Beginner's Guide to Aviation Biofuels

Reference version, May 2009

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Contents

The importance of aviation[1]

- **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 2.2 billion passengers annually.**
- **The air transport industry generates a total of 32 million jobs globally.**
- **Aviation's global economic impact (direct, indirect, induced and catalytic) is estimated at USD 3,560 billion, equivalent to 7.5% of world gross domestic product.**
- **Aviation is responsibly reducing its environmental impact.**
- **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 70% more fuel-efficient than 40 years ago, consuming 3.5 litres per passenger per 100km. The Airbus A380 and the Boeing 787 – consuming less than 3 litres/100 km – compare favourably with small family cars.**

[1] The Economic and Social Benefits of Air Transport, ATAG (2008): http://www.atag.org/files/ATAG%20brochure-124015A.pdf

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's about to change.

The world is turning to governments and business to reduce the human impact on climate change. And the aviation industry is about to embark 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?

Key points about biofuels

- Produced from renewable biological resources such as plant material (rather than traditional fossil fuels like coal, oil and natural gas).
- Absorbs 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 are 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.

However, bio-derived oil, commonly sourced from plants such as corn, soybeans, algae, jatropha, halophytes and camelina, is processed and can either be 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 6 for further information).

Biofuels – providing environmental benefits

Relative to fossil fuels, sustainably produced biofuels result in a reduction in CO_2 emissions across their lifecycle. Carbon dioxide absorbed by plants during the growth of the biomass is roughly equivalent to the amount of carbon produced when the fuel is burned in a combustion engine[2] – which is simply returning the CO_2 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, biofuels are still anticipated to provide an estimated 80% reduction in overall CO_2 lifecycle emissions compared to fossil fuels[3]. For example, analysis of camelina feedstock use for aviation has shown even better results, with an 84% reduction in lifecycle emissions[4]. 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[5]. Biomass thrives on carbon dioxide as it is grown, which makes it ideal for removing CO_2 from the atmosphere.

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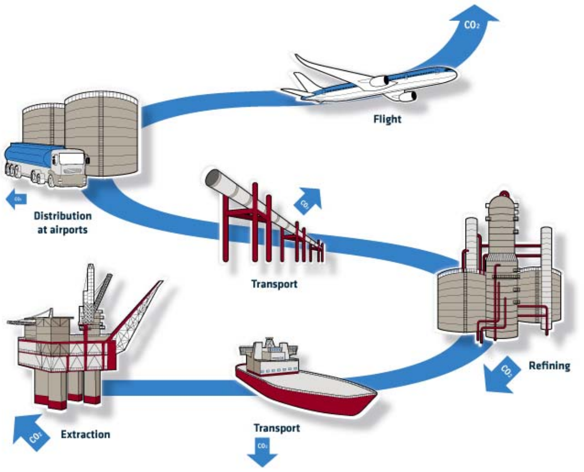
[2] Alternative Fuels for Commercial Transports, Oren Hadaller and Dave Dagget, Boeing Commercial Airplanes (2007)
[3] Alternative Fuels for Commercial Transports, Oren Hadaller and Dave Dagget, Boeing Commercial Airplanes (2007)
[4] Sustainable Oils, Honeywell UOP analysis: http://www.susoils.com/dynamic-content/csArticles/articles/000000/000045.htm
[5] Sustainable Biofuels for Aviation: Path to Commercialisation, Boeing (March 2008)

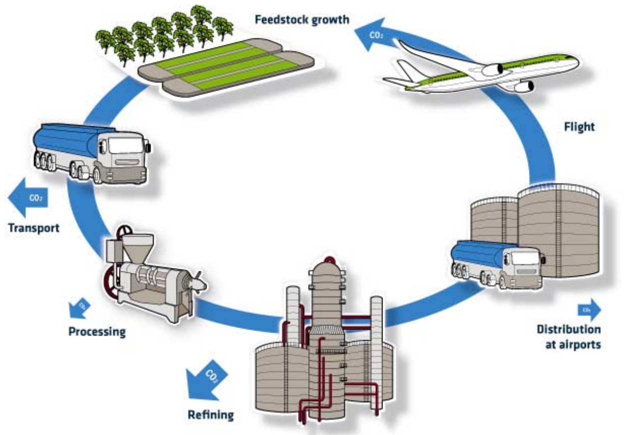
Carbon lifecycle diagrams

Fossil fuels



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

Biofuels



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

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, biofuel feedstock can be grown in many places around the world, where the aviation industry needs it. And while, as for petroleum, there will be major producers of biofuel feedstock and it will likely be transported to where it can best be used, it is also likely that local smaller scale supply chains will be established.

