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Alternative Aviation Fuel Types Used in Aircraft Engine

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Abstract: Air transportation is a preferred mode of transportation due to the fastest of methods transport. In this respect, air transport in terms of passengers and freight has been increasing continuously since the 1970s. Due to the increasing number of aircraft and flights, the demand for aviation fuel also increases. Jet engines and auxiliary power unit (APU) are the two main sources of aircraft emissions as they use fuel. Aircraft engine emissions have not received as much attention as emissions from other energy sources until recent years. However, the International Civil Aviation Organization (ICAO) has set limits for commercial jet engines in respect to nitrogen oxides, unburned hydrocarbons, carbon monoxide and smoke emissions. These limitations were determined for a specified landing and take-off cycle (LTO) to limit emissions near ground level as well as indirectly limit emissions at altitude. The world's carbon dioxide emissions of 2%, originate from air transportation. In order to reduce greenhouse gas (GHG) emissions, especially carbon dioxide emissions, the use of alternative fuels instead of fossil fuels is increasing in aviation transportation. In this study, it is aimed to examine the use of alternative aviation fuel types produced by different methods in aircraft engines.

Keywords: Aircrafts, Kerosene, Vegetable oil, Sustainable aviation fuels, Emissions

Introduction

The jet fuel used in aircraft engines to obtain propulsion as a result of combustion is of petroleum origin. According to United States (US) Energy Information Administration (EIA), approximately 3-4 gallons of jet fuel are obtained from a 42-gallon barrel of crude oil (Refining crude oil - U.S. Energy Information Administration (EIA), 2023) and fuel costs of airlines are approximately 30% of their operating costs (Chiaramonti et al., 2014). Air transport produced 781 million tons of CO_2, which corresponds to 2% of greenhouse gas, by consuming 177 billion liters of kerosene from 25000 aircraft to carry 6 billion passengers in 2015 (Baumi et al., 2020). The percentages of carbon dioxide by sectors between the years 2019-2022 are shown in the Figure 1 (Global CO_2 emissions by sector, 2019-2022 – Charts – Data & Statistics, 2023), carbon dioxide emissions are in the order of highest to lowest in power, industry, transportation and buildings. Global carbon dioxide emissions fluctuated during this three-year period. The distribution of carbon dioxide emissions in transport sector is shown Figure 2 (Global transport CO_2 emissions breakdown 2021, 2023).

When we look at the CO_2 emissions of transportation vehicles in particular, it can be seen from the Fig. 2 that the aviation sector is 9%. Due to the fact that the number of passenger vehicles is higher than other vehicle types the highest percentage was realized in passenger cars with 39%.

In addition to carbon dioxide emissions that cause global warming, The ICAO has get limitations for nitrogen oxides, unburned hydrocarbons, carbon monoxide and smoke emissions from commercial jet engines according to landing and take-off cycle (LTO). Figure 3 (ICAO Standards and Recommended Practices: Annex 16, Volume II, 2023), depicted to ICAO engine emission certification LTO cycle.

