The search for an alternative aviation fuel has moved from technical feasibility studies of candidate fuels, to one of establishing commercial and economic viability. Algae-produced biofuel now seems to be the leading contender. Programmes are in place to start producing it on an industrial scale.

The development of alternative fuels

Finding an alternative to fossil fuels continues to be important for the aviation industry. A number of methods, both currently operational and in development stages, address the need to reduce aviation's carbon footprint. One is to limit the carbon dioxide (CO2) emissions of aviation through carbon trading, which will be fully operational for aviation in Europe by 2012. Another is finding an acceptable alternative to fossil fuels, not just to reduce carbon emissions, but also for economic reasons.

Fuel consumption

According to Paul Nash, head of new energies at Airbus, the growth in air transport is likely to see aviation's fuel consumption double over the next 30 years. Air BP calculates that the current global demand for jet fuel is about 250 million tonnes, with Air BP accounting for about a tenth of this market.

The aviation industry has recovered from the last recession, with some older aircraft types being brought back into service. The 25- to 30-year service life of jetliners, and the new types' incremental improvements in fuel efficiency mean that the fuel consumption per passenger is improving slowly.

Fast growing rates of traffic mean that technological advances in the efficient use of fuel, and the fuel used, are needed.

According to the International Air Transport Association (IATA), air transport's annual fuel costs have risen by more than 380% in the 10 years since 2001, with a particularly steep rise in 2008 before prices fell in 2009. Aviation's global fuel bill was $43 billion in 2001 and is forecast to be $166 billion in 2011.

While political unrest in oil-producing areas has been one cause of this relentless rise, the main factor is continued global economic growth and demand for hydrocarbon fuels.

The improved fuel efficiency of some aircraft types has only partially offset higher fuel prices. In fact IATA's estimates for the industry's total fuel cost in 2008 and 2009 were 12% and 7% lower than the actual cost. "It is now unlikely that we will ever see a significant drop in fuel prices," says Ian Britchford, fuel saving manager at ETS Aviation Ltd. "This makes more efficient engines, airframes and methods of flying even more needed.

"Biofuels are being relied on to solve aviation's economic and environmental problems, but airlines must keep up the pressure on original equipment manufacturers (OEMs) to improve technology. While the A320neo promises fuel savings of up to 12%, a totally new platform could save 25%," continues Britchford. "Fuel has always been an important part of an airline's costs, accounting, on average, for nearly a third, and in some cases as much as 40%. It is difficult for airlines to quantify exactly how much they might be saving with their fuel-saving programmes."

Some methods are within an airline's control, such as flying at more fuel-efficient speeds and using better flight despatch methods. Others are dependent on aviation authorities, including air traffic management and airport arrival & departure flight paths *(see Proven techniques to reduce fuel burn, Aircraft Commerce, April/May 2010, page 21).*

GLOBAL COMMERCIAL AVIATION FUEL CONSUMPTION AND FLEET DEVELOPMENT

Year	1985	1995	2000	2005	2008	2009	2010E	2011F	2025F
Passenger numbers -million	896	1,304	1,672	2,022	2,293	2,277	2,439	2,570	4,500
Cargo tonnes - million	13.7	22.2	30.4	37.6	40.5	36.9	43.6	46.2	110
Airline & cargo revenue - $ billion			329	413	564	482	552	594	
Airline & freight expenses - $billion			318	409	573	486	524	575	
Global consumption of Jet fuel - billion US gallons	33.6	46.7/43.7		63.3		63.5			128
Global fuel expense - $billion		17.2	46	91	189	125	139	166	
Crude oil - $/barrel		29	28.8	54.5	99	62	79.4	96	
Active passenger & cargo aircraft (according to ACAS on 1st of January each year)	14,407	21,606	23,075	24,300	25,845	25,660	25,715	26,367	45,129*

Sources: Airbus & Boeing growth rates. IATA (2007 & 2011 data) and USDOT

* Aircraft Commerce estimate taking into account all sources

The 25- to 30-year life of commercial aircraft means the global fleet is replaced, by modern and more fuel-efficient types, in a slow and protracted process. The fuel consumed per available seat-mile can therefore only be expected to decline gradually.

Carbon trading

The largest system for counting and capping carbon emissions is the European Union's (EU) Emissions Trading Scheme (ETS). This has been operating for a number of years, and covers several industries. Aviation is expected to be fully compliant from 2012.

