Fuels for the aviation industry

IFP Energies nouvelles (IFPEN) is a public-sector research, innovation and training center active in the fields of energy, transport and the environment. Its mission is to provide public players and industry with efficient, economical, clean and sustainable technologies to take up the three major challenges facing society in the 21st century: climate change and environmental impacts, energy diversification and water resource management. It boasts world-class expertise.

IFPEN sets out 5 complementary, inextricably-linked strategic priorities that are central to its public-interest mission:

- producing fuels, chemical intermediates and energy from renewable sources,
- producing energy while mitigating the environmental footprint,
- developing fuel-efficient, environmentally-friendly transport,
- producing environmentally-friendly fuels and chemical intermediates from fossil resources,
- providing environmentally-friendly technologies and pushing back the current boundaries of oil and gas reserves.

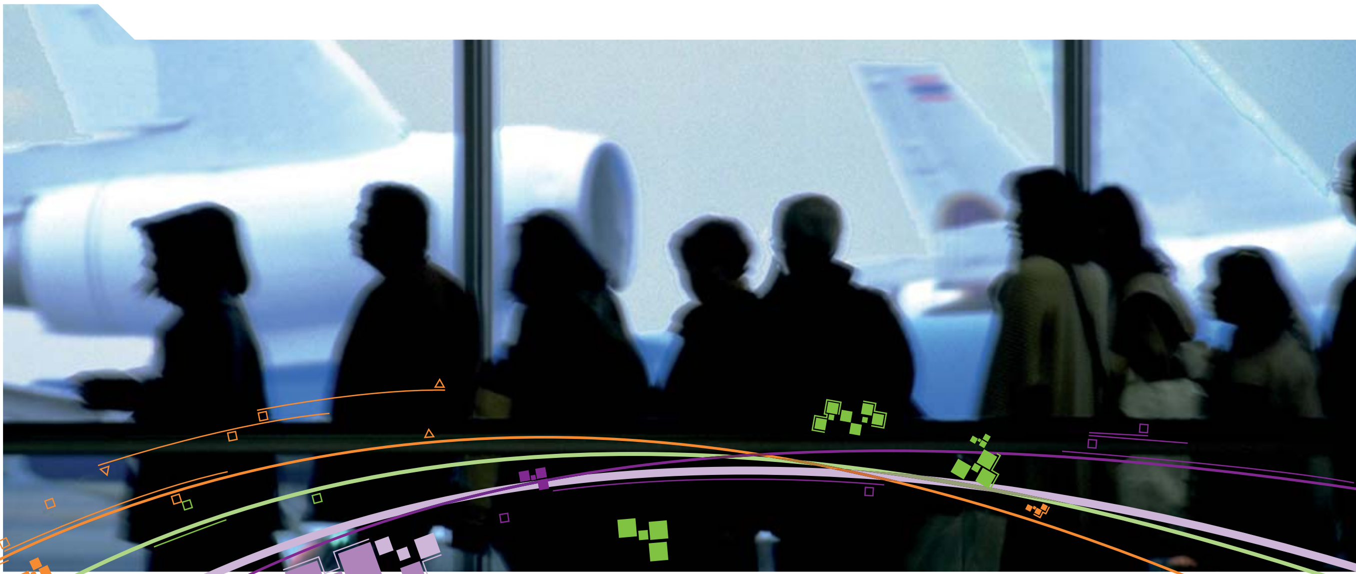
An integral part of IFPEN, its graduate engineering school prepares future generations to take up these challenges.

Producing fuels, chemical intermediates and energy from renewable sources

In order to tackle the greenhouse effect causing climate change and alleviate the transport sector's reliance on oil, IFPEN works on the production of biofuels, chemical intermediates and energy via the transformation of biomass. It also designs the technological solutions required to harness marine resources.