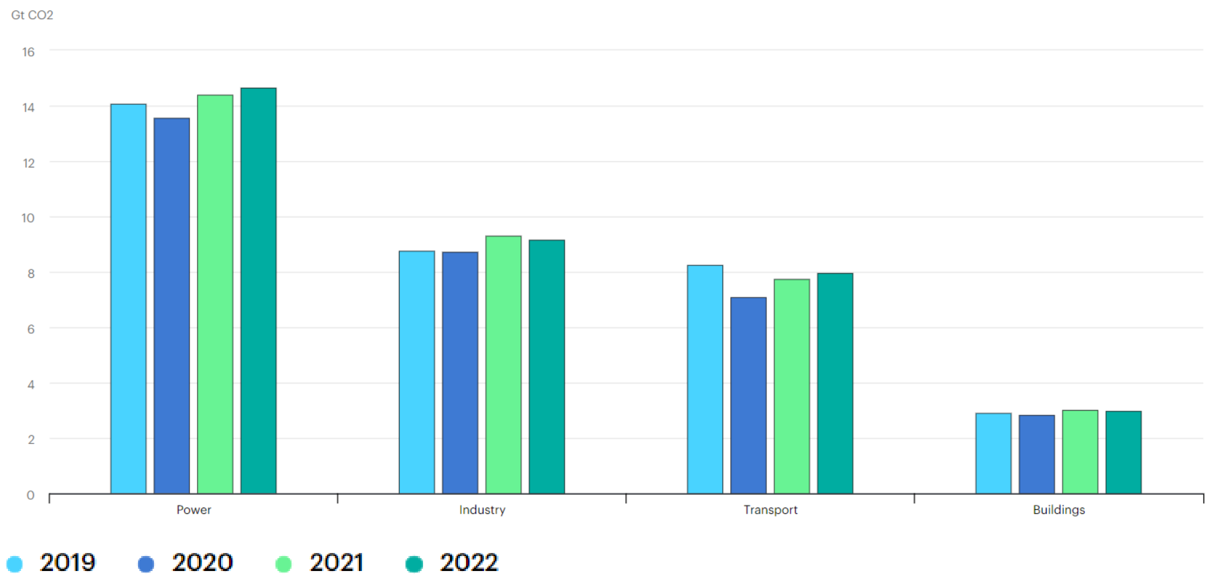

Figure 1. Global CO_2 emissions by sector, 2019-2022 (Global CO_2 emissions by sector, 2019-2022 – Charts – Data & Statistics, 2023)

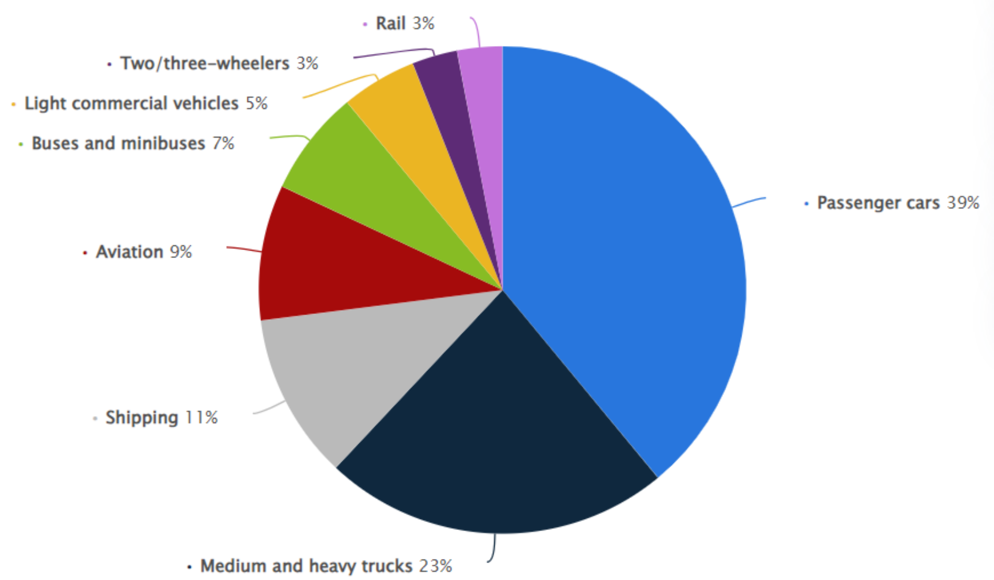

Figure 2. CO_2 emissions from mode of transports worldwide in 2021 (Global transport CO_2 emissions breakdown 2021, 2023)