The ETS requires a company to record the CO2 emissions it emits over a given year through the amount, and type, of fuel it uses. The amount it produces in subsequent years is then capped, using certificates, which act as a CO2 emissions quota. Airlines can increase their quota by purchasing quota from companies that may not have used all their allocation. The aviation sector's cap for 2012 is 210 million tonnes of CO2, equal to 97% of its average annual emissions in 2004-2006. Of this amount, 85% will be shared out as free certificates among participating airlines, depending on their reported needs in 2010. The remaining 15% will be available to buy.

Other countries with carbon trading or cap-and-trade schemes include Switzerland; Australia, the introduction of whose scheme has been delayed until 2013; New Zealand, whose scheme began in 2008, with transport joining in 2010; and the US, where emissions trading has been in operation since 1990, with the aim of reducing sulphur dioxide.

Various US states have now developed their CO2 emission capping or trading schemes. In 2008 the US President said that he intended the US to enter a cap-and-trade scheme. With some analysts saying that only a global scheme can truly work, and California talking to the EU about collaborating, it is possible that the US will join the EU ETS.

Alternative emissions

An airline can reduce its CO2 emissions (and other emissions, such as NOx) without reducing the amount of fuel it uses, by using alternative fuels.

The EU's rules state that conventional jet fuel emits 3.15kg of CO2 per kg of fuel burned. Within the EU's ETS, the use of a biofuel means an emission factor of zero, so burning a kg of biofuel has a CO2 emission of zero kg, because growing the crop to produce the biofuel absorbs CO2 from the atmosphere prior to it being emitted when the fuel is burnt.

Operational practicalities necessitate mixing a biofuel with traditional kerosene-based fuels, but net emissions would still be lower than for kerosene.

A US initiative to reduce carbon emissions and encourage the use of renewable fuels (those with net or zero carbon emissions) is the National Renewable Fuel Standard (RFS).

Alternative fuels

Traditional aviation fuels have always been derived from fossil fuels: either petroleum or crude oil, which are in danger of running out and are considered serious polluters of the ozone layer. This is exacerbated by aviation, because aircraft release harmful greenhouse gases (GHG) at a higher altitude into the atmosphere. So, while aviation is only a small part of the CO2 issue, with only 2-4% of all CO2 emissions globally, the location of the released GHGs increases the attention it gets.

Any alternative to traditional aviation fuel has to comply with a number of specifications and physical properties that are also common to traditional fuels: flash point, freeze point, smoke point and energy content *(see The development of alternative fuels, Aircraft Commerce, page 31, April/May 2009)*. The two main fuel grades are Jet A in the US, and Jet A-1 in most other countries.

A third standard is authorised in GOST 10227 TS-1, which covers fuel used in the Commonwealth of Independent States. Other standards are available, for example in China, but these will all follow the same principles.

Jet B is wide-cut kerosene (a blend of gasoline and kerosene), which is almost solely used in very cold climates.

Any alternative fuel must also pass specifications for thermal stability, cold flow properties, and finally emissions.

The second important factor of any potential alternative fuel is cost. The finished product should cost no more per US Gallon (USG) than Jet A/A-1 and, ideally, be cheaper. This has been a real stumbling block for the commercial production of biofuels. For an alternative aviation fuel to be commercially viable, it must be produced in quantities, and at a price, that airlines can sensibly use.

Synthetic fuels are already approved for use on commercial aircraft and are produced in large quantities at competitive prices. However, they are not always sustainably produced, and their CO2 emissions remain high.

Biofuels rely on large and sustainable stocks of plant matter, which are currently being developed. Prices per USG of the finished product can therefore vary drastically, and cost more than traditional fuel. Airlines are simply unable to afford them, so they have to continue using traditional jet fuel.

These uncertainties raise questions. Are passengers more concerned about the cost of their flight than the size of its emissions? Will the extra CO2 certificates under the EU's ETS cost less than, the same as, or more than the price difference between traditional fuels and biofuels?

Finally, any alternative fuel must have the ability to be just 'dropped in', so that ground equipment will not have to be adapted, and no additional aircraft technology will be needed.

Ultimately the alternative fuel should be competitively priced, and perform as well as, or better than, traditional fossil-based jet fuels, with no changes to the effects on an engine's hot section and seals, as well as the fuel system generally.

Industry consumption of fuel in 2025 is forecast to be double the amount used by the industry in 2009. This compares with a predicted 76% increase in the fleet size over the same period.

Synthetic fossil fuels

Sasol in South Africa manufacture an alternative fuel that has been used commercially for a number of years. This is produced from coal using the Fischer Tropsch (FT) process, which is also used to develop fuel from gas and biomass.

