Projected fleet growth means the industry's jet fuel consumption will probably double by 2027. A variety of alternative fuels which have overall lower CO2 life cycle emissions are being studied, and several biofuels have emerged as likely replacements for petroleum-based fuels.

The development of alternative fuels

The International Air Transport Authority (IATA) says that while current generation aircraft are 70% more fuel-efficient than they were 40 years ago, and 20% more than 10 years ago, airlines are aiming to further improve fuel efficiency by 25% by 2020.

New designs in airframe and engine technology can reduce fuel consumption. The new Boeing 787 has been designed to emit 15% less carbon dioxide (CO2) than current aircraft, but the 787 and other environmentally friendly aircraft will not enter service until 2010 at the earliest.

Engine designs can also reduce CO2 emissions. Pratt and Whitney has introduced an engine that uses an internal gearbox connected to the fan. This has the effect of reducing fuel consumption and therefore the CO2 emissions by 12-15% compared to alternative engines.

IATA states that for every kilogram (kg) of fuel saved, the amount of CO2 released into the atmosphere is also reduced by 3.16kg (6.97lbs).

The number of passenger and freight aircraft in active service has nearly doubled in the last 20 years. This rate is unlikely to slow down over the next 20 years according to aircraft manufacturers' forecasts. At the same time, the steady rise in fuel costs in recent years, increasing CO2 emissions from a growing airliner fleet and the industry's commitment to reducing global carbon emissions has stimulated the need to develop alternative fuels.

CO2 emissions

The industry has steadily grown, and data show that the number of passengers, the size of the aircraft fleet and the amount of fuel consumed approximately doubled from 1985 to 2005 *(see table, this page)*. Forecasts are that if the industry continues to grow unhindered, its fuel consumption will rise from the current level of 68 billion USG to 136 billion USG in 2027.

The environmental argument for reducing fuel consumption relates to the carbon emissions from jet fuel, which originates from a non-renewable source. The major emission is CO2, but nitrogen oxides (NOx) are also a problem.

The United Nations (UN) believes that current global CO2 emissions from all sources total 23 million metric tons. Half of the CO2 emissions are absorbed by oceans and land vegetation, but the remainder cause a rise in levels of atmospheric CO2 by 10% every 20 years. The UN's data from 1995 put the CO2 emitted by developed countries at 82% of all greenhouse emissions. Its data also show that 96% of these CO2 emissions from developed countries came from fuel combustion: 78% of all global CO2 emissions. Transport accounts for 22% of global CO2 emissions but is growing at a rate of 2.5% each year.

By 2004 the Intergovernmental Panel on Climate Change (IPCC) had found that transport produced 13% of global greenhouse gases (GHG). The IPCC also stated that aviation alone accounts for 2% of total global CO2 emissions, compared to road transport, which produces over five times as much.

The first step in reducing CO2 emissions has been accepted as working towards carbon-neutral growth, while alternative fuels are researched. This is assisted by an airline's operational procedures, air traffic control, as well as new engine and airframe design that reduces the amount of fuel consumed.

Most of the world's governments have collectively agreed on the Kyoto Protocol to reduce harmful emissions produced through various means, and also to introduce international emissions trading.

Carbon trading

Signatories to the Kyoto Protocol committed to reducing emissions over a specified period of time. Countries are allowed under Annex 17 to trade with other countries any excess emission units that they have not used in a certain period. CO2 is the most commonly traded emission. The European Union Emissions Trading System (ETS) is the largest trading scheme between countries.

Aviation has not escaped the emissions regulations, and airlines will need to submit their CO2 emissions yearly from 2010 covering very flight they have flown. There will be an agreed cap on emissions and anything in excess will have to be paid for with emissions

GLOBAL FLEET DEVELOPMENT & FUEL CONSUMPTION

Year	1985	1995	2005	2009F	2025F	2027F
Passenger numbers -million	896	1,304	2,022	2,118	4,500*	4,952*
Cargo tons -million	13.7	22.2	37.6	34.6	110	
Active passenger & cargo aircraft**	14,631	22,176	24,494	26,173	46,050*	47,900*
Fuel consumption-USG billion	33.6	46.7	63.3	63.5	128.2*	136.2*
Crude oil - $/barrel		17.2	54.5	50		
Fuel expense - $million		29	91	116		

