the price difference between SAF and fossil jet fuel.

Yet, care needs to be taken to safeguard sustainable feedstock supply, efficient conversion, and reliable sustainability certification. Sustainability criteria for SAF need to be harmonized globally, along with an internationally agreed method of calculating carbon intensity (i.e. GHG emissions) of SAF and an international SAF registry, enabling supply, trade and use of SAF globally. With this, the aviation sector can continue operating internationally while reducing its carbon footprint.

The Advanced Motor Fuels TCP is eager to support this development through cooperative R&D and information exchange. Several areas of interest have been identified as follows:

- Based on the overview on the current status of SAF development and deployment, as provided through the work at hand, AMF could provide short summary reports (2-3 pages) to support and inform IEA analysis, e.g. on the current status; the key components for successful policy design; how to ensure sustainable production of SAF and SAF feedstocks; technology primers.
- Further desktop work, potentially in collaboration with the Bioenergy TCP, could include:
    - Monitoring of SAF R&D, demonstration projects or production deployment
    - Analysis of the potential role of SAFs in decarbonizing aviation in IEA

scenarios
    - Policy recommendations to governments interested in scaling up SAF production or adoption
    - Quantification of the environmental impact of book and claim systems
- Experimental work, potentially in collaboration with the Combustion TCP, could include:
    - Impact of SAF utilization on non-CO_2 effects (contrails, spray formation)
    - Status and developments of engine technology in aviation
    - Identification of production process parameters and desirable end-use properties, relevant to mixture preparation, combustion, stability and emission formation through experiments and simulations (take off, cruise etc.)
    - SAF evaluation, testing, qualification, and specification, to support the development of new ASTM standards
    - Enable the use of drop-in unblended SAF and SAF blends up to 100%
    - Investigate novel jet fuels that offer performance or producibility advantages
    - Integrate SAF into fuel distribution infrastructure

References and further reading

Airport use of Sustainable Aviation Fuels. Map. URL: https://www.google.com/maps/d/viewer?mid=14ALRPxtGBk_hBMXbjTC9wTZzCZZTn61f&ouid=102488039596029972836&ll=14.434680085317883%2C-88.03197929999988&z=2

Argonne National Laboratory. GREET Aviation model. URL: https://greet.es.anl.gov/greet_aviation

Aviation Transition Strategy (2022). Making Net-Zero Aviation Possible. An industry-backed, 1,5°C-aligned transition strategy. URL: https://missionpossiblepartnership.org/wp-content/uploads/2023/01/Making-Net-Zero-Aviation-possible.pdf

Bullerdiek, N. et. al. (2019) Use of multiblend JET A-1in practice. Summary of the results from the model project of the Mobility and Fuel Strategy (DEMO-SPK). Final report: https://www.dbfz.de/fileadmin/user_upload/Download/Extern/DEMO-SPK_Final_report.pdf

Database on facilities for the production of advanced liquid and gaseous biofuels for transport. URL: https://demoplants.best-research.eu/

Doliente, S., Narayan, A., Tapia, J., Samsatli, N., Zhao, Y., & Samsatli, S. (2020). Retrieved from Bio-aviation Fuel: A Comprehensive Review and Analysis of the Supply Chain Components: https://www.frontiersin.org/articles/10.3389/fenrg.2020.00110/full

EPE (2021). Comitê Técnico – Combustível para o Futuro. Subcomitê ProBioQAV. Metodologias e Estimativas para o QAV. URL: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro/subcomites-1/probioqav/participacao-social/ap-epe-dpg-sdb-2021-43-probioqav_26-08-2021.pdf

European Civil Aviation Conference (2023). ECAC Guidance on Sustainable Avitaion Fuels (SAF). URL: https://ecac-ceac.org/images/activities/environment/ECAC_Guidance_on_SAF_DGs_endorsed_HighRes_v02.pdf

European Commission (2019). Taxes in the Field of Aviation and their impact. URL: https://op.europa.eu/o/opportal-service/download-handler?identifier=0b1c6cdd-88d3-11e9-9369-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part

Malina, R. et. al. World Bank Group (2022). The role of SAF in decarbonizing air transport. URL: https://openknowledge.worldbank.org/server/api/core/bitstreams/cf151df5-5de5-5ed0-9e6e-2a02ccad4541/content

SAF Grand Challenge Roadmap. Flight Plan for Sustainable Aviation Fuels. URL: https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf

Tanzil, A. et. al. (2021). Strategic assessment of sustainable aviation fuel production technologies: Yield improvement and cost reduction opportunities. https://doi.org/10.1016/j.biombioe.2020.105942

The International Council on Clean Transportation (ICCT) (2019). The cost of supporting alternative jet fuels in the European Union. URL: https://theicct.org/wp-content/uploads/2021/06/Alternative_jet_fuels_cost_EU_2020_06_v3.pdf

The International Council on Clean Transportation (ICCT) (2021). Assessing the sustainability implications of alternative aviation fuels. URL: https://theicct.org/wp-content/uploads/2021/06/Alt-aviation-fuel-sustainability-mar2021.pdf

ICAO (2022). Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO_2-emission reductions. URL: https://www.icao.int/environmental-protection/LTAG/Documents/REPORT%20ON%20THE%20FEASIBILITY%20OF%20A%20LONG-TERM%20ASPIRATIONAL%20GOAL_en.pdf

ICAO SAF facility map. URL: https://lookerstudio.google.com/reporting/2532150c-ff4c-4659-9cf3-9e1ea457b8a3/page/p_2sq3qol5nc?s=mGz_sTv1l-c

ICAO Short-Term Projections On SAF Production. URL: https://www.icao.int/environmental-protection/Documents/SAF/ICAO%20SAF%20short-term%20projections%20-%20methodology%20and%20results.pdf

IEA AMF. Task 63 Sustainable Aviation Fuels Website: https://iea-amf.org/content/projects/map_projects/63

IRENA (2021). Reaching Zero with Renewables – Biojet Fuels. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jul/IRENA_Reaching_Zero_Biojet_Fuels_2021.pdf

International Civil Aviation Organization (ICAO). Conversion process. URL: https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx

International Civil Aviation Organization (ICAO). Power-to-Liquids (PtL): Sustainable Fuels for Aviation. URL: https://www.icao.int/Meetings/a40/Documents/WP/wp_526_en.pdf

International Civil Aviation Organization (ICAO). SAF Offtake agreements. URL: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx#InplviewHashef347ce3-9fcc-4b72-be6a-207e60680777=ShowInGrid%3DTrue

International Civil Aviation Organization (ICAO). SAF Offtake agreements Dashboard. URL: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx

Van Dyk, S. and Saddler J. IEA Bioenergy Task 39. Progress in commercialization of biojet/Sustainable Aviation Fuels (SAF) – Technologies, potential and challenges. URL: https://task39.ieabioenergy.com/wp-content/uploads/sites/37/2023/01/Progress-in-commercialization-of-biojet-Sustainable-Aviation-Fuels-SAF-Technologies-potential-and-challenges.pdf

Voices from the sky. Expert perspectives on Sustainable Aviation Fuels. URL: https://www.topsoe.com/