Gasification of the original feedstock is followed by the FT process. This chemically breaks down a fossil fuel into liquid form that is suitable for use on aircraft. The finished product is known as coal-to-liquid (CTL), gas-to-liquid (GTL), or biomass-to-liquid (BTL) fuel. Collectively they are known as synthetic paraffinic Kerosene (SPK) fuels.

Using one fossil fuel to make another type of fuel is not ideal, because synthetic fuels still have high net CO2 emissions in their manufacturing process, and when they are burned. Even so, their fuel burn is cleaner (in terms of aromatics such as sulphur and nitrogen) and is 1-2% lower than that of crude-oil-based fuels. If carbon capture & storage (CCS) or carbon capture & recycle (CCR) can be used in their manufacture, their effect on the environment will be improved.

Biofuels

Biofuels are classified into three generations. The first generation is a biomass that is also a traditional food stuff, such as soybean or coconut. This is not a popular source of biomass: food is diverted from the food chain, thereby increasing prices; and the additional land needed to grow the necessary quantities could result in deforestation, soil depletion, and the overuse of water.

Moreover, even if agricultural land is sacrificed for fuel production, it will not be enough to solve the demand for fuel even in the US alone. IATA states that the global production of palm oil would only satisfy 43% of the US's jet fuel needs, with none left over for food. Global production of soya and rapeseed would only meet 34% and 18% of US demand.

All three oils on a global scale could only deal with 95% of the US's aviation fuel consumption. This gives an idea of the volumes that the industry needs.

Second generation

Second generation biofuels are derived from sustainable non-food sources such as waste biomass (cropstalks and sawdust), municipal waste and inedible plants. These are more popular than first generation biofuels because they do not, in theory, affect food production, but if their sources are not managed efficiently some could still displace food.

As many of these fuels have absorbed CO2 during their life, IATA believes the lifecycle GHG emissions could be at least 60% lower than traditional jet fuel. This figure is likely to rise as production techniques and efficiencies improve.

The three main sources of second generation biofuels are: Camelina, Jatropha and waste (both municipal and biomass).

Camelina is a rotation crop, which means it is farmed together with traditional crops. It has a short life span, and is typically harvested just 100 days after planting. On this basis, it could be farmed as a catch crop, grown quickly between two main crops. The seeds have an oil yield of 35-40%, and IATA says that one hectare produces 2,500-3,000kg of seeds. Oil yield would therefore be up to 1,200kg per hectare, although it could be higher with some new varieties.

The by-product of the seeds, when the oil has been extracted, has a high economic value as a farm animal feed. This additional income could provide convincing economics for farms to produce camelina oil. Sustainable Oils has partnered with Boeing and UOP to increase this fuel's commercial viability.

Jatropha grows in most soil types, but also on waste land or other ground unsuitable for agriculture. The seeds yield 30-40% oil, with one hectare of jatropha, according to 2009 data, yielding two tons of seed. Oil production is therefore about 800kg per hectare. After the seeds are crushed to produce the oil, the residue can be used as an agricultural fertiliser, which can give the producer additional income and an overall economic case for producing the crop. The oil is refined using various methods to produce a hydrotreated renewable jet (HRJ) fuel.

This plant could be grown by small farms in remote areas, and thus improve the economics of a region. IATA agrees that jatropha will probably be limited to small regional applications, since it is unlikely to replace large quantities of conventional jet fuel. A Yale University study on the environmental and socio-economic benefits of jatropha farming in South America, funded by Boeing, found that the fuel derived from produced 60% less GHGs than fossil fuels.

Biomass and waste are readily available, and are often removed at a cost to the producer. With landfills filling up, and costs for business waste removal rising, industrial-scale plants that use this waste to produce fuel and power are likely to be popular. The local population may not wish to have a biofuel plant on its doorstep, but it can be a useful addition in the supply of an increasing jet fuel demand. If these plants are run alongside CCR or CCS, then the GHG emissions, in the manufacture and use of these fuels, are reduced.

Boeing is also involved in a project in Abu Dhabi, with Etihad and the Masdar Institute, to confirm that saltwater plants are suitable for providing biofuels, and are a viable alternative to land-based and freshwater-reliant options.

