Institute for Energy Economics
and Financial Analysis

Briefing Note

August 2024

Abhishek Sinha || Energy Finance Analyst, Petrochemical

Sustainable Aviation Fuel: Not a Panacea, but Likely Helpful if Key Issues Are Resolved

- *In the effort to reduce the aviation industry's carbon footprint, sustainable aviation fuel isn't a panacea but increasingly shows potential as a promising alternative to fossil fuel.*
- *According to the EIA, global commercial jet fuel demand is expected to grow in the coming years and SAF can help the industry meet its sustainability goals, especially in the near term.*
- *While SAF holds great promise, widespread adoption faces several challenges including cost and environmental concerns.*
- *Technological advancements, coupled with growing environmental awareness, are encouraging the adoption of SAF across the aviation industry.*

The aviation industry faces challenges in the effort to reduce its carbon footprint. Sustainable aviation fuel (SAF) isn't a panacea but increasingly shows potential as a promising alternative to fossil fuel. However, cost barriers and other concerns must be overcome to reap potential benefits from the fuel.

Aviation Is a Substantial Emission Source and Is Getting Worse as Fuel Economy Measures Fail To Curb Rising Demand

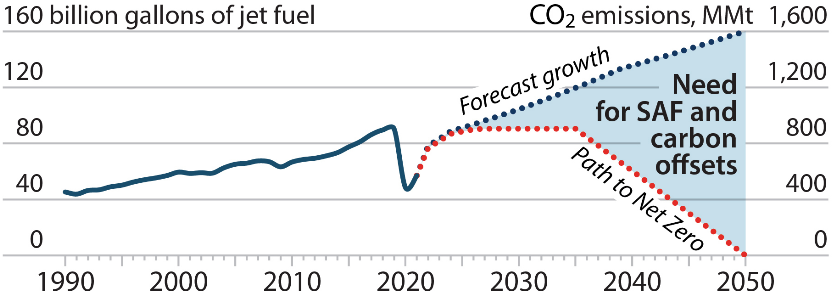
Aviation emissions in 2022 reached almost 800 million tonnes per year (mmtpa) of carbon dioxide (CO2), representing about 2% of global energy-related CO2 emissions. This marks a significant—although partial—rebound from the pandemic-driven downturn, with emissions returning to approximately 80% of pre-pandemic levels. According to the International Air Transport Association (IATA), an airline industry trade advocacy organization, the expected 2021-50 carbon emissions on a "business as usual" trajectory is more than 21 gigatons of CO2, which is an approximately 13% compound annual growth rate (CAGR). The IATA reports that the airline industry has set a goal to reduce carbon emissions to net zero by 2050.

The easiest way to lower aviation-related emissions would be to improve fuel economy. But based on International Energy Agency (IEA) data, the average fuel efficiency in aviation has improved by less than 2% over the last 10-year period, while expected growth in the sector is more than 4% CAGR for the next 10 years. Based on the IEA data, it is evident that the easier work has been done in terms of efficiency improvement, and the current engine technology could be approaching the boundaries of material science. The rate of improved efficiency is likely to slow in future generations.

Figure 1: Projections for Jet Fuel Demand and Emissions

The Potential Role for Sustainable Aviation Fuel

Used as an alternative to fossil fuels, SAF could cut CO_2 emissions



Sources: IATA, Air Transport Action Group and Barclays Research (2022) IEEFA

Jet Fuel Demand Is Expected To Soar

The U.S. Energy Information Administration (EIA) expects global commercial jet fuel consumption to more than double from 96 billion gallons in 2018 to 215 billion gallons in 2050. Annual jet fuel consumption in the United States grew in 2023 for the third year in a row but remained below the pre-pandemic peak in 2019. U.S. jet fuel consumption averaged 1.65 million barrels per day (b/d) in 2023, 5% below the pre-pandemic high in 2019. So far this year, airline passenger volumes have surpassed 2019 levels and are consistently higher than in 2023. EIA projects global demand for jet fuel to continue increasing through 2050 at a CAGR of approximately 2.5%.

