EASA 2024 REPORT

State of the EU SAF market in 2023

Fuel reference prices, SAF capacity assessments

Disclaimer

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Photocredits

Executive summary

The ReFuelEU Aviation Regulation (Regulation (EU) 2023/2405, "RFEUA") establishes under Article 13 that EASA is required to prepare and publish a RFEUA annual technical report every year, starting in 2025. The annual technical report shall contain various elements, including information on the status of compliance of the parties obligated under RFEUA[1] as well as on the state and development of the sustainable aviation fuel (SAF) market in the European Union (EU) and its Member States.

The *State of the EU SAF Market in 2023* report serves as a precursor to the first EASA annual technical report due in 2025. Importantly, it includes the determination of reference prices for the different RFEUA eligible aviation fuel types as well as a SAF production capacity assessment for the European Union (EU) and its Member States.

Fuel Reference Prices

The *State of the EU SAF Market in 2023* report aims to transparently present the methodology and approach developed and used to determine the fuel reference prices for all RFEUA eligible aviation fuels. For the price assessment, a methodology was developed to determine the 2023 average prices based on the market availability of the aviation fuel types defined under Article 3 of RFEUA. In particular, price reporting agency (PRA) indexes were used, which provide a reliable and widely recognised benchmark for price assessments. Whereas 2023 prices for conventional aviation fuels (CAF) and aviation biofuels were available through multiple PRA indexes, the market for other RFEUA aviation fuel types was either non-existent or not yet liquid enough to determine actual reference market prices for 2023. For these fuel types, a bottom-up production cost estimation[2] was developed to provide indicative results.

The aviation fuel categories defined under RFEUA, and for which price references were established, are listed in Table 1 below. The categories are based on the definitions laid down in RFEUA, the Renewable Energy Directive (EU) 2018/2011 (RED)[3] as well as the Gas Directive (EU) 2024/1788[4], respectively.

➨ **Table 1** RFEUA aviation fuel categories

TYPE OF RFEUA AVIATION FUEL	DEFINITION IN RFEUA	PRICE AVAILABILITY IN 2023	COMMENTS
Categories of sustainable aviation fuels (SAF) under RFEUA that are drop-in fuels manufactured for direct use by aircraft			
Synthetic aviation fuels	Art 3(12)	No	Renewable fuels of non-biological origin as defined in RED
Advanced aviation biofuels	Art 3(8)(a)	No	Biofuels produced from feedstock listed in Part A Annex IX of RED

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[1] Status of compliance of (1) aircraft operators regarding reporting obligations and refuelling obligations, (2) aviation fuel suppliers regarding reporting and supplying RFEUA eligible fuels minimum shares, and (3) Union airports in facilitating the access of aircraft operators to aviation fuels containing RFEUA eligible fuels minimum shares.

[2] Bottom-up production fuel cost estimation is a detailed method of calculating the total cost of fuel production. It involves estimating the cost of each individual process or component involved in fuel production. The total cost is then obtained by summing up these individual estimates.

[3] Renewable Energy Directive (RED): Directive (EU) 2018/2001

[4] Gas Directive (EU) 2024/1788

TYPE OF RFEUA AVIATION FUEL	DEFINITION IN RFEUA	PRICE AVAILABILITY IN 2023	COMMENTS
Aviation biofuels	Art 3(8)(b)	Yes	Biofuels produced from feedstock listed in Part B Annex IX of RED
Other aviation biofuels[5]	Art 3(8)(c)	No	Biofuels produced from feedstock not listed in Annex IX of RED[6]
Recycled carbon aviation fuels	Art 3(9)	No	Recycled carbon fuels as defined in RED
Categories of other renewable and low-carbon aviation fuels eligible under RFEUA			
Renewable hydrogen for aviation	Art 3(16)	No	Hydrogen for aviation that is renewable fuel of non-biological origin as defined in RED
Low-carbon hydrogen for aviation	Art 3(15)	No	Hydrogen for aviation that is produced from non-fossil non-renewable sources as defined in the Gas Directive
Synthetic low-carbon aviation fuels	Art 3(13)	No	Drop-in aviation fuel produced from non-fossil non-renewable sources as defined in the Gas Directive
Other relevant aviation fuels under RFEUA			
Conventional aviation fuel	Art 3(14)	Yes	Aviation fuels produced from fossil non-renewable sources of hydrocarbon fuels

Fuel Reference Prices: Real index pricing

The reference price for CAF in 2023 was determined based on CAF price indexes compiled by PRAs. CAF price indexes by PRAs are well established and widely recognised in the industry. The 2023 weighted average CAF price for the European area, based on data gathered from the PRAs S&P Global Commodity Insights (Platts)[7], Argus Media (Argus)[8] and General Index (GX)[9], was determined to be **816 EUR/tonne**. Establishing the annual average CAF price is essential given the fundamental reference role of the CAF price in the determination of various penalties under RFEUA.

The reference price for RFEUA eligible aviation fuel supplied to the Union market and for which market prices were available in 2023 was determined based on SAF price indexes compiled by PRAs ("real index pricing"). The only SAF transactions in the European area which occurred in 2023 were for SAF classified as *aviation biofuel* under RFEUA (Hydrotreated Esters and Fatty Acids (HEFA) SAF). The majority of SAF transacted was produced from waste oils listed in Part B of Annex IX to RED. The 2023 weighted average SAF price for the European area was determined to be **2,768 EUR/tonne**[10] for the aviation biofuels category, as shown in Fig. 1.

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[5] other aviation biofuels are covered in the aviation biofuels section

[6] …and except for those produced from food and feed crops, intermediate crops, palm fatty acid distillate and palm and soy-derived materials, and soap stock and its derivatives

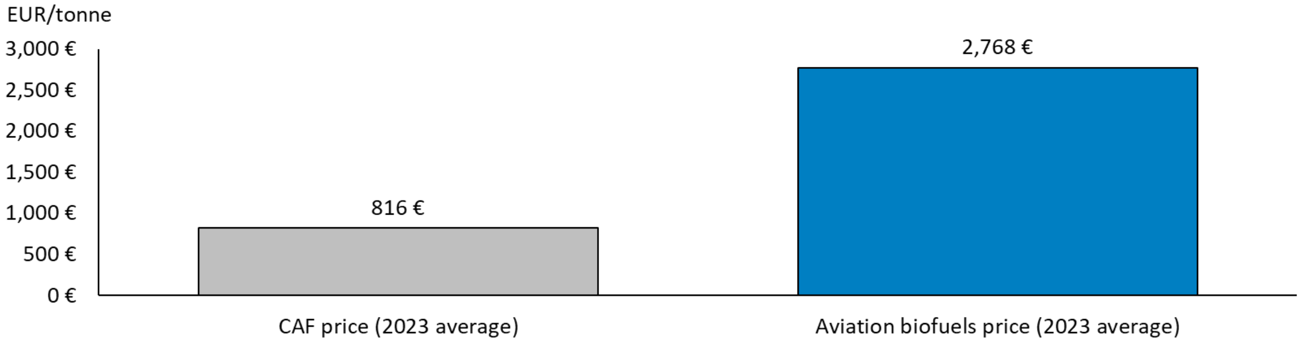
[7] (S&P Global Commodity Insights, n.d.)

[8] (Argus media, n.d.)

[9] (General Index, n.d.)

[10] Considering the ECB 2023 average USD/EUR conversion rate

Figure 1 Reference RFEUA prices for available aviation fuel supplied to the Union market in 2023



Note: The price assessment methodology for the determination of CAF and SAF prices is based on the data gathered from PRAs, focusing on the previous year (2023 in this case). This enables a straightforward, transparent and widely recognised approach for assessing prices based on the actual transactions in the market.

Fuel Reference Prices: Production cost estimations

The reference prices for RFEUA eligible aviation fuels for which market prices were not available in 2023 were determined using a bottom-up production cost estimation methodology ("back-up pricing"). Due to lower technology readiness levels, advanced SAF production technologies (Alcohol-to-Jet, Fischer-Tropsch, etc.) were not yet mature enough to result in commercial quantities of SAF being produced and traded in 2023. As a result, reference prices for these fuel types could not be established based on real index pricing, instead necessitating the use of a bottom-up production cost estimation methodology (back-up pricing). To develop bottom-up production cost estimations with a levelised cost of production approach, data on the main cost-drivers for these technologies (such as feedstock and utility costs) were collected from PRAs where possible. This approach enabled capturing the actual regional and global dynamics that occurred in 2023. Where PRA data was not available for 2023, publicly available online sources and EU databases were utilised with a focus on 2023 EU averages. Data collected from PRAs and other sources were then fed into models[11] to develop production cost estimations for the different aviation fuel categories with no market availability in 2023. The results of this assessment are presented in Figure 2 below. It is important to note that several aviation fuel types under RFEUA can be produced through various feedstock and technology combinations. The relevant combinations used for the bottom-up production cost estimations were selected based on the announced facilities in the EU as well as the availability of ASTM approval of the technology. For each combination, a cost range is estimated. Finally, weighted averages are developed based on the announced capacity per the combination considered, where possible.

Importantly, these production costs should be treated as indicative results only, since no liquid market existed in 2023 for those fuel types. For reference, aviation biofuel production cost in 2023 was estimated to be 1,770 EUR/tonne in Europe[12] – considering the average SAF price in 2023 (2,768 EUR/tonne), the average margin was therefore close to 1,000 EUR/tonne and reflects additional costs like transportation as well as commercial margins.

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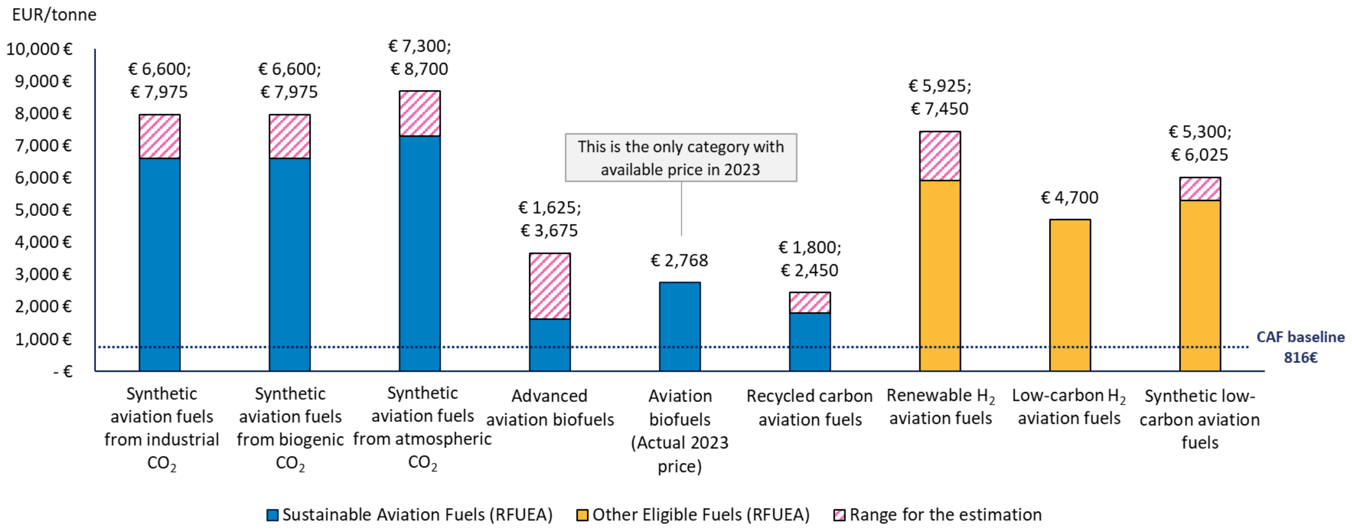
[11] A combination of internal ICF models with Cleopatra, a capital cost estimating tool, and DWSIM, a process simulation tool, were utilised to develop the production cost estimates.