Third generation

Third generation biofuels are derived from organisms such as algae, which

British Airways and Solena have formed a partnership to develop a facility to produce biofuel from organic waste. The fuel will emit 90% fewer greenhouse gases than kerosene. Enough fuel should be produced by the facility to power most or all of BA's operations from London City Airport.

consume CO_2, emit oxygen and grow well in dirty water. This can mean a completely carbon-neutral fuel when its full lifecycle is taken into account.

Algae is the favoured organism, due to its higher and more sustainable levels of oil yield. It can be grown in open systems, such as ponds, or closed systems, such as tubes or bags. Both methods, especially the latter, mean no conflict with food production, since large-scale agricultural production is not needed.

Airbus, British Airways, Cranfield University, Finnair, Gatwick Airport, IATA and Rolls Royce have all joined together as the Sustainable Use of Renewable Fuels (SURF) consortium to look at growing microalgae in near-shore ocean water facilities. Facilities can be out at sea as open systems, or in layers as closed systems on land to save space. The algae will still need CO_2 and light for photosynthetic growth to take place.

"Open ponds are cheaper to instigate, but annual yields are smaller, with 30 tonnes per hectare," says Peter van den Dorpel, chief executive officer at AlgaeLink. "Closed land-based systems, however, can produce up to 300 tonnes of dry weight algae biomass per hectare per year.

"With the current algae yield factors, global jet fuel needs could be supplied from a land mass the size of the Netherlands," continues van den Dorpel. "This is a big improvement on the yields of two to three years ago, when a land mass twice the size of the earth would have been needed to supply global jet fuel needs. At AlgaeLink, we use a closed photo bioreactor system that improves the yield by a factor of 50, and can also support diverse algae species."

Algae can be fed on carbon that comes directly from factories traditionally seen as polluters. This could have positive environmental and financial effects under schemes such as the EU's ETS.

The biomass left over after oil is extracted from algae, is becoming popular as a farm animal feed and in nutraceuticals. The algae oil can be refined into jet fuel in a number of ways, such as hydropressing.

Algae could be the miracle cure to the fuel problem, but a lot more work has to be done before it is commercially available. "An algae farm needs to be on land that is cheap, and located near a water source and transport infrastructure to keep transport costs down," says van den Dorpel. "Ideally it should be close to a CO_2 emitting facility so that CO_2 could be pumped into the open or closed systems. However, the air should not be too dirty, so coal stacks producing air that is high in sulphur are undesirable."

When built in conjunction with a CO_2 emitting facility, such as a power station, less CO_2 will released into the air overall, so the local community will benefit. So too does the bank balance of the GHG emitting facility through CCR, especially if it is in a carbon trading zone.

Programmes in operation

The aviation industry has many development programmes looking at alternative fuels. Many are now focusing on commercialising the process. "The sustainability and support of local communities is is important to Airbus," says Nash.

SkyNRG includes the Air France-KLM Group, North Sea Group and Spring Associates. It aims to create and accelerate the development of a market for sustainable jet fuels. Iberia has joined the Spanish Government and Airbus to look at how an alternative fuel can be produced on a commercial scale for the Spanish aviation industry.

In 2009 and 2010, UOP was involved in the production of 190,000 gallons of alternative fuel for the US Navy, and 400,000 gallons for the US Air Force as part of a military certification process. It is also in development agreements with a number of engine and airframe manufacturers (e.g., Boeing), airlines (e.g., Etihad), and oil companies, using a number of different feedstocks.

Rentech is uniquely positioned as a company with a commercially viable jet fuel in operation. It has agreed to supply a number of US passenger and cargo operators with over 16,000 barrels per day of its synthetic fuel, RenJet. As well as GTL fuels, Rentech produces fuel from biomass, and a renewable diesel that is used by some ground service equipment at Los Angeles International Airport.

Second generation biofuels

Nash says that Airbus is keen on involvement in Brazil, where a lot of jatropha is grown in the wild, and South America generally, due to its indigenous jatropha production. Airbus has linked up with TAM in Brazil and InterJet in Mexico to show the commercial viability of the fuel. It is talking to governments, airports, operators and farmers about the benefits of growing, producing and using jatropha and its associated jet fuel. Airbus wants to encourage local jobs for local products. For example at Rio Airport, a refinery is only 5km away, so that transport and logistics are minimised, through Air BP's assistance. "This is an implementation project, not a feasibility study," says Nash. "Annual production of 80,000 tonnes is expected from 2013, representing 25% of TAM's jet fuel demand, although production will increase year-on-year as experience and the amount of feedstock grow."

The Brazilian Alliance for Aviation Biofuels was formed in March 2010 to promote alternative aviation fuels in the area, and to harness the potential of jatropha, although other feedstock is being looked at.