Developing fuel-efficient, environmentally-friendly transport

Drawing on its experience in the field of powertrains, acquired in partnership with the world's major automobile manufacturers, IFPEN designs and perfects technological solutions aimed at further reducing fuel consumption and minimizing the environmental impact of vehicles. It also works on the development of low CO_2-emitting engines for the aviation industry.



Overview and issues

A rapidly expanding sector

Today, about 1,700 airline companies are operating over 27,000 civil aircraft from more than 3,600 airports throughout the world. There are over 29 million departures each year, totaling more than 80,000 flights per day. It is therefore estimated that between 500,000 and 1 million people are in the skies at any one time.

On average, air traffic has grown between 5 and 6% every year since the mid-1980s, except during periods of recession (2001, 2009). Such a remarkable growth is set to continue over the coming decades. If indeed such forecasts become a reality, air traffic will double worldwide by 2025.

Against a backdrop of waning fossil fuel reserves and risks associated with climate change, the environmental consequences of air transport need to be taken into account.

Among the measures considered to limit the demand of kerosene related to air traffic growth, improving the energy efficiency of aircraft (and therefore cutting their carbon intensity) is a prime concern. This primarily involves improving the management of air traffic and existing aircraft — by changing engines, for instance — and designing new, more efficient aircraft (related to the number of aircraft replacements).

BACKGROUND

Today, air transport accounts for 8% of oil consumption. According to forecasts made by the IEA (International Energy Agency), the energy demand of air transport throughout the world will total 630 Mtoe and 530 Mtoe respectively for Baseline and Blue Map scenarios in 2050. This would account for 11 and 17% of world oil demand.

Growth and pollution

Air transport has an impact on the environment both at local (atmospheric and noise pollution) and global (global warming, greenhouse gas emissions) levels.

As far as local pollution is concerned, the main harmful emissions from aircraft include nitrogen oxides (NOx), particles and unburned hydrocarbons. Cutting emissions is not easy, given that no after-treatment system similar to those used for land transport can be adapted to a turbine. The main areas of focus involve improving turbine operating efficiency and technology. Alternative fuels can therefore play a crucial role. With a low sulfur content and simple chemical

Learn more

Some oil cuts (heavy naphtha) can be used as either kerosene or gasoline. Similarly, some light gas oil can be used as kerosene or gas oil. Such flexibility means that needs can be met through refining. While in the United States a proportion of kerosene cuts is used to meet the significant gasoline demand, around 50% of these cuts is used to meet the gas oil demand in Europe. One way of increasing the proportion of kerosene in fuel production would be to reduce the demand for gasoline or gas oil. In order for this to happen, however, the road transport sector would have to find the technological and societal solutions to reduce its reliance on oil.

composition, the biofuels currently considered could significantly cut particle and sulfur emissions.

In terms of global pollution, air traffic is responsible for direct and indirect emissions of several greenhouse gases: CO_2 (2% of global emissions according to the IATA — International Air Transport Agency), tropospheric ozone, methane and so on.

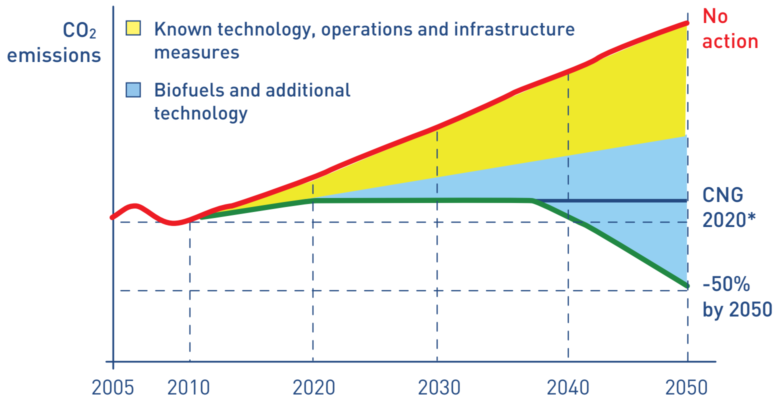
Ambitious commitments

Ambitious targets in terms of incorporating biofuels and reducing GHG emissions[1] have been set for the transport sector and particularly the aviation industry. In the last European Commission and Parliament Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC), a 10% target for energy from renewable sources in transport must be achieved by all Member States by 2020.

