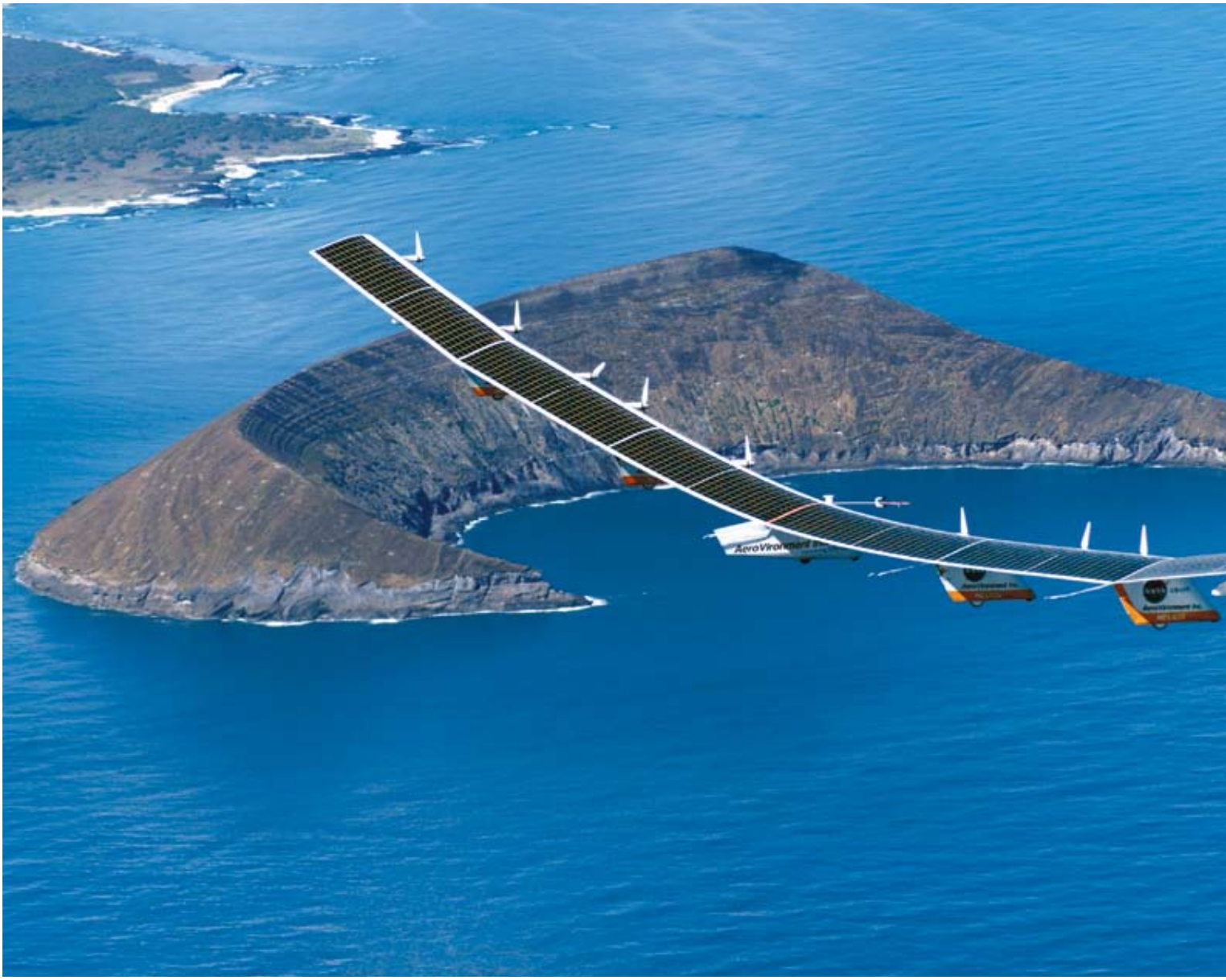
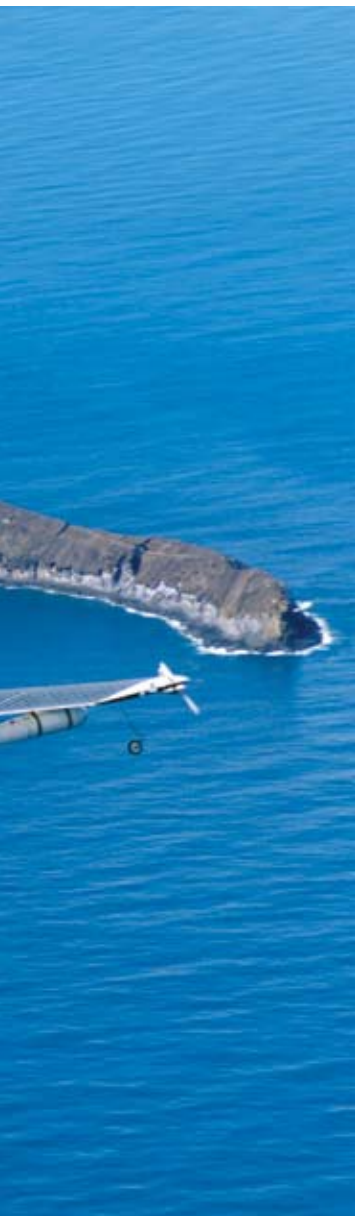
# When kerosene becomes scarce …

