Alternative fuels for aviation: possible alternatives and practical prospects of biofuels

Renata Adami*1, Patrizia Lamberti1, Vincenzo Tucci1, Liberata Guadagno1, Rosa Arnaldo Valdés2, Oleksandr Zaporozhets3, Pawel Wacnik4, Serhat Burmaoglu5

1 University of Salerno, via Giovanni Paolo II 132, 84084 Fisciano (Italy)
2 Universidad Politécnica de Madrid (Spain)
3 National Aviation University, Kiev (Ukraine)
4 INNpuls Sp. z o.o Hetmańska 40A Street 35-045 Rzeszów (Poland)
5 İzmir Kâtip Çelebi University, İzmir (Turkey)

*Corresponding author: radami@unisa.it

Abstract. The successful implementation of the new European Green Deal in aviation depends on the European aeronautics industry’s ability to develop new technologies able to face the climate changes. The decarbonization in the aviation is very difficult, compared to other transport sector, and one possibility to reduce emissions is by increasing the usage of low-carbon alternative fuels. Among the analyses carried out within the Horizon 2020 project PARE – Perspectives for Aeronautical Research in Europe, one relevant aspect concerns the possible strategies already applied or under study to reach the zero-emission target using alternative fuels.

1. Introduction

Aviation is considered the most difficult transport sector to decarbonize. One possibility to dramatically reduce emissions within the aviation is through the use of low-carbon alternative fuels. Sustainable Aviation Fuels (SAF) are required in order to reach the goals of new EU Green Deal, and the development of these fuels is one of the main commitments of the next EU Framework Program Horizon Europe. The deadline for the complete decarbonization given by the EU is 2050.

The European Union has devoted a great interest in decarbonization and SAF already in H2020 program. According to a query made on the CORDIS EUROPA platform on June 2020, using as keywords: aviation, aeronautic, biofuel, advanced biofuel, sustainable aviation fuel, 43 projects linked to SAF have been financed by the H2020 program. Among them, 25 are specifically funded for the study of SAF. Of these ones, 13 ended on June 2020. The total amount funded by EU is €84.8 and 188 partners from all the European countries have been involved in such SAF-related projects. In particular, in Figure 1 the distribution of the most funded nations is reported by considering the funding associated to the coordinator of the project. The United Kingdom has the highest total contribution EU (€24,734,539), followed by Italy and Germany (respectively €15,217,675 and €15,147,324).
Among the possible solutions for decarbonization of aviation, battery-electric propulsion has the best climate impact because it causes no emissions or emission-related effects. Nevertheless, batteries still suffer from low gravimetric energy densities of 0.2 to 0.5 kW/h per kilogram and limited life-time cycles. In addition, the problems associated to the recharging of the batteries have to be considered. To overcome this drawback, batteries can also be applied in combination with conventional propulsion (turbo-electric aircraft) or hydrogen fuel cell to improve their performance, but the development of new engines for the aircrafts and airport infrastructures is necessary to put them in operation. For these limitations this technology is not ready to be used.

Sustainable aviation fuels at this stage play an important role in contributing to the target of reduction of CO$_2$ emission by 2050. The studies carried out by International Civil Aviation Organization (ICAO) show that the target can be reached only with the introduction of radical new technologies together with the development and use of sustainable alternative fuels [1].

Among several developed SAF, power-to-liquid fuels, also known as synfuels, are very promising. They are synthesized from hydrogen and CO$_2$ taken from various sources: industrial, biomass or direct-air capture, have no direct CO$_2$ emission, but for their characteristics have significant limitations. One of the great disadvantages is the need of liquefy the synfuel for transportation and utilization.

Another category of SAF are biofuels that are obtained from biomass or waste, such as cooking oils and fats, and advanced biofuels that are synthesized from several kind of solid feedstock, biomass like crops, or algae. They developed faster compared to other SAF and have a great diffusion, because of combustion characteristics and handling possibilities similar to kerosene.

The possible strategies to reduce emissions associated to the aviation sector have been considered within the EU Horizon 2020 project PARE – Perspectives for Aeronautical Research in Europe. In this paper the main results concerning low-carbon alternative fuels obtained from a literature analysis on open source data and information are presented.

