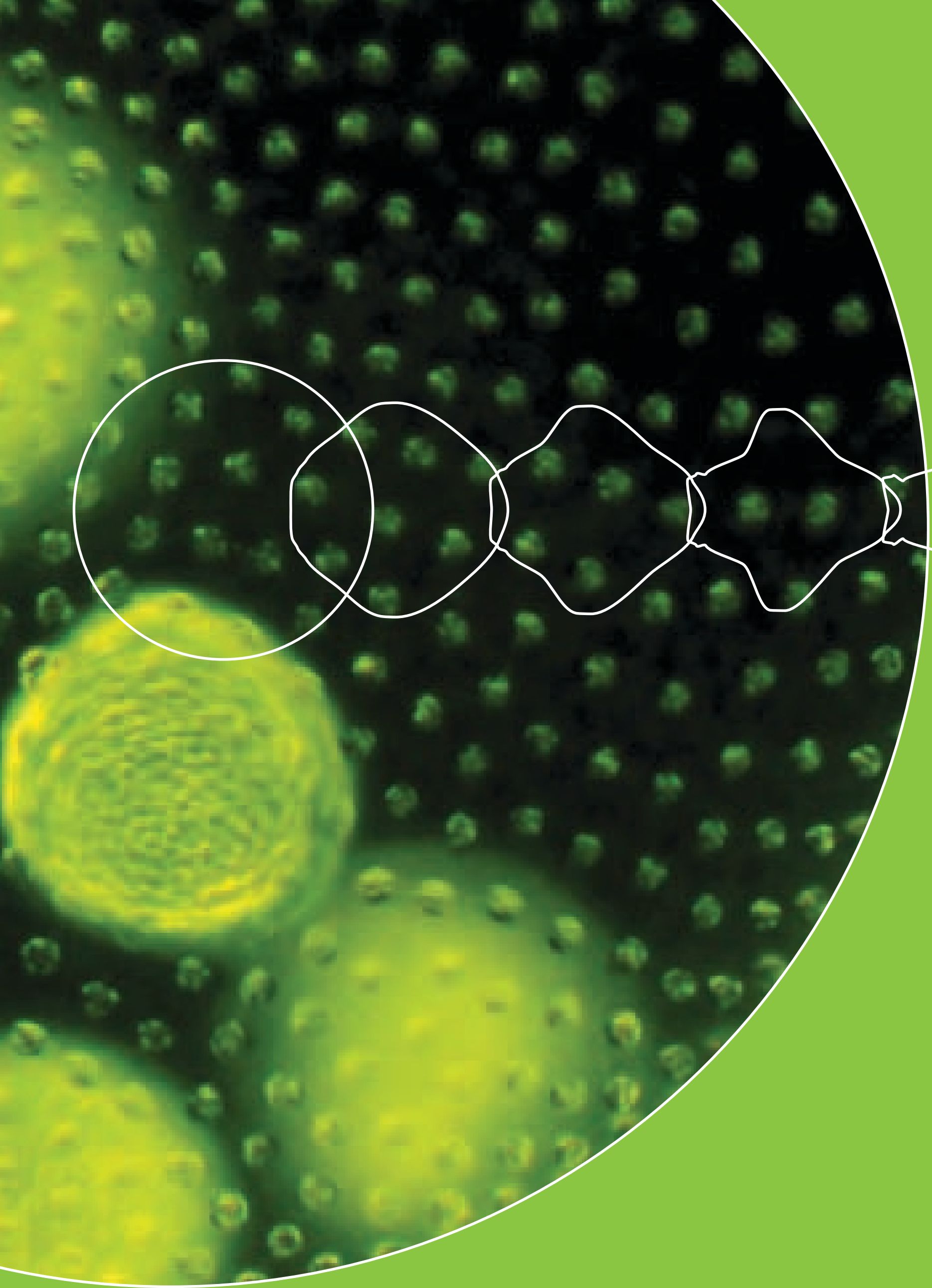


Beginner's Guide to **Aviation Biofuels**

Edition 2, September 2011

ATAG
AIR TRANSPORT ACTION GROUP

www.enviro.aero™

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 over 2.4 billion passengers annually.
- The air transport industry generates a total of 33 million jobs globally.
- Aviation's global economic impact is estimated at USD 425 billion, with indirect, induced and tourism benefits adding over a trillion dollars to aviation's global economic impact. If the aviation industry were a country, it would rank 21st in the world in terms of GDP.
- Aviation is reducing its environmental impact responsibly through an ambitious, global set of targets: www.enviro.aero/cng2020.
- Air transport's contribution to climate change represents 2% of man-made CO_2 emissions and this could reach 3% by 2050, according to updated figures from the Intergovernmental Panel on Climate Change (IPCC).
- This evolution is based on a growth in aviation CO_2 emissions of 2-3% per year, with an annual traffic growth of 5%. The air transport industry is now working towards carbon-neutral growth – no increase in carbon emissions in spite of traffic growth – as a first step towards a carbon-free future.
- Aircraft entering today's fleet are well over 70% more fuel-efficient than the first jet aircraft in the 1960s, 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.

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

Introduction

In the early days of the jet age, speed and luxury were the drivers of intercontinental travel. Today, our engines are at the cutting edge of efficiency. 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 more environmentally-friendly operations at airports. But we are still 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. And the aviation industry is embarking on a new journey. Sustainable biofuels are 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 journey on our planet.

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

What are biofuels?

> *Biofuels are produced from renewable biological resources such as plant material.*

Key points about biofuels

- Produced from renewable biological resources such as plant or animal material (rather than traditional fossil fuels like coal, oil and natural gas).
- Absorb carbon dioxide from the atmosphere as the plant matter (biomass) is grown, which is then released back into the atmosphere when the fuel is burnt.
- First-generation biofuels have been used for a number of years for transport, home heating, power generation from stationary engines, and cooking.
- Second-generation biofuels should be derived from new sources that do not compete for resources with food supplies and can be used in aviation.

Theoretically, biofuels can be produced from any renewable biological carbon material, although the most common sources are plants that absorb carbon dioxide (CO_2) and use sunlight to grow. Globally, biofuels are most commonly used for transport, home heating, power generation from stationary engines, and for cooking. The two most common feedstock sources for making biofuels are plants rich in sugars and bio-derived oils.

Crops that are rich in sugars (such as sugar cane) or starch (such as corn) can be processed to release their sugar content. This is fermented to make ethanol, which can be used directly as a petroleum substitute or additive.

These fuels, known as first-generation biofuels, are typically not suitable for use in aircraft, as they do not have the necessary performance and safety attributes for modern jet engine use and often come from feed stocks that are not sustainable.

However, bio-derived fuel, sourced from oil plants such as algae, jatropha, halophytes and camelina, or from other sources such as municipal waste, can be processed and either burned directly or converted by chemical processes to make high-quality jet and diesel fuels. These are known as second-generation biofuels and can be used for aviation (see page 4 for further information), they also mainly come from sustainable feedstocks.

