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# Aviation Gas Turbine Engine Emissions: Drop in Alternative Fuel and its Challenges

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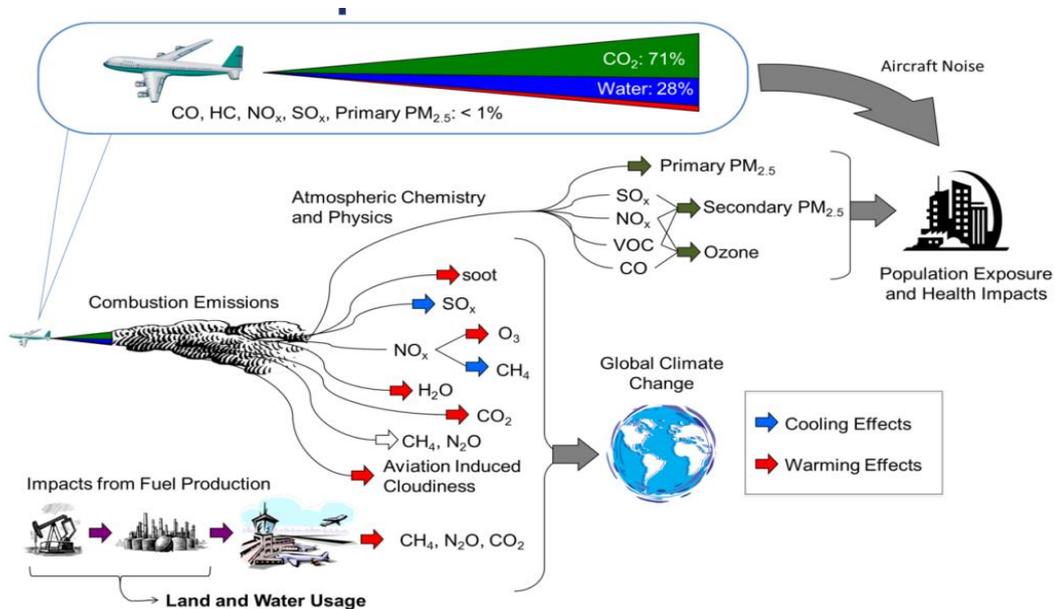
**Abstract.** The growing demand of air travel in aviation industries contributes to increases in carbon emissions. As far as technological, infrastructure and operation is concerned, carbon-neutral growth (CNG) cannot be achieved due to fossil fuel usage. The involvement of biojet fuel is the only measures that can be adapted to reduce up to -50% of Carbon emissions. This paper will discuss the gas emissions from the aircraft engine and the challenges it poses to Airlines and operation as well as adapting the Alternative drop-in fuel as its solutions. Alternative fuel using biomass has been approved by American Society for Testing and Materials (ASTM) to be a drop-in fuel with no alteration on the gas turbine engine, hence will ease and generate cost saving for the Airlines. The challenges remain, as the concern on the fuel properties and characteristics, distributions, environment and economic, have been the focal point for policymakers and researchers. As a conclusion, the authority and the government need to join hand in creating the opportunity for alternative fuel in the aviation industries to ensure the reduction in aviation carbon emissions.

## 1. Introduction

Aviation industries are growing and seeking for its expansion. The rapid growth resulting in the rise of aviation greenhouse gas emissions (GHG). The serious concern about the growth trajectory of the industry and emissions have led to call for market measures such as emissions trading and carbon levies to be introduced to restrict demand and prompt innovation [1]–[4]. The Aircraft emissions will give the impact surface to air quality through the formation of ozone and Particulate Matter (PM) as shown in figure 1. PM with a diameter less than 2.5  $\mu\text{m}$  (PM<sub>2.5</sub>) can be generated either by direct emission (e.g. engine soot) or by way of gaseous precursors e.g. Nitrogen Oxide (NO<sub>x</sub>) and Sulphur Oxide (SO<sub>2</sub>), which can be oxidized to form additional PM<sub>2.5</sub>. Increases in ground-level ozone and PM<sub>2.5</sub> and subsequent population exposure can lead to a higher frequency of human health incidences, such as morbidity or mortality [5]. The environmental impacts of Aviation under the