Furthermore, players from the aviation industry, brought together within the IATA, announced the following targets in 2010:

- increase energy efficiency by 1.5% per year until 2020,
- cap CO_2 emissions from 2020 (carbon-neutral growth),
- reduce CO_2 emissions by 50% by 2050 compared to 2005.

1 *Greenhouse gas*



**Carbon-neutral growth 2020*

BACKGROUND

Much of the work carried out to reduce aircraft consumption has already led to significant progress. As such, fuel consumption per passenger/km has dropped by two thirds between an airliner from the 1960s and a modern-day aircraft (source:* Direction générale de l'aviation civile, *2003).

Learn more

A survey carried out as part of the European Alfa-Bird project forecasts an average yearly increase in world air traffic of around 4.7% by 2025. With such growth in traffic, global kerosene demand should increase by around 38% between 2008 and 2025, an average annual growth rate of around 1.9%. In order to break the link between air traffic growth and the corresponding kerosene demand, fleet energy efficiency needs to improve by 32% between 2008 and 2025. Reducing the environmental impact of air transport is indeed inextricably linked to technological advances.

In order to reach these targets, the aviation industry is banking on a multitude of technological solutions that are either currently available or that will soon be. Solutions include lightening aircraft, improving the aerodynamics of new fuselages, reducing engine fuel consumption, fluidifying air traffic and substituting a portion of kerosene with alternative fuels that have a more favorable assessment, from Well-to-Wake, in terms of CO_2 emissions.

Drop in alternative fuels

Drop in alternative fuels can be blended with conventional kerosene in any proportion in aircraft engines without affecting its properties. They must have the following characteristics, in particular:

- worldwide distribution on account of intercontinental flights requiring the implementation of alternative fuel production criteria with a consistent quality at international level,
- great life span of aircraft (over 30 years on average) requiring the compatibility of alternative fuels and existing fuels without any need to make significant changes to the engine or aircraft architecture,
- all aircraft parts must undergo a series of tests before certification in order to ensure flight safety and reduce the risk of any incidents. The same goes for fuel, which must undergo stringent certification procedures with a view to demonstrating its full compatibility with all engine parts and materials in contact with the fuel (from logistics and distribution to combustion),
- an incredibly restrictive operating mode, since fuel is used by aircraft in a wide range of conditions of use such as varying temperatures (between almost -60°C at very high altitude and +50°C when stationary on tarmac) and varying pressures (atmospheric pressure at ground level, pressure around 0.3 bar at high altitude).

BACKGROUND

The introduction of alternative fuels in aircraft is subject to very specific constraints (safety, logistics, temperature, etc.). Over the short and medium terms, we can only consider drop in solutions, fuels with similar properties to those of kerosene, which do not require drastic changes to be made to equipment architecture and infrastructures, given the degree of investment in air transport.

The development of alternative fuel research for the aviation industry is crucial to securing the long-term future of air transport. Some of the main issues to overcome are related to energy (ensure the refueling of aircraft, for which liquid fuels seem to be the only viable solution over the short and medium terms), cost (fuel accounts for over 35% of airline running costs for long-distance flights), geopolitics (diversification of resources) and the environment. The latter is guiding current research into biofuels.

A joint effort

IFPEN's research in the field of alternative fuels for the aviation industry is carried out in partnership with the main industrial players (Airbus, Dassault, EADS, Onera, Snecma, etc.) as part of joint projects:

- Calin[2], a project conducted by Airbus, for which IFPEN is investigating the thermal stability of biofuels. In September 2010, the project was awarded a prize by the Aerospace Valley competitiveness cluster in the "Sustainable Development" category,
- Swafea[3], a European project which aims to provide a roadmap for the medium-term introduction of alternative fuels, by examining the technological, economic and social conditions.