Biofuels – providing economic and social benefits

Fuel is one of the biggest operating costs for the aviation industry[6]. 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 source of energy.

Biofuels 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 second-generation biofuel crops. Many of these countries are developing nations that could benefit greatly from a new industry such as sustainable aviation biofuels.

[6] Alternative Fuels: Engine Manufacturers' Role and the Approval Process, Pratt and Witney Fuels Technology Manager at the 2nd Annual Flight Operations Conference (November 2008)

What are second-generation aviation biofuels?

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 consuming valuable food, land and water resources;
- can be mass grown in locations almost worldwide, including in deserts and salt water;
- include bio-derived oil, sourced from feedstocks such as jatropha, camelina, algae and halophytes;
- have the potential to deliver large quantities of greener fuel for aviation at more stable prices – although aviation will not rely on just one type of feedstock.

The production of first-generation 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 of the first-generation 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 looking at second-, or next-generation, biofuels that are sustainable. This new generation of biofuels is derived from non-food crop sources. Second-generation biofuels can also be mass 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 and potentially cheaper 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.

Potential second-generation biofuel feedstocks

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 toxic to both humans and animals and are therefore not a food source.

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 "waste" from the oil extraction can also be used as feed for chickens in small proportions. 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.

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[7]. 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.

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 14 for a map outlining where these feedstocks could be grown.)

[7] Algae: Biofuel of the Future?, Science Daily: http://www.sciencedaily.com/releases/2008/08/080818184434.htm

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.

What a load of rubbish
One of the other feedstock avenues being explored is the use of biological waste material. There are ongoing experiments into the use of such varied waste as wood products, paper, food scraps, forestry waste, agricultural residues, industrial residues, animal by-products, sewage, municipal solid waste and even tyres, 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 an estimated 577 million tonnes of waste from entering landfill sites annually.

Why use biofuels for aviation?

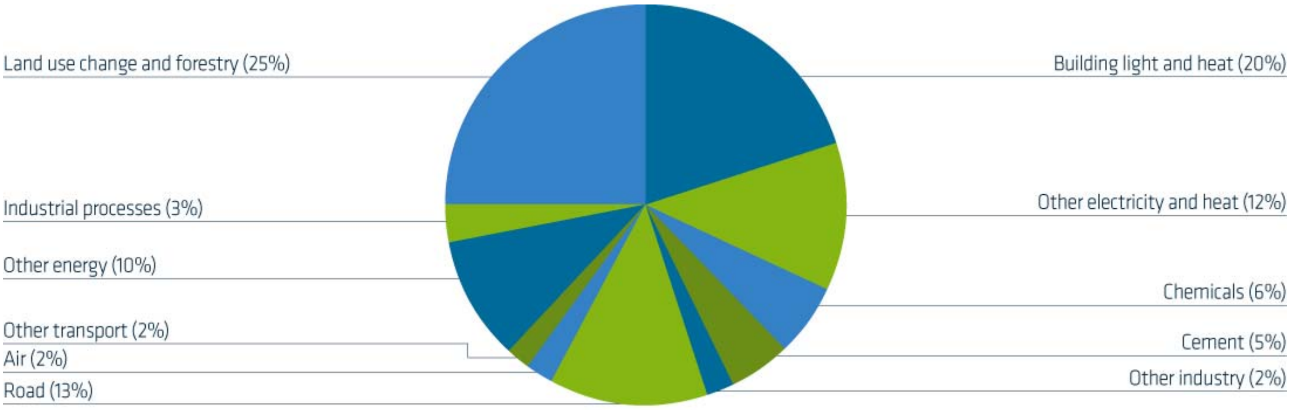
Developing sustainable biofuels for aviation will:

- 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;
- be easier to implement than for other transport modes.