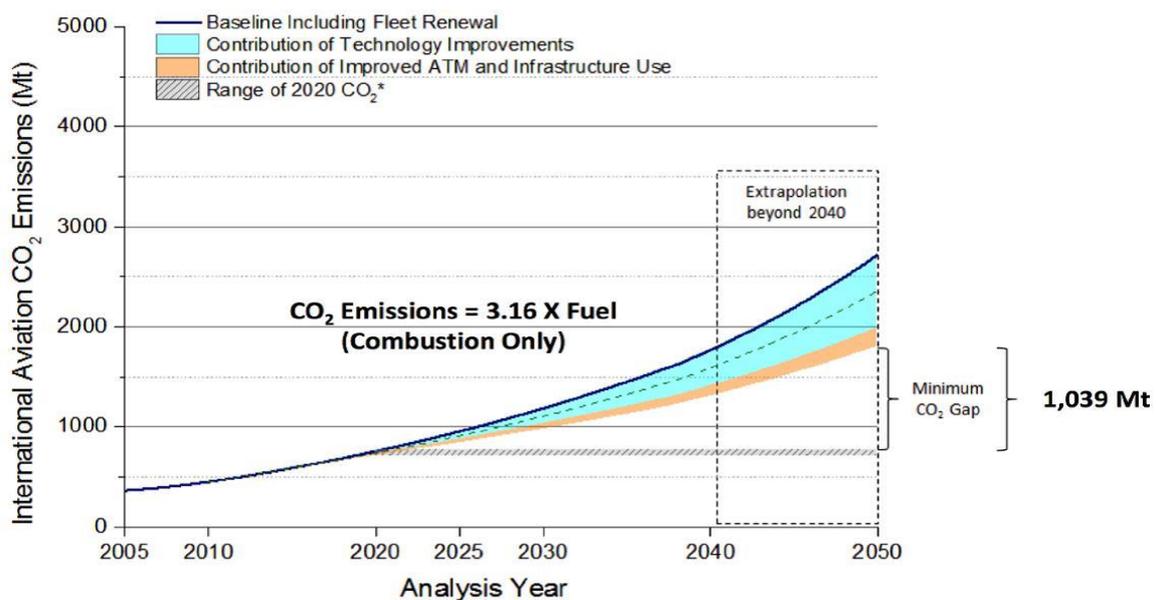


Atmospheric Chemistry and Physics can be seen in figure 1, considering the impacts of noise and emissions and interdependencies of potential mitigation option [5]–[7].



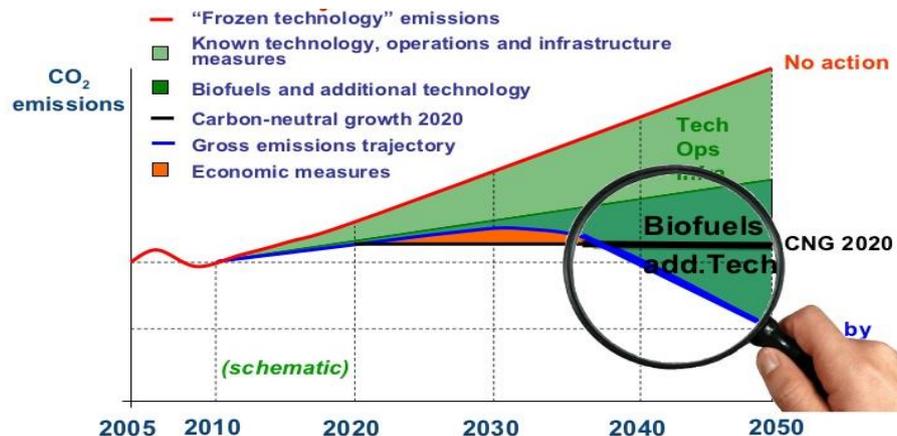
**Figure 1.** Environmental impact of Aviation considering environmental impacts of noise and emissions and interdependencies of potential mitigation options (source by IATA)

