Framework conditions for SAF development in Europe and MIC

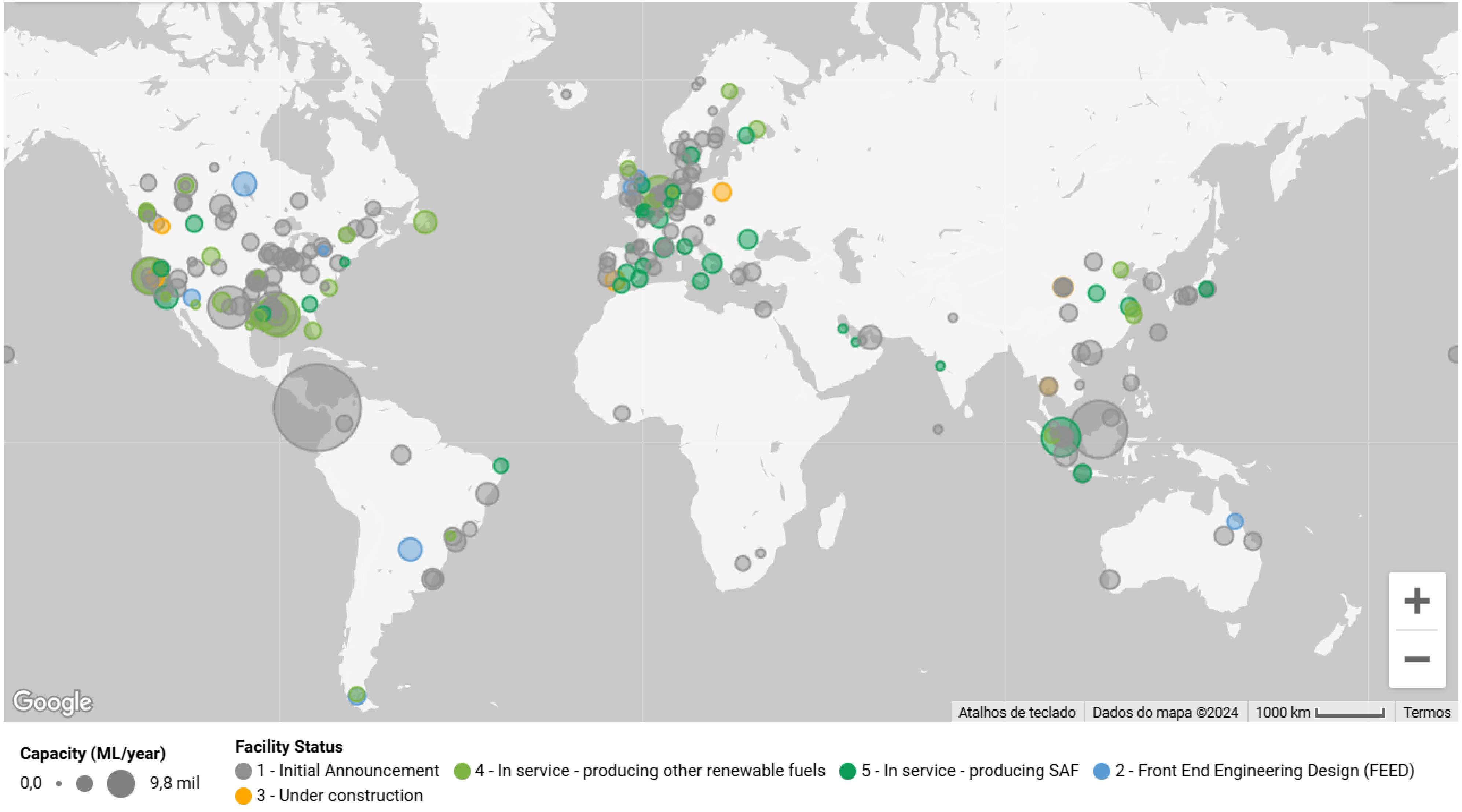
Francisco Gírio

LNEG, Lisboa, Portugal

Brazilian Bioenergy Science and Technology Conference

IEA Bioenergy

Distribution of SAF facilities worlwide



- 33 SAF plants in operation
- 9 200 ML/yr

In: ICAO, 2024

Regulatory Framework for SAF

The regulatory landscape for SAF is evolving rapidly. Governments and aviation authorities are implementing policies to promote SAF production and use.

