Beginner's Guide to **Sustainable Aviation Fuel**

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ATAG
AIR TRANSPORT ACTION GROUP

CLIMATE ACTION TAKES FLIGHT

Contents

The importance of aviation

- Aviation provides the only rapid worldwide transportation network, is indispensable for tourism and facilitates world trade. Air transport improves quality of life in countless ways.
- Air transport moves roughly 3.8 billion passengers annually.
- The air transport industry generates a total of 63 million jobs globally.
- Air transport is responsible for transporting 35% of world trade by value.
- 54% of international tourists travel to their destination by air.
- Aviation's global economic impact is estimated at USD 2.7 trillion (including direct, indirect, induced and tourism catalytic). If the aviation industry were a country, it would rank 21st in the world in terms of GDP.
- Aviation is responsibly reducing its environmental impact through an ambitious, global set of goals: **www.enviro.aero**.
- The global aviation industry produces around 2% of all human-induced carbon dioxide (CO_2) emissions. The International Panel on Climate Change (IPCC) forecasts that its share of global manmade CO_2 emissions will increase to around 3% in 2050.
- Despite growth in passenger numbers at an average of 5% each year, aviation has managed to decouple its emissions growth to around 3%. This is through massive investment in new technology and coordinated action to implement new operating procedures.
- Aircraft entering today's fleet are over 80% more fuel-efficient than the first jet aircraft in the 1950s, consuming an average 3.5 litres per passenger per 100km. The Airbus A380 and the Boeing 787 – consuming less than 3 litres per 100 passenger kilometres – compare favourably with small family cars, with aircraft also having a higher average occupancy rate.

Introduction

In the early days of the jet age, speed and luxury were the drivers of intercontinental travel. Since then, efficiency has been a tremendous driver that has made air travel and transport central to modern life. Indeed, today, our engines are at the cutting edge of efficiency and our aircraft are more aerodynamic and lighter than ever before. We are making huge improvements in our air traffic control efficiency, how we fly our aircraft and in developing less environmentally-impacting operations at airports. But we are still, for the vast majority of flights, using the same fuel.

That is changing right now

The world is turning to governments and business to reduce the human impact on climate change. While aviation's drive for fuel and operational efficiency has helped the industry limit its emissions, to go even further the aviation industry is embarking on a new journey. Sustainable aviation fuel is crucial to providing a cleaner source of fuel to power the world's fleet of aircraft and help the billions of people who travel by air each year to lower the impact of their journeys on our planet.

This guide looks at the opportunities and challenges in developing sustainable aviation fuel. To discover the other technology, operations and infrastructure improvements underway across the aviation industry, check out **www.enviro.aero.**

What is sustainable aviation fuel?

> *Relative to fossil fuels, sustainably-produced, unconventional, jet fuel results in a reduction in carbon dioxide emissions across its life cycle.*

- Sustainable aviation fuel (SAF) is the term preferred by the aviation industry because the scope of the use of this term is broader than aviation biofuels. 'Biofuels' generally refers to fuels produced from biological resources (plant or animal material). However, current technology allows fuel to be produced from other alternative sources, including non-biological resources; thus the term is adjusted to highlight the sustainable nature of these fuels.
- SAF is made by blending conventional kerosene (fossil-based) with renewable hydrocarbon. They are certified as "Jet-A1" fuel and can be used without any technical modifications to aircraft.
- Other terms such as renewable aviation fuel, renewable jet fuel, alternative fuel, biojet fuel, and sustainable alternative fuel have similar intended meaning.

Sustainable aviation fuel consists of three key elements:

Sustainability in this context is defined as something that can be continually and repeatedly resourced in a manner consistent with economic, social and environmental aims, specifically something that conserves an ecological balance by avoiding depletion of natural resources and does not contribute to climate change.

It is **alternative**, in this case non-conventional or advanced fuels, and includes any materials or substances that can be used as fuels, other than conventional, fossil-sources (such as oil, coal, and natural gas). It is also processed to jet fuel in an alternative manner. Feedstocks for SAF are varied; ranging from cooking oil, plant oils, municipal waste, waste gases, and agricultural residues – to name a few. Further information about this can be found on pages 6 and 7.

Fuel means jet fuel that meets the technical and certification requirements for use in commercial aircraft.

The International Civil Aviation Organization (ICAO), a United Nations specialised agency, has used 'Alternative Fuels' as its terminology, and it is defined as 'any fuel that has the potential to generate lower carbon emissions than conventional kerosene on a life cycle basis'. ICAO also uses the term 'sustainable aviation fuel'.

Sustainable aviation fuel – providing environmental benefits

Relative to fossil fuels, sustainably-produced, unconventional, jet fuel results in a reduction in carbon dioxide (CO_2) emissions across its life cycle. Carbon dioxide absorbed by plants during the growth of biomass is roughly equivalent to the amount of carbon dioxide produced when the fuel is burned in a combustion engine , which is simply returned to the atmosphere. This would allow the SAF to be approximately carbon-neutral over its life cycle. However, there are emissions produced during the production of SAF, from the equipment needed to grow the crop, transport the raw goods, refine the fuel and so on. When these elements are accounted for, the use of sustainable aviation fuel has been shown to provide significant reductions in overall CO_2 lifecycle emissions compared to fossil fuels, up to 80% in some cases. Furthermore, SAF contains fewer impurities (such as sulphur), which enables an even greater reduction in sulphur dioxide and particulate matter emissions than present technology has achieved.

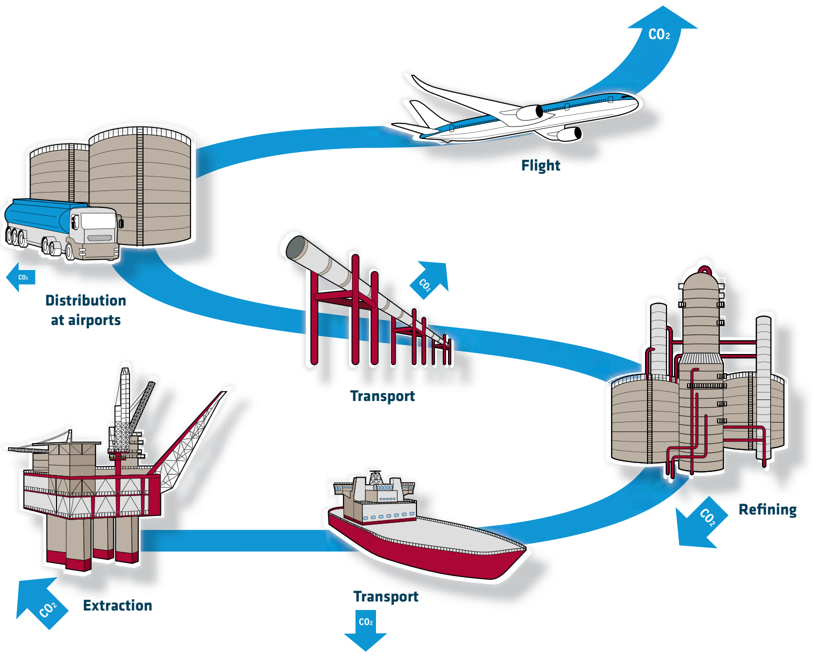
In the case of SAF produced from municipal waste, the environmental gains are derived both from avoiding petroleum use and from the fact that the waste would be otherwise left to decompose in landfill sites, producing no further benefits, rather than being used to power a commercial flight, which would otherwise be powered by unsustainable, fossil-based fuel.

Providing diversified supply

The airline industry's reliance on fossil fuels means that it is affected by a range of fluctuations, such as the changing price of crude oil and problems with supply and demand. SAF is an attractive alternative as its production is not limited to locations where fossil fuels can be drilled, enabling a more diverse geographic

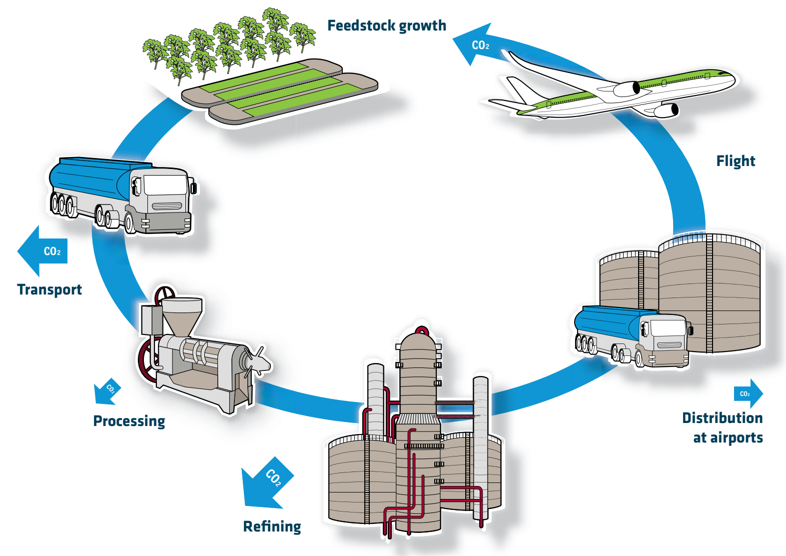
> *A range of SAF feedstocks can be grown or collected in differing conditions around the world, depending on the natural environment.*

Carbon lifecycle diagram: fossil fuels



At each stage in the distribution chain, carbon dioxide is emitted through energy use by extraction, transport, etc.

Carbon lifecycle diagram: Sustainable aviation fuel



Carbon dioxide will be reabsorbed as the next generation of feedstock is grown.
Note: *the diagram above does not demonstrate the lifecycle process of SAF derived from municipal waste.*

supply and a degree of energy security for states and airlines. In theory, a range of SAF feedstocks can be grown or collected in differing conditions around the world, depending on the natural environment, wherever the aviation industry needs it. As is the case with the petroleum industry, there will likely be major producers of SAF feedstock (which will be transported to where it needs to be used), and it is also likely that local smaller scale supply chains will be established.

Providing economic and social benefits

Fuel is typically the single largest operating cost for the airline industry. The fluctuating price of crude oil also makes it very difficult to plan and budget for operating expenses long-term. SAF may offer a solution to this problem since its production can be spread worldwide, and across a number of different feedstocks, thereby reducing airlines' exposure to the fuel cost volatility that comes with having a single energy source.

SAF can also provide economic benefits to parts of the world that have large amounts of marginal or unviable land for food crops, but are suitable for growing SAF crops, or which have other sources of feedstock such as municipal waste. Many of these countries are developing nations that could benefit greatly from a new industry such as sustainable aviation fuel production without negatively impacting their local food production ability. It is also not uncommon for waste to be an environmental problem in developing countries. An example of a project that takes advantage of local conditions is project Solaris, a joint effort between Boeing and South African Airways, which is beginning to produce SAF using nicotine-free tobacco, allowing local farmers with specialised skills to continue production of tobacco without it being used for smoking.

Why do we say ‘sustainable aviation fuel’, rather than ‘biofuels’?

> *“The aviation industry has been careful to promote only sustainably-sourced alternative fuels, so as to avoid negative environmental impacts.”*

Why call it ‘sustainable aviation fuel’?

- There are a number of terms used to describe non-fossil based hydrocarbon fuel. Often, the term ‘biofuel’ is used, however, the aviation industry avoids this terminology as it does not specify the sustainability aspect of these fuels.
- Some biofuels, if produced from non-sustainable feedstocks, such as unsustainably-produced palm oil or crops that require deforestation, can cause additional environmental damage, making them unsuitable for aviation’s purposes.
- The phrase ‘advanced biofuels’ is also sometimes used to distinguish between sustainably sourced and non-sustainably sourced fuels.

When biofuels, as a general power source, first came onto the market, they were initially produced and aimed at substituting fossil fuel consumption in the road transport sector. These are sometimes termed ‘first-generation’ biofuels. The main types of biofuels used for automobiles are biodiesel and bioethanol. They are derived from crops such as rapeseed, sugarcane, corn, palm oil, and soybean – which typically can also be used as food for humans and animals. Consequently, the production of this type of biofuel can raise a number of concerns, including potential changes in the use of agricultural land, water use, the effect on food prices; and the impact of irrigation, pesticides and fertilisers on local environments. While these feedstocks could be used to create jet fuel through different processes, the aviation industry has been keen to avoid using them due to sustainability concerns.

To avoid these negative environmental impacts, the aviation industry has been careful to promote only sustainably-sourced alternative fuels. This is why the industry uses the term ‘sustainable aviation fuel’ (SAF), which has also sometimes been referred to as ‘next-generation’ or ‘advanced’ biofuels. Additionally, some of the feedstocks used to create SAF are not strictly biological in nature (such as municipal waste), making the term ‘biofuel’ slightly misleading.

As their chemical and physical characteristics are almost identical to those of conventional jet fuel, they can be safely mixed with the latter to varying degrees, use the same supply infrastructure and do not require the adaptation of aircraft or engines. Fuels with these properties are called **“drop-in fuels” (i.e. fuels that can be automatically incorporated into existing airport fuelling systems)**. Moreover, they also meet sustainability criteria such as lifecycle carbon emissions reduction, limited fresh water requirements, no competition with needed food production and no deforestation.