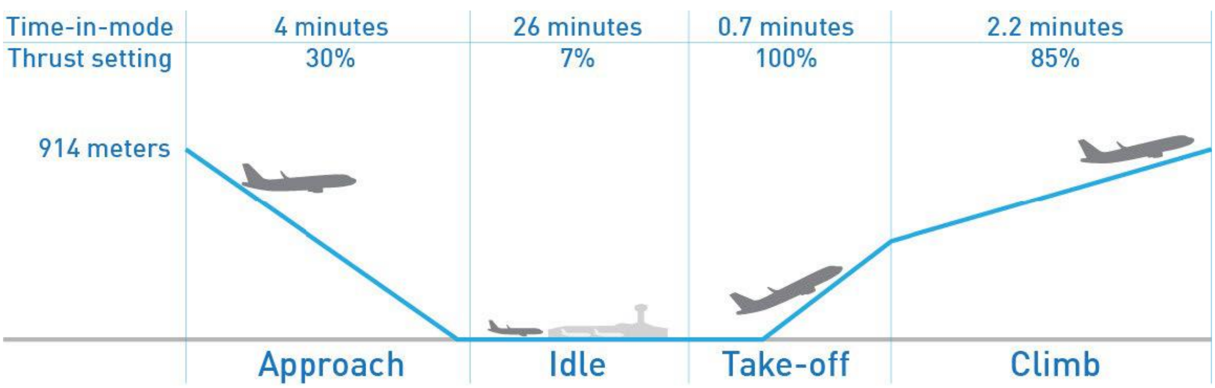

Figure 3. ICAO engine emission certification landing and take-off (LTO) cycle (ICAO Standards and Recommended Practices: Annex 16, Volume II, 2023)

Figure 4 (Tokuşlu, 2021), indicates the NOx, CO and HC emissions for LTO modes. The highest NOx was in the climb mode, CO in taxi mode and HC in taxi mode. Table 1 (Tokuşlu, 2021), shows the emission factors of a number of aircrafts that from the ICAO Engine Exhaust Emission Databank.

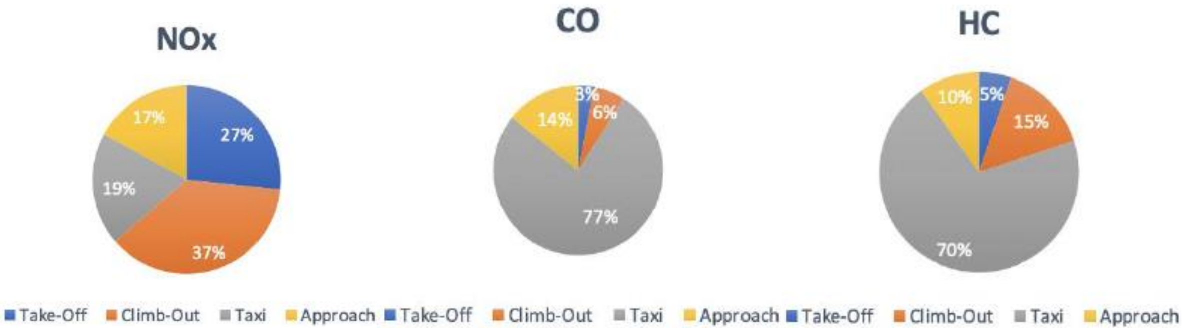

Figure 4. The distribution of aircraft emissions (NOx, CO, HC) for LTO modes (Tokuşlu, 2021)

Liu et al., (2020) in their study on alcohol/kerosene mixtures; short-chain alcohols such as ethanol, n-propanol and n-butanol were blended with aviation kerosene (RP-3) at 30%, 50% and 70% by volume, respectively. They found that the brake thermal efficiency (BTE) (alcohol content ≥ 50%) of alcohol/kerosene mixtures is higher than gasoline. The brake thermal efficiency of E70, P70 and B70 was improved 2.15%, 3.52% and 6.51%, respectively. In terms of carbon monoxide (CO) and nitrogen oxides (NOx), lower values were obtained in the blended fuels. The CO emissions of E70, P70 and B70 fuels reduced by 39.8%, 38.5% and 49%, respectively, and also decreased in HC, CO and soot emissions as the alcohol content in the mixture increased. Among the experimental fuels, n-butanol/kerosene blends had better combustion and lower emissions, with higher efficiency and reduced HC, CO and soot emissions (Liu et al., 2020).