[12] (S&P Global Commodity Insights, n.d.)

Figure 2 Production cost estimations for SAF and other eligible aviation fuels under RFEUA for 2023



> Note: It is important to emphasise that these results are 2023 production cost estimations, developed using feedstock, energy and technology deployment costs, as well as production capacity expectations for 2023. Facilities are designed as first-of-a-kind (FOAK) facilities, with smaller capacities[13] to better represent the case for production in 2023. These production costs are expected to reduce as emerging production technologies scale up, and associated costs reduce.

A summary of the cost estimations for the different types of fuels under RFEUA in 2023 is outlined in Table 2 below. Assumptions, inputs, process configurations and the modelling approach used in the production cost estimations are presented in detail in the body of this report.

Table 2 2023 market prices and production cost estimations for RFEUA aviation fuels

RFEUA AVIATION FUEL CATEGORY	MARKET PRICE IN 2023	PRODUCTION COST ESTIMATION FOR 2023[14]
Categories of sustainable aviation fuels (SAF)		
Weighted average synthetic aviation fuels	N/A	Average 7,500 €/tonne [6,600 – 8,700] €/tonne
Synthetic aviation fuels from industrial CO_2	N/A	Average[15] 7,500 €/tonne [6,600 – 7,975] €/tonne
Synthetic aviation fuels from biogenic CO_2	N/A	Average 7,500 €/tonne [6,600 – 7,975] €/tonne
Synthetic aviation fuels from atmospheric CO_2[16]	N/A	Average 8,225 €/tonne [7,300 – 8,700] €/tonne
Advanced aviation biofuels	N/A	Average 2,675 €/tonne

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[13] Results reflect production cost estimations, not prices (apart from aviation biofuels). They do not include profit margin as the market is still not established enough to determine an accurate margin.

[14] Aviation biofuel and CAF data are price realisations

[15] Weighted averages are calculated using the announced production capacity in the EU

[16] Production cost estimation for synthetic aviation fuels produced from DAC CO_2 range between 7,300 EUR/t and 8,700 EUR/t, with 8,225 EUR/t as average

Production cost estimation for synthetic aviation fuels produced from biogenic and industrial PSC CO_2 range between 6600 EUR/t and 7975 EUR/t, with 7,500 EUR/t as average

RFEUA AVIATION FUEL CATEGORY	MARKET PRICE IN 2023	PRODUCTION COST ESTIMATION FOR 2023[14]
		[1,625- 3,675] €/tonne
Aviation biofuels	2,768 €/tonne	N/A
Recycled carbon aviation fuels	N/A	Average 2,125 €/tonne [1,800 – 2,450] €/tonne
Categories of other eligible renewable and low-carbon aviation fuels		
Renewable hydrogen for aviation	N/A	Average 6,925 €/tonne [5,925 - 7,450] €/tonne
Low-carbon hydrogen for aviation	N/A	4,700 €/tonne
Synthetic low-carbon aviation fuels	N/A	Average 5,300 €/tonne [17] [5,300 - 6,025] €/tonne
Other aviation fuels		
Conventional aviation fuel	816 €/tonne	N/A

Fuel Reference Prices: Average prices

Under Article 4 and Annex I, RFEUA establishes minimum shares of SAF and synthetic aviation fuels. As part of the analysis conducted for this report, the 2023 weighted average prices of CAF, SAF and synthetic aviation fuels were determined (Table 3). The methodology used to calculate these prices is briefly explained below. Additional details can be found in the body of the report:

- The **2023 weighted average price of CAF** is the weighted average market price as presented in section 3.1.1.
- The **2023 weighted average price of SAF**[18] is the weighted average price between (1) aviation biofuels, (2) advanced aviation biofuels and (3) recycled carbon aviation biofuels, based on the availability of each of those aviation fuel types on the market during the 2023 reference period. For 2023, only (1) aviation biofuels had available market prices through PRAs.
- The **2023 weighted average price of synthetic aviation fuels** is the weighted average price between (1) synthetic aviation fuel from industrial CO_2, (2) synthetic aviation fuel from biogenic CO_2 and (3) synthetic aviation fuel from atmospheric CO_2. In 2023, synthetic aviation fuels were not available in the market, therefore necessitating the use of a production cost estimation driven back-up pricing methodology, factoring in the announced production capacity for each of the synthetic aviation fuel types in the EU to determine the weighting of each type for the weighted average price. Note that production cost estimations do not include any profit margin.

➨ **Table 3:** 2023 weighted average prices of CAF, SAF and synthetic aviation fuels

RFEUA AVIATION FUEL CATEGORY	2023 REFERENCE PRICE
Conventional aviation fuel	816 €/tonne
Sustainable aviation fuel (excluding synthetic aviation fuels)	2,768 €/tonne
Synthetic aviation fuels[19]	7,500 €/tonne (Back-up pricing)

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[17] Weighted average

[18] Excluding synthetic aviation fuels

[19] Considering no synthetic aviation fuel was available in 2023, this yearly average price is a production cost estimation average

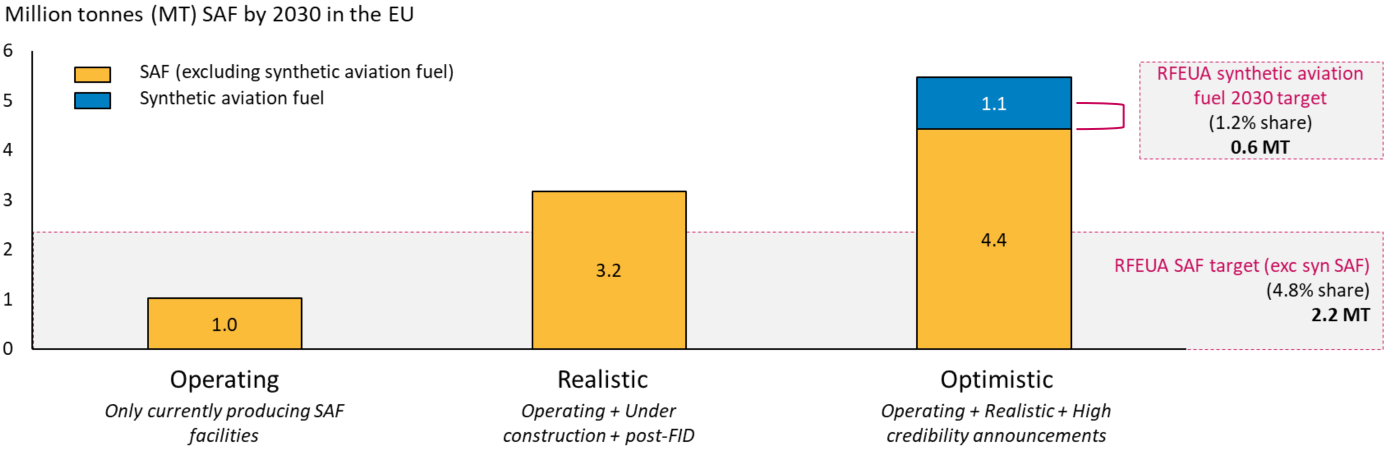
SAF production capacity assessment

The production capacity assessment for the EU showed that the announced SAF capacity is expected to meet the minimum SAF share required under RFEUA by 2030. At the same time, rapid action is needed to meet the synthetic aviation fuel minimum share requirements. Based on the SAF facility data collected from EU Member States, publicly available plant capacity information, and following a maturity assessment to determine the potential success of a facility, 3.2 million tonnes (MT) of SAF are expected to be produced in the EU by 2030[20] (realistic case), with a pipeline of 5.5 MT of SAF capacity[21] (optimistic case).

This estimation is based on the maturity assessment approach developed for this analysis[22]. Expected capacity refers to facilities that are already operating, under construction or with small operating/under construction pilot plants. Pipeline refers to other facilities which have announced main facility attributes, such as technology, feedstock, SAF capacity, commissioning year, location, and upstream/downstream partners. The application of the maturity criteria developed for this analysis and used for the *realistic* case led to the exclusion of facilities which had not gone through final investment decision (FID) at the time of assessment. There is a strong pipeline of synthetic aviation fuel projects in the EU, estimated at 1.1 MT by 2030, but at the time of assessment, none of these facilities had gone through FID. They were therefore not included in the *realistic* capacity estimation.

The minimum SAF share required under RFEUA by 2030 in the EU is estimated at 2.8 million tonnes based on jet fuel consumption forecast of 46 MT[23] and a minimum SAF share of 6% under RFEUA. The 1.2% synthetic aviation fuel minimum share translates into a 0.6 MT requirement. Considering the 3.2 MT expected capacity, the EU is well positioned to meet the 2030 RFEUA SAF requirement relying on locally produced fuel. However, this would require the successful commissioning of the announced facilities. To be able to meet the synthetic aviation fuel minimum shares, announced synthetic aviation fuel facilities would need to reach FID within the next couple of years. On top of this, continuous scale-up in SAF capacity would be needed to comply with RFEUA by 2035, as the minimum SAF share required increases from 6% to 20% by that date.

Figure 3 2030 EU estimated annual SAF production volume



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[20] The analysis was concluded as of April 2024. Facility announcements made after this date were therefore not considered

[21] EU Member States only, excluding EFTA States

[22] Maturity assessment is explained in further detail in the body of the report – Section 4.2

[23] Current landscape and future of SAF industry, European Aviation Environmental report (EASA, 2022)

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Abbreviations

ACRONYM	DESCRIPTION
AACE	Association for the Advancement of Cost Engineering
ARA	Amsterdam–Rotterdam–Antwerp
ASTM	ASTM International
ATJ	Alcohol-To-Jet
CAF	Conventional Aviation Fuel
CAPEX	Capital Expenditure
CEPCI	Chemical Engineering Plant Cost Index
CHJ	Catalytic Hydrothermolysis
CIF	Cost, Insurance and Freight
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DAC	Direct Air Capture
EASA	European Union Aviation Safety Agency
ECB	European Central Bank
EPC	Engineering, Procurement, Construction
ETS	Emissions Trading System
EXW	Ex-Works
FEL	Front End Loading
FID	Final Investment Decision
FOB	Free on Board
FT	Fischer-Tropsch
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HEFA	Hydrotreated Esters and Fatty Acids
HtL	Hydrothermal Liquefaction
HVO	Hydrotreated Vegetable Oil
ISBL	Inside the Boundary Limits
LPG	Liquified Petroleum Gas
MED	Mediterranean
MtJ	Methanol-to-Jet
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MT	Million Tonnes
mt	Metric Tonnes
MW	Megawatts
NREL	National Renewable Energy Laboratory
NWE	Northwest Europe

OPEX	Operating Expenditures
OSBL	Outside the Boundary Limits
PEM	Proton Membrane Exchange
PFAD	Palm Fatty Acid Distillate
PPA	Power Purchase Agreements
PRA	Pricing Reporting Agencies
PSC	Point Source Capture
RCF	Recycled Carbon Fuel
RFEUA	ReFuelEU Aviation
RFNBO	Renewable Fuels of Non-Biological Origin
SAF	Sustainable Aviation Fuel
SG&A	Selling, General, and Administrative
SIP	Synthesised Iso-Paraffins
SPK	Synthetic Paraffinic Kerosene
TRL	Technology Readiness Level
UCO	Used Cooking Oil
USGC	US Gulf Coast
USWC	US West Coast

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1. Introduction

Aviation is vital to reuniting families and friends, facilitating business and trade, and ensuring connectivity and cohesion across the EU. It provides employment for nearly 5 million people and contributes to 2.1% of the EU's Gross Domestic Product (GDP)[24]. In 2022, however, the industry also contributed to 3.8% and 13.9% of the EUs total and transport-related Greenhouse Gas (GHG) emissions, respectively [25]. While other transportation modes can decarbonise through electrification and other means, aviation's limited options make it a hard-to-abate sector.

