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# SUSTAINABLE PROPULSION FACT SHEET

## Helping aviation achieve its green potential

## Introduction

Earth's fossil fuels are quickly becoming depleted. No one knows exactly when, but the fact is that eventually they will run out – perhaps even in this century. The aviation industry is highly dependent on these fuels, and is diligently searching for methods to become more sustainable. Instead of kerosene as jet fuel, a variety of scientists and organisations are developing and testing revolutionary methods for future use by aircraft. Many methods are potentially suitable candidates, however some possess characteristics which make their large scale application questionable. This fact sheet focuses on biofuels, electricity and hydrogen as alternatives to kerosene. In a related issue, the combustion of kerosene has a large environmental impact. Aircraft engines could be made more economical, reducing harmful emissions and lowering fuel consumption. This factsheet therefore aims to provide readers with information about recent developments in aviation, as the stakeholders involved move to ensure greater environmental consideration. There is a Dutch summary at the end of this fact sheet.

# Optimising engines

Today's high-bypass turbofan engines are efficient, but slight improvementscould be made at a component level, which would create better fuel efficiency and reduce emissions.

### Combustors

There have been many advances in the area of aircraft engine combustors. The main target of these improvements has been to reduce (mono-)nitrogen oxides ($NO_x$) emissions. This compensates forthe main disadvantage of high combustion temperature, which increases engine efficiency, but also increases the formation of $NO_x$. To meet the temperature value of 1800 Kelvin in the turbine entrance, ceramic matrix composites (CMCs)[1,3] are expected to be used in the near future. Although modern combustor designs are already efficient and have a very low pressure drop, combustor liners made out of CMC could reduce $NO_x$ by 20% because of their high temperature capability and absence of film cooling compared to metallic liners. Most of the major engine manufacturers are developing advanced combustors that will be available between 2015-2020.[2] Some of the new combustors include the General Electrics (GE) Twin Annular Premixing Swirler (TAPS) combustor and the Pratt & Whitney (P&W) Talon X combustor. The Talon X lean-burn combustor is a refined third-generation combustor. Like previous Talon combustors, it features a short axial length and simpler fuel nozzles. It should reduce $NO_x$ emission dramatically with its rich burn-quench lean approach.

### eCore

The eCore initiative was announced in 2008 by GE as a response to the P&W Geared Turbofan. This program will build on the LEAP56 (Leading Edge Aviation Propulsion) program and GEnx technology to achieve a 15-20% reduction in fuel burn and up to a 50-60% reduction in $NO_x$ emissions. In order to realise this, several new features have been implemented, such as ultra-high bypass ratios of 15:1 to 20:1, an eight-stage high-pressure compressor and ceramic-matrix composite high-pressure turbine blades. GE predicts that by 2020, a full open-rotor engine fitted with eCore could be available. Aside from increasing the compression ratio of the engine core, other research is being carried out as well. There are four main examples of progress in aeronautical engine core technology:

- Intercooled recuperative aero engines- these use heat exchanger modules in the main exhaust to extract thermal energy and transfer it back into the combustion chamber, which results in fuel savingsof up to 17%.
- Active core engines – these adapt the core to each phase of the mission, using thermal and mechanical active turbine tip clearance and active surge control with air injection in the compression stages, whichimproves efficiency.

- Flow-controlled engines – these provide flow stability control, which increases efficiency by 2.5%.
- Intercooled engines – air exiting the low pressure compressor is cooled before entering the high pressure compressor using bypass air scooped into a set of heat exchangers, which reduces core size and $NO_x$ emissions

**Geared turbofan**

The geared turbofan, previously known as the Advanced Technology Fan Integrator, is a next-generation high bypass-ratio turbofan engine under development by P&W. The unique feature of this concept is an epicyclical gearing system in the shaft, connecting the fan and the low-pressure compressor and turbine stages. With 18 fan blades, the geared turbofan has fewer and lighter parts, which will reduce fuel burn by 12%. Mitsubishi Heavy Industry has already selected geared turbofansas the power plant for its new 70- and 90-seater Mitsubishi Regional Jet (MRJ). Bombardier selected geared turbofan as the exclusive propulsion system for its C series, which entered service in 2013. By 2020, P&W is planning to improve the fuel burn of geared turbofans even further by 5-7%.

