Sustainable aviation fuels

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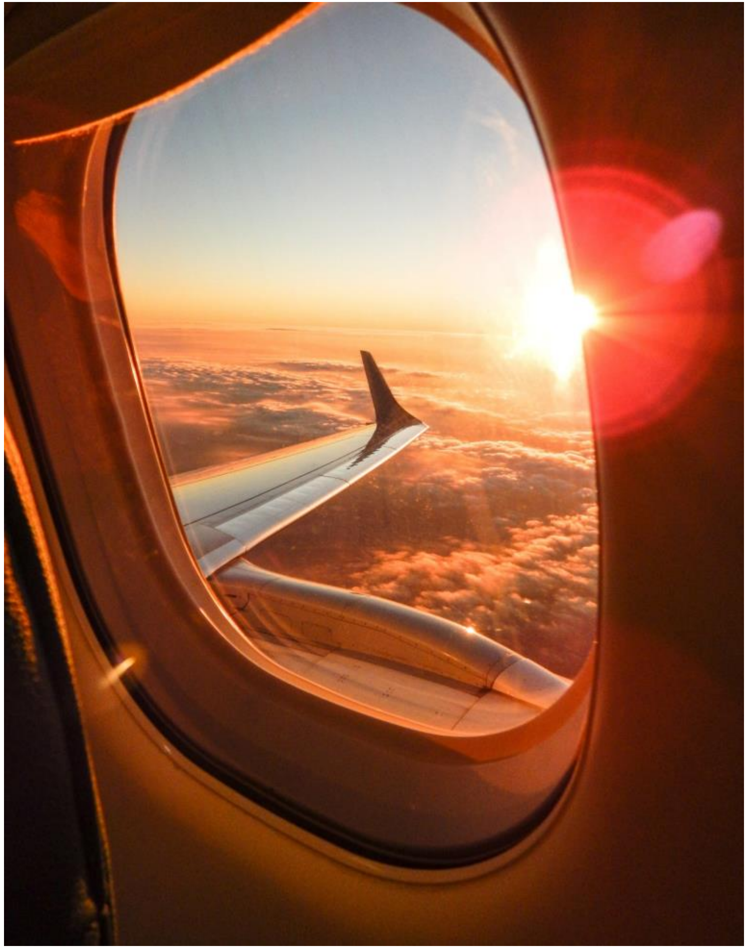


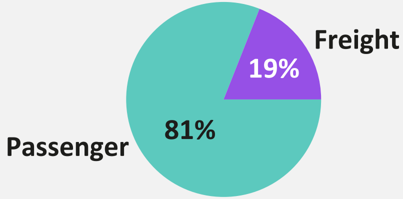
1. Background

Aviation accounts for about 12% of global transport CO_2 emissions

Energy consumption and emissions in aviation

- More than 99% of energy consumption in aviation is met by fossil fuels:[1]
  - Jet A-1 (unleaded kerosene)
  - Jet B (naphtha-kerosene)
  - Avgas (aviation gasoline)
- Global CO_2 emissions from commercial passenger and freight aviation totaled 918 $MtCO_2$ in 2018 or 2.5% of global energy-related CO_2 emissions.[2]
- Passenger aviation accounts for the majority of aviation emissions.

Share of CO_2 emissions from aviation[3]
918 $MtCO_2$ total in 2018



Possible solutions to decarbonize

- Fuel shifts including to:
  - Alternative fuels, known also as sustainable aviation fuels (SAF), including biofuels, electrofuels made from green renewable electricity and fuels made from carbon capture and utilization.
  - Hybrid electric aircraft, battery electric and hydrogen-fueled planes.[4]
- Energy efficiency measures including:
  - Retrofits to existing aircrafts.
  - Acquisition of new-generation aircrafts.
  - Increase utilization rates, e.g. increasing the number of passengers per flight.
  - Improved air traffic management and infrastructure.
- Modal shifts to other modes of transport, e.g. high-speed rail.
- Reduction in travel demand due a shift towards video conferencing and cultural shifts.

Sources: [1]IRENA, 2017: Biofuels for aviation, Technology brief; [2]IEA, 2019: Aviation, tracking clean energy progress; [3]ICCT, 2019: CO_2 emissions from commercial aviation, 2018; [4] ETC, 2018: Mission Possible.