Source: 2007 IATA Data & ICAO (E-estimate, F-forecast)
*** Aircraft Commerce estimate using Airbus & Boeing growth rates**
**** ACAS data**

TRADITIONAL AND ALTERNATIVE FUEL SPECIFICATIONS

	Jet A/A1	Jet B	FT/Synthetic Fuel such as Sasol	Liquid Hydrogen	Liquid Methane	Biodiesel (typical)	Jatropha
Specific energy content -MJ/kg	43.2	42.8+	44.2	120	50	36-39	43.5
Relative density at 15degC -g/ml	0.808		0.759	0.071	0.424	0.87-0.89	
Energy Density -MJ/L	34.9		33.6	8.4	21.2	33.9	
Freezing point -degC	-40/-47	-51				~ 0	-69
Flash point -degC	40-45		46 min			100	
Boiling point -degC	150-300	270	158	-253	-162		

allowances. The previous year's emissions can be paid for either by using allowances that airlines have bought, or by covering excess emissions with extra allowances bought at auction - carbon trading. This is expected to have a very small negative effect on growth in the European aviation industry. The cap for 2012 currently stands at 97% of an airline's 2004-2006 average CO2 emissions, decreasing to 95% for 2013 and onwards.

All airlines that fly into the European Union will be affected by the new laws, including all foreign carriers.

Many of Europe's national carriers have proposed an alternative to the ETS. It is essentially the same, except that it would use the amount of fuel consumed, rather than the emissions. This might placate those critics of the ETS, who say that it will not necessarily encourage innovation and the use of biofuels in the aviation industry to reduce fuel consumption and CO2 emissions.

Governments will meet later this year to further discuss this subject with a view to replacing the Kyoto Protocol, which expires in 2012.

Traditional jet fuels

The majority of traditional aviation fuel or kerosene is manufactured from petroleum or crude oil. Jet fuel has to meet strict specifications for smoke and freeze points, as well as energy content.

Aviation turbine fuels are not to be confused with Avgas, a high-octane aviation fuel used to power many general aviation aircraft and racing cars. Outside former communist areas, two main grades of turbine fuel are currently used in civil commercial aviation: Jet A-1 and Jet A, which are both kerosene-type fuels. Another grade of jet fuel, Jet B, is a wide-cut kerosene (a blend of gasoline and kerosene) rarely used except in very cold climates.

Jet A-1 is a kerosene grade of fuel suitable for most turbine-engined aircraft. It is produced to stringent internationally agreed standards, has a flash point above 38°C (100°F) and a freeze point maximum of -47°C. It is widely available outside the US.

Jet A is a similar kerosene type of fuel, produced to an ASTM specification and normally only available in the US. It has the same flash point as Jet A-1, but a higher freeze point maximum (-40°C).

Fuel approval process

There are three main international standards authorities for commercial jet fuel. These have similar requirements and work with engine and airframe manufacturers on the fuel specifications of an aircraft's initial certification. Through experience and testing, these authorities know what is required from a jet fuel, so their assumptions and requirements have to be met by possible alternative fuels.

The first standard is the UK MOD Defence Standard 91-91 Jet A-1, which is followed by most of the world, according to Chevron Aviation. The second standard is ASTM D1655 Jet A/Jet A-1. The third standard, GOST 10227 TS-1, covers fuel used in the Russian Federation and the rest of the Commonwealth of Independent States (CIS). There are other standards, including one in China, but they are much smaller and will follow on from the main three.

A manufacturer of an alternative fuel would need to have its product approved by one of these authorities. Sasol of South Africa's synthetic fuel is the only alternative fuel to be approved to date.

There are demands by the industry for a generic process for the approval of synthetic fuels to be authorised, rather than just the one produced by Sasol. This would save every manufacturer having to gain approval, and would make a generic synthetic fuel available in much the same way as standard traditional fuels.