The aviation industry has seen huge growth since its beginning. Today, more than two billion people enjoy the social and economic benefits of flight each year. The industry worldwide provides jobs to some 32 million people and has a global economic benefit of around 7.5% of world gross domestic product[8]. 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 2008, the commercial aviation industry produced 677 million tonnes of carbon dioxide (CO_2)[9]. This is around 2% of the total man-made CO_2 emissions[10] 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 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.



Source: World Resources Institute 2002

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. 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 more than 70% more fuel-efficient over the past 40 years. The industry will continue to make technology improvements in the way aircraft are constructed and how they are flown, with some significant improvements in progress. 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

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[8] The Economic and Social Benefits of Air Transport, ATAG (2008): http://www.atag.org/files/ATAG%20brochure-124015A.pdf

[9] IATA Economics (May 2009)

[10] Intergovernmental Panel on Climate Change, Fourth Assessment Report (2007), World Resources Institute (2002)

sustainable way to supply the industry's needs. 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.

Implementing 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[11]. This compares to a relatively smaller number of airport fuel depots: 1,679 airports handle more than 95% of the world's passengers[12].

Similarly, there are around 580 million vehicles on the road today[13], compared to around 23,000 aircraft[14]. And while many of those road vehicles are owned by individuals or families, there are only around 2,000 airlines in the world[15].

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.

11 National Petroleum News (2008)

12 Airports Council International: www.aci.aero

13 IPCC Fourth Assessment Report (2007): http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter5.pdf

14 The Economic and Social Benefits of Air Transport, ATAG (2008): http://www.atag.org/files/ATAG%20brochure-124015A.pdf

15 The Economic and Social Benefits of Air Transport, ATAG (2008): http://www.atag.org/files/ATAG%20brochure-124015A.pdf

Biofuels for aviation – technical challenges

Technical requirements for aviation biofuels

- A high-performance fuel that can withstand a range of operational conditions.
- A fuel that can directly substitute traditional jet fuel for aviation.
- A fuel that does not compromise safety.
- A fuel that meets stringent performance targets.

Second-generation biofuels must have the ability to directly substitute 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 airlines 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 as a 100% replacement.

Some first-generation 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	Second-generation 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 interested in 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 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 compete 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;
- provide socio-economic value to 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.

There are a number of organisations investigating ways to certify the sustainability credentials of biofuel supplies[16]. It is also vital that farmers don't replace food crops on fertile land with biofuel crops, simply to make more money. It is essential that stringent criteria are applied so that airlines can buy biofuels from truly sustainable sources.

[16] Including the Roundtable on Sustainable Biofuels (BSR), the United Nations Environmental Programme (UNEP), the Global Bioenergy Partnership, the International Energy Agency, the European Union and the Sustainable Aviation Fuel Users Group.

Biofuels for aviation – testing

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 biofuels must undergo dozens of experiments in the laboratory, on the ground and in the air.
- This exhaustive process determines those biofuels suitable for aviation.

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.

In the laboratory

Researchers develop a biofuel that has similar properties to traditional jet fuel, Jet A-1. The aircraft and engine manufacturers and other systems suppliers then run compatibility tests. 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

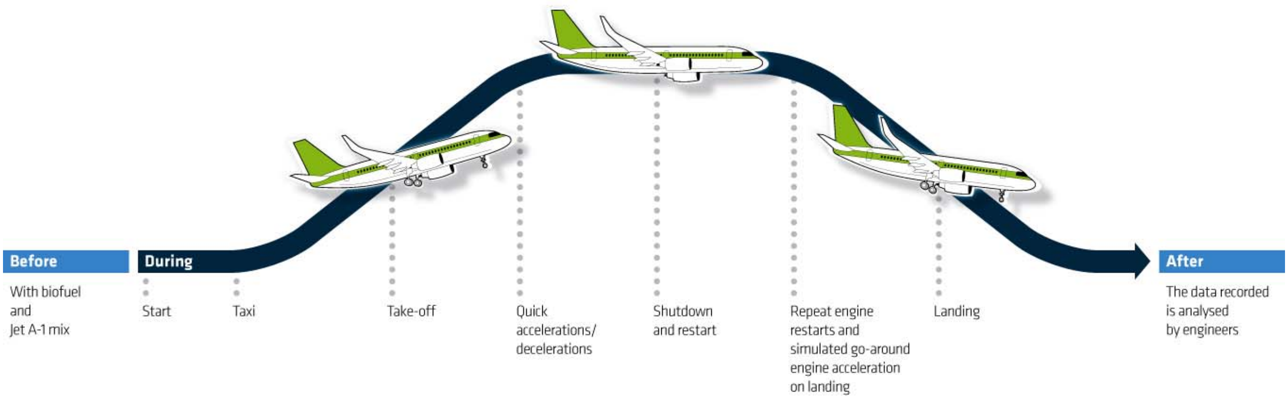
Tests look at specific fuel consumption at several power settings from ground idle to take-off speed, which is then compared to performance with traditional Jet A-1. Tests are also completed on the amount of time it takes for the engine to start, how well the fuel stays ignited in the engine and how the fuel performs in acceleration and deceleration. Finally, an emissions test determines the gaseous emissions and smoke levels for the biofuels.