2 Carburants ALternatifs et INnnovations en combustion (Alternative fuels and combustion innovations)

3 Sustainable Way for Alternative Fuels and Energy for Aviation

Which technologies
for alternative fuels to fossil kerosene?

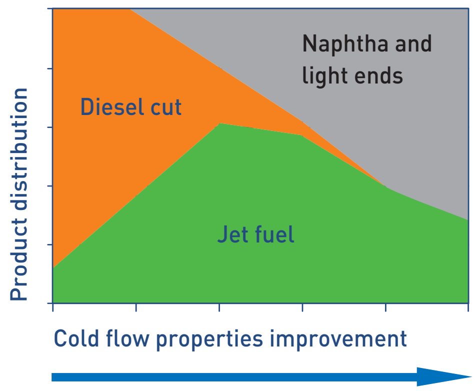
Vegetable oils

One technology being examined transforms vegetable oils and animal fats, high in triglyceride and/or fatty acid content, into paraffin kerosene cuts as an alternative to fossil kerosene.

The process involves processing the oils or fats in the presence of hydrogen, to remove the oxygen they contain and to produce HVO (Hydrotreated Vegetable Oil), a pure paraffin, containing no sulfur or aromatics. A second hydroisomerization stage can be required to attain the standardized low-temperature properties.

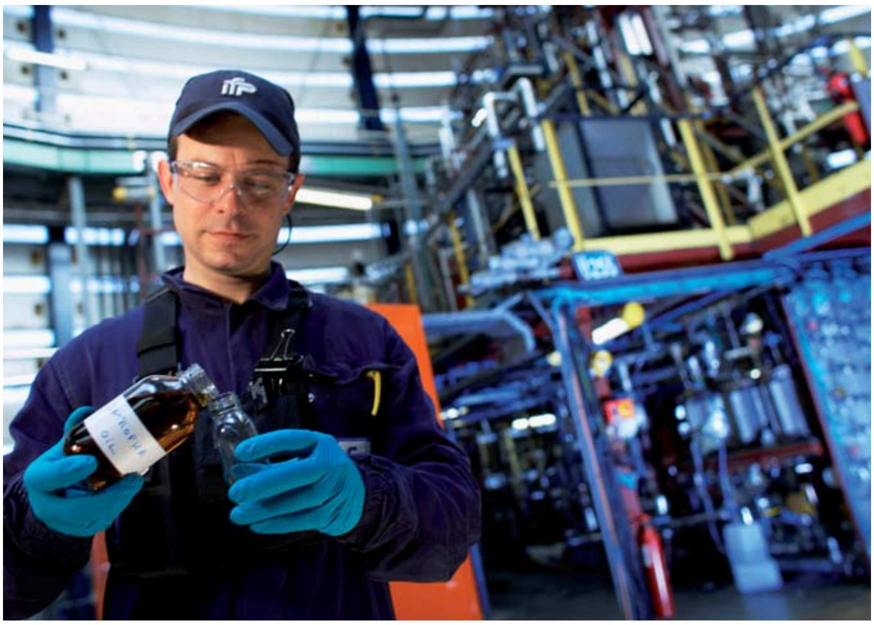
The process is very flexible, insofar as it can produce, depending on the need, the amount of product required. In other words, it can produce either a kerosene cut with adjustable low-temperature properties, which can be blended in any portion with fossil kerosene, or a product that fits within the distillation range of gas oil, with outstanding qualities in terms of cetane.

The main challenge faced by the HVO process is having sufficient resources that are not in competition with the food industry nor in terms of land use.



Commercial airlines have already conducted test flights using a biokerosene blend on at least one of the engines.