1. Background

The aviation industry is currently relying heavily on fossil-based fuels

Current applications and associated CO_2 emissions	• Global aviation fuel consumption was 275 million tons (341 billion liters) in 2017,[1] equivalent to 12% of global fuel consumption for transportation.[2] • Global CO_2 emissions from commercial passenger and freight aviation totaled 918 $MtCO_2$ in 2018 or around 2.5% of global energy-related CO_2 emissions. • The average carbon intensity of passenger aviation flights is 88gCO_2 per passenger-km (p-km); for flights of less than 500km, this is significantly higher at 160gCO_2/p-km.[3]
Forecasted developments in a business-as-usual scenario	• Under a BAU scenario, the International Civil Aviation Organization (ICAO) forecasts that passenger aviation transport demand will grow by 4.1% p.a. over 2015-2045.[4] • If no action is taken (except for fleet renewal), emissions could increase three-fold to 2,700 $MtCO_2$ by 2050.[5]
Obstacles to decarbonizing aviation	• High costs for alternative fuels: Alternative fuels are 1.5-8 times more expensive than conventional aviation fuels, depending on the technologies and type of alternative fuels. • Efficiency improvement: Energy efficiency improvements can only provide an incremental emission reductions; aviation efficiency improved by 2.9% per year over 2000-2016.[6] • Limited policy incentives: One-third of passenger-related aviation emissions are from international aviation.[3] In most jurisdictions, international aviation fuels are not taxed and it would be difficult to harmonize national policies on decarbonizing aviation. The Carbon Offsetting Scheme for International Aviation (CORSIA) aims to stabilize net international aviation CO_2 emissions at 2020 levels; offsetting will be a key measure to achieving this target.[7] This measure does not cover non-CO_2 emissions which can have a warming impact equivalent to more than double the CO_2-induced warming impact.[8]

Sources: [1]Air Transport Action Group, 2018: *Aviation benefits beyond borders*; [2]IRENA, 2017: *Biofuels for aviation, Technology brief*; [3]ICCT, 2019: *CO_2 emissions from commercial aviation, 2018*; [4]ICAO, 2018: *ICAO Long-term traffic forecasts*; [5]ICAO, 2016: *Environmental Report 2016*. [6]IEA, 2019: *Aviation, tracking clean energy progress*. [7]IATA, 2019: *Fact sheet: CORSIA*. [8]Carbon Brief, 2017: *Explainer: The challenge of tackling aviation's non-CO_2 emissions*.

2. Description of sustainable aviation fuels

Overview

Description of the new solution concept	• Sustainable aviation fuels (SAF) are alternative fuels such as biofuels, electrofuels made from renewable electricity, and fuels made from carbon capture and utilization. To be considered a SAF, it must:[1] - Meet the same safety standards as conventional aviation fuels. - Be a "drop-in" fuel, that is compatible with existing aircraft and fuel-supply systems. - Meet the sustainability criteria defined by ICAO (see next slide). • SAF is blended with conventional aviation fuel, with a limit of up to 50% for compatibility and safety reasons.[2] It is expected that blending limits will be increased during the 2020s. • Currently, most SAF is made from bio-based feedstocks such as cooking oil, palm oil and tallow.
Rationale for developing this solution	• Long distance flights are likely to be fueled by liquid hydrocarbon fuels in the future. Due to weight and volume constraints, battery-electric planes will not be feasible for long-distance flights,[3] although hybrid electric aircraft could significantly reduce the emissions intensity of flying.[4] Hydrogen-fueled aircraft could be a potential long-term technology for long-haul aviation but would require a significant redesign of aircraft • Burning 1 kg of conventional aviation fuels leads to 3.16 kg of CO_2 emissions. Switching to SAF can reduce the emissions intensity of fuel consumption, when considering full lifecycle emissions.[2] • As SAF blends are drop-in fuels which can be handled in the same way as conventional aviation fuels, it can be used in existing technologies and fuel supply infrastructure. This means that SAF could play an important role in reducing aviation emissions over the short to medium term.
Assessment of technology readiness status	• SAF production is relatively small in scale. 6 conversion processes for SAF have been certified for use in aviation. 7 airports are regularly distributing a blend of SAF and conventional fuel and over 200,000 commercial flights have used such blends.[2] • The number of offtake agreements between SAF producers and airlines is growing. • Many aviation fuel pipeline operators are assessing the transportation of blended SAF in existing pipeline infrastructure.