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 have 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.



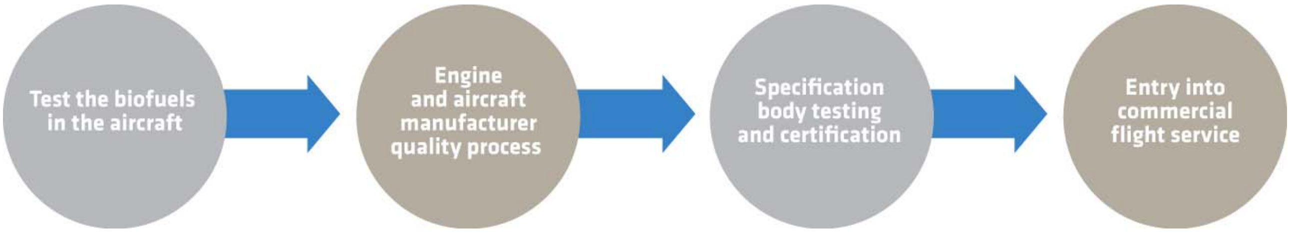
Biofuels for aviation – the certification process

Certification of biofuels for aviation use

- Once flight trials are successfully completed, biofuels need to be certified for commercial use.
- This is the role of the fuel specification bodies responsible for testing aviation fuels according to key criteria before the fuel is certified for commercial use.
- The certification approval process looks at a minimum of 11 key performance properties.
- The target is to certify biofuels as safe for aviation use by 2013, but latest information is that certification could be completed before 2011.

Following the success of flight trials, biofuels need to be certified as safe and appropriate for commercial use. The aviation industry is working closely with fuel specification bodies, such as the American Society for Testing and Materials (ASTM) International and the UK's Defence Standards Agency.

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 which would make it fit for aviation use. The target is to certify aviation biofuels by 2013, although there is now a possibility that a 50/50 blend of biofuels mixed with Jet A-1 fuel could be certified before 2011. Due to recent advances in research and technology, aviation biofuel might be available for commercial use within five years, once the feedstock production process has been set in motion.



Biofuels for aviation – economic viability

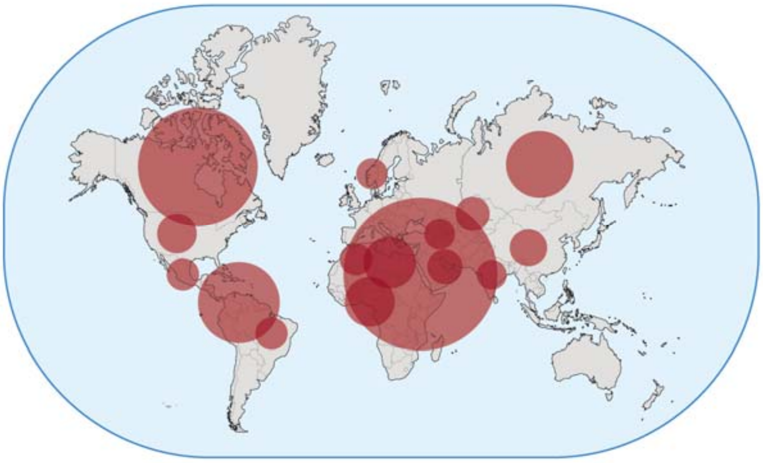
Economic viability of biofuels for aviation

- 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.