Any alternative fuel must pass the same tests and meet certain specifications in order to be approved. The fuel must be compatible with the aircraft's fuel system, and the engine's hot section and seals. Cold flow properties, thermal stability, emissions and performance must all meet certain guidelines. It must perform as well as a kerosene fuel, with as many further advantages as possible. "Boeing's goal," says Terrance Scott, environmental communications at Boeing, "is to accelerate the development, certification and acceptance of these sustainable biofuels for aviation use. Working with academia, environmental groups, leaders in fuel processing and feedstock growers, we are hopeful this advanced generation of fuels will be available for commercial use in the next 3-5 years or sooner."

The test programme involves many levels resulting in an engine test that is reported to the engine manufacturer, which then reviews the data and puts its views forward. If the standards authority is happy and no further data are required, then the fuel is considered for approval.

Alternative fuels

Most forms of transport have been looking at ways to reduce their costs and CO2 emissions. This has led to research for alternative fuels and energy sources, in particular those that give as many physical benefits as current fuels and with lower CO2 emissions. To release energy a fuel needs to react rapidly with oxygen at a high temperature to produce combustion.

The many forms of alternative fuel have yet to be fully researched. All need to meet several physical criteria so that they are of practical use to the global air transport industry.

The energy produced by the fuel needs to be viable compared to the current fuels (a minimum of 42.8MJ/kg is required according to IATA), and so not reduce aircraft performance. Alternative fuels must not form deposits in the high temperature section of the engine (by absorbing excess heat poorly), or require any engine to undergo modifications. They must also function in the conditions specific to aviation fuel, so they must not freeze at low temperatures, for example.

Global availability and transportation is another consideration, since an alternative fuel must be stable enough to be transported to airports via pipelines, ships or trucks from the point of manufacture. The fuels also need to be easily stored both at their inception and at the airports where they will be used, while their volume needs to be similar to or smaller than that of traditional aviation fuels.

IATA groups aviation fuels, both current and alternative ones, into three categories: traditional jet fuels, synthetic fuels and biofuels.

Fischer Tropsch fuel

The Fischer Tropsch (FT) process breaks down raw materials at high temperatures to then chemically rebuild the molecules into hydrocarbons, which are further developed into aviation fuel. The process can turn almost any source of carbon, such as coal or gas, into jet fuel via several levels of processing and

Jatropha is one plant that can be used to extract oils for production of a jet biofuel. The plant has the benefits of being able to grow in poor soils and dry regions, and thus not compete with current agriculture for production of food for human consumption.

distilling. These are classed as synthetic fuels.

The FT process produces a fuel that is virtually free of aromatics such as sulphur and nitrogen compounds. This produces a cleaner burn, which benefits local air quality, according to Dr Rainer von Wrede, head of environment engineering and R&T at Airbus. "There is a 1-2% fuel burn reduction when using FT synthetic fuels, which can be made from any hydrocarbon source," he adds. Even though FT fuels emit up to twice the amount of CO_2 during the manufacturing and burning process than fuels derived from crude oil, this CO_2 can be collected and stored (CCS), rather than released into the air. This would make FT synthetic fuels a cleaner alternative in both manufacturing and in combustion and, in theory, cut out all CO_2 emissions. Storing CO_2 emitted in processing is a new idea, however, and needs further development. Although FT synthetic fuel is clean burning, its energy density is below the requirements for aviation fuel. This is overcome by mixing FT fuel with traditional fuel or additives, which reduces the environmental benefits.

The FT method of producing synthetic fuels has been adapted in different ways by companies including Sasol and Syntroleum, who treat it as a proprietary process.

Sasol has already produced a 100% synthetic fuel that has been approved by the two major specification bodies for use as JetA-1 fuel for commercial use in all types of turbine aircraft. After 10 years of producing part synthetic, part JetA-1 fuel for airlines flying out of Tambo International Airport, Johannesburg, Sasol now has international approval for a totally synthetic fuel. The ideal solution would be to use CCS alongside a biomass source for the synthetic fuel.

Biofuels

Biofuels are derived from dead biological material, like plants, animals and their by-products (manure, garden waste and agricultural crop remnants). Fossil fuels are derived from long-dead biological materials, such as oil and coal.

Biofuels still produce sulphur dioxide (SO_2), CO_2 and NO_x during combustion for energy. The emissions are generally less than those produced by burning fossil fuels, however. Moreover, the plants from which biofuels are derived absorb CO_2 from the atmosphere as they grow, so biofuels produce less net CO_2 in their life cycle than fossil fuels. This makes them more desirable than FT fuels.