Table 1. Emission factors (Tokuşlu, 2021)

Aircraft	CO (kg/LTO)	NO_X (kg/LTO)	HC (kg/LTO)
Boeing 737	16.9	9.0	4.1
Boeing 727, 757	25.4	13.4	6.1
Boeing 747	65.8	47.7	19.6
Boeing 767, 707	119.1	11.6	99.0
Airbus A300, 310	119.1	11.6	99.0
Airbus A319	6.35	8.73	0.59
Airbus A320	24.6	9.7	5.9
Tupolev 154	25.4	13.4	6.1
Tupolev 134	24.6	9.7	5.9
Saab 340	22.1	0.3	14.1
DC9	16.9	9.0	4.1
CRJ2	4.14	4.41	0.04
Tupolev 154	25.4	13.4	6.1
Tupolev 134	24.6	9.7	5.9
Fokker F27	22.1	0.3	14.1
Fokker F28, 50, 100	64.1	8.2	47.1
Concorde	384	41	112

SAF, which is used to propel the aircraft engine, is a biofuel with similar properties to conventional jet fuel, but with lower carbon footprint. Thanks to the technology and raw materials used to obtain SAF can significantly greenhouse gas emissions compared to conventional jet fuel (Sustainable Aviation Fuels, 2023). Governments assent to the usage of SAF and its amendment effect on the decarbonization, which was held in October 2022 of 41st Assembly of the ICAO for Long Term Aspirational Goal (LTAG) about climate (IATA, 2023).

Thanks to SAFs, which can be obtained from waste oils and fats, green and municipal wastes and non-food products and used in aviation today, CO_2 emissions are reduced by up to 80% (Net zero 2050: sustainable aviation fuels, 2023). With the use of SAFs, it aims to achieve net zero carbon emissions through the impact of innovative propulsion technologies and other efficiency developments to ensure maximum reduction in emissions in the aviation industry. Figure 5 (Developing Sustainable Aviation Fuel (SAF), 2023), shows the projection for net zero carbon attain in 2050. To achieve this purpose, SAF production is increasing rapidly. Table 2 (IATA, 2023), proves this increment.

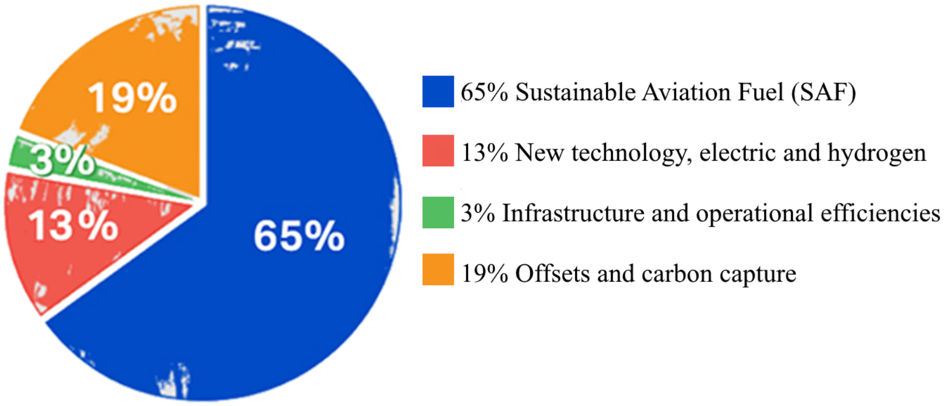

Figure 5. Projection for net zero carbon attain in 2050 (Developing Sustainable Aviation Fuel (SAF), 2023)

Table 2. SAF production (IATA, 2023)

Year	2019	2020	2021	2022E
Estimated SAF output (Million liters)	25	62.5	100	300-450

There are technical impediments to the changeover to electric or hydrogen powered aircraft and it is anticipated that liquid fuels will continue until 2050. This is especially true for medium and long distance flights, which account for two-thirds of aviation emissions. Sustainable aviation fuels (SAF) will be important for the goal of reducing greenhouse gas (GHG) emissions by 50% by 2050. It is stated that the carbon intensity of petroleum-derived jet fuel is between 85 and 95 grams of carbon dioxide equivalent per megajoule of fuel (g CO_2e/MJ) of which approximately 73 g CO_2e/MJ is due to the combustion of the fuel and the rest is due to the extraction, refining process and transportation of this fuel (Pavlenko & Searle, 2021). Although synthetic jet fuels have advantages such as without sulfur, low viscosity at low temperatures, high thermal stability and reduced particulate emission, they also have the disadvantages of poor lubricating properties, low volumetric thermal content, prone to fuel system elastomer leakage and increased CO_2 emissions through the production process (Daggett et al., 2006).

