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Will Sustainable Aviation Fuel Take Off?

Overview

Commercial air travel accounts for 3% to 4% of total GHG emissions in the U.S. and 2% to 3% of global GHG emissions (Chokshi & Krauss, 2021; Coykendall et al., 2021). The Air Transport Action Group (2021) suggests by 2050, over 10 billion passengers will be carried by air some 22 trillion kilometers each year and without any additional improvement in technology, fuels, or in operations, this activity would generate close to 2,000 megatonnes of CO_2. Whalen et al. (2021) predicts without action to decarbonize, the airline industry's global emissions could reach 20% by 2050; Coykendall et al. (2021) estimates aviation emissions could reach 22% of global emissions by 2050 without decarbonization. A Roland Berger's forecast suggests that if airline operations, fleet composition and propulsion architectures remain at the current pace, the global fleet grows 4% annually, and new aircrafts are 1% more efficient year on year, aviation could account for up to 24% of global emissions by 2050 (Thomson et al., 2020).

Sustainable Aviation Fuel (SAF) can play a critical role in reducing GHG emissions in the aviation sector, with the potential to reduce lifecycle emissions by up to 80% compared with conventional aviation fuel (International Air Transport Association, 2022).

The U.S and the UK among other countries have committed to using SAF as a part of their net zero plans. However, China is the biggest emitter globally and hardly mentions future use of SAF and expects most jet fuel will be fossil fuel by 2050 (Pang, 2021). Major airlines predict SAF will be part of the solution if not one of the most significant pathways to reach carbon neutrality or net zero goals. Many aircraft manufacturers are prepared to incorporate full SAF capabilities by 2030.

The lack of SAF being produced and the high cost do not make SAF viable to use in large amounts at present. However, there is significant investment being made to expand production and increase the use of SAF from a 50% blend capacity to 100%. SAF has the potential to be the primary propulsion source for aviation, but it remains unclear which type of SAF will be most viable in terms of cost and readily available feedstock. Federal legislation and incentive programs will be key to determining which SAF takes off. Reliance on alcohol feedstocks and fats, oils, and greases (FOGs) feedstocks may become unsustainable given the rising prices of corn and soybeans and increasing agricultural instability. However, more reliable feedstocks include those from renewable energy. A more focused effort by governments to incentivize SAFs with reliable feedstocks coupled with airlines and fuel producers mobilizing to scale production is key to reaching 100% SAF incorporation.

What is SAF?

Although there is no globally agreed upon definition of SAF, the International Civil Aviation Organization (ICAO) defines SAF as renewable or waste-derived aviation fuels that meets sustainability criteria (ICAO, 2018). The American Society for Testing and Materials (ASTM) International manages jet fuel specification and SAF must be approved through the ASTM D4054 process which ensures the safety and performance of fuel (Holladay et al., 2020). Upon completion of the D4054 tests, the approval process for ASTM D7566 begins (Holladay et al., 2020). If the SAF has equivalent properties and characteristics to conventional jet fuel, then it is referred to as a drop-in fuel and the pathway used to develop the fuel can be included under ASTM D7566 (Holladay et al., 2020). Current ASTM D7566 specifications limit most pathways to between 10% and 50% by volume blending with conventional jet fuel (Federal Aviation Administration, 2021).

Through Federal Aviation Administration support, seven SAFs have been annexed in ASTM D7566 for commercial use:

1. Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) is produced from the gasification of coal, natural gas, or biomass into synthesis gas (syngas); the syngas is then converted into liquid hydrocarbons (Green Car Congress, 2020). Fischer-Tropsch Synthesized Kerosene with Aromatics (FT-SPK/A) is a variation of the FT process producing a fully synthetic alternative aviation fuel containing aromatics (IATA, n.d.).

2. Hydroprocessed Esters and Fatty Acids (HEFA-SPK) is produced by deoxygenating and then hydroprocessing plant and animal FOGs to produce hydrocarbons (Green Car Congress, 2020; IATA, n.d.).

3. Hydroprocessed Fermented Sugars to Synthetic Iso-Paraffins (HFS-SIP) uses modified yeasts to ferment sugar feed stocks into hydrocarbons (Green Car Congress, 2020; IATA, n.d.).

4. Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK) converts alcohol feedstocks (ethanol and isobutanol) to hydrocarbons through dehydration, oligomerization, and hydro processing (Green Car Congress, 2020; IATA, n.d.).

