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TECHNOLOGICAL PROCESSES IN THE PRODUCTION OF SUSTAINABLE AVIATION FUELS

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Abstract: *Air transport expansion in recent decades has been continuous. The main aviation fuels used so far are mainly petroleum products, the annual consumption of which (2017) amounts to approximately 300 Mt. The gases emitted by the aviation industry (carbon dioxide CO_2, nitrogen oxides, sulfur dioxide) exert a powerful pressure on the environment. The development of the aviation industry will also provoke a growing demand for fuels, and the fuels used will deepen the environmental, social and economic effects. This necessitates the implementation of the concept of sustainability of aviation transport and the replacement of conventional with sustainable aviation fuels (SAF). In the coming years, the production of aviation biofuels will increase as part of the use of renewable energy and the development of the circular economy-bioeconomy. This report briefly presents the current status of developed and deployed bioreactive fuels in aviation; certified technologies; the potential raw materials that can be used and an assessment of the economic and environmental characteristics of biokerosenes. The report also indicates global initiatives and policies to promote the use of biofuels, as well as the commitments made by the airlines.*

Keywords*: *jet fuel, greenhouse gases (GHG), sustainable aviation fuel (SAF), feedstocks and processes for SAF

1. Introduction

Air transport is among the most dynamic and profitable sectors of the world economy. It is a powerful enabler of economic growth, employment, trade and tourism. It transports billions of passengers and cargo between remote regions. According to an estimate by The International Air Transport Association (IATA), in the upcoming years the number of passengers will grow from 3.8 billion in 2017 to 8.2 billion by 2037, and by 2050 they will be approximately 16 billion. At the same time, the aviation industry has a negative impact on the environment. The main impacts caused by aircraft are related to high levels of noise, toxic and acidic waste gases released into the atmosphere, as well as greenhouse gases with a proven effect on global warming. To date, evaluations by experts indicate that CO_2 emissions in this sector are relatively low when compared to other parts of the transportation sector. Although aviation currently contributes only 2-3% of total greenhouse gas emissions, this share will increase in parallel with the expected growth of the industry by 4-5% per year. In response to the growing problem, the IATA has set a challenging target to reduce net CO_2 emissions from the aviation industry by 50% by 2050 compared to 2005 levels [1].

Negative impacts from aviation are mainly due to the burning of conventional kerosene, in which about 2.5 kg of CO_2 is released from one liter of kerosene. Each

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medium-sized medium-haul airplane, e.g. Airbus A320, uses about 2,700 liters of kerosene per flight hour, emitting 6,750 kg of CO_2 at that time [2].

The main technological solutions to reduce the impact of air transport on the environment are aimed at achieving improvements in the design and characteristics of the engine and airframe, as well as at the development of alternative aviation fuels. Efforts to achieve the former are focused on maximizing the fuel efficiency of aircraft, both by reducing the weight and drag of the airframes and by increasing the energy conversion efficiency of the engines.

The obligatory inclusion of airlines in the European Union Emissions Trading System (EU ETS) for intra-European flights is the first step towards achieving the goals [3]. Implementation of the strategy to improve aviation's sustainable independence from fossil fuels is of utmost importance. The ultimate goal is to replace conventional (CAF-conventional aviation fuels) aviation fuels with alternative aviation fuels (AAF-alternative aviation fuels).

Conventional aviation fuels (CAF) are obtained entirely from petroleum sources such as crude oil, liquid natural gas condensates, heavy oil, and produced by refining and secondary processing of oil. A common example of a CAF is the traditional Jet-A1 fuel. Unlike CAF, alternative aviation fuels (AAF) originate from non-petroleum sources. These sources can be renewable or non-renewable (e.g. biomass, natural gas, electricity or hydrogen). In fact, fuels based on renewable sources in the AAF are called SAF [2].

2. CORSIA Sustainable Aviation Fuels

To be eligible for ICAO CORSIA, CORSIA eligible fuel (CEF) need to adhere to sustainability standards. These are fuels with life-cycle greenhouse gas emissions of at least 10% less than petroleum jet fuel and are not produced from biomass derived from high-carbon land. Based on a comprehensive assessment of petroleum jet fuel production, the average life-cycle greenhouse gases (GHG) value is determined to be 89 gCO_2 e/MJ well-to-track (WTW), including crude oil production, transportation and refining, transportation of jet fuel and its combustion. Two categories of CEF fuels exist: SAF and low carbon aviation fuels (LCAF). While SAFs can be produced from renewable energy sources or waste, LCAFs refer to fossil fuels; however, they have at least 10% lower life-cycle greenhouse gas emissions than the base petroleum jet fuel [4].