The Air Transport Action Group (ATAG), an air transport industry advocacy nonprofit organization, predicts a 3.1% annual increase in air traffic, projecting a total of 10 billion passengers by 2050, almost 2.6 times higher than 2019 levels.

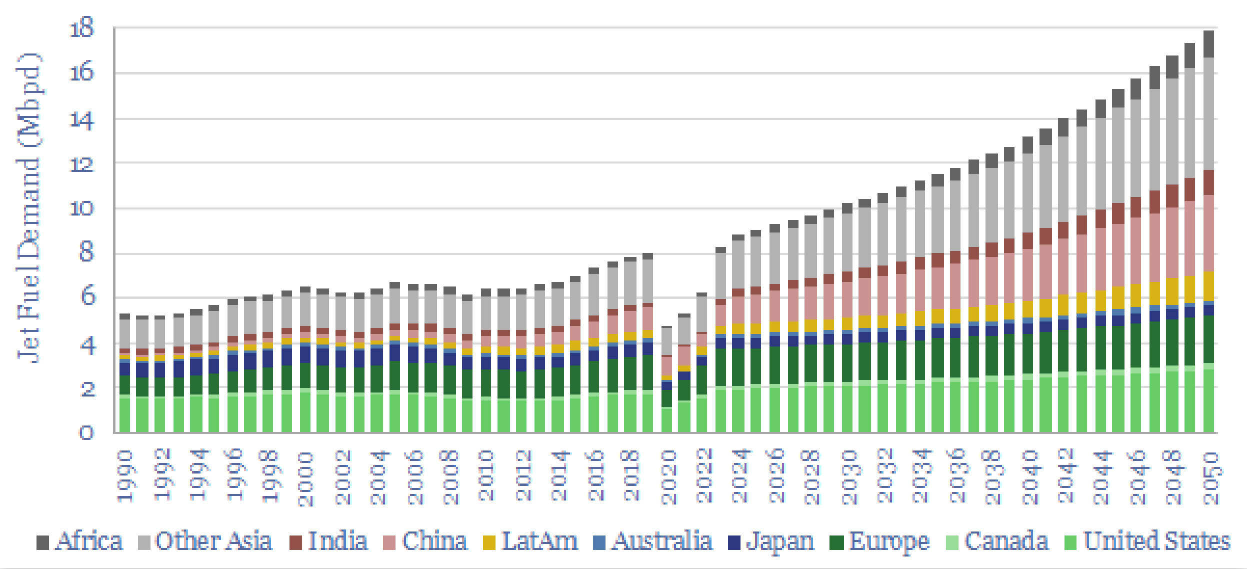
Even without considering fuel efficiency improvements, the air traffic trajectory expected by ATAG would lead aviation energy demand to approach almost 240 billion gallons of jet fuel (equivalent to over 15 million barrels per day of oil demand) by 2050, resulting in approximately 2.3 billion metric tons of CO2 emissions. Airbus and Boeing, the leading aircraft manufacturers globally, have each projected the number of flights and planes in operation will double in the next 30 years. The IEA expects jet fuel demand to hit a record later this decade, while Rystad expects global jet fuel demand to cross 8 million barrels per day in 2026.

According to NREL, jet fuel demand is expected to more than double by 2050. The U.S. EIA projects that the global commercial jet fuel market, which is currently 106 billion gallons, will grow to more than 230 billion gallons by 2050. A report by research consultant Thunder Said

Energy similarly expects jet fuel demand to more than double from 2019 levels by 2050.

The United States is the largest consumer of jet fuels in the world, accounting for as much as 26 billion gallons annually. According to the EIA, jet fuel demand in the United States is estimated to be about 30 billion gallons per year in 2030.

Figure 2: Jet Fuel Demand by Region



Source: Thunder Said Energy

SAF Can Help the Aviation Industry Meet Its Targets, Especially in the Near Term

SAF is fuel derived from alternative feedstocks (such as biomass or waste oils), which is converted to conventional kerosene and tailored for use in aviation. The two primary considerations for aviation fuel to be deemed sustainable are:

1. The fuel must deliver low-carbon or zero-carbon emissions when burned, and
2. It must be a “drop-in” fuel, similar in chemistry to fossil jet fuel such that it can be easily integrated with existing infrastructure and blended with traditional jet fuel.