Sources: [1]ICAO, 2018: *Implementation of low emissions measures: sustainable aviation fuels*; [2]ICAO: *Frequently asked questions*; [3]ETC, 2018: *Mission Possible*; [4]Airbus, *E-Fan X*.

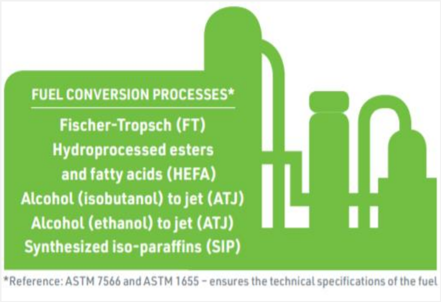
2. Description of sustainable aviation fuels

From feedstock to approval for use

- Several feedstocks and fuel conversion processes can be used to produce SAF. SAF need to be certified by ASTM International, an international standard setting organization, under standard ASTM D-7566 prior to being blended with conventional aviation fuels for use in aircraft. As of 2017, five conversion pathways are approved under D7566 for SAF production.[1] However, only the hydroprocessed esters and fatty acids (HEFA) process is currently technically mature and commercialized.[2]
- In addition, ASTM D1655 allows co-processing of up to 5% of lipidic feedstock, e.g. vegetable oils, in the petroleum refinery processes.[3]

Feedstock

Fuel Conversion



- SAF sustainability criteria has been developed as part of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Standard development process. Airlines can reduce their CORSIA offsetting requirements if the SAF meet the following sustainability criteria:[4]
  - The fuel must achieve net GHG emission reductions of at least 10% compared to conventional aviation fuels on a lifecycle basis (LCA).
  - The fuel should not be made from biomass obtained from land with high carbon stock.
- Sustainability certification schemes will work with fuel producers to certify fuels under this criteria.

Sources: [1]ICAO: *Frequently asked questions*; [2]IEA, 2019: *Are aviation biofuels ready for take off?*; [3]European Aviation Safety Agency: *Sustainable Aviation Fuels*; [4]ICAO, 2019: *CORSIA Sustainability Criteria for CORSIA Eligible Fuels*; ICAO, 2019: *An Overview of CORSIA Eligible Fuels (CEF)*..

2. Description of sustainable aviation fuels

Examples of demand for SAF

Several SAF off-take agreements between producers and airlines/airports have been signed. While long-term off-take agreements can support the development of SAF markets by securing supply/demand, deeper partnerships are needed to further de-risk SAF investments (see page 12).

Producer/Distributor	Purchaser	Location (Airport)	Annual Offtake Production (kt)	Start Date	Length of Agreement (yrs)
Air Total	Airbus/China Southern Airlines	Airbus- Toulouse		2017	
AirBP	Airbus/Jet Blue	Airbus- Mobile		2018	1
AirBP	Avinor	Bergen		2017	
AirBP	SAS, BRA, Kalmar Municipiality	Kalmar Airport	<1	2018	3
Amyris/Total	Airbus/Cathay Pacific			2016	2
Fulcrum	AirBP		152	2020	10
Fulcrum	Cathay Pacific		114	2020	10
Fulcrum	United		274	2020	10
Fulcrum	Japan Airlines			2020	
Gevo	Lufthansa		24		5
Gevo	Virgin Australia			2017	
LanzaTech	All Nippon Airways	San Francisco International Airport		2021	
LanzaTech	Virgin Atlantic				
Neste/Air BP	Swedavia	Stockholm Arlanda, Åre-Östersund, Malmö, Göteborg Landvetter and Umeå Airports			
Red Rock	FedEx		1		7
Red Rock	Southwest		9		1
SG Preston	Jet Blue		100	2019	10
SG Preston	Qantas	Los Angeles	24	2020	10
SkyNRG	KLM	Schiphol	75	2022	
World Energy (AltAir)	Gulfstream/ World Fuel			2015	3
World Energy (AltAir)	SkyNRG/ KLM	Los Angeles		2016	3
World Energy (AltAir)	SkyNRG/ KLM	Växjö Småland Airport	<1	2018	0.5
World Energy (AltAir)	Swedavia	Stockholm Arlanda, Göteborg, Landvetter, Bromma Stockholm, Visby, Luleå Airports	<1	2016	
World Energy (AltAir)	United	Los Angeles	15	2016	3
World Energy/Neste	KLM/ SAS/ Lufthansa/ AirBP	Oslo Airport	1	2016	3
World Energy/ Shell	SkyNRG/ KLM/ SAS/ Finnair	San Francisco International Airport		2018	