ReFuelEU Aviation, 2024

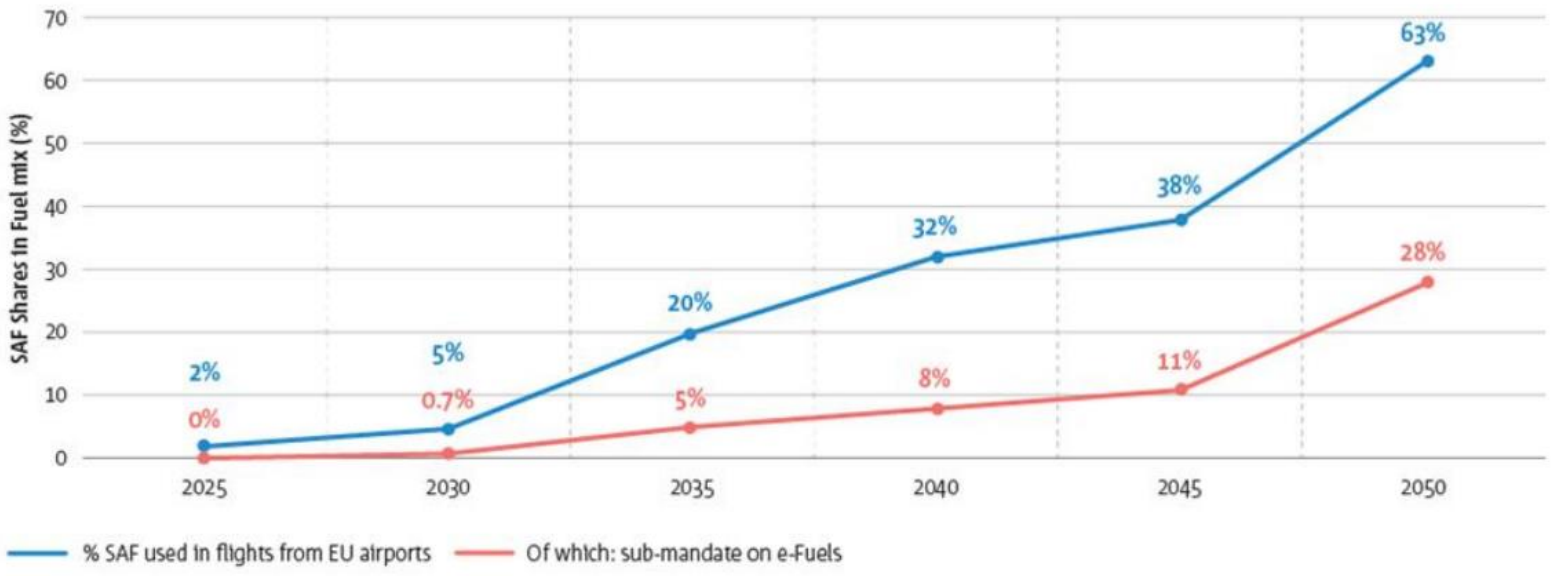


Figure 18 - Net-Zero target for international aviation leaving EU airports..

CORSIA

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (CORSIA) **encourages airlines to airlines to invest in SAF and other sustainability initiatives**. **initiatives**.

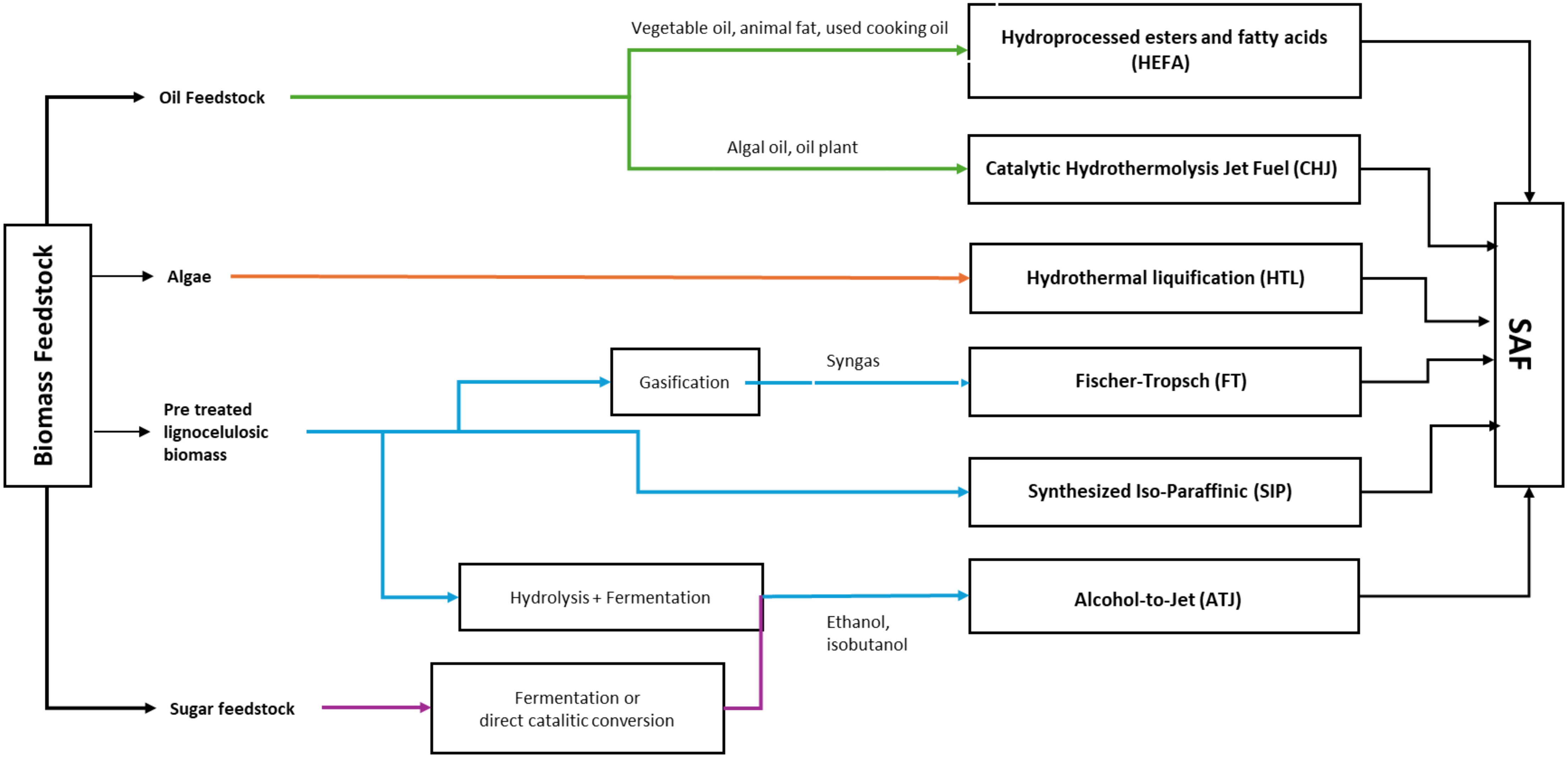
National Policies

Several countries, including the UK, France, and Germany**, did did introduce national policies** to stimulate SAF production and production and deployment.