## Aviation Biofuels

**What are biofuels?**

Biofuels, also known as agrofuels, are fuels produced from renewable resources such as plant biomass, vegetable oils or treated municipal and industry wastes. Biofuel can be used for many purposes. However, they are mainly used today in the transportation sector. Vehicle engines require fuels that are not contaminated (with water, particulate or microbial growth), are in liquid form and are dense in order to make storage easier. Biofuels are a great way to reduce additional emissions of greenhouse gases – fossil fuels release carbon dioxide ($CO_2$)[5] into the air, whereas biofuels can recycle itand use it for growth. In addition, they can be seen as an alternative for fossil fuels that are limited in availability, and will eventually run out. Today, the use of biofuels has expanded throughout the globe, and on the continuously-expanding aviation sector.

**Aviation Biofuel**

The aviation industry’s share of greenhouse gas emissions is expected to grow as air travel increases and ground vehicles increasingly use alternative fuels such as ethanol and biodiesel. In 2012, air transport produced 689 million tonnes of $CO_2$, around two percent of global $CO_2$ emissions. This is expected to reach up to three percent by 2050. In addition to building more fuel efficient aircraft and operating them more efficiently, changing the fuel source is one of the few options the aviation industry has left for reducing its carbon footprint. While solar, electric and hydrogen propelled aircraft are also being researched, it is not expected they will be feasible in the near future due to aviation's need for a high power-to-weight ratio and globally compatible infrastructure.

Not all types of biofuels are suitable for use in the aviation industry. Fuels such as methanol and ethanol are not appropriate because they have low energy densities. Planes would either be severely limited in their range or would not be able to take off due to the weight of the fuel they would need to carry. Aviation fuel has an energy density which is roughly the same as gasoline, so biofuels have to match this performance. The production of aviation fuel focuses on providing high power outputs and stable performance during all phases of flight. In addition, aviation fuel must have a low risk of explosions and must not freeze when the aircraft is cruising at altitudes at which the temperature can be as low as minus 50 degrees Celsius. Preventing contamination of fuel by water is also of high importance. Water in aviation fuel can freeze and cause the fuel lines to become obstructed. Therefore alcohols, which tend to attract water, are not useful as aviation fuels. However, alcohols can be converted to kerosene, which is the main component in aviation fuel.

**Realised biofuel flights**

The very first example of an aircraft flying on biofuel occurred when an unmodified Czechoslovakian jet (a 1968 L-29 dubbed BioJet 1, see **Figure 1**), took off from Reno Stead airport (Texas, USA) on 2 October 2007 and flew up to 5180 meters over 37 minutes, burning nothing but cooking oil. A three minute, 15 second test the day before was the world's first flight fuelledentirely by cooking oil. The Green Flight team responsible for this feat used fresh canola oil refined into biodiesel as fuel.

Other test flights followed between 2008 and 2011[6], with a large variety of aircraft and fuel mixtures. Since 2011, when the aviation industry was given approval to use biofuels in passenger flights, more than 1600 flights have flown on biofuels. The world's first commercial biofuel flight was a Boeing 737-800 from KLM (Royal Dutch Airlines), carrying 171 passengers from Amsterdam to Paris in June 2011.

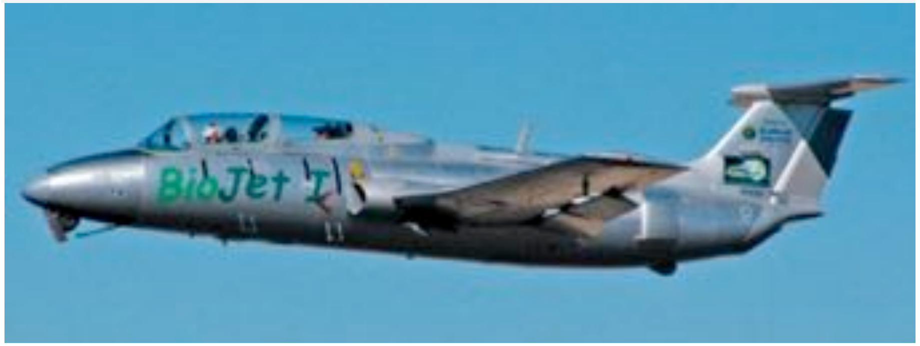


*Figure 1. The Biojet 1 on its biofuel flight on 2 October 2007*

**Why aviation biofuel?**

The International Air Transport Association (IATA) member airlines and the wider aviation industry are collectively committed to reducing emissions. IATA recognized the need to address global climate change and adopted a set of ambitious targets to mitigate $CO_2$ emissions from air transport. These targets aim for an average fuel efficiency improvement of 1.5% per year from 2009 to 2020, a cap on net aviation $CO_2$ emissions from 2020 (carbon-neutral growth) and a reduction in net aviation $CO_2$ emissions of 50% by 2050, relative to 2005 levels. IATA's vision is to significantly reduce the carbon footprint of the aviation sector over the next decades and to develop a long term, sustainable alternative for petroleum-based jet fuel. Its objectives are:

- Continuity: build a long-term sustainable aviation industry;
- Climate: deliver on industry-stated environmental goals;
- Cost-competitiveness: pursue affordable biojet solutions.