Biofuels – providing environmental benefits

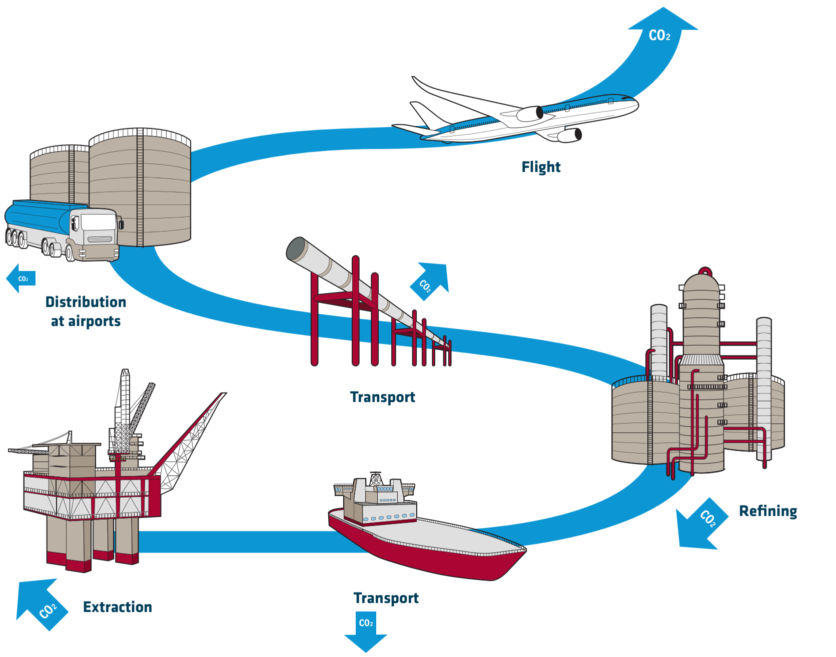
Relative to fossil fuels, sustainably produced biofuels result in a reduction in CO_2 emissions across their life cycle. Carbon dioxide absorbed by plants during the growth of the biomass is roughly equivalent to the amount of carbon dioxide produced when the fuel is burned in a combustion engine – which is simply returned to the atmosphere. This would allow the biofuel to be approximately carbon neutral over its life cycle. However, there are emissions produced during the production of biofuels, from the equipment needed to grow the crop, transport the raw goods, refine the fuel and so on. When these elements are accounted for, many biofuels are still expected to provide an anticipated reduction in overall CO_2 lifecycle emissions of up to 80% compared to fossil fuels. Furthermore, biofuels contain fewer impurities (such as sulphur), which enables an even greater reduction in sulphur dioxide and soot emissions than present technology has achieved.

Biofuels – providing diversified supply

The airline industry's reliance on fossil fuels means it is affected by a range of fluctuations, such as the changing price of crude oil and problems with supply and demand. Sustainable biofuels could be an attractive alternative as their production is not limited to locations where fossil fuels can be drilled, enabling a more diverse geographic supply. In theory, various biofuel feedstocks can be grown in many places around the world, wherever the aviation industry needs it. Although as for petroleum, there will likely be major producers of biofuel feedstock (which will be transported to where it needs to be used), it is also likely that local smaller scale supply chains will be established.

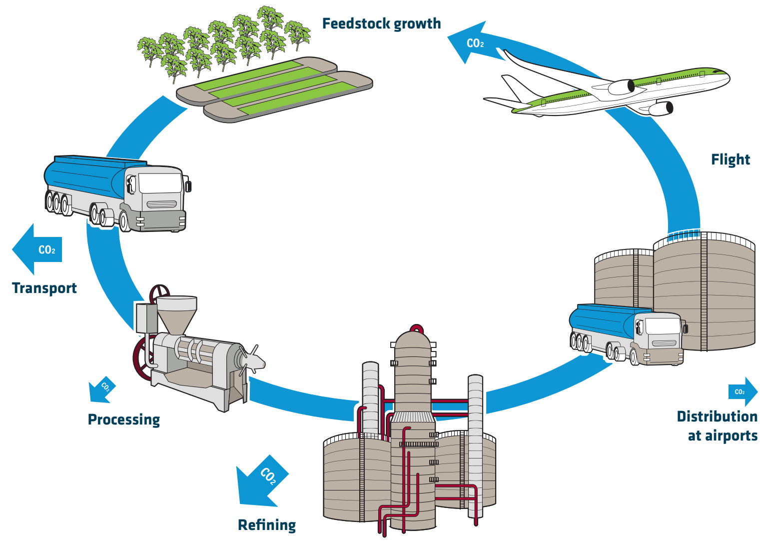
> *The production of sustainable biofuels is flexible and biofuel feedstock can be grown in many places around the world according to the aviation industry's needs and demands.*

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: biofuels



Carbon dioxide will be reabsorbed as the next generation of biofuel feedstock is grown.

Biofuels – providing economic and social benefits

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

Biofuels can also provide economic benefits to parts of the world that have large amounts of land that is either unviable or marginal for food crops, but are suitable for growing second-generation biofuel crops. Many of these countries are developing nations that could benefit greatly from a new industry such as sustainable aviation biofuel production.

> *"Sustainably produced biofuels result in a reduction in CO_2 emissions across their lifecycle."*

What are second-generation aviation biofuels?

> *Second-generation biofuels use a sustainable resource to produce a fuel that can replace traditional jet fuel, while not consuming valuable food, land and water resources.*

Second-generation biofuels for aviation:

- use a sustainable resource to produce a fuel that can be considered as a replacement for traditional jet fuel, while not negatively impacting valuable food, land and water resources;
- can be mass grown in most locations worldwide, including in deserts and salt water;
- have the potential to deliver large quantities of greener fuel for aviation at more stable prices.

The production of the first-generation of road transport biofuels (derived from food crops such as rapeseed, sugarcane and corn – which can also be used as food for humans and animals) has raised a number of important questions. These include questions about changes in use of agricultural land, the effect on food prices and the impact of irrigation, pesticides and fertilisers on local environments.

In addition, some biofuels, such as biodiesel and ethanol (produced from corn) are not suitable fuels for powering commercial aircraft. Many of these fuels don't meet the high performance or safety specifications for jet fuel.

Learning from the experience of other industries, the aviation industry is therefore focusing on second-generation, biofuels that are sustainable. This new generation of biofuels can be derived from non-food crop sources. Second-generation biofuels can also be grown in a range of locations, including deserts and salt water.

Each of the second-generation feedstocks being investigated for aviation use has the potential to deliver large quantities of greener fuel. It is unlikely, however, that the aviation industry will rely on just one type of feedstock. Some feedstocks are better suited to some climates and locations than others and so the most appropriate crop will be grown in the most suitable location. It is likely that aircraft will be powered by blends of biofuel from different types of feedstocks along with jet fuel.

Some potential sustainable aviation biofuel feedstocks

Camelina is primarily an energy crop, with high lipid oil content. The primary market for camelina oil is as a feedstock to produce renewable fuels. The left over solid 'meal' from the oil extraction process can also be used as a feed supplement for poultry and livestock. Camelina is often grown as a rotational crop with wheat and other cereal crops 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.

Algae are potentially the most promising feedstock for producing large quantities of sustainable aviation biofuel. 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 capture (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.

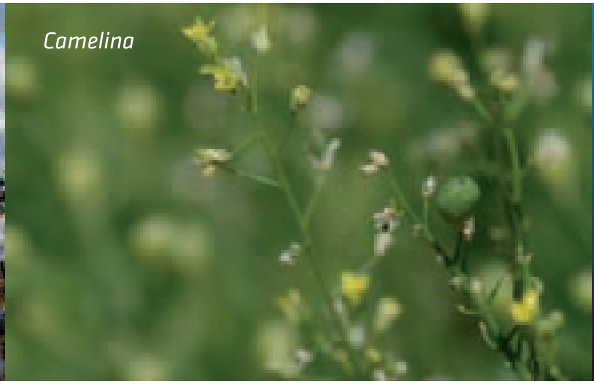
Jatropha is a plant that produces seeds containing inedible lipid oil that can be used to produce fuel. Each seed produces 30 to 40% of its mass in oil. Jatropha can be grown in a range of difficult soil conditions, including arid and otherwise non-arable areas, leaving prime land available for food crops. The seeds are mildly toxic to both humans and animals and are therefore not a food source.