According to [4] International Civil Aviation Organization (ICAO) forecasts in its ‘2016 Environmental Report’ in comparison to 2010, as shown in figure 2, when the annual international aviation emissions stood at 448Mt, the international aviation emissions will increase by 52% to 68%. It is estimated that the annual emissions of Carbon Oxide ( $CO_2$ )(682Mt to 755Mt) by 2020. On the other hands, between 169% and 185% (estimated annual emissions of 1205Mt to 1278Mt) by the year 2040 and up to 284% to 300% (estimated annual emissions of 1721Mt to 1794Mt) by 2050 depending on the level of technological and operational improvements.



**Figure 2.** International Aviation emissions and Analysis (Source by ICAO)

Thus, even under the most optimistic scenario, taken into account the effectiveness of technical and operational measures, the aviation CO<sub>2</sub> emissions in 2050 are still expected to be 3.8 times higher than in 2010 emissions due to the forecasted strong increase in aviation activities. Technical and operational measures are therefore on their own insufficient to achieve CNG from 2020, see Figure 3 [4].



**Figure 3.** Emissions Reduction roadmap

Aviation Initiative for Renewable Energy in Germany or Aireg has come and joined forces with the policymakers, the scientific community in a plan to halve its carbon emissions by 2050. In mid-June 2011, Aireg has reached a milestone for more renewable energy in aviation using biofuels as an indispensable to achieving this aim [8]. According to [9], CO<sub>2</sub> emissions study continues with the evaluation of CO<sub>2</sub> emissions' data growth from the year 2010 to 2013. This data sources are gathered from the European Commission's Eurostat Air Transport Statistics (Eurostat) and EUROCONTROL flight plans database. The study (Table 1) has shown the decrease of CO<sub>2</sub> emissions in 29 countries in 2013, together with the evolution of CO<sub>2</sub> from 2010. Overall, there is a reduction of 3.1%, 209.1 Mtonnes due to new technologies, Air Traffic Management (ATM) and new renewable energy. The changes in the fuel efficiency are analyzed and the potential reasons for those changes are investigated [10].

The aviation biojet fuel was solely depending on its feasibility studies to compare with the rail and road transport, where electric propulsion systems do not offer an alternative way to reduce the emissions. While batteries remain too weak and too heavy for aircraft. The possibility of using renewable wind, hydro, and solar power in commercial aviation, unfortunately, is ruled out for the foreseeable future. So, the capability to offer climate-friendly mobility from renewable energies in aviation is the only mode of transport that has to rely on the use of biofuel [11].

## 2. Definition of drop-in biofuels

Safety is paramount to aviation authority, hence there will be no requirement of any changes to aircraft engine fuel systems, distribution methods, or storage facilities [12]. Therefore, aviation biofuel can be a "drop-in" fuel that meets or exceeds internationally recognised as biojet fuel. As ASTM D4054 is where the approval for biojet fuel specification with unchanged operating.

The ASTM D4054 [13] was developed as a guide related to testing and the procedures ensuring certification of the drop in alternative fuels have remained unchanged to the limitation of engine operating and aircraft operations, (Figure 4). Some aviation alternative fuels may require new specialized fuel handling systems, which is why the drop-in approach is the only practical solution for aviation [14]. A series of test flights in 2008 until 2017 demonstrated the viability of a drop-in aviation biofuel where among contributors were Virgin Atlantic, Air New Zealand, Continental Airlines, Japan Airlines and KLM Royal Dutch Airlines in cooperation with Boeing, Airbus, UOP, CFM, Pratt &

Whitney, and GE [15]. Figure 5 below demonstrates the global biojet fuel flights showing the support and initiatives from various airlines and biofuel producers with the number of commercial flight using biojet fuel.