Airline	Type of aircraft	Type of fuel	Date
Air New Zealand	Boeing 747-400 (1 engine)	50-50 blend of HVO from jatropha and Jet A1	December 2008
Continental Airlines	Boeing 737-800 (1 engine)	50-50 blend of HVO from jatropha and algae oil and Jet A1	January 2009



Vegan™ process

IFPEN is working on the hydrogenation of vegetable oils to produce a very high-quality base for kerosene. A version of the process, developed with Axens, was brought to market in 2011 as Vegan™.

BioTfueL project

Launched in 2010, the BioTfueL project aims to develop a production chain for 2nd-generation gas oil- and kerosene-type biofuels. The objective is to develop a competitive and sustainable integrated process, making it possible to treat biomass with other resources, such as oil residue and coal (co-treatment), by 2017. The project brings together R&D bodies (IFPEN and the CEA — French Atomic Energy Commission) and industrial players (Axens, Sofiprotéol, Total and Uhde).

Synthetic biokerosene

The BtL (Biomass to Liquids) process consists in converting lignocellulosic biomass (wood residues, cereal straw, forestry waste) into synthetic fuels (biokerosene and biodiesel).

It is a four-step process: biomass pre-treatment, gasification, purification of the synthetic gas and Fischer-Tropsch (FT) synthesis, which produces hydrocarbon wax. The hydrocarbon wax then undergoes another hydroisomerization stage which makes it possible to direct production, depending on needs, towards kerosene, diesel or naphtha cuts.

The kerosene fraction obtained using the BtL process is of very good quality, free from sulfur and other impurities.

The technologies exist for the first three stages of pre-treatment, gasification and purification, but they are variable in terms of maturity and are generally only used to treat fossil feeds. So they first need to be adapted to biomass and then, the various technological obstacles that still exist need to be overcome so that they can be used on an industrial scale.
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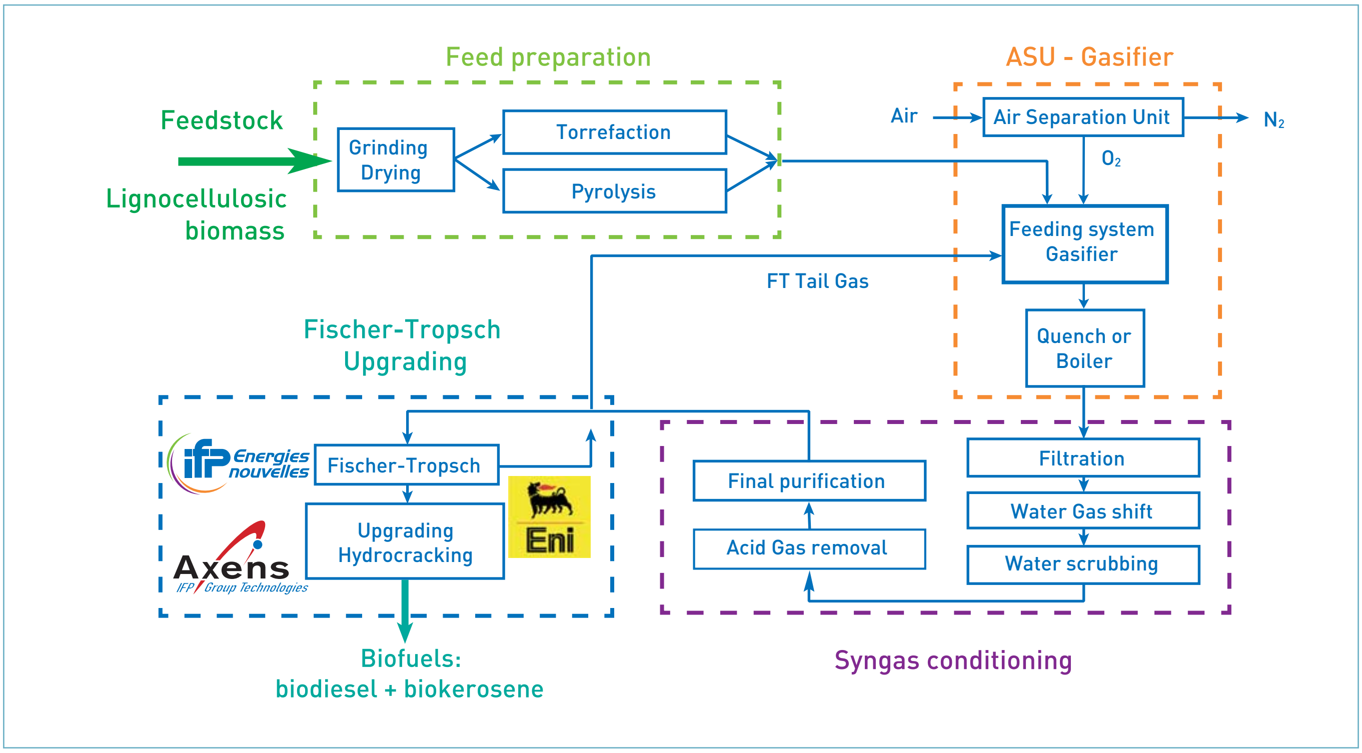

