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IDENTIFYING SUSTAINABLE PATHWAYS FOR SAF PRODUCTION

FUELING CHANGE

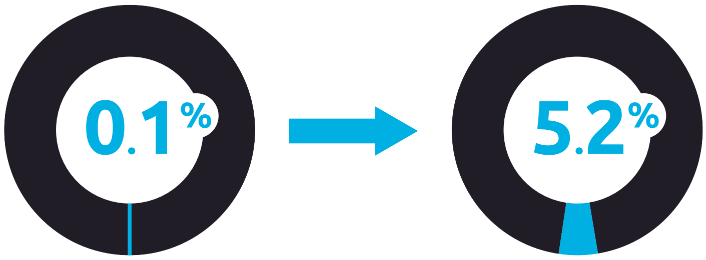
Mounting pressure on the aeronautics industry to reduce its carbon footprint necessitates a set of solid technical solutions, together with behavioral and societal changes. The only currently mature technical lever is sustainable aviation fuel (SAF), whose use can reach 50–80% of what is required to meet the industry's net zero goals, in accordance with the Paris Agreement. However, SAFs currently account for only 0.1% of the total jet fuel produced worldwide – and this was after its production volume doubled from 2021 to 2022. According to the International Air Transport Association (IATA), we must produce SAF that constitutes at least 5.2% of the total jet fuel requirement by 2030 to meet the 2050 net zero target. The question is, how do we scale up sustainably, economically, and effectively?

we need **65%** **of SAF adoption to meet net zero target by 2050**

With 5.2% of total fuel requirement, 2030 milestone is a key step for SAF production ramp up

2022*

2030*



0.3 BILLION*
LITERS OF SAF PRODUCED

EQUIVALENT TO
23 BILLION*
LITERS OF SAF PRODUCED

TECHNOLOGY INVESTMENT

- R&D investments in Aircraft design for improving efficiency
- Investment in PtL, Hydrogen and Electricity technologies

SAF SCALE UP

- Scaling up the SAF production from sustainable sources
- Revamping Airport infrastructure for SAF transportation

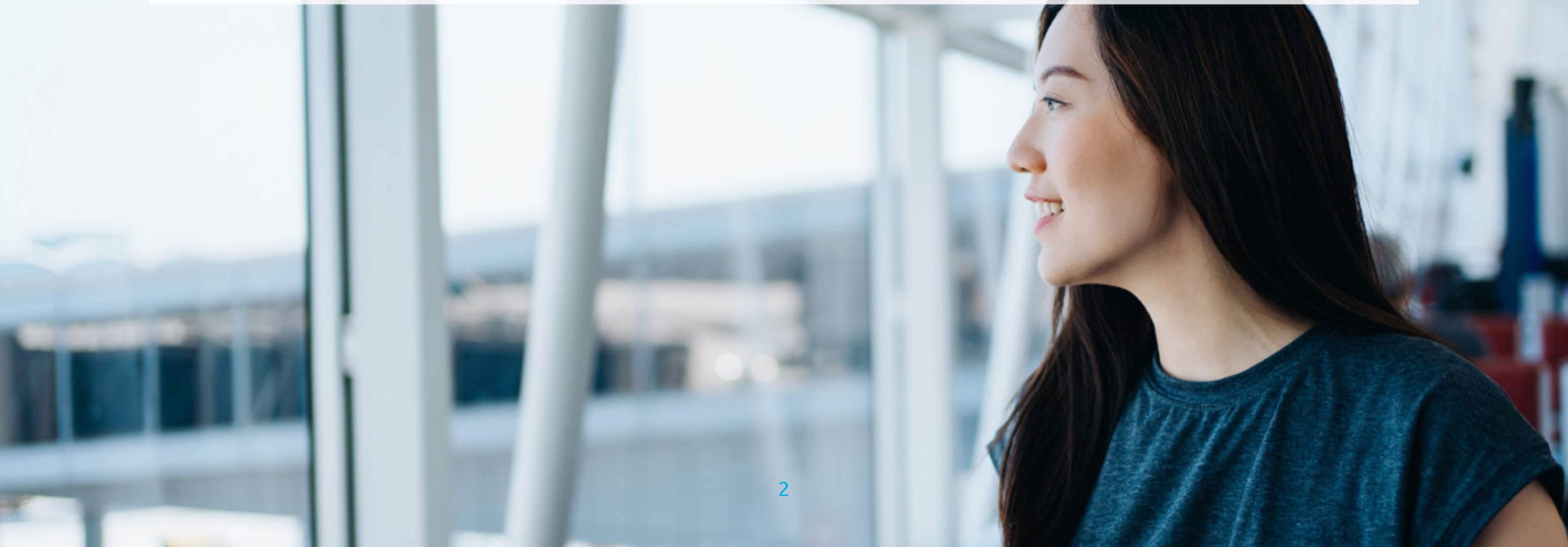
GOVERNANCE

- Policy set up to support cleaner fuel production and consumption
- Incentivize SAF producers to encourage production

Figure 1: SAF production ramp-up requirement

**Source : IATA 2022 & 2023*

The answer to this question requires a comprehensive understanding of various aspects that converge in the production of SAFs – as well as their impact – namely: feedstock availability, sustainability, social impacts, the economic and regulatory landscape of each region, the production process yield, and possible competition with other sectors. To gain the maximum benefit from SAFs requires a delicate balancing act so as to avoid a cascading effect on local economies, the displacement of food crops, and other unintended consequences.