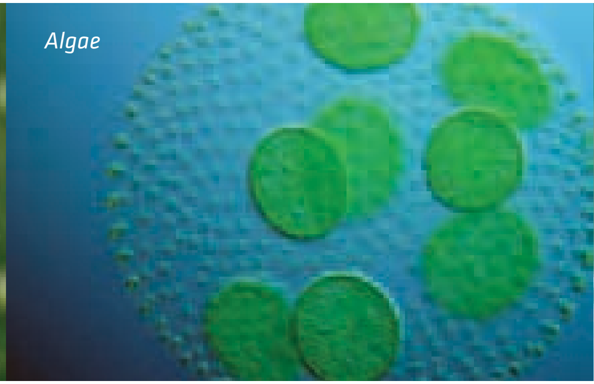
Halophytes are salt marsh grasses and other saline habitat species that can grow either in salt water or in areas affected by sea spray where plants would not normally be able to grow.

(See page 15 for a map outlining where these feedstocks could be grown.)

> *Sustainable biofuels are already being trialled in commercial flights.*


Municipal waste


Camelina


Algae


Halophytes

Biofuel feedstock does not just need to be grown. ***Household and municipal waste*** is also a very promising source of sustainable aviation biofuels, not to mention the waste by-products of the forestry industry or the cultivation of crops. Advanced planning is already underway for building a number of biofuel plants that use such varied waste as wood products, paper, food scraps, forestry waste, agricultural residues, industrial residues, animal by-products, sewage and municipal solid waste, which through various processes can potentially be turned into jet fuel. These may provide feedstock sources to complement the specially grown biofuel supply and could also prevent several hundred million tonnes of waste from entering landfill sites annually.

Key advantages of second-generation biofuels for aviation

- Environmental benefits: sustainably produced biofuels result in a reduction in CO_2 emissions across their lifecycle.
- Diversified supply: second-generation biofuels offer a viable alternative to fossil fuels and can substitute traditional jet fuel, with a more diverse geographical fuel supply through non-food crop sources.
- Economic and social benefits: sustainable biofuels provide a solution to the price fluctuations related to fuel cost volatility facing aviation. Biofuels can provide economic benefits to parts of the world, especially developing nations that have unviable land for food crops that is suitable for second-generation biofuel crop growth.

Why use biofuels for aviation?

> *Biofuels provide the aviation industry with the capability to partially, and perhaps one day fully, replace carbon-intensive petroleum fuels.*

Developing sustainable biofuels for aviation will:

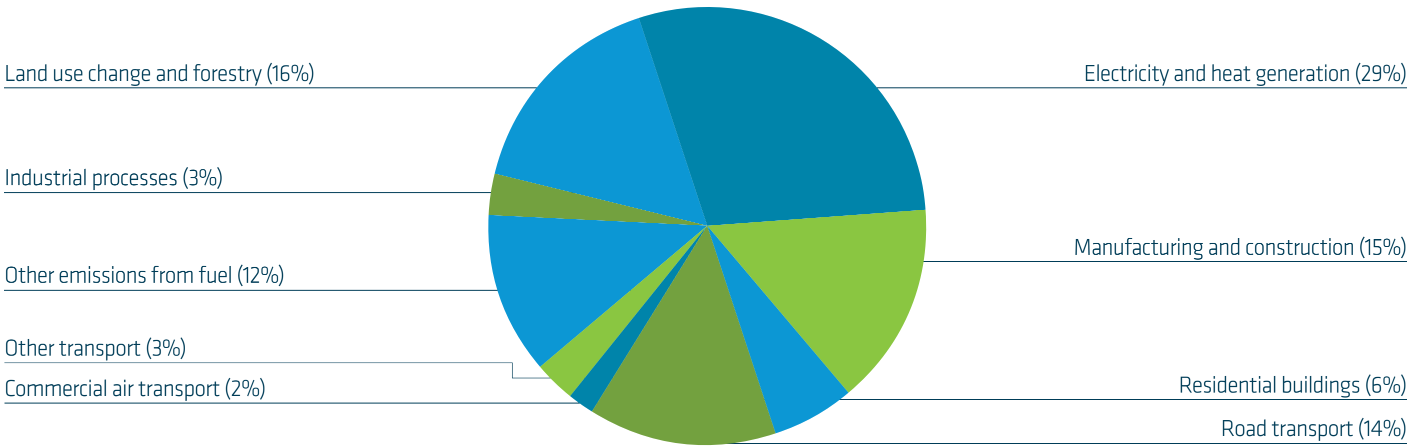
- provide the aviation industry with an alternative to petroleum-based fuels;
- enable the industry to reduce its carbon footprint by reducing its greenhouse gas emissions;
- allow it to draw upon a variety of different fuel sources.

The aviation industry has seen huge growth since its beginning. Today, more than two billion passengers enjoy the social and economic benefits of flight each year. The industry worldwide provides jobs to some 33 million people and has a global economic benefit of around 7.5% of world gross domestic product. The ability to fly conveniently and efficiently between nations has been a catalyst for the global economy and has shrunk cultural barriers like no other transport sector. But this progress comes at a cost.

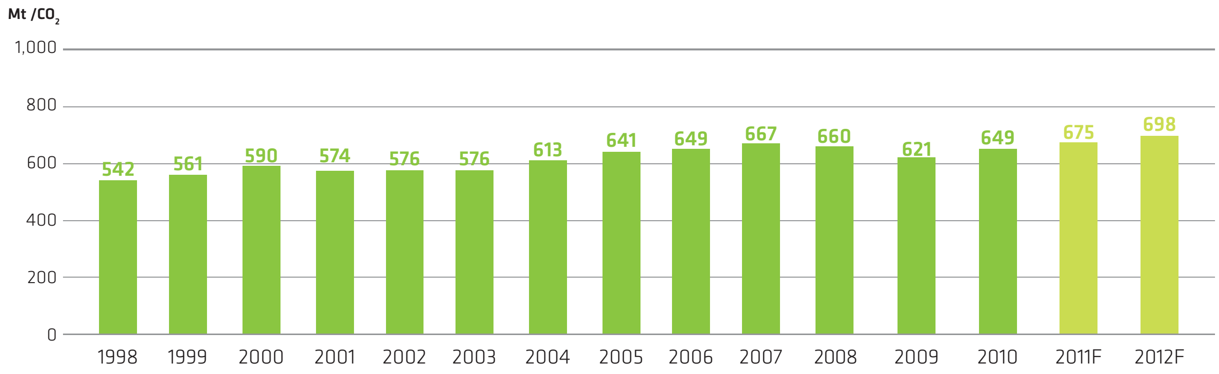
In 2010, the commercial aviation industry produced 649 million tonnes of carbon dioxide (CO_2). This is around 2% of the total man-made CO_2 emissions of more than 34 billion tonnes. While this amount is small compared with other industry sectors, such as power generation and ground transport, these 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 aviation industry has identified the development of biofuels as one of the major ways it can reduce its greenhouse gas emissions. Biofuels provide 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.

Global CO_2 emissions



Total tonnes of CO_2 emitted by aviation over the last 10 years and forecast to 2012



F = Forecast

This graph shows the total tonnes of CO_2 emissions attributable to commercial aviation and a forecast for the coming years. However, the forecast emissions are simply based on a 'business-as-usual' scenario, not taking into account any major advances in technology or the introduction of biofuels.

The decrease in emissions between 2008 and 2009 can partially be attributed to a fall in traffic due to the recession. However, 2% of this reduction comes from efficiency increases.

Technology has much more to offer, but may not be enough

The progress the aviation industry has made in reducing its impact on the environment is remarkable. 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 a lot more than 70% more fuel-efficient since the start of the jet age in the 1960s. The industry will continue to make technology improvements in the way aircraft are constructed and how they are flown, with some significant improvements already in place. But while cutting-edge technology means aircraft are now more fuel-efficient than many cars per 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, there is no foreseeable new technology to power flight beyond hydrocarbon fuels. 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. There is research underway using nanotechnology as a potential for storing hydrogen in a convenient and safe way for air transport, but the conclusion of this research and potential commercialisation is a long way off. The use of sustainable biofuels can provide the air transport industry with a near-term solution to provide a fuel with a lower environmental impact than petroleum-based fuels.