SAFs are now a reality. Their production is based on various processes of conversion of certain raw materials. A large number (over 200,000) of commercial flights are now operated with SAF [5]. The main raw material for the production of biokerosene is biomass or substances obtained from it, as well as waste products from various technological processes. In compliance with European Renewable Energy Directive, which meets the sustainability criteria of CORSIA, some of the raw materials for obtaining SAF are presented in Table 1 [6].

3. Technological Processes for the Production of SAF

Various types of raw materials can be converted into aviation fuels through specific technological processes. The drop-in biofuel production, for example, generally proceeds in two distinct phases that include the production of an intermediate product and a second phase of

Table 1 Feedstocks for SAF

Feedstocks for SAF		
Residues & waste	**Oil**	**Biomass**
Agricultural residues	Corn oil	Sugarcane
Foresrtry residues	Soybean oil	Sugar beet
Minicipal solid waste (organics)	Rapesced oil	Poplar

Used cooking oil	Palm oil	Miscantus
Tallow	Oil for *Brassika carinata*	Palm fattyacid distillate

upgrading the intermediate into finished fuels. The American Society for Testing and Materials (ASTM) has certified six processes for the production of fuels for use in aircraft that meet the ASTM D7566 standard. The technical specifications of the fuel ensure that the product is safe for usage in aircraft by meeting the same standards for safety as conventional jet fuel -ASTM D1655 [7].

Of all the potentially defined SAF sustainable aviation fuels, biokerosene and synthetic kerosene appear to be the most promising and with a possible short deployment period. The maximum permissible share of these fuels when mixed with conventional fuels is up to 50%. The primary source for manufacturing biokerosene is biomass or its derived substances. Waste generated from diverse technological processes can also be used. Among the most suitable biomass feedstocks are algal species as well as lignocellulosic cover crops, which are grown for erosion control and soil fertility improvement. These crops are characterized by intensive growth and the ability to repeatedly generate a considerable portion of biomass. Valuable sources for obtaining biokerosene are the species Miscanthus (elephant grass), Panicum virgatum (arrow grass), corn, sugar cane [6].

For the processing of each group of potential raw materials, specific chemical and physical processes, apparatus and technologies are used. Specific chemical and physical processes, apparatus, and technologies are used for the processing of each group of potential raw materials.

3.1. Fisher-Tropsch-*Biomass to Liquid* (FT-*BTL*)

Hydrotreated synthetic paraffinic kerosene (SPK) is produced primarily from wood and plant biomass and solid organic waste (MSW). The initial raw materials - sawdust, straw and other types of plant mass - are initially converted into gas for biosynthesis through gasification. Gasification is preceded by preliminary processing of the raw materials - sieving, cutting into certain sizes and drying. In a gasifier, under conditions of high pressure (between 20 and 70 atm) as well as high temperature (above 1000 °C), the biomass is fluidized through the use of air, oxygen or gasifying agent. The products of the process are solid, liquid and gaseous substances. Of all the gases in the largest volume are: CO (21-22 %), H_2 (16-21 %), CO_2 (10-12 %), CH_4 (3-4 %) and N_2 [8]. This is followed by a purification step to obtain pure biosynthesis gas that meets the requirements for Fischer-Tropsch synthesis. The third stage takes place in a Fischer-Tropsch catalytic reactor for the synthesis of hydrocarbons, from which the fuel fractions are separated after refining. A schematic of the Fischer-Tropsch-Biomass to Liquid (FT-BTL) process is shown in Figure 1. In the Fischer-Tropsch synthesis, transition metals (such as cobalt, iron, ruthenium) are used as catalysts. Nickel favors the formation of methane.