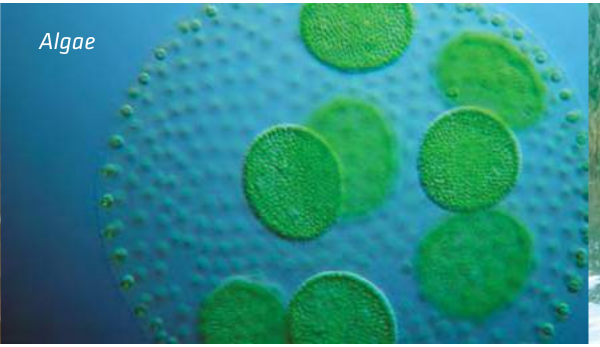
Current technology allows sustainable aviation fuels to be produced from a wide range of feedstocks, including:

Municipal solid waste: waste that comes from households and businesses. Some examples include: product packaging, grass clippings, furniture, clothing, bottles, food scraps and newspapers. There is a lot of potential to use municipal solid waste as a sustainable feedstock, due to its vast supply. Rather than simply dumping municipal waste in a landfill site, where it will gradually emit CO_2 and other gases into the atmosphere, it can be used to create jet fuel instead.

Cellulosic waste: the excess wood, agricultural, and forestry residues. These residues can be processed into synthetic fuel via the Fischer-Tropsch process or converted into renewable isobutanol and, further, into jet fuel through the “alcohol-to-jet” (AtJ) process. Other processes are under development.

Used cooking oil: this typically comes from plant or animal fat that has been used for cooking and is no longer usable for further cooking.

Camelina: primarily an energy crop, with high lipid oil content. The primary market for camelina oil is as a feedstock to produce renewable fuels. The leftover ‘meal’ from the oil extraction can also be used as animal feed in small proportions. Camelina is often grown as a fast-growing rotational crop with wheat and other cereal crops within the same year, when the land would otherwise be left fallow (unplanted) as part of the normal crop rotation programme. It, therefore, provides growers with an opportunity to diversify their crop base and reduce mono-cropping (planting the same crop year after year), which has been shown to degrade soil and reduce yields and resistance to pests and diseases. Camelina also has the added advantage over other rotational crops in that it can be grown alongside wheat in one year, rather than organising crop rotation on an annual basis. Notably, carinata is also demonstrating such promise.



Jatropha: a plant that produces seeds containing inedible lipid oil that can be used to produce fuel. Each seed produces 30 to 40% of its mass in oil. Jatropha can be grown in a range of difficult soil conditions, including arid and otherwise non-arable areas, leaving prime land available for food crops. The seeds are toxic to both humans and animals and are, therefore, not a food source. However, there remain issues with crop yield in certain conditions, with earlier estimates on the viability of jatropha as an appropriate feedstock having been somewhat overstated.

Halophytes: salt marsh grasses and other saline habitat species that can grow either in salt water or in areas affected by sea spray where plants would not normally be able to grow.

Algae: potentially the most promising feedstock for producing large quantities of SAF. These microscopic plants can be grown in polluted or salt water, deserts and other inhospitable places. They thrive off carbon dioxide, which makes them ideal for carbon sequestration (absorbing carbon dioxide) from sources like power plants. One of the biggest advantages of algae for oil production is the speed at which the feedstock can grow. It has been estimated that algae produces up to 15 times more oil per square kilometre than other biofuel crops. Another advantage of algae is that it can be grown on marginal lands that aren't used for growing food, such as on the edges of deserts. To date, we have not seen algae fulfil its early promise due to challenges surrounding commercialisation. However, continued research and development may result in wider application of this feedstock in the future.

Non-biological alternative fuels include 'power-to-liquid', which typically involves creating jet fuel through a process involving electric energy, water and CO_2. This fuel can be sustainable if the inputs are recovered as by-products of manufacturing otherwise taking place and/or if renewable electric energy is used in its production. For example, using the waste gases produced as a by-product in steel manufacturing to produce sustainable aviation fuel is showing great promise. While direct power-to-liquid options are based on technically proven steps, the process is currently prohibitively expensive and needs further development. Other, more advanced, technologies are in early stages of development, such as solar jet fuel (or sun-to-liquid), which uses highly concentrated sunlight to break up water and CO_2 molecules.

Whilst we are discussing these feedstocks in the context of SAF, it is important to highlight that fuels produced using these feedstocks can be both sustainable and unsustainable, depending on the methods used to produce the feedstocks and the process used to create the fuel. This is why the aviation industry is careful to follow strict, independently-verified sustainability standards.

Key advantages of SAF for aviation

- **Environmental benefits:** sustainably produced alternative jet fuel results in up to an 80% reduction in CO_2 emissions across their lifecycle.
- **Diversified supply:** SAF offers a viable alternative to conventional fuel and can substitute traditional jet fuel with a more diverse geographical fuel supply through non-food crop sources.
- **Economic and social benefits:** SAF provides a solution to the price fluctuations related to fuel cost volatility facing aviation. SAF can provide economic benefits to parts of the world, especially developing nations, that have land that is unviable for food crops, but that is suitable for SAF feedstock growth. Refining infrastructure is often installed close to feedstock sources, generating additional jobs and economic activity.

Why use sustainable aviation fuel for aviation?

> *“SAF produces up to 80% less CO_2 over its lifecycle, compared to conventional jet fuel.”*

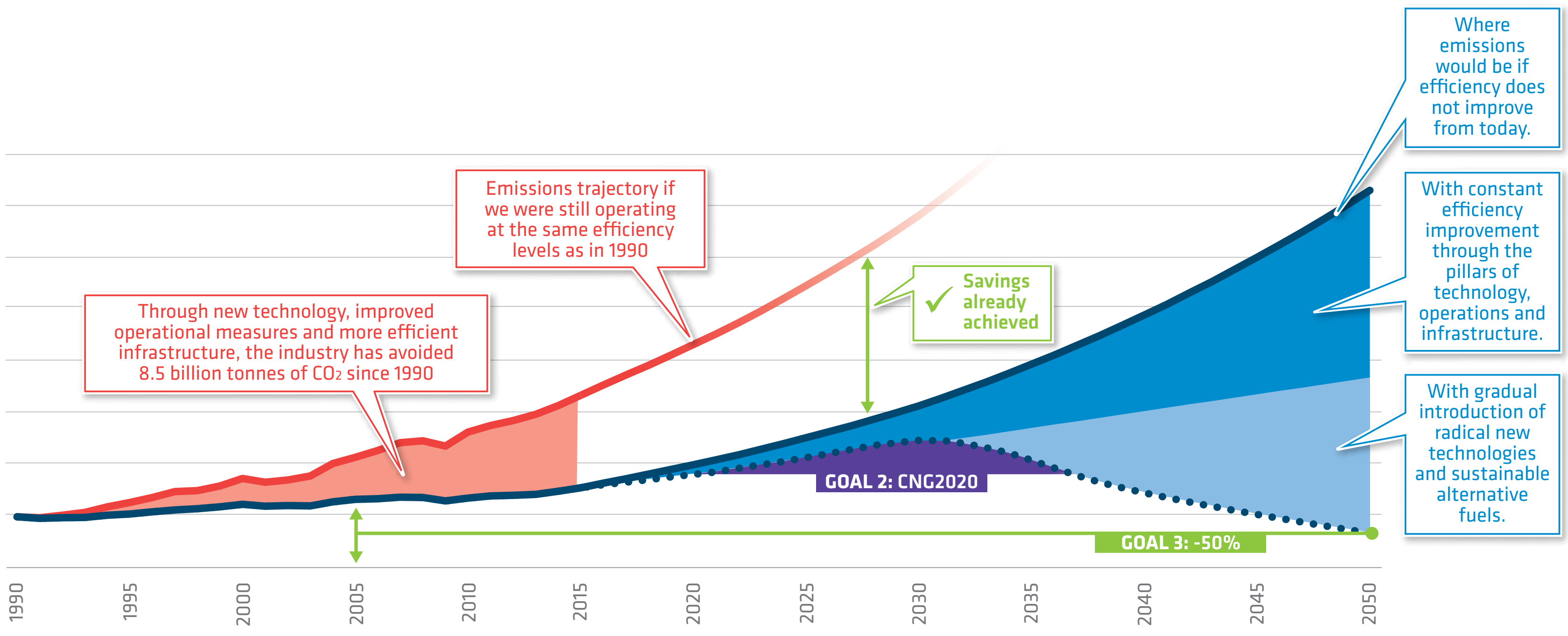
The aviation industry has set three global goals to address its climate impacts:

- an average annual improvement in fuel efficiency of 1.5% from 2009 to 2020;
- a cap on net aviation CO_2 emissions at 2020 levels through carbon-neutral growth;
- halving net CO_2 emissions by 2050, compared to 2005 levels.

At the current traffic rate (there were 35.8 million scheduled commercial flights carrying 3.8 billion passengers in 2016), the aviation industry produces roughly 2% of global manmade carbon emissions (equivalent to 781 million tonnes of carbon dioxide). Aviation's annual passenger numbers are expected to grow up to 6.9 billion by 2035, meaning that effective action on reducing carbon emissions is essential to ensure the sustainable development of the industry.

Companies across this sector are collaborating to reduce emissions through a four-pillar strategy of new technology, efficient operations, improved infrastructure and a global market-based measure to fill the remaining emissions gap.

Developing SAF will provide the aviation industry with an alternative to petroleum-based fuels, enable the industry to reduce its carbon footprint by reducing its



lifecycle greenhouse gas emissions by up to 80%, allow it to draw upon a variety of different fuel sources, and be easier to implement than for other transport modes. SAF provides aviation with the capability to partially, and perhaps one day fully, replace carbon-intensive petroleum fuels. They will, over time, enable the industry to reduce its carbon footprint significantly.

While aviation emissions are small compared to other industry sectors, such as power generation and ground transport, these industries have a wide variety of viable alternative energy sources currently available. For example, the power generation industry can look to wind, hydro, nuclear and solar technologies to make electricity without producing much CO_2. Cars and buses can run on hybrid, flexible fuel engines or electricity. Electric-powered trains can replace diesel locomotives. The technology to power a commercial aircraft on anything other than liquid fuel does not currently exist and, while this is hoped to become feasible in the future, aviation must concentrate on increasing aircraft fuel efficiency, as well as developing SAF.

Aviation efficiency – technology will only take us so far

The progress the aviation industry has made in reducing its impact on the environment is remarkable and has become one of the industry's central motivations. The aerodynamics of aircraft, the performance and efficiency of modern engines and the operational improvements by airlines, airports and air traffic systems have all combined to make aircraft over 80% more fuel-efficient since the start of the jet age in the 1950s.

The industry will continue to make technology improvements in the way aircraft are manufactured and how they are flown, with some significant improvements already in place. But while cutting-edge technology means the most modern aircraft are now more fuel-efficient than many cars per passenger-kilometre (below 3 litres per 100 passenger-kilometre), the forecast growth in the number of people flying will see the industry's emissions continue to rise unless other means to reduce emissions are found.

Hydrocarbon fuel is the only option for aviation... for now

At this stage, the only option to power commercial aircraft sustainably in the coming decades is by using hydrocarbon fuels. Encouraging progress has been made in recent years in the development of electric aircraft, with a number of small-scale prototypes having already been flown. It is expected that in a few decades, short-range commercial aircraft will be technically feasible.

Hydrogen can be burned in a turbine engine for aviation. However, there are significant technical challenges in designing a hydrogen-powered aircraft for commercial aviation and in producing enough hydrogen in a sustainable way to supply the industry's needs worldwide.

Implementing SAF – easier than for other transport modes

The supply of fuel to the commercial aviation industry is on a relatively small scale and the distribution network is less complex than for other forms of transport. For this reason, it is anticipated that it will be easier to fully implement the use of SAF than in other transport systems. For example, there were about 121,446 retail petrol stations in 2016 in the United States. This compares to a relatively smaller number of global airport fuel depots: 180 which handle more than 90% of the world's passengers.

Similarly, there were around 1.2 billion vehicles on the road in 2014, compared to around 26,000 commercial aircraft in service . And while many of those road vehicles are owned by individuals or families, there are only around 1,400 airlines in the world.

The centralised nature of aviation fuelling means that the integration of SAF into the aviation system is potentially a lot easier than it would be in a more dispersed, less controlled, public fuel delivery system.

> *Modern aircraft are over 80% more fuel-efficient than those flown at the start of the jet age in the 1950s.*

Technical certification

> *SAF must undergo strict laboratory, ground, and flight tests under an internationally-recognised standard.*

Technical requirements for SAF

- A high-performance fuel that can withstand a wide range of operational conditions.
- A fuel that can directly substitute conventional jet fuel for aviation with no requirement for different airframe, engine or logistical infrastructure.
- A fuel that meets or exceeds current jet fuel specifications.

SAF must have the same qualities and characteristics as conventional jet fuel in order to substitute it. This is important to ensure that manufacturers do not have to redesign engines or aircraft, and that fuel suppliers and airports do not have to build new fuel delivery systems. At present, the industry is focused on producing SAF for a "drop-in" replacement to conventional jet fuel. Drop-in fuels are combined with the petroleum-based fuel either as a blend or potentially, in the future, as a 100% replacement.

In brief, the diagram below explains how conventional jet fuel is blended with SAF, and approved for technical compliance.

To ensure technical and safety compliance, SAF must undergo strict laboratory, ground, and flight tests under an internationally-recognised standard.