Mandates applied to the production and/or use of SAF worldwide

Country/Area	Policy	Commitments	refs
Canada	Clean Fuel Standard (CFS)	Aims to reduce the carbon intensity of fuels used in Canada, including aviation fuels. It encourages the use of lower carbon fuels, energy sources, and technologies. Industry-led initiatives and governmental regulations, including British Columbia's mandates to increase renewable fuel percentage in jet fuel, aimed at scaling up SAF usage.	(2)
India	SAF Mandate for Airlines	A forthcoming mandate for the use of 1% SAF in domestic airlines by 2025 to align with emissions reduction goals.	(3)
UK	Jet Zero strategy	Considering a SAF mandate at least10% by 2030	
Brazil	National SAF Program (PROBIOQAV)	A policy targeting the inclusion of SAF into the Brazilian energy matrix from January 2027 to curb airline emissions.	(4)
US	Sustainable Aviation Fuel Grand Challenge	Aims to produce 3 billion gallons of SAF per year by 2030 and reduce aviation emissions by 20% by 2035. The initiative involves collaboration between various federal agencies to support SAF development and deployment.	(5)
Finland	SAF mandate	Considering a SAF mandate of 30% by 2030 in order to meet the global country target of carbon-neutrality in…2035!	

SAF Pathways



SAF Standards: Defining Quality and Sustainability

The ASTM D7566-23b annex defines the standards for SAF, including specifications for fuel properties, environmental impact, and sustainability.

In 2020, it was approved **FT-Coprocessing** pathway under ASTM D1655, Annex A1

Annex	Title	Product name	Manufacture	Max. Blending
A1	Fischer-tropsch hydroprocessed synthesized paraffinic kerosine	FT-SPK	Fischer-Tropsch (FT) process using Iron or Cobalt catalyst with subsequent hydroprocessing.	50%
A2	Synthesized paraffinic kerosine from hydroprocessed esters and fatty acids	HEFA SPK	Hydrogenation and deoxy-genation of fatty acid esters and free fatty acids with subsequent hydroprocessing.	50%
A3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Hydroprocessed synthesized iso-paraffins wholly derived from farnesene produced from fermentable sugars with subsequent hydroprocessing.	10%
A4	Synthesized kerosine with aromatics derived by alkylation of light aromatics from non-petroleum sources	SPK/A	FT SPK as defined in Annex A1 combined with synthesized aromatics from the alkylation of non-petroleum derived light aromatics (primarily benzene) with subsequent hydroprocessing.	50%
A5	Alcohol-to-jet synthetic paraffinic kerosene (atj-spk)	ATJ-SPK	Synthesized paraffinic kerosene wholly derived from either ethanol or isobutanol through oligomerization, hydrogenation, and fractionation.	50%
A6	Synthesized kerosine from hydrothermal conversion of fatty acid esters and fatty acids	CHJ (Catalytic Hydrothermolysis Jet)	Hydrothermal conversion of fatty acid esters and free fatty acids with subsequent hydroprocessing.	50%
A7	Synthesized paraffinic kerosine from hydroprocessed hydrocarbons, esters and fatty acids	HC-HEFA SPK	Paraffins derived from hydrogenation and deoxy-genation of bio-derived hydrocarbons (Botryococcus braunii species of algae), fatty acid esters, and free fatty acids.	10%
A8	Alcohol-to-jet synthetic paraffinic kerosene with aromatics (atj-ska)	ATJ-SKA	Addition to ATJ-SPK of an aromatic product stream comprising dehydration, aromatization, hydrogenation, and fractionation.	50%

Challenges to SAF Market Deployment

Despite the potential of SAF, significant barriers hinder its widespread adoption and market penetration.

1 **Cost**

SAF currently costs significantly more than conventional jet fuel, making it a challenge for airlines to adopt.

2 **Scale**

Production capacity for SAF needs to be scaled up significantly to meet the growing demand from the aviation sector.

3 **Infrastructure**

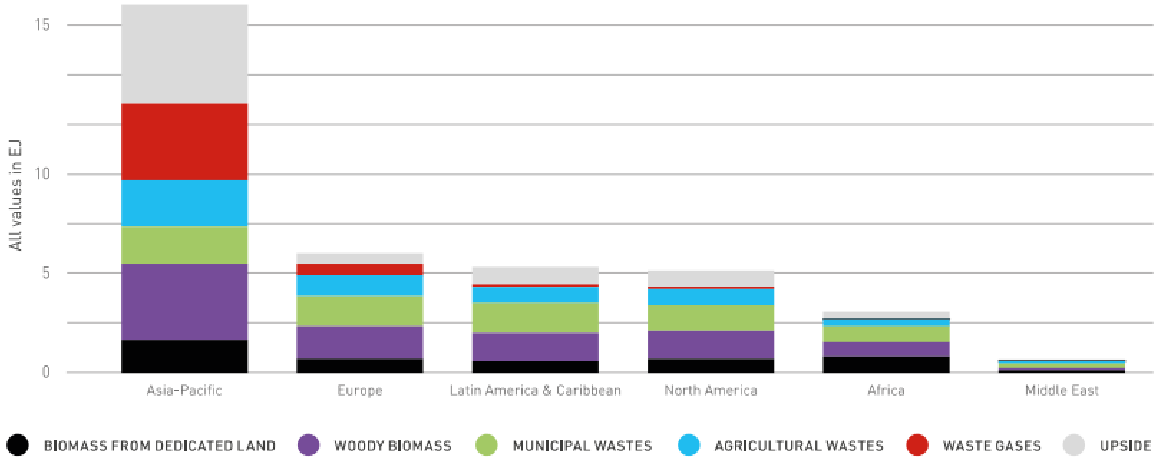
Adapting existing airport infrastructure and supply chains to handle SAF presents a logistical challenge.

4 **Feedstock Sustainability**

Ensuring the sustainable sourcing of feedstocks for SAF is crucial to avoid unintended environmental consequences.

