Sustainable Aviation Fuel (SAF) Supply

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Abstract. The aviation industry is a major contributor to greenhouse gas emissions, responsible for approximately 2% of global emissions. Sustainable Aviation Fuel (SAF), if produced from renewable or waste-based feedstocks, can reduce greenhouse gas emissions by up to 80% compared to traditional jet fuels. The push towards SAF is not the only response to the growing environmental concerns but is also a result of stringent regulations set by entities such as the EU commission. The aim of the paper is to analyse the SAF supply challenges and the current policy frameworks to incentivise supply of SAF. This analysis reviews the supply from a regulatory and industrial production policy perspective, both against the EU mandates of SAF (Refuel EU) and the proposed use of SAF (e.g., CORSIA/ETS). Further literary analysis explores why a supply gap arises. The role of technology and the need for a standardised method for measuring the life cycles of energy conversions are also important factors for increasing SAF supply. The paper concludes with policy recommendations.

Keywords: Sustainable aviation fuel · Aviation fuel policy · aviation sustainability · SAF supply · SAF production · aviation fuel

1 Introduction

Sustainable Aviation Fuel (SAF) offers a reduction of up to 80% in CO_2 emissions over the entire life cycle compared to conventional fossil-based kerosene [1]. The International Air Transport Association (IATA) has set a goal of achieving net-zero carbon emissions from aviation by 2050, and SAF is expected to play a key role in achieving this goal [2]. Hence, the global market for SAF is expected to grow significantly in the coming years, driven by the increasing demand for sustainable aviation solutions. However, there are a number of challenges that need to be addressed in order to increase the use of SAF [3].

This paper aims to analyse the SAF supply market, its challenges and the need for policy support to incentivise supply of sustainable aviation fuels. More specifically, it evaluates the relation between current policy regulations to the regulatory requirements needed for the forecasted supply of SAF, both from a mandated perspective, lifecycle analysis of the pathway and feedstock availability.

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2 Sustainable Aviation Fuels (SAF) and the Aviation Industry's Transition to a Low-Carbon Economy

There has been a lot of emphasis placed on the technological pathways for the production of SAF. By design, these SAFs are drop-in solutions, which can be directly blended into existing fuel infrastructure at airports and are compatible with modern aircraft [4] Having bigger diversity of pathways available is important as this allows SAF production from diversified feedstock. There are currently seven biofuel production pathways that are certified to produce SAF, which perform at operationally equivalent levels to Jet A1 fuel. The most widely used technologies of production that currently allow a 50% blend are:

- Fischer-Tropsch (FT): This technology converts biomass or waste into liquid fuels using a Fischer-Tropsch synthesis reactor.
- Hydroprocessed esters and fatty acids (HEFA): This technology converts vegetable oils or animal fats into liquid fuels using a hydro processing process.
- Power-to-liquid (PtL): This technology uses renewable electricity to produce hydrogen, which is then used to synthesise liquid fuels.
- Methanol to Jet technology can deliver e-jet fuel from renewable electricity, water, and CO_2 or advanced biofuel from solid biomass feedstocks.

One of the biggest challenges for the further deployment of SAF is the cost, which is currently at least twice as high as conventional jet fuel (Fig. 1). During 2022, the average SAF price estimate was around USD 2,400/t, albeit with significant differences across regions. Moreover, the cost of producing SAF varies depending on the technology used and the feedstock.

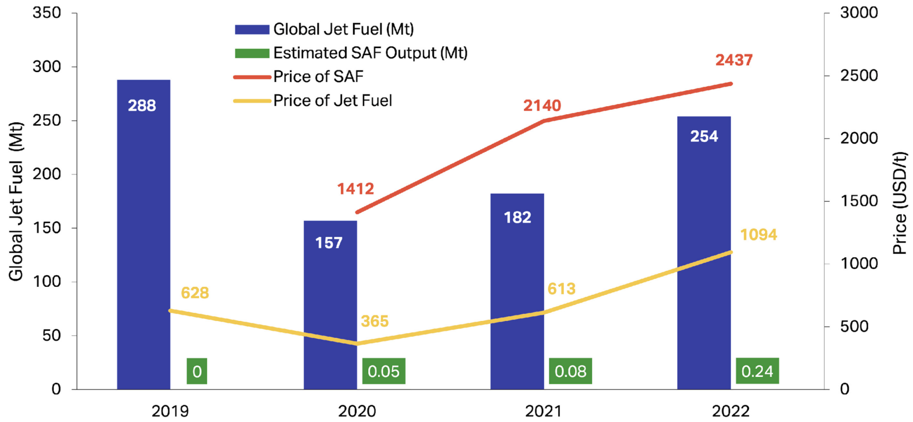

Fig. 1. Global Jet and SAF fuel price analysis 2023 [5]