Testing

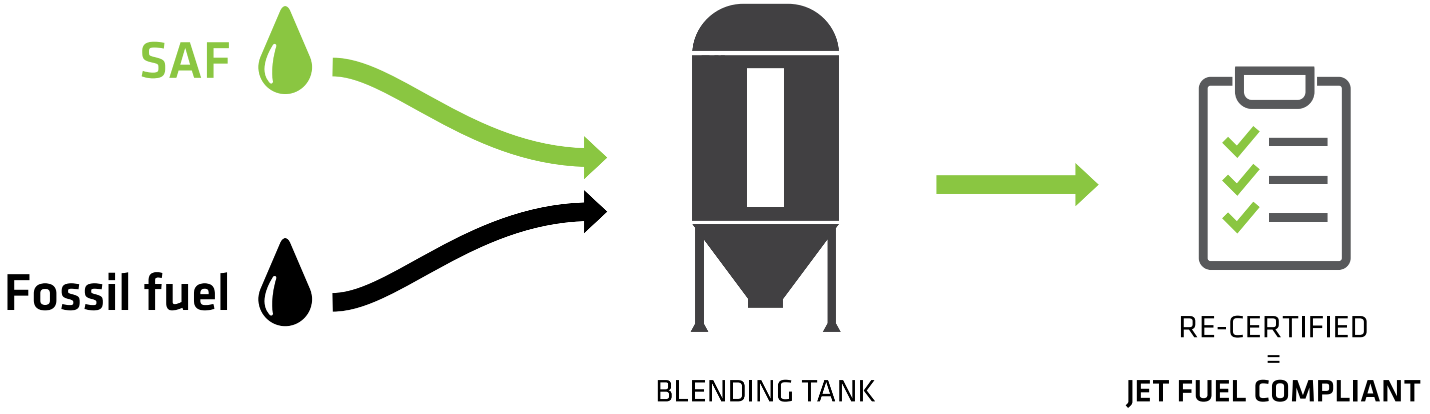
Safety is the aviation industry's top priority. Given this and the specific requirements of any fuels used in aircraft, the process for testing potential new fuels is particularly rigorous. Through testing in laboratories, in equipment on the ground, and under the extreme conditions of in-flight operations, an exhaustive process determines suitability of SAF.

In the laboratory

Researchers develop SAF that has similar properties to conventional jet fuel, Jet A-1. This is important because fuel is used for many purposes inside the aircraft and engine, including as a lubricant, cooling fluid and hydraulic fluid, as well as for combustion.

On the ground

Tests look at specific fuel consumption at several power settings from ground idle to take-off speed, which is then compared to performance with conventional jet fuel. Tests are also completed on the amount of time



it takes for the engine to start, how well the fuel stays ignited in the engine and how the fuel performs in acceleration and deceleration. Tests are also completed to ensure that the fuels don't have a negative impact on the materials used in building aircraft and components. Finally, an emissions test determines the exhaust emissions and smoke levels for the SAF.

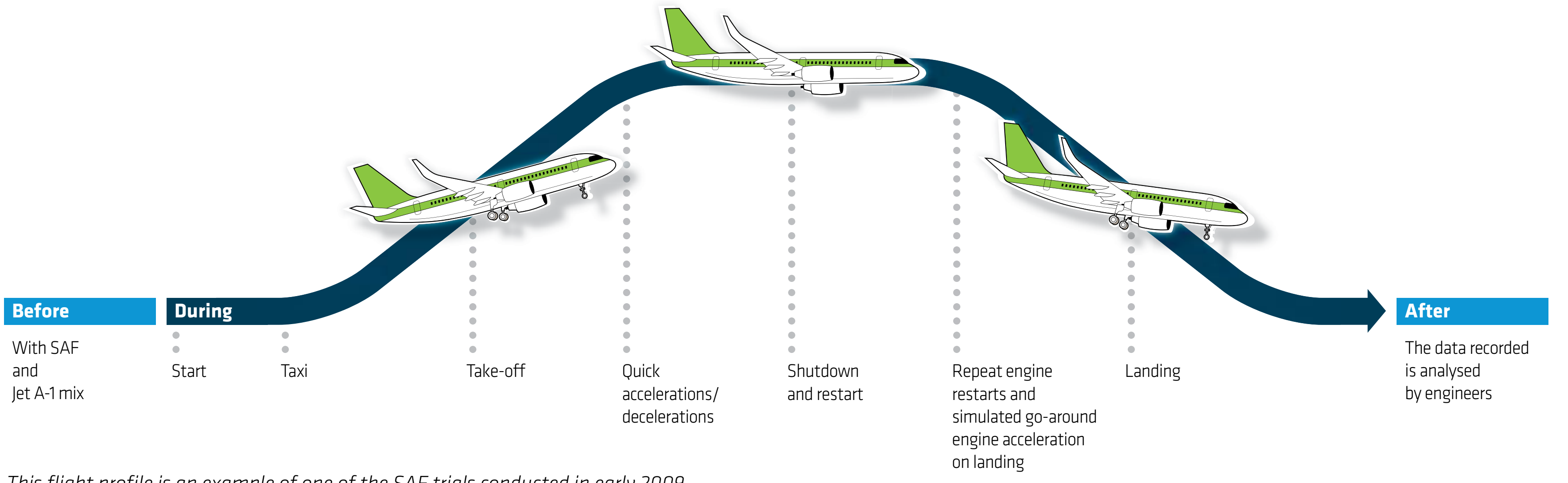
In the air

Once the lab and ground testing have been completed, the fuel is ready to be tested on aircraft under normal operating conditions. A number of airlines provided aircraft for non-conventional fuel flight trials designed to:

- provide data to support fuel qualification and certification for use by the aviation industry;
- demonstrate that SAF is safe and reliable; and
- stimulate SAF research and development.

During the test flight, pilots perform a number of standard tests, as well as simulating exceptional circumstances, to ensure the fuel can withstand use under any operating condition.

Flight trials – evaluation of engine performance during all phases of flight: including a number of extraordinary "manoeuvres" (e.g. shutting down the engine in-flight and ensuring it can restart)



This flight profile is an example of one of the SAF trials conducted in early 2009.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> *Once a fuel has been fully certified, it is recognised as jet fuel and can be used without any restrictions.*

Approval

The approval process has three parts: the test programme; the original equipment manufacturer internal review; and a determination by the specification body as to the correct specification for the fuel. The approval process looks at a minimum of 11 key properties, including energy density, freezing point, appearance, composition.

Certification

Because of the very strict standards required in the aviation industry, SAF needs to be approved as safe and appropriate for commercial use. The aviation industry works closely with international fuel specification bodies to develop standards and certificates, such as ASTM International.

To become approved for use, SAF must meet certain specifications from ASTM. Once it has demonstrated compliance with the requirements, it is blended with no more than 50% by volume (according to current standards) with conventional jet fuel and re-tested to show compliance. The reasons for the current blend limits are to ensure the appropriate level of safety and compatibility with the aircraft fuelling systems (mainly due to the level of aromatics which are necessary for the different systems). It is, however, likely that higher blend limits will be approved in the future.

Once a fuel has been fully certified, it is recognised as jet fuel and can be used without any restrictions, allowing it to become compliant with other international standards.

Jet fuel specifications

Criteria	Explanation	Jet A-1 specification
Flash point	The temperature at which the fuel ignites in the engine to cause combustion to occur (°C)	38° minimum
Freezing point	The temperature at which the fuel would freeze (°C)	-47°
Combustion heat	The amount of energy that is released during combustion, per kilo of fuel (MJ/kg)	42.8 MJ/kg minimum
Viscosity	The thickness of the fluid or ability to flow (mm^2/s)	8.000 max
Sulphur content	The amount of sulphur in the fuel (parts per million)	0.30
Density	How heavy the fuel is per litre (kg/m^3)	775-840

Sustainability commitment

Sustainability

The aviation industry is focused on developing fuels that can be mass produced at a low cost and high yield with minimal environmental impact. Today's technology has allowed SAF to be produced from feedstocks that limit the risk of unintended environmental and social consequences. Moreover, to ensure that fuels are sustainably produced, many airlines require SAF suppliers to provide a Certificate of Sustainability (CoS) or similar sustainability documentation in addition to a technical compliance certification.

The goal of achieving a net carbon emissions reduction is the main motivation for using SAF in order to meet the aviation industry's ambitious climate goals. However, simply deploying any form of alternative fuel on aircraft does not necessarily reduce overall carbon emissions. The fuels used must demonstrate a net carbon reduction through lifecycle analysis (LCA) as well as other sustainability metrics in order to be deemed 'sustainable aviation fuel'.

The Sustainable Aviation Fuel Users Group (SAFUG), which represents approximately one third of commercial aviation fuel demand, has signed a pledge for high sustainability commitment that is consistent with and/or complementary to internationally-recognised biofuel sustainability standards such as the Roundtable on Sustainable Biomaterials (RSB). By doing so, SAFUG airline members pay particular attention to:

- Lifecycle greenhouse emissions
- Direct and indirect land use change
- Water supplies
- High conservation value area and biodiversity
- Socio-economic conditions of farmers and local population (particularly in developing countries).

In addition to RSB, there are a number of other public and private bodies that issue Certificates of Sustainability or similar documents, including the International Sustainability and Carbon Certification (ISCC), which also covers SAF.

It is expected that the Committee on Aviation Environmental Protection in ICAO will develop sustainability criteria for SAF eligibility under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

In some countries, particularly in the US and EU Member States, governments offer financial incentives for alternative fuels that meet sustainability criteria; and a document confirming sustainability is one of the pre-requisites to demonstrate eligibility. Moreover, in the US and the Netherlands (with more EU States potentially to follow) deployment of alternative fuel can contribute towards the overall targets for renewable transport fuels.

In the US, a coalition of airlines, manufacturers, energy producers and US government agencies have joined together to form the Commercial Aviation Alternative Fuels Initiative (CAAFI), which aims to facilitate the commercial deployment of SAF, making it economically viable and environmentally sound.

> *"The development of SAF will support a number of the UN Sustainable Development Goals."*

It is possible that future policy around the world may consider incentivising the use of SAF that meet particularly high standards of sustainability.

SAF and the Sustainable Development Goals

In 2015, the United Nations announced the 2030 Agenda for Sustainable Development. Underpinning the Agenda is a set of 17 Sustainable Development Goals (SDGs), which are intended to address the roots causes of poverty and drive development.

Aviation, in general, supports many of the aims of the goals, with the increasing use of SAF helping to work towards SDG 7 (Affordable and clean energy) and SDG 13 (Climate action). Through the diversification of feedstock supply, the commercialisation of SAF can also help support some of the more socially and economic-focused SDGs (such as 'No poverty' and 'Reduced inequalities'), by providing employment opportunities in developing countries. As the production of SAF is scaled up, the industry will also be focusing on avoiding negative impacts on SDG 6 (Clean water and sanitation) and SDG 15 (Life on land).

For more information see www.aviationbenefits.org/SDGs

Economic viability

Economic viability of SAF

- SAF will become economically viable and compete with fossil-based fuels as costs are lowered by improvements in production technology and through economies of scale in production.
- They may also provide valuable economic opportunities to communities that can develop new sources of income – including in many developing nations.

The fossil fuel industry has a 100-year head start compared to SAF, which is still emerging technologically. A concerted effort by governments is required to foster these promising renewable options to help drive their long-term viability.

Since the first test flight in 2008, the technological progress has been remarkable, however, the actual uptake of sustainable aviation fuel is modest relative to total industry demand. This is in part due to these fuels still being produced in relatively small quantities. Without economies of scale the unit cost of production remains, in general, higher than traditional fuel and this price impediment is limiting its wider use. For SAF to be scaled up to commercially viable levels, substantial capital is required to develop the refining and process capacity.

Moving a technology from the research to the commercial phase can be extremely challenging and requires substantial investment. Building a small scale demonstration facility requires a fraction of the capital required to develop a commercial scale facility. However, even if a demonstration scale facility performs as expected, moving from small scale to commercial scale can still be risky. Addressing this funding gap should be a priority for policy makers who have the available tools and mechanisms to bridge the gap and enable progress in this new industry.

However, once the cost of production facilities has been de-risked, it is likely that the cost of the new fuel will drop considerably, as has been seen in other renewable energy markets. Global policy developments are making SAF a more important strategic consideration for aircraft operators and we have already seen some massive forward purchase agreements from airlines, with most able to negotiate SAF at only slightly higher cost than traditional jet fuel.

As more airlines commit to purchasing SAF, including projects to deploy at airports, existing producers will attract more investment and the incentive to start new SAF companies will be created. As the economic potential of SAF is increasingly demonstrated, it is probable that traditional energy companies will use their investment resources to acquire or develop sustainable aviation fuel businesses as part of their total product offering. Many of the traditional energy names are working on projects, with perhaps the most public intention of commitment shown by Air BP with a $30 million investment in sustainable aviation fuel company Fulcrum in 2016.

In addition, with the conclusion of the negotiations of the global market-based measure in October 2016, and the subsequent introduction of the global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), it is expected that international aviation will continue to be exempt from inclusion in the ETS. The technical elements of CORSIA, including compliance criteria for sustainable aviation fuel is expected to be finalised by ICAO in 2018.

Under the CORSIA agreement, the use of sustainable aviation fuel by airlines will count towards their CO_2 emissions reduction efforts and will be accounted for under the scheme. ICAO's technical working group, the Committee on Aviation Environmental Protection (CAEP), will refine how exactly alternative fuels will play a role in emissions accounting in the coming years including defining the required sustainability eligibility criteria. This decision will be made before CORSIA's formal introduction in 2020.

> *"The use of SAF will be taken into consideration under CORSIA."*


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> **Bringing SAF from feedstock to jet fuel supply**
>
> - This will require the production of sufficient sustainable raw materials and industrial capability to process and refine it into fuel.
> - The worldwide aviation industry consumes about 278 billion litres of jet fuel annually.