Biogenic Feedstocks

Feedstocks	SAF production route	Commercialization Projects/Proposals
Biomass-based feedstock (e.g. Agri-forest residues, municipal solid waste, etc)	Fischer-Tropsch (FT)	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
Biomass, municipal solid waste (MSW), natural gas, coal	Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics (FT-SKA)	Sasol, Shell, Syntroleum, Velocys, Solena Fuels
Oil-based feedstock	Hydroprocessed esters and fatty acids (HEFA)	World Energy, Honeywell UOP,Neste Oil,Dynamic Fuels,EERC
Lignocellulosic biomass	Synthesized Iso-Paraffinic (SIP)	Amyris,Total
Ethanol, isobutanol, Lignocellulosic biomass or sugar-based feedstock	Alcohol-to-Jet (ATJ)	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy
Algae, waste oil, oil plants	Catalytic Hydrothermolysis Jet Fuel (CHJ)	Applied Research Associates
Algae, moisture-rich feedstocks such as sewage, manure, and food processing waste	Hydrothermal upgrading (HTL)	Firefly

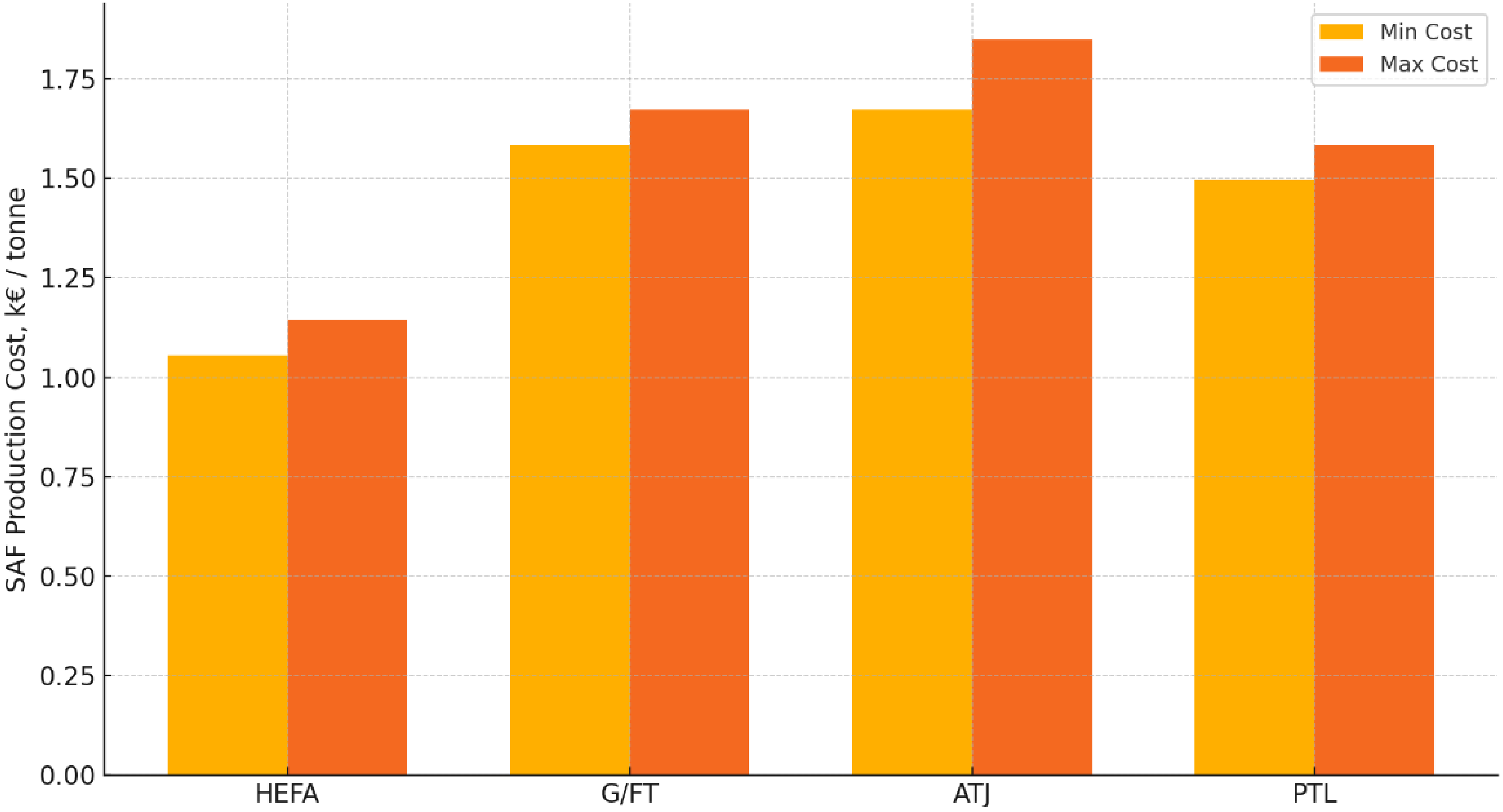


In: EC Transport Action Group, 2021

- The global SAF production capacity through the HEFA route using used cooking oils ranges **between 7.8 and 10.1 Mton/year (**and for the EU between 2.3 and 3 Mton/year)

- If animal fats (tallow), oils from paper production, and residue streams from corn and palm oil production are also considered as feedstock, then will increase to **11-15 Mt of HEFA globally**.