The European Union has set an ambitious target of EU climate neutrality by 2050 and of reducing GHG emissions in the EU by at least 55% by 2030 compared to 1990 levels. TheReFuelEU Aviation Regulation (RFEUA) was proposed as part of the "Fit for 55" legislative package in 2021 by the European Commission, adopted by the European Parliament and the Council on 18 October 2023 and entered into force on 20 November 2023. RFEUA aims at decarbonising aviation while promoting growth and ensuring fair competition in sustainable air travel. A major aspect of the regulation involves mandating aviation fuel suppliers to incorporate a set percentage of SAF into the aviation fuel supply for aircraft departing from Union airports[26], starting at 2% in 2025 and gradually increasing up to 70% by 2050 (Table 4). RFEUA also includes a synthetic fuel sub-mandate that aims at stimulating the production and supply of synthetic aviation fuels.

➨ **Table 4:** ReFuelEU Aviation regulation SAF minimum shares

YEAR	SAF MINIMUM SHARES (TOTAL)	SYNTHETIC AVIATION FUELS MINIMUM SHARES
2025	2%	0%
2030	6%	1.2%
2032	6%	2%
2035	20%	5%
2040	34%	10%
2045	42%	15%
2050	70%	35%

Article 13 of RFEUA requires EASA to prepare and publish an annual technical report. The report will, notably, provide information on the compliance status of aviation fuel suppliers, aircraft operators and Union airport managing bodies with regard to their obligations under the regulation, as well as provide an update on the state and development of the EU SAF market. The annual technical report will be published in 2025 for the first time, and annually thereafter.

Note: This publication, focused on the state of the EU SAF market in 2023, serves as a precursor to the first EASA annual technical report as per Article 13 of RFEUA, to be released in 2025.

The 'State of the EU SAF market in 2023' report provides a snapshot of the 2023 market situation based on publicly available information, data from price reporting agencies as well as inputs from EU Member States and EFTA States. At present, the EU SAF market is still in a nascent stage and expected to evolve significantly in the years to come. The EASA annual technical reports will aim at reflecting these developments.

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[24] Air transport modes in EU (European Commission, 2024)

[25] Reducing emissions from aviation (European Commission, 2024)

[26] Union airport is defined in Article 3.1 of the RFEUA regulation as airports *where passenger traffic was higher than 800,000 passengers or where the freight traffic was higher than 100,000 tonnes in the previous reporting period, and which is not situated in an outermost region* (European Commission, 2023)

2. RFEUA eligible aviation fuels overview

2.1 RFEUA eligible aviation fuel categories

Assessing fuel reference prices and market dynamics requires an understanding of the RFEUA aviation fuel categories and the feedstock/technology combinations that underpin them. This chapter therefore aims to provide this overview.

The sustainability criteria laid down in the EU Renewable Energy Directive (RED) form the basis for establishing the eligibility of the majority of fuels defined under the RFEUA regulation. For other aviation fuel categories, namely low-carbon hydrogen and synthetic low-carbon aviation fuels, the RFEUA regulation references "relevant Union law", i.e., the Gas Directive (EU) 2024/1788[27]. RFEUA fuel categories are defined mainly based on the feedstock (Table 5). The feedstocks that can be utilised for producing aviation fuels in each category are further detailed in Appendix 6.2.

Table 5: RFEUA eligible aviation fuel categories

TYPE OF RFEUA AVIATION FUEL	DEFINITION IN RFEUA	COMMENTS
Synthetic aviation fuels	Art 3(12)	Renewable fuels of non-biological origin in the Renewable Energy Directive (RED)[28]
Advanced aviation biofuels	Art 3(8)(a)	Biofuels produced from feedstock listed in Part A Annex IX of RED
Aviation biofuels	Art 3(8)(b)	Biofuels produced from feedstock listed in Part B Annex IX of RED
Other aviation biofuels[29]	Art 3(8)(c)	Biofuels produced from feedstock not listed in Annex IX of RED and except for those produced from food and feed crops, intermediate crops, palm fatty acid distillate and palm and soy-derived materials, and soap stock and its derivatives
Recycled carbon aviation fuels	Art 3(9)	Recycled carbon fuels in RED
Renewable hydrogen for aviation	Art 3(16)	Hydrogen for aviation that is renewable fuel of non-biological origin in RED
Low-carbon hydrogen for aviation	Art 3(15)	Hydrogen for aviation that is produced from non-fossil non-renewable sources
Synthetic low-carbon aviation fuels	Art 3(13)	Drop-in aviation fuel produced from non-fossil non-renewable sources

2.1.1 Synthetic aviation fuels

Synthetic aviation fuels are defined under RFEUA Art 3(12) as drop-in renewable fuels of non-biological origin (RFNBO), the energy content of which is derived from renewable sources other than biomass. Fuels falling under this category are typically produced from hydrogen produced using renewable electricity and carbon dioxide (CO_2) captured from point sources that would have otherwise released that CO_2 into the atmosphere,

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[27] Gas Directive (EU) 2024/1788, (European Commission, 2024)

[28] Renewable Energy Directive (RED): Directive (EU) 2018/2001

[29] other aviation biofuels are covered in the aviation biofuels section

and through Direct Air Capture (DAC). The fuel is also required to meet a lifecycle emissions savings threshold of 70%.

Within the EU, more than 15 synthetic aviation fuel production facilities have been announced, primarily in countries with considerable renewable electricity capacity or infrastructure. The advantage of these fuels is that their production is, in principle, better scalable than the production of biofuels as the CO_2 is more abundant than other feedstocks. However, the necessity for large quantities of renewable electricity is a key factor. Some elements of the technology are to be proved at a commercial scale, including the reverse water gas shift (RWGS) which is typically used to produce carbon monoxide (CO) from CO_2, optimising the conversion process. The requirement for large quantities of and current cost of electricity, combined with the limited sources of eligible carbon in appropriate locations drives up the cost associated with this pathway. The resulting production price is currently non-competitive with other forms of SAF production (particularly HEFA). Therefore, the development of synthetic aviation fuels is likely to be driven by the RFEUA sub-mandate that requires their supply.

While the majority of facility announcements in the EU are expected to use point source captured CO_2, DAC technology continues to mature and point source facilities will become less available over time. Overall, DAC technology is less mature than point source capture and was listed at a technology readiness level (TRL) of 7 out of 9 by the United States Government Accountability Office in 2022 while point source capture was listed at a 9[30]. A TRL of 7 indicates that the technology has been demonstrated at full scale but has not been fully commercialised. As of 2024, 27 DAC facilities have been commissioned globally[31] including the Orca facility in Iceland. The Orca facility is a DAC facility that has been in operation since 2021 and captures up to 4,000 TPY of CO_2[32].

Within the industry, hydrocarbons in the *synthetic aviation fuels*, *synthetic low-carbon aviation fuels*, and *recycled carbon fuels* categories are often referred to as *Power-to-Liquid (PtL) SAF* or e-SAF. Synthetic aviation fuel has a specific definition in the RFEUA regulation (RFNBO), which only includes synthetic fuel produced using point source or atmospheric CO_2 and hydrogen that meets stringent sustainability criteria[33]. Multiple technologies can be used for synthetic SAF production, such as Fischer-Tropsch (FT) and potentially Methanol-to-Jet (MtJ).

Carbon capture as an input for synthetic fuels is regulated in the Annex of the Commission delegated regulation (EU) 2923/1185[34]. Any CO_2 that has been captured from the air (DAC), or from a point source that would have otherwise been emitted as CO_2 into the atmosphere and fulfils at least one of the below conditions, is treated as incurring zero emissions at the combustion step of the fuel and therefore, is suitable for producing synthetic aviation fuels:

- CO_2 (of non-renewable origin) captured from an activity listed under Annex I of EU ETS Directive and accounted upstream in an effective carbon pricing system (i.e. EU ETS, CH ETS and UK ETS) for fuels produced before 2036 for CO_2 from electricity generation or before 2041 in the other cases; or

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[30] GAO-22-105274, (United States Government Accountability Office, 2022)

[31] Direct Air Capture - Energy System - (IEA, n.d.)

[32] Orca is Climeworks' new large-scale carbon dioxide removal plant, (Climeworks, 2021)

[33] Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin and Commission Delegated Regulation (EU) 2023/1185 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a minimum threshold for greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels.

[34] Commission Delegated Regulation (EU) 2023/1185 (European Union, 2023)

- CO_2 stems from the production or the combustion of sustainable (according RED) biofuels, bioliquids and the CO_2 capture did not receive credits for emission savings from CO_2 capture and replacement in RED; or
- CO_2 stems from the combustion of RFNBO or RCFs complying with the 70% GHG emissions saving criteria; or
- CO_2 stems from a geological source of CO_2 and the CO_2 was previously released naturally.

2.1.2 Advanced aviation biofuels

Under Directive (EU) 2018/2001 (RED), aviation biofuels are classified as *advanced biofuels* depending on the feedstock used. Advanced biofuels are produced from feedstock listed in Part A of Annex IX of RED. These feedstocks include agricultural, forestry, household and industrial bio-wastes, algae and others[35]. Since a revision in March 2024[36], Part A of Annex IX includes specific types of intermediate crops, such as cover crops not leading to additional demand for land, where used for the production of biofuels for the aviation sector[37]. The announced or operational facilities producing advanced biofuels in the EU utilise the ASTM-approved HEFA (HEFA-SPK), FT- Synthetic Paraffinic Kerosene (FT-SPK) and Alcohol to Jet (AtJ) pathways. The fuel is also required to meet a lifecycle emissions savings threshold of 65% compared to the fossil fuel baseline as defined under the EU RED for facilities starting operation after 2021[38].

The HEFA process has been successfully commercialised for a long time, especially for the production of renewable diesel, and is already used for the production of aviation biofuels from RED Annex IX part B feedstocks, such as UCO or tallow. Still, the utilisation of other waste oils is more challenging given the pretreatments needed, risk of contamination of the catalysts and carbon chains lengths, and often limited availability per type. While less developed and commercialised, the process is however suitable and used to a limited degree already for fuel production based on lipids included in RED Annex IX part A[39]. These lipidic feedstocks can also be used to produce *Advanced aviation biofuels* via the co-processing technology.