### 2. Discussion

Biofuels and advanced biofuels have the advantage over the other SAF of being “drop-in fuels” that do not require changes in aircraft, neither for the engines nor for the fuel tanks, and fuel infrastructure or airport facilities. Moreover, they are applicable across all aircraft segments. Biofuels are already commercially available. Anyway, it should be considered that they rely on feedstock, that often requires changes in land use, high water usage and monoculture, since sometimes it is necessary the production of a single crop. This means that the aviation industry will be competing with industries that need the feedstocks for their other purposes.

The composition of these fuels is mostly paraffinic; indeed, they are also known as Synthetic Paraffinic Kerosene (SPK) or iso-paraffins. They can be blended with conventional commercial fuel in variable...
amounts up to 50%, depending on the fuel type. There is also the synthetic kerosene with the addition of aromatics (SKA) that can be used interchangeably with fossil fuels. Blending is required with SPK fuels because they lack sufficient aromatic hydrocarbons, which are present in conventional jet fuel. Aromatics hydrocarbons are limited in jet fuel to prevent smoke formation during combustion. However, a minimum aromatic content is needed to cause elastomer swell in aircraft fuel systems and increase fuel density [2].

Before the biofuels can be included on the market, they require a long and expensive procedure to get the ASMT (American Society for Testing and Materials) certification and hence being approved. The legislative basis for use of advanced sustainable biofuels in Europe is the revision of the Renewable Energy Directive (RED II) [3].

The Commercial Aviation Alternative Fuels Initiative (CAAFI) reports that there are 7 major fuel routes approved by the ASTM D7566 standard and there are other 6 routes currently under approval process, furthermore 15 more are waiting to enter the qualification process [4, 5]. In Table 1 the approved advanced biofuels, the feedstock used to produce them and their main characteristic are reported. They are all synthetic kerosene that are processed in order to become liquid. In some of them, aromatics or other compounds are added in order to reach the same performances of traditional fuels.

Table 1 is updated to September 2020, and it is going to fast develop in the next months, due to the urgency to have in a short time an increasing number of alternative fuels. Sustainability of the reported pathways depends upon the feedstock and way of production [4, 5].

| Pathways Processes | Feedstock | Date of Approval | Blending ratio by Vol |
|--------------------|-----------|------------------|----------------------|
| Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) | Biomass: forestry residues, grasses, municipal solid waste | 2009 | 50% |
| Hydroprocessed Esters and Fatty Acids (HEFA-SPK) | Oil-bearing biomass: jatropha, camellia, carinata | 2011 | 50% |
| Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (SIP-HFS) | Microbial conversion of sugars to hydrocarbon | 2014 | 10% |
| FT-SPK with aromatics (FT-SPK/A) | Renewable biomass: municipal solid waste, agricultural wastes and forestry residues, wood and energy crops | 2015 | 50% |
| Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) | Agricultural wastes products: stover, grasses, forestry slash, crop straws | 2016 | 50% |
| Hydroprocessed Esters and Fatty Acids Plus (HEFA +) | Oil-bearing biomass: algae, jatropha, camellia, carinata | 2021 (?) | 50% |
| Catalytic Hydrothermolysis Synthesized Kerosene (CH-SK, or CHJ) | fatty acids and fatty acid esters, lipids that come from plant and animal fats, oils and greases (FOGs) | 2020 | 50% |
| Hydroprocessed Hydrocarbons (HH-SPK, or HC-HEFA) | bio-derived hydrocarbons, directly from oils (triterpenes) produced by the Botryococcus braunii algae | 2020 | 10% |
| Co-processing | Fats, oils, and, greases (FOG), from petroleum refining, biocrude | 2018 | 5% |

Table 1. Pathway processes approved by ASTM [6]

The pathways for the production of the advanced biofuels consist in the extraction of the needed compounds and their treatment, then they are processed using a variety of traditional transformation techniques. Among them there are:

- **Traditional hydrotreating**, that is used in petroleum refineries and involves reacting the feedstock, mainly lipids, with hydrogen under elevated temperatures and pressures in the presence of a catalyst.
- **Biological sugar upgrading**, that is a biochemical process, similar to the one used for cellulosic ethanol, adding micro-organisms that convert sugars to hydrocarbons.
Catalytic conversion of sugars, that is a series of catalytic reactions converting a carbohydrate stream into hydrocarbon fuels.

Gasification, in which the biomass is thermally converted to syngas and catalytically converted to hydrocarbon fuels.