Distributing biofuels for aviation – easier than for other transport modes

The supply of fuel to the commercial aviation industry is on a relatively small scale and 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 sustainable biofuels in aviation than in other transport systems. For example, there are 161,768 retail petrol stations in the United States alone. This compares to a relatively smaller number of airport fuel depots: 1,679 airports handle more than 95% of the world's passengers.

Similarly, there are around 580 million vehicles on the road today , compared to around 23,000 aircraft. And while many of those road vehicles are owned by individuals or families, there are only around 2,000 airlines in the world.

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

> *"The use of sustainable biofuels can provide the air transport industry with a near-term solution to provide a fuel with a lower environmental impact than petroleum-based fuels."*

Biofuels for aviation – technical challenges

> *Second-generation biofuels must have the ability to substitute traditional jet fuel for aviation (known as Jet A and Jet A-1) with the same qualities and characteristics.*

Technical requirements for aviation biofuels

- A high-performance fuel that can withstand a wide range of operational conditions.
- A fuel that can directly substitute conventional jet fuel for aviation.
- A fuel that does not compromise safety.

Second-generation biofuels must have the ability to directly substitute and mix with traditional jet fuel for aviation (known as Jet A and Jet A-1) and have the same qualities and characteristics. 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 develop new fuel delivery systems. At present, the industry is focused on producing biofuels from sustainable sources that will enable the fuel to be a “drop-in” replacement to traditional jet fuel. Drop-in fuels are combined with the petroleum-based fuel either as a blend or potentially as a 100% replacement.

Some biofuels, such as biodiesel and ethanol, are not suitable fuels for powering commercial aircraft. Many of these fuels don’t meet the high performance or safety specifications for jet fuel.

Recent advances in fuel production technology have resulted in jet fuel produced from bio-derived sources that not only meets but exceeds many of the current specifications for jet fuel.

Jet fuel specifications

Criteria	Explanation	Jet A-1 specification	Aviation biofuel
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	✓

Biofuels for aviation – sustainability challenges

Developing sustainable biofuels

The aviation industry is focused on developing fuels that can be mass produced at a low cost and high yield with minimal environmental impact. These biofuels should be made from crops that are fast growing plants that require minimum fresh water, don't take up productive arable land; do not require excessive farming techniques or threaten biodiversity; provide socio-economic value to local communities and importantly result in a lower carbon footprint.

Many first-generation biofuel sources, such as ethanol produced from corn, compete for valuable land with food crops and can contribute to deforestation and pressure on freshwater resources. The aviation industry is committed to using only biofuels that are grown in a sustainable way that do not put food security at risk by competing for land or water with food crops.

The aviation industry is seeking biofuels made from crops that:

- are fast growing, non-food plants that don't take up productive arable land which would otherwise be used for food production;
- do not require excessive supplies of pesticides, fertiliser or irrigation and do not threaten biodiversity;
- do not require excessive amounts of fresh water to grow;
- provide socio-economic value to crop-growing local communities;
- result in a lower carbon footprint on a total carbon lifecycle basis and provide an equal or higher energy content than the current petroleum-based traditional jet fuel, Jet A-1, used by the industry.

Ensuring that a fuel meets these key criteria is an important part of making sure any biofuel really does meet the sustainability goals of the industry. It will be important to ensure that farmers and feedstock producers don't start using the more fertile land for these crops at the cost of food supplies.

There are a number of organisations investigating ways to certify the sustainability credentials of biofuel supplies.It is essential that stringent criteria are applied so that airlines can buy biofuels from truly sustainable sources. The aviation industry is working with these groups to put in place sustainability criteria so that when it comes time to buy biofuels in large quantities, its sustainability can be assured. It is also vital to ensure that a sustainability standard is recognised at a global level – so airlines can comply once and use the same fuels wherever they fly.

> *"The aviation industry is committed to using only biofuels that are grown in a sustainable way that do not compete for land or water with food crops."*

Biofuels for aviation – testing and approval

Biofuels testing is imperative to determine suitability for aviation

- The aviation industry has a rigorous testing process to maintain the highest standards of safety.
- This means that aviation biofuels must undergo extensive experiments in the laboratory, on the ground and in the air.
- This exhaustive process determines those biofuels suitable for aviation.
- Now that the testing process has been successfully completed, several types of aviation biofuels are approved for commercial use.

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 operating conditions that the aviation industry requires, an exhaustive process determines those biofuels that are suitable for aviation.

Because of the very strict standards required in the aviation industry, biofuels needed to be approved as safe and appropriate for commercial use. The aviation industry worked closely with fuel specification bodies, such as the ASTM International and the UK's Defence Standards Agency.

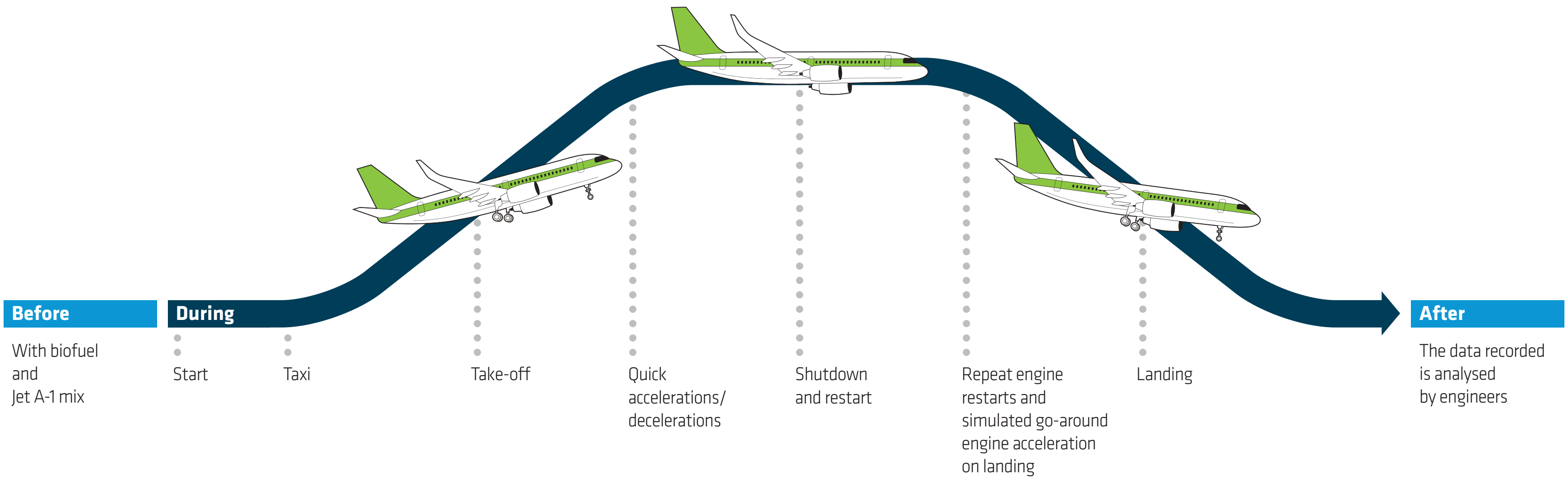
In the laboratory

Researchers develop a biofuel that has similar properties to traditional 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 traditional Jet A-1. 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 biofuels.

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 biofuel trials conducted in early 2009.

In the air

Once the lab and on-the-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 biofuel flight trials designed to:

- provide data to support fuel qualification and certification for use by the aviation industry;
- demonstrate that biofuels are safe and that they work; and
- stimulate research and development into biofuels.