PATHWAYS AND FEEDSTOCK ASSESSMENTS

SAF is synthesized from sustainable and renewable feedstock like municipal waste, agricultural and forest residues, and waste lipids. The currently established and certified processes for SAF production include hydroprocessed esters and fatty acids (HEFA), the Fischer Tropsch (FT) process, the Ethanol-to-Jet (EtJ) process, and the Alcohol-to-Jet (AtJ) process. The suitability of a process depends on the technological maturity and feedstock availability of a given region. Each pathway has its own production lifecycle.
In general, these lifecycles consist of feedstock production; transportation to processing centers; feedstock processing; SAF refinery; and SAF transport via distribution centers.

1 FEEDSTOCK IS GROWN IN FARMS

CO_2 IS ABSORBED FROM AIR

Feedstock is produced using sustainable methods. Some of the feedstock that are by-product are agricultural residue and forest residue. Some are specially cultivated – like energy crops

2 TRANSPORT TO PROCESSING CENTERS

CO_2 IS EMITTED IN AIR

Feedstock is centrally collected in a hub and transported. The emphasis is to add minimum carbon footprint while transporting the feedstock

3 FEEDSTOCK PROCESSING CENTRES

CO_2 IS EMITTED IN AIR

The process produces intermediaries that is used in the production of actual SAF

4 SAF REFINERY

CO_2 IS EMITTED IN AIR

Here the actual SAF is produced from intermediaries.
The SAF yield depends in the feedstock and the pathway

5 DISTRIBUTION CENTRE

CO_2 IS EMITTED IN AIR

SAF is transported to airports from the distribution centres

Figure 2: typical SAF value chain

We have focused our attention on the four processes and tested them with 19 different feedstocks, which are the most widely used and approved by the ASTM as referenced in the ASTM D7566 standard. According to the IATA, there is enough feedstock available worldwide to produce the required quantity of SAF to meet the 2050 target.

COMPETITION WITH AGRICULTURE

We assessed 24 combined pathways between the four processes and 19 feedstocks and evaluated them in terms of competition with agriculture impact severity, which is determined by looking at total crop production, total area under cultivation, and human consumption. The combinations are assigned with no, low, medium, and high competition. Overall, the FT method has been shown to be the most effective with no competition across the board resulting from its application to six feedstocks (agricultural residues, forestry residues, municipal solid waste (MSW), poplar, miscanthus, and switchgrass).

YIELD

We focused our attention on the USA and Europe for process yields. The lowest intermediate yield was seen in oil seeds, but it produced the highest final yield. The highest intermediate yields were seen in sugar beet, agricultural residues, and woody and energy crops. The FT pathway had the lowest process yields but one of the highest intermediate yields.

PATHWAY	S NO	FEEDSTOCK	INTERMEDIATE YIELD		SAF YIELD	
			USA	EUROPE	USA	EUROPE
FT	PW-1	Agricultural residues (Corn-US/ Wheat-EU)	+	+	−	+
	PW-2	Forestry residues	NO STUDY FOUND	+	+	+
	PW-3	Municipal solid waste (MSW), 0% NBC	NO STUDY FOUND	−	−	−
	PW-4	Poplar (short-rotation woody crops)	+	NA	−	NA
	PW-5&6	Miscanthus & switchgrass (herbaceous energy crops)	NO STUDY FOUND	+	−	+
SIP	PW-7	Sugarcane	+	NA	+	NA
	PW-8	Sugar beet	+	+	+	+
HEFA	PW-9	Tallow	−	NA	+	NA
	PW-12	Corn oil	−	NA	NO STUDY FOUND	NA
	PW-13	Soybean oil	−	−	+	+
	PW-14	Rapeseed oil	+	−	+	+
	PW-17	Camelina oil	+	NA	+	NA
ATJ	PW-18	Agricultural residues (Corn-US/ Wheat-EU)	NO STUDY FOUND	+	+	−
	PW-19	Forestry residues	NO STUDY FOUND	+	+	−
	PW-20	Sugarcane	+	NA	+	NA
	PW-21	Corn grain	NA	NA	+	NA
	PW-22&23	Miscanthus & switchgrass (herbaceous energy crops)	NO STUDY FOUND	+	+	+

Figure 3: Process yield of pathways taking the US and EU as examples

It's important to note that high intermediate yields allow other industries (like mobility for road fuels) to use the products produced by the remainder, whereas high final yields deplete the production of other outputs, thus increasing competition between industries.

ASSESSMENT OF FEEDSTOCK

INDUSTRIAL

The assessment of feedstock needs to consider its availability for SAF at the expense of other industrial uses. This is dependent on social, economic, and political factors – the economy of a region is affected by feedstock, so it needs to be considered.