Crude oil is a finite resource. This is a known fact. The real crux of this issue is how long the worldwide reserves will actually last. Long-term, air transport will have to learn to accept that kerosene will become more scarce – and more expensive. This is why Lufthansa has an eye on tomorrow's fuel supply, today.



**Kerosene fuels the** air transport industry. Turbofan and turboprop aircraft engines have been operated so far almost exclusively with kerosene based on crude oil. So airlines – for whom this fuel represents one of the biggest cost items – are directly affected by the supply situation and the price developments in the crude oil markets. And in the long run, the supply of crude oil will become scarce, while prices will continue to rise.



The sun provides unlimited energy: During daylight hours, the 14 electric engines of NASA's prototype "Helios" has an infinite supply of "fuel" at its disposal. The required energy is delivered by 62,000 solar cells on its wings. NASA uses this ultra-light aircraft to conduct atmospheric research.

## Declining crude oil reserves

The situation: About 42,000 oil fields have been discovered to date, the most important ones about 50 years ago. The 400 largest fields comprise more than 75 percent of the world's known crude oil reserves.[2] The annual discoveries of new reserves have been in decline since the 1960s. And since 1981, the world has consumed more oil each year than geologists have discovered in new reserves. Requirements are covered predominately from exploited fields. According to the International Energy Agency (IEA), secure crude oil supplies will last until 2030.

Energy companies and industry associations, on the other hand, are more optimistic and see sufficient supplies until the middle of the 21st century. After all, there is the possibility that rising oil prices in tandem with technological progress in production methods will make the exploration of currently unprofitable reserves attractive. In this way, the declining production from conventional reserves could be compensated for the time being.

**Kerosene**

Produced by distilling crude oil, kerosene's characteristics make it the ideal fuel for air transport. Kerosene is characterized by an extremely high energy density of 43.1 megajoule per kilogram, which has a positive effect on total aircraft weight. In addition, it has a very low freezing point and remains liquid in aircraft tanks at ambient temperatures between minus 60 and minus 75 degrees Celsius. Thus, kerosene is a fuel suitable for cruising altitudes between 10,000 and 12,000 meters. Given these advantages, the entire air transport industry has been fully adapted to the use of kerosene. This is true for the engines and fuel tank systems of aircraft as well as for the supply infrastructure on the ground.

However, critical voices expect a decline in crude oil production over the short term and refer to the so-called "peak oil theory" of geologist M. King Hubbert. It claims that the maximum in oil production will be reached in the first half of the 21st century. This means that worldwide production cannot be increased any further. The result: The price of oil would inevitably increase, as supply can no longer meet steadily-rising demand. In the opinion of the Federal Institute for Geosciences and Natural Resources (BGR), no spectacular discoveries of new reserves are to be expected.

## Unrelenting demand

On the demand side, the trend clearly points upward. Since 1970, global crude oil consumption has nearly doubled while kerosene consumption has even quintupled. And an end of this trend is nowhere in sight: As recently as in 2004, worldwide demand for oil increased by 3.6 percent – the highest growth rate since 1978.

2 See the study commissioned by Lufthansa and conducted by the German Energy Agency (dena, Deutsche Energie-Agentur) "Kerosene: Availability and Alternatives," p. 8, referred to as "dena study" in the following.