The gasification FT process, originally developed for coal, has been successfully commercialised for decades. While it has been used primarily with coal, there is growing interest in using biomass or Municipal Solid Waste (MSW-biogenic part) as feedstocks for SAF production. However, this transition presents significant challenges due to differences in syngas composition and energy density. These factors can impact process performance, equipment durability, product yields, and overall efficiency. As a result, the TRL of biomass-to-SAF gasification FT facilities is lower than those using coal.

The AtJ process converts alcohols into jet fuel. Most announced AtJ facilities plan to use alcohols fermented from corn or sugarcane, especially in the US and Brazil. However, this renders the resulting SAF ineligible under RFEUA due to those feedstocks being food and feed crops. Using lignocellulosic wastes and residues instead can produce RFEUA-eligible alcohols, and while global production of such ethanol is still limited, there is significant potential for scale-up due to the relative abundance of such wastes and residues.

2.1.3 Aviation biofuels / other aviation biofuels

Aviation biofuels, as defined under RFEUA, are aviation fuels produced from feedstock that is listed in Part B of Annex IX of the RED. Feedstocks in this category include waste materials, such as Used Cooking Oil (UCO), animal fats or damaged crops that are not fit for use in the food or feed sectors. The fuel is also required to

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[35] Please see Appendix 6.2 for the comprehensive list

[36] Commission Delegated Directive (EU) 2024/1405 of 14 March 2024 amending Annex IX to Directive (EU) 2018/2001 of the European Parliament and of the Council as regards adding feedstock for the production of biofuels and biogas (European Union, 2024)

[37] Renewable Energy – Recast to 2030 (RED II) (European Commission, 2018)

[38] Article 29 (10) RED, for production facilities that started operation at an earlier date, a lower GHG threshold is set.

[39] such as POME or tall oil, or some industrial wastes from, such as olive oil production

meet a lifecycle emissions savings threshold of 65% compared to the fossil fuel baseline as defined under the EU RED for facilities starting operations after 2021[40].

Other aviation biofuels are aviation fuels produced from biomass feedstocks that are not listed in Part A or Part B of Annex IX of the RED and that are not produced from food or feed crops, intermediate crops, palm fatty acid distillate and palm and soy-derived materials, or soap stock and its derivatives, yet which meet the sustainability and life cycle emissions savings criteria laid down in the RED. Feedstocks in this category are typically waste materials, such as certain animal fats, or energy crops that do not match definitions in Annex IX A or B. Similarly, *other aviation biofuels* are also required to meet a lifecycle emissions savings threshold of 65% compared to the fossil fuel baseline as defined under the EU RED.

The majority of SAF produced globally in 2023 was produced using feedstocks in Part B of Annex IX, with the HEFA pathway dominating in terms of technologies used. The HEFA process is a well-established and widely used technology for converting fats, oils, and greases into hydrocarbons. These feedstocks, which include used cooking oils, animal fats, and other lipid-rich organic materials, are converted into SAF through a series of chemical reactions. While some crop-based vegetable oils were also used in other countries for HEFA SAF production, they are not eligible under the category of “aviation biofuels” in the RFEUA.

The HEFA pathway’s current dominance is largely due to its comparatively lower cost of production (which is still higher than fossil kerosene, however), technology maturity and the industry developed for renewable diesel production over the past decade. While this technology is projected to play a key role in global SAF production through 2030, the growth of the HEFA industry is expected to plateau due to constraints on the volume of feedstock.

2.1.4 Recycled carbon aviation fuels

Recycled carbon aviation fuels (RCF), as defined under RFEUA Article 3(9), with reference to RED, are aviation fuels that are *produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations*. These fuels are required to meet a lifecycle emission savings threshold of at least 70%.

Fuels in this category could include fuels produced using the various processes but for which sources of carbon, hydrogen or energy for the process are non-renewable. Potential examples of producing RCFs include fermentation of industrial waste gases to produce ethanol, and then producing SAF with the AtJ technology, or gasification of waste plastics. The delegated regulation specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels[41], provides the key elements for differentiating RFNBO from RCF.

2.1.5 Renewable hydrogen for aviation and low-carbon hydrogen for aviation

Renewable hydrogen for aviation is defined under RFEUA Art 3(16) as hydrogen for use in aircraft that qualifies as RFNBO (section 2.1.1), i.e., the energy content of which is derived from renewable sources other than biomass. These fuels must have a resulting lifecycle emission savings of at least 70% as defined under the EU RED.

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[40] Article 29 (10) RED, for production facilities that started operation at an earlier date, a lower GHG threshold is set.

[41] Commission Delegated Regulation (EU) 2023/1185 of 10 February 2023 supplementing Directive (EU) 2018/2001 (European Union, 2023)

Low-carbon hydrogen for aviation is defined under RFEUA Art 3(15) as hydrogen whose energy content is derived from non-fossil non-renewable sources, that meet a lifecycle emissions savings threshold of 70%, as defined under the Gas Directive[42].

Hydrogen as fuel is not compatible with current aviation fuel infrastructure and also requires new aircraft design capable of storing hydrogen either as a liquid or gas and utilising it in a jet engine or in a fuel cell[43]. Additionally, new airport infrastructure is needed to store and distribute hydrogen. Therefore, whilst a promising future solution, renewable hydrogen for direct use in aircraft is not expected to be able to play a major role in the near term.

2.1.6 Synthetic low-carbon aviation fuels

Synthetic low-carbon aviation fuels as defined under RFEUA Art 3(13) are aviation fuels that are of non-biological origin, the energy content of which is derived from non-fossil low-carbon hydrogen, which meet a lifecycle emission threshold of at least 70%, as defined under the Gas Directive[44].

Aviation fuels fall under this category if they are produced in the same manner as synthetic aviation fuels, though using non-fossil low-carbon energy (e.g., nuclear energy), instead of non-biogenic renewable energy sources.

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[42] By the time of issuing this report, the relevant methodology has not been adopted yet.

[43] ASTM is currently developing a certification for hydrogen as a fuel through its subcommittee D03.14 on hydrogen and fuel cells (ASTM, n.d.)

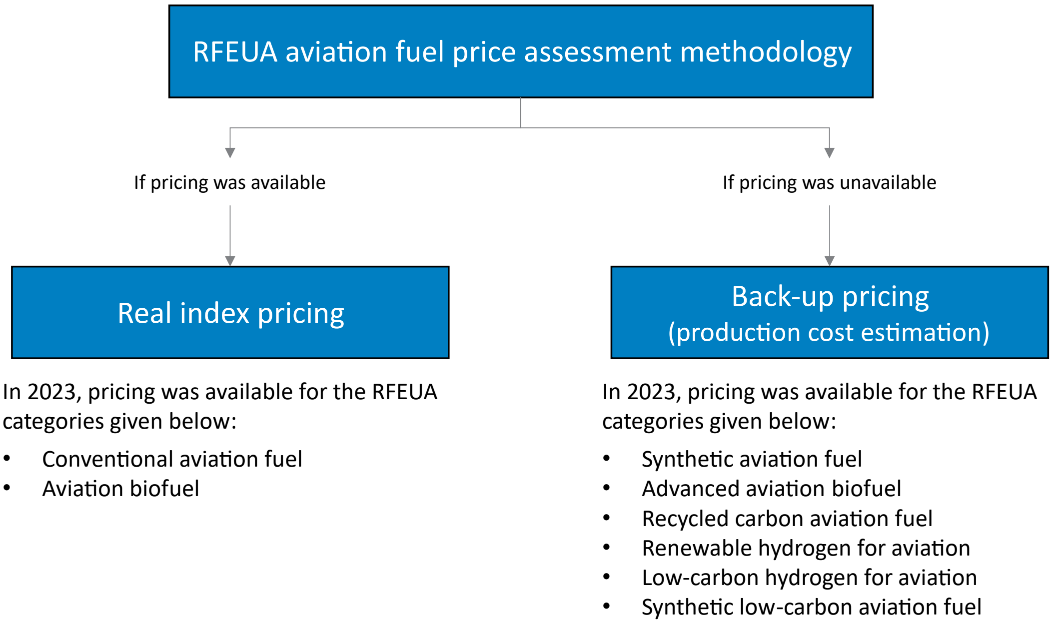
[44] By the time of issuing this report, the relevant methodology has not been adopted yet.

3. RFEUA aviation fuels price assessment

To determine the 2023 average prices of the aviation fuels defined under RFEUA, a methodology was developed based on the availability of market prices for each RFEUA aviation fuel type. Conventional aviation fuel (CAF) was also included in the assessment, given its fundamental reference role in the implementation of the regulation. If a market price for a given RFEUA aviation fuel type was available in 2023, then a **real index pricing** methodology was used. This method utilises existing price data, provided by price reporting agencies (PRAs). If the fuel was not publicly traded in 2023, and hence did not have a real index price through PRAs, a bottom-up levelised cost of production estimation-based methodology (**back-up pricing**) was used. This approach leveraged market transaction-based price data where available, in the absence of which, bottom-up estimations were developed.

During 2023, only CAF and aviation biofuel (HEFA SAF) were available on the market. Therefore, a price index for these fuels was available through PRAs. Other RFEUA aviation fuels were not available in the market, therefore the back-up pricing methodology was applied to them as illustrated Figure 4. It is important to note that only annual average prices and data inputs were required for each category. Therefore, PRA data was received on an annual average basis where possible.

➨ **Figure 4:** Price assessment methodology



In 2023, pricing was available for the RFEUA categories given below:

- Conventional aviation fuel
- Aviation biofuel

In 2023, pricing was available for the RFEUA categories given below:

- Synthetic aviation fuel
- Advanced aviation biofuel
- Recycled carbon aviation fuel
- Renewable hydrogen for aviation
- Low-carbon hydrogen for aviation
- Synthetic low-carbon aviation fuel

3.1 Real index pricing

The real index pricing approach involves applying an arithmetical average[45] to 2023 historical spot market price data from PRAs. The preconditions for use of PRA data were mainly their ability to provide price indexes for CAF and SAF for the reporting period of 2023, in addition to their broad recognition in the pricing industry.

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[45] The arithmetic mean weighing all items equally, making it suitable when no specific item should dominate the index. In addition to commonly used economics indices like the Consumer Price Index (CPI) and Producer Price Index (PPI), global PRAs also use the arithmetic mean to develop their pricing indexes

Exploring the PRA market showed that only Argus Media (Argus), S&P Global Commodity Insights (Platts) and General Index (GX) had SAF and CAF-related data for 2023. For this assessment, transaction-based market prices were prioritised for SAF.

3.1.1 CAF real index pricing

CAF price indices have been widely used in the aviation industry for decades. Given the large quantities of daily fuel transactions and the liquidity of the market, PRAs tend to receive numerous survey answers and publish very accurate fuel prices.

The CAF pricing information indices provided by Argus, Platts and GX are highly regarded and extensively used in the aviation sector, as they accurately represent market dynamics and daily transactions across various regions and International Commercial Terms [46]. The development of these indices is based on two key factors: the transaction's location and the mode of transportation used. In the EU, the majority of fuel transactions occur in Northwest Europe (NWE) and Mediterranean (MED) with limited CAF price difference between the two hubs.