Other potential solutions

In addition to HVO and BtL, there are other possible alternative solutions. Gas to Liquids (GtL) and Coal to Liquids (CtL) solutions make it possible to diversify supplies, but existing technologies are no more efficient than conventional options using oil. Three other possible biokerosene production options, which are less developed than those outlined above, include among others: EtK, the chemical conversion of sugars and the use of flash pyrolysis.

Ethanol to Kerosene (EtK)

IFPEN is studying the conversion of ethanol, and even other alcohols, into kerosene (EtK). Used as a feed, ethanol can be produced either by fermenting sugars or starch (1st-generation), or from lignocellulose, transformed to sugars beforehand. The production of ethanol using sugars from macroalgae is also to be explored.

Chemical conversion of sugars

The conversion of sugars can also be directly carried out using chemical catalysts. The main drawbacks include the material yield and the diversity of the products obtained, which significantly limit the final yield to the kerosene cut.

Flash pyrolysis

Flash pyrolysis processes of biomass make it possible to liquefy it directly. When turning this liquid into fuel such as kerosene, the major hurdle to overcome is achieving a sustainable and low-cost after-treatment of the liquefiates.

Guarantee engine/fuel compatibility

All research currently being conducted involve the development of drop in fuels which must comply with the ASTM[4] D1655 standard (Specification for Aviation Turbine Fuels) and be approved according to a specific standard, ASTM D4054 (Guidelines for the qualification and approval of new aviation turbine fuels and additives). This standard provides for several validation steps relating to the fuel itself (specification compliance) and how it works with the turbines (testing, test flights). During the tests, the fuel must demonstrate its innocuousness as regards existing systems. Engine designers and aircraft manufacturers validate the all system using a research report.

In the longer term, the development of new fuels could call for the optimization of engine parts in order to make the most out of their properties. Such developments shall be carried out with a constant view to safety. As such, any modification improving turbines shall guarantee its full compatibility with the use of fossil or alternative kerosene.

Alfa-Bird European project

As part of the Alfa-Bird project, IFPEN is leading the first sub-project, which assesses the potential of various alternative fuels for aircraft from a technical point of view and their impact on turbine operation. These include synfuels from biomass, gas or coal, HVO fuels, esters and sugar derivatives.

Among the technological solutions studied to produce alternative fuels to fossil kerosene, some are already being used, while others still remain to be developed. They all face the same challenge: resource availability.

4 *American Society for Testing and Materials*

Which level of substitution?

Resource availability

Among the biofuels which can be used by the aviation industry, there are technologies that use three types of biomass: oil crops for HVO production, lignocellulosic biomass for BtL, and in the longer term, plants rich in sugars for ethanol (EtK).