Sustainable Aviation Fuel Pathways

Figure 6 (Cabrera & de Sousa, 2022), demonstrates the sustainable aviation fuel pathways today. These pathways will be explained below.

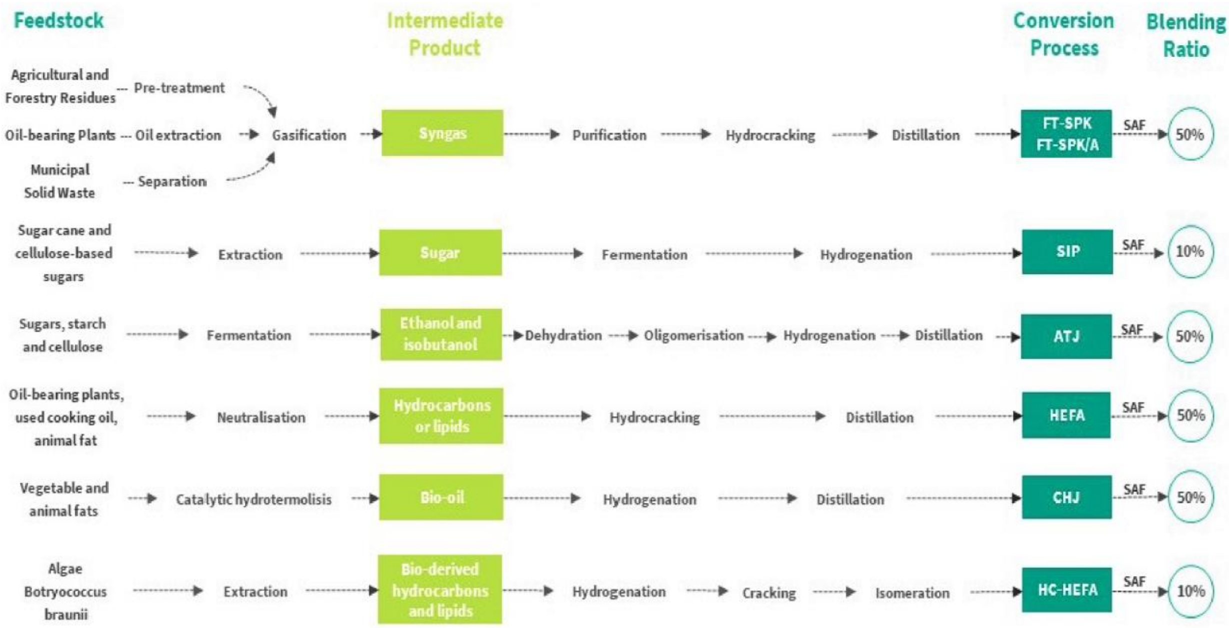

Figure 6. Approved SAF produce methods for D7566 (Cabrera & de Sousa, 2022)

Fischer Tropsch Synthesized Isoparaffinic Kerosene (FT-SPK)

Franz Fischer and Hans Tropsch discovered the method of producing liquid hydrocarbons from coal in the 1920s. Fischer Tropsch-synthesized isoparaffinic kerosene (FT-SPK) FT-SPK was certified by ASTM for inclusion in ASTM D7566 in September 2009. In the FTSPK process, feedstocks such as coal (coal-to-liquid-CtL), natural gas (GtL) or biomass (BtL) are first pre-treated to achieve a homogeneous consistency, followed by a partial oxidation process called gasification to produce synthesis gas or syngas. This syngas consists mainly of a mixture of CO and H_2, with smaller amounts of other gases such as CO_2 and CH_4. It is then cleaned, conditioned and purified. From this syngas is obtained the desired final product such as liquid hydrocarbon fuel (synthetic kerosene and diesel) by means of the catalytic conversion in that using cobalt and iron as catalyst in the FT reactor. FT-SPK/A is a variant of the FT process containing alkylation of light aromatics, mainly benzene in which a fully synthetic alternative aviation fuel is produced, and was approved for inclusion in ASTM D7566 in November 2015.