Argus, GX and Platts provided Jet Fuel prices for the two European locations (NWE and MED). International Commercial Terms play an important role in CAF pricing. Free On Board (FOB) excludes shipping, insurance, and any other costs from the port of origin, which are the responsibility of the buyer. Cost Insurance and Freight (CIF) includes the shipping, insurance, and other costs up to the destination and can be more expensive than FOB but closer to what an aircraft operator is paying, therefore CIF was the basis of the assessment.

The difference between NWE and MED prices is primarily due to the transportation costs of crude and refined oil from the Middle East to the respective locations, though it was assessed to be minimal and resulted in a cost difference of approximately 2 EUR/tonne in 2023. In the case of SAF, most of the international supply is directed to NWE, hence an additional minimal cost of transportation can be expected within the EU. As the price information provided from the three PRAs were very similar, calculating the arithmetic mean of the three CIF prices resulted in a 2023 average CAF price of **816 EUR/tonne**.

3.1.2 Aviation biofuels real index pricing

SAF is an emerging commodity that PRAs have only recently started to evaluate. In general, the ability of a PRA to calculate a price is contingent upon the number and transparency of transactions. While the SAF market is currently small and fragmented, several PRAs have started to develop indices. For instance, Argus and Platts have established SAF market spot price indices, while GX was focusing on production cost estimation. SAF is also not a homogenous commodity as different carbon intensities and feedstocks drive price variations. So far, PRAs have focused on very specific sub-categories of SAF, though the indices are likely to become more complex and sophisticated to recognise the varying SAF attributes, even within categories of the RFEUA as presented in the backup pricing section.

For 2023, Argus and Platts were the only entities that released spot price indices for the SAF market. Such SAF was mainly produced from feedstock eligible in RED Annex IX Part B and is classified as “aviation biofuel” under RFEUA.

Argus Media initiated the publication of these indices in 2021, followed by Platts in September 2023. Before September 2023, Platts only had SAF production cost estimation. Consequently, it is not feasible to compute a full-year average for both agencies for the year 2023, but this complication will not persist beyond 2023, as both PRAs will have SAF prices for the full year of 2024, and onwards. To address this, a particular methodology has been adopted for the year 2023.

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[46] Incoterms

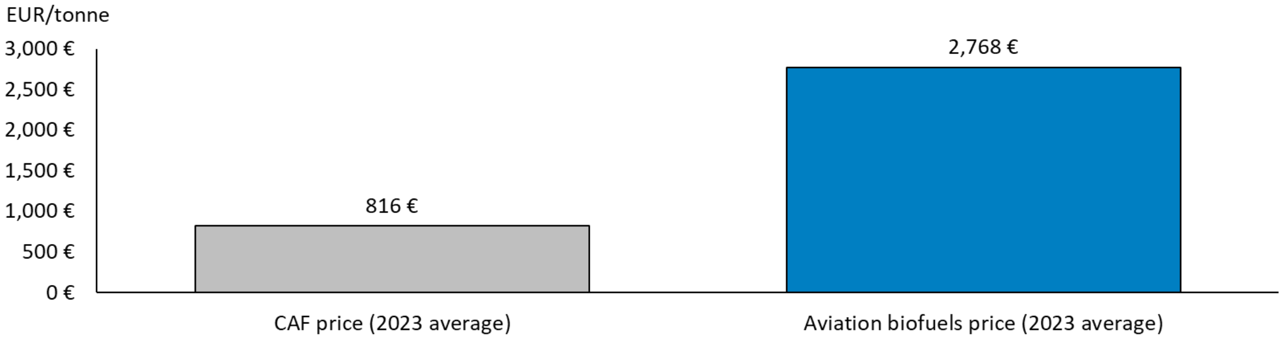
Given that Platts has been publishing SAF production costs covering 2023, the Argus price estimation was used for Jan-Sep 2023, and an arithmetic average of Platts and Argus was used for Sep-Dec 2023. This assessment resulted in an average 2023 aviation biofuel SAF price of **2,768 EUR/tonne**.

3.1.3 Reference RFEUA aviation fuels prices under real index pricing

Given the international nature of the fuels industry, USD is the widely used currency for price assessments. However, EASA intends to report its findings in Euros (EUR). This necessitates the application of a 2023 currency exchange rate to translate all prices from USD into EUR. The European Central Bank (ECB) publishes daily EUR/USD exchange rates that will be used in this report to determine the fuel prices in EUR. As per the ECB, the yearly 2023 average was **1.0813 USD/EUR**[47].

Taking the above-mentioned exchange rate from the European Central Bank, the 2023 yearly average CAF price was calculated as **816 EUR/tonne**, and that of the SAF price in 2023 was **2,768 EUR/tonne**[48]. These average prices were calculated based on real market transactions in 2023.

➨ **Figure 5:** Reference RFEUA prices for fuel supplied to the Union market and available in 2023



3.2 Back-up pricing

While the real index pricing methodology used the historical prices of SAF that are currently available, the back-up pricing methodology will focus on production cost estimations for eligible RFEUA aviation fuel categories that were not publicly traded in 2023. Platts has estimated that the average production cost for HEFA SAF (aviation biofuels RFEUA category) for 2023 was 1,770 EUR/tonne in Europe. Considering the 2023 average SAF price of 2,768 EUR/tonne, a substantial SAF margin exists. This SAF margin, which includes additional costs like transportation and commercial margins of the different stakeholders, is driven by market dynamics, primarily the scarcity of SAF, and is difficult to estimate for all other categories. Therefore, this assessment focuses on production cost estimations only.

3.2.1 Methodology

To develop a robust RFEUA eligible fuels production cost estimation for 2023, it is important to identify which costs must be estimated and which method to use for estimation. While RFEUA considers multiple categories of eligible aviation fuels for compliance with the minimum shares, fuels within each category can be produced through multiple technology pathways. As such, fuels within the same RFEUA category may have differing

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[47] (European Central Bank, 2024)

[48] An analysis was performed to evaluate the impact of converting daily PRA prices with daily exchange rates , and applying the yearly average exchange rate to the yearly average PRA data. The difference between two approaches was less than +/- 2€. Although this result is not significant enough to differentiate the methodology this year, this analysis will be performed every year to ensure the exchange rates fluctuations during the reporting period do not impact the results

production costs. Variables that contribute to driving the production cost include location, technology, license fee, labour rates, specific technology process guarantees, the capital cost versus efficiency of the selected equipment, inflation rates, cost escalation, profitability required for investment, distance to feedstock, distance to off-takers, contractual terms, feedstock type, the quality of selected feedstock and the source of electricity.

The first task therefore is to identify the most viable feedstock and technology combinations for fuels among the various RFEUA aviation fuel categories.

3.2.1.1 Feedstock and technology combination selection

Feedstock and technology combinations were selected based on the technology maturity and the market dynamics of both the feedstock and the technology, with a focus on 2023 dynamics.

Technology maturity

The Technology Readiness Level (TRL) scale measures the development stage of SAF technologies, ranging from 1 (basic principles) to 9 (operational environment). Only ASTM-approved SAF is allowed in commercial aviation, limiting the eligible technologies to those indicated in Appendix 6.1. While Methanol-to-Jet (MtJ) and Hydrothermal Liquefaction (HtL) can be considered feasible technologies, they lack ASTM D4054 certification to-date and are not considered in this study.

Market dynamics

Market readiness, gauged by the number of facilities and projects announced in the EU using the specific technology pathway dedicated to SAF production, considered to indicate the willingness of the market to deploy at a commercial scale. For example, some technologies may be well understood but are uneconomic under the current and expected policy regime. Others may be developed even though they have not yet been fully proven in operational environments.

Identified scope of work

In this study, the RFEUA eligible fuel categories were divided into sub-categories, providing a comprehensive overview of the production process, CO_2 capture methods, and cost factors for each type of SAF. This detailed breakdown was used to identify SAF combinations selected in the production cost estimation process. Combinations given in Table 6 were identified given their strong potential for implementation either due to facilities already announced in Europe or by the type of technology already expected by regulators (synthetic aviation fuels and hydrogen)[49].

Table 6: Selected production pathway and feedstock combinations under each RFEUA category

TYPE OF ELIGIBLE AVIATION FUEL	PRODUCTION PATHWAY	FEEDSTOCK
Synthetic aviation fuels	FT (PtL)	Biogenic and industrial CO_2 from PSC and hydrogen from electrolysis using renewable electricity
		Atmospheric CO_2 from DAC and hydrogen from electrolysis using renewable electricity
Advanced aviation biofuels	Gasification FT	MSW (biomass fraction, compliant with Annex IX.A)
		Forest Residue
	AtJ	Bioethanol from feedstock listed in Annex IX.A

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[49] Other aviation biofuels had previously included cover crops, which have been moved to Advanced biofuels category after the regulatory update on 14 March 2024.

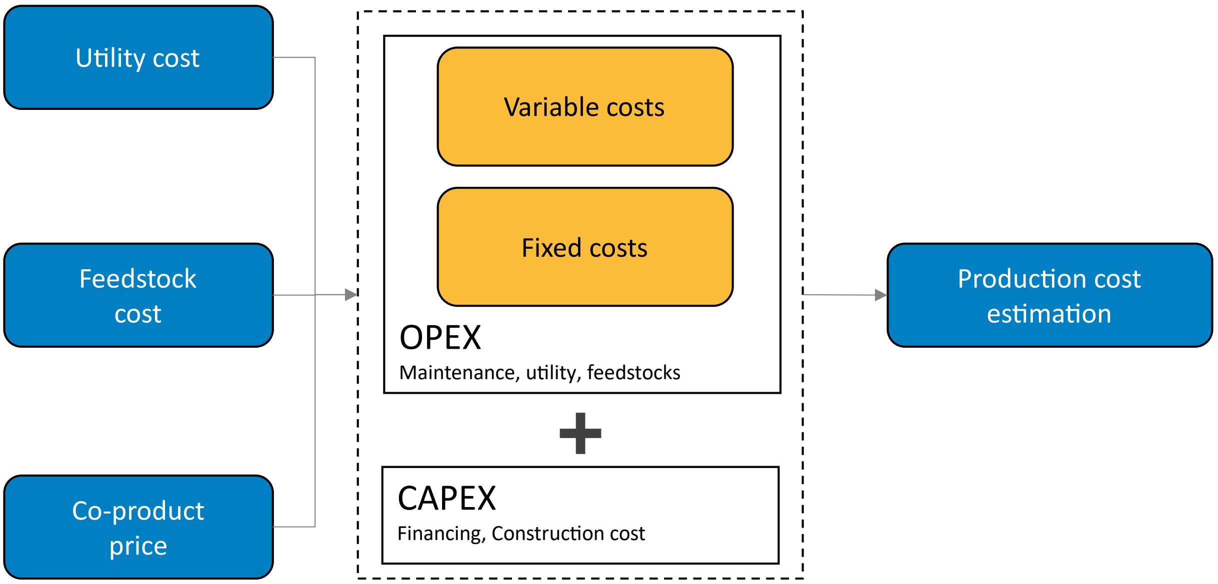
TYPE OF ELIGIBLE AVIATION FUEL	PRODUCTION PATHWAY	FEEDSTOCK
Recycled carbon aviation fuels	AtJ	Fossil CO_2 from Point Source Capture (PSC), fermantation to ethanol
	FT (PtL)	Fossil CO_2 from Point Source Capture (PSC) and hydrogen from electrolysis using renewable electricity
Renewable hydrogen for aviation	Alkaline electrolysis	Green hydrogen from electrolysis using renewable electricity
Low-carbon hydrogen for aviation	Alkaline electrolysis	Hydrogen from electrolysis using nuclear electricity
Synthetic low-carbon aviation fuels	FT (PtL)	Biogenic and industrial CO_2 from PSC and hydrogen from electrolysis using renewable electricity
		Atmospheric CO_2 from DAC and hydrogen from electrolysis using renewable electricity

3.2.2 Production cost estimation model

Production cost estimation provides the base for the minimum fuel selling price. Given the complexities involved in developing SAF facilities, accurately calculating production costs is challenging, particularly for technology pathways that were not operational as of 2023. These estimations include a high-level Class 5 capital cost estimation based on the AACE cost classification system and come with an expected accuracy range of -30% to +50%[50]. For more accurate cost predictions, detailed project and site-specific information are required. While the production costs estimated here apply broadly across the EU, it is important to note that variable costs such as utilities, feedstock, labour and materials can differ by location.