Now that SAF has been approved as suitable for use on commercial flights (and that thousands of commercial flights have now been operated using the fuel), economically competitive feedstock supply is a challenge to sustain production. The worldwide aviation industry consumes about 278 billion litres of jet fuel annually. IATA analysis suggests that a viable market for SAF can be maintained when as little as 1% of world jet fuel supply is substituted by SAF (or, put another way, 10% of the world's aircraft fleet is running on a blend of 10% SAF and 90% Jet A-1).

Substantial progress has been seen within the period of 2013-2016 where a number of off-take agreements have been made between suppliers and airlines. As of September 2017, there were four airports worldwide that have regular supplies of SAF: Oslo, Los Angeles, Bergen and Stockholm. There are also a number of other airports currently exploring the possibility of regularly supplying SAF to airlines flying out of them.

To keep track of new SAF orders, offtake agreements and the number of commercial flights operated on SAF, visit: www.enviro.aero/SAF

Sustainable Aviation Fuel Pathways

There are currently five approved SAF production pathways, and each represents different processes and different feedstocks.

Each of these pathways has its benefits, such as the availability of feedstock, cost of the feedstock, carbon reduction or cost of processing. Some may be more suitable than others in certain areas of the world. But all of them have the potential to help the aviation sector reduce its carbon footprint significantly, assuming all sustainability criteria are met.

While blend limits exist today for technical and safety reasons, this is not seen as an impediment to SAF development. SAF production is in the early stages of development and is not likely to be limited by the technical blend limitations for some years. The continued testing and development of new processes and feedstocks will yield useful data to support revision of the specification to allow more flexibility in the supply chain, as well as potential benefits in terms of fuel price stability and availability.

> *Thousands of commercial flights have now been operated using SAF.*

Pathways Processes	Feedstock	Date of Approval	Blending Limit
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)	Biomass (forestry residues, grasses, municipal solid waste)	2009	up to 50%
Hydroprocessed Esters and Fatty Acids (HEFA-SPK)	Oil-bearing biomass, e.g., algae, jatropha, camelina, carinata	2011	up to 50%
Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (HFS-SIP)	Microbial conversion of sugars to hydrocarbon	2014	up to 10%
FT-SPK with aromatics (FT-SPK/A)	Renewable biomass such as municipal solid waste, agricultural wastes and forestry residues, wood and energy crops	2015	up to 50%
Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)	Agricultural wastes products (stover, grasses, forestry slash, crop straws)	2016	up to 30%
Hydroprocessed Esters and Fatty Acids Plus (HEFA +)	Oil-bearing biomass, e.g., algae, jatropha, camelina, carinata	To be determined. *It is expected to be approved by ASTM by the middle of 2018.*	up to 50%

The next steps

> *Five pathways have now been approved, with others undergoing assessment.*

The extensive commercial flights and testing in numerous demonstration flights by over 20 different airlines has demonstrated that the barriers to increased SAF deployment are not technical, but rather economic and political. Some of the key challenges that remain include:

- ensuring an adequate supply of sustainable feedstock;
- optimising logistics to include using airport hydrant systems and efficient blending locations;
- ensuring that the cost is competitive, in order to compete with petroleum-based jet fuel;
- ensuring that aviation receives an appropriate allocation, relative to other forms of transport, of available sustainable feedstocks;
- ensuring that governments implement appropriate policy mechanisms to allow the SAF industry to scale up and deliver the economic economy of scale benefits.

With five pathways now certified for the production of SAF, and other potential pathways under consideration, options are increasing for the deployment of SAF, from both a technical perspective and feedstock diversity angle.

In January 2016, SAF entered the 'commercial deployment phase' with the first continuous production and supply entering the common airport distribution system at Oslo Airport, with Los Angeles International Airport and Stockholm Arlanda Airport following later in the same year. It is expected that similar initiatives, either driven by substantial airline offtake agreements or airports working with operators to promote greener operations, will follow in the medium-term.

The aviation industry is committed to a high standard of sustainability and many standards require the sustainability claim of SAF to be independently verified by a recognised entity. This can also allow eligibility for incentives should the SAF meet a defined sustainability criteria.

The industry has called on governments to assist potential SAF suppliers to develop the necessary feedstock and refining systems – at least until the fledgling industry has achieved the necessary critical mass.

In an earlier report produced by ATAG, *Powering the Future of Flight*, the aviation industry presented six steps that governments could take to help aviation transition towards the commercial-scale use of SAF. These are:

1. Foster research into new feedstock sources and refining processes
2. De-risk public and private investments in SAF
3. Provide incentives for airlines to use SAF from an early stage
4. Encourage stakeholders to commit to robust international sustainability criteria
5. Understand local green growth opportunities
6. Establish coalitions encompassing all parts of the supply chain

While these are not minor hurdles, they are not insurmountable. The history of aviation is marked by people achieving extraordinary things, despite many at the time telling them it couldn't be done.

The aviation industry is now on the verge of making another extraordinary step forward, but the challenge of commercialising SAF is one that the entire industry needs to meet together. The industry made a bold commitment to begin the use of SAF on commercial flights, a vision which was realised in 2011. It is very possible that a significant supply of alternative fuel in the jet fuel mix could be achieved by 2020. It is now up to dedicated stakeholders across the aviation sector, with help from governments, feedstock and fuel suppliers to ensure that the low-carbon, alternative future for flight becomes a reality.

Definitions

Alternative fuel: has a specific meaning defined by ICAO, which is 'any fuel that has the potential to generate lower carbon emissions than conventional kerosene on a life cycle basis'. It is also used as a general term to describe any alternative to petroleum-based fuels, including liquid fuel produced from natural gas, liquid fuel from coal and biofuels. While the aerospace sector is investigating some of the gas-to-liquid and coal-to-liquid fuel production processes, these are not generally considered to produce significantly lower emissions than current petroleum-based fuel supplies. Indeed, many of these products will produce more CO_2 when their production is taken into account. Aviation is already making limited use of these fuels and this may increase in the future, but the real solution to reducing emissions is to leave all fossil fuels behind. Biofuels are therefore the answer for sustainable energy.

ASTM International: originally known as the American Society for Testing and Materials, this international standards organisation develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. ASTM International works with aircraft and engine manufacturers, government authorities and fuel suppliers to set the standards for aviation fuels such as the required characteristics for jet fuel.

Biodiesel: a fatty acid ester diesel fuel produced from biomass; chemically different from conventional diesel and other fuels from crude oil. Not suitable for use in aviation.

Biomass: any renewable material, including wastes and residues, of biological origin (plants, algae, animal fats and so on).

Carbon footprint: net amount of carbon dioxide emissions attributable to a product or service (emissions from production and combustion, minus absorption during plant growth). For fossil fuels, the absorption of carbon dioxide occurred millions of years ago and so their carbon footprint is simply 100% of their carbon output.

Carbon neutral: being carbon neutral, or having a net zero carbon footprint, refers to achieving net zero carbon emissions by balancing a measured amount of carbon released by an activity with an equivalent amount captured or offset. Biofuels represent a step towards carbon neutrality: virtually all of the CO_2 they release during combustion has been previously absorbed by growing plants, however emissions from feedstock and fuel production and transport have to be subtracted.

Carbon-neutral growth: the situation where an industry emits the same amount of carbon dioxide year on year while growing in volume. For the aviation industry this means being able to continue to increase passenger traffic and aircraft movements, while keeping aviation industry emissions at the same level.

Drop-in fuel: a fuel that is chemically indistinguishable from conventional jet fuel, so no changes would be required in aircraft or engine fuel systems, distribution infrastructure or storage facility. It can be mixed interchangeably with existing jet fuel.

Ethanol: a fuel produced from sugar-rich crops such as corn and sugarcane and used by ground vehicles. Not suitable for aviation use.

Feedstock: raw material from which fuels are produced.

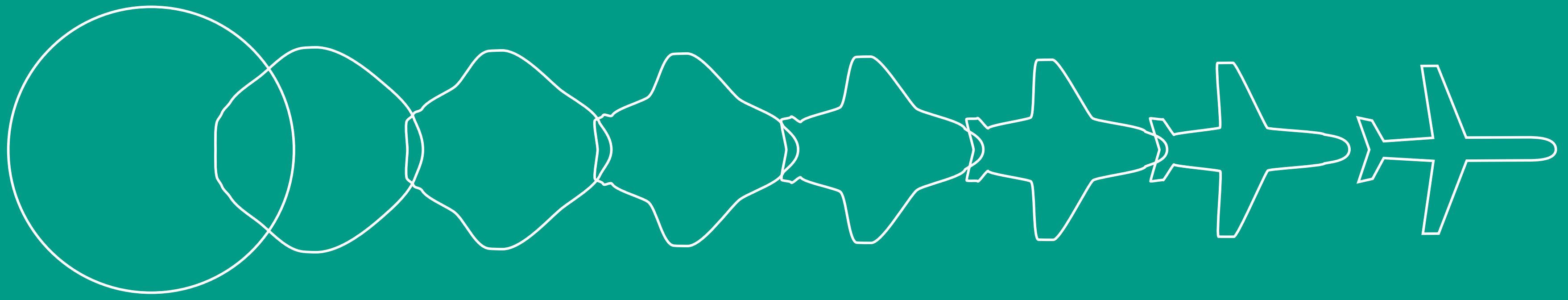
Greenhouse gases: gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which trap the warmth generated from sunlight in the atmosphere rather than allowing it to escape back into space, replicating the effect glass has in a greenhouse. Human activities such as fossil fuel combustion and land-use change increase the emission of greenhouse gases into the atmosphere.

Jet A: commercial jet fuel specification for North America.

Jet A-1: common jet fuel specification outside North America. (These two fuels are very similar and throughout this guide we used the term jet fuel to mean the fuel used by aviation).

Kerosene: the common name for petroleum-derived jet fuel such as Jet A-1, kerosene is one of the fuels that can be made by refining crude oil. It is also used for a variety of other purposes.

Sustainability: the ability for resources to be used in such a way so as not to be depleted or to create irreversible damages. For humans to live sustainably, the earth's resources must be used at a rate at which they can be replenished, providing economic growth and social development to meet the needs of today without compromising the needs of tomorrow.



Sources for diagrams and a reference version of this document are available at www.enviro.aero

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ATAG AIR TRANSPORT ACTION GROUP

CLIMATE ACTION TAKES FLIGHT

FUELING THE FUTURE

Sustainable Aviation Fuel Guide

EDITION 2 | 2020

Brought to you by

THE BUSINESS AVIATION COALITION FOR SUSTAINABLE AVIATION FUEL


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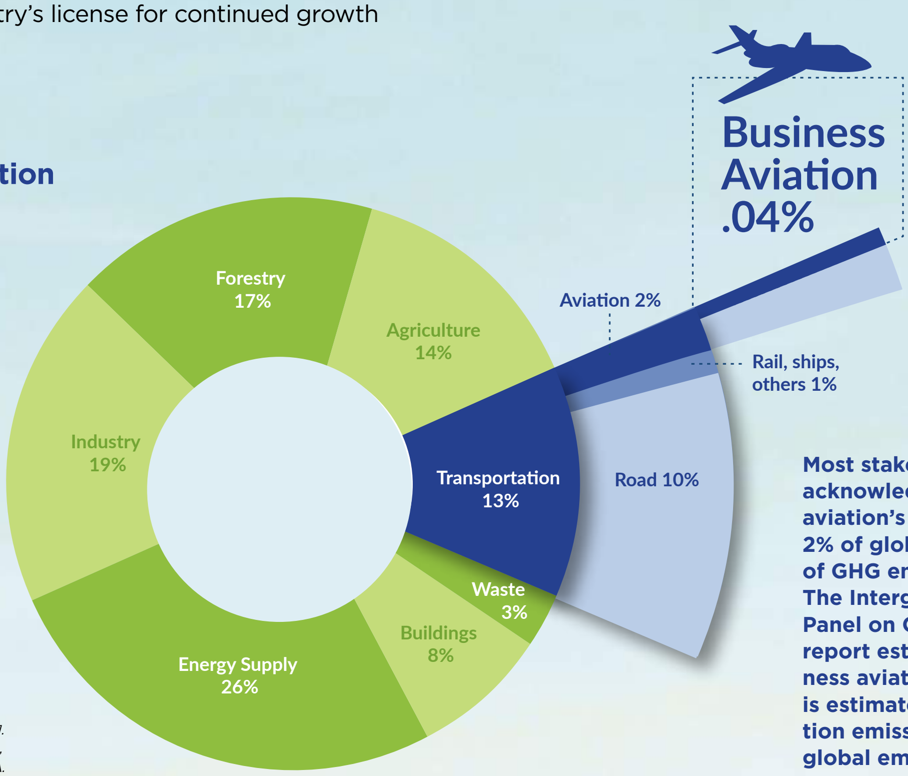
INTRODUCTION

Why This Guide?

Awareness and concern continue to grow about the harmful effects on the atmosphere of greenhouse gas (GHG) emissions from industrial installations, power plants, surface vehicles, ocean-going vessels and aircraft. The aviation industry leads the way in taking steps to improve its efficiency, and address its emissions impact.

Aviation—including business aviation—is a key contributor to global economic growth, commercial trade and increased prosperity, enhancing communication, linking markets and people, while providing economic opportunity and well-paying, high-skill jobs for millions of people. The industry contributes positively to the bottom line of businesses that depend on flexibility and efficiency to optimize economic opportunities, regardless of where they are located. But the industry's license for continued growth is dependent on its ability to do so in a sustainable, environmentally responsible manner. According to the International Civil Aviation Organization (ICAO) 2019 Environmental Report, global business aviation operations represent 0.04% of CO_2 emissions caused by human activity.[1] Although this represents a tiny fraction of overall emissions, it is vital that business aviation does its part to continue the industry's successful work to date to reduce this footprint.