The boom in demand is driven above all by consumers in Asia. China, a net oil exporter until 1992, has evolved into the second-largest consumer of crude oil following the USA.[3] In addition, India's recent economic growth has generated unforeseen oil needs. This trend is also reflected in the worldwide consumption of kerosene: While it stood at about 200 million tons in 2004, it is expected to rise to 285 million tons in 2015, according to estimates by the German Aerospace Center (DLR). NASA, the American aeronautical and space agency, predicts an increase to as much as 309 million tons.[4]

The world market prices for crude oil have also risen continuously since 2002, reaching the record high of US$ 78.40 per barrel in July 2006. Responsible for this increase and the ever-stronger fluctuations in oil prices is not only rising demand but also a higher speculative influence. Fear of possible supply bottlenecks are driving prices up even before the resource has actually become more scarce.

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A further central factor influencing price developments on the oil market is refinery capacity. Capacities are limited not only generally, but above all structurally. Consequently, there are bottlenecks in turning heavier products into lighter ones, such as kerosene. This situation may become even more critical long-term, as the future offerings of lighter types of crude oil, such as West Texas Intermediate (WTI) or Brent, will decline. And the important oil reserves in the Middle East consist primarily of heavier varieties, which yield a lower share of light products. "On the other hand, important refining and conversion capacities are now under construction, so this situation will ease up appreciably in a few years, at least for the time being," explains Helmut Fredrich, head of the Lufthansa Group's fuel management.

### Possible alternatives for kerosene

Yet rising oil prices harbor not only risks but also opportunities for alternative fuels not based on crude oil. Today, there are a number of options for replacing kerosene, either partly or fully. Each of these options has its advantages and disadvantages. "All told, it must be possible to produce an alternative fuel in sufficient quantities and at acceptable costs and to obtain its certification for use in aviation. The most important aspect here is flight safety," explains Dr. Karlheinz Haag, head of Group Environmental Concepts at Lufthansa. Before being introduced in the market, alternative fuels must fulfill numerous criteria. These concern their combustion performance, compatibility with other materials, handling, fluidity at low temperatures, nozzle atomization and vaporization characteristics, the possibility of restarting the engines in flight, their compatibility with additives and other characteristics. Meanwhile, the International Air Transport Association (IATA) has taken up the subject of "Alternative fuels for jets."

### Option 1: Oil sands

In the area of non-conventional types of oil, great hopes are being placed on oil sands, the greatest deposits of which are found in Canada and Venezuela. They contain not oil, but bitumen, which can be treated to yield synthetic crude oil. Producing oil from oil sands is, however, extremely energy intensive. The production process itself requires half of the energy won, whereas the energy efficiency for producing conventional oil is above 90 percent.[5] And the environmental effects are problematic as well: For each barrel of synthetic oil produced from oil sands, more than 80 kilos of greenhouse gases and about 4 barrels of wastewater are generated. Additionally, it must be taken into consideration that even a massive expansion of oil sand extraction in Canada would cover less than 3 percent of current oil production.

**Award-winning fuel management**

In February 2007, the Armbrust Aviation Group again honored Lufthansa for the airline industry's best fuel management. In seven of the eight individual categories, the fuel suppliers surveyed ranked the Lufthansa Group number one. Among others, the company received awards in the categories "Best employees," "Quality-mindedness" and "Innovations." "Our long-term approach of taking the entire process of fuel management into consideration is paying off," says Helmut Fredrich, who heads Fuel Management at Lufthansa. Since 1990, the Group has successfully used hedging instruments to secure fuel prices and to protect itself against fluctuations in oil prices. In this period, fuel hedging has helped save the airline more than 1.5 billion euros.

### Option 2: Blending

Blending, or stretching conventional kerosene with alternative fuel, could be a comparatively practicable solution. But research at Purdue University in the USA on blending kerosene with biodiesel produced on the basis of soybean oil has come up with fairly sobering results: The current composition standards for kerosene types Jet A and Jet A1 can only be maintained by a blending of maximum 2 percent. Furthermore, biodiesel tends toward a biologically induced reduction of its energy content, which is highly problematic in aviation.

### Option 3: Synthetic kerosene

Mid- to long-term, the most promising option for civil aviation is the one offered by synthetic carbon-based fuels based on the Fischer-Tropsch or other methods of synthesis. This is the conclusion of the study "Kerosene: Availability and Alternatives,"

3 dena study, pp. 11–13.

4 dena study, p. 21.

5 dena study, p. 11.

