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BIOMASS AS RAW MATERIAL OF AIRCRAFT FUELS

Biomass can be found in our every day life, because it surrounds us. We can eat it, we can cook with it, and it can become waste. However, it can also be used as raw materials for a range of products, for example, for aircraft fuel production, which fuel emits less pollutants, and furthermore can solve enviromental problems too. Along with passenger and agricultural aircraft, military aircraft also use fuels for their flights, which is made from animal fat, vegetable oil or solid waste, ie biomass. In this paper I would like to introduce several types of bio fuel depending on their raw material and their production method.

Keywords: *aviation, biomass, bio jet fuel, bioalcohol, HEFA, FAME, SAF*

INTRODUCTION

The origin of the biomass can be plant or animal and its consistency can be solid, liquid or gaseous. Their formation takes place in anaerobic manner as the raw materials of fossil fuels, only in a much shorter period of time. It can contributes to sustainable development, since it has still been classified as a renewable energy source in the EU and UN legal frameworks because photosynthesis cycles the CO_2 back into new crops. It is enough to mention that the CO_2 prportion has already reached a record in 2016 (403,3 ppm[1]) [2].

Biomass can be used in many ways: for human nutrition, for animal feed, for raw material and energy production. It is the fourth largest energy source of the world, just its fossil-derived companions, like petroleum, natural gas, coal preceds it [3].

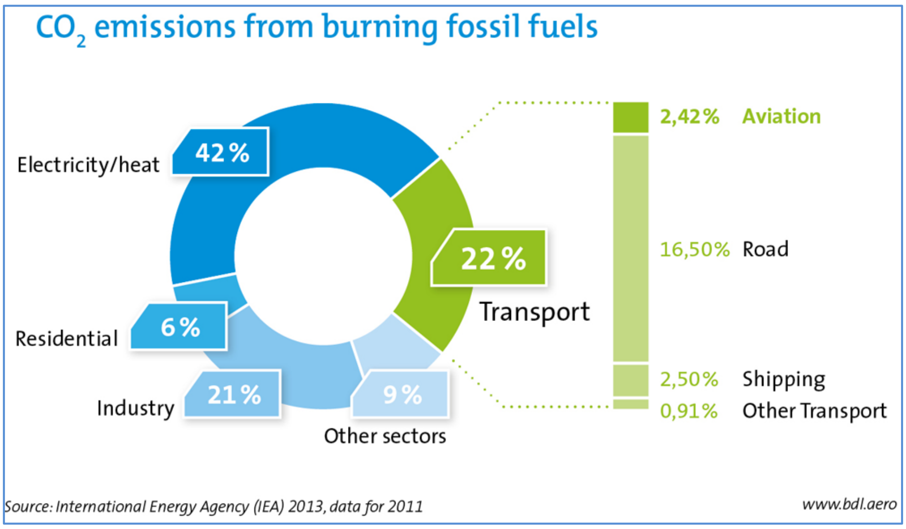

Figure 1. CO_2 emission from fossil fuels [4]

[1] ppm – particle per million

Aviation, along with several other human activities, contributes to the increase of the carbon dioxide level in the atmosphere, which increases the greenhouse effect (Figure 1). Additionally, pollutants from the combustion of conventional fuels are added to atmospheric contamination. Depending on the growing environmental aspects and the rising prices of the currently used fuels, it is necessary to introduce alternative fuels. In order for this to happen, the new fuel must correspond the same standards as those on the market, but it is recommended to fulfill additional criteria, such as:

- during the combustion process far less pollutants should be emitted into the environment than using their conventional counterparts;
- their production should be economical using renewable energy sources;
- currently used fuel systems should not or only slightly be modified.

BIOMASS AS RAW MATERIAL OF FUELS

There are several types of biomass used as raw material for fuel. Biofuels are usually classified into generations, depending on the feedstocks and the type of land used to grow plants. These categorisation can be seen below:

- first generation: They are produced from arable crops intended for food and feed (corn, potato, sunflower). From these through various chemical processes, starch (sugar) and oil are extracted as source of biodiesel and bioethanol.
- second generation: They are produced from plants, which not suitable for food and feeding and enough to use of poorer quality land where food crops may not be able to grow.
- third generation: They are produced from oil of algae, which grows in out- and indoor pools laying on unsuitable land for cultivations.
- fourth generation: Algae and cyanobacteria are used as catalysts in their production with sunlight. Biomass is not damaged in this case.