As a drop-in fuel, SAF can be used without modifications to current engines or fuel infrastructure. Although the CO2 emissions directly released from SAF combustion are comparable to those of conventional jet fuel (about 9.75 kilograms of CO2 per gallon), depending on the feedstock and technologies used to produce SAF, it can reduce life cycle greenhouse gas (GHG) emissions dramatically compared to conventional jet fuel. Some emerging SAF pathways even have a net-negative GHG footprint.

The production of SAF involves various technologies and feedstocks. Biomass-based SAF is derived from organic materials such as agricultural residues, woody biomass, and algae. Typical feedstocks include corn grain; oil seeds; algae; fats, oil and greases (FOG); forestry and agricultural residues; wood mill waste; wet wastes; and solid waste from homes and businesses—such as packaging, textiles and food scraps—that would otherwise go to a landfill or incinerator. Waste oils, including used cooking oil and animal fats, can also be converted into high-quality aviation fuel. Renewable electricity can be used to produce synthetic fuels through processes such as electrolysis and Fischer-Tropsch synthesis. There are 11 main conversion processes for SAF production approved by the American Society for Testing and Materials (ASTM), and 11 other conversion processes are currently being evaluated.

Table 1: Approved Conversion Processes

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
ASTM D7566 Annex A1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Coal, natural gas, biomass	50%
ASTM D7566 Annex A2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Vegetable oils, animal fats, used cooking oils	50%
ASTM D7566 Annex A3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%
ASTM D7566 Annex A4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%
ASTM D7566 Annex A5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Ethanol, isobutanol and isobutene from biomass	50%
ASTM D7566 Annex A6	Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oils, animal fats, used cooking oils	50%
ASTM D7566 Annex A7	Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%
ASTM D7566 Annex A8	Synthetic paraffinic kerosene with aromatics	ATJ-SKA	C2-C5 alcohols from biomass	50%
ASTM D1655 Annex A1	Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery		Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum	5%
ASTM D1655 Annex A1	Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery		Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
ASTM D1655 Annex A1	Co-processing of HEFA	Hydroprocessed esters/fatty acids from biomass		10%

Source: International Civic Aviation Organization (ICAO)

Three of the approved processes, outlined in red in the table above, appear more promising in terms of lowering GHG emissions based on availability of feedstocks, higher percentage blend (50%) with commercial fossil-derived jet fuels, and commercial scalability:

1. HEFA (hydroprocessed esters and fatty acids): The fuel properties for this pathway are similar to those of conventional petroleum fuel, but HEFA has the advantages of a higher cetane number, lower aromatic content, lower sulfur content, and potentially lower GHG emissions. Feedstock includes lipids from fats, oils, & greases (FOGs). Priority is placed on sustainable waste oils, notably used cooking oil (UCO) and animal fat residues. The HEFA fuel product leverages existing refining know-how as the hydro-processing conversion technologies are matured and are commercially available. HEFA has a 50% blend limitation and is currently the only commercial scale process for aviation biofuel production that has been tested on a large scale. Looking at the offtake agreements for 2024, HEFA appears to be taking a lion's share of the total investments in SAF.
2. Fischer-Tropsch (FT) Pathway Production Process: In this pathway, biomass is first converted to syngas using gasification and then to jet fuel components using the FT synthesis reaction. Feedstocks for this pathway include various sources of renewable biomass but focus mainly on woody biomass, such as municipal solid waste, agricultural waste, forest waste, and energy crops. The approved blend limitation for jet fuel produced by the FT pathway is 50%. The cost stack of FT pathways is the inversion of HEFA, with very high capital costs and low feedstock costs.
3. The Alcohol-to-Jet (ATJ) Technology Pathway: This pathway uses fermentation to convert sugars, starches, or hydrolyzed cellulose into an intermediate alcohol, either isobutanol or ethanol, which is then further processed and upgraded into a mix of hydrocarbons. Feedstocks such as sugar cane, corn grain and switchgrass are used via fermentation of sugars to ethanol or other alcohols. The approved blend limitation for jet fuel produced by the ATJ pathway is 50%.