5. Catalytic Hydrothermolysis Synthesized Kerosene containing aromatic compounds (CH-SK or CHJ) is produced from hydrothermal conversion of fatty acid esters and free fatty acids with fractionation and any combination of hydrotreating, hydrocracking, or hydroisomerization (Applied Research Associates, 2021).

6. Hydroprocessed Hydrocarbons Synthesized Paraffinic Kerosene (HC-HEFA-SPK or HH-SPK) is produced from the hydroprocessing of bio-derived hydrocarbons which comes from the oils found in algae known as botryococcus braunii (IATA, n.d.).

Airbus, a commercial aircraft manufacturer, claims the most commonly used feedstocks are FOGs derived from crops (Airbus, 2021). The EU's most developed process is HEFA-SPK (EASA, n.d.). Investments into the other ASTM-certified pathways does not seem to be a priority for major industrial players in Europe (EASA, n.d.). HEFA-SPK is projected to have a lower cost and better sustainability profile compared to ATJ-SPK, CH-SK, and HFS-SIP by 2030 (Thomson et al., 2020). However, Fischer-Tropsch Power-to Liquid (FT-PtL) has the potential to outshine all the current SAFs annexed in ASTM D7566 for commercial use in terms of environmental benefits, reliable feedstock, and cost (Thomson et al., 2020).

FT-PtL, an e-SAF, is a synthetic fuel derived from non-bio-based feedstocks such as renewable energy (EASA, n.d.). FT-PtL uses renewable electricity to produce hydrogen from water by electrolysis and a combination with carbon from CO_2 captured from the air (EASA, n.d.). FT-PtL's "well-to-wheel" emissions can be reduced by as much as 90% compared to fossil fuels which is significantly better than the approved SAFs (Airbus, 2021). FT-PtL relies on a vast amount of renewable energy and using electrofuels to meet the expected fuel demand for aviation in 2050 would require 95% of the electricity currently generated from renewables in Europe (EASA, n.d.). The future of FT-PtL relies on renewable energy costs to reduce (Thomson et al., 2020). However, governments and airlines have made commitments to net zero and carbon neutrality which will likely increase the availability and lower the cost of renewable energy in the years to come.

Current Usage of SAF

According to the International Air Transport Association (IATA), over 370,000 flights have used SAF since 2016, around 14 billion liters of SAF are in forward purchase agreements, and more than 45 airlines now have experience with SAF (IATA, 2022). The production and use of SAF is predicted to enable aviation emissions to drop 20% by 2030 (The White House, 2021). However, SAF accounts for less than 0.1% of the aviation fuel market (Zacks, 2021). The U.S. Energy Information Administration released U.S. capacity data for biorefineries that produce renewable fuels and identified six facilities that were operational with a combined nameplate capacity of 791 million gallons per year as of January 1, 2021 (Voegele, 2021). In 2020, the U.S. produced 4.5 million gallons of SAF, but 18.3 billion gallons of jet fuel was consumed in 2019 (Overton, 2022). Aviation fuel demand is projected to be around 35 billion gallons per year by 2050 (Federal Aviation Administration, 2021).

The Federal Aviation Administration (FAA) released its Aviation Climate Action Plan in November 2021 detailing how the current administration plans to achieve net zero GHG emissions in the U.S aviation sector by 2050 (Myatt, 2022). In September 2021, the administration committed to producing 3 billion gallons of SAF per year by 2030 (Federal Aviation Administration, 2021). On

February 4, 2022, the Business Aviation Coalition for Sustainable Aviation Fuel called on EPA Administrator Michael Regan to expand the list of eligible feedstocks, approve new process technologies and bio intermediate opportunities, and ensure that the volumes for advanced biofuels are set at levels that will allow greater supplies of those fuels in response to a request for comments on proposed updates to the Renewable Fuel Standard (Hubbard, 2022). Private and public sector participation will be crucial to increasing SAF production and significant progress is already being made.

Top 10 Airlines Using SAF

1. United Airlines aims to reduce its GHG emissions 100% by 2050, without relying on carbon offsets (United, 2021). United remains an industry leader having used more SAF than any other airline globally and holds 70% of all publicly announced purchase agreements for SAF (United, 2021). United was able to receive special permissions to operate the first commercial demonstration flight on December 1, 2021, using 100% SAF in one of the Boeing 737 Max 8 aircraft engines with the other engine using conventional jet fuel (Hood, 2021).

