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.

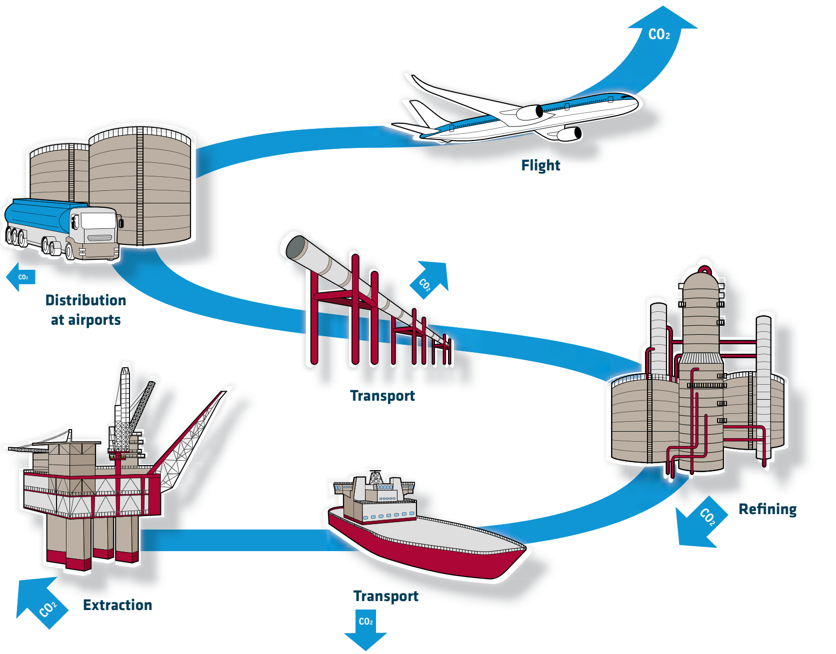
In the case of SAF produced from municipal waste, the environmental gains are derived both from avoiding petroleum use and from the fact that the waste would be otherwise left to decompose in landfill sites, producing no further benefits, rather than being used to power a commercial flight, which would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

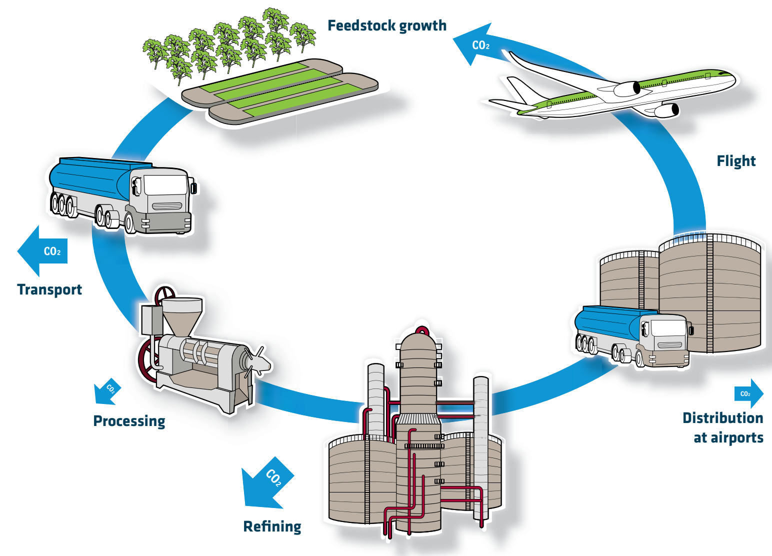
> *A range of SAF feedstocks can be grown or collected in differing conditions around the world, depending on the natural environment.*

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.

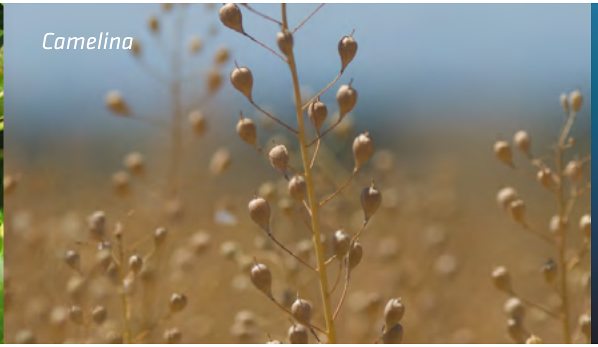
Current technology allows sustainable aviation fuels to be produced from a wide range of feedstocks, including:

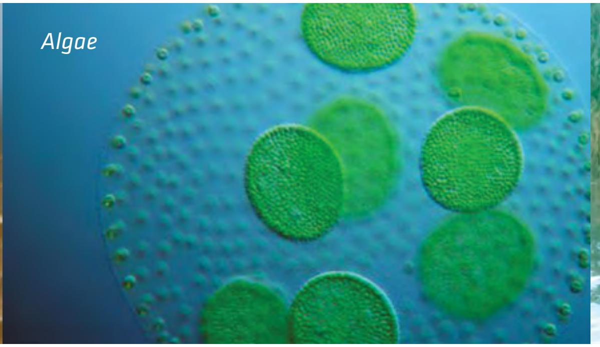
Municipal solid waste: waste that comes from households and businesses. Some examples include: product packaging, grass clippings, furniture, clothing, bottles, food scraps and newspapers. There is a lot of potential to use municipal solid waste as a sustainable feedstock, due to its vast supply. Rather 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.