Fischer Tropsch fuels are characterized by non-toxic, low sulfur, and contain very few aromatics compared to diesel and gasoline, which results in lower emissions such as particulate matter, carbon dioxide and hydrocarbon emissions. Thanks to the higher hydrogen-to-carbon ratio (H/C-ratio) decreased particulate emission may result. Due to the high thermal stability of FT fuels, it is possible to use them at high engine fuel temperatures. In this way, engine fuel efficiency can be increased. On the other hand, the low viscosity of FT fuels at low temperatures improves the operability of aircraft at high altitudes and low temperatures. In addition, thanks to the capability of decrease the temperature of the cooling air of turbine blades and lowering the engine oil temperature increase the durability of the engine. In accordance with the ASTM D7566 standard for SPK and SIP fuels, the aromatic amount should not exceed 0.5% by volume; hereby, the low amount of aromatic should not lead to a notable problem. However, the absence of aromatics can result in lower lubricity properties and seal swelling. The lubricating properties of FT fuels are low, just like HEFA, due to the lack of sulfur (Cabrera & de Sousa, 2022; Fact Sheet 2 – IATA, 2023; Pavlenko & Searle, 2021; Kaltschmitt & Neuling, 2017; Detsios et al., 2023; Marszałek & Lis, 2022; Daggett et al., 2006).

Synthesized Iso-Paraffins (SIP)

Synthesized iso-paraffins (SIP) was also entitled to as direct sugar to hydrocarbon process (DHSC). Synthesized iso-paraffins (SIP) process was approved into ASTM D7566 in July, 2014 by ASTM. From feedstocks such as cellulosic sugars, halophytes, sugar beets, sugar cane and sweet sorghum, with biochemical conversion technology, sugar is converted into hydrocarbon fuel by fermentation. The DHSC process consists of hydrolysis of the biomass, carbohydrate fermentation, purification and hydroprocessing. The sugars are converted into C15 alkene with four double bonded hydrocarbons, called farnesene ($C_{15}H_{24}$) by fermentation which has a higher energy density and longer carbon chain than ethanol or isobutanol. Farnesene is converted into alkane hydrocarbons, called farnesane ($C_{14}H_{32}$), which is afterwards distilled to obtain at 10% blend levels in jet aviation fuel. The DSHC method is the most expensive alternative fuel conversion method, as the complexity and low efficiency of the steps in transforming lignocellulosic sugars into fuels via DSHC lead to high raw material cost and higher energy consumption. Although DSHC-SIP fuel is successful in test flights with a mixing ratio of 20%, it should be used in mixtures with a mixing ratio not exceeding 10%, since there is no synthesized paraffinic kerosene such as FT and HEFA (Fact Sheet 2 – IATA, 2023; Pavlenko & Searle, 2021; Cabrera & de Sousa, 2022; Detsios et al., 2023; Marszałek & Lis, 2022).

HH-SPK (Hydroprocessed Hydrocarbons- Synthesized Isoparaffinic Kerosene) or HC-HEFA

HH-SPK (Isoparaffinic kerosene synthesized with Hydroprocessed Hydrocarbons) denominated as HC-HEFA was certified to ASTM D7566 in May 2020. The feature that distinguishes HC-HEFA from HEFA is that algae called Botryococcus braunii are used as raw materials in HC-HEFA, and HC-HEFA blending ratio up to the 10% (Fact Sheet 2 – IATA, 2023; Cabrera & de Sousa, 2022; Detsios et al., 2023).