2. American Airlines committed to reach net zero emissions by 2050 and in early 2020 agreed to purchase 9 million gallons of SAF over three years from Neste (American Airlines Group Inc, 2020). In July 2021, American Airlines announced plans to purchase up to 10 million gallons of SAF produced by Prometheus Fuels with plans to begin production in 2022 (American Airlines Group Inc, 2020). American predicts SAF will be 39% of the solution to reach net zero by 2050, which is the largest solution pathway identified by American (American Airlines Group Inc, 2020).

3. British Airways (BA) has a goal to achieve net zero carbon emissions by 2050 with plans to purchase enough SAF to reduce lifecycle CO_2 emissions by almost 100,000 tonnes (Webber, 2021). BA entered into a multi-year supply agreement with Phillips 66 to produce renewable fuels from recycled cooking oil at the Humber Refinery in North Lincolnshire (Webber, 2021).

4. Alaska Airlines (2021) aims to reach zero carbon emissions by 2040 and has a partnership with SkyNRG Americas to produce SAF from municipal solid waste (MSW).

5. Qantas aims to be carbon neutral by 2050 and has signed an agreement with BP plc to buy 10 million liters of SAF across 2022 (Curran, 2021).

6. Etihad Airways aims to achieve net-zero emissions by 2050 and cut its 2019 emissions in half by 2035 (Etihad, 2020). Etihad is a founding partner of the Sustainable Bioenergy Research Consortium and is partnering in the development of biofuel refined in Abu Dhabi from saltwater-tolerant plants and is committed to support the development of SAF from MSW in Abu Dhabi (Etihad, 2020).

7. Air France-KLM Group aims to reach net zero emissions by 2050 and starting January 10, 2022, KLM is adding 0.5% SAF for flights departing from Amsterdam (Amstelveen, 2022). In addition, KLM will offer its customers the option of purchasing an extra amount of SAF when booking via the CO_2ZERO program (Amstelveen, 2022).

8. The Cathay Pacific Group has committed to achieving net-zero carbon emissions by 2050 and to purchasing 1.1 million tonnes of SAF over 10 years, which will cover around 2% of its total fuel requirements from 2023 onwards (Cathay Pacific, 2021).

9. Southwest has a 10-year plan to maintain carbon neutrality to 2019 levels and has committed to replacing 10% of total jet fuel consumption with SAF by 2030 (Southwest, 2021).

10. Delta committed to carbon neutrality from March 2020 onward and to replacing 10% of conventional jet fuel with SAFs by the end of 2030 (DeLuca, 2021).

Top 10 Producers of SAF

1. Finnish Neste currently has an annual capacity of 100,000 tons of SAF (Neste, n.d.). With the Singapore refinery expansion on the way, and an additional investment into the Rotterdam refinery, Neste expects to have the capacity to produce 1.5 million tons of SAF annually by the end of 2023 (Neste, n.d.). Neste partnered with Air BP to deliver SAF to customers in Sweden and France. In addition, Lufthansa and KLM use their SAF on flights departing from Frankfurt and Schiphol Airport (Neste, n.d.).

2. Royal Dutch Shell plc plans to generate about 2 million tons of SAF a year by 2025 and aims for SAF to account for at least 10% of aviation fuel sales by 2030 (Zacks, 2021). Royal Dutch Shell plc also plans to construct an 820,000-tonne-per-year biofuels facility at the Shell Energy and Chemicals Park Rotterdam in the Netherlands (Zacks, 2021). When completed, the plant will be one of the largest producers of SAF and renewable diesel from MSW in Europe (Zacks, 2021).

3. Eni plans to reach bio refining capacity of 5 to 6 million tonnes/year by 2050 with an aim to reach a production capacity of at least 500,000 tonnes/year of biojet by 2030 (eni, 2021). Eni SAFs are produced exclusively from waste and residues (eni, 2021).

4. LanzaJet plans to produce 1 billion gallons of SAF per year by 2030 from ethanol derived from waste sources (White House, 2021). In February 2022, LanzaJet entered into a memorandum of understanding with Marquis SAF to construct a 120 million gallons per year integrated SAF plant in Illinois, scheduled to begin engineering in 2022, using low-carbon intensity (CI) feedstocks to produce SAF from corn via the LanzaJet™ ATJ-SPK process (LanzaJet, 2022). LanzaJet's first plant in Georgia is expected to enter commercial operations in 2023 (LanzaJet, 2022).