The following Figure also shows how many types of biomass exist and how many different processes can be used to make alternative fuels available for aviation.

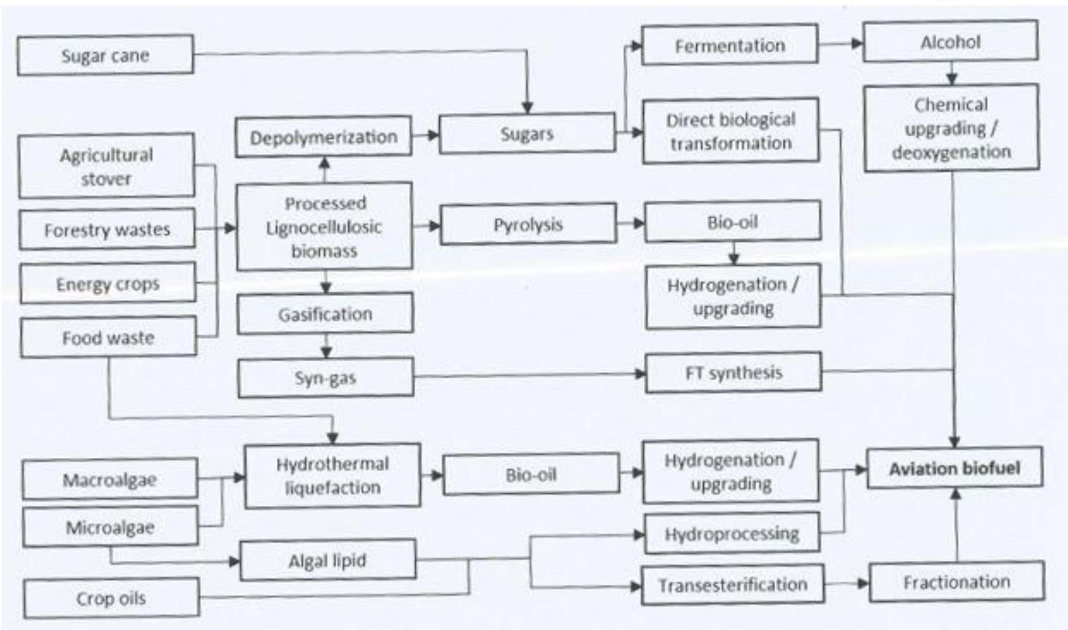

Figure 2. The major routes to aviation biofuels [5]

California-based Fulcrum BioEnergy produces jet fuel from municipal solid waste according to the Fischer-Tropsch method. Already in 2014, the ASTM (American Society for Testing and Materials) validated their kerosene and diesel for using in air and land vehicles. The United Airlines, the Cathay Pacific, the American Air Force and Navy joined into the programme of the company. In 2017 the firm began to build its first plant in Reno, Nevada, and the second plant will be built in 2020 in Gary, Indiana. The new plant is expected to process about 700,000 tonnes of waste and to produce about 125 million liters of alternative fuel. They claim that using this fuel will reduce greenhouse gas emissions by 80% compared to their fossil counterparts [6][7].

Figure 3. Sierra Biofuel plant visual design [8]

They are not only trying to recycle waste in North America, but also in South America, exactly in Brazil. In this country, several types of fish are bred, with the largest amount of tilapia. They use only just fillets of these fishes for human consumption. This part accounts for 30% of the whole fish, so the remaining 70% was discarded as a waste that could be harmful for the enviroment. Brazilian researchers investigated the use of non-edible parts and concluded that from extruded oil of these parts can be raw material of an alternative fuel just like diesel, which is illustrated in the table below [9][10].