IATA's focus[7] **(Figure 2)** is to bring different stakeholders together from industry and policymakers in the alternative fuel area and facilitate cooperation and partnerships between them. It will also provide policy support at national, regional and international levels to create the necessary framework for the commercialization of sustainable aviation fuels. It wishes to work towards removing obstacles to the realization of a cost-competitive, sustainable aviation jet fuel market and establish a roadmap evaluating the short- and long-term potential of alternative fuels. IATA wants to promote the use of sustainable aviation fuels in compliance with robust sustainability criteria and raise public awareness for related industry efforts. It also wants to play a leading role in standard-setting for alternative drop-in fuels in the areas of technical certification and logistics, and provide related technical support. Finally, it wants to create a platform for knowledge exchange, among airlines and


*Figure 2. IATA's focuses and achievements*

external partners (e.g. airports).

**Relative merits**[8]

Advantages

Biofuel advocates frequently point out the advantages of these plant- and animal-based fuels.

*Source material*: Whereas oil is a limited resource that comes from specific materials, biofuels can be manufactured from a wide range of materials including crop waste, manure, and other by-products. This makes it an efficient step in recycling.

*Renewability*: It takes a very long time for fossil fuels to be produced, but biofuels are much more easily renewable as new crops are grown and(industrial or municipal) waste material is collected.

*Security*: Biofuels can be produced locally, which decreases a nation's dependence upon foreign energy. By reducing dependence on foreign fuel sources, countries can protect the integrity of their energy resources and make them safe from outside influences.

*Economic stimulation*: Because biofuels are produced locally, biofuel manufacturing plants can employ hundreds or thousands of workers, creating new jobs in rural areas. Biofuel production will also increase the demand for suitable biofuel crops, providing economic stimulation to the agriculture industry.

*Lower carbon emissions*: When biofuels burn, they produce less carbon output (because they needed $CO_2$to grow) and fewer toxins, making them a safer alternative to preserve atmospheric quality and lower air pollution.

Disadvantages

Despite the many positive characteristics of biofuels, there are also many disadvantages to these energy sources.

*Energy output*: Biofuels have a lower energy output than traditional fuels and therefore require greater quantities to be consumed in order to produce the same energy level. This has led some noted energy analyststo believe that biofuels are not worth the work.

*Production carbon emissions*: Several studies have been conducted to analyse the carbon footprint of biofuels, and while they may be cleaner to burn, there are strong indications that the process to produce the fuel – including the machinery necessary to cultivate the crops and the plants to produce the fuel – has hefty carbon emissions.

*High cost*: A high initial investment is often required to refine biofuels to more efficient energy outputs, and to build the necessary manufacturing plants to increase biofuel quantities.

*Food prices*: As demand for food crops such as corn grows for biofuel production, it could also raise prices for necessary staple food crops.

*Food shortages*: There is concern that using valuable farm land to grow fuel crops could have an impact on the cost of food and could possibly lead to food shortages.

*Water use*: Massive quantities of water are required for the proper irrigation of biofuel crops ad to manufacture the fuel, which could strain local and regional water resources **(Table 1)**.

| Advantages | Disadvantages |
|---|---|
| Source material | Energy output |
| Renewability | Production carbon emissions |
| Security | High investment cost |
| Economic stimulation | Food prices |
| Lower carbon emissions | Food shortages |
| | Water use |

*Table 1. Advantages and disadvantages of biofuel*

## Alternative technologies

**Beyond biofuels**

Improving engine efficiency and switching to sustainable biofuels can go a long way to helping the aviation industry become greener. However, biofuels, as previously discussed, are not without problems. They may therefore not be a permanent solution but rather a way to bridge the transition towards completely different concepts in the future. This chapter explores some of the alternative technologies that may one day revolutionise air transport.