Utility cost, feedstock cost, equipment cost and co-product prices are the four key drivers for SAF production cost, as illustrated in the Figure 6.

Figure 6: Production cost input/output flowchart



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[50] Recommended Practice No. 56R-08 Cost estimate classification system (AACE Internationale, 2020)

Technology costs incorporated in the production cost estimation include operating expenditures (OPEX) and capital expenditures (CAPEX). The costs included in OPEX and CAPEX are described below. Please visit Appendix 6.4 for assumptions. The production costs are calculated in EUR per tonne.

3.2.2.1 OPEX

OPEX includes expenses incurred through the operation of the facility. OPEX is comprised of both variable and fixed costs. Variable costs include utility costs (the cost of electricity, natural gas, process water, wastewater disposal, chemical inputs) and feedstock. The variable costs are calculated based on feedstock and utility pricing information, process energy, chemical requirements, and feedstock requirements for the facility. These costs vary depending on the production pathway.

Fixed costs are those costs which do not vary by the operation of the facility. These costs include labour, maintenance, insurance and permitting, as well as selling, general and administrative (SG&A) costs. These costs can be influenced by the complexity of a facility and the requirements of the owner. High-cost infrequent maintenance activities, known as major maintenance or capital expenses (e.g., catalyst replacement), are often included in the fixed cost category.

1. Utility Costs

The utility costs encompass the essential services and resources consumed during the production of SAF, such as water, electricity and heat. Accurately accounting for these inputs is crucial as they represent a substantial portion of the variable operating expenses.

2. Feedstock Costs

Feedstock, which encompasses the raw materials used in the production of SAF, is an essential component of the variable operating expenses. Depending on the technology, the cost of feedstock accounts for approximately 20% and 80% of the overall production cost, directly influencing the base price of the fuel. By analysing the market prices and availability of various feedstocks, a more accurate cost estimate is generated. This analysis aims to ensure that estimations reflect current market dynamics and resource availability, through data inputs from PRAs, as possible.

3.2.2.2 CAPEX

CAPEX represents the initial investment required for equipment and infrastructure essential for the project implementation. CAPEX is comprised of direct costs, such as the equipment and labour needed to build the facility, and indirect costs, such as the offices needed to support construction and taxes. Owner's costs are also included, consisting of expenses related to project financing, engineering and permitting.

Equipment costs are categorised into two main types: Inside the Boundary Limits (ISBL) costs, which pertain to the primary technology vendor's proprietary equipment, and Outside the Boundary Limits (OSBL) costs, which involve ancillary equipment necessary for operations such as cooling towers, feedstock dryers and other utilities.

The cost estimates presented in this report are derived a capital cost estimating tool[51] at an AACE Class 5 level. The total CAPEX cost is then annualised based on assumptions of how the project is financed and the definition of the loan term and interest rate. To achieve more precise cost estimates, project-specific information and vendor quotes are required.

Co-products prices

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[51] ICF's internal capital cost modeling tool was utilised for CAPEX estimations. Cleopatra capital cost estimating software was utilised for equipment cost comparisons as needed.

Co-products are the valuable by-products generated alongside SAF. These can include gases, chemicals, or other materials that have their own market value. In the cost estimation model, the impact[52] from co-products was accounted for by deducting their associated costs from the total fuel production cost. This approach ensures a more accurate and fair pricing of the primary product, SAF, by recognising the economic contribution of co-products. Renewable diesel and naphtha co-products have expected selling prices, as provided by Argus. These co-products are not expected to be able to be sold at a premium from comparable products, so the costs associated with each co-product are limited by the selling price of the co-product. The excess costs are attributed to the SAF product to better reflect the production cost impact of new SAF development.

SAF and hydrogen production cost estimation

The primary output of this model is the cost estimation for SAF and hydrogen production. This estimation results from the aggregation of all aforementioned costs, adjusted by subtracting the value derived from co-products. The model accounts for the share of co-product revenues within the total valuable output of the facility, ensuring a comprehensive assessment of the net production costs.

3.2.3 Application of the methodology and assumptions

Two main types of data sources were used for the assessment: PRA data and publicly available data published by European institutions. Where these were not available, internally developed assumptions and models based on industry knowledge and experience were utilised.

3.2.3.1 Utilities

The utility costs of a SAF production facility depend strongly on the technology and feedstock used. Appendix 6.4.1 lists the main utility variables, and the associated assumptions used. Utility prices and consumption rates are based on PRA responses, publicly available information and internal modelling. The methodology in this report prioritises PRA data when possible to ensure continuity with the other cost sources, and alignment with the most recent market and global dynamics. 2023 EU average electricity prices from Argus were gathered and utilised. The dataset did not cover the cost of all EU countries. However when calculating the production cost using EU average price and Argus historical pricing, the overall production costs was calculated to be quite similar.

3.2.3.2 Feedstock

Feedstocks are the other input variable in the production cost estimation model. Different SAF categories will require different feedstocks. Feedstock prices are based on PRAs responses, publicly available information and internal modelling. Sources with an average price for all EU countries in 2023 were prioritised when possible. Some prices are based on specific countries or data from earlier years when 2023 information was not available. Bioethanol, forest residue MSW, and renewable hydrogen prices have multiple prices based on varying assumptions or price availability, so multiple production costs were calculated. Appendix 6.4.2 lists all the feedstock-related assumptions.

Specifically, hydrogen prices assumptions rely on market data gathered from PRAs in 2023. Ranging from 5,920 EUR/tonne to 7,450 EUR/tonne, the PRA published prices align with the latest results of the pilot auction for renewable hydrogen from the first EU-wide auction launched in November 2023 (IF 23) [53] with ranges from 5,300 EUR/tonne to 13,500 EUR/tonne.

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[52] The cost impact is the result of multiplying the price of each co-product, as provided by Argus Media, by the annual co-product produced. The sum of the estimated production costs of all co-product is then deducted from the annual production cost of the biofuel facility and divided by the SAF generated to get the SAF production cost in €/tonne SAF.

[53] Results of the IF23 pilot auction for renewable hydrogen production (European Commission, 2023)

3.2.3.3 Co-product yield

In addition to jet fuel, co-products are other valuable facility outputs that generate economic value. The main co-products are generally renewable diesel (HVO) and bionaphtha. The share of each co-product is determined by the fuel producer depending on multiple economic and technological variables (Appendix 6.5). For all pathways, the process was modelled to maximise SAF production. Renewable diesel and bionaphtha can be produced alongside SAF in many of the processes considered. Co-product selling price was calculated using 2023 average price information provided by Argus. Appendix 6.4.3 lists all average 2023 prices used for co-products.

3.2.3.4 Technology costs

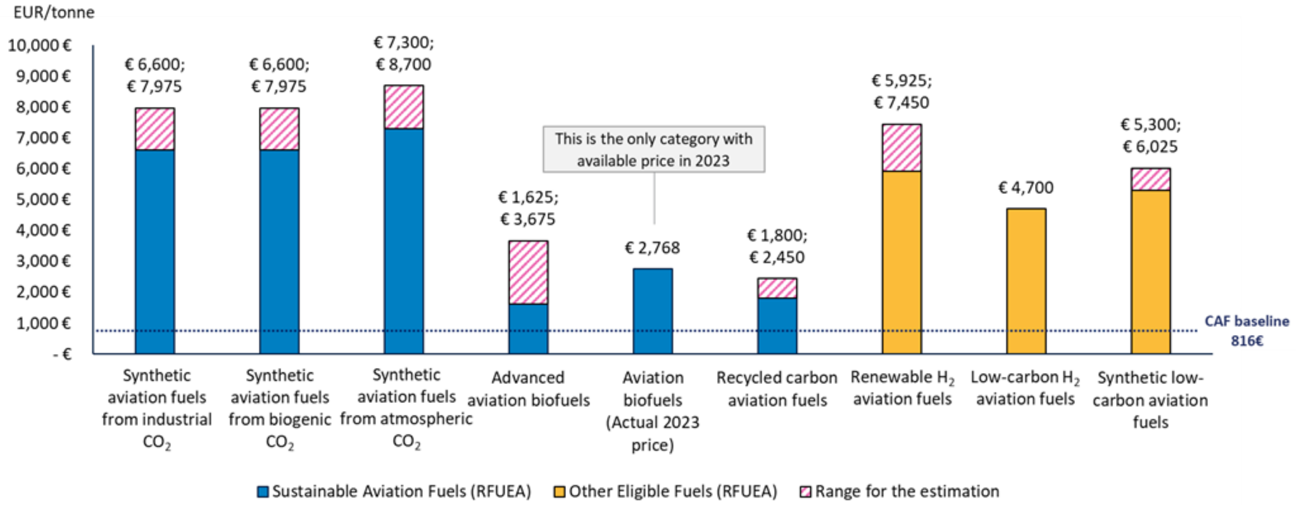
SAF production costs include CAPEX which encompasses the initial investments for setting up the facility and OPEX for ongoing operations, including the procurement of equipment, construction of the plant, and other infrastructure-related costs. Understanding this distinction is crucial for assessing economic feasibility. Appendix 6.4.4 provides details on the cost estimation assumptions.

3.3 Results

SAF facilities explored as a part of the backup pricing methodology utilise emerging technologies and were considered as first of a kind (FOAK) pioneer facilities. While this assessment provides results for the most promising technologies, it does not include future cost reductions resulting from economies of scale or technology advancement.

Figure 7 below presents the results of the production cost assessment. It should be noted that only *CAF* and *aviation biofuels* (HEFA SAF produced from UCO and/or waste animal fats (Cat. 1,2) mainly) categories were available in 2023. For other categories, production cost estimations were calculated, and the results are presented as ranges[54].

➨ **Figure 7:** Production cost estimations for SAF and other eligible aviation fuels under RFEUA (2023 EU estimations)



Each estimation included a cost driver analysis to identify the primary factors influencing the cost of SAF production, such as feedstock costs, energy consumption, labour costs and capital investment. This granular

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[54] Some eligible fuel categories under RFEUA cover multiple pathways (feedstock and/or technology combinations). Therefore, amongst a single pathway, different inputs can also be considered accounting for locations and/or optimistic/realistic scenarios. Consequently, this report presents ranges that consist of the lowest and the highest production cost estimation pathways per category.

approach allows for a detailed understanding of the cost structure, thereby enabling Member States to adapt their costs according to their own specificities. For instance, a country with abundant feedstock might focus on reducing raw material costs, while another with high labour costs might investigate increasing its fixed cost share. This tailored approach ensures that each Member State can optimise SAF production costs based on their unique circumstances and resources. Appendix 6.3 presents the result of all scenarios explored, and the building blocks of the production cost estimations in terms of the share of various inputs in total cost.