Figure 1. Business Aviation Sector's Contribution to Global GHG Emissions



Source: IPCC (2014). Climate Change 2014: Mitigation of Climate Change . Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Most stakeholders acknowledge civil aviation's contribution of 2% of global CO_2 and 3% of GHG emissions, as per The Intergovernmental Panel on Climate Change report estimates. The business aviation contribution is estimated at 2% of aviation emissions or 0.04% of global emissions.

1. https://www.icao.int/environmental-protection/Pages/envrep2019.aspx

The aviation industry is among the first to have developed internationally-agreed-upon carbon emission-reduction standards for both aircraft and operators, yet more must be done, including a focus on improving the efficiency of products and operations.

The good news is, considerable progress has been made in this regard. In 2009, the business aviation industry — representing the manufacturer and operator sectors — announced specific commitments regarding emissions reduction.[2] To achieve the goals outlined in that announcement, a four-pillar strategy was set forth – those four pillars are outlined in more detail later in this publication.

The single-largest potential reduction in aviation's GHG emissions — and the key to reaching goals for reducing them — will come about through the broad adoption of sustainable aviation fuel (SAF) in place of conventional jet fuel in use today. There are other, cleaner alternatives to fossil fuels being developed in addition to SAF (e.g., electrification and hydrogen fuel), but these remain longer-term alternatives, whereas SAF has been proven to work, and is ready to be scaled today.

Increasing the industry's uptake of SAF is important, but it is clear, and understandable, that many questions remain about SAF, especially as it is still relatively new. This guide is designed, in part, to explain what SAF is, and what it is not. The aim of this resource is to answer questions and allay concerns for the community of aircraft operators, fixed-base operators (FBOs), owners, pilots, fuel providers, airports and others regarding the performance, safety and appropriateness of using SAF wherever it is available.

SAF is available today, but not widely so. Certain factors are holding back the full deployment and commercialization of SAF, though safety and performance are not among them. In fact, SAF have undergone a rigorous certification process.

What If SAF Is Unavailable?

Given the relatively limited availability of SAF, the industry is pursuing innovative measures to augment or stand in for use of the fuel. These include:

Book-and-Claim. **Under this program, business jet operators can purchase SAF at an airport where it is unavailable, and receive credit for its supply and use at an airport where it is available.**

Carbon Offsets. **Using carbon-offset programs, individuals or organizations can compensate for their proportion of an aircraft's carbon emissions on a particular mission, by purchasing or making a dedicated charge that would be invested in carbon-reduction projects that have a lower emissions output.**

Carbon offsetting would ideally be used in conjunction with other carbon reduction measures, such as SAF.

2. https://gama.aero/news-and-events/press-releases/global-business-aviation-community-announces-commitment-on-climate-change/

As outlined below, SAF that has been produced to meet the requirements of ASTM D7566 and re-identified as ASTM D1655 (known as Jet-A, or Jet A-1) has gone through an exhaustive and resource-intensive testing program before approval for use. Civil aviation authorities and aviation industry stakeholders, including original equipment manufacturers (OEMs), have put in place a comprehensive and thorough process to test and approve SAF. In addition, the world's leading aviation regulatory authorities – including the Federal Aviation Administration (FAA), the European Aviation Safety Agency (EASA) and others – have issued clear guidance allowing the use of SAF, following blending that has been re-identified and certified as meeting ASTM D1655 standards in turbine aircraft.

As the world's leading business aviation industry associations representing manufacturers, operators, FBOs and others – and with the support of the Commercial Aviation Alternative Fuels Initiative (CAAFI) – the European Business Aviation Association (EBAA), the General Aviation Manufacturers Association (GAMA), the International Business Aviation Council (IBAC) and its constituents, the National Air Transportation Association (NATA) and the National Business Aviation Association (NBAA) are confident that this guide will answer questions about SAF. This resource also includes organizational contact and other information for further questions, or information needs.

SAF: Increasing Regulatory Acceptance

Increasingly, the availability and growing use of sustainable aviation fuel (SAF) is a top priority for civil aviation worldwide. In September 2019, the 40th Assembly of the International Civil Aviation Organization acknowledged the need for SAF to be developed and deployed in an economically feasible manner and requested that its 193 member states adopt positive measures to encourage increased production and consumption of SAF for aviation.

Concurrently, the European Union established the European Green Deal to tackle climate change and environmental-related challenges; it supports an increase in SAF production and availability as playing a significant role in reducing the environmental impact of civil aviation.

Worth noting, numerous key Civil Aviation Authorities globally are actively supporting the sustainable growth of civil aviation in their respective countries, and focus on SAF as an important component in this drive towards sustainability. In addition to the U.S. Federal Aviation Administration (see above) – other leading CAAs publicly calling for increased SAF use include: the European Union Aviation Safety Agency, Transport Canada Civil Aviation, National Civil Aviation Agency in Brazil, and the Civil Aviation Authority of Singapore, to name a few.

BACKGROUND

What is the role of sustainable aviation fuel (SAF) in helping the industry meet its climate change commitments?

Sustainable Aviation Fuel (SAF)[3]

is a colloquial term used in two primary ways:

1. To describe the family of jet fuels comprised of a blend of conventional jet fuel with non-conventional, more sustainable blending agents. This SAF blend is what is defined as the fully ready drop-in fuel that can be used to replace conventional jet fuel.
2. To serve as the moniker for the sustainable blending component alone, because it is the blending component that enables the reduction in net greenhouse gas emissions for the industry. The SAF blending component is also referred to as "neat SAF," or in some cases, simply SAF.

> ***"SAF is a critical drop-in jet fuel technology with significant potential to address aviation environmental and energy concerns. FAA has sponsored SAF development via CAAFI and other programs since 2006."***
>
> **Kevin Welsh**, Executive Director, Office of Environment & Energy, Federal Aviation Administration

The discussion that follows points to the fact that the term can be used either way, and highlights the focus of the industry on production of the blending agent, whether in neat or blended form. As SAF development continues to expand and mature, it is likely a point will be reached where some SAF blending components will be able to be used as drop-in fuels without requiring initial blending; therefore, the dual usage is sufficient for now, given that both uses will be needed in the near future.

SAF is being pursued by the industry to:

- **Reduce net life-cycle carbon dioxide (CO_2) emissions** from aviation operations.
- **Enhance the sustainability of aviation** with a fuel source superior to conventional jet fuel in economic, social and environmental aspects.
- **Enable drop-in jet fuel production** from non-conventional sources (multiple feedstocks and conversion processes), so no changes are required in aircraft or engine fuel systems, distribution infrastructure or storage facilities.

Because SAF is a relatively recently adopted term, some who have been working in this field for a while may also use the terms bio-jet, renewable jet, bio-kerosene, alternative jet, non-conventional jet fuel, etc., or specifically by the several names for the conversion pathways outlined in ASTM D7566 (e.g., HEFA-SPK, or Synthetic Paraffinic Kerosene produced from the Hydroprocessing of Esters and Fatty Acids). Any SAF compliant with the requirements of ASTM D7566 is recognized as meeting the characteristics of traditional petroleum-based conventional jet fuel approved under ASTM D1655 (see next page).

3. Note that in the 2018 version of this guide, we used the terminology sustainable alternative jet fuel (SAJF). Since that version was published, the International Civil Aviation Organization (ICAO) adopted a simplified name and acronym for this fuel, sustainable aviation fuel or SAF, and has asked the entire industry to follow suit.

The name "Sustainable Aviation Fuel" denotes three key elements, two of which are reflected in the name, and another that is inherent in achieving sustainability:

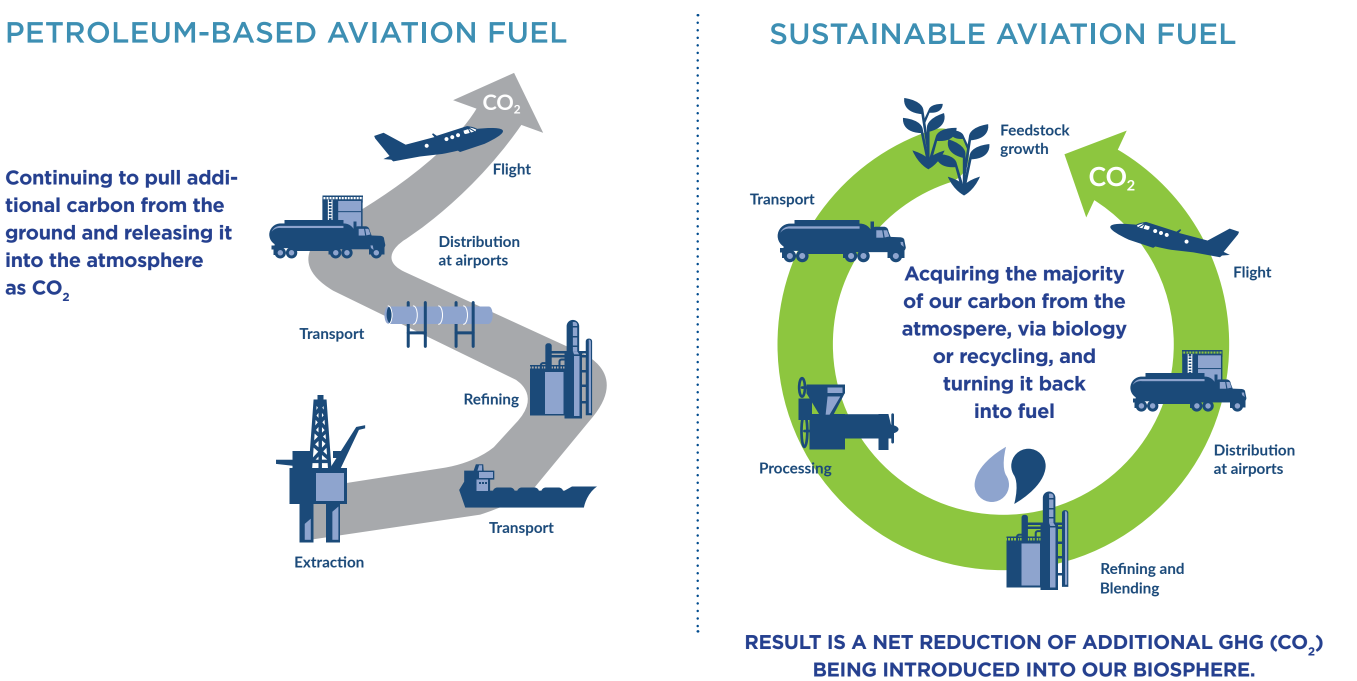
1. **Sustainability:** This is defined as something that can be continually and repeatedly resourced in a manner consistent with economic, social and environmental aims; specifically, something that conserves and promotes an ecological balance by avoiding depletion of natural resources and mitigates contribution to climate change, as well as other sustainability criteria generally.

2. **Aviation Fuel:** SAF blends, when produced to the requirements established and approved by the industry as outlined in ASTM D7566, meet all the technical and certification requirements for use in turbine-powered aircraft engines, and can be re-identified as meeting the ASTM D1655 standard.

3. **Consistently Defined:** An SAF blend is a blend of conventional fuel[4] and non-conventionally synthesized blending agents.[5] The non-conventional agents may be derived from many sources whose chemical constituents can be converted to the set of pure hydrocarbons that comprise jet fuel. These substances are also processed into jet-fuel-compatible molecules in an alternate manner to simply refining crude oil (e.g., via thermochemical, biochemical and catalytic production processes). Feedstocks for SAF are also varied; they include cooking oil, plant oils, solid municipal waste (trash), wood waste, waste gases, sugars, purpose-grown biomass and agricultural residues, among others.

The level of carbon intensity or GHG reduction that can be claimed by the end user is almost exclusively driven by the life-cycle assessment of the renewable

Figure 2. Achieving Net Lifecycle GHG Reductions With SAF



4. *ASTM D1655 currently defines conventional fuel in Paragraph 6.1.1 as: Aviation turbine fuel, except as otherwise specified in this specification, shall consist predominantly of refined hydrocarbons derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, shale oil and oil sands. So, ASTM D7566 was created to govern the properties of jet fuel produced from any other sources (i.e., alternative or non-conventional).*

5. *It is possible that the industry will approve 100% drop-in synthetic fuels within a few years, and in that case, there will be no blending requirement.*

6. *Carbon Index is a term that refers to the amount of net lifecycle CO_2 contained within a fuel. It is expressed in units of equivalent grams of CO_2 per energy content, or gCO_{2e}/MJ. ICAO has established a standard level of carbon index for petroleum fuels of 89 gCO_{2e}/MJ.*

component of the blended fuel. So, the level of blending does matter to the end user, who may be interested in understanding exactly how much they are improving their carbon footprint, or to others involved in the supply chain, who are interested in understanding how well their SAF complies with policy mandates and incentives. Different types of SAF also have different sustainability or carbon index scores[6], depending on the type of feedstock used, the conversion technology and the logistics of the supply chain.

Relative to petroleum-based conventional fuels, SAF blending components may deliver a net reduction in carbon dioxide (CO_2) emissions across its life-cycle. This means that even when taking into consideration the CO_2 emissions generated during the production of the SAF (from the equipment needed to grow crops, transport the raw material, refine the fuel and distribute it), its use has been proven to provide significant reductions in overall CO_2 lifecycle emissions, compared to conventional fuels. This is because the feedstocks that are used to produce the SAF blending components – cooking oil, plant oils, solid municipal waste (trash), wood waste, waste gases, sugars, purpose-grown biomass and agricultural residues, among others – consume carbon from the CO_2 already in Earth's biosphere, and not out of petroleum that is sequestered in the ground (see Figure 2).