During a flight, pilots perform a number of ordinary and not-so-ordinary tests to ensure the fuel can withstand use under any operating condition.

Approval of biofuels for aviation use

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, volatility, fluidity and many other characteristics that will make it fit for aviation use.

ASTM International and other lead certification agencies, have spent the last couple of years working with various parties across the aviation industry, fuel suppliers and researchers before committing to change the specification of aviation jet fuel to include fuel from sources other than fossil fuels. The agencies approved one process for biofuel production – 'biomass to liquid' using the Fischer-Tropsch process – in 2009, and in July 2011, approval was granted to conduct passenger flights using biofuel produced through the 'hydro-processed esters and fatty acids' process. There are a number of other processes that can potentially be used to produce biofuels suitable for aviation: testing and evaluation is currently underway for these.

Following this approval, airlines are now able to use biofuels in commercial passenger flights up to a blend of 50% with Jet A-1.

> *"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."*

Biofuels for aviation – economic viability

Economic viability of biofuels for aviation

- Sustainable biofuels will become economically viable and compete with petroleum-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 who can develop new sources of income – including in many developing nations.

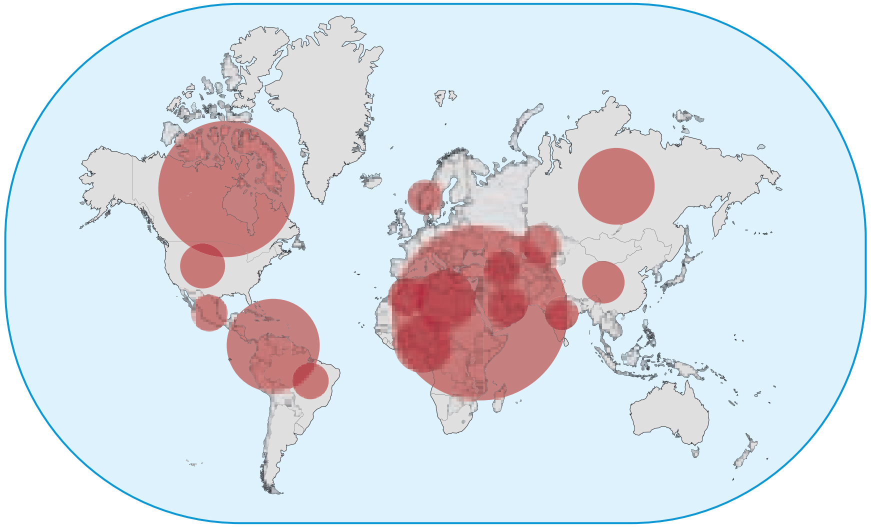
The fossil fuel industry has a 100-year head start compared to sustainable biofuels, which are still emerging technologically. A concerted effort by governments is required to foster these promising renewable options to help drive their long-term viability. Supporting this case are two major trends developing in the economics of fuel.

First, fossil fuels are forecast to become increasingly scarce and as a result will become more expensive. Second, advanced biofuels that stem from sustainable feedstocks will become less expensive as the relevant science and business models mature. It is estimated that up to 85% of biofuel production costs relates to the cost of the feedstock. As technology to harvest and process these feedstocks progresses and as they become available in commercial quantities, the price will drop. Many companies are also developing ways to refine advanced biofuels, including the use of bacteria and other natural processes, cheaper conversion and refinement, or the use of less costly feedstocks, including waste products. Owing to their renewable nature, if grown sustainably, these feedstocks will not be exhausted one day – contrary to crude oil and other fossil energy sources.

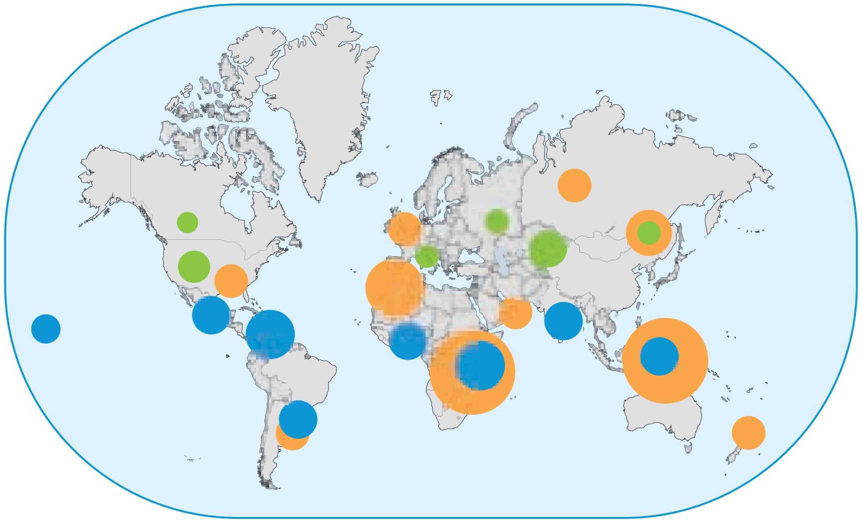
The price of oil can vary substantially, falling from a high of USD$147 per barrel in June 2008 to $40 in December 2008 and increasing again in early 2011. As the volatility of oil prices continues, it makes predicting when biofuels will be cost-competitive difficult. However, it is forecast that the price of oil will continue to rise and the cost of biofuel production will continue to fall.

Key oil-producing regions of the world

Circles represent current oil reserves



Optimum land for growing sustainable aviation biofuels

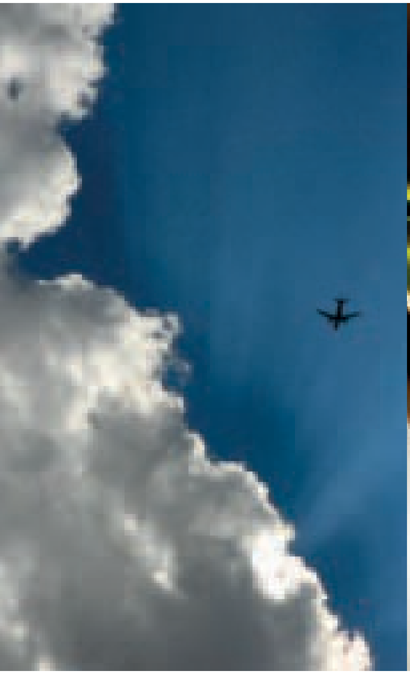


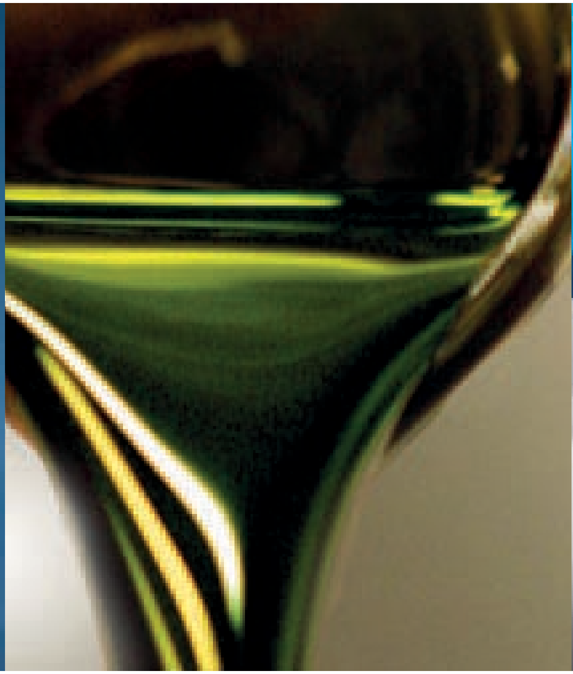
- Algae
- Jatropha
- Camelina
- Biofuels using municipal waste can potentially be produced near any urban area.