> Note: The costs presented in Figure 7 are based on 2023 inputs. Geopolitical events, such as the Russian invasion of Ukraine, have highly disrupted supply chains of some feedstocks (such as hydrogen) in 2023, which impacted the production cost estimations. As these technologies become increasingly accessible and available, production costs are expected to decline.

A summary of the cost estimations for the different types of aviation fuels under RFEUA in 2023 are outlined below (Table 7). Finally, the assumptions, inputs, process configurations and modelling approach used in production cost estimations are presented in detail in Appendix 6.5.

Table 7: 2023 market prices and production cost estimations for RFEUA fuels

RFEUA AVIATION FUEL CATEGORY	MARKET PRICE IN 2023	PRODUCTION COST ESTIMATION FOR 2023[55]
Categories of sustainable aviation fuels (SAF)		
Weighted average synthetic aviation fuels[56]	N/A	Average 7,500 €/tonne [6,600 – 8,700] €/tonne
Synthetic aviation fuels from industrial CO_2	N/A	Average 7,500 €/tonne [6,600 – 7,975] €/tonne
Synthetic aviation fuels from biogenic CO_2	N/A	Average 7,500 €/tonne [6,600 – 7,975] €/tonne
Synthetic aviation fuels from atmospheric CO_2[57]	N/A	Average 8,225 €/tonne [7,300 – 8,700] €/tonne
Advanced aviation biofuels	N/A	Average 2,675 €/tonne [1,625- 3,675] €/tonne
Aviation biofuels	2,768 €/tonne	1,770 €/tonne
Recycled carbon aviation fuels	N/A	Average 2,125 €/tonne [1,800 – 2,450] €/tonne
Categories of other eligible renewable and low-carbon aviation fuels		
Renewable hydrogen for aviation	N/A	Average 6,925 €/tonne [5,925 - 7,450] €/tonne
Low-carbon hydrogen for aviation	N/A	4,700 €/tonne
Synthetic low-carbon aviation fuels	N/A	Average 5,300 €/tonne [58] [5,300 - 6,025] €/tonne
Other aviation fuels		
Conventional aviation fuel	816 €/tonne	N/A

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[55] Aviation biofuel and CAF data are price realisations

[56] Weighted averages are calculated using the announced production capacity in the EU

[57] Production cost estimation for synthetic aviation fuels produced from DAC CO_2 range between 7,300 EUR/t and 8,700 EUR/t, with 8,225 EUR/t as average
Production cost estimation for synthetic aviation fuels produced from biogenic and industrial PSC CO_2 range between 6600 EUR/t and 7975 EUR/t, with 7,500 EUR/t as average

[58] Weighted average

3.4 2023 weighted average prices for CAF, SAF and synthetic aviation fuels

Under Article 4 and Annex I, RFEUA establishes minimum shares of SAF and synthetic aviation fuels. As part of the analysis conducted for this report, the 2023 weighted average prices of CAF, SAF and synthetic aviation fuels were determined (Table 8). The methodology used to calculate these prices is briefly explained below. Additional details can be found in the body of the report:

- The **2023 weighted average price of CAF** is the weighted average market price as presented in section 3.1.1.
- The **2023 weighted average price of SAF**[59] is the weighted average price between (1) aviation biofuels, (2) advanced aviation biofuels and (3) recycled carbon aviation biofuels, based on the availability of each of those aviation fuel types on the market during the 2023 reference period. For 2023, only (1) aviation biofuels had available market prices through PRAs.
- The **2023 weighted average price of synthetic aviation fuels** is the weighted average price between (1) synthetic aviation fuel from industrial CO_2, (2) synthetic aviation fuel from biogenic CO_2 and (3) synthetic aviation fuel from atmospheric CO_2. In 2023, synthetic aviation fuels were not available in the market, therefore necessitating the use of a production cost estimation driven back-up pricing methodology, factoring in the announced production capacity for each of the synthetic aviation fuel types in the EU to determine the weighting of each type for the weighted average price. Note that production cost estimations do not include any profit margin.

Table 8: 2023 weighted average prices of CAF, SAF and synthetic aviation fuels

RFEUA AVIATION FUEL CATEGORY	2023 REFERENCE PRICE
Conventional aviation fuel	816 €/tonne
Sustainable aviation fuel (excluding synthetic aviation fuels)	2,768 €/tonne
Synthetic aviation fuels[60]	7,500 €/tonne (Back-up pricing)

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[59] Excluding synthetic aviation fuels

[60] Considering no synthetic aviation fuel was available in 2023, this yearly average price is a yearly production cost estimation average

4. EU SAF production capacity assessment

SAF production in the EU is already a reality, primarily through co-processing in conventional refineries, as well as a number of dedicated HEFA plants, such as Neste's Poorvo and St1's Gothenburg refineries. Despite these efforts, the EU SAF market is still nascent, requiring a rapid ramp-up to establish sufficient domestic production capacity within the EU. This acceleration will be crucial to allow aviation fuel suppliers to comply with their RFEUA obligations while mitigating reliance on imports.

Out of the 27 EU Member States and 3 EFTA States contacted for this analysis, 15 reported at least one SAF production facility in operation or announced (Table 9). A significant proportion of these projects is still in the early stages and financial constraints may prevent them from becoming fully operational facilities, however the overall picture clearly points towards an EU SAF industry on a growth path.

➨ **Table 9:** Status of EU Member States SAF production facility announcements

EU MEMBER STATES WITH AT LEAST ONE OPERATING OR ANNOUNCED SAF FACILITY	EU MEMBER STATES WITH NO ANNOUNCED SAF FACILITY
Austria, Denmark, Finland, France, Germany, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden	Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Ireland, Latvia, Lithuania, Luxemburg, Malta, Slovakia, Slovenia

The analysis conducted focuses on assessing the production capacity for SAF within the EU, and also covers Iceland, Norway, Liechtenstein and Switzerland[61]. In a first step, a detailed desktop research was conducted to identify publicly announced SAF projects in each country, with the goal of compiling essential information about these SAF facilities, such as:

- Producer: the entity responsible for the SAF project
- Facility location: the geographical location of the project (e.g. city or region)
- Expected SAF production capacity per year: the expected annual SAF output from the plant
- Feedstock: the raw materials/ energy used in the production process
- Expected commissioning year: anticipated operational start date
- Additional information: any other relevant project details (ex. partnerships, CAPEX, etc.)

The second step of the data collection process involved verifying the compiled information with the authorities from each country of interest. In April 2024, the dataset containing information on announced facilities and projects specific to each country was shared with the EU and EFTA States. Over the course of three weeks, feedback was received from the respective authorities, and this feedback was then used to further refine the dataset as needed.

4.1 SAF production capacity estimations

The analysis was conducted with the objective of providing a comprehensive understanding of the SAF production capacity within the EU. To compare announced SAF production volumes with the projected minimum SAF shares required under RFEUA by 2030, this section analyses quantitative data from various sources. While some sources provide specific SAF volumes, others require estimation based on total facility

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[61] EEA States (Norway, Liechtenstein, Iceland) and Switzerland will be referred to as EFTA States

output and yield assumptions. Different pathways and plant configurations can impact SAF output. The analysis uses publicly available data whenever possible, with estimated SAF volumes based on yield benchmarks where necessary. The yields presented in Appendix 6.5 were utilised in this analysis to determine the SAF share from the total nameplate capacity where required.

4.1.1 Co-processing capacity estimations

Co-processing renewable feedstock in conventional refineries is a common method for producing SAF in the EU. Co-processing requires comparatively lower capital investment and may be a cost-effective way for complying with RFEUA minimum shares in the early stages. While co-processing is used somewhat widely, actual co-processed SAF volumes are difficult to determine due to limited available data. As a result, a methodology for estimating the potential 2030 SAF capacity from each refinery that relies on co-processing was established as part of this analysis. The current ASTM-approved volume of biogenic feedstock, which can be fed into a co-processing unit is 5%[62,63]. Using this percentage of feedstock and the maximum annual crude oil capacity of a refinery, an estimation for SAF volumes was determined. Additionally, a conversion efficiency of 85% was assumed to account for losses in the process. Finally, a 25% SAF yield was assumed with the rest of the output being co-products such as renewable diesel and naphtha. Via this methodology a potential maximum SAF output from each co-processing facility was deduced.

There is potential for an increase in co-processing volumes due to the possibility of an increase in the maximum biogenic feedstock blending ratio from 5% to 30%[64]. However, this is presently still under evaluation. If accepted, the increase in co-processed volumes could support contributions towards compliance with the RFEUA minimum shares as most conventional refineries already co-process to SAF in the EU.

4.2 Maturity assessment

The SAF production market is inherently volatile, underpinned by several factors. These include the high CAPEX required, feedstock supply chain limitations, and risks associated with investing in early-stage technologies. While many projects are announced, some may not reach commercialisation.

Figure 8 below depicts the typical stages involved in achieving commercial production of SAF. Each stage comes with its own challenges, and the duration spent in each stage depends on the technology and scale of the facility. Overall, it takes between 6 to 8 years for a project to become fully operational.

During the Front-End Engineering Design (FEED) phase, the project's business potential, risks, and available technology options are carefully evaluated. If the project is deemed promising, the development stage commences, encompassing activities such as site selection, obtaining necessary permits, choosing the appropriate technology, conducting basic engineering, selecting an Engineering, Procurement, Construction (EPC) contractor, procuring equipment and materials, securing project financing, negotiating offtake agreements, and developing a comprehensive risk management plan.

These efforts culminate in the creation of a project schedule, a Class 3 AACE budget estimate (with an accuracy range of +/- 10-30%), and a financial pro forma. Subsequently, this essential project information is meticulously analysed to support a well-informed final investment decision (FID) for investors and executives.

Upon approval of the FID, the project enters the execution phase, involving the awarding of the EPC contract, detailed engineering, finalisation of equipment and material orders, as well as construction. Once construction

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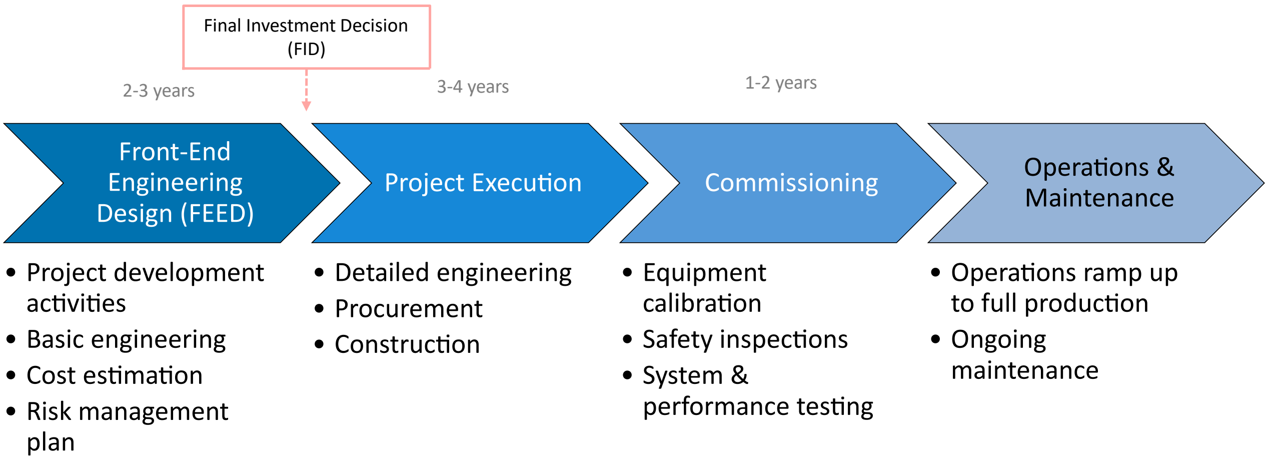
[62] (ICAO SAF conversion processes, 2024)

[63] 24% for hydrotreated lipids, ASTM D1655-23

[64] (ICAO SAF conversion processes, 2024)

is completed, the commissioning process follows, which includes calibrating equipment, conducting safety inspections, and testing the facility's systems and performance. Upon successful commissioning, the operations team commences SAF production on a small scale, gradually ramping up production as consistent operationa and product quality are achieved and maintained.