Not only rape, but any kind of biomass – from sugarcane and straw to wood chips and algae – is a suitable raw material for the production of synthetic fuel.

commissioned by Lufthansa and conducted by the German Energy Agency (dena). Suitable raw materials are biomass, natural gas and coal. The chemical scientists Franz Fischer and Hans Tropsch developed the eponymous procedure for the large-scale industrial conversion of synthesis gas to liquid hydrocarbons back in 1925. The key advantage of this method is that kerosene thus produced is not only identical to kerosene based on crude oil, but also chemically more pure.

### BTL, or biomass to liquid

Before the end of this decade, the first companies intend to produce synthetic fuel from biomass on a large industrial scale. All types of biomass are suitable as raw material – from "energy plants" such as rape and sugarcane to straw, wood chips and algae. After purification, the synthetic gas thus won is used to synthesize the type of fuel desired. The advantage: The fuel's characteristics can be adapted specifically to current and future requirements of engine and motor technology. In cooperation with industry, scientists at the German Energy Agency are currently mapping out the creation of the technical and economic prerequisites for further investments in this area.[6]

BTL fuels are free from sulfur and nearly odorless. Furthermore, the combustion process releases only that quantity of $CO_2$ that the plants previously absorbed from the atmosphere to support their growth process. The overall climate balance sheet for biofuels, however, depends on how many emissions are generated by cultivation, processing and transport. Beyond that, the large-scale cultivation of energy plants can damage the environment: Pesticides and fertilizers are used on fields, and carbons are released from the soil.

Ultimately, however, the success of BTL as the future fuel for aviation depends on the availability of the raw material, biomass. Both the automobile industry and – more recently – the energy industry are relying increasingly on biomass as a raw material. Furthermore, those plants grown for fuel production are not available for food production, though their cultivation does offer farmers new economic perspectives.

BTL is one of the second-generation biofuels. In comparison with bioethanol, biodiesel and vegetable oil – all first-generation biofuels – these make much more effective use of the energy potential of the plants involved. This is because their production uses not just specific plant parts containing oil, sugar or starch, but the entire plant.

### GTL, or gas to liquid

Synthetic fuels on the basis of natural gas are gaining in importance. They are produced by the same means of synthesis as BTL. This technology gives mineral oil companies and countries with large natural gas reserves a solution for the transport

6 dena study, pp. 23–24.


Hydrogen is also a potential energy source for air transport. The greatest advantage is its high energy content in relation to its weight. Using it, however, would require the construction of an entirely new supply infrastructure – worldwide.

problems associated with natural gas. GTL is an alternative to liquefying natural gas by cooling (LNG, Liquefied Natural Gas). Pilot plants are now producing fuel for jet engines in the USA, and Shell has been operating the first commercial low-temperature GTL plant since 1993 in Malaysia. Currently, the GTL process is still very energy intensive, however. Another significant disadvantage of GTL in comparison with BTL is $CO_2$ emission, as this is still a fossil energy source and not a raw material that grows again.

### CTL, or coal to liquid

The most comprehensive experience with Fischer-Tropsch fuels is associated with coal gasification. The South African mineral oil and chemicals group Sasol has been producing CTL fuels for more than 40 years. At Johannesburg International Airport, the company supplies more than 80 percent of its kerosene with a CTL share of about 40 percent. In addition, the U.S. Department of Defense finances programs to produce fuels from coal. Compared with conventional kerosene, CTL fuels have a significantly lower sulfur content. However, their $CO_2$ balance sheet is considerably worse than for GTL or especially than for BTL.

## Option 4: Hydrogen

Hydrogen is also among the potential energy sources for aviation. In the second half of the 20th century, several attempts were made to use hydrogen as fuel in jet engines. In the late 1980s, for instance, a three-engined Tupolev TU154 fueled with liquid hydrogen and liquid natural gas proved especially popular. Hydrogen's biggest advantage is its energy content in relation to its weight: At the same energy content, hydrogen is 2.8 times more lightweight than kerosene – but also 4.1 times more voluminous. Hydrogren's large volume and the need to cool it to minus 253 degrees Celsius imply a momentous challenge, as the aircraft's entire architecture would have to be changed accordingly.

Should hydrogen ever be used as a fuel in aviation, an entirely new supply infrastructure would also have to be constructed. Current fueling systems, hydrant systems, pipelines and supply tanks at airports are all optimally adapted for the use of oil-based kerosene. Should an alternative fuel such as hydrogen require a system change, parallel supply infrastructures for the old and the new fuels would have to be made available at airports worldwide during a transition phase. And aircraft's long life spans would lead to correspondingly long transition phases.