The US Department of Agriculture (USDA) is working with Boeing and the

Solena is partnering with Qantas to investigate the possibility of producing biofuel in a similar programme that will operate between Solena and BA.

Air Transport Association (ATA) to develop sustainable biofuel feedstock, through rural development and promotion of these crops.

Airbus is working with Iberia on further developing the use of camelina. "We are working to keep it sustainable and beneficial to the local community," says Nash. "We are also working near Bucharest, Romania, where there is both mass agricultural experience and a good history of refining technology. This is a good central location with a number of airports relatively nearby that can utilise the fuel, when production rates exceed those required by airline partner Tarom. One of the AltAir facilities in the US will use camelina oil, with capacity expected to be about 100 million gallons per year."

Many oil companies are also at the forefront of development and production. Air BP, for example, is involved in the TAM and Airbus project, looking at the operations and logistics side of the venture.

In 2009 British Airways formed a partnership with Solena and London City Council to develop a plant that will produce biofuel, energy and heat. The London plant will be centrally located to use much of the organic waste that would otherwise go to landfill. This will be thermally converted into a renewable biosynthetic gas, 500,000 tonnes of which should be produced each year. The FT process will be used to make 1,170 barrels per day of biojet fuel.

Additional products include green energy, bionaphtha and heat that could be used in a district heating system. The resultant fuel burn will contain 90% less GHG emissions when the whole carbon lifecycle is taken into account, and will release fewer aromatics and no sulphur. The facility should be fully operational from 2014, with British Airways using the resultant fuel to power most, if not all, of its London City Airport operations. Solena is also partnering Qantas to look at the feasibility of doing something similar in Australia. Qantas says it used 4.6 billion litres of jet fuel at a cost of $3.3 billion during 2009/2010, so access to a large supply of biofuel would significantly reduce its emissions.

Third generation biofuels

The Qatari government and Qatar Airlines are already heavily involved in the mass production of natural gas-derived jet fuel. However, with the supply of natural gas running out, land has been bought in Qatar to build a facility that will produce jet fuel from algae to enable the Qataris to build on their position in the fuel market and be ready for the next option. The Qatar Advanced Biofuel Platform (QAPB) consortium aims to develop the world's first large-scale, algae-derived, bio-jet-fuel value chain.

"Two years ago an algae farm needed 2.5 million Euros in investment per hectare. Now it is 250,000 Euros," says van den Dorpel. "This is due to optimised systems, lower operating costs and higher crop yields. We are working on developing ways to reach a price of $150 per barrel ($3.6 per USG) of algae jet fuel. This competitive meeting point with fossil fuel should be reached in about a year. Hundreds of facilities are starting to scale up production with this in mind."

Overview

While CTL fuels are commercially available and GTL fuels are very close to being commercially available in large quantities, BTL is still struggling with quantity. Until the supply increases and the cost of production comes down, this is not likely to improve biofuel's chances as an alternative fuel. At the end of 2010, IATA estimated that BTL fuels could cost $1.20-1.40 per litre ($5.40-6.30 per USG), which at the time was double the cost of conventional jet fuel. Yields should increase as production procedures improve so the cost of BTL fuel will go down. The IEA suggests, having looked at historical data, that for every doubling in capacity, a facility can expect its costs to be reduced by 10-20% per unit of production. These reductions in the cost of biofuel, along with increases in fossil fuel prices, mean parity could be reached within a few years. This should, in theory, put no hurdles in the way of biofuels replacing fossil fuels, provided approval is fully gained for 100% use, and supply keeps up with demand.

"Supply can be improved by mixing fuels, since you can have different plant stock depending on your location," says Nash. "Many plant-based biofuels could be commercially viable in just a few years, but algae can be added to this mix in about 10 years".

"Algae will not be the complete answer to the problem, because multiple sources will be needed depending on a location's needs and production capacity," says van den Dorpel.

The IEA, contrary to many aviation stakeholders, does not seem quite as positive about the immediate future of biofuels. It calculates that in 2050 the biofuel supply market will only be providing 200 billion litres (44 billion USG) of jet fuel, representing just 30% of global commercial airline needs.

Alternative fuels will not currently, or in the near future, solve the financial issue, but they will help environmentally. If they are to help airlines financially in the long term, this will require some impressive yields and production methods to drive down the cost. If alternative carbon neutral fuels become easily accessible and increasingly cheaper, they will have a dramatic effect on global fuel consumption. AC