There are many other methods to transform biomass into an aviation fuel, including chemical reactions such as hydrotreating and low-temperature hydro-cracking, which involve plant oil to biofuel. These are favoured by Boeing, which also favours the development of enzymatic/microbial conversion. This involves a cellulose-to-biofuel process, which can turn almost any biomass into a molecular structure similar to jet fuel, but takes less energy than manufacturing traditional jet fuel. "The fuel-processing technology to make these fuels exists today," says Scott. "What is needed are sustainable growing systems that provide socio-economic value to the communities where they are grown, and to ensure there is an adequate supply of biomass from which to make a meaningful impact on the aviation fuel supply."

Biofuel can be solid (such as wood or straw) or liquid. Aviation clearly needs a fuel that is in a liquid state, both for use in the aircraft and for transportation. Liquid biofuels are sub-divided into first-, second- and third-generation biofuels.

First-generation biofuels

First-generation biofuels are made from traditional foodstuffs, turned into fuel using conventional technology. These fuels have found a strong market in the automotive industry, but have limited use in the aviation industry, because many fail to meet all aviation fuel specifications.

Food materials that could be used are seeds or grains that are fermented to produce bioethanol. Ethanol is the most common biofuel worldwide, but its numerous chemical and physical differences compared to jet fuel, not to mention its corrosive effect on fuel systems and combustion chambers, make it unpopular as an aviation fuel.

Biodiesel can be made from the oils of many different crops including soybean, rapeseed, coconut and palm, but it is not thermally stable.

Many believe that the biggest problem with first-generation biofuels is the very ingredient that makes it - food. Removing this from the food chain causes prices to rise, while deforestation, overuse of water and soil depletion, among other possible negative environmental consequences, may result from the additional agriculture needed to produce the fuels.

Second-generation biofuels

These biofuels are made from sustainable non-food sources such as waste biomass (crop stalks and sawdust), municipal waste and inedible plants. These materials are more popular, since they do not divert food away from the animal or human food chain, and in many cases utilise a waste product.

IATA believes that second-generation biofuels possess no technical production hurdles, and their lifecycle greenhouse gas emissions are 60% lower than those of traditional jet fuel emissions. This figure could even rise as techniques and production efficiencies improve.

Popular inedible plants for making biofuels include jatropha, halophytes, switchgrass, babassu and camelina. These apparently contribute neither to deforestation, nor displace food production on land being used for agriculture.

Jatropha grows in most soil types, including arid areas and wasteland. Halophytes like salty ground, where few other plant types tend to grow. Switchgrass grows with very little water, but produces a large amount of material. Babassu is a tree native to Brazil, whose nut has a high oil yield. Camelina is an energy crop, traditionally grown in rotation with cereal crops.

Amanda Pinto, director, business development for Terasol Energy, Inc., says that: "Jatropha could be used as a drop-in fuel and is indistinguishable from, and sometimes performs better than, traditional fuel. One acre of jatropha could produce two tons of seed, which in turn can produce 0.8 tons of oil. The process involves crushing the seeds to extract the oil. The seeds will yield 30-40% oil with the residue being used as a fertiliser." The oil is refined using de-oxygenation and selective hydrocracking techniques to produce jet fuel.

Scientists are working on genetically modifying the DNA of some plants to increase the biofuel potential. It is also possible to combine the different raw materials to produce a biofuel with the positive properties of each ingredient. "There is no single answer to the issue," says Pinto, "but a combination of many different options, with jatropha being just one."

Third-generation biofuels

Third-generation biofuels are made from algae which, like many other biofuels, are relatively harmless to the environment if accidentally spilled because they are biodegradable. The algae can be cultivated in salt or even polluted waters, and produce a high yield for a low input. Algae can produce 30 times more energy and 250 times more oil per acre than crops such as soybeans.

It is estimated that to produce enough algae fuel to meet current global jet fuel requirements, 27,000 square miles (17.3 million acres) of algae farming would be needed. To put this in perspective, the US agriculture industry alone uses about 940 million acres. The amount of land needed for biofuel production is therefore small compared to that used globally for food production.

The US Department of Energy estimates that if algae fuel replaced all the Jet A fuel used in the US, it would require 15,000 square miles (9.6 million acres).