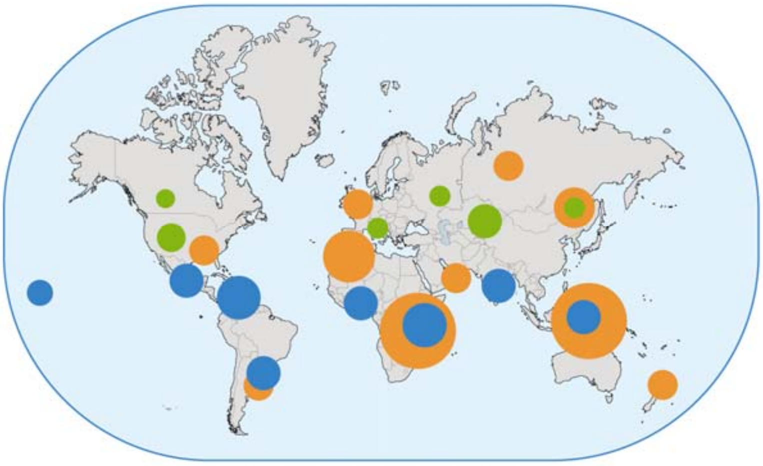
First, fossil fuels are forecast to become increasingly scarce and as a result will become more expensive. Second, advanced biofuels that stem from sustainable feedstocks will become less expensive as the relevant science and business models mature. It is estimated that 85% of biofuel production costs 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. Owing to their renewable nature, these feedstocks can continue to be produced, over and over again.

The price of oil can vary substantially, falling from a high of USD$147 per barrel in June 2008 to $40 in December 2008. This makes it difficult to project when biofuels would be competitive, but there are strong indications that biofuels would become cost-comparable with traditional jet fuel, Jet A-1 by around 2020[17].



Key oil-producing regions of the world[18].

Circles represent current oil reserves.



Optimum land for growing sustainable aviation biofuels[19]:

- **Algae**
- **Jatropha**
- **Camelina**

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

[17] IATA Economics

[18] Map produced from details provided in the Oil and Gas Journal: http://www.greenstreetinvestor.com/wp-content/uploads/2008/06/oil_reserves.jpg

[19] Map produced by ATAG, based on data from various media and industry sources. Jatropha information from a presentation by Prof. Mittelbach, University of Graz, detailing the so-called "Jatropha Belt" existing between the latitudes 30° north to 35° south.

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 fuel, 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.

Many companies are 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.

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.
- Some estimates indicate that biofuels will be commercially viable when they reach 1% of the total jet fuel supply.

Now that biofuels for aviation are a confirmed viable option and the certification process is underway, 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 mix of 10% biofuel and 90% Jet A-1).

So, when will the industry be able to reach that point? If the certification process goes well, it could be as early as 2015. Some parts of the industry are aiming 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 normal 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 be grown on wasteland and in areas where other crops would not survive. 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.

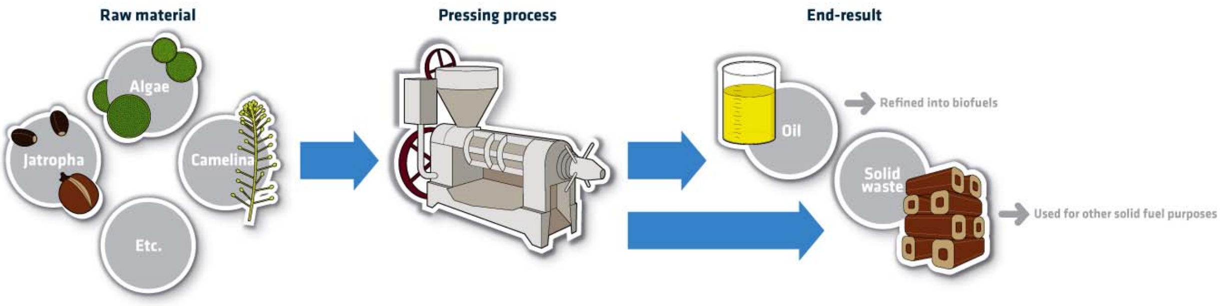
Land area equivalents required to produce enough fuel to completely supply the aviation industry[20]	
Algae	68,000 sq km
Ireland	70,280 sq km
Montana	380,000 sq km
World annual corn crop[21]	809,000 sq km
Camelina	2,000,000 sq km
Jatropha	2,700,000 sq km
Australia	7,617,930 sq km

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.