These particular pathways show that through the utilization of SAF, airlines can notably diminish their carbon footprints and alleviate the environmental repercussions of air travel. SAF also promotes energy security by diversifying fuel sources and reducing reliance on finite fossil fuels. Unlike conventional jet fuel derived from petroleum, SAF is primarily plant-based, and can be produced from various renewable feedstocks such as cooking oils, agricultural residues, and non-food crops. This shift to renewable sources helps mitigate the geopolitical and economic risks associated with the volatile fossil fuel market.

Other Alternatives to Fossil-Based Aviation Fuel Exist but Are Currently Limited

Electrically-powered (primarily running on batteries) and hydrogen-powered aircraft are often discussed as alternatives to SAF, but they have limitations.

Currently, the lower energy density of batteries (1/40th vs kerosene-based jet fuel) is limiting the success of electrically-powered aircraft to smaller aircraft taking short-range flights, due to weight and storage area concerns.

Technology and design improvements may allow battery-electric airplanes to play a more significant role in the future. Recent research jointly undertaken by Elysian Aircraft, a startup company, and the Delft University of Technology, both based in The Netherlands, re-examined the assumptions that have led to the conclusion of the limited applicability of battery-electric airplanes. The researchers identified design changes that could allow greater use of battery-electric power in aviation.[1] Also, the leading electric battery maker, CATL, recently tested an ultra-dense EV battery in a 4-ton electric plane and plans to reveal battery technology to service an 8-ton electric plane with a range of 1,200-1,800 miles by 2028—suitable for private and business jets. Another battery maker, Amprius Technologies (AMPX), announced last year that it secured orders from three electric aircraft developers. However, Amprius is mostly targeting small aircraft that carry just a few passengers.

Hydrogen presents substantial barriers for hydrogen-powered aircraft that may be more difficult to overcome. The lower volumetric density of hydrogen (1/4th the energy of an equivalent volume of kerosene-based jet fuel) increases the space requirements for fuel storage in a plane. Also, hydrogen must also be cooled to around -300°C to store in its liquid state, and specialized storage tanks may further add weight and volume to the aircraft. The lack of infrastructure to deliver hydrogen to the airplanes is another hurdle to overcome. Hydrogen fuel cell technology, as an alternative to liquid hydrogen fuel, "must become lighter, more powerful, and more durable to make large, fuel cell-powered transport aircraft feasible." Finally, if the hydrogen is produced from natural gas rather than from water using renewable energy, it will have a significant greenhouse gas footprint.

The Aviation Industry Includes SAF in Its Sustainability Plans

As noted above, the aviation industry has pledged to reduce carbon emissions by 50% from the 2005 level by 2050. An increasing number of airlines are choosing to blend lower-carbon SAF with fossil jet fuel to achieve this objective. Major U.S. airlines have announced plans to ramp up SAF usage—including American and Delta—to 10% of total fuel consumption by 2030.[2, 3] Current use by these airlines, however, is very low.[4] Major manufacturers such as Airbus and Boeing are aiming to achieve 100% SAF capability by 2030, compared to the current 50%.[5, 6]

Numerous airlines and airports have already adopted SAF as a key component of their sustainability initiatives. For example, KLM Royal Dutch Airlines has conducted multiple flights using SAF blends, resulting in a notable reduction in their carbon emissions. Similarly, San Francisco International Airport is actively receiving the highest volume of SAF of any airport in the world.