Production Costs



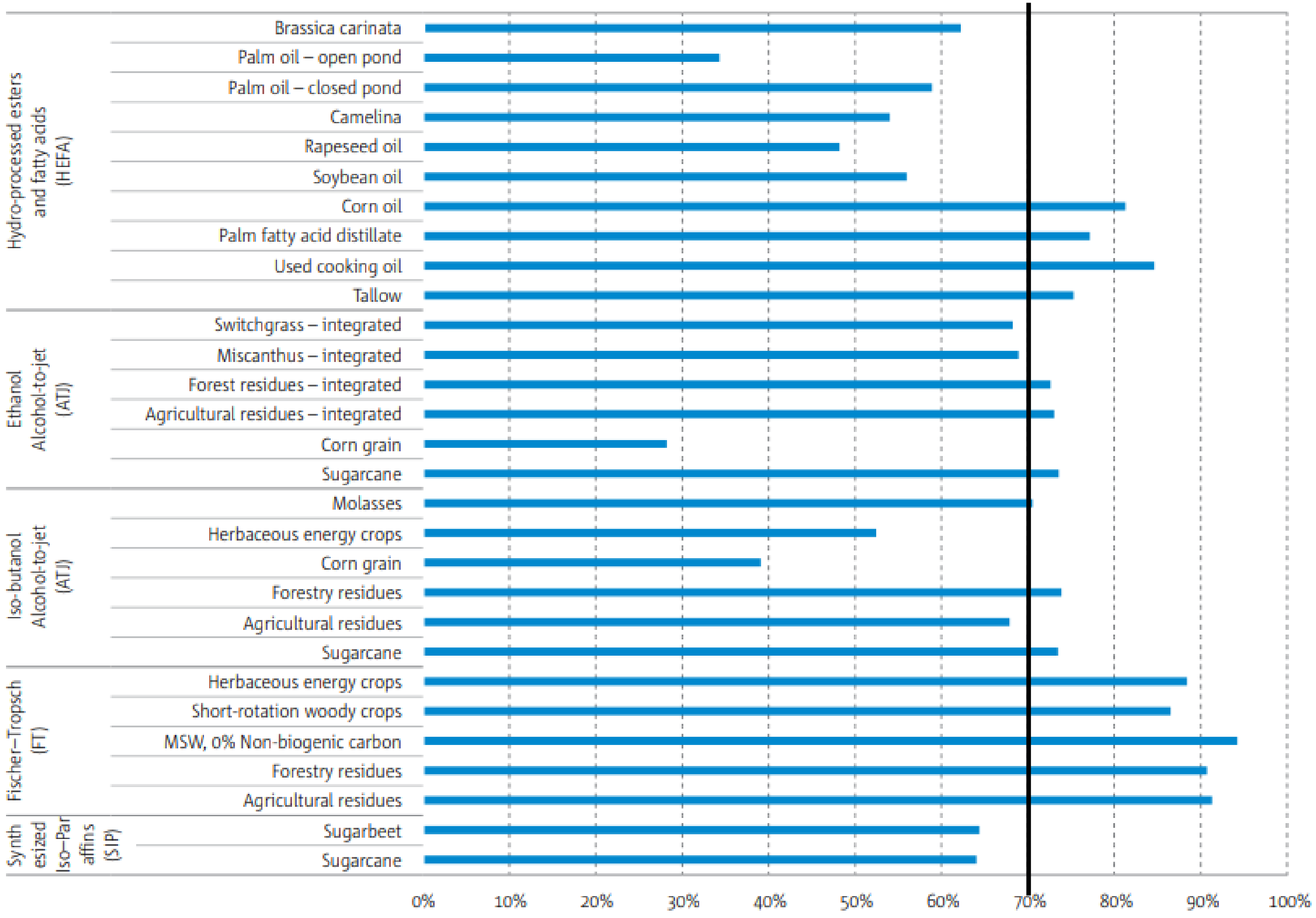
Adapted from: Wolf, (2021)

- SAF prices are **1.5 to 6 times higher** than conventional jet fuel (EASA, 2022)

- Wholesale price of SAF in 2023 was 2200 €/ton, 2.8 times more expensive than conventional jet fuel (IATA, 2024)

- However, it is important to emphasize that the **selling price of SAFs** is not only influenced by the cost of production, but also by availability and demand. So, sales and market prices of SAF may differ significantly.

% GHG emission savings



- The critical SAF benchmarks are mostly:
  - % GHG savings
  - minimal biodiversity impact
  - no competition with essential resources, like food and water

In: EASA (2022).
Reference Jet A1 value: 89 g CO2eq/MJ

Adapted from: Wolf, (2021)

Water usage & Energy Eff.

Pathway	Source	Water consumption	
		m^3/GJ	L_{water}/L_{SAF}
HEFA	pongamia oil	11.8	409
	microalgae oil	13.9	482
	soybean oil	106.8	3705
SIP	sugarcane	147	5099
	switchgrass	104.7	3633
	corn grain	85.81	2977

- ❑ SIP pathway has higher water usage than HEFA route

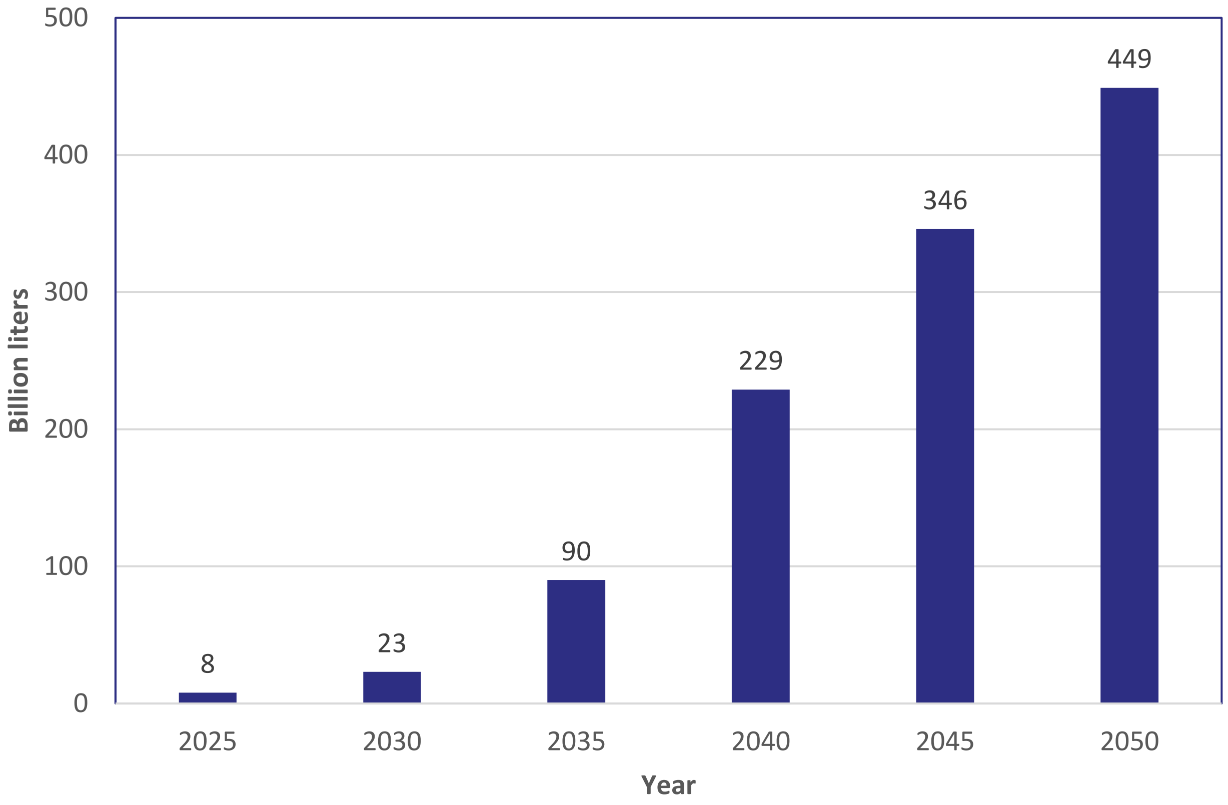
Adapted from: Shahriar and Khanal, (2022)