Features	**Fishbiodiesel**	**ANP[2] recommended limits**
Specific mass at 20 °C [kg/m^3]	877	850–900
Kinematic viscosity at 40 °C [mm^2/s]	5,34	3,0–6,0
Water level [mg/kg]	95	500-ig
Acidity level [mg KOH/g]	0,19	max. 0,50
Flash point [°C]	145	min. 100,0
Oxidation stability at 110 °C [H]	8,7	min. 6
Inferior heating power [MJ/kg]	35,479	not specified by the rule ANP N°7/2008
Superior heating power [MJ/kg]	38,531	not specified by the rule ANP N°7/2008

Table 1. Results of physical and chemical analysis of fish oil [10]

In Europe, Sweden occupies a leading position in taking out of fossil fuels. Over the last three years, it has doubled the use of biofuels, which are made from mainly wastes from forestry logging. As an airport operator, Swedavia AB has set itself the goal of exempting Swedish domestic and foreign flights from fossil fuels by 2045. At the moment airplanes can refuel sustainable aviation fuel at their five airports (Stockholm, Göteborg, Bromma, Visby, Luleå),

[2] ANP: Brazilian National Agency for Petroleum, Natural Gas and Biofuels

which is produced by World Energy in Los Angeles and supplied by SkyNRG and Shell through the Fly Green Fund. They can reduce carbon dioxid emissions by applying this alternative fuel. In addition, Swedavia plans to electrify the ground service vehicles [11][12].

Figure 4. Richard Bokström refuelling the first biojet flight, SK1419, an Airbus A320 Neo [13]

Microalgae have emerged as the raw material for third-generation biofuels, which are made up of a single cell, but significant in the biosphere of Earth, because they produce nearly half of the oxygen in the atmosphere while using carbon dioxide for their growth. From them several types of alternative fuel can be produced: biomethane, biodiesel, biohydrogen, depending on how the algae are processed. Two main production methods are used: raceway pond and photobioreactor. It is difficult to decide which is the better option for algae cultivation, because one is an open system that can be infected by other organisms, while the other is a closed unit, which is more difficult and expensive to maintain. The table below shows the amount of oil that can be obtained from 100 tons of algae for the two methods mentioned above [14][15].

Variable	**Photobioreactor facility**	**Raceway ponds**
Annual biomass production [kg]	100000	100000
Volumetric productivity [kg/m^3d][3]	1,535	0,117
Areal productivity [kg/m^2d][4]	0,048[a] 0,072[c]	0,035[b]
Biomass concentration in broth [kg/m^3]	4,00	0,14
Dilution rate [1/d]	0,384	0,250
Area needed [m^2]	5681	7828
Oil yield [m^3/ha]	136,9[d] 58,7[e]	99,4[d] 42,6[e]
Annual CO_2 consumption [kg]	183,333	183,333
System geometry	132 parallel tubes/unit; 80 m long tubes; 0.06 m tube diameter	978 m^2/pond; 12 m wide, 82 m long, 0.30 m deep
Number of units	6	8

Table 2. Comparison of photobioreactor and raceway ponds production per 100 t of biomass (You can find the letters from the table in the footnote.)[5] [14]

[3] kg/m^3d: kilogram per qubic meter day, productivity of one cubic meter volume for one day.
[4] kg/m^2d: kilogram per square meter day, productivity of one square meter area for one day.
[5] a: Based on facility area., b: Based on actual pond area., c: Based on projected area of photobioreactor tubes., d: Based on 70% by weight oil in biomass., e: Based on 30% by weight oil in biomass.

Most of the researches has been carried out in relation to biodiesel, which is obtained by further processing of oil extracted from algae. Its disadvantage is that its production requires a lot of water, but it has the advantage of being non-toxic and readily degradable material and using it reduces carbon dioxide, soot into the atmosphere, and it does not contain sulfur [16]. Several foreign companies are also involved in converting oil extracted from microalgae into aviation fuel, which I will present in another chapter.

New research is going on Salicornia also. In Masdar Institute of Science and Technology, United Arab Emirates Salicornia was grown in a pilot project, which was already harvested at the end of 2017. This plant is rich in oil, so it is thought that it can be a good raw material for aircraft fuel. It belongs to the group of halophytes, which are not only salt-tolerant, but specifically need the proper concentrate from this mineral to be able to germinate, so seawater is suitable for them, no fresh water is needed. As a component of a biological system, they are installed in aquaculture, where fish and shrimp are bred also. All this is done by using a sustainable model: Salicornia field is fertilized with water used for fish and shrimp breeding, the residual water is cleaned by the mangrove trees, fish lives among the roots of the trees, while they using carbon dioxide from the atmosphere for their photosynthesis. Attempts are going on in six units at the moment. The project involved Boeing, General Electric, Safran, Takreer (oil refining) and Etihad airline, which will carry out test flights with their aircraft using conventional fuel mixed with Salicornia oil [17].