**Table 1.** CO<sub>2</sub> Emissions in 29 countries.

	Country	CO <sub>2</sub> emissions 2013 (Mtonnes)	Changes from 2010 (%)
1	<b>UK</b>	<b>47.36</b>	<b>-2.60%</b>
2	<b>Germany</b>	<b>37.62</b>	<b>-4.20%</b>
3	<b>France</b>	<b>26.92</b>	<b>-4.30%</b>
4	<b>Spain</b>	<b>17.49</b>	<b>-11.50%</b>
5	<b>The Netherlands</b>	<b>16.12</b>	<b>-0.60%</b>
6	<b>Italy</b>	<b>15.05</b>	<b>-4.30%</b>
7	Switzerland	6.56	9.00%
8	Belgium	5.38	-4.90%
9	Greece	4.69	0.60%
10	Portugal	4.21	0.00%
11	Denmark	3.44	5.50%
12	Norway	3.26	18.50%
13	Sweden	3.16	2.60%
14	Austria	2.99	-9.70%
15	Ireland	2.85	9.20%
16	Finland	2.56	5.80%
17	Poland	2.07	-8.40%
18	Czech Republic	1.3	-4.40%
19	Cyprus	1.14	2.70%
20	Bulgaria	1.03	19.80%
21	Luxembourg	0.9	-30.20%
22	Romania	0.84	-10.60%
23	Hungary	0.59	-32.20%
24	Latvia	0.49	16.70%
25	Malta	0.37	12.10%
26	Lithuania	0.24	20.00%
27	Estonia	0.17	41.70%
28	Slovakia	0.17	-15.00%
29	Slovenia	0.14	-12.50%
	<b>Total EU27+2</b>	<b>209.1</b>	<b>-3.10%</b>



**Figure 4.** ASTM Approval Specification with no changes in aircraft engine,

Aircraft Flight Manual and Aircraft Operating limits

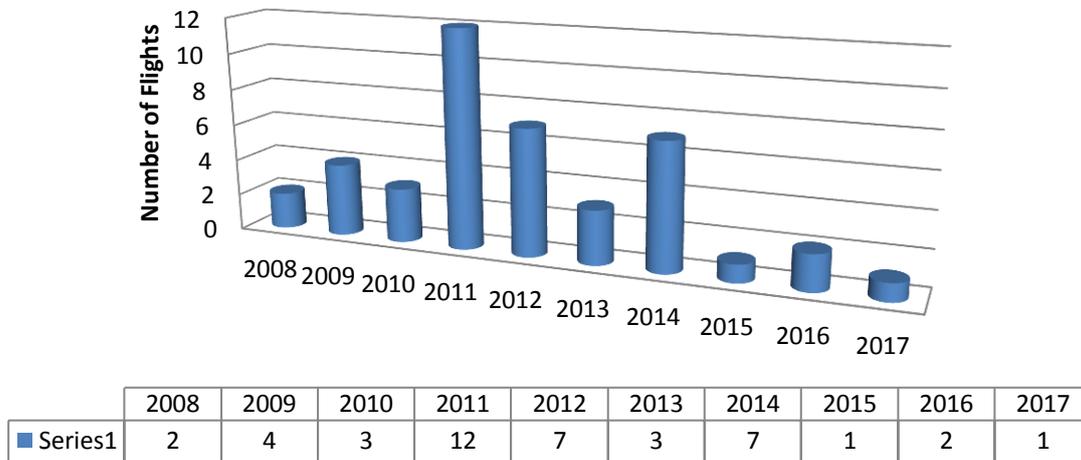


Figure 5. Biojet fuel Commercial Flight from 2009 to 2017.

Considering the diversity of drop-in biofuel processes and product options, the following definition is used throughout this report to provide a functional representation of what is meant by a drop-in biofuel. Conventional biofuels have a distinct chemical nature, and so they can be accurately defined by their chemical composition alone. In contrast, drop-in biofuels consist of a mixture of many different types of hydrocarbons, the properties of which, just like petroleum fuels, is typically characterized by the mixtures’ functional characteristics such as distillation profile, viscosity, acidity and more. It should be able to be readily “dropped in” to the existing petroleum infrastructure and be handled in the same way as petroleum fuels, without requiring significant infrastructure adjustments. Future technology in global biojet fuel adaptation will take into consideration all as mentioned in figure 6, where starting from handling safety to Material Compatibility in the overall aspect of future Technology.