The list includes major agreements announced before June 2019.

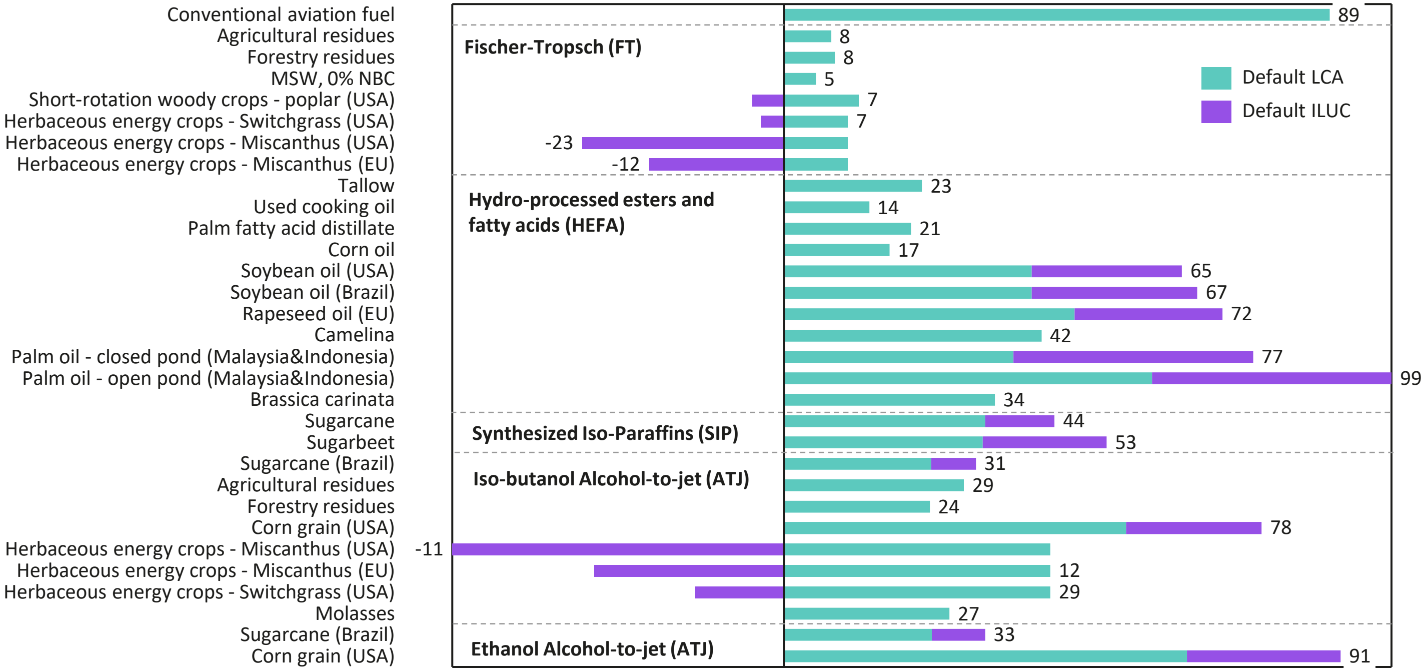
Source: Navigant analysis.