Figure 5. Salicornia [18]

I think biomass-based fuels have future, because we have these raw materials and they can be well integrated into sustainable development, and they can serve the aircraft that are currently in use (however, temporarily they can only be blended), but there are ethical questions about creating some of them. Can we use plants as raw materials that are suitable for human nutrition and, as we know, many people are hungry on Earth? Can we produce energy-producing plants on arable land that would also serve as food crops? However, the third and fourth generation biofuels will solve these problems.

SOME TYPES OF BIOFUELS

Biomass-based fuels that can be used in flight must meet several requirements, as I mentioned above, but at the moment it is perhaps most important that they must be perfectly compattible to burn in the engines of today used aircraft. In the Standard D1655 of American Society for Testing Materials (ASTM), entitled Standard Specification for Aviation Turbine Fuels, there is a list of materials that can be used as raw materials for fuels. This list includes crude oil, natural gas as liquid condensate, heavy oil, slate oil and oil sands, and has recently been expanded with methods for producing alternative fuels. The ASTM D7566 Standard already specifies alternative fuels which, when used as a mixture (result: semi-synthetis fuel), can meet the requirements of D1655 preconditioning. In that case, if a new propellant meets the above two standards, it can be used up to a maximum of 50% as a mixture in fossil fuels [19].

Bioalcohols

Ethanol is the most widespread bio-alcohol, which are derived from starch, cellulose and sugar from plants. This alcohol has low energy density, cetane number, flash point and heating value, which would need 1.7 times larger fuel tank of the aircraft fueled with it. (Fig. 6.) [20][21].

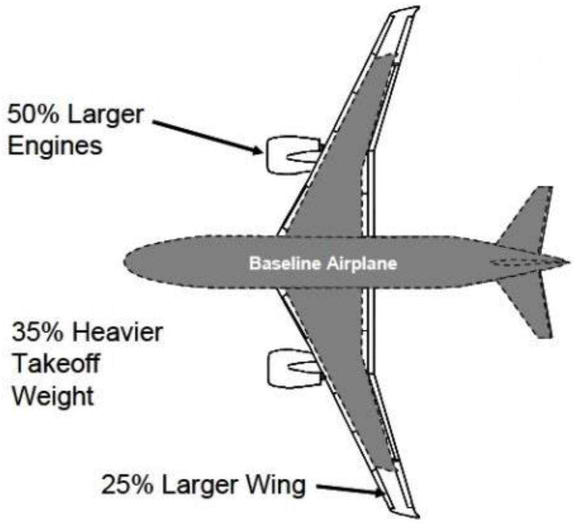

Figure 6. Ethanol powered plane [22]

Compared to conventional fuels, they burn more clearly, resulting in fewer pollutants in the atmosphere (no heavy metals, no more than a quarter of carbon monoxide, one fifth of sulfur oxides comparing to the traditional kerozen). It also has the disadvantage that it can initiate corrosion in some metal parts, so it is not recommended in itself but as an additive for the operation of aircraft [20][21].

There are also companies, such as Byogy Renewables, which produce a mixture of long-chain hydrocarbons from ethanol or other alcohol (Fig. 7), which can also be used for aircraft.

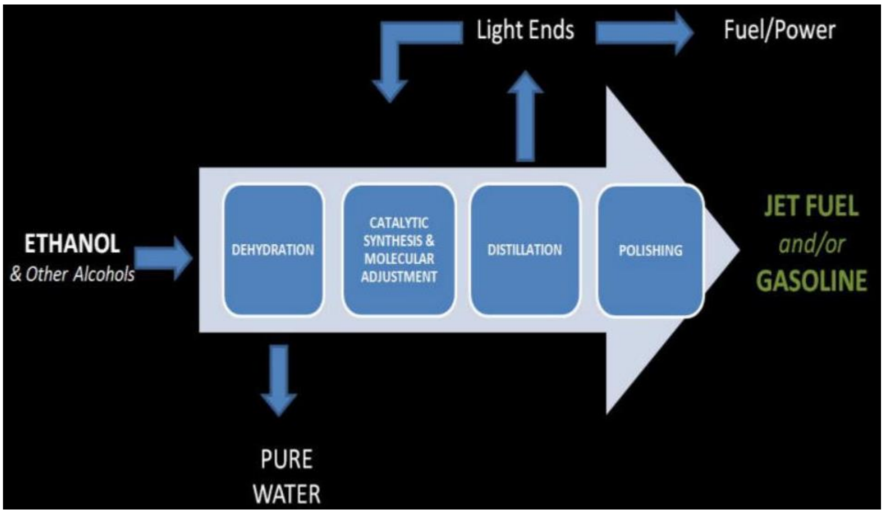

Figure 7. Byogy Renewables method [23]