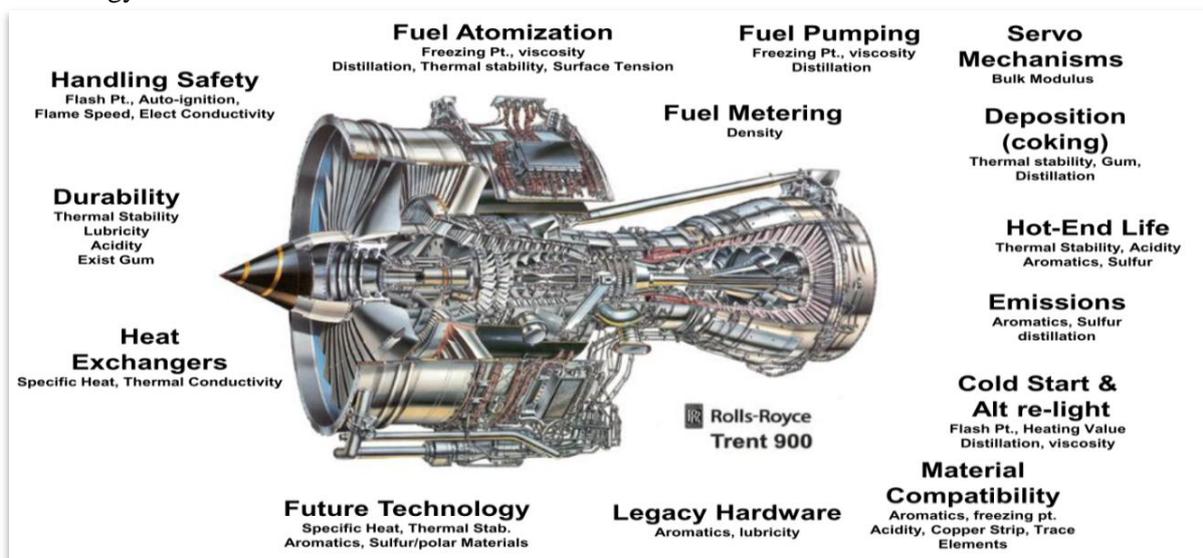


Figure 6. Future technology in global Biojet fuel adaptation (Source IATA)

### 3. Biojet fuels challenges

The demand and needs of this alternative fuel are exceeding, but there are many challenges need to be tackled. Challenges to overcome and eliminate the drawbacks of the biojet fuel will be crucial such as the technical and production issues, the environmental challenges, distribution problems, feedstock availability and sustainability [16]. In promoting biojet fuel to Airlines industries, the different incentive policies around the world are revised and compared to, and some indications are offered on the most recommendable procedures that might be carried out in the near future [17]. This can be a support for refuelling the future with the new alternative biojet fuel. This paper will place the interest of the main challenges that need to be addressed and provides an overview of the recent developments worldwide toward commercial-scale deployment.

#### 3.1. Technical and production issues

The increase in commercial flights using alternative fuel demonstrated the technical feasibility of these fuels in aviation and the keen interest of airlines. Designer (manufacturer) and maintenance cannot be isolated. The airworthiness of the aircraft fuel systems needs to be ensured to enable the aircraft to fly and to prevent any malfunctions in the system throughout the flight. In this case, when the new alternative energy and the use of biojet fuel by airlines are mandated in European countries, a closer alignment of goals is needed, the new policies and standard among engine manufacturers, the airlines and the MRO, where engine contracts such as total care and other service elements should be revised and be considered priorities [18]. However, the production of these fuels is still in its early phase with only a limited volume currently available. There are still significant challenges to overcome before these fuels can represent a substantial share of the global jet fuel supply[19].