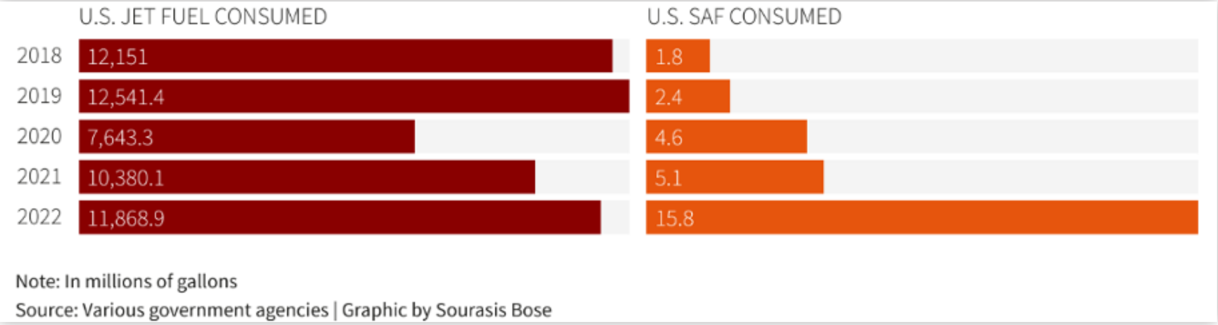
The SAF market is anticipated to experience significant growth, with projections indicating it will reach $25 billion by 2030. This expansion is driven by regulatory mandates and corporate commitments to decarbonization.

The U.S. Department of Energy (DOE), for example, has established a target of achieving 3 billion gallons of SAF usage by 2030, equivalent to approximately 12% of the EIA's projected U.S. jet fuel demand for that year. Additionally, the SAF Grand Challenge is an effort of the DOE, the U.S. Department of Transportation (DOT), and the U.S. Department of Agriculture (USDA) to reduce the cost, enhance the sustainability, and expand the production and use of SAF while:

- Achieving a minimum of a 50% reduction in life cycle greenhouse gas emissions compared to conventional fuel.
- Meeting a goal of supplying sufficient SAF to meet 100% of aviation fuel demand by 2050.

In 2022, U.S. consumption of SAF was approximately 16 million gallons. The EU has committed to mandatory goals for SAF utilization, starting at 2% of total consumption in 2025, escalating to 6% in 2030, 20% in 2035, and ultimately reaching 70% by 2050.

Figure 3: SAF Makes Up a Fraction of Total U.S. Jet Fuel Consumption

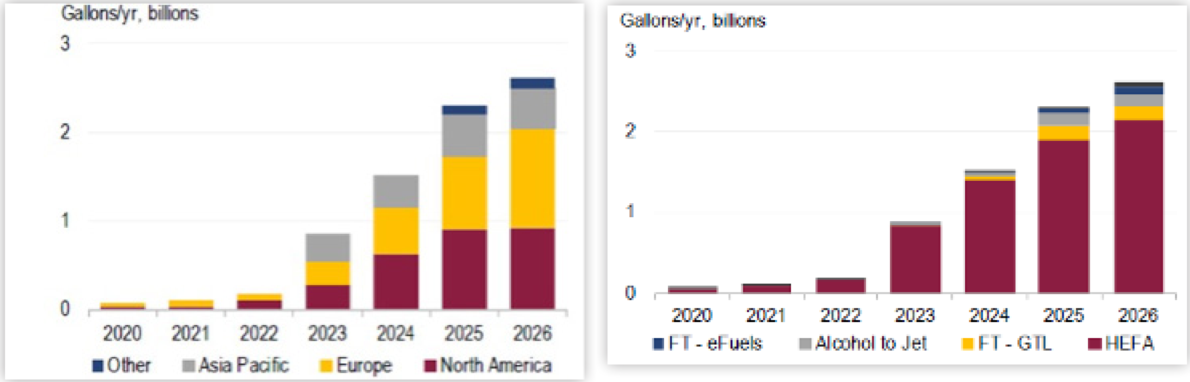


Note: In millions of gallons
Source: Various government agencies | Graphic by Sourasis Bose

The SAF Supply Is Growing but Still Far From What Is Needed To Meet Sustainability Objectives

Global supply of SAF in 2021 was just 26 million gallons. This represented less than 0.03% of the jet fuel demand in 2019. However, the industry is projected to reach more than 2 billion gallons of annual SAF capacity by 2025. This would still be less than 2% of the pre-pandemic jet fuel demand. BloombergNEF (BNEF) expects jet fuel demand to reach pre-pandemic levels by 2025. The HEFA pathway takes the lion's share of near-term capacity growth, and most of the capacity additions are in North America and Europe. Even if SAF supply reaches 5.4 billion gallons, it would still be 5% of global jet fuel consumption.