Hydroprocessed Esters and Fatty Acids (HEFA)

The Hydroprocessed Esters and Fatty Acids (HEFA), also known as Hydroprocessesd Renewable Jet Fuel (HRJ), can be based on animal fat, vegetable oils, or even used cookin oil. These mixtures contain carbon, so they produce greenhouse gases when burned, but not as much as conventional fuels, and they free from ash, sulfur and aromatic compounds. Because of their good properties, such as high energy content and cetane number, they do not cause corrosion, thermally stable liquids, they can be used in conventional engines, but they have a high paraffin content, so their freezing point is inadequate. Researchers from IFPEN[6] and Shell have jointly produced two types of HEFA (HEFA 1 and HEFA 2), which have been mixed with Jet A-1 fuel and have been tested. Their results are shown in Table 3 [20][24].

Analysis	Density at 15 °C [kg/m^3]	Freezing point [°C]	Viscosity at 20 °C [mm^2/s]	Flashpoint [°C]
Jet A-1 specification	775-840	–47 max.	8,0 max.	38 min
HEFA1	773,5	–27,0	11,72	67
Jet + 10% HEFA1	800,0	–49,0	4,426	43
Jet + 20% HEFA1	797,0	–46,5	4,859	43,5
Jet + 30% HEFA1	794,0	–44,5	5,363	45
HEFA2	765,9	–57,5	7,517	68
Jet + 75% HEFA2	775,0	–56	6,335	58

Table 3. Characteristics of Jet A-1, HEFA1 and HEFA2 fuels and their mixtures (own edition) [24]

From the Table above, it can be seen that conventional and alternative fuel blends meet their requirements.

Biodiesels

Biodiesels are based on plant oils (coconut, palm kernel, babassu, etc.) or animal fats, just like HEFA. They can be used alone or as a mix, because their viscosity and specific energy value are close to the traditional fuels, in addition, they have excellent lubricating properties, but its inflammation point is much higher. Their disadvantage is that they have a higher freezing point compared to kerosene. More attention should also be paid to storage, because the fatty acids in

[6] IFP Energies nouvelles

them are highly susceptible to oxidation, but this can be eliminated by adding various additives. During their burning, 98% less sulfur and 50% less floating particle are released into the environment [20].

Researhers are conducting promising research with Fatty Acid Methyl Esters (FAME) to produce biodiesels. The advantage of this alternative fuel is that it contains oxygen that can reduce the carbon and soot content of the fuel during burning, furthermore that it can be produced with less energy, like traditional companions. The following Table shows the properties of Distilled Fatty Acid Methyl Esters (DFAME) from palm kernel and commercially available Jet A-1 blends [19].

Palm kernel DFAME (PDFAME)					
% DFAME		0	5	10	20
Colour and aspect		clear	clear	clear	clear
Elemental composition	**C [%]**	84.12	84.47	84.17	82,57
	H [%]	14.67	14.24	13.97	14.11
	O [%]	1.22	1.29	1.86	3.32
	N [%]	-	-	-	-
	S [%]	-	-	-	-
Density at 15 °C [kg/m^3]		791.0	802.3	805.5	811.8
Higher heating value [MJ/kg]		46.04	45.68	45.17	44.21
Lower heating value [MJ/kg]		42.90	42,64	42.18	41.19
Energy density [GJ/m^3]		33.93	34.21	33.98	33.44
Viscosity at –20 °C [mm^2/s]		3.42	3.51	3.67	4.06
Viscosity at 40 °C [mm^2/s]		-	-	-	-
Flash point [°C]		43.0	43.5	45.0	45.5
Freezing point [°C]		–62.0	–60.0	–48.3	–41.5
Smoke point [mm]		23.33	24.33	25.67	26.67
Copper strip corrosion, class		1a	1a	1a	1a

Table 4. Properties of the Blends of Palm Kernel with Fossil Kerosene with Additives Jet A-1 [19]

METHODS OF PRODUCING BIOFUELS

At the moment, it is not just a question of a new fuel that does not pollute its environment during combustion, but if possible, use renewable energy sources to produce it. There are several ways to produce biofuels for aircraft. Applying of these methods depends largely on the raw material and the type of final product. The methods presented can be used alone or as part of a process.