Hydroprocessed Fatty Acid Esters and Fatty Acids (HEFA)

Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK): HEFA is obtained from jatropha, algae, camelina, and yellow grease and so on by deoxygenation followed by hydrotreating, hydroisomerization, or hydro-cracking. HEFA was certificated by ASTM for ASTM D7566 in June, 2011.

Priorly 2011, the expression of Hydroprocessed Esters and Fatty Acids was often termed to as hydrotreated vegetable oils (HVO), but a new abbreviation, HRJ, stands for hydroprocessed renewable jet, was emmerged to cover all possible types of raw materials. The type of catalyst used influences the efficiency of the hydrotreating of triglycerides and the composition of products. These products have different carbon number such as green diesel (C14-C20), green jet fuel (C11-C13), green naphtha (C5-C10), and and even green liquid petroleum gas (LPG). HEFA fuels have similar properties to petroleum-based fuels, as well as advantages such as high cetane number, low aromatic content, low sulfur and low greenhouse gases (Sotelo-Boyás et al., 2012; Fact Sheet 2 – IATA, 2023; Tao et al., 2017; Pavlenko & Searle, 2021; Cabrera & de Sousa, 2022).

Alcohol to Jet (ATJ)

Alcohol to jet (ATJ) endorsement for ASTM D7566 is taken place in April 2016 for isobutanol with a blend limit of 50% and for ethanol at blend limit 50% in April 2018. For an alcoholic fermentation can use sugary, starchy and lignocellulosic biomass such as sugar cane, sugar beet, switchgrass, maize and wheat. Producing ATJ fuels as a pure hydrocarbon can be done through biochemical or thermochemical conversion involved dehydration (water elimination), oligomerization (creation of more complex molecules), and hydro processing (addition of hydrogen). The blend ratio of 50% is allowed. If ever there was the aircraft fully Ethanol-powered: Since the ethanol fuel needs approximately 64% more storage volume to meet the energy amount of kerosene, the increase in storage volume causes the aircraft wing to be made 25% larger, resulting in an increase in the empty weight of the aircraft by 20% (Fact Sheet 2 – IATA, 2023; Pavlenko & Searle, 2021; Kaltschmitt & Neuling, 2017; Cabrera & de Sousa, 2022; Detsios et al., 2023; Daggett et al., 2006; Yao et al., 2017).

Catalytic Hydrothermolysis Jet Fuel (CHJ)

The catalytic hydrothermolysis jet (CHJ) process (also denominated hydrothermal liquefaction) similar to those of the HEFA was receive certification in 2020 with a maximum blending ratio of 50%. The reaction steps are cracking, hydrolysis, decarboxylation, isomerization and cyclization that progress at presence of supercritical water (SCW) and with/without a catalyst under high temperature and pressure conditions. FFAs from fats, oils, and greases (FOGs) convert into paraffin, isoparaffin, cycloparaffin, and aromatic compounds (Fact Sheet 2 – IATA, 2023; Pavlenko & Searle, 2021; Cabrera & de Sousa, 2022; Detsios et al., 2023; Marszałek & Lis, 2022).

Co-processing

Co-processing has been approved to ASTM D-1655 in April 2018. Fats, oils and greases are mixed up to 5% by volume with fossil crude for supplying the refining process in conventional petroleum refinery. This method may be cheaper as it can use the existing oil refining infrastructure and save the burden of building a dedicated biorefinery (Prussi et al., 2019; Marszałek & Lis, 2022; Cabrera & de Sousa, 2022; Pavlenko & Searle, 2021).

Conclusion

While studies on reducing the environmental impact of Greenhouse gas (GHG) emissions have been going on in road transport for decades, these studies within the aviation sector have become official since 2009 that FT-SPK as Sustainable Aviation Fuel (SAF) was the first approved (SAF) by ASTM. In order to reduce the carbon footprint, on the one hand, studies on various types of Sustainable aviation fuels have been and continue to be made, and on the other hand, the production and use of SAF fuel is increasing. As a result, International Air Transport Association (IATA) is aimed to attain for net zero carbon in 2050.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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