It should be noted that the ideas discussed hereafter are currently not viable methods for generalised application in large commercial aircraft, although in each case, proof-of-concept experiments have been conducted on smaller scales. Provided certain challenges can be overcome, these technologies could be turned into practical designs within a few decades.

**Chemistry 101: hydrogen**

One of the most basic chemical reactions is the rearrangement of two hydrogen molecules and one oxygen molecule into water:

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Unlike hydrocarbon-based fuels (fossil and bio), no $CO_2$ is released by this combustion due to the absence of carbon atoms, although some toxic $NO_X$ by-products still occur due to the nitrogen in the air. It is, however, a much cleaner reaction overall. As for the energy released by the combustion, hydrogen, even when compressed, is not as efficient as an equivalent volume of fossil fuel. However, since hydrogen has an extremely low density, it actually is more efficient than those fuels when looking at mass instead of volume. This is especially relevant for the aviation industry, since minimising aircraft weight is a key objective.

*Figure 3. The Solar Impulse, a solar powered aircraft*

So why is hydrogen not used to propel commercial aircraft yet? The first problem is a technical one: hydrogen, which takes the form of a gas except at extremely low temperatures, needs to be compressed significantly in order to be used as a fuel due to its low energy density per unit of volume. This requires the gas to be stored in relatively heavy, pressure-resistant tanks which can be susceptible to leakages. Liquefying the hydrogen, as is done on some spacecraft, is also a possibility. However, this involves extremely low temperatures and again necessitates special pressurised and/or cooled containers, adding significant mass to the aircraft.[10] In addition, hydrogen's extreme volatility is particularly dangerous on aircraft if not properly addressed and may cause some issues during the ignition inside the engine.

These technical problems arenot insurmountable. There is, however, another issue: hydrogen gas is present in Earth's atmosphere in very limited quantities. For industrial uses, hydrogen must be produced, either from fossil fuels (which would defeat the own purpose in this case) or through the electrolysis of water. The latter method is currently very expensive, in part due to the limited quantities being produced. It should also be noted that the electricity has to be generated in an environmental-friendly way for the argument of sustainability to hold true. Still, even though it is difficult to say whether hydrogen might become the successor to jet fuel, it is a plausible option as it is within reach of current-day technology.

**The power of the electron**

As electric cars slowly start to gain popularity thanks to their extremely clean and quiet engines, one might ask if a similar phenomenon could occur with aircraft. However, major problems currently prevent this from being a viable solution. First and foremost, a commercial aircraft would require enormous amounts of electricity to achieve decent performance. Electric cars, for example, have significantly shorter ranges than their traditional counterparts. This is not necessarily a problem on the ground if they are used for relatively short distances, as recharging stations are becoming an increasingly common sight. In the air, however, the only practical way of 'recharging' is through solar panels **(Figure 3)**. In addition to only working during the daytime, solar panels do not produce an amount of energy per unit of surface that is high enough for practical use in commercial aviation.

Could one charge aircraft on the ground and use them for short-range flights? First of all, as with hydrogen production, this raises the question of the electricity's possibly non-sustainable origin. But a more severe problem is that the electricity would have to be stored in batteries. This works for cars, but not quite as well for aircraft, as batteries tend to be very heavy and have a relatively low energy storage density compared to their mass. Also, batteries tend to contain toxic materials, which somewhat diminishes their ecological appeal. The concept of a battery-powered plane has nonetheless been demonstrated to work on very light one- and two-seater aircraft and may possibly gain some traction there. But using it on heavy commercial aircraft is currently not a viable option. An alternative possibility would be to build a hybrid aircraft that uses electricity during certain phases such as take-off and landing, which would at the very least resolve the noise pollution aspect.

So while it is certainly possible to have an electrical propeller-driven aircraft, this is only feasible for certain specific applications given our current technologies. Light general aviation would probably be the first to make the transition; it would take a major breakthrough in electricity storage technologies to make this a practical option for commercial aviation.[1]

**Who needs wings?**

Assuming a relatively clean and durable propulsion method can be developed, one issue remains: how to use it as efficiently as possible.

So far, the assumption has been made that the propulsion is to be used on traditional fixed-wing airplanes. This has one major drawback, in that the lift force has to be generated through a combination of speed and wing size, both of which also increase drag. Some of the power from the engines, regardless of their fuel, is always 'wasted' on the generation of lift by having to compensate for the resulting parasitic and induced drag forces. A potential solution for this may be found in a seemingly outdated technology. Up to the Second World War, several countries experimented with so-called 'airships'. These machines generate their lift by being lighter-than-air through the use of hydrogen gas, significantly reducing their power requirements.