Pathway	Process Yield[1] ton SAF/ton feedstock	Energy Efficiency[2] GJ_{OUTPUT}/GJ_{INPUT}
HEFA	0.75-0.83	0.92
FT	0.13-0.22	0.40-0.53
ATJ	0.56	0.91
SIP	0.17	0.50
HTL	0.18-0.36	0.64
Pyrolysis	0.16-0.36	0.63-0.77

Adapted from: De Jong et al. (2015)

- ❑ HEFA and ATJ have the higher process yield with yields up to 0.8 ton and 0.6 ton SAF/ton feedstock, respectively

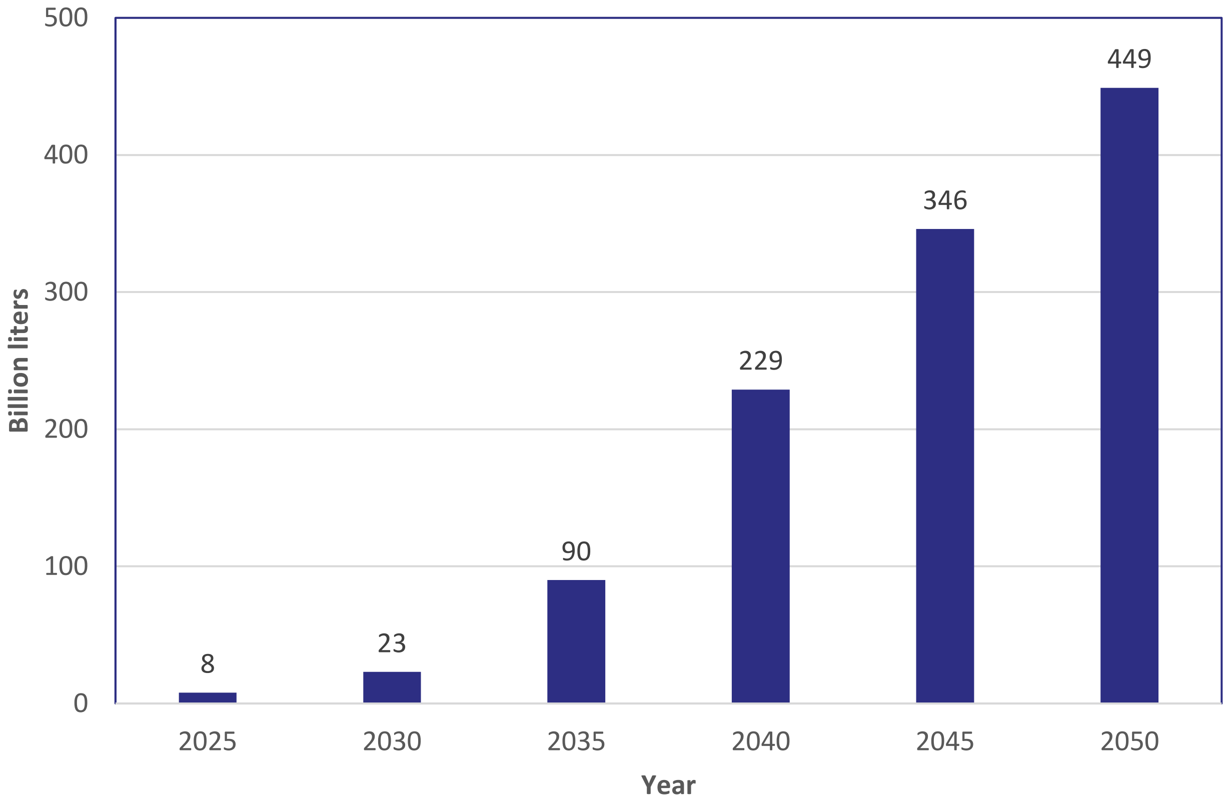
SAF needs to reach net zero goals in World (global demand)