3. GHG reduction potential of sustainable aviation fuels

Lifecycle GHG emissions of SAF compared to conventional aviation fuels

Default emissions factors compared to conventional aviation fuel (gCO_2e/MJ)[1]

Sum of LCA and ILUC values shown at end of bar



- Lifecycle assessment (LCA) emissions include emissions associated with full supply chain of SAF production and use including cultivation, harvesting, processing, transport, conversion and combustion.
- Indirect land use change (ILUC) emissions take into account emissions related to land use change caused by planting biofuel crops.
- The total emissions intensity of SAFs depends on feedstock type, geographical origin of feedstock and conversion process.

Source: [1]ICAO, 2019: *CORSIA Eligible Fuels – Life Cycle Assessment Methodology*.

4. Cost assessment and sensitivity analysis of SAF options

- The cost of SAFs is difficult to estimate as it is typically traded on a bilateral basis between fuel producers and airlines, and prices are not generally disclosed.
- Techno-economic analysis can give an indication of the scale of costs for SAF (see table below). These do not include the logistics costs or the cost of integration with the existing jet fuel supply chain.
- SAF costs are reportedly from 1.5 to up to 8 times higher than the price of conventional aviation fuels.
- The costs of SAFs produced by a first of a kind plants are likely to be significantly more expensive than nth of a kind plants.

Techno-economic analysis* of the cost of SAF production

Conversion process	Feedstock	Cost
HEFA	Camelina oil	USD $0.80/l
	Palm oil	USD $0.70–0.79/l
	Soybean oil	USD $1.01–1.16/l
	Yellow grease Tallow	USD $0.88–1.25/l
	Waste oil	USD $1.03/l
FT	Corn-stover (gasification)	USD $0.90/l
	Switchgrass (gasification)	USD $1.10/l
	Lignocellulose (gasification)	USD $1.96/l
	Wood (gasification)	USD $1.14–1.22/l
	Wood (gasification)	USD $1.13/l
ATJ	Sugarcane (ethanol)	USD $1.56/l
	Corn (ethanol)	USD $1.75/l
	Switchgrass (ethanol)	USD $2.30/l
	Lignocellulose (syngas)	USD $1.80/l
	Lignocellulose (syngas)	USD $2.00/l
	Sugarcane (ethanol)	USD $2.76/l

*For comparison, the average price of US Gulf Coast Kerosene Jet Fuel was USD $0.59/l between Jan 2013-April 2016

Source: ICAO, 2017: *Sustainable Aviation Fuels Guide*.

5. New partnership opportunities

New cross-sectoral collaborations are essential to accelerating the uptake of SAFs

SAF producers

Airlines

Corporate customers

SAF producers and fuel suppliers need to work together to make provisions for SAF producers to access conventional fuel infrastructure

Airlines can support the financing of SAFs at airports. An additional fee could be integrated into the airline operating agreement signed with airports.[1]

Airlines and airports can develop financing schemes in partnership with corporate customers to finance the additional cost of SAFs.

Fuel suppliers

Airports

Airports can negotiate SAF supply agreements with fuel suppliers to supply a low share of SAFs as standard to all flights refueling at the airport. Airports can develop funding mechanisms to cover the cost premium of SAFs.[1]

Source: [1]Adapted from Klauber, A. et al., 2017: *Innovative Funding for Sustainable Aviation Fuel at U.S. Airports: Explored at Seattle-Tacoma International*.

6. Sustainable aviation fuels SWOT analysis

Strengths

- Deployment of SAF in aviation can enable the sector to reduce GHG emissions and meet climate targets.
- SAF can have other environmental benefits such as improved local air quality due to reduced PM and sulfur emissions.[1]
- SAF is a drop in fuel which can be used in aviation without need for further modification to the engines and/or infrastructures.
- The production of SAF can create an additional distribution channel for agricultural products with a potential to improve rural economies.

Opportunities

- SAF is supported in key international markets, including the EU (Renewable Energy Directive II) and USA (Renewable Fuel Standard).
- There is potential for SAF price reductions through improvements in process efficiency, economies of scale, as well as development of new feedstocks and processing technologies.
- SAF can decrease dependency on fossil fuel imports.

Weaknesses

- Production capacity is currently constrained and limited ability to scale up supply of sustainable oil-based feedstock used in the HEFA route. Other SAF conversion processes can use more abundant feedstock, but these processes are not yet commercialized.
- SAF is currently consumed in very small volumes (<1% of total fuel demand).
- SAF is currently restricted to a maximum 50% blend.
- The current high price for SAF—from 1.5 to up to 8 times the price of conventional aviation fuel—is impeding demand.

