REDUCING AVIATION EMISSIONS: NAVIGATING CHALLENGES TOWARDS SUSTAINABLE AVIATION FUELS (SAFs)

The aviation industry represents a critical component of today's global economy, transporting 3.8 billion people annually along with $5.5 trillion worth of goods representing 35% of world trade by value in 2016. Such transportation was estimated to have generated 65 million jobs and $2.7 trillion worth of GDP and by 2018, passenger numbers have risen to 4.4 billion. Passenger numbers are only expected to continue to increase with projections estimating passenger numbers to double to around 8.2 billion by 2037 according to the International Air Transport Association (IATA) [1]. As such, the demand and consumption of jet fuels and by extension, production of greenhouse gases, are projected to increase accordingly. With such a critical importance to not only the global economy, but the interconnectedness and cohesion of the modern world, it is imperative that aviation does its part to minimize its environmental impact so that it can continue to provide services and transportation to billions of people around the globe.

In the face of global warming and rising fuel consumption, the aviation industry has committed to increase fuel efficiency by 1.5% on average annually, stabilize net aviation emissions by 2020, and cut emissions by 50% by 2050 [2] compared to 2005 levels in accordance with the International Civil Aviation Organization (ICAO) [3] Carbon Offsetting Reduction Scheme for International Aviation (CORSIA). Currently, aviation emissions represent 2.5% of global CO_2 emissions and a major pathway to achieve the goals of the CORSIA plan is the ongoing commercialization of sustainable aviation fuels (SAFs) since the aviation industry has less options to reduce CO_2-emisions as ground transportation and other new alternatives pass through long and stringent certification processes [4].

SAFs can be defined as aviation fuels whose net emissions from production to use are deemed to be lower than that of conventional fuels by the ICAO and have been used in commercial flights since the first flight utilizing a blend of conventional jet fuel and SAF in 2008 by Virgin Atlantic with over 165,000 flights utilizing SAFs a decade after. Since 2011, international standards body ASTM accepts blending ratios up to 50% of bio-derived synthetic blending components added to conventional jet fuel under ASTM D7566 and the annexes A-F classify different pathways by conversion process and type of feedstock. According to the IATA, SAF blends of up to 50% with conventional jet fuel known as Jet A or Jet A-1 can reduce overall CO_2 emissions by up to 40%. This potential to cut CO_2 emissions has led to significant investments in the research and development of the production and use of SAFs as a way of achieving the goals outlined by CORSIA. As such, more and more airlines and airports have committed to purchasing sustainable jet fuels and incorporating them into their aircraft. Companies such as Japan Airlines have invested $9 million to partner with biofuel producers such as Fulcrum BioEnergy to produce SAFs and similar investments will only continue to be made in the future in efforts to achieve emission reductions [5]. While SAFs seem to be the most viable path for air traffic decarbonization, significant challenges remain as only 0.1% of total global

Figure 1: Upcoming and available capacities for SAF. Current production of SAF is low with 6.45 million liters produced per year as of 2018 but is projected to grow to 7,000 million liters in 2030

[https://www.icao.int/environmental-protection/Pages/SAF_Stocktaking.aspx].

consumption of jet fuel corresponds to SAFs [6]. In order for the aviation industry to achieve the emission reduction goals set by CORSIA, significant further investment into the production of SAFs must be made to overcome current challenges and low production volume so that SAFs can represent a larger portion of jet fuel consumption and effectively reduce CO_2 emissions.

One of the foremost challenges towards the full commercialization of SAFs is the extensive testing and review by ASTM that designates the SAF as commercially approved for aviation use. There are three relevant ASTM standard specifications in relation to SAFs: ASTM D1655, ASTM D7566, and ASTM D4054. The standard set specifications for conventional aviation fuels Jet A and Jet A-1 are outlined in ASTM D1655 Standard Specifications for Aviation Turbine Fuels which outlines specific properties such as its composition, volatility, and thermal stability. For SAFs, requirements are outlined in ASTM D7566 Standard Specifications for Aviation Turbine Fuel Containing Synthesized Hydrocarbons and once a SAF and its production pathway are annexed into ASTM D7566, the SAF fulfills the requirements set by ASTM D1655 and can be blended with conventional jet fuels. As of 2020, ASTM D7566-19b has approved six production pathways of synthesized paraffinic kerosene (SPK) for approval [7]:

a. Annex A1 "Fischer-Tropsch hydro-processed synthesized paraffinic kerosene"
b. Annex A2 "Hydro-processed esters and fatty acids"
c. Annex A3 "Iso-paraffins from hydro-processed fermented sugars"
d. Annex A4 "Aromatics derived by alkylation of light aromatics from non-petroleum sources"
e. Annex A5 "Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK)"
f. Annex A6 "Catalytic Hydrothermolysis Synthesized Kerosene (CH-SK, or CHJ)"