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Why use sustainable aviation fuel for aviation?

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

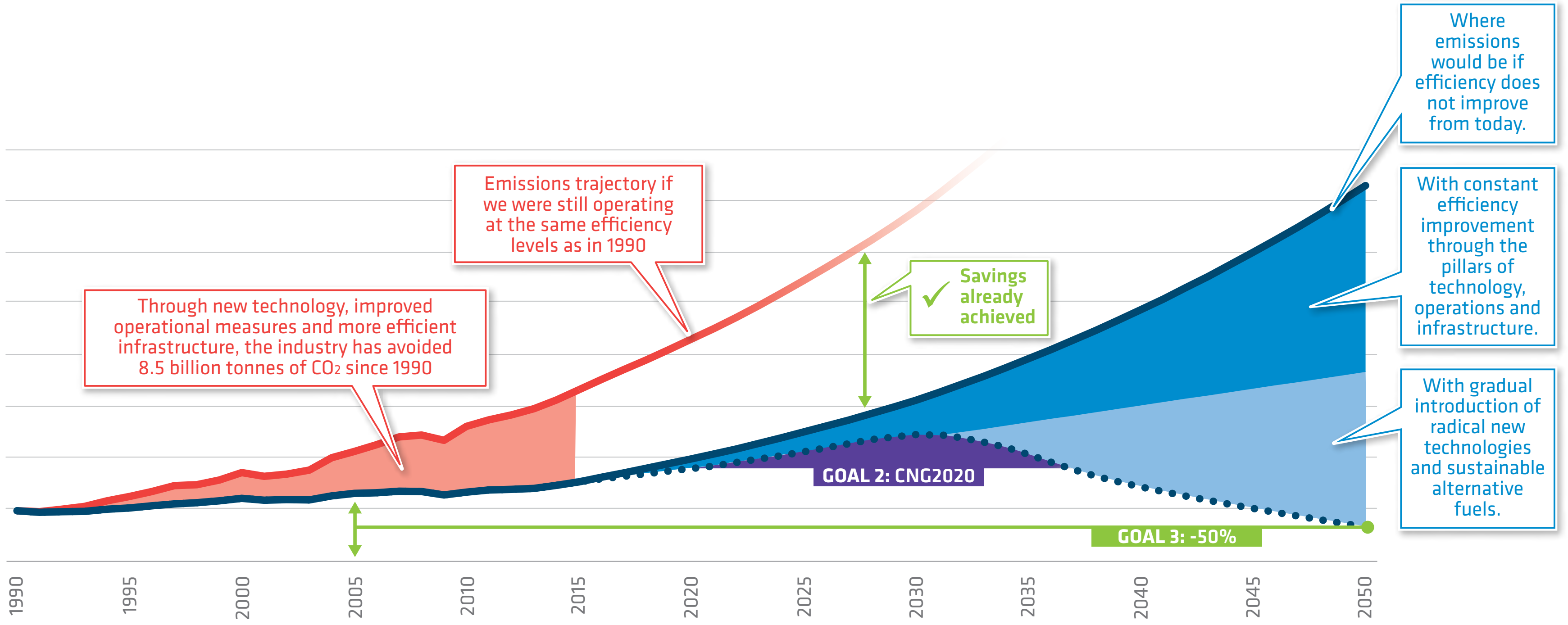
The aviation industry has set three global goals to address its climate impacts:

- 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

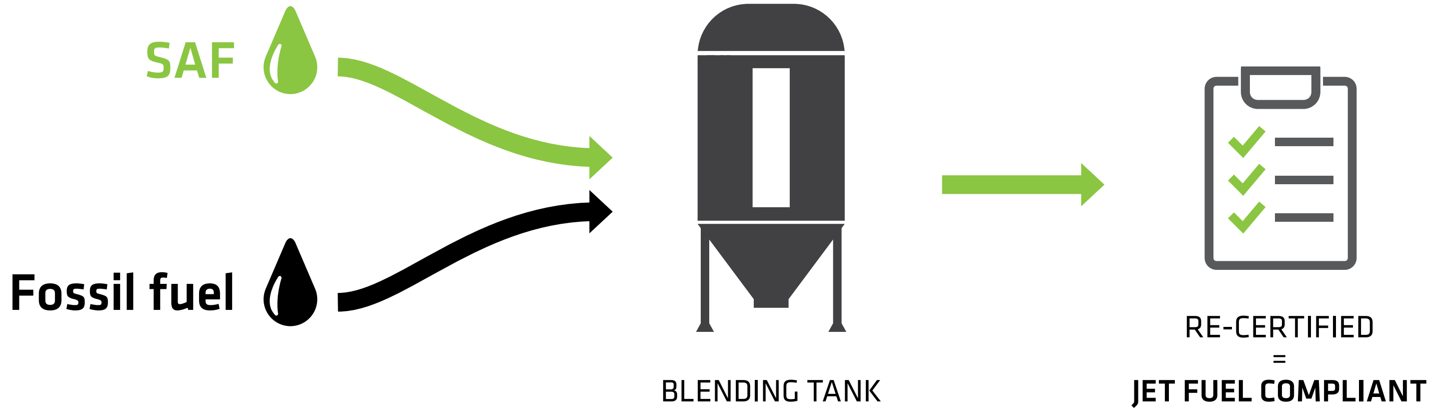
Safety is the aviation industry’s top priority. Given this and the specific requirements of any fuels used in aircraft, the process for testing potential new fuels is particularly rigorous. Through testing in laboratories, in equipment on the ground, and under the extreme conditions of in-flight operations,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