[20] Boeing analysis, based on: Total current aviation fuel usage of 1.6 billion bbls = 67 Billion gallons. Algae, average predicted yield 4,000 g/ac/yr (reasonable high-mid projection for commercial farms). Algae land area required = 67B / 4000 = 16.75 million acres = 68,000 sq km. Jatropha, average prediced yield 200 G/ac/yr (very conservative, low yields, marginal land). Jatropha land reqd = 67B / 100 = 670 million acres = 2.7 million sq km. Camelina, average predicted yield 135 G/ac/yr (reasonable based on current + agronomy/breeding improvements). Camelina land required = 67B / 135 = 500 million acres = 2 million sq km.

[21] Around 80 million acres of corn are grown in the USA each year, which represents around 40% of the world's corn crop: http://www.answers.com/topic/corn-oklahoma. About a third of the US corn crop is used to produce ethanol, a first-generation biofuel feedstock.

Processing
Once the crop has been harvested, oil needs to be extracted from its biomass. The feedstock is pressed, which produces oil and a leftover substance: the meal. In many cases this meal can also be used. The solid waste 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.



Refining the bio-oil
The bio-oil can then be refined into renewable jet fuel using conventional hydro-processing technology applied in petroleum refineries around the world today. The process first removes oxygen from the feedstock oil. The product is then further refined through isomerisation, a process by which one molecule is cracked open and re-arranged to form another shape of molecule, to meet the specifications needed for jet fuel.

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” to traditional fuel.

As the aviation industry and potential fuel suppliers go through the process of certification and 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, a blending may be undertaken at a biofuel refinery, a petroleum-fuel refinery, at a separate facility, or even at the airport fuel facility itself.

The next steps

Once testing has been undertaken, the aviation industry knows that biofuels can work and certification 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 right, 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; and
- ensuring that the industry is looking to governments to help with incentives for fuel suppliers to bring enough of the fuel to market.

With the testing process nearing completion and an accelerated certification programme underway, sustainable biofuels could be just a few years away from introduction to commercial 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 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 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.

The positive incentives required include:

- Assistance in identifying the most suitable areas in which to grow these crops.
- Support in starting the farming and production of algae – building of facilities, hiring labour resources, buying seeds and setting up any irrigation components.
- Incentives for companies to develop the processing and refining capacity needed to turn raw feedstock into biofuel crude oil and then into biojet fuel.
- Positive fiscal and legal frameworks to facilitate the economic viability of these new types of fuels so that airlines can use them as quickly as possible.

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. The industry is committed to sustainable biofuels use in commercial flights to become a reality by 2012 and a significant supply of biofuel in the jet fuel mix should be a reality before 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.

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 far 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 A-1 and, soon, biojet.

Biodiesel: diesel fuel produced from biomass. Not suitable for use in aviation.

Biofuel: fuel produced from renewable resources. First-generation biofuels: biofuels produced from biomass that competes with food production and fresh water use, and/or causes deforestation or reduced biodiversity. Examples include sugar cane, corn and wheat.

Second-generation biofuels: sustainable biomass that is not a food source and does not impact the food supply chain or fresh water resources, or cause deforestation. Examples include jatropha, camelina, halophytes and algae. Also known as next-generation or sustainable biofuels.

Biojet fuel: jet fuel produced from bio-derived resources.

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 with an equivalent amount sequestered 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 and absorbed again afterwards as new plants grow.

Carbon-neutral growth: where the same amount of carbon dioxide is emitted year on year. 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.

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 fuel sources that can be made by refining crude oil. It is also used for a variety of other purposes.

Greenhouse gases: emissions of gases such as carbon dioxide (CO_2), methane (CH_4) and oxides of nitrogen (NOx), arising from fossil fuel combustion and land-use change as a result of human activities. These gases trap the warmth generated from sunlight in the atmosphere rather than allowing them to escape back into space, replicating the effect glass has in a greenhouse.

Sustainability: the ability for resources to be used in such a way so as not to be depleted. 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.