Each pathway undergoes years of stringent testing and certification as outlined by the ASTM D4054 Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives (Figure 2). This requires millions of USD in financial investment along with the production of a demo plant and tens of cubic meters of produced SAF [8]. In addition, internal review at several steps in the research and development process can cause setbacks if any point in the production process is deemed not up to standard. As such, it is too early to favor one of these pathways, because:

a. The mid-term & long-term volumes and local availabilities of CO_2-neutral or renewable resources are unclear
b. CO_2-neutral or renewable resources can be declassified as such when negative life cycle analysis is completed (Example: Palm oil was declassified by European Commission delegation regulation (EU) 2019/807 of 13 March 2019) [9,10]
c. The technology readiness level of process equipment for large scale production is unclear as well as their investment and running costs

This ends up with the commercialization of SAFs taking several years just to reach a small sliver of the aviation market with high investment costs. As a result, the current approved ASTM pathways are still limited to pilot and early commercializations scales with low capacities. However, investments for biofuel plants with higher capacities are underway or have become recently operational with NESTE investing in a plant in Singapore with 1.3 million tons total capacity, TOTAL with a plant in La Mede (France) with 500,000 tons capacity, and ENI with plants in Italy (Porto Magher and Gela) with capacities of 1.35 million tons.

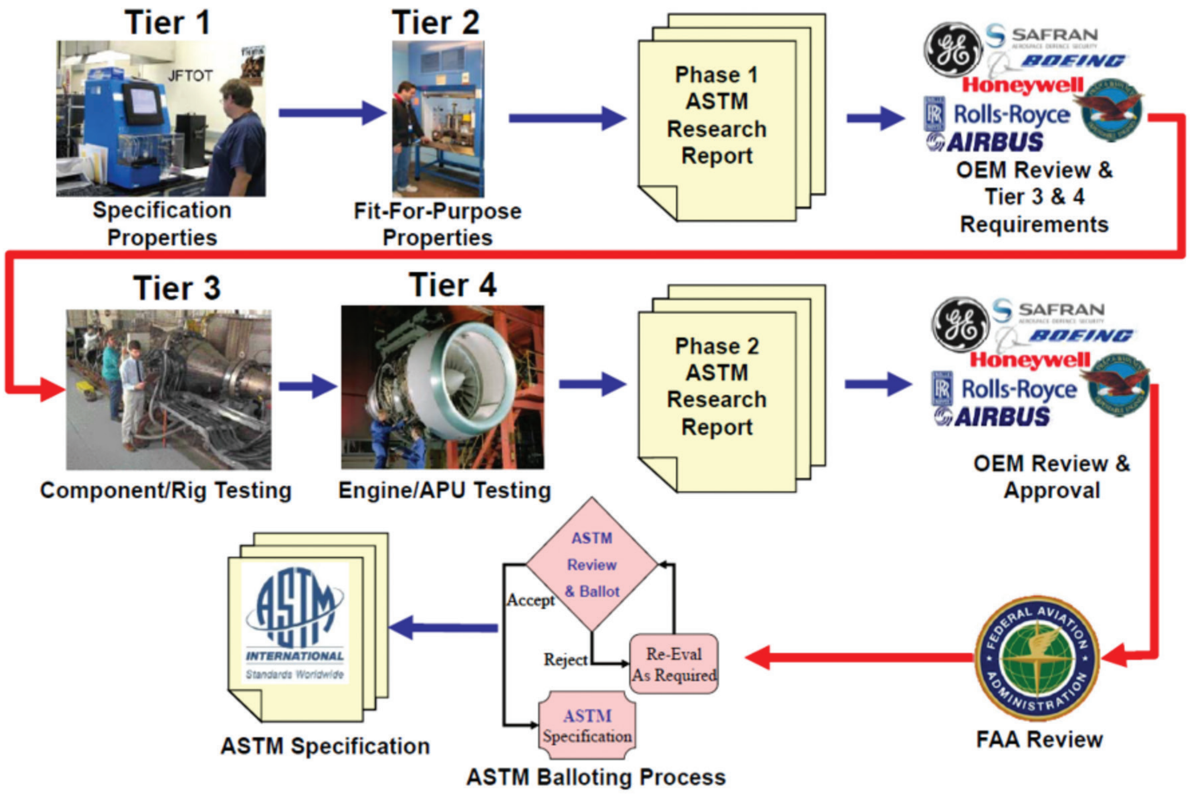

Figure 2: ASTM D4054, Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives

The second major challenge lies with the feedstock supply and associated costs for the production of SAFs. A common concern is the question of whether the needed volumes of renewable resources actually exists and whether enough of it can be utilized for SAF production. SAFs can be synthesized using a wide range of raw materials such as waste animal tallow (fat), used cooking oil, sugar, algae, cellulosic waste such as excess wood, forestry residues, vegetable oils such as palm, camelina, jatropha, carinata, and corn oils and even municipal solid waste. Each production pathway approved by ASTM has its own range of these feedstocks that work with the production method and therefore some production pathways may have less feedstock supply available to it than others. For example, Fischer-Tropsch processes are quite versatile in that its feedstock includes industrial waste processes from coal and natural gases in addition to biomass while HEFA processes are limited to just used cooking oils and waste fats or biofuel crops that increase land usage thus limiting the feasible scalability of the process. Without interfering with food production, cellulose is the most abundant biomass. In Europe alone, the total above ground woody biomass stock of EU-28 forests was estimated to be 18,600 Mt of dry matter. According to Joint Research Center (JRC) estimates over a ten-year average, 1,466 Mt of dry matter biomass are produced annually by the land-based sectors of the EU (Agriculture: 956 Mt and Forestry 510 Mt) [11]. Production from fisheries and aquaculture by the EU-28 Member States reached 6.8 Mt live weight in 2014 representing a relatively small total of the supply. The theoretical total amount of forest based lignocellulosic biomass usable for energy in 2013 (EU28 + Western Balkans, Ukraine, Belarus) was 530 Mt (485 Mt of which were in EU28) plus an additional 10% of agricultural (non-lignocellulosic) biomass, of which the conversion yield to fuels is approximately 70% of the total tonnage. This volume of biomass resources tends to match fuel demand as shown by comparison with the EU27 fuel demand in 2018 [Mt/a]: Jet fuel: 62.8, Diesel: 292.6, Gasoline: 80.1 with the total demand for refined oil products of EU28 countries projected to reach 638.5 million tons in 2028 [8,11]. In total, the EU annually uses more than 1,013 Mt of dry matter of biomass and as a result the production of renewable fuels and materials can be fed the difference between biomass production and usage (~453 Mt) [11]. These figures underline a theoretically secured supply of renewable resources, assuming it is fully accessible for SAF production.