The industry has been predominantly focused on SAF blending components that provide greater than 50 percent reductions in net greenhouse gases because various policies incentivize such reductions. However, some sustainable fuel production approaches are more aggressive by preventing additional emissions from related processes (e.g., reduction of landfill gas production), putting carbon back into the ground via production and use of biochar, or use of gaseous CO2 sequestration. SAF also contains fewer impurities, such as sulphur or complex hydrocarbons that do not burn well (such as naphthalenes), leading to even greater reductions in sulphur dioxide (SO_2) and particulate matter (PM) emissions and improved local air quality.

Progress on developing SAF has been moderate, but is accelerating. Technical barriers to the production of SAF have been largely overcome. There are now several different "pathways" approved by international aviation regulatory authorities and available to producers to convert different feedstocks into SAF blending agents.[7] There are also other pathways currently under review by the industry for potential inclusion under ASTM D7566. Up to this point, there has been a modest level of commercial-scale investment in production facilities for SAF, but a great deal more is still needed to make the deployment and commercialization of SAF a mainstream occurrence in the near term.

7. *As of this writing, there are seven pathways. Up to date information can be found in ASTM D7566, or at one of several reference sites including CAAFI's: http://www.caafi.org/focus_areas/fuel_qualification.html*

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Currently, the ability for business aviation to use SAF is hampered due to inadequate production, a lack of supply chain infrastructure and a lack of understanding, and compelling economic proposition, about the fuel. Despite these realities, the use of SAF by aviation worldwide is growing, with several hundred thousand flights having already been conducted by the civil aviation sector with SAF, and with OEMs, airlines and others having undertaken countless demonstration flights.

SAF has been made available for continuous delivery to a number of major airports worldwide, based on long-term contracting between airlines and producers/suppliers. In these cases, SAF is not sequestered for use on individual operations; rather it is incorporated directly into airport fuel farms, and the benefits are allocated only to the end-use purchaser. SAF has also been made available on an ad hoc basis to several business aviation locations around the world, most being associated with high-profile events intended to serve as educational and awareness initiatives for industry, policymakers and the general public. The civil aviation industry is working to make it more routinely available and in greater quantities.

The routine use of SAF is expected to continue to expand to additional airports worldwide, based on previous and ongoing commercialization announcements and supply chain infrastructure initiatives.[8] A critical piece to scaling up the supply and use of SAF is industry buy-in. The industry can help advance this priority by indicating its interest in SAF to fuel suppliers and government officials.

8. *For an up-to-date set of statistics, check www.enviro.aero/SAF*

Industry Commitments on Climate Change:

In November 2009, the business aviation community — comprised of the International Business Aviation Council (IBAC) representing the operators, and the General Aviation Manufacturers Association (GAMA) representing the manufacturers — published the Business Aviation Commitment on Climate Change (BACCC), which announced three aspirational goals to mitigate the industry's emissions impact.[9] These goals are:

1. **To achieve carbon-neutral growth from 2020;**
2. **To improve fuel efficiency by two percent per year from 2010 until 2020, and;**
3. **To reduce CO_2 emissions by 50 percent by 2050 relative to 2005.**

When the industry introduced this roadmap in 2009, it was clear that achievement of these goals would depend on improvements across four pillars:[10]

1.

Technology

More efficient engines and airframes, and adoption of other technologies;

2.

Sustainable Aviation Fuel

The development and commercialization of non-conventional jet fuels (SAF) that deliver reductions in net lifecycle greenhouse gases versus petroleum-derived jet fuel;

3.

Operations and Infrastructure

More efficient operations, stemming from continued progress on air-traffic management, along with measures including reduced payload, streamlined flight planning, single-engine taxiing, etc.;

4.

Market-based Measures

Policy instruments that place a cost on carbon emissions and are considered temporary measures until, combined with the effects of the other pillars, the intended target is met. Such measures include carbon offsetting and emissions trading, each of which have features to reduce their costs by using SAF.

A critical piece to scaling up the supply and use of SAF is industry buy-in.

9. *http://tinyurl.com/GAMA-CO2*

10. *These pillars were represented as technology (including SAF), operations, infrastructure, and market-based measures by the previous version of this guide. This current representation is reflective of the original BACCC.*

Progress on each of these pillars requires action and significant investment by the aviation industry, as well as other stakeholders and governments. While progress has been uneven, the aviation industry has kept its focus on improving efficiency and reducing its CO_2 footprint via the four pillars. Consider the following record of accomplishment:

Technology

Manufacturers are developing and bringing to market new engines, airframes and other aircraft components and materials that produce improvements in fuel efficiency; they are also developing avionics that allow more efficient and safe routing, bringing additional savings in CO_2 emissions.

Sustainable Aviation Fuel

This "pillar" is the focus of this publication. The development and commercial deployment of SAF offers the most promising opportunity for reducing net GHG emissions from aviation operations. This is because GHG reductions commence immediately with the use of SAF —operators do not have to wait for advanced technologies to make their way into the operational fleet via replacement or addition of new aircraft.

Operations and Infrastructure

Operators are implementing efficiency improvements in the air and on the ground, such as increased use of electrical ground power, more direct routing and other weight reductions on flights, etc. Although much progress has been made, much work remains to be done to complete the transformation of air traffic control (ATC) from a ground-based to a satellite-based system. Authorities and political leaders need to make the necessary, continued investment in this vital infrastructure, given the myriad benefits of full ATC modernization, including system-wide efficiencies that reduce GHG emissions.

Market-Based Measures

In 2016, ICAO member states agreed to design a global carbon offsetting program, a market-based measure (MBM), as part of its broader strategy to reduce emissions from international aviation through its 'basket of measures' approach (similar to the industry's four pillars): new technologies, improved operations, modernized infrastructure and ATM, and a global MBM. The new MBM, in the form of CORSIA, was intended to cap the growth of international aviation emissions from 2021 through the use of purchased offsets.

Under the CORSIA plan, certain operators will have to offset carbon emissions (their obligation) from their international operations that are above the 2019 baseline by purchasing either approved CORSIA Eligible Emission Units or CORSIA Eligible Fuels[11] to meet their obligation, or a combination of both.

In practice, CORSIA applies to only a small percentage of business aviation operators globally. A credit process has been developed by ICAO technical bodies that will define how credit will be given for the use of "CORSIA Eligible Fuels," which includes SAF, by operators in meeting CORSIA obligations once the scheme starts with its Pilot Phase in January 2021 (when emissions obligations will start).

Detailed information on CORSIA, CORSIA Eligible Fuels and CORSIA Eligible Emission Units can be found on the ICAO website.[12] In addition, IBAC has prepared a "Countdown to CORSIA" resource page[13] on its website, with information specifically tailored to the business aviation community.

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11. *CORSIA eligible fuels (CEF) include Sustainable Aviation Fuels (SAF) and Lower Carbon Aviation Fuels (LCF). https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx*
12. *https://www.icao.int/environmental-protection/Pages/market-based-measures.aspx*
13. *https://gwbaa.com/resources/Documents/SSD%202018%20Presentations/IBAC%20GWBAA%20SSD%20Presentation%20.pdf*

The EU ETS[14] also provides incentives to aircraft operators for the use of SAF that must comply with sustainability criteria defined in the Renewable Energy Directive (RED), which offers emissions credits under the ETS. As the use of SAF reduces an aircraft operator's overall emissions output, this would ultimately reduce the number of EU ETS allowances it would be required to purchase. Operators should check directly with their competent authority where they are registered for the EU ETS to determine the level of credit that would be given for the use of SAF under the system.

The aviation industry has kept its focus on improving efficiency and reducing its CO_2 footprint via the pillars.

14. https://ec.europa.eu/clima/policies/ets_en

SAF VALIDATION: THE TECHNICAL BASICS

SAF blending agents must have the same qualities and characteristics as conventional jet fuel in order to substitute and be blended with conventional jet fuel. This is important to ensure that manufacturers do not have to redesign or recertify engines or aircraft, and that fuel suppliers and airports do not have to modify or build new jet fuel supply chain infrastructure and support systems.

At present, the industry and regulators are focused on approving multiple pathways for the production of SAF, and when these blending components are blended with conventional jet fuel to the requirements of ASTM D7566, to produce a drop-in replacement to conventional jet fuel. As of this writing, the maximum permissible blending level for the different pathways ranges from 10 to 50 percent.

Going forward, industry representatives are working on approaches that may allow for the approval of drop-in fuels that don't require blending. Intermediate steps between now and then may allow for increasingly higher blending levels. For the moment, the following summary details the path to SAF validation.

SAF meets or exceeds current jet fuel specifications.

ASTM D1655 (Standard Specification for Aviation Turbine Fuel)

This designation defines specific types of aviation turbine fuel for civil use in the operation and certification of aircraft, and describes fuel found satisfactory by the OEMs and regulatory authorities for the operation of aircraft and engines. The specification can be used as a standard in describing the quality of aviation turbine fuel from the refinery to the aircraft wing tip; the designation covers two types (or grades) of commonly used jet fuel that differ in freeze point:

- **Jet-A:** commercial jet fuel grade commonly used in North America (-40ºC/-40ºF freeze point).
- **Jet A-1:** jet fuel grade commonly used in Canada and outside of North America (-47ºC/-52.6ºF freeze point).

ASTM D7566 (Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons)

This designation defines characteristics and properties of both the neat synthesized blending components, as well as the blended aviation turbine fuel equivalent (jet fuel). The synthesized components can be derived from many sources, not just those from which conventional jet fuel is refined (petroleum, shale oil, oil sands). This can include jet fuel produced from coal, natural gas, landfill recovery gas, biomass (lignocellulose, sugars, fats, oils and greases), waste streams, synthetic gas, etc. However, jet fuel produced from coal and natural gas will not meet sustainability requirements, meaning such synthetic fuels would not be characterized as SAF.

ASTM D1655 allows fuel that meets the requirements of ASTM D7566 to be recertified as ASTM D1655 fuel. See the end of this document for details on the ASTM international-approved pathways to SAF production under ASTM specifications.

Before being approved by the industry for addition to the D7566 specification, each SAF pathway must undergo strict testing (including, for example, laboratory, component, engine and flight tests) to ensure technical and safety compliance under an internationally recognized standard. This rigorous and comprehensive technical review is a resource-intensive process, which takes time and considerable funding. The industry developed an ASTM standard practice that defines this process: ASTM D4054.[15]

The technical requirements for an SAF can be summarized thus:

- A high-performance fuel that can withstand the full range of operational conditions required to maintain the certification basis of the aircraft, engine and APU.
- A fuel that can directly substitute conventional jet fuel for turbine-powered aircraft with no requirement for different airframe, engine or logistical infrastructure, or changes to the way the aircraft is operated.
- A fuel that meets or exceeds current jet fuel specifications (see discussion of D1655 above).

Testing

Safety is the aviation industry's top priority, which means the specific requirements of any fuels used in aircraft, and the process for testing potential new fuels, are particularly rigorous. Through testing in laboratories, in equipment on the ground and under the extreme conditions of in-flight operations, an exhaustive process determines the suitability of SAF.

In the laboratory

Researchers develop SAF that has similar properties to conventional jet fuel, Jet-A or Jet A-1. This is important, because fuels are used for many purposes inside the aircraft and engine, including as a lubricant, cooling fluid and hydraulic fluid, as well as for combustion.[16]

On the ground

Tests evaluate performance and operability at several power settings from ground-idle to take-off, which is then compared to performance with conventional jet fuel. Tests include measuring the amount of time it takes for an engine to start, how well the fuel stays ignited in the engine and how the fuel performs in acceleration and deceleration. Tests are also completed to ensure the fuels do not have a negative impact on the materials used in building aircraft components. Other tests are aimed at checking APU and aircraft fuel system components (including fuel control, pumping and gauging). Finally, emissions testing compares the exhaust emissions and smoke levels for the SAF to those produced by using conventional jet fuel. As an aside, the industry has shown that use of SAF will reduce operational emissions of sulfur oxides, particulate matter (both count and mass) and carbon monoxide.

In the air

Once the lab and ground tests have been completed and analyzed, the OEMs determine whether additional flight testing is needed to address any unique concerns, up to and including endurance testing. Several OEMs, airlines and operators have provided aircraft for non-conventional fuel flight trials designed to:

- Provide data to support fuel qualification and certification for use by the aviation industry;
- Demonstrate that SAF is safe and reliable; and
- Stimulate SAF research and development.

During test flights, pilots perform a number of standard tests, and simulate exceptional flight circumstances, to validate that the fuel delivers operability and performance under all certified operating conditions.

15 *The Commercial Aviation Alternative Fuels Initiative (CAAFI) has developed a guide for ASTM D4054. It can be found at: http://www.caafi.org/information/pdf/d4054_users_guide_v6_2.pdf*

16 *In general, the synthesized fuel molecules are identical to those found in petroleum-based jet fuel (pure hydrocarbons comprised of paraffins, isoparaffins, cyclo-paraffins and aromatics in the C7-C17 chain-length range). However, they may not all be present, or present in the ratios typically found in petroleum-based jet fuel; hence, the aviation community may require these fuels to be blended with petroleum-based jet fuel, but limited to certain maximum levels.*

Approval for Specification Inclusion

The approval process has three parts: the test program, the original equipment manufacturer internal review and a determination by a body of experts from aviation and petroleum as to the correct specification for the fuel. The approval process takes place in the Emerging Fuels Section of ASTM's Aviation Fuels Subcommittee, D02.J. This process reviews all the evaluations of the candidate fuel versus the D1655 requirements, as well as any additional special considerations imposed by the industry depending on unique attributes associated with the non-conventional fuel's feedstock or conversion process.