5. Velocys plans to produce 300 million gallons of blended SAF per year from waste woody biomass and MSW by FT-SPK processing (White House, 2021).

6. World Energy plans to produce 150 million gallons of SAF per year by 2024 from FOGs by hydroprocessing (White House, 2021).

7. Fulcrum plans to produce more than 33 million gallons of SAF per year by 2022 from MSW by FT-SPK processing (White House, 2021).

8. Abu Dhabi Waste Management Centre (Tadweer) signed a Joint Project Development Agreement with Etihad Airways to facilitate the development of the first Waste-to-SAF plant in the Middle East Region (Alarabiya news, 2021). The plant will have the potential to convert 4 million tonnes of MSW into SAF and will divert 75% of MSW away from landfills (Alarabiya news, 2021).

9. Gevo plans to produce over 150 million gallons of SAF per year by 2025 from crop residue to ethanol by ATJ-SPK processing (White House, 2021). Chevron U.S.A. Inc., and Gevo, Inc. announced an agreement to jointly invest in building and operating one or more new facilities that would process inedible corn to produce SAF (Chevron, 2021). Gevo would operate its proprietary technology to produce SAF and Chevron would have the right to offtake approximately 150 million gallons per year to market to customers (Chevron, 2021). ADM and Gevo entered into a memorandum of understanding to produce ethanol and isobutanol that would then be transformed into renewable low carbon-footprint hydrocarbons, using Gevo's processing technology and capabilities resulting in approximately 500 million gallons of SAF and other renewable hydrocarbons (Abdo, 2022).

10. Virent, a wholly owned subsidiary of Marathon Petroleum Corporation, created the SAF used to power the United Airlines commercial demonstration flight on December 1, 2021, using 100% SAF in one of the Boeing 737 Max 8 aircraft engines (Johnson Matthey Plc, 2021). Their BioForming® technology converts sugar feedstocks into a product known as BioFormate® via a catalytic process (Johnson Matthey Plc, 2021). BioFormate is used to create biofuels, including BioForm® synthesised aromatic kerosene, which is blended with renewable paraffinic kerosene to produce 100% SAF (Johnson Matthey Plc, 2021).

Cost and Regulations

Even if production ramps up, SAF is currently four times more expensive than petroleum jet fuel (Reichmann, 2021). E-SAF can be eight times the cost of conventional jet fuel and two to three times the cost of HEFA-SPK (Moyes & Nowobilski, 2022). Programs such as California's Low Carbon Fuel Standard (LCFS) will be important to incentivize the production of SAF. The LCFS sets annual CI standards which reduce overtime for gasoline, diesel, and the fuels that replace them (Reichmann, 2021). The LCFS gives credits to fuels with low CIs and deficits for high CIs (Reichmann, 2021). LCFS prices have already reached their cap of $200. Also, the Sustainable Skies Act introduced in May 2021 would establish a $1.50 per gallon tax credit through 2031 for SAF that reduces emissions by 50%; if the reduction is over 50%, $0.01 is added for every percentage point maxing out at $2 (Reichmann, 2021).

France is adopting more stringent policies to accelerate SAF. Starting January 1, 2022, the French Government introduced a 1% SAF mandate on all flights departing from the country which also calls for aircrafts to use at least 2% biojet fuel by 2025 and 5% by 2030 (TotalEnergies, 2021). A surcharge fee, ranging between €1 and €12 depending on the flight distance and cabin class, will apply on ticket prices (Transport & Environment, 2022). As a result, ExxonMobil has reached an agreement with SAF producer Neste to distribute commercially Neste MY Sustainable Aviation Fuel at France's largest airports which is made of FOGs (biofuels international, 2022). The SAF will be a 30% mixture with conventional jet fuel (biofuels international, 2022). In April 2021, TotalEnergies started producing SAF at the La Mèdebio refinery in southern France and the Oudalle facility near Le Havre which will also be delivered to French airports (TotalEnergies, 2021).