But they are also currently being used in several ways by different sectors, especially for producing energy. It is therefore necessary to develop new resources which meet the growing needs and various economic and environmental constraints.

Oil-related resources

The main oleaginous, terrestrial crops considered for the production of HVO are palm, rapeseed and soya. These crops are primarily used by the food industry, and also for the production of biodiesel for road transport. To guarantee that resources are not directly competing with the food industry, oily resources have been considered. These resources such as jatropha, camelina and, as part of a more forward-looking approach, lipid microalgae, have not yet been marketed by the food industry and can potentially be cultivated on non-agricultural land.

BACKGROUND

The development of biodiesel solutions already seems to be limited to the medium term, with almost 50% of oil production used for rapeseed-derived biodiesel in Europe. On an international scale, around 40% of this oil is put to uses other than food, almost 10% of which is used for energy. On a local level, waste oil and animal fat can also be used as a back-up.

Jatropha, a small shrub growing in dry and subtropical areas, produces fruit containing inedible oil. Camelina, a plant from milder climes, is a low-input crop. Both are currently being domesticated. Their potential for development is related to managing and harnessing marginal or abandoned land in developing countries.

If intensive farming becomes necessary to improve yields, needs in terms of water and input will also rise. Furthermore, the fact that these resources are not currently being used by the food industry could, one day, change. Take rapeseed, for instance, which was once deemed inedible.

As far as lipid microalgae from an aquatic environment are concerned, their theoretical oil productivity is significantly higher than that of terrestrial plants (twenty times higher at laboratory scale) and their development potential requires little or no agricultural land to be available. However, all species require water and input. For autotrophic systems (photosynthesis), a significant light source is required. As for heterotrophic systems, a supply of sugar or equivalent needs to be ensured, which raises questions as to whether producing this sugar will be sustainable.

In order for this option to take on industrial proportions, we need to fully master the technological building blocks and their integration:

- strain selection and production/ reproduction conditions,
- cultivation methods and modes,
- transportation and pre-treatment,
- oil extraction and recovery conditions,
- by-product valorisation,
- conditions for converting lipids into fuels,
- product quality.

Significant technological obstacles are yet to be overcome (algae cultivation modes, economic and environmental performance), making it inconceivable to consider mass production over the short term.

Lignocellulosic biomass resources

The resource considered for the BtL process is a biomass that produces high levels of dry substance, with no connection to the food industry. This involves harnessing agricultural and forestry by-products (straw, waste, wood residues), as well as dedicated crops such as miscanthus, switchgrass, short rotation coppice, etc.
These crops are currently being domesticated and will require existing agricultural and even forestry land for harvesting. In the long term, overall energy potential of lignocellulosic biomass is estimated at approximately 2 Gtep per year.

Actual availability of biomass for energy is highly dependent on policies in support of the industries. If biomass supply conditions are potentially met, significant work will remain to ensure its long-term availability (managing under-exploited forests, harnessing marginal and abandoned land, developing supply logistics and aquatic biomass knowledge, etc.).

Regulatory incentives and limitations

A standard relating to the technical limitations of blending fossil kerosene and alternative fuels is in the process of being created. The first alternative fuel to be approved in the aviation industry was a 50-50 blend with a CtL, developed by Sasol in the 1990s. In 2009, a new specification, ASTM D7566, was approved for a 50-50 blend with all Fischer-Tropsch synfuels (CtL, GtL, BtL). As far as hydrogenated vegetable oils are concerned, the approval process for a 50-50 blend should reach completion in 2011.

A number of criteria must be met if fuels from biomass are to be used in sustainable conditions from an environmental point of view, while meeting the European Union's target (10% of energy from renewable sources in transport by 2020). These include minimum requirements for reducing GHG emissions as well as criteria for using land that is used to produce biomass.

While most lignocellulosic biofuel processes, particularly BtL, should meet these environmental requirements, some HVO processes may not on account of the way the oil crop is produced. Considerations in assessments pertaining to the use of land could also bring some processes into question if, for instance, an area was to be deforested to make way for a crop dedicated to energy.