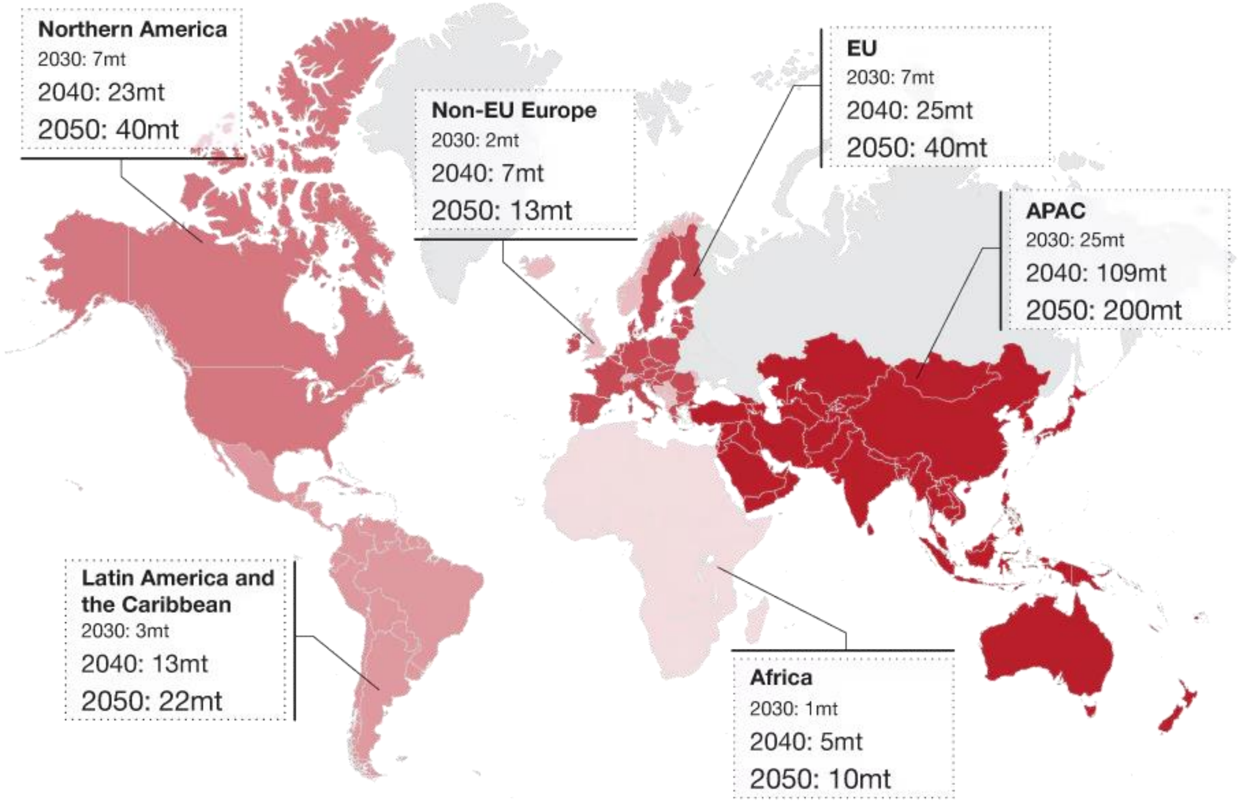
In: IATA (2024)

- ❑Huge challenge necessary in SAF production, to support the aviation industry's decarbonization efforts (current production is 9 Billion Litres)

SAF needs to reach net zero goals in World (global demand)