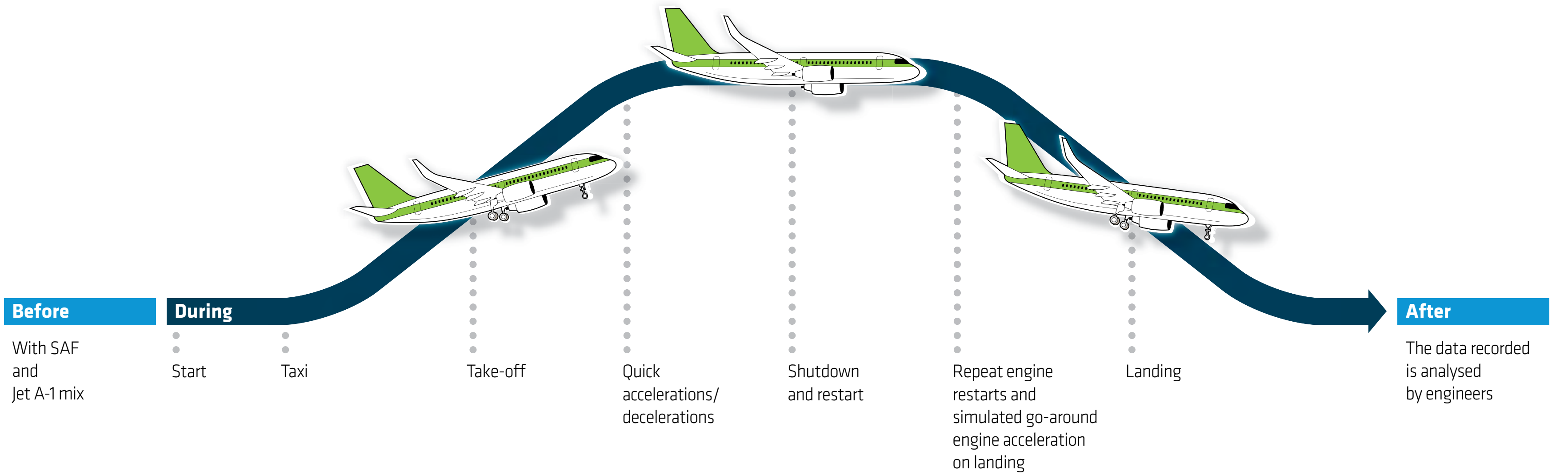
In the air

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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From the fields to the wings

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%


AIRBUS

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.

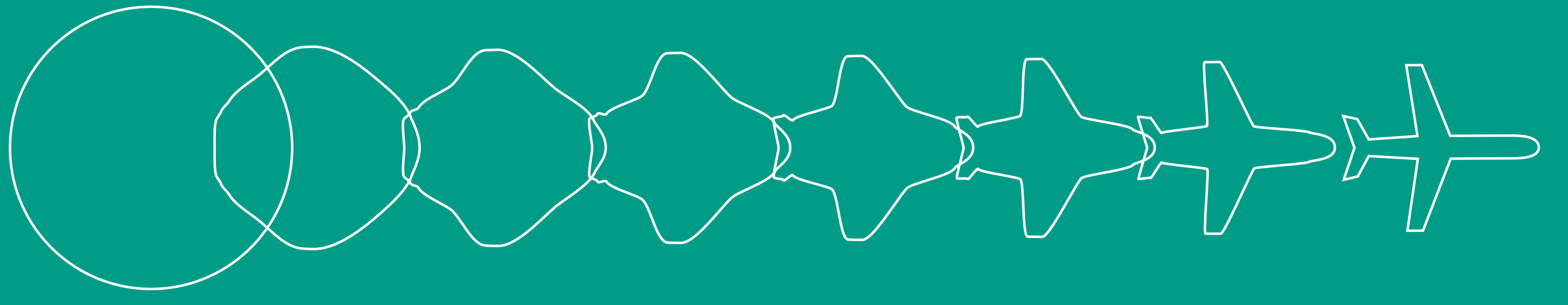
Greenhouse gases: gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which trap the warmth generated from sunlight in the atmosphere rather than allowing it to escape back into space, replicating the effect glass has in a greenhouse. Human activities such as fossil fuel combustion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