Biochemical procedures

Alcohol can be produced in several steps using biochemical methods, which are based on carbohydrates (they produce from biomass). The basis of the Direct Sugar to Hydrocarbon (DSHC) process is the sugar that can be obtained directly from plants or from complex carbohydrates (cellulose, starch). In the DSHC method, hydrolysis followed by fermentation followed by hydroprocessing is used to obtain the desired compound. Burning the resulting fuel produces 82% less greenhouse gases [20].

For the Alcohol To Jet (ATJ) method, alcohol is produced from carbohydrates (sugar, starch, cellulose) in the course of fermenatation or from synthesis gas (from waste). The resulting compound has to undergo dehydration, oligomerization, distillation and hydrogenation to produce a hydrocarbon fuel. The process is not costly, and the raw materials are not expensive and so it can be considered economical [20].

Thermochemical procedures

In addition to biochemical methods, thermochemical processes are also used to produce biofuels. One of the most significant is Fischer-Tropsch synthesis (Fig. 8), which is also used as a self- or intermediate process.

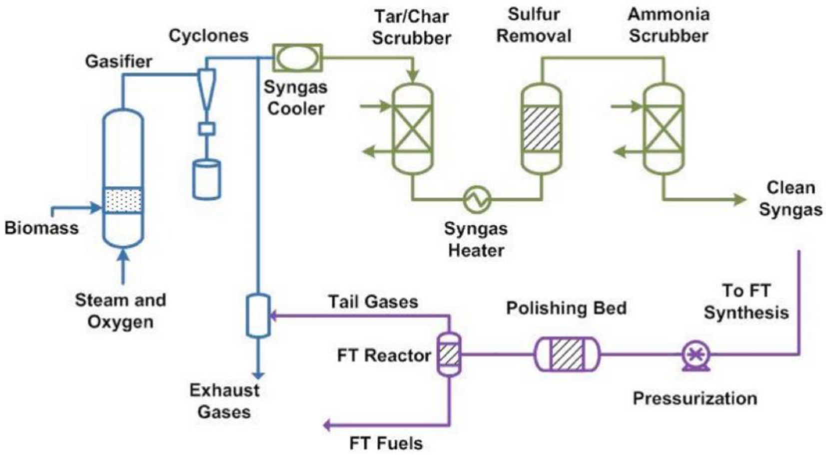

Figure 8. Fischer-Tropsch synthesis [25]

At the beginning of this method, the biomass is gasified with oxygen and steam to form a synthesis gas consisting of CO and H_2. This process takes place between 150 and 300 °C using catalysts from various metals (nickel, iron, etc.). Several types of hydrocarbons can be formed at the end of the process, which depend on the applied temperature and the catalysts as well. About the produced alternative fuel can be said to burn more clearly (does not contain sulfur and aromatic compounds), but its lubricating ability is much lower than its conventional counterparts, and is therefore used as a mixture rather than in itself. The process itself is very costly, but researchers, developers are trying to make it more economical and fitting it into sustainability [20].

In the Biomass To Liquid (BTL) process (Fig. 9.) FT synthesis is used. Before it the biomass is pretreated in mechanical and/or chemical paths, using gasification, purification. If the above mentioned procedure is omitted, pyrolysis is used instead of it and then hydroprocessing [20].

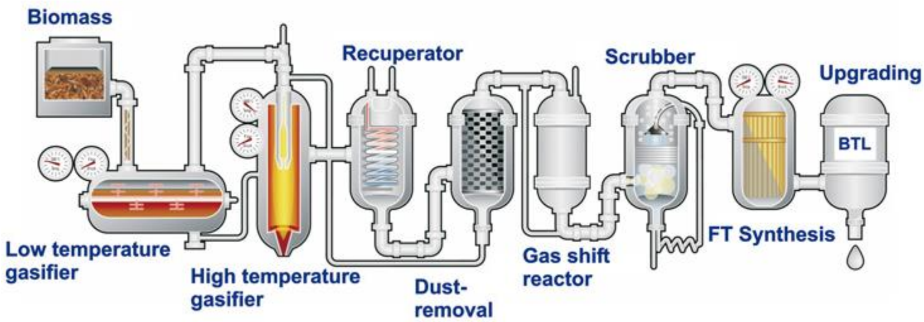

Figure 9. Equipment for the BTL procedure [26]

Pyrolysis is used to break down biomass, which can take place at different temperatures in an oxygen-poor or free environment:

- low temperature (above 500 °C alatt), carbonization;

- medium temperature (500–800 °C), quick pyrolisis;
- high temperature (above 800 °C), gasification [27].