The cost of FT-SAF is currently the highest, but it is expected to come down as the technology matures [5]. The cost of HEFA-SAF and PtL-SAF is lower, but they are still more expensive than conventional jet fuel. The availability of feedstock is also an important factor in the production of SAF [6]. Within a competitive market framework, increased production levels and expansion of the feedstock mix should exert downward pressure on SAF prices, progressively closing the gap to fossil-based jet fuel and easing the financial burden on airlines.

It should be noted that not all SAF are the same and the blended maximum with normal Jet fuel is currently 50%. Aromatics in jet fuel are needed for maintaining seal compatibility. A lack of aromatics can result in seal shrinkage which can lead to fuel leakage and seal failures with certain types of seals that exist in older legacy engine products, airframes, facilities and fuelling trucks. Fuel-seal compatibility is a key consideration for SAF certification and blending limits [7]. There is still a lack of clarity of research and current certification by aircraft manufacturers on the effect older aircraft and implications of going to 100% blending rates may have on the operating economics of older aircraft and the resultant maintenance costs for operators in developing or emerging economies.

It is likely that aviation will need between 330–445 million tonnes of SAF per annum by 2050. The scale-up will be a significant challenge. Up to $1.45 trillion worth of investment over the next 30 years will be required to develop this new energy system The Waypoint analysis (Table 1) provides scenarios about the SAF growth needed, but assumes that the jet fuel production plants come on line as exactly forecasted and have the required funding. This is a large assumption given the pressure from other modes of transport and the growth rate of air transport. There is still a clear production shortfall and the added factor of offtake agreements, which today are only in the forum of memorandum of understanding, raise doubts over each of these scenarios.

Table 1. Estimate of annual global SAF production (F1) from announced and in-production SAF plants and off-take agreements.

Year		2020	2021E	2023F	2024F	2025F	2027F	2028F	2030F
F1	000 tonnes	**50.4**	**80**	**1,092**	**1,877**	**3,071**	**4,914**	**6,142**	**9,213**
	M litres	63	100	1,365	2,346	3,839	6,142	7,677	11,516
	% of fuel	0.03%	0.04%	0.4%	0.6%	1%	1.5%	1.8%	2.5%
F1 high	000 tonnes	**50.4**	**95**	**1,632**	**2,806**	**4,591**	**7,346**	**9,182**	**13,773**
	M litres	63	119	2,040	3,507	5,739	9,182	11,477	17,216
	% of fuel	0.03	0.05%	0.6%	0.9%	1.5%	2.2%	2.6%	3.7%
F1 high+	000 tonnes		**166**	**2,838**	**4,879**	**7,984**	**12,774**	**15,968**	**23,952**
	M litres		208	3,548	6,099	9,980	15,968	19,960	29,940
	% of fuel		0.09%	1%	1.6%	2.6%	3.8%	4.6%	6.5%

Current production intends to follow the F1 trajectory, but the expected policy environment in the next 2–4 years aims to shift towards the F1 high trajectory at a global level. The F1 high+ trajectory is very feasible, but extra policy initiatives are needed to reach that point: recent announcements suggest this could be a possibility towards the 2030 timeframe. Practicalities of financing, construction and production timelines around the world mean getting above F1 high + is unlikely before 2030.

Another pertinent point to the SAF discourse is the entire lifecycle analysis or Life Cycle Assessment (LCA) [8]. The LCA is used to evaluate the environmental impact of

SAF production, ranging from the impact of feedstock production, sorting and refining to SAF production, transportation and use. LCA studies have shown that SAF can reduce lifecycle greenhouse gas emissions by up to 80% compared to conventional fossil-based jet fuel [9]. The environmental impact of SAF depends on the technology used for its production and the feedstock sources. To be characterised as Sustainable Aviation Fuel (SAF) qualifying oriented, a biofuel should have a LCA result that meets certain sustainability criteria [10]. The Life cycle emission value is composed of two main elements: (1) Core Life Cycle Assessment emissions, which looks at emissions related to feedstock, fuel production facilities, transportation and fuel combustion and (2) Induced land-use change (ILUC) emissions which may require additional land use in the production with feedstock.