Figure 4: SAF Production Levels by Region and Process Type



SAF Production by Region

SAF Production by Process Type

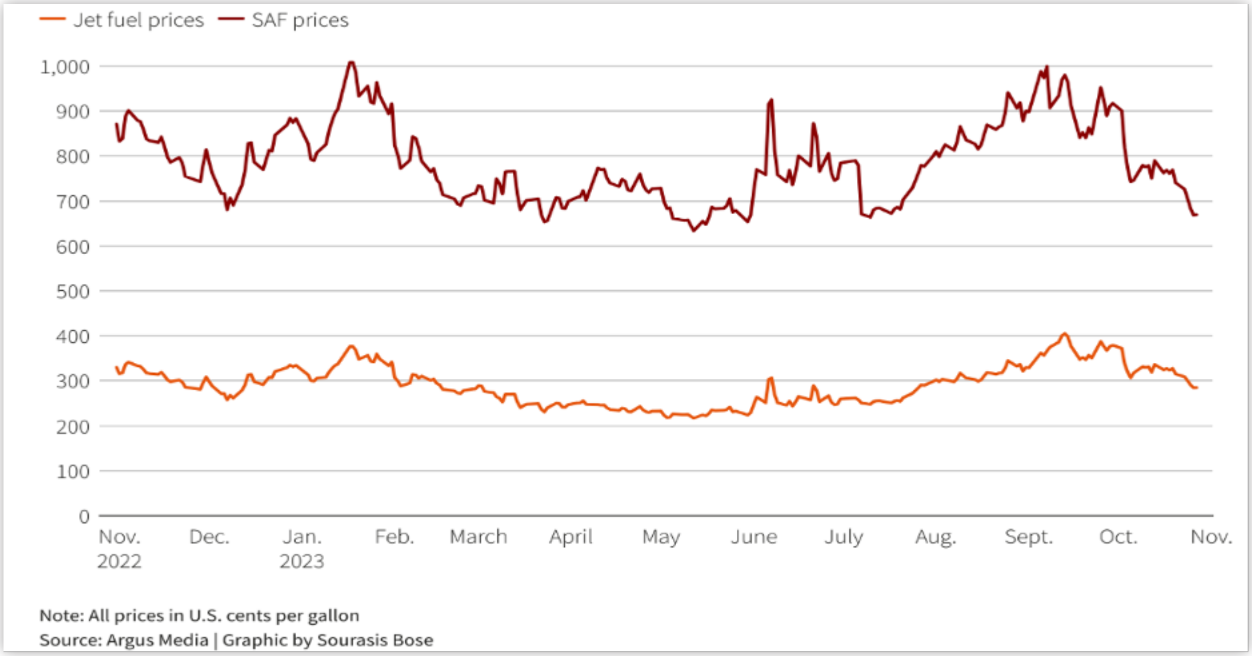
Source: CIBC World Markets

Source: CIBC World Markets

Cost Is a Problem: SAF Is Far More Expensive Than Fossil Fuel at This Time

While SAF holds great promise, widespread adoption faces several challenges and cost is one of them. Fuel expenses typically represent [20% to 30%] of an airline's total expenses. Any additional costs resulting from increased SAF usage could have a significant effect on ticket prices. SAF comes with a green cost premium of two to five times more than conventional jet fuel. A 50% SAF blend at three times the cost of traditional jet fuel could double fuel costs.

Figure 5: SAF Trades at a Premium Over Jet Fuel



Note: All prices in U.S. cents per gallon
Source: Argus Media | Graphic by Sourasis Bose

SAF producers will need to reduce costs to a level closer to that of traditional jet fuel to encourage widespread adoption.