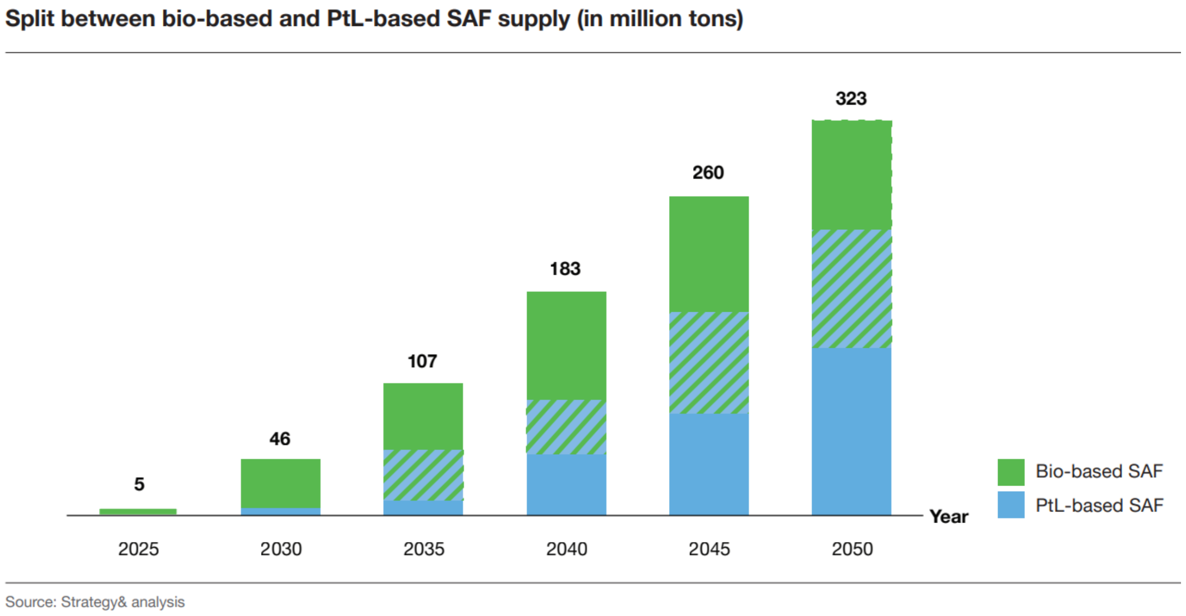


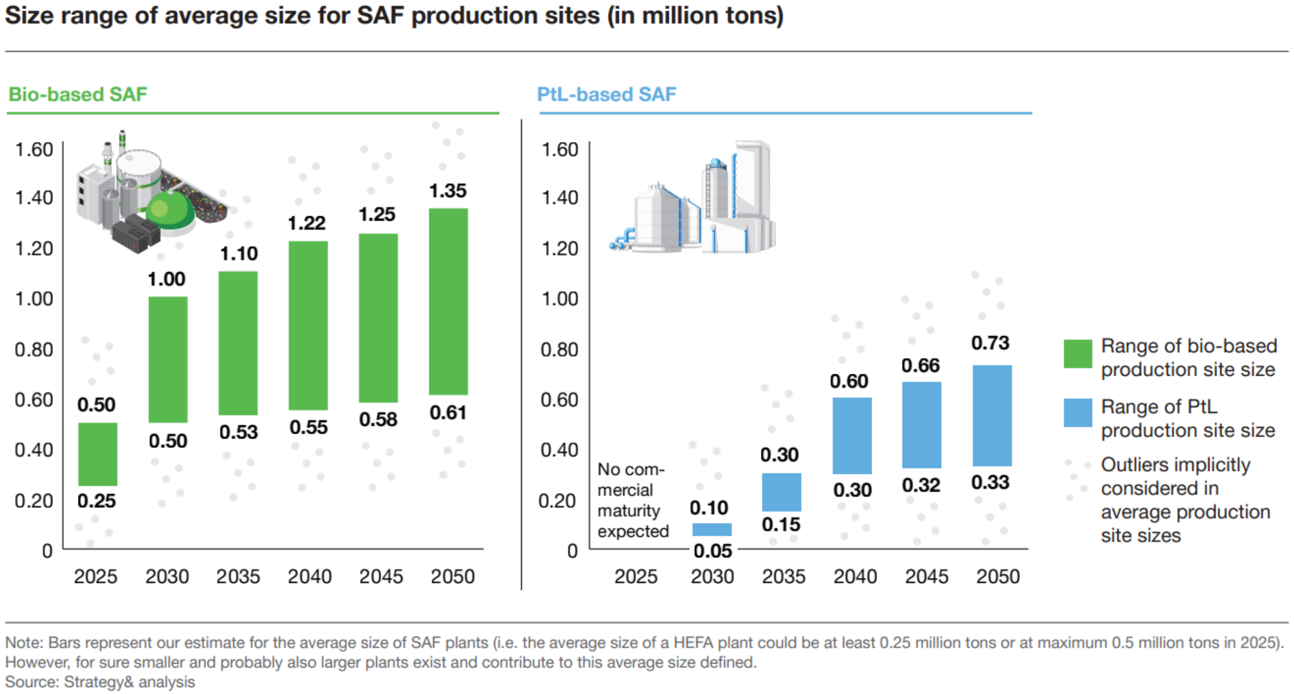
In: IATA (2024)



In: PwC Strategy&: From feedstock to flight (2023)

SAF needs to reach net zero goals in World (global production – split SAF & PtL)





In: PwC Strategy&: From feedstock to flight (2023)

The ICARUS Project: Objectives

This study aims to comprehensively assess the **current state of the art and framework conditions for SAF development in both Europe and MIC**. It focuses on identifying and evaluating the most promising pathways for SAF production, considering their **technical feasibility, economic viability, and environmental impact**.

1 **Biocrude Oils to SAF (HEFA)**

Evaluating and analyzing innovative and promising catalytic hydrotreatment approaches for biocrudes produced through Hydrothermal Liquefaction (HTL).

2 **Alcohols to SAF (ATJ)**

Exploring various methods for converting alcohols, such as ethanol and methanol, into sustainable aviation fuels, taking into account technological advancements and economic considerations.

3 **Syngas to SAF (FT)**

Assessing the current and emerging technologies for syngas production from gasification, gas conditioning, and upgrading, as well as analyzing the relevant policy developments and regulatory frameworks.

HEFA - Biocrude oils to SAF

- Feedstock Sourcing
- Biocrude Production
- Upgrading
- Hydroprocessing
- SAF Production

- ❑ Main production pathway (nowadays)
- ❑ Technologically mature
- ❑ Feedstock availability (sustainable) is an issue
- ❑ No aromatic content, i.e., no 100% usage possible

ATJ - Alcohol to SAF

- Feedstock Sourcing
- Isobutanol Fermentation
- ISPR
- Destillation → Isobutanol
- SAF Production – ATJ

- Sustainable biomass availability
- 2G ethanol /isobutanol production still is not competitive (price)
- Less adequate for EU; More adequate for Brazil, US, India... (1G plants)

FT- Syngas to SAF

Direct Syngas-to-Jet

An integrated FT-based catalyst design to deviate from the ASF distribution and produce jet fuel in one step;

Syngas-to-Olefins(-to-Jet)

A more alternative pathway with a potentially higher carbon selectivity to SAF compared to traditional FTS. The required oligomerization and hydrogenation to produce jet-grade SAF is considered

Syngas-to-Alcohols(-to-Jet)

Pathway for the conversion of syngas into alcohols, followed by a series of subsequent steps to produce SAF. The alcohol-to-jet (ATJ) pathway is a well-established approach, but further research is ongoing to optimize the process and reduce production costs.

- ❑ Sustainable biomass availability
- ❑ Syngas cleaning at low cost
- ❑ Catalysts production complexity and stability
- ❑ Carbon selectivity differs (e.g., syngas to olefins is lower than syngas to SAF)

PtL - to SAF

- Water treatment
- RES power production
- Green hydrogen prod. via water electrolysis & carbon capture
- Methanol synthesis
- Methanol to kerosene (*catalitically conversion to olefins*)

- Water treatment
- RES power production
- Green hydrogen prod. via water electrolysis & carbon capture
- FT synthesis
- Refining FT Liquids

- ❑ Not mature
- ❑ Under RED III, all H2 prod. must comply with defined criteria regarding electricity and CO2 sources
- ❑ Biogenic CO2 sourcing is limited
- ❑ DAC is at low TRL

Take-home messages

- ❑ SAF production is expected to grow worldwide (and fast).

- ❑ The SAF production challenges are, however, still enormous.

- ❑ Is H2 or Batteries development interfering with the current forecasts for SAF market?

- ❑ Is PtL developing faster than advanced biofuels in SAF market?

In: ICAO (2024)

icarus

Thank you

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Francisco Gírio, ICARUS WP1 Coordinator

francisco.girio@lneg.pt

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