Threats

- Competing demand for sustainable bio-based feedstock, such as biofuel mandate-driven demand from the road transport sector, shipping and industry sectors.
- Policies driving decarbonization of the aviation sector are currently relatively limited. CORSIA applies only to international aviation, and it is unlikely to stimulate substantial SAF demand as compliance via offset purchases will come at a lower cost.
- Lack of financing options for development of the supply chain and R&D for development of new processes.
- Stakeholder concerns over the sustainability of SAF.

Source: [1]SkyNRG: *Sustainable Aviation Fuel*.

7. Success factors

Robust policies and regulations

Policies providing long-term certainty are important to stimulating broader investments in SAF capacity and related infrastructure. Global policies would be most effective, but national/regional policies could also incentivize SAF greater demand and production capacity. Policies should ideally be aligned within the framework of other transport sector policies, and could include mandates for SAF use, carbon pricing mechanisms and reduced landing fees for planes fueled with SAF and taxation of conventional aviation fuels.

Deeper partnerships to de-risk SAF investments

Current offtake agreements between SAF producers and consumers can de-risk some SAF investments, but most do not come with long-term financial commitments to mitigate deployment risks. Floor prices for off-takes, as well as other deeper partnerships such as joint investments and virtual equity would further de-risk investments in supply chain and technology improvements.

Engagement from airport operators

For SAF to be widely used, airports need to encourage the use of SAF and play an active role in the wider deployment of SAF as infrastructure investments may be needed, e.g. dedicated storage facilities.

Development of SAF production routes

Current SAFs used today are mostly HEFA based and it will be challenging to scale up production to volumes necessary to make an impact on emissions as sustainable feedstock is limited. R&D is needed to commercialize SAF production routes which have greater potential for scaling up and cost reductions, including those using non-oil based feedstock such as agricultural and forestry residues.

8. Sustainable aviation fuels: Case studies (1/3)

Airport operator

Swedavia (Sweden)	
Context	• Swedavia owns and operates ten airports in Sweden. • Swedavia's aims to produce zero CO_2 emissions from its own operations by 2020 but wants to contribute to emission reductions beyond own operations.
Project description & objectives	• Swedavia is a partner in the Fly Green Fund which enables companies and leisure travelers to contribute funds that will enable SAFs to be bought and used at Swedish airports. Of the funds raised, 75% is to purchase SAFs and the remainder is used for market development and R&D.[1] • Since 2016, Swedavia has purchased 450 tons of SAFs annually through the Fly Green Fund, corresponding to the amount of fossil jet fuel consumed for business travel. In 2017, the SAF was purchased at a cost SEK7.5 million (USD $825,000).[2] • In 2018, SAF consumption was 0.4% of total fuel consumption from Swedish domestic air travel compared to 0.01% in 2017.[3] Swedavia makes it available to all airlines at no additional cost.[4] • Swedavia has procured SAFs from World Energy (delivered by SkyNRG) and Neste (supplied by AirBP). • In 2019, Swedavia set a target of using 5% renewable jet fuel by Swedish airports by 2025.[3] Together with other organizations, it also carried out a public tender to procure 560 tons of SAF for 2020, and plans to launch a similar tender future SAF procurement.[5]

Sources: [1]Swedavia: *Biofuel – for a fossil-free future*; [2]Swedavia, 2017: *Inaugural fuelling with Swedavia's aviation biofuel at Stockholm Arlanda Airport today*; [3]Swedavia: *Annual and Sustainability Report 2018*; [4]AIN, 2019: *Swedavia and Heathrow Looking To Increase SAF Uptake*; [5]Swedavia, 2019: *Swedavia brings together different organisations in public tender for bio jet fuel*; Swedavia: *Operation in 2017*.