Feasibility of Feedstocks

FOGs under HEFA-SPK are the most widely accepted SAF feedstock with soybean oil being a frontrunner in the United States. The United States and Brazil are the two largest producers of soybeans in the world (Ritchie & Roser, 2021). More than three-quarters (77%) of the global soy produced is used as feed for livestock, 19.2% for human consumption, and 3.8% for industry of which 2.8% is used for biodiesel (Ritchie & Roser, 2021). Biodiesel production accounts for about 30% of domestic soybean oil disposition in the U.S and continues to grow (Hanson, 2019).

However, the food versus fuel debate remains. Jenna Higgins of the National Biodiesel Board mentions increasing the use of soy for biodiesel would positively affect the food supply (Wired, 2006). Higgins states the biodiesel market is a great way to use leftover oil since the demand is higher for soybean meal; a greater demand for soybean oil may cause the price to increase and decrease the price of soybean meal which means cheaper livestock feed (Wired, 2006). However, the U.S Department of Agriculture estimated Brazil's soybean production for the 2021/2022 marketing year at 134 million metric tons, down 3% from last season's record crop due to lack of rainfall in November and December during critical reproductive crop stages in the southern state of Paraná (United States Department of Agriculture, 2022). The more recent lack of soy production due to agricultural volatility may lead to increased prices in soybeans and therefore high prices for SAF derived from soybean oil.

Alcohol feedstocks under ATJ-SPK are also dependent on reliable crop yields but in this case from corn. The U.S is the largest producer of corn and roughly 40% is used for ethanol and 36% for animal feed (Foley, 2013). U.S corn prices in 2019 increased because significant flooding in the Midwest delayed expected harvests and lowered corn yields (Hanson, 2019). Higher feedstock costs and relatively unchanged ethanol demand drove ethanol margins and profitability to multiyear lows, which negatively affected ethanol production (Hanson, 2019). As of March 25, 2022, the price of corn is a little over $7.50 per bushel which has increased since October 2020 (Macrotrends LLC, n.d.). Holladay et al. (2020) suggest sourcing the alcohol from high-cost sugars such as biomass is not feasible. Reports suggest that a $0.01 increase in sugar cost results in a $0.20 increase in fuel cost (Holladay et al., 2020; Gruber, 2018). The historic volatile weather has shown to affect corn production and the price of SAF dependent on alcohol feedstocks. Therefore, dependence on alcohol feedstocks for SAF may become an unsustainable option.

The USDA is investing in research to develop oilseed crops including carinata (Dwivedi, 2021). The oil obtained from crushed carinata seeds can be refined to produce SAF reducing up to 68% of carbon emissions compared to a unit of conventional fuel (Dwivedi, 2021). Carinata is known to improve water quality and prevent soil erosions (Dwivedi, 2021). The residues after crushing the carinata are high in protein and can be used as animal feed (Dwivedi, 2021). As of February 2022, Nuseed and BP Products North America Inc., have entered into a long-term strategic offtake and market development agreement to develop carinata as a SAF feedstock (Nuseed, 2022). Nuseed is increasing carinata oil production in Argentina and expanding its network of growers in South America and the United States (Nuseed, 2022). Nuseed plans to deliver carinata oil to BP Products North America Inc for it to be processed and sold into growing markets for the production of SAF (Nuseed, 2022). Carinata has the potential to be a more reliable feedstock given it is a non-food cover crop, but current production is low.

Conclusion

HEFA-SPK remains a short-term solution as it is commercial (Holladay et al., 2020). However, the purification of the lipid feedstock remains expensive (Holladay et al., 2020). Also, HEFA-SPK relies on successful yields from crops such as soybeans which is becoming more unpredictable given the increase in extreme weather. Oilseed crops such as carinata are only in the beginning stages but offer a more reliable feedstock option. FT-PtL is a potential long-term solution. However, FT-PtL is dependent on decreasing renewable energy costs. The future of SAF relies on government guidance through legislation and incentive programs to ensure SAF is affordable. The stakes are high for airlines, aircraft manufacturers, and governments to ensure SAF is viable, but the consequences are more serious for the planet.

About the Author

Katie Zona
Sustainability and Engagement Research Analyst

Ms. Zona is a Research Analyst for the Boston Partners Sustainability and Engagement Team. She is responsible for original ESG/Sustainability research on companies held in Boston Partners' portfolios. Ms. Zona holds a B.A. degree in Communications from Boston College, with a double minor in Managing for Social Impact and the Public Good and Applied Psychology and Human Development. She has significant sustainability internship experience.

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