All these properties can be found in the specification, including energy density, freezing point, volatility, thermal stability, viscosity, etc.

ASTM 4054 was developed by the engine and airplane OEMs with ASTM International member support, in order to provide the producer of a non-conventional jet fuel with guidance regarding testing and property targets necessary to evaluate a candidate non-conventional jet fuel.[17]

SUMMARY

Technical Background

Civil aviation authorities and aviation industry stakeholders, including OEMs, have put in place an exhaustive and thorough process to evaluate and approve SAF. These stakeholders work closely with international fuel specification bodies, such as ASTM International to develop standards and certificates. Prior to being approved, SAF must meet certain specifications established by the aviation community itself, and as outlined in the appropriate specifications (ASTM D7566, D1655).

The ASTM specifications simply identify approaches the industry has deemed acceptable to offer D1655 equivalency. Once a non-conventional fuel has been fully vetted, and the industry has approved its inclusion as an annex to ASTM D7566, it is recognized as offering D1655 conventional fuel equivalence. It can then be produced by multiple producers utilizing the technology defined in the D7566 spec. If the non-conventional fuel meets certain sustainability attributes, it can be called SAF. Such fuel can be used without any additional restrictions, allowing it to be adopted by other international standards.[18]

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17 The Commercial Aviation Alternative Fuel Initiative (CAAFI) has prepared an "ASTM D4054 User's Guide" which can be found at http://www.caafi.org/information/pdf/d4054_users_guide_v6_2.pdf

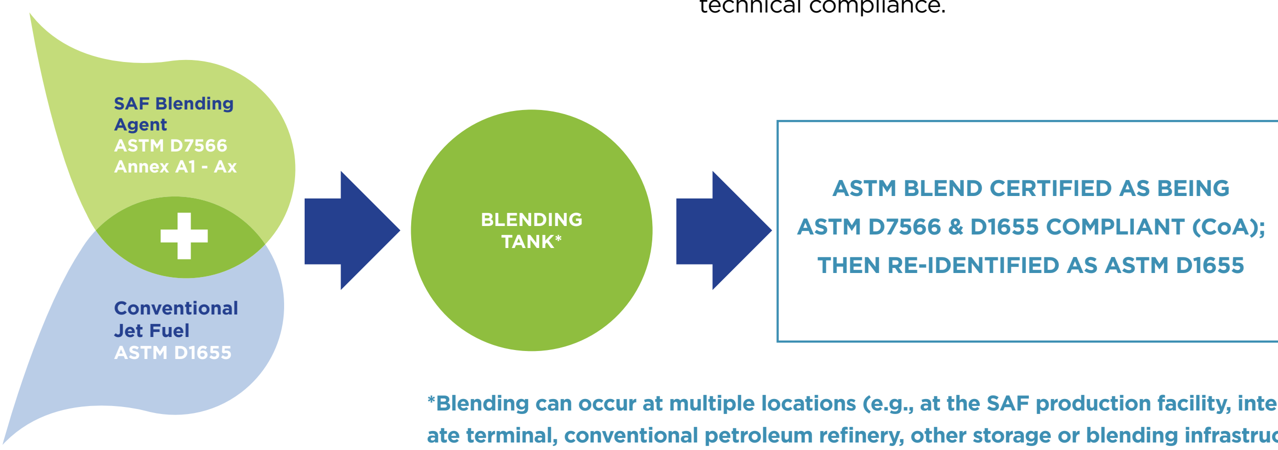
18 There are other specifications, beyond ASTM D1655, for jet fuel in various countries around the world, (e.g., GOST in the former Soviet States, DEF STAN 91-091 for some British Commonwealth states, and several other country-based specs such as China's No. 3 Jet Fuel and Brazil's QAV-1). In most cases, these specs are being updated to include new D7566 annexes as they are added. These other standards only come into play with someone operating a non-Western certificated product whose operating manual might make a different fuel reference, or when someone attempts to purchase fuel in one of these countries where ASTM is not the standard specification.

SAF Production Today

Any SAF considered for use by the industry must meet all the criteria of, and be included in, ASTM D7566. These criteria apply to both the neat (un-blended) synthetic fuel component, as well as those of the blended jet fuel. That is, the non-conventional component must meet the requirements of the annexes therein, and it then must be blended with conventional fuel and be certified as meeting the requirements of D1655, before becoming fungible within the industry's jet fuel supply chain systems.

The reasons for the current blend limits are to ensure the appropriate level of safety and compatibility with the aircraft fueling systems (e.g., maintaining a minimum level of aromatics, which are necessary for the different systems, or to meet the density requirements of ASTM D1655). It is, however, likely that higher blend limits may be approved in the future, and that some non-conventional types may contain a full suite of hydrocarbon molecules that fully mimic those found in jet fuel, and not require blending.

The diagram below illustrates how conventional jet fuel is blended with SAF blending agents and approved for technical compliance.



*Blending can occur at multiple locations (e.g., at the SAF production facility, intermediate terminal, conventional petroleum refinery, other storage or blending infrastructure), but must be followed by batch compliance testing and certification as identified in D7566 and D1655.

Purchasing SAF Today

At this time, SAF is not widely available, but this is expected to change. There are currently a limited number of airports and operators using SAF on a routine, ongoing basis. Business aviation manufacturers and fuel suppliers are also working to help business aircraft operators increase their use of SAF. Several business aviation operators and manufacturers have secured contracts with suppliers for SAF. Most of the manufacturers and operators use these fuels on a routine basis to satisfy sustainability goals, and have undertaken many high-profile flights using SAF. The industry is trending in the right direction, with the use of SAF steadily expanding around the globe, driven by a desire to be a responsible steward of the environment.

ECONOMICS

The broader aviation industry has long been committed to the development of sustainable aviation fuel as part of its commitment to curb emissions. The industry is well positioned to be a priority user of non-conventional fuels within the transportation sector, due to factors such as the relatively low number of operators, the prevalence of fleets, especially among the airline segment (as opposed to individual owners of cars, for example), a relatively small distribution network (compared to autos and trucks, for example) and an industry already committed to the fuel's production, availability and use. Production of SAF may become more economically viable and compete with conventional fuels as costs are lowered by improvements in production technology, and through economies of scale in production and integration into the supply chain, plus regulatory incentives or credits, or as the price of petroleum-based jet fuel rises due to the cost of crude, cost of refining and/or policy changes.

Since the first SAF-fueled test flight in 2008, technological progress has been remarkable. However, the actual uptake of SAF is modest, relative to total industry demand. This is in part due to relatively small production levels. Without economies of scale, the unit cost of production remains, in general, higher than conventional fuels, and this impedes its wider use. For SAF to be scaled up to commercially viable levels, substantial capital investments are required to develop refining and processing capacity.

Worldwide SAF Production Forecast

Announced intentions* with specific commitments to SAF

Through testing in laboratories, in equipment on the ground and elsewhere, an exhaustive process determines SAF suitability.

University of Dayton Research Institute

There have been some long-term offtake agreements from airlines and business aviation manufacturers. These agreements have been modest in scale, in part because the fuel is more expensive than conventional jet fuel. In these cases, SAF is not sequestered for use by an individual operator; rather, it is incorporated directly into airport fuel farms, and, while all operators there could use it, the credit benefits for carbon reduction are allocated to the purchasing entity. SAF has also been made available on an ad hoc basis to several business aviation locations around the world, most associated with educational and awareness initiatives for industry, policymakers and the general public.

As this trend continues, new and existing producers will be able to attract more investment, while many of the largest refiners contemplate participating in some fashion (e.g., through joint ventures or other agreements), resulting in potential growth of the non-conventional fuel industry. A key factor for enabling producers to attract investment is obtaining offtake agreements. Business aviation can potentially participate in facilitating offtake via fuel suppliers, FBOs or directly with producers.

The industry is well positioned to be a priority user of non-conventional fuels within the transportation sector.

Why Should You Use SAF?

What's in it for your company's bottom line? There are several concrete benefits flowing from the use of SAF. For some of the largest business aviation operators, the implementation of CORSIA for international operations globally will provide those covered operators opportunities to meet their obligations through increasing their use of SAF.

As noted earlier in this publication, the use of SAF is beneficial under the obligations of both CORSIA and the EU ETS. In straightforward terms, the overall life-cycle emissions output of SAF is lower than that of the life-cycle emissions for conventional jet fuel, which means that through the use of SAF, an operator has already reduced its overall emissions output. Therefore, any emissions obligations under both schemes are reduced, so less offsetting would be required.

Last, but not least, the use of SAF may contribute to the achievement of your corporate social responsibility policy objectives and corporate sustainability metrics – or those of your company – as reported to shareholders and investors.

In the end, the business aviation industry and its stakeholders must demonstrate that they remain a responsible stewards of the environment for many reasons, including the need to preserve its ability to grow and fend off onerous regulatory and/or legislative measures that might constrain such growth.

FREQUENTLY ASKED QUESTIONS | OPERATORS & OWNERS

GENERAL

How can I help to increase the use of SAF?

Make your desire for SAF known to your FBO and fuel supplier. Indicating your commitment to purchasing the fuel, should it become available to you, will help producers, suppliers and FBOs to understand the level of future demand and encourage them to move forward with contracting for greater volumes of SAF. Additionally, communicate with your government representatives, as they may be able to assist the commercialization of SAF through various policy options.

REGULATORY

Do I need special approval for my aircraft to fly with SAF?

No, not if the SAF is produced to the requirements of ASTM D7566 and re-identified as ASTM D1655 jet fuel. FAA Special Airworthiness Information Bulletin (SAIB) NE-11-56R2 summarizes:

"...jet fuel made from...synthetic blending components that meet the requirements of ASTM International Standard D7566 are acceptable for use on aircraft and engines certificated for operation with D1655 Jet-A or Jet A-1 fuel if they are re-identified as D1655 fuel...When D7566 jet fuels are re-identified as D1655 fuel, they meet all the specification requirements of D1655 fuel and, therefore, meet the approved operating limitations for aircraft and engines certificated to operate with D1655 fuel, unless otherwise prohibited by the engine or aircraft type certificate (TC) holder."

The same bulletin states the following in its recommendations:

1. *"These fuels are acceptable for use on those aircraft and engines that are approved to operate with Jet-A or Jet A-1 fuels that meet the D1655 standard.*
2. *Aircraft Flight Manuals, Pilot Operating Instructions, or TCDs that specify ASTM D1655 Jet-A or Jet A-1 fuel as an operating limitation do not require revision to use these fuels.*
3. *Current aircraft placards that specify Jet-A or Jet A-1 fuels do not require revision and are acceptable for use with these fuels.*
4. *Operating, maintenance, or other service documents for aircraft and engines that are approved to operate with ASTM D1655 Jet-A or Jet A-1 fuel do not require revision and are acceptable for use when operating with these fuels.*
5. *There are no additional or revised maintenance actions, inspections or service requirements necessary when operating with these fuels."*[19]

Do I need to register my aircraft any differently if I use SAF?

No.

Is SAF recognized by the FAA and other aviation authorities?

Yes. These fuels are acceptable for use on aircraft and engines approved to operate with Jet-A or Jet A-1 fuels meeting the D1655 standard.[20] The same is true for EASA, as per CM-PIFS-009.[21] Not all aviation authorities have released formal guidance documentation. However, if the SAF enters the fuel distribution system as D1655, no formal guidance is required for operations already meeting regulatory compliance (engine or aircraft manuals, or operating certificates) via the use of D1655 fuel.

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19 https://rgl.faa.gov/Regulatory_and_Guidance_Library/rgSAIB.nsf/0/DB5A49761FE02E8B86257FB8006C963B?OpenDocument&Highlight=%2011-56r2

20 https://rgl.faa.gov/Regulatory_and_Guidance_Library/rgSAIB.nsf/0/DB5A49761FE02E8B86257FB8006C963B?OpenDocument&Highlight=%2011-56r2

21 https://www.easa.europa.eu/sites/default/files/dfu/certification-memoranda-import-EASA%20Proposed%20CM-PIFS-009%20Issue%2001_Fuel%20Specification%20Changes.pdf

TECHNICAL OPERATIONS

Does the use of SAF have any negative impact on APU and main power plant performance, other components — including fuel tanks and fuel systems — airframe, maintenance procedures/requirements, and/or product warranties?

No. Selected aircraft OEMs, engine and APU manufacturers, as well as manufacturers of other components, participated in the testing process, and that testing found that SAF is compatible for use in their products with no modifications required, and with no need for recertification or additional validation.

FLIGHT OPERATIONS

Will my aircraft perform the same under all conditions (for example, extreme hot and cold temperatures)?

SAF is fully approved to meet the specifications of conventional jet fuel. This means that it performs just like conventional jet fuel, as it meets the specifications contained in ASTM D1655.

SAF blending agents (i.e., synthetically produced hydrocarbons defined in ASTM D7566 prior to blending with conventional jet fuel) generally have a lower mass density than conventional fuels, but final SAF blended fuels still fall within the ASTM D1655 specification. They also have had slightly higher energy mass content. Operators should be aware of the specifications of the fuel, and follow standard flight-planning practices.

Can SAF be used on all fixed wing and rotor wing aircraft?

Yes, any SAF compliant with the requirements of ASTM D7566 (including blending) is recognized as meeting the characteristics of traditional petroleum-based conventional jet fuel approved under ASTM D1655, which can be used in all fixed-wing and rotor-wing aircraft using conventional jet fuel.