The final product is gaseous (methane) and liquid (hydrocarbon) materials.

Hydroprocessing

A hydroprocessing method is a complex process consisting of two parts:

- first refine the animal fat or vegetable oil with a hydrogenation catalyst,
- followed by isomerization to change the structure of the compounds formed in the previous process so that their composition remains the same.

During the process, oxygen is withdrawn from the system and hydrogen is introduced, which has two variants: one does not change the fatty acid chain even after hydrotreatment, but the water appears next to it, at the other the chain is shorter than the other, and CO_2 is produced. In both cases, HEFA (HRJ) fuel is generated, which, as described in the previous chapter, can only be used as an additive for the time being. (Fig. 10.) [24].

Figure 10. HRJ blends [28]

Transesterification

Transesterification can produce biodiesel from vegetable oil or animal fat. During the process, the raw material is reacted three times as much with alcohol (economically methanol) and catalyst (alkali), and at the end of the process biodiesel and glycerol are produced. The obtained alternative fuel is not in use at this status because of the presence of glycerine and alcohol residues. These compounds are removed by repeated aqueous passage [14].

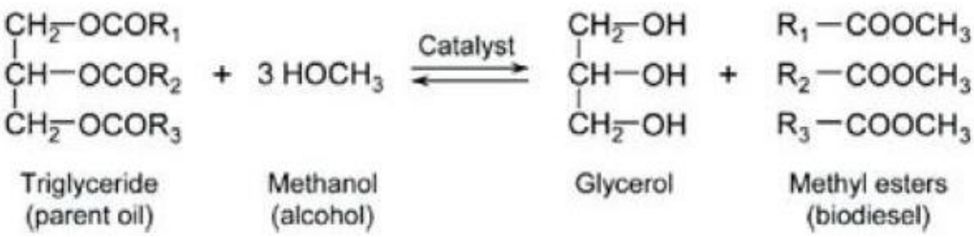

Figure 11. Process of transesterification [14]

SOME APPLICATIONS OF BIO FUELS

The Ipanema EMB 202A aircraft manufactured by the Brazilian Embraer company works with ethanol. They are mainly used in agriculture. In Brazil, ethanol is principally produced from sugar cane, so the producers of this plant are mostly the users of the above mentioned aircraft. By 2014, 269 of these aircraft were sold [29].

Figure 12. Ipanema EMB 202A [30]

In 2013, a successful test flight was performed by a Sikorsky UH-60 Black Hawk helicopter of the US Army (Fig. 13) with a 50% ATJ (produced from corn) blend, which produced by Gevo company. In the following years, the US Navy also tested it in the „Farm to Fleet" program together with the US Army [31].

Figure 13. Black Hawk helicopter flying with 50% ATJ blend [31]

Not only the US Army made an agreement with Gevo. Working in partnership with the Queensland Government, Brisbane Airport Corporation, US-based biofuel producer Gevo, Inc. and supply chain partners Caltex and DB Schenker, Virgin Australia led the procurement and blending of sustainable aviation fuel, or biojet, with traditional jet fuel for supply into the fuel infrastructure at Brisbane Airport. As a result of the trial, biojet has now been used to fuel 195 domestic and international flights departing from Brisbane Airport, travelling more than 430,000 kilometres to destinations across Queensland, Australia and around the globe [32].

In the summer of 2018, in Leeuwarden airbase of the Royal Netherlands Air Force launched a test of Sustainable Aviation Fuel (SAF) on a F-16 fighter aircraft, which was successful. For the time being, according to plans F-16s will be flying with this 5% blend. This fuel is made from used cooking oil at Paramount, California, in the plan of the World Energy company. Two other companies were involved in the acquisition and delivery: SkyNRG and Shell Aviation.