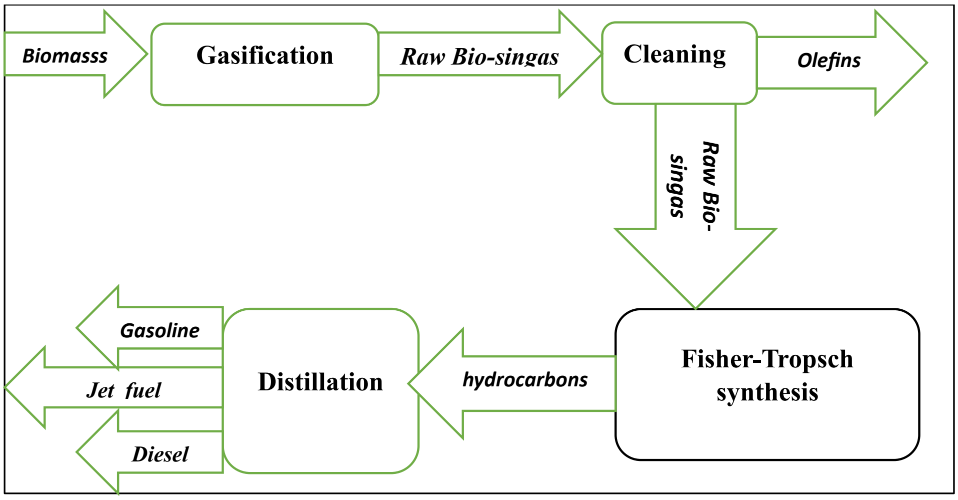

Figure 1: Schematic of the Fisher-Tropsch-Biomass to Liquid (FT-BTL)

3.2. Alcohol-to-Fuel

Alcohol-to-Jet (ATJ) is a fuel obtained by converting both lower alcohols (ethanol, methanol, butanol) and higher fatty alcohols. The process of turning alcohol into fuel involves three stages-dehydration, oligomerization, and hydrogenation. A schematic of the ATJ process is shown in Figure 2.

The starting alcohols are obtained by fermentation of sugars (carbohydrates) or synthetically. Ethanol requires a purity of 99.5-99.9% (anhydrous). The conversion of *n*-butanol and *i*-butanol into hydrocarbons containing from 8 to 32 carbon atoms proceeds according to an analogous scheme.

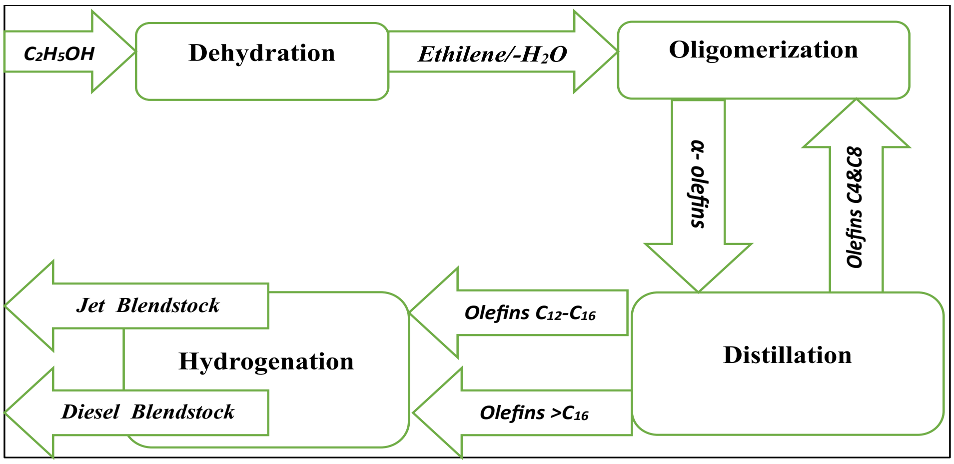

Figure 2: Schematic of the Alcohol-to-Jet (ATJ) process

3.3. Oil-to-Jet (OTJ) Fuel

This type of synthetic paraffinic kerosene is produced from hydrotreated esters and fatty acids (HEFA), from vegetable and animal fats, as well as from waste cooking fats. Three main processes are used for OTJ conversion: hydrotreated esters and fatty acids (HEFA); catalytic hydrothermolysis (CH) and hydrotreated depolymerized cellulose jet (HDCJ), also known as fast pyrolysis with upgrade to jet fuel. For now, only HEFA fuels have been approved for blending with conventional fuel and possess an ASTM specification [7].

The starting materials are triglycerides (from oils) and free fatty acids. Renewable fats and oils of vegetable origin contain residues of both saturated and unsaturated higher fatty acids. Through catalytic hydrogenation, unsaturated fatty acids and triglycerides are converted to saturated. The next stage is the hydrolysis of triglycerides to glycerol and the three moles of higher fatty acids. Free fatty acids undergo decarboxylation and subsequent hydrocracking and hydroisomerization (Figure 3).