While the concept lost traction after a series of accidents (including the infamous 1937 Hindenburg disaster) and the rise of modern airliners, it has not disappeared completely. The flammability problem arising from the use of hydrogen can easily be solved by using helium instead. Small helium-filled airships, although uncommon, have already been used for various commercial purposes, such as advertising and sightseeing. In recent years, however, the concept of airships has regained some popularity, as several companies have proposed building much larger variants designed for transport purposes **(Figure 4)**. While much slower than traditional aircraft, they are also much more fuel-efficient, a trade-off that seems increasingly more attractive, especially for cargo transport.[9] As a side-benefit, their large surface area and low-energy consumption may potentially be suited for the use of solar power, while their vertical take-off and landing VTOL capabilities allow them to operate from almost anywhere.

Still, there are several major problems with this idea that are likely to impede a comeback in the foreseeable future. As mentioned, airships have cruising speeds that are an order of magnitude lower than those of traditional commercial aircraft. This makes the concept much less attractive than focussing on improving the aerodynamics of traditional planes. Furthermore, airships still require some form of power, such as biofuels, hydrogen or electricity (all of which, as discussed, have several inherent problems). This technology merely offers a way to reduce the power requirements, and is not a complete replacement for these options. Finally, it should be noted that the only current large-scale production method for the required helium is through extraction from natural gas, a non-renewable resource.

While there are certainly some arguments to be made in favour of airships, it remains hard to saywhether their application will ever spread outside niche markets, as this depends on a great number of technological, economic and social variables. At the very least, however, they offer an interesting alternative to get the highest possible efficiency out of a particular propulsion method, should energy ever truly become a more precious resource than time.

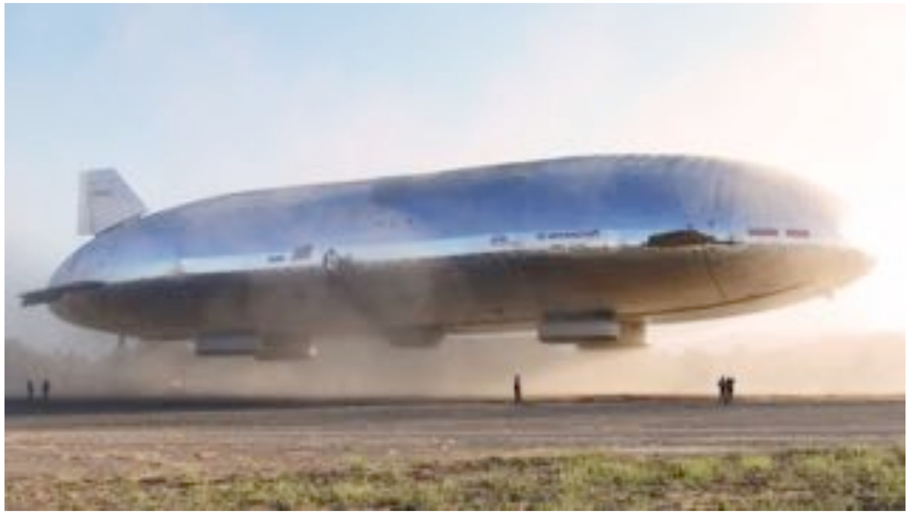

*Figure 4. The Dragon Dream, an experimental cargo airship*

## Glossary

- *Agrofuel*: see biofuel.
- *Biofuel*: fuel produced from renewable resources, such as plant biomass, vegetable oils or treated municipal and industry wastes.
- *International Air Transport Association (IATA)*: The global trade association for the airline industry. With 260 airline member that comprises 83% of total air traffic.

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## Dutch Summary

De luchtvaart zoals we gewend zijn, zal moeten veranderen om duurzamer te worden en zijn belasting op het milieu te verminderen. Er wordt nu al gewerkt aan het zuiniger maken van de vliegtuigmotoren en het zoeken naar alternatieve brandstoffen. Dit probleem zou mogelijk aan de hand van biobrandstoffen, waterstof en/of elektriciteit opgelost kunnen worden. Ook zou het nodig motorvermogen aanzienlijk kunnen worden verminderd door voor bepaalde toepassingen over te stappen op met helium gevulde luchtschepen, al gaat dit ten koste van de snelheid.

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