## Option 5: LNG and biogas

The use of liquefied natural gas (LNG) places similar demands on aircraft design. This type of fuel must also be cooled. And in relation to its weight, LNG does not have even half the energy content of hydrogen. On the other hand, its energy content is greater than that of conventional kerosene. However, the IPCC (Intergovernmental Panel on Climate Change) reaches the conclusion that methane (LNG or biogas) provides a less favorable result energetically than kerosene. As a result, the intergovernmental committee set up by

the United Nations Environmental Program (UNEP) and the World Meteorological Organization (WMO) have dismissed this option.

### Kerosene conservation helps secure crude oil reserves and reduces $CO_2$ emissions

To secure the world's limited crude oil reserves, the most obvious alternative for the time being remains the conservation of kerosene. The very best example for this approach is the continuous modernization of the Lufthansa fleet. New aircraft consume less fuel and reduce the output of emissions at the same time. Beyond this, Lufthansa counts on a broad spectrum of conservation measures in daily operations. These include adapting flight speeds, implementing more direct routes in Asian airspace, and reducing the service-related weight on aircraft. The airline achieves the latter, for example, by installing more lightweight seats on the aircraft of its European fleet and by more accurately adapting the quantities of reserve fuel and freshwater carried to actual needs.

The figures substantiate the airline's success in this area: Since 1991, Lufthansa has increased its efficiency by about 30 percent. In the same period, its specific fuel consumption has declined by almost 2 liters per 100 passenger kilometers. If the Lufthansa Passenger Airlines had produced their 2006 transport performance with their 1991 fleet, they would have consumed almost 1.9 million more tons of kerosene and emitted 5.9 million more tons of carbon dioxide. Viewed over a longer term, this efficiency gain becomes even more pronounced: While in the 1970s aircraft consumed 12 liters to carry one passenger over a distance of 100 kilometers, today a Lufthansa Airbus A340-600 burns only 4 liters to do the same job. And Lufthansa's new flagship, the Airbus A380-800, is expected to lower this value by about another 15 percent to around 3.4 liters.

Global warming and climate change make fuel conservation and the search for plausible alternatives all the more urgent, as kerosene consumption causes $CO_2$ emissions that are harmful for the Earth's climate. Lufthansa counts on sustainable business development and has therefore adopted numerous measures and developed innovative ideas to limit $CO_2$ emissions more strongly. At the same time, the political process can also help conserve more kerosene and thus limit emissions. By creating a standardized European airspace and improving air traffic management, up to 12 percent of the kerosene used in the skies above Europe could be conserved. Nevertheless, Europe's politicians are quite slow to tackle this long-standing demand on the part of its airlines.

### Best alternative: BTL

The overview of kerosene's alternatives shows there is no simple substitute solution. A switch to hydrogen as aviation's preferred fuel would imply that the industry would have to change its entire supply system on the ground as well as aircraft structures. "The big challenge, therefore, is to find a fuel that avoids an extremely costly system conversion, but still offers a viable alternative to kerosene," says Haag, the head of Group Environmental Concepts. "We have to find a fuel that fulfills the specifications of kerosene exactly. From an ecological perspective, BTL would be the best alternative for Lufthansa."

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> Dr. Karlheinz Haag, Head of Group Environmental Concepts

The study by the German Energy Agency also concludes that over the mid-term an increasing share of jet fuel will be synthesized from coal, natural gas and biomass. This would be "a realistic alternative." The clear advantage of this fuel is that it is almost completely compatible with the aircraft propulsion systems and supply infrastructures currently in use, says the study. In addition, the greenhouse gas emissions from BTL are significantly lower than those of kerosene.

It will be a number of years, however, before the use of BTL is an economic and technological possibility over a wide geographical area. According to the German Energy Agency, further steps on the part of industry and politics are necessary to make large-scale BTL production economically feasible and to take full advantage of the technology's potentials. Recommended control instruments would be increased support for research and development on the one hand, and reliable political and fiscal conditions on the other. "During this transition period, the air transport industry must reduce its kerosene consumption further by means of improvements, such as in the area of engine technology," Haag emphasizes. He also forecasts: "By 2025, synthetic fuels could cover as much as 20 percent of the needs of the world energy market."