3 Policies Related to SAF SUPPLY

SAF without policy support would remain an underinvested private sector [11]. There are various policy options that can support SAF, such as blending mandates, excise duty reductions/exemptions, research, development and demonstration funding and financial de-risking measures. For example, the Biorefinery Assistance Program, established within the Farm Bill, provides a loan guarantee for companies that turn waste into renewable jet fuel. The most important legislative measures related to biofuels in Europe are the Renewable Energy Directive (RED), the Energy Taxation Directive and the Directive on the Quality of Petrol and Diesel Fuels (FQD). The EU's recast RED II, which was ratified by the EU parliament in September 2023, sets out the EU's stricter bioenergy sustainability criteria and includes advanced biofuels & renewable fuels of non-biological origin for aviation as part of its higher renewable energy targets [12]. The regulation provides incentives, such as financial support for research and development, to promote SAF technologies and scale-up initiatives [13].

The intertwining of European and international regulations is catalysing a shift towards SAF in Europe's aviation sector. The ReFuelEU regulation requires fuel suppliers to blend a minimum share of SAF into all aviation fuel sold in the EU with the minimum share of SAF supplied at each EU airport. The minimum blend for SAF will be 2% by 2025, 6% by 2030, 34% by 2040 and 70% by 2050. The minimum share of synthetic aviation fuels will be 0.7% in 2030, 5% by 2035, 15% by 2045 and 35% by 2050.

Feedstock acquisition is a significant portion of SAF production cost and is linked to feedstock procurement, such as used cooking oils, agricultural residues, and dedicated energy crops [14]. Subsidies to the energy sector is a common practice and subsidies can support the supply of SAF (REF Efthymiou and Ryley, 2022). Direct subsidies for biofuels are only 6% (USD 38 billion) of the total amount and have mainly come from the EU (USD 11.4 billion) and the United States (USD 14.1 billion), whereas direct subsidies to fossil fuels exceeding the subsidies for renewable energy by a factor of 19 [15]. Europe needs to consider direct subsidies per output of biomass or input (indirect) subsidies for the production of biomass along with support to the full supply chain.

The technology and infrastructure needs for the scalability of SAF production processes like Hydro processed Esters and Fatty Acids (HEFA) and Fischer-Tropsch necessitate substantial investment in technology and infrastructural development [15]. There is currently a need for increased investments in research to enable 100% SAF certification without blending requirements [16] which will allow wider deployment of SAF at scale and simplify consumption by operators with respect to infrastructure requirements at airports. Policy should further support Research and Development (R&D) of new technological pathways to scale up and deliver SAF.

In addition, regulatory measures like ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), EU Emissions Trading Scheme (EU ETS) and net-zero emissions targets adopted by the aviation industry are important to support the uptake of SAF. Moreover, policy should support SAF uptake by also taxing aviation fossil fuel to close the gap and allow price parity.

4 Conclusion

This paper evaluated the SAF supply challenges to meet the forecasted supply of SAF, both from a mandated perspective, lifecycle analysis of fuel produced and from a feedstock cost. This paper concludes that central to the challenge will be price and availability of feedstock for the SAF quantities needed to fulfil current REFuelEU mandate. The paper also argued that the need for policy support and national government funding and incentives to build up SAF production infrastructure and stimulate supply.

Many challenges remain in the production and supply of SAF to meet the targets of 2050, with the price of SAF playing an important role. By a combination of scaling up of commercial PtL and SAF in general, the effect will be an improvement of lifecycle emissions performance as well as better economics for production. Despite the challenges, the outlook for the global SAF market is positive; with increasing demand for sustainable aviation solutions, combined with technological advancements and growing economies of scale, which are expected to drive the growth of the SAF market in the coming years and will help overcome price barriers in the long term.

The contribution of the paper is shedding light on the cost and production challenges that exist today and suggesting policy solutions that will allow the further deployment of SAF. More importantly, we want to highlight the need for effective policy support that considers effects like the Jevons paradox and the Green paradox of Sinn and approach decarbonisation policy in a system way.

The paper argues that further research and development into new production methods is essential for driving down production costs and discovering new, efficient production methods. By combining and prioritising these policy and incentive drivers, governments and institutions need to provide incentives for private sector participation, such as tax breaks or direct subsidies. The paper addresses the research gap of aviation decarbonisation by bringing together the policy and the free market performance of SAF highlighting the challenges.

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