Pyrolysis, that involves the chemical decomposition of organic materials at elevated temperatures in an oxygen free environment. The produced liquid oil can be upgraded to hydrocarbon fuels.

Hydrothermal processing, that uses high pressure and moderate temperature to start the chemical decomposition of biomass or wet waste materials to produce an oil that may be catalytically transformed in hydrocarbon fuels.

Because of the transformation techniques, advanced biofuels have chemical and physical properties similar to the corresponding fossil kerosene, thus further reducing compatibility issues with existing airport infrastructure and aircraft engines.

The feedstock materials considered for the production of aviation advanced biofuels are lipids, such as waste oils (like used cooking oil), residual animal or vegetable oils from industries, vegetable oils (like camelina oil), algae, cellulosic material such as tobacco, jatropha, sugars from sugarcane, lignocellulosic material, lignin residues, municipal solid wastes, dedicated energy crops. All the kinds of feedstock themselves cannot be considered sustainable: the sustainability is related to the specific production chain in which are entered, according to internationally recognized standards like RSB [7] or ISCC [8] and the Directive 2009/28/EC. Wastes and residues that do not require land to be produced have less sustainability concerns. Microalgae are very promising for the future of advanced biofuels, since their use does not require use of large amounts of water or dedicated fields and there is no competition with other possible applications.

To be sustainable, within the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the life-cycle emissions of alternative jet fuels have to demonstrate a minimum Green House Gas (GHG) saving of 10%, as direct and indirect emissions, compared to fossil kerosene. Concerning the carbon dioxide emissions, advanced biofuels are not carbon-free. Moreover, the emissions associated with feedstock production should also be considered since they make a significant contribution to the overall GHG intensity of the biofuel. Though, they can reduce lifecycle emissions between 20% and 95% when compared with petroleum-derived jet fuels [9]. This is because carbon dioxide captured by growing feedstocks reduces overall GHG emissions by balancing carbon dioxide released from burning renewable hydrocarbon biofuels.

Following ethical aspects related to the environment, sustainable biofuels should not be produced from biomass obtained from land converted after 2009 and the feedstock has to be based on fallow land rotation (RED II) [10]. This has in impact also on biodiversity and on the ecosystem, that have to be in any case protected. In this contest, microalgae have the advantages that yield more oil per hectare of land and produce higher-quality fuel [11].

The risks associated to the use of advanced biofuels are mainly technical, and are related to their performance and combustion. Performance characteristics are crucially important to ensure fuel safety and reliability. Among them there are: low-temperature fluidity, thermal oxidation stability, combustion property, fuel volatility, and fuel metering and aircraft range [12]. Combustion characteristics have major importance in GHG emissions and climate change. The smoke point is fundamental for a complete combustion. Emissions of particulate matter, monoxide and carbon dioxide, derived cetane number define the fuel ignition features [13]. Other risks are related to the supply chain and are linked to the transportation and storage. Indeed, the main subsystems of the biofuel chains include the transport of chemicals, by-products and biomass towards the plant, and the transport of biofuel from the plant to the stations [14].

As it concerns the security of advanced biofuels, it is mainly related to the agrobioterrorism. In particular, the use of pathogens or toxins against agricultural products or facilities may be one possible way to interrupt the production process by contaminating or eliminating feedstocks [15].
As it regards, the economic aspects, the actual barrier for the total replacement of traditional kerosene with advanced biofuels is the price. In perspective, this is going to increase thus affecting the ticket price that is expected to increase accordingly [16]. The costs are mainly related to the feedstocks. In fact, the process technologies are similar to traditional ones. In summary, for a full SAF adoption, the costs of production must decrease significantly, below that of jet fuel plus conventional carbon offsets. The fact that SAF are admissible under CORSIA will aid their economic viability over the next years. Moreover, as various projects scale up and economies of scale kick in, costs should naturally come down. Another aspect to be considered is the increase of carbon taxes that in the near future will affect more the price of kerosene, reducing the gap between the sustainable and traditional fuels.

The easy diffusion of advanced biofuels is mainly related to the fact that the feedstocks used are easily available and there is no need to change the existing engines of the aircrafts, due to the compatibility of biofuels once blended with fossil kerosene.