BACKGROUND

Setting the incorporation target at 50% requires the biokerosene produced to have outstanding qualities, particularly regarding low-temperature properties. However, in guaranteeing these properties, the yield of the production process drops significantly. A standard defined on the basis of incorporating between 10% and 20% could, provided that certification works are conducted, relax biokerosene specifications, and, as a consequence, improve the yield per hectare by almost 10%.

Learn more

Overall energy potential of lignocellulosic biomass is estimated at 2 Gtep per year. However, this maximum estimation does not take into account exploitation obstacles (geographic, geopolitical, climatic constraints, etc.). It is to be split between the various uses: energy production, chemical industries and fuel production (land, sea and air transport needs). Coordinating the bioenergy production targets in the various sectors is essential to ensuring efficient distribution of resource uses.

Standards for fuel blends	Since 2010: up to a **50-50 blend of FT fuel** (including BtL) and conventional kerosene.	Undergoing development: up to a 50-50 blend of HVO and conventional kerosene.
Production/ reduction targets	IATA: **halve** the aviation industry's GHG emissions by 2050 compared to 2005.	European Commission Transport White Paper 2011: **substitute 40%** of fossil kerosene with low-carbon fuels by 2050.
Biofuels eligibility criteria by 2020	2017: reduce GHG emissions relating to **the use of biofuels by at least 50%** compared to the fossil fuels. 2018: further reduce these emissions to at least **60%** for new facilities.	Biofuels do not need to be produced using raw materials from lands that: • are of high value in terms of **biological diversity**[5], • boast significant **carbon stocks**[6], • are peat bogs since 2008.

5 Old-growth forests, protected areas (countryside, ecosystems and species), high-value natural meadows in terms of biodiversity, etc.

6 Damp areas, extensive areas of forest

Roadmap

While the technological and economic maturity of lignocellulosic processes (BtL) is yet to be demonstrated, they seem to have several advantages when compared to oil processes (HVO):

- greater biomass potential,
- greater yield per hectare,
- greater environmental result.

To date, the cost of producing biokerosene is markedly higher than that of producing fossil kerosene. Public authorities must therefore intervene to ensure the emergence of these processes and their long-term viability. Provided that sufficient measures are taken to ensure this, it may be possible to substitute kerosene with hydrogenated vegetable oils, though in somewhat limited proportions given the limited availability of oleaginous crops.

Sometime around 2020-2025, the co-production of synthetic biokerosene using BtL facilities should provide additional substitution. BtL should potentially be followed by an increase in HVO production using algae oil.

By 2030, an optimistic scenario of resource mobilisation for the aviation industry — 15% of global production of oils and 20% of lignocellulosic biomass potential — would ensure a substitution level of about 15%. This level could be increased by significant developments in algae processes, additional lignocellulosic resources and the use of the EtK process.

The substitution of fossil kerosene by biofuels is therefore limited in volume, and the European Commission's substitution objective of 40% by 2050 appears to be an extremely ambitious one.

Process Business Unit

IFP Energies nouvelles' objective is to develop new processes that are more economical, cleaner and safer for the production of fuels, chemical intermediates and hydrogen from all available carbon sources (oil, gas, coal and biomass). With regards to motor fuels, the aim is to put forward innovative solutions for the medium term – sulfur-free fuels, richer in hydrogen, with a significantly higher renewable content. As for the production of chemical intermediates, IFP Energies nouvelles strives to identify innovative technologies using biomass, in particular.

The research programs focus on:

- the conversion of biomass into fuels,
- the conversion of biomass into chemical intermediates,
- residue and heavy oil conversion processes,
- middle distillate conversion and purification processes,
- gasoline production and purification,
- hydrogen production,
- production of petrochemical bases,
- the conversion of gas into fuels,
- the conversion of coal into fuels.

Innovating for energy

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