Circles indicate potential locations for biofuel feedstock growth (indicative estimate)

However, there may be costs to using fossil fuels in addition to the price of the fuel itself. Legislation passed by the European Union in 2008 to include aviation in the EU's emissions trading scheme (ETS) will add a carbon cost to aviation, requiring airlines to pay for their carbon emissions from 2012.

It is possible that emissions trading schemes will also be developed in other parts of the world. This makes alternative fuel technologies, which reduce emissions compared to traditional jet fuelbut cost the same as Jet A1, especially attractive. Under the European ETS legislation, biofuel use is zero-rated for emissions. Other policies could reduce tax levels on low-carbon fuels such as biofuel. The United States and other governments are on course to make significant investments in sustainable biofuel development.





"Biofuels may provide valuable economic opportunities to communities who can develop new sources of income – including in many developing nations."

From the fields to the wings

Bringing biofuels from feedstock to jet fuel supply

- This will require the production of sufficient sustainable raw materials and the industrial capability to process and refine it into fuel.
- The worldwide aviation industry consumes some 1.5 to 1.7 billion barrels of traditional jet fuel annually.
- Analysis suggests that a viable market for biofuels can be maintained when as little as 1% of world jet fuel supply is substituted by a biofuel.

Now that biofuels for aviation have been approved as suitable for use on commercial flights, one of the biggest challenges is cultivating the required quantity of feedstocks. The worldwide aviation industry consumes some 1.5 to 1.7 billion barrels of Jet A-1 annually (about 250 billion litres, or 70 billion gallons). Analysis suggests that a viable market for biofuels can be maintained when as little as 1% of world jet fuel supply is substituted by a biofuel (or, put another way, 10% of the world's aircraft fleet is running on a blend of 10% biofuel and 90% Jet A-1).

So, when will the industry be able to reach that point? If the commercialisation process goes well, it could be as early as 2015. Some parts of the aviation industry have put in place a goal to operate the fleet using 25% biofuel by 2025, which would be increased to 30% by 2030. However, for these targets to be reached, it is necessary to produce sustainable feedstocks in commercial-scale quantities.

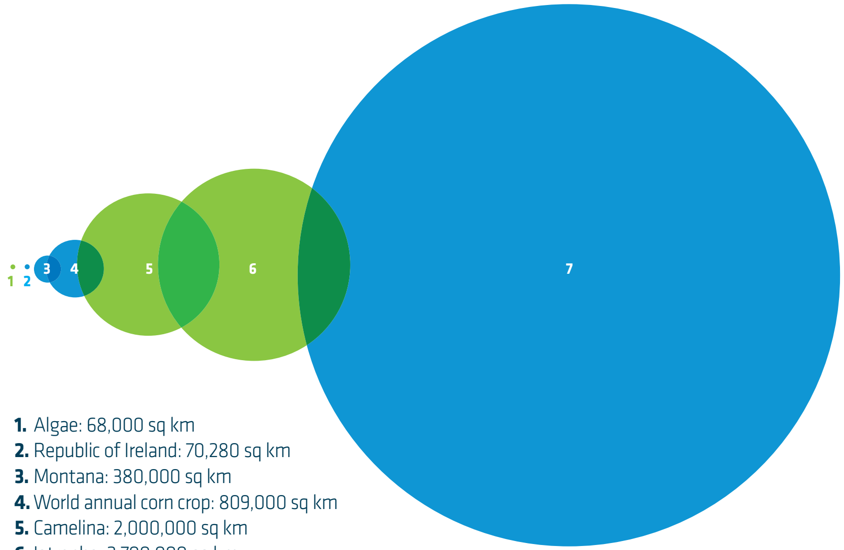
Growing biofuel feedstock

Second-generation biofuels can be grown in fairly harsh conditions, requiring little or no fresh water and soil that is not at a premium for food crops. So how much land will it take to grow enough feedstock to supply the world's airline fleet with biofuel?

Most of the potential biofuel feedstocks can be grown as conventional crops. They just need to be planted and cared for, cultivated and harvested before being processed. Jatropha can be grown on the land surrounding other crops, as a natural barrier on the edge of fields.

It can also potentially be grown on wasteland and in areas where other crops would not survive – but it is very important that this is done without having a negative impact on sustainability. While algae can grow in almost all types of water, including seawater, on wastewater ponds and in lakes, they grow fastest in algae incubators called photo bioreactors, or in special ponds to enhance the amount of carbon dioxide and sunlight they can capture to grow. Increasing the productivity through advanced methods, while decreasing the cost-to-unit ratio, is one of the major challenges facing the scaling up of algae feedstock production.

Land area equivalents required to produce enough fuel to completely supply the aviation industry with 100% biofuel



1. Algae: 68,000 sq km
2. Republic of Ireland: 70,280 sq km
3. Montana: 380,000 sq km
4. World annual corn crop: 809,000 sq km
5. Camelina: 2,000,000 sq km
6. Jatropha: 2,700,000 sq km
7. Australia: 7,617,930 sq km

These diagrams represent the amount of land that would be needed to replace the amount of jet fuel currently used with just one of these sources (as well as a comparison with different land areas). But it is unlikely that aviation will rely on just one type of biofuel, so a bit of each will be used. This portfolio approach will allow us to use the most appropriate supply in each country and will mean that the amount of land required for crops can be kept to a minimum.

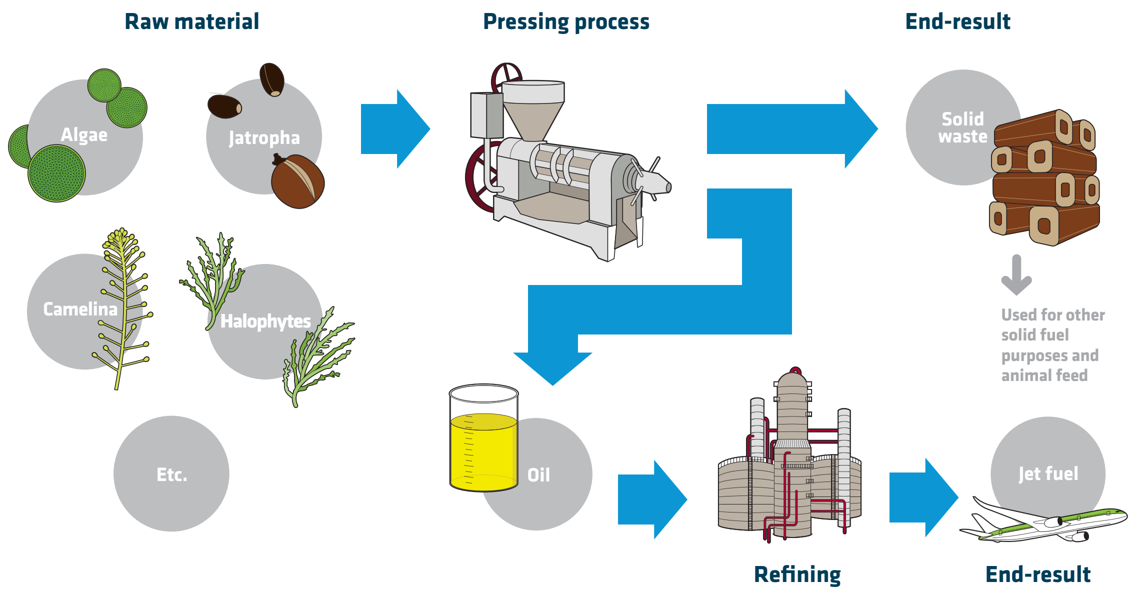
Of course, one of the feedstocks that doesn't require fields or cultivation is the use of waste products. These could deal with a municipal or agricultural issue, while also providing feed for a jet biofuel process.