"There are many types of algae and it is a case of finding the right one that produces a lot of oil with little water, and has molecules similar to traditional jet fuel," says von Wrede. "Algae can be farmed by small suppliers or on a large scale without as many of the transport issues of larger biomass materials." The major advantage of algae is that it does not necessarily need the cleanest of water or air to grow in, so large expanses of it can be grown using contaminated water from other industries, thereby finding a use for waste products and producing an environmentally friendly fuel.

Commercial developments

For over 20 years many of the big manufacturers of aviation fuel, engines and airframes have been researching the various alternative fuel options. This has now culminated with them working together to test various developments.

However successful alternatives are in the development stage, they need to be successful commercially. Linda Gallaher, manager, product quality and fuels technology aviation at Chevron Global Aviation, comments: "A big focus is on finding the combinations of feedstocks and conversion technologies that are compatible with the existing infrastructure for refining, transporting and marketing transportation fuels."

In early 2008, following the certification of a 100% coal-to-liquid

(CTL) fuel, Airbus tested one engine of an A380 with an FT gas-to-liquid (GTL) fuel. The mix was 40% GTL and 60% traditional kerosene. The GTL fuel was supplied by Shell from its new plant in Qatar. All involved feel that it could be a precursor to biofuels, until they are produced in large enough quantities.

The hope is that suitable quantities of GTL fuel will be available in locations such as Qatar. In fact Qatar Airways hopes to fuel most, if not all, of its fleet with local GTL FT fuel. Airbus believes that the GTL fuel will have a similar CO2 life cycle to traditional jet fuel, which is an improvement on CTL. von Wrede comments that: "Certification of a 50/50 GTL mix with kerosene should be expected in 2010 with certification of 100% GTL aimed at 2013." The data from this test flight are not yet fully available, but the outlook is good. von Wrede says that Airbus expects 25% of aviation fuel to be an alternative type by 2025, and 30% by 2030.

Also in early 2008, a 747-400 Virgin Atlantic aircraft was flown with one GE engine running on a 80% traditional fuel and 20% biofuel, the latter manufactured from babassu and coconut oil. This joint venture (JV) was the first biomass fuel flight, so while the ingredients were not ideal (coconut oil being a food), it showed what was possible.

Boeing's next JV was with Air New Zealand, Rolls Royce and UOP (a Honeywell company). A 747-400 was again flown with a second-generation biofuel mix, consisting of 50% jatropha and 50% jet fuel, used to power one engine. The test at the end of 2008 was a success. UOP had produced the fuel using jatropha oil sourced by Terasol Energy, which Pinto says was responsible for sourcing the oil: "We ensured that it was produced in a sustainable manner, with no communities displaced or land diverted from food production. Although jatropha oil can be used for automotive diesel engines, it needs further work before it can be used for aviation fuel."

While the flight was a success, Pinto says that it will be 5-6 years before jatropha is developed enough to be used as a widespread drop-in aviation fuel. A lot more research is required into this and other second-generation biofuels, before they are serious contenders.

January 2009 saw another JV flight, but this time it was the first to use a narrowbody jet. A Continental Airlines' 737-800 flew with one engine powered by a 50:50 mix of jet fuel and biofuel, which was a mix of second- and third-generation biomass: jatropha and algae.

At the same time Japan Airlines ran a 747-300 with one engine testing a 50:50 mix of jet fuel and a biofuel made of camelina, jatropha and algae. "Relative to our four test flights conducted over the past year," says Scott, "all the fuels meet or exceed the ASTM fuel specification standards for energy density, freezing point, and material compatibility."

With many aviation fuel alternatives now being researched and developed by various parties, it is difficult to see which will win. Algae would be ideal, but needs more development. Gallaher says that Chevron believes that: "Biofuels will play a growing role in meeting the world's energy demand, including that for aviation fuels. Ultimately, the consumer will determine the specific roles and market shares of these fuels, taking into account cost, quality, availability and environmental impact". Scott adds that: "The aviation sector is much closer to making these new generations of alternative fuels available than many would be led to believe. Tremendous strides have been made over the past 2-3 years as the industry moves closer to a renewable fuel supply that can lessen dependency on petroleum fuels." AC