According to ICAO [17], the situation of distributing blended alternative fuels up to 2019 is as follows:

- 185,000 commercial flights since 2011
- SAF volume approximately 0.01% of total fuel demand
- Approximately 6 billion SAF liters in forward purchase agreement
- More than 40 airlines already used or are using SAF.

Furthermore, the number of locations offering daily flights is increasing fast from 2018 and in the past 18 months a higher number of major constructions has been announced.

The Figure 2 reports the SAF production capacity described by SkyNRG, that is the global market leader for SAF solutions, updated to 2020.

![Figure 2. Sustainable aviation fuel ramp-up, Source: SkyNRG, 2020 [18]](image)

### 3. Conclusion

In this paper an overview of the different perspectives associated to the use of sustainable aviation fuels have been briefly reviewed. In particular, some of the analyses available within the Chapter 19 of the 3rd Year Report of the Horizon 2020 project PARE have been summarized. Among all the SAF, advanced biofuels offer many benefits, such as engine and infrastructure compatibility, increased energy security, lower GHG emissions, more flexibility. Though, before
biofuels become a real alternative to traditional petroleum fuels in aviation, several aspects concerning environmental, economic, safety, ethical and other issues have to be deeply considered.

There is still a significant price gap between sustainable and conventional jet fuels because of the high production costs of SAF. However, since other propulsion technologies are not mature, SAF play an important role in taking the edge off the environmental impacts of aviation. In order to reach 100% SAF utilization, engine design changes will be necessary to maintain optimal engine performance, to deal with the different chemical compositions of SAF compared to conventional kerosene.

The outcome of all the considerations done in this paper is that the involvement of the largest possible assembly of stakeholders is required to keep into account the different perspectives associated to such multi-facet and challenging r-evolution toward the aviation of the future.

Acknowledgements
The authors acknowledge the project PARE (Perspectives for Aeronautical Research in Europe) funded by European Union's Horizon 2020 research and innovation programme under GA no. 769220.

References
[1] Sustainable Aviation Fuels Guide, ICAO-UNDP-GEF assistance project, 2018.
[2] Maniatis, K. EU Transport & Renewable Energy policies: The role of Advanced Biofuels in Decarbonising Transport. EU-India Conference on Advanced Biofuels, 6-8 March 2018, New Delhi. Available at https://ec.europa.eu/energy/en/content/conference-presentati.
[3] "DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of energy from renewable sources," Official Journal of the European Union, 11 December 2018.
[4] Steve Csonka (2016) “CAAFI – CORE-JetFuel Cooperation Workshop”. Available at: www.core-jetfuel.eu.
[5] http://www.caafi.org/focus_areas/fuel_qualification.html.
[6] ASTM (2016) “ASTM D7566-16, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons”. Available at: http://www.astm.org/Standards/D7566.htm.
[7] www.rsb.org.
[8] www.iscc-system.org.
[9] European Commission, Carbon accounting for forest bioenergy, 2014.
[10] "https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii".
[11] "Ouagrham-Gormley, Sonia Ben & Fye-Marnien, Shannon (2018) The bright side of synthetic biology and Crispr, Bulletin of the Atomic Scientists, 74:1, 19-26, DOI: 10.1080/00963402.2017.1413056".
[12] "Chuck C.J., Donnelly J.; “The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene”; Appl Energy 2014; 118: 83–91.".
[13] "Corporan E., DeWitt M.J., Belovich V., Pawlik R., Lynch A.C., Gord J.R., et al.; “Emissions characteristics of a turbine engine and research combustor burning a Fischer-Tropsch jet fuel”; Energy Fuels 2007; 21: 2615–2626.”.
[14] "Riviere, C., & Marlair, G. (2009). BIOSAFUEL®, a pre-diagnosis tool of risks pertaining to biofuels chains. Journal of Loss Prevention in the Process Industries, 22(2), 228-236.".
[15] "Ban J. Agricultural biological warfare: an overview, vol. 9. Alexandria: Chemical and Biological Arms Control Institute; 2000. p. 1–8.”.
[16] Roadmap to decarbonizing European aviation, October 2018, Transport & Environment.
[17] Bruno Silva, Environment Officer, ICAO, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and Sustainable Aviation Fuels, Sustainable aviation fuels at ISCC meetings and conferences (2019).
[18] https://www.adsgroup.org.uk/blog/sustainable-aviation-fuels/.