Processing

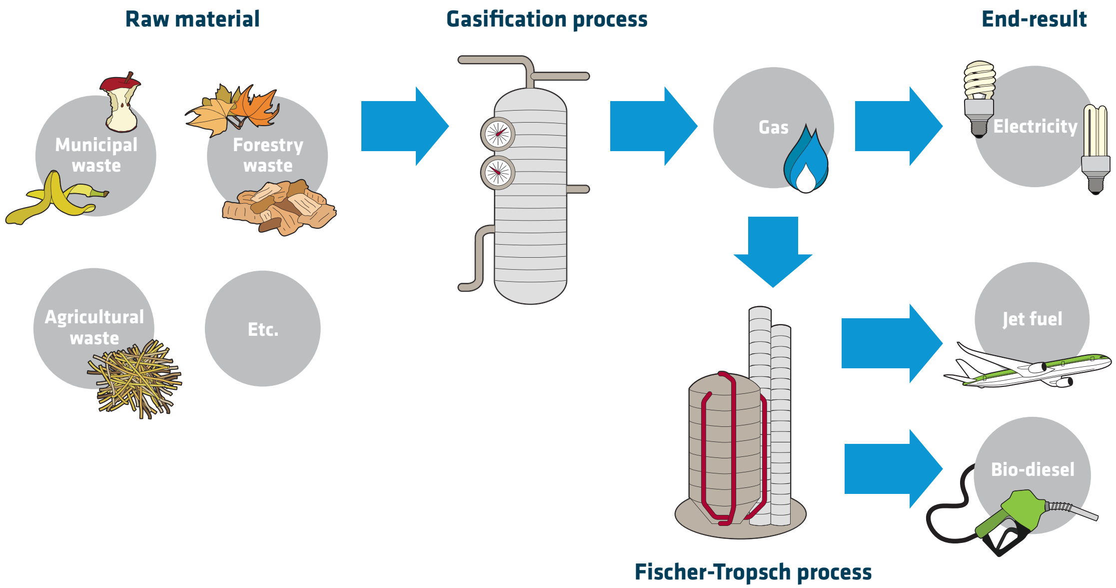
Once the feedstock has been harvested or collected, it is processed. There are a number of different processing techniques. Two have received approval for use in aviation fuel, up to a blend of 50% with traditional jet fuel – biomass to liquid (BtL) and hydroprocessed esters and fatty acids (HEFA) and there are a number of other processes being developed. Development testing of new processes will advance the scientific understanding and therefore support the longer-term aim to enable the use of sustainable fuel within the aviation transport sector and thus improve the overall environmental performance relative to current operations.

Although the processes are fairly complex, a simple explanation of the **HEFA** process (which is also known as hytrotreated renewable jet, or HRJ) is that biomass such as algae, jatropha or camelina is pressed to extract the oils inside, which are then refined into jet fuel in a similar way that crude fossil oil is refined. One of the other outcomes of the pressing process is a leftover substance: the meal. In many cases this meal can also be used. The solid residues left from the processing of jatropha, for example, can be used as fuel for burning on fires and in stoves. The meal from algae oil production can be used for fertiliser, animal feed and other purposes, and camelina meal can be used as animal feed.

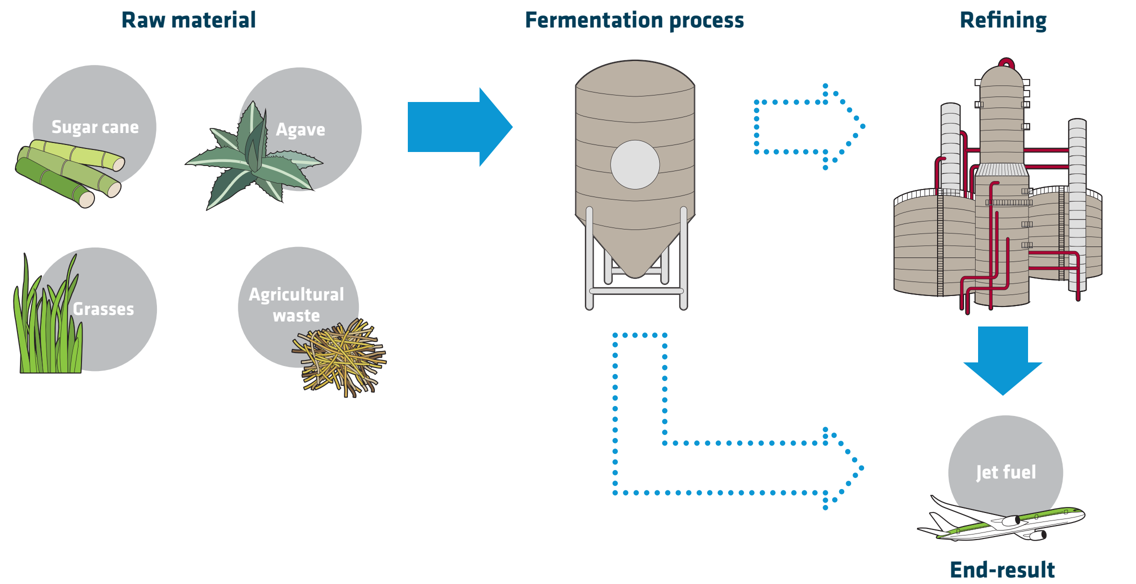
Hydroprocessed esters and fatty acids (HEFA) process



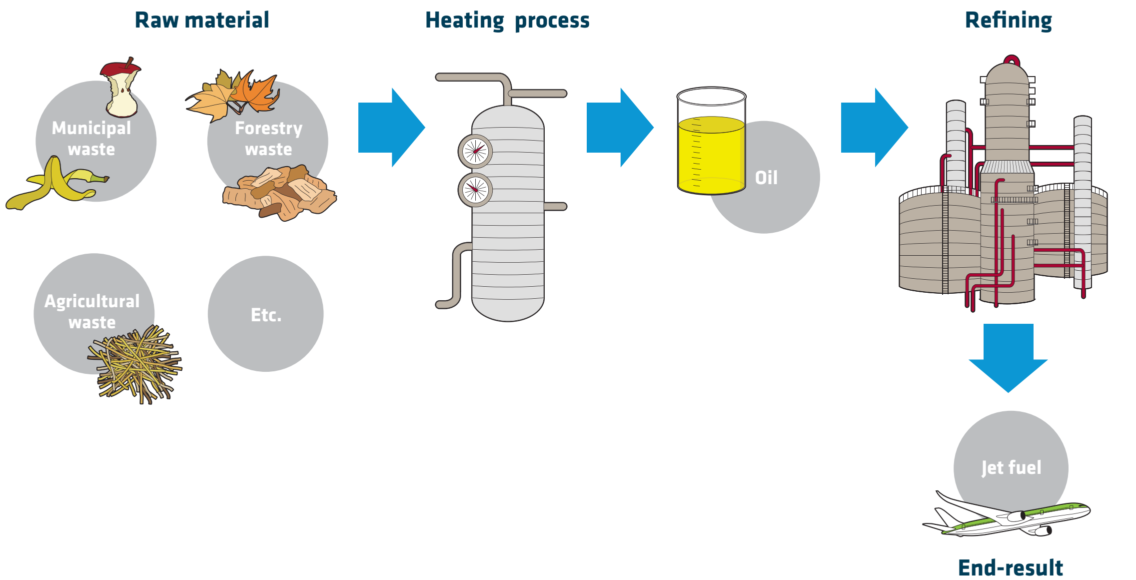
Biomass-to-liquid (BtL) process



Alcohol-to-jet process



Pyrolosis process



In the **BtL** process, the feedstock is broken down through gasification, a process by which the biomass is heated to an extremely high temperature which cracks the molecules and produces a gas. This gas is then converted into liquid jet fuel through the Fischer-Tropsch process. There are a few different BtL processes, but one being implemented in London, California, Australia and Italy will process municipal waste to produce some 16 million gallons of jet fuel a year from each plant. It will also produce electricity (which can be used to run the plant and also feed excess into the national grid) and bio-diesel for use in cars.