The only three feedstocks that do not compete with other industrial applications are miscanthus, switchgrass, and poplar. Despite being used in other industries, tallow, used cooking oil, palm fatty acid distillate, brassica oil, and camelina oil have low impact on the economy, so these could also be considered for SAF production if they are available in sufficient quantities. Corn, sugarcane, sugar beet, molasses, agricultural residue, soybean oil, rapeseed oil, and MSW have medium to high economic impact, so they should be considered carefully.

ENVIRONMENTAL

Assessing feedstock with regard to its effects on the environment is done based on its impact on soil health and CO2 emissions.

Results showed that only using forest and agricultural residues has a negative impact on soil health – despite their utility as feedstock sources, they cannot be solely used due to these environmental considerations. Conversely, feedstocks like corn, soy, rapeseed, sunflower, sugar beet, sugarcane, and miscanthus have actually been shown to have a positive impact on soil quality.

On CO2 emission reduction, the FT process results in lesser emissions compared to the AtJ process. From the 24 pathways assessed, 14 are capable of high reduction (by 68–95%) in CO2 emissions, six of medium reduction (by 36–67%), and three of low reduction (by less than 35%).

ECONOMIC

All SAF production costs more than jet fuel as of 2023. The cheapest of the processes was the HEFA process, whose cost is close to that of jet fuel (at $1/L) and has the highest level of maturity. The FT and AtJ are the second- and third-cheapest processes, respectively, but are the least mature processes. The SIP process is the most expensive and has a medium level of maturity.

RECOMMENDATIONS FOR THE USA

The results of a comparison based on a two-by-two matrix of agricultural availability and industrial competition, forest residue, tallow, and used cooking oil have been shown to be the optimal choices for the USA. Secondary choices could be MSW and agricultural residues. Lastly, if cultivated sustainably, miscanthus, switchgrass, and poplar can be considered.

The clear winners overall for the USA were the FT process with forest residues and the HEFA process with used cooking oil, as seen from the standpoint of emission reduction and process yield.

Cost-wise, the FT process's production cost will be related to gasifier building, while the HEFA process will be driven by feedstocks and H2 prices (depending on the market). Funding mechanisms will be set up by the US government to facilitate these processes in the form of tax credits and grants.

RECOMMENDATIONS FOR THE EU

Based on the same comparison method mentioned above, we found that forest residues was the clear winner. However, when relaxing our criteria for this matrix to include all feedstock in the high and medium zone of agricultural availability, MSW, used cooking oil, poplar, miscanthus, and switchgrass (which must follow sustainable criteria as per EU Renewable Energy Directive) were found to be well suited as feedstock for SAF production.

Moreover, food and feed crops (incl. palm and soy), as well as palm and soy derived products are now banned in the EU for SAF production according to the April 2023 regulations.

In terms of process and feedstock together, the FT process wins across the board when combined with forest residues, used cooking oil, and MSW. Other options were also good enough for consideration.

Additionally, these options do not have a negative social impact due to no land competition or human rights and labor standards consequences.

WILL LEGISLATION ACT AS A TAILWIND?

Europe and the USA are currently at the forefront of formulating legislation to address SAFs. The EU has already made clear foundations for mandating the use of SAFs combined with jet fuel, with the blend target increasing incrementally from 2% in 2025 to 70% in 2050, while the USA has a target to reduce aviation emissions by 20% by 2030. As a major consumer and producer of SAFs, Brazil has launched a national biokerosene program with a clear SAF mandate expected to emerge by 2027.

Asia has not yet legislatively moved in the SAF direction. India, China, and Japan are discussing SAF mandates, but the decisions are still pending in their parliaments. These big economies need to begin implementing such mandates to boost industrial SAF production and consumption by airlines.

OPPORTUNITIES BEYOND NET ZERO

Aside from the reduction of CO_2 emissions, SAF production can have social benefits such as sustainable waste disposal, extra income for farmers, and increasing energy sovereignty. When implemented sustainably, SAF production can address good health and wellbeing; affordable clean energy; industry, innovation, and infrastructure; decent work and economic growth; and climate action – the five sustainable development goals outlined by the United Nations.

CONCLUSION

Finding and following sustainable pathways for increased SAF production are essential in the decarbonization of the aeronautics industry on our collective path toward net zero. The world produced 300 million liters of SAF in 2022. According to the IATA, the world will need 23 billion liters in production in 2030 and 450 billion liters by 2050.

There are many factors in the analysis and evaluation of SAF production pathways – feedstock availability, production processes, local economies, emission reduction prospects, and industrial competition all need to be looked at together to find the best options for each region.

Finally, although SAF can be considered as a major decarbonization lever, the development of SAF alone will not allow a full decarbonization of the aviation sector. Thus, this lever must be considered as part of a set of technical solutions and societal changes to ensure that the aviation industry achieves a fully net zero decarbonization by 2050.

For more details on the analysis of these pathways and their contingencies, as well as a deeper dive in the current and projected state of legislation across regions, you can read the full research report here.

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