8. Sustainable aviation fuels: Case studies (2/3)

Airline

Lufthansa (Germany)	
Context	• Lufthansa is the second largest airline in Europe in terms of passengers carried, when combined with its subsidiaries.
Project 1: Use of SAF in regular flights	• In 2011, Lufthansa was the first airline to test SAF in regular operations, operating a total of 1,187 flights over 6 months.[1] • Lufthansa currently has supply contracts with Shell Aviation[2] and World Energy at San Francisco Airport (for up to 1 million gallons) and with Neste[3] for SAFs at Frankfurt airport.
Project 2: Procurement of electrofuels	• Lufthansa has signed a contract with Heide Refinery to procure a synthetic kerosene SAF, which will be available by 2024.[4] The synthetic kerosene will be an electrofuel made from the decomposition of water into hydrogen and oxygen using surplus wind power, and CO_2.
Project 3: Enabling customer SAF purchase	• In 2019, Lufthansa launched the Compensaid platform.[5] It enables passengers on any flight to offset their conventional aviation fuel consumption by paying for the additional cost of SAFs. Lufthansa will use the funds raised to purchase SAFs which will displace fossil fuel consumption on Lufthansa flights within six months.

Sources: [1]Lufthansa, 2019: *Balance – Sustainability Report 2019*; [2]Biofuels International, 2020: *Shell Aviation, World Energy to increase supply of sustainable aviation fuel*; [3]Green Car Congress, 2019: *Lufthansa to use Neste sustainable aviation fuel blends on flights departing from Frankfurt*; [4]Transport & Environment, 2019: *Lufthansa takes first steps towards non-fossil kerosene*; [5]Lufthansa: *Compensaid*.

8. Sustainable aviation fuels: Case studies (3/3)

Jet fuel producer

Air BP	
Context	• Air BP is a supplier of aviation fuels whose services are available at over 1000 airport locations in 70 countries
Project description & objectives	• Air BP has supplied SAF to 20 customers at 15 locations in five countries. • Air BP also produces a SAF called BP Biojet which can reduce lifecycle GHG emissions by up to 80% compared to fossil fuels. Air BP were the first operator to start commercial supply of SAFs through an existing hydrant fueling system at Oslo Airport in 2016. • BP Biojet has been supplied at 16 airports, including in Norway, Sweden, France and the US. • BP created a partnership with Fulcrum BioEnergy in 2016, with an initial investment of USD $30 million. Fulcrum BioEnergy is building a production facility in Reno, Nevada, which will to produce SAFs from household waste. First supply is expected to be in 2022. • Air BP also signed an agreement with Neste in 2018 to develop new SAF supply chains.

Source: Air BP, 2019: *What is sustainable aviation fuel (SAF)?*; Air BP: *Sustainable aviation fuel*.

9. Summary

Emissions and energy	• Global CO_2 emissions from commercial passenger and freight aviation totaled 918 $MtCO_2$ in 2018 or around 2.5% of global energy-related CO_2 emissions. • Under a BAU scenario, CO_2 emissions from passenger aviation transport could increase threefold – to 2,700 $MtCO_2$ – by 2050.
Solution	• Sustainable aviation fuels (SAF) are alternative fuels such as biofuels and electrofuels made from renewable electricity. • Prior to use on aircrafts, SAFs are blended with conventional aviation fuels, with a limit of up to 50% SAFs for compatibility and safety reasons. • Several feedstocks and fuel conversion processes can be used to produce SAF. • SAFs are "drop-in" fuels for use in existing aircraft technologies and fuel supply infrastructure.
Avoided GHG emissions and co-benefits	• SAF life cycle GHG emissions depending on the feedstock type, geographical origin of feedstock and the conversion process. • SAFs can also have other environmental benefits, such as reduced sulfur and particulate matter emissions.
Readiness status	• Globally, seven airports regularly distribute SAF blends and over 200,000 commercial flights have used such fuels. • SAF production is still relatively small in scale and accounts for less than 0.1% of total aviation fuel consumption..
Barriers	• The price of SAFs ranges from 1.5 to 8 times the price of conventional aviation fuels. • Production capacity is currently constrained, and it will be challenging to scale up the supply of oil-based feedstock due to limits in availability and sustainability concerns.
Success factors	• Robust policies and regulations, such as mandates for SAF use. • Carbon pricing or the taxation of conventional aviation fuels to overcome the barriers. • Research and development in fuel conversion processes that use non-oil-based feedstock to enable the scaling up of SAF production.

10. Key sources and references on SAF

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