However, that is not the case in reality as the remaining supply of biomass is used for a multitude other economic processes other than biofuels. For dry matter agricultural biomass, 54% of the biomass produced is consumed for economic production, that is grains, fruits, roots, tubers, i.e. the reason why the crop is cultivated. The remaining 46% is above ground biomass from by-products and residues such as leaves and stems, which may also have an economic value (for animal bedding or for bioenergy production), and are also important for ecosystem services such as maintaining organic carbon levels in soil or preventing soil erosion. The same is done for forest based biomass as well and as such, the total biomass available for SAF production is lessened considerably. The resulting biomass flows depicted using Sankey diagrams by the JRC, show that more than 60% is used in the feed and food sector, followed by bioenergy (19.1%) and biomaterials (18.8%) [9]. Even worse, SAFs synthesized from compatible biomass can end up competing with CO_2-neutral fuels derived from other sources such as CO_2-capturing, green hydrogen, and green electricity thereby lowering the actual amount of SAF for industry utilization even further. This competition over the supply of biomass in addition to competing CO_2-neutral fuels only serves to exacerbate the challenge of fully implementing SAF in the aviation industry.

In addition to supply issues, the end cost of the SAF product is much higher than that of conventional jet fuel and can vary significantly for each production pathway of SAFs depending on the choice of feedstock. For HEFA processes, the minimum jet fuel selling price can vary anywhere from 1.63-31.9 USD per gallon compared to the average price of jet fuel of 2.07 USD per gallon in 2018. For the majority of these ASTM approved SAF processes, the minimum jet fuel selling price to break even exceeds the average cost of conventional jet fuel with Fischer Tropsch processes ranging from 6.23-7.57 USD per gallon, alcohol to jet processes ranging from 3.65-10.91 USD per gallon, and catalytic hydrothermolysis processes ranging from 2.48-5.06 USD per gallon [12]. The fact that the price to simply break even for SAFs is significantly higher explains the 0.1% utilization of SAFs in comparison to conventional jet fuels. Current SAF production scales are not financially competitive nor profitable regardless of the pathway and as a result, SAFs are simply much too expensive to capture a significant portion of jet fuel consumption. All in all, the issue is not necessarily a lack of renewable resources, but the combination of competing end users for that supply lessening the portion available for SAF production considerably and the market introduction of a more expensive product (fuel) that takes several years of significant investment, stringent testing, and certification by ASTM for a small portion of market share.

In spite of these challenges, ongoing research and development has led to growing scales of production and lowering costs for SAFs. While SAFs are currently not financially competitive enough

* Certified by RSB (Roundtable on Sustainable Biomaterials Association)

Figure 3: Examples of market introduction of sustainable alternative jet fuel (SAF)
Source: M. Woydt

to capture a significant portion of jet fuel usage regardless of the production pathway, they remain a promising option to minimize CO_2 emissions due to diverse feedstock supply and ease of implementation in current jet turbines and airport infrastructure. In addition, CO_2 emissions are increasingly being taxed which may close the cost gap with conventional jet fuels.

As the production pathways of SAFs reach maturity, greater financial investment from both aviation companies and policymakers is necessary to meet industry emission reduction goals outlined by plans like CORSIA. With multiple approaches to introducing SAFs along each point in the value chain of the airline service as shown in Figure 3, the aviation industry can meet its commitments to combat global environmental dangers posed by rising emissions.

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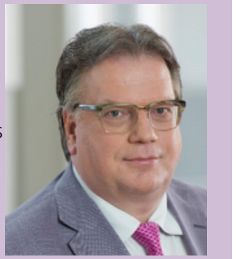

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