The SAF reduces carbon dioxide (CO_2) emissions with sixty to eighty percent compared to conventional fuel. The Royal Netherlands Air Force plans to use this fuel more and more on its aircraft at every air base, furthermore, it wants to reduce the use of fossil fuels by 20% by 2030 and by 70% by 2050 [33].

Figure 14. One of the F-16 of the Royal Netherlands Air Force refueled with a mixture of SAF and conventional fuel at Leeuwarden Air Base [33]

California based Solazyme company grows microalgae, from which industrial lubricants and four types of fuel are produced, including for aircraft, called Solajet. Their fuel meets ASTM D 1655 Standard. According to the company, conventional fuels can be replaced with it, reduced smoke emissions from aircraft, reduced maintenance costs, it has longer storage times, and lower levels of flammability [34].

Solajet fuel was also used for test flight with 60% conventional kerosene on November 7, 2011 on United Airlines Boeing 737-800 aircraft for the first time in the world. Within the Eco-Skies program, a flight flew from Houston to Chicago [35].

Figure 15. United Airlines Eco-Skies programme [36]

Within the ecoDemonstrator program, a Boeing 737-800 passenger aircraft was completed in 2012 to test various environmentally friendly technologies, including alternative fuels. These investigations were conducted in December 2014 with a so-called "green diesel" made from animal fat, vegetable and used cooikng oil, which is similar to HEFA and has already been used in ground transport. For the first time in the successful test flight, only one engine of the aircraft was fed with its 15% mixture, and later both [37][38].

Figure 16. Boeing 787 is on test flight with „green diesel" [38]

CONCLUSION

Aviation, either civilian or military heavily involved in environmental pollution CO_2 emission, but it is not just one aspect that motivates researchers to create a new alternative fuel, but also that the price of crude oil is gradually rising, because its economically exploitable quantity decreases. Formerly the main reason of using alternative fuel was that it had emitted less pollutants into the atmosphere while burning. Nowadays, this is not the only reason that makes it as part of the sustainable development, same important that renewable energies are used for its production, and it can be used in existing aircraft without transforming the fuel system (aircraft that are being built today will run for about 30 years).

There are several types of alternative fuel. If we consider the principle of sustainable development and recycling, less solutions are avilable. Humanity is producing more and more waste every day, which can be communal and industrial. It is logical to use them as a raw material for fuels, thus solving the problem of waste disposal. Another viable option is to produce various fuels from algae oil. Here, too, we can solve several problems at the same time, because we can produce fuel decrising the atmospheric CO_2, like the algae use carbon dioxide from the atmosphere for their survival and growth, reducing the amount of this component in the atmosphere. Abroad, there are so-called algae farms that have been installed next to large polluting plants or airports to clean the air.

Testing biofuels has been going on for years in both the military and civilian sectors. Aircraft companies, airlines, various agencies, departments, universities, research institutes, fuel companies and, last but not least, users have join their forces with each other to develop the right biofuels that are less polluting like the today used traditional fuels. It is true that aviation adds about 3% to environmental pollution, but it should also be keep in mind that the number of flights have been increasing year by year, as more and more people have chosen this way of traveling, so it is likely that value will only increase if we do not change our attitude towards our environment.

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BIOMASSZA, MINT A LÉGIJÁRMŰVEK TÜZELŐANYAGAINAK NYERSANYAGA

A biomasszával nap, mint nap találkozhatunk, hiszen körülvesz minket, ételként fogyaszthatjuk, főzhetünk vele, hulladékká válhat. Ugyanakkor nyersanyagként is használhatjuk őket. Olyan tüzelőanyagok állíthatók elő belőle légijárművek számára, amelyek ezeket alkalmazva kevesebb károsanyagot bocsátanak ki, ráadásul egyéb környezetet védő megoldást is nyújtanak. Már utasszállító és mezőgazdasági repülőgépek mellett katonai légijárművek is használnak repülésükhöz olyan tüzelőanyagokat, melyeket állati zsiradékból, növényi olajból vagy szilárd hulladékból, azaz biomasszából állítanak elő. Több fajtájuk is létezik alapanyaguktól és előállítási módjuktól függően, melyek bemutatásra kerülnek a cikkben.

Kulcsszavak: *repülés, biomassza, biotüzelőanyag, bioalkohol, HEFA, FAME, SAF*

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A kutatás a fenti projekt „AVIATION_FUEL” nevű kiemelt kutatási területén valósult meg.

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