#### 3.2. The environmental challenges

The rising on the demands of air travel will increase the emissions of CO<sub>2</sub>. Due to that, the potential of alternative fuels for GHG emissions reductions is a strong motivator for their introduction into commercial aviation operations. Moreover, the aviation community has demonstrated its commitment to the environmental, social and economic pillars of the sustainability of alternative fuels [20]. A large number of aviation stakeholders are represented in organizations such as the Roundtable for Sustainable Biomaterials (RSB) and the Sustainable Aviation Fuel User Group (SAFUG), which aims to promote sustainable practices in agriculture and energy biomass production [15]. The outcomes of the life cycles analysis in measuring the CO<sub>2</sub> emission can be at par for the total emissions contribution in reducing the environmental impact [21].

#### 3.3. Distribution challenges

One of the biggest challenges in enhancing the projection of biojet fuel is the distribution challenges. The lack of certainty of fuel supply availability at an acceptable cost over a long term can be a significant barrier to achieving increased deployment of many bioenergy projects. Most food and crops are grown and sold on an annual basis, often for widely varying commodity prices. So there may be a reticence by growers at committing to continue to grow specific energy crops over an extended period. The developers of a large plant may, therefore, take overall responsibility for obtaining the required biomass, either by securing long-term contracts well in advance or producing their biomass supplies [22]. If using local landowners to grow the biomass crops under contract, they will need to specify the form in which the biomass feedstock is required and even have significant input.

#### 3.4. Economic challenges

Economic can be another challenge that is covering all Aviation industry players. The specific market can be a finite decision for any biofuel producers. As bioenergy developer will not invest in constructing a bioenergy plant without first securing a biomass fuel supply over the long term. A reliable market for the heat, power or biofuels to be produced also needs to be identified and purchase agreements signed. As current, government initiative and act as an investor or banker will need to have

confidence that all aspects of the project are well defined, and contracts and warranties are all in place because a plant is likely to require a substantial financial commitment over a relatively extended period before a return on investment results.

Many bioenergy projects are technically feasible, but investments do not proceed because other forms of energy appear to be more cost competitive. A significant barrier results where the relatively high costs for or biofuels as demand is not promising at this instant hence, cannot compete on purely economic terms with fossil fuels used to provide the same amount of useful energy.

#### **4. Conclusions**

The mandate of using biojet fuel will be soon to be implied with the EU Clean Sky Initiative in European countries and will be projected to be oblique around the world as one of the step in going green.

##### *4.1. Authority role and responsibilities*

IATA and ICAO are playing important roles in the projection of the drop in biojet fuel into Airlines. The research, initiatives, economic measures, the policy will be covered through its role. As IATA's role representing the global community of international airlines is to: Play a leading role in standard setting for alternative drop-in fuels by in the areas of technical certification and logistics, and provide related technical support [23]. Renewable jet fuel is designed to be compliant with Jet a/a-1 fuel specifications and its crucial to make sure the drop-in alternative to conventional petroleum-derived fuel in a range of performance metrics, including fit for purpose, combustion performance and greenhouse gas emission reduction potential, without compromising on performance quality.

As far as jet fuel properties are concerned, Aviation will ensure that safety is the top priority, and all fuels are suited for aviation. While there are about a dozen other properties that have to be met by fuels to qualify for ASTM certification as usable in existing engines, the oxygen content (or H/C ratio) and carbon number range can be considered as the minimum, most basic characteristics need to be monitored. The authorities, together with non-government organisations, will need to join hand and putting a stake in biojet fuel project. In tackling the carbon emissions reduction, future interest could include policy planners, local government agencies, transport authorities, civil aviation authorities, health and safety bodies, environmental and amenity groups, landowners and potential growers of the biomass.

The challenges can lead to opportunities of this new alternative energy which needs to be broadened in various aspects for sustainability. Turbine engine can be focusing in its maintainability in towards the aircraft system, where supporting the demand for engine technology. In addition, biofuels may provide valuable economic opportunities to communities that can develop new sources of income in many developing nations. The opportunity can overcome the challenges, and its measurement of the readiness is crucial in biojet fuel adaptation in the aviation industry.

#### **Acknowledgment**

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