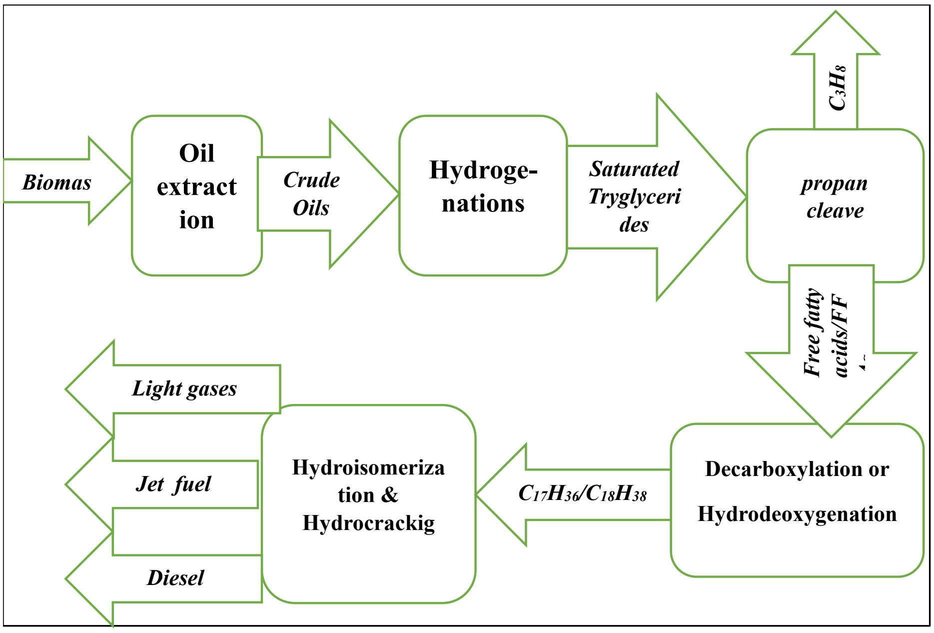

Figure 3: Schematic of the Oil-to-Jet (OTJ) process

3.4. Hydroprocessing of Fermented Sugars-Synthetic Iso-Paraffinic Fuels

HFS-SIP fuel originates from fermenting sugars sourced from renewable materials like corn and sugarcane, resulting in bioalcohols such as ethanol or butanol. Through hydroprocessing, these bioalcohols are converted into a range of hydrocarbons. The HFS-SIP process involves multiple stages and technologies, including preparing raw materials, fermentation, hydrotreatment, refining, and blending [9].

SIP from hydroprocessed fermented sugars as well as “Sugar to Jet” (STJ) technologies have been developed and evaluated in terms of their efficiency and applicability. Other technologies are at the stage of scientific research and development, whose refinement and approval are pending. The European Parliament and the Council of the EU reached an agreement on the use of SAF at EU airports in the following way: 2% by 2025, 6% by 2030 and 20% by 2035, up to a maximum of 70 % by 2050 [9]. Of these amounts, 1.2% in 2030 and 5% in 2035, rising to 35% by 2050, will be produced by converting power to liquid (PTL- Power to liquid).

Several studies [2, 10], including those focusing on the environment, have examined the economic impacts of using SAF versus traditional fossil kerosene. The production costs for various Bio-Jet Fuels range from $2.5 to $9.5 per gallon, while the base minimum price is considerably higher than the market jet fuel price (2–4 fold). Continued advancements in these emerging technologies are expected to drive down costs and prices over time. Economic experts forecast that the SAF market will grow substantially by 2030, reaching a value of 15-16 billion USD, compared to the 220 million USD before 2021. There is still a substantial journey ahead before renewable aviation fuels turn into economically feasible products. Without some kind of motivation to encourage their adoption, the aviation industry will persist in relying on conventional fuels.

4. Conclusions

The complex application of technological, administrative and regulatory measures will undoubtedly lead to a reduction of the pressure of aviation on the environment. The introduction of sustainable aviation fuels will significantly decrease carbon emissions on the one hand, but will also contribute other benefits (the development of new industry, reduction of dependence on oil, development of agriculture in less fertile areas, afforestation of terrains). Along with the expected benefits, the negative consequences should also be mentioned: depletion and exhaustion of the soil, increased consumption and pollution of water with fertilizers and agrochemicals, disruption of the market balance (due to subsidizing the cultivation of organic crops), increase in the prices of agricultural goods (which are both raw materials in the food industry and in the production of biofuels), danger of excessive deforestation and others. In the short term, SAFs can contribute to benefit the sustainability of the aviation sector. Achieving global long-term goals for zero carbon emissions requires the implementation of revolutionary new technologies to propel aircraft through new energy sources-liquid hydrogen, electricity, or a hybrid system. The mass implementation of scientific applications in this field is yet to come.

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