Government Policies and Regulations May Help Make SAF More Competitive With Fossil Fuel

Government policies and regulations play a pivotal role in shaping the adoption of SAF. Numerous nations have introduced incentives, mandates, and goals to promote the production and adoption of SAF. The EU, for example, has established ambitious targets for incorporating renewable fuels in aviation, spurring investment and advancements within the sector.

The U.S. Renewable Fuel Standard program (RFS) allows SAF to generate D4, D5, and D7 renewable identification numbers (RINs)—credits used for compliance with the RFS—if they are produced by hydrotreating using eligible feedstocks (D4, D5) or produced from cellulosic material (D7). This approach helps make SAF more competitive with renewable diesel and increases familiarity with SAF. The regulatory approach does not establish a mandated use obligation. Under the RFS, SAF is eligible to receive 1.6 D4 RINs per gallon when produced using the hydrotreating pathway.

Under the Inflation Reduction Act (IRA) SAF 40B tax incentives,[7] SAF producers are eligible for a tax credit of $1.25 to $1.75 per gallon. SAF that achieves a GHG emissions reduction of 50% is eligible for the $1.25 credit per gallon amount, and SAF that achieves a GHG emissions reduction of more than 50% is eligible for an additional $0.01 per gallon for each percentage point the reduction exceeds 50%, up to $0.50 per gallon.[8] The 40B credits, however, expire at the end of this year, after which the Clean Fuel Production Credit (§ 45Z) comes into effect.[9] These credits would be transferable and bankable, enabling small companies, who might not have a large enough tax bill to benefit by direct application of the credit, to benefit from those offsets. At the state level, the low carbon fuel standard (LCFS), enacted by California, Oregon and Washington, provides a credit value per gallon for SAF.

Environmental Challenges of SAF Must Be Addressed

We would be remiss if we do not mention that the production of SAF involves environmental challenges that need to be addressed to ensure their sustainability and minimize negative impacts. One environmental challenge involves land use and deforestation. If sustainable agricultural practices are not adopted, the production of SAF could lead to deforestation, loss of biodiversity and competition for land with food crops. Water usage poses other challenges. The production of biofuels often requires significant water resources for irrigation, which can strain local water supplies and affect water quality.

Conclusion

As we look to the future, the trajectory of SAF seems promising. Technological advancements, coupled with growing environmental awareness, are encouraging the adoption of SAF across the aviation industry. With continued innovation, collaboration, and investment, SAF has the potential to pave the way toward a greener, more sustainable future for air travel. The majority of major oil and gas companies—such as ExxonMobil, Chevron, and Shell—are reassessing their refinery processes and evaluating how to effectively tackle the issue of carbon emissions as part of their sustainability strategies. We are keenly interested in closely examining the results of these efforts.

Finally, the industry should conduct a more rigorous analysis to understand what it means to propose large-scale use of biofuels in relation to food supply and water use. We need to get a good grasp of how the analysis needs to be adjusted for sustainability and how it might affect IATA's goals.

Endnotes

1 R. Wolleswinkel, et al. A new perspective on battery-electric aviation, part I: Reassessment of achievable range. Presented at 2024 AIAA SciTech Forum. January 12, 2024. Also see: Reynard de Vries, et al. A new perspective on battery-electric aviation, part II: Conceptual design of a 90-seater. Presented at AIAA 2024 SciTech Forum. January 4, 2024. Also see: ABC News. How passenger electric planes could become a reality within the next decade. January 10, 2024.

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3 American Airlines. American furthers its commitment to sustainable aviation fuel. July 22, 2022.

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7 The IRA tax credit program for SAF is codified at 26 USC § 40B

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About the Author

Abhishek Sinha

Abhishek Sinha is an energy finance analyst at IEEFA. He analyzes petrochemical industry trends, regulations and company data. Abhishek covered the energy and chemicals sectors at Thrivent Asset Management for five years. He has a mechanical engineering degree from Bangalore University, a master's in management information systems from Texas Tech University and an MBA from Columbia University.

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