Do I have to fly differently if I have SAF in the tank?

No, SAF does not affect how you fly the aircraft. Flight planning should consider the appropriate fuel density, just as it does for conventional jet fuel.

Do I have to obtain a certificate of analysis?

No, an approved fuel certificate of analysis is not required. However, you can obtain a certificate, upon request, from your fuel supplier.

Do I require a special placard for my aircraft?

No.

Can biocide additives be added to SAF blended fuel?

Yes. SAF, once blended correctly to ASTM D7566 requirements and distributed to the end user, is a drop-in, fungible fuel, and is considered ASTM D1655 jet fuel. Approved biocides may be added at aircraft manufacturers' required dosages, the same as allowable in Jet-A ASTM D1655 fuels.

Does the use of SAF contribute to microbial growth in fuel tanks?

There is no evidence that SAF blends exacerbate microbial growth in fuel tanks. The front end of the SAF refining process is adapted for the feedstock (to access the hydrocarbons via deconstruction and conversion), while the rest of the process produces physical fuel molecules that are pure hydrocarbons. There is no extraneous material from the process that would support microbes any better. While it is true that there is less sulfur in SAF, studies have shown that low sulfur fuels do not lead to an increase in microbial contamination volume. SAF should not be confused with other "biofuels" (e.g., biodiesel or ethanol), which are not direct replacements for the conventional fuel they are displacing. Finally, microbial growth is more directly related to handling and storage, and the introduction of water and other particulates, emphasizing the need for diligence in managing any type of jet fuel – conventional or SAF.

22 https://www.astm.org/Standards/D7566.htm. (Document is available for purchase).

FUEL CHARACTERISTICS

What is SAF (sustainable aviation fuel)?

SAF is Jet-A/A-1 fuel that meets requirements per ASTM D1655 (US), Def. Std. 91-91 (British) and CAN/CGSB-3-23 (Canadian) jet fuel specifications, whose origin is ASTM D7566 (Aviation Turbine Fuel Containing Synthesized Hydrocarbons), and is re-identified as D1655 Jet-A or Jet A-1 fuel.

Is SAF the same as bio jet fuel, synthetic jet fuel or renewable jet fuel?

There are various terms used to describe non-fossil-based hydrocarbon fuel. Often, the term "biofuel" is used. However, the aviation industry avoids this terminology, as the term is not sufficiently broad to cover all envisioned feedstocks, nor does it specify the sustainability aspect of these fuels (which aviation highlights). Some biofuels, if produced from non-sustainable feedstocks, such as unsustainably produced crops that foster significant land-use change, can cause additional environmental damage, making them unsustainable for aviation's purposes.

How is SAF made?

Specialized production facilities convert sustainable (e.g., renewable or recycled) materials to pure hydrocarbons found in jet fuel. The renewable content is then blended with conventional jet fuel to produce a final product that meets the D1655 conventional jet fuel specification. If the entire process is shown to meet certain sustainability requirements, the fuel can be called SAF, or an SAF blend. SAF blends are mixtures of conventional Jet-A/A-1 fuels and synthetic fuel blending agents produced via one of several industry-approved "pathways" (See ASTM D7566 Annexes A1 - Ax).[22]

What fraction of non-conventional/renewable molecules might we expect to get in an SAF blend?

As stated above, SAF blends are originally created by blending renewable molecules (neat SAF) with conventional fuel. The amount of blending may vary by process and manufacturer, but may not exceed the limits in the D7566 specification, with maximum levels ranging from 10 to 50 percent. There is no minimum level defined. The actual level will be determined by how the SAF was originally created, and whether it continued to be blended with additional jet fuel along the supply chain.

Does it matter how much renewable content is in my SAF?

The level of carbon intensity that can be claimed by the end user will be driven by the life-cycle assessment of the renewable component of the blended fuel. So, the level of blending does matter to the end user, who may be interested in understanding exactly how much they are improving their carbon footprint. Different SAFs also have different sustainability or carbon index scores depending on the type of feedstock used, the conversion technology and the logistics of the supply chain.

How is SAF handled?

While ASTM D7566 and D1655 do not specifically call out quality control and handling practices, they do say to follow industry standards such as, but not limited to, standards provided by the Energy Institute (EI), the Joint Inspection Group (JIG) and Airlines for America (A4A). The manufacturing and blending of the conventional and non-conventional agents, as well as the procedures and quality control practices shall be conducted at locations that follow these standards. Example: EI/JIG Standard 1530 - Quality assurance requirements for manufacture, storage and distribution of aviation fuel to airports.

Can I mix SAF coming from multiple feedstocks, conversion processes or producers?

Yes. Following its initial blending, SAF is a "drop-in" fuel and can therefore be co-mingled with other equivalent specification fuel (e.g., ASTM D1655) without limitations in railway cars, fuel trucks, airport fuel storage facilities and aircraft fuel tanks.

FINANCIAL CONSIDERATIONS

Will flying with SAF have an impact on my CORSIA contribution in the future?

Yes. ICAO has developed monitoring, reporting and verification (MRV) standards for compliance with CORSIA, for operators that are not subject to certain exemption criteria. The proper crediting of carbon emissions reductions from the use of CORSIA Eligible Fuels, including SAF, by operators with obligations under the scheme can be determined through the ICAO CORSIA Supporting Document – CORSIA Eligible Fuels, available from the ICAO CORSIA website. This document details any credit or physical obligation reduction commensurate with the net life-cycle analysis (LCA) CO_2 reduction of the SAF purchased/used by the operator.

Is SAF more expensive than traditional jet fuel?

Today, the cost of SAF is typically higher than the price of petroleum-based Jet-A. Additionally, transportation costs for the fuel will vary and can add to the overall cost of the fuel. Several federal, state and regional policy incentives targeting the reduction of carbon emissions may also impact the price of fuel for certain purchasers and at certain locations.

Can I get financial compensation/a tax incentive for using SAF?

As noted above, those operators (generally only the largest) who may be subject to CORSIA will likely be able to meet and reduce their obligations via the purchase of SAF, or a combination of SAF and offsetting.

The EU ETS also provides incentives to aircraft operators for the use of SAF that must comply with sustainability criteria defined in the Renewable Energy Directive (RED), which provides emissions credits under the ETS. As the use of SAF reduces an aircraft operator's overall emissions output, this would ultimately reduce the number of EU ETS allowances it would be required to purchase. Operators should check directly with the competent authority where they are registered for the EU ETS to determine the level of credit that would be given for the use of SAF under the system.

Given that SAF costs more and – as a small- to medium-sized business aviation operator – I may not even be subject to ICAO's CORSIA scheme, why should I bother using SAF? What's in it for my company?

The business aviation industry committed in 2009 to improve its efficiency and do its part to curb emissions.

There is considerable political pressure in many parts of the world to reduce emissions from aviation by restricting flying, or imposing severe extraneous costs on it. Business aviation is often portrayed as an inefficient and wasteful mode of transportation used only by wealthy individuals.

The industry has worked hard, with some success, to counter these myths and to emphasize the bottom-line value of business aviation to companies and to the economy. This is not enough, however – it is important for the long-term economic survival of business aviation that the industry can demonstrate through concrete measures that it is a responsible steward of the environment.

The aviation industry is at the forefront of environmental responsibility, and is the first industry to have developed international environmental standards for both manufacturers and operators. The industry's proactive stance has helped stave off significantly more restrictive environmental standards and regulations globally; stakeholders have also been instrumental in designing environmentally meaningful standards, as well as supporting national and regional regulations that allow the industry to grow in a sustainable manner. The business aviation sector is aggressively promoting the use of SAF in recognition of the importance of ensuring that the industry can continue its sustainable growth.

Companies can also voluntarily participate in carbon-offsetting programs that are available in their region or country, which may provide added incentives.

What sort of actual emissions reductions can I expect to achieve by using SAF?

The use of SAF results in a reduction in carbon dioxide (CO_2) emissions across its life-cycle. That is, even when considering the emissions produced in growing, transporting, harvesting, processing and refining a particular feedstock, SAF has been shown to provide significant reductions in overall CO_2 lifecycle emissions compared to conventional fuels. Improvements in CO_2 emissions can be determined based on an approved life-cycle analysis (LCA) method.

An illustrative example: a large-cabin modern business jet on a 1,000 nautical-mile mission might burn enough fuel to produce approximately 22,787 pounds of CO_2. If such a flight were to use SAF (HEFA-SPK pathway) at a blend of 30 percent SAF to 70 percent conventional Jet-A fuel, the same mission would result in a net reduction of CO_2 emissions of approximately 4,100 pounds (18 percent) on a lifecycle basis (assumes an LCA of 60 percent reduction in CO_2 for the 30 percent SAF).

FREQUENTLY ASKED QUESTIONS

FIXED BASE OPERATORS (FBOs)

If an FBO is interested in purchasing and selling SAF, what should it do?

It is important for an FBO desiring to sell SAF to:

- Contact the fuel supplier for information on SAF.
- Become well acquainted in advance with the relevant ASTM D7566 standard, to ensure that only qualified fuels are involved in any supply transactions.
- Understand how, if at all, the FBO could participate in the acquisition and handling of fuel to facilitate the introduction of SAF (e.g., taking SAF from multiple producers or suppliers).

How does an FBO receive SAF?

The fuel supplier will arrange transportation of SAF to the FBO. Standard fuel acceptance procedures should be used.

Are there special procedures required for storage and delivery of SAF?

There is no difference between SAF blends and conventional jet fuel regarding their delivery, storage and quality control procedures. A key factor to consider is whether the SAF is purchased for a single client (who may desire sequestration of the fuel for fueling specific aircraft), or for general use. SAF blends are fully fungible; thus, they can be commingled in airport storage tanks with existing ASTM D1655 Jet-A/A1 fuels.

Is special training required for FBO employees to handle SAF?

While all FBOs should provide comprehensive training in the handling of aviation fuels, no additional training is required for the handling of SAF blends. FBOs should coordinate with their fuel supplier to identify any unique training requirements based upon their specific operating conditions. FBOs should educate their staffs on the values of SAF, and encourage them to promote its use, when available.

Is there an industry standard for defueling an aircraft using SAF?

As with all defueling operations, fuel removed from an aircraft containing SAF should be either disposed of or returned to the aircraft from which it was removed. If any methods other than the standard procedures are being considered, the persons defueling the aircraft should contact their fuel supplier to ensure proper quality assurance and certification procedures are followed to ensure the integrity of the fuel.

How should an FBO handle client concerns regarding compatibility of SAF with aircraft components?

Aircraft OEMs, engine and APU manufacturers – as well as manufacturers of other components – participated in the testing process, and that testing found that SAF is compatible for use in their products with no modifications required, and no need for recertification or additional validation. FBOs can provide a certificate of analysis for the SAF, which is available from the FBO's fuel supplier.

If clients still have concerns, the FBO should direct clients to contact their OEM regarding any compatibility issues.

ADDITIONAL TECHNICAL INFORMATION

Industry-approved methods for SAF blending component production are found in the annexes of ASTM International Specification D7566, as follows (as of the time of this publication):

- **Annex A1:** The Fischer Tropsch (FT) Synthetic Paraffinic Kerosene **(FT-SPK)** process that converts coal, natural gas or biomass into liquid hydrocarbons through an initial gasification step, followed by the Fischer-Tropsch synthesis. Blending limit: up to 50%;
- **Annex A2:** The Hydro-processed Esters and Fatty Acids **(HEFA-SPK)** process, which converts vegetable oils and animal fats into hydrocarbons by deoxygenation and hydroprocessing. Blending limit: up to 50%;
- **Annex A3:** Synthetic Iso-paraffin from Hydro-processed Fermented Sugar **(HFS-SIP)**, (formerly referred to as Direct-sugar-to-Hydrocarbon [DSHC]), converts sugars to pure paraffin molecules using an advanced fermentation process. Blending limit: up to 10%;
- **Annex A4:** Fischer Tropsch (FT) Synthetic Kerosene with Aromatics **(FT-SKA)**, same as Annex A1 but adds some alkylated benzenes (e.g., from the processing of coal tar or other refinery sources) to provide aromatic content to the SAF. Blending limit: up to 50%;
- **Annex A5:** The Alcohol to Jet SPK **(ATJ-SPK)** pathway starts from an alcohol to produce an SPK (through dehydration of the alcohol to an olefinic gas, followed by oligomerization to obtain liquid olefins of a longer chain length, hydrogenation and fractionation). This annex is intended to eventually cover any C2-C5 alcohol feedstock; at present, it only covers the use of isobutanol and ethanol. Blending limit: up to 50%;

- **Annex A6:** Catalytic Hydrothermolysis Synthesized Kerosene **(CH-SK or CHJ)**. Hydroprocessed synthesized kerosene containing normal and iso-paraffins, cycloparaffins and aromatics produced from hydrothermal conversion of fatty acid esters and free fatty acids (lipids or fats, oils and greases) along with any combination of hydrotreating, hydrocracking or hydroisomerization, and other conventional refinery processes, but including fractionation as a final process step. Blending limit: up to 50%;
- **Annex A7:** Hydroprocessed Hydrocarbons **(HHC-SPK or HC-HEFA)**. This conversion process is similar to Annex A2, but expands the definition of allowable feedstocks to include pure hydrocarbons produced from biological sources (as opposed to free fatty acids and fatty acid esters), for instance from the algae species *Botryococcus braunii* that produces tri-terpenes that can be hydroprocessed to jet fuel blending agents. Blending limit: up to 10%.

This guide was created by the Business Aviation Coalition for Sustainable Aviation Fuel with the support of its member companies.

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