There are two other pathways that are currently being explored in detail:

Alcohol-to-jet is a process using the fermentation of cellulose and sugars. Various microbes, yeasts or bacteria are used to process agricultural waste products (stover, grasses, forestry slash, crop straws) to be converted either directly to jet fuel or through a group of alcohol conversion pathways. This is potentially a cheaper process, as the feedstocks are easy to obtain and don't cost a lot. It is also an efficient process that doesn't require much energy.

Pyrolysis of biomass is where the biomass (from industrial, agricultural, municipal or forestry waste) is heated in a special process to produce an oily substance, which is then refined to produce jet fuel. While creating jet fuel, this also solves the problem of using waste resources which would otherwise produce greenhouse gases as they decompose.

> *One of the biggest challenges in developing biofuels is cultivating the quantities of feedstock needed to produce it and developing the facilities to process and refine the fuel.*

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. At this stage, approval has been given for airlines to operate flights using the BtL and HEFA processes up to a limit of 50% biofuel and 50% conventional fuel. This is a precautionary measure enabling the industry to start using biofuels while additional assessments are undertaken on the need to maintain required levels of aromatic content in fuels. Aromatics are hydrocarbons found naturally in fossil-based fuels and are a necessary component for conventional jet fuels, forming up to 25% of the volume. They are not found in biomass-sourced fuels and this restricts the use of jet biofuels to 50% blends in order to guarantee aromatic content. The restriction allows time for an assessment of whether a synthetic aromatic source needs to be developed.

In any case, the amounts of biofuels that can be supplied are a number of years away from reaching 50% of the jet fuel market. But 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.

Quality control

Current jet fuel quality controls have been in place for many years and work very well to ensure that the jet fuel used in flight remains free from contaminants. The entry of new manufacturers, new processes and products, off-refinery blending and the relative immaturity of the aviation biofuel industry means that airlines and the aviation system will need to ensure those stringent standards of quality control remain in place. This may require new processes or a more watchful eye on the quality assurance and control standards being used throughout the supply chain.

Blending of fuels and delivery to the aircraft

Once it is refined, the biofuel needs to get to the aircraft tank, initially as a drop-in blend with traditional jet fuel. Because the industry is pursuing biofuels that can be blended with existing fuel supplies, the industry can start using the new fuel as it becomes available, in increasing quantities, as a ‘drop-in’ mixed with conventional Jet A-1 fuel.

As the aviation industry and potential fuel suppliers go through the process of production development, they will also be investigating how to deliver the vast quantities of fuel to the world's airports. During the years when blending of biofuel and traditional Jet A-1 fuel takes place, blending could be undertaken at a biofuel refinery, a petroleum-fuel refinery, at a separate facility, or even at the airport fuel facility itself. But this is quite a significant departure from the way that fuel has been delivered to aircraft for the past 60 years. Not only will some of the infrastructure need to be built upon, but the very rigorous fuel quality checking process currently in place will also need to be expanded to include new suppliers, sources and quality control checkpoints.

The next steps

Now that testing has been undertaken, the aviation industry knows that biofuels are technically up to the job and approval for use in passenger flight is complete. The hurdles that remain are:

- ensuring a steady supply of the feedstock is grown and then processed into biofuel;
- ensuring that the facilities are in place to refine and blend the biofuel into current jet fuel;
- ensuring that the cost is competitive, in order to compete with petroleum-based jet fuel;
- ensuring that aviation is allocated its share of biofuel supply despite competition for that supply with other forms of transport;
- ensuring that the industry is looking to governments to help with incentives for fuel suppliers to bring enough of the fuel to market; and
- ensuring new fuel suppliers can produce and handle the new fuels in accordance with today's stringent quality control standards.

With the testing and certification process on the first types of biofuel now complete, sustainable biofuels are already being used on limited numbers of passenger flights. The aviation industry has set itself the task of developing a set of sustainability criteria – to ensure that the biofuels it is being supplied are genuinely sustainable and have no negative impact on people's lives in the communities that grow them. The main hurdles are in attracting investment for biofuels production and distribution and ensuring that the industry has access to this biofuel stock, at a price that is cost-competitive with using traditional jet fuel.

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

In a recent report *Powering the Future of Flight* (available through the website www.enviro.aero/biofuels), the aviation industry presented six steps that governments could take to help aviation transition towards sustainable biofuel use:

1. Foster research into new feedstock sources and refining processes
2. De-risk public and private investments in aviation biofuels
3. Provide incentives for airlines to use biofuels 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 the conventional wisdom of the time telling them it couldn't be done.

The aviation industry is now on the verge of another extraordinary step – but it is a challenge that the entire industry needs to take on together. A few years ago, the industry committed to sustainable biofuels use in commercial flights becoming reality and in 2011 this has happened. It is very possible that a significant supply of biofuel 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, biomass and fuel suppliers to ensure that the low-carbon, biofuelled future for flight becomes a reality.

“*The history of aviation is marked by people achieving extraordinary things, despite the conventional wisdom of the time telling them it couldn't be done.*”

Definitions

Alternative fuel: the 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 be significantly greener 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.

Biofuel: fuel produced from renewable resources. While there is no globally-agreed definitions of first- and second-generation biofuels, in this publication we have broadly used the following terms.

First-generation biofuels: biofuels such as most current ethanol and biodiesel produced from biomass that competes with food production and fresh water use, and/or causes deforestation or reduced biodiversity.

Second-generation biofuels: fuel produced in using new processes and that utilises sustainable biomass that can be grown without negatively impacting the food supply chain or fresh water resources, or causing deforestation. Examples include jatropha, camelina, halophytes, municipal waste and algae. Also known as next-generation or sustainable biofuels.

There is also discussion about **third-generation** and **advanced-generation** biofuels (which some consider algae to be), or the aviation biofuels that could potentially by produced using an alcohol-to-jet process.

Biomass: any renewable material of biological origin (plants, algae, waste 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 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 because most of the CO_2 they release during combustion has been previously absorbed by growing plants.

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 inter-changeably 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.

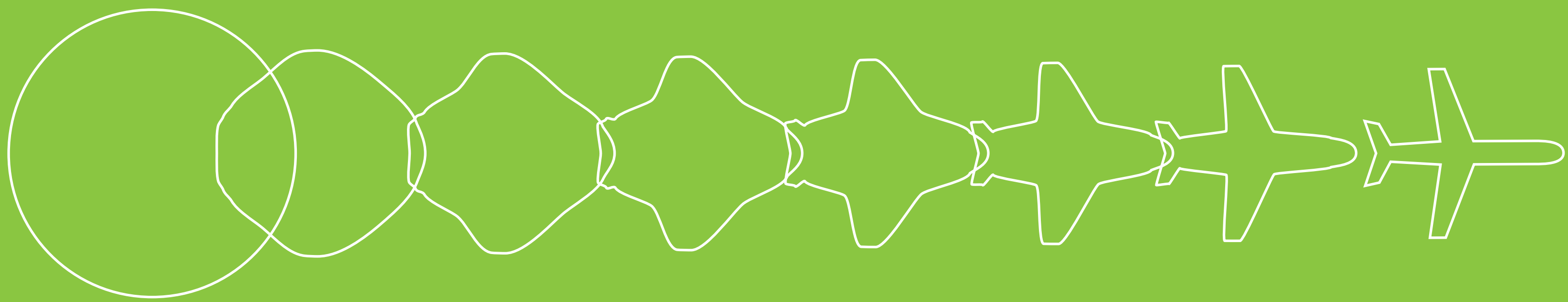
Jet A: Commercial jet fuel specification for North America.

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/biofuels



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