➨ **Figure 8:** Project development phases



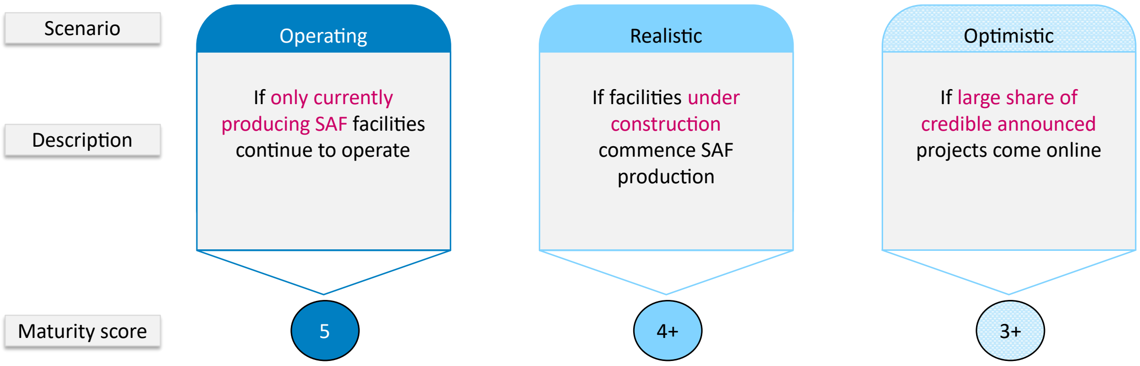
To account for these uncertainties when estimating availability of future SAF production volumes, a maturity ranking was developed specifically for use in this analysis. This ranking is based on the criteria described below (Table 10).

➨ **Table 10:** Maturity assessment ranking

PROJECT MATURITY SCORE	CRITERIA
5	Commercial scale SAF facility (In service)
4	Under construction OR Small operating/under construction pilot plant
3	Main facility attributes announced: technology, feedstock, SAF capacity, commissioning year, location, upstream/downstream partners
2	Only limited information announced
1	Very limited information OR Non-ASTM approved pathway

Applying these criteria allowed for the development of scenarios for future SAF production, contingent upon the likelihood of each facility reaching the commissioning stage. Three scenarios were formulated based on the maturity scores assigned to each project, namely “operating”, “realistic” and “optimistic”, as depicted in **Figure 9**.

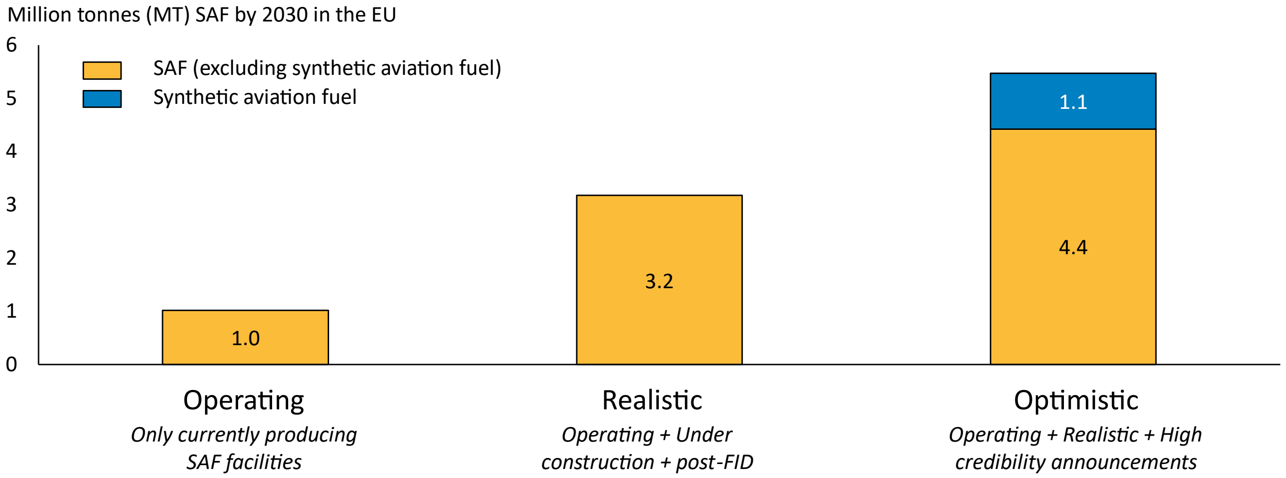
Figure 9: SAF capacity estimation scenarios



4.3 Results of SAF production capacity analysis

The development of the three main scenarios resulted in the projections presented in **Figure 10,** providing a more comprehensive understanding of the potential outlook for future SAF production capacity in the EU.

Figure 10: 2030 EU SAF capacity estimations by scenario



In the **Operating scenario**, which covers only projects currently producing SAF in the EU, volumes amount to just above 1 million tonnes (MT) by 2030. The obligation to supply minimum shares of RFEUA eligible aviation fuels will kick in starting in 2025, requiring a 2% minimum share obligation to be met by the end of that year. Considering the pipeline of facilities, the 2% minimum share for 2025 is also expected to be met.

There are SAF projects which have passed the FID stage and are currently under construction. Such facilities are captured in the **Realistic scenario**, which combines the operating facilities with the ones currently being developed. If all facilities under construction are finalised and begin SAF production on time, the SAF capacity in the EU by 2030 would amount to 3.2 MT, including estimated co-processing volumes. Applying the established criteria for projects beyond the FID stage, the Realistic scenario has no capacity coming from PtL facilities however. Such projects have been receiving considerable interest due to the dedicated synthetic aviation fuel sub-mandate in the RFEUA regulation. However, as of September 2024, no synthetic aviation fuel facility in the EU has passed the FID stage yet[65, 66].

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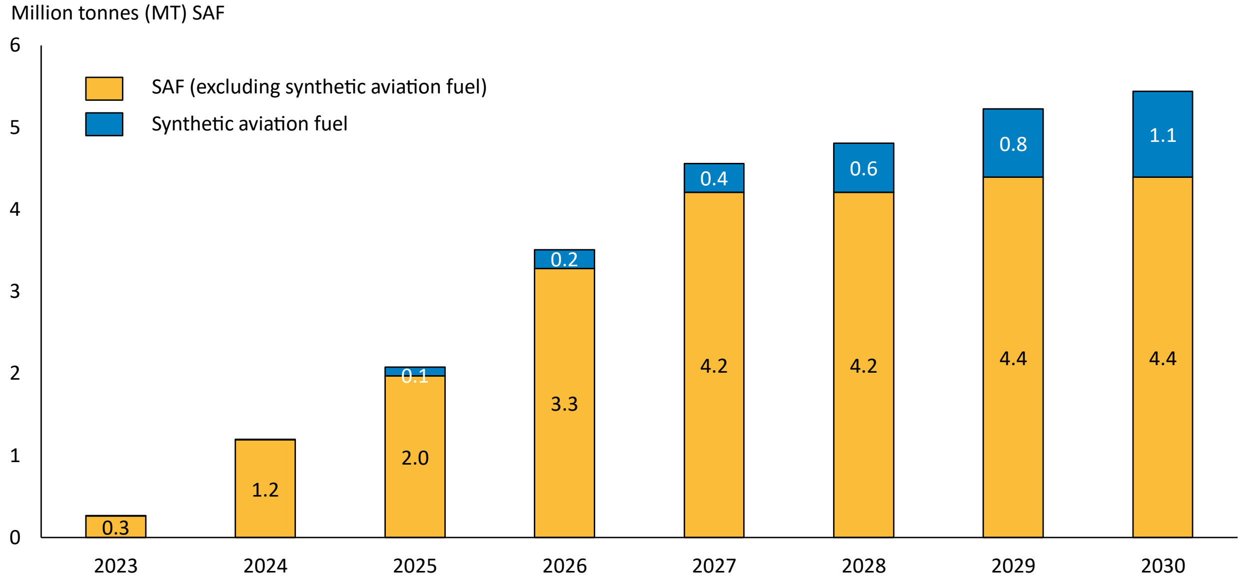
[65] (Transport & Environment, 2024)

[66] (Project SkyPower, 2024)

Note: This analysis was based on existing facility announcements. Given the long lead time for development, most facilities that are likely to be operational by 2030 will already be announced or under development today. However, it is still possible that additional facilities may be announced, built, and commissioned in time, and that could add to the projected volumes as well as offset some of the capacity that faces delays or other challenges.

The **Optimistic scenario** was constructed to account for the pipeline of projects, including for synthetic aviation fuel, which might contribute to the production capacity in the EU, provided they attract the required investment. This scenario captures all operating facilities, projects under construction, as well as those with high credibility and potential to pass through the planning phases and become fully operational by 2030 (assigned maturity score of 3 and above). The Optimstic scenario results in 5.5 MT of SAF production capacity in the EU by 2030 (**Figure 11**). However, it is important to reiterate that these facilities still have not gone through the FID stage, and their likelihood of delivering SAF within the next couple of years is is less certain.

Figure 11: 2030 EU SAF capacity estimation, optimistic scenario (pipeline)



In addition, an analysis covering all announcements related to SAF production in the EU was carried out. However, this is not included in Figures 10 and 11 due to the large uncertainty surrounding many of these announcements. The analysis aimed at capturing all SAF project announcements together with declarations for SAF production targets by 2030 voiced producers, many of which are highly uncertain at present and do not link to specific facilities/locations. Examples of such announcements include those of large oil and gas producers including OMV[67] (0.7 MT by 2030), Eni[68] (0.5 MT by 2030) and ExxonMobil[69] (9.3 MT of biofuels, including SAF, by 2030). The analysis also considered facilities targeting non-ASTM approved pathways such as MtJ and HtL and other highly uncertain announcements, which may span beyond the 2030 timeline. The assessment resulted in a projected production capacity of around 7.7 MT of SAF (including synthetic aviation fuel) in the EU by 2030, though it is crucial to note that this can be considered a highly optimistic scenario and only a fraction of the announcements may materialise.

Main observations

HEFA is anticipated to dominate the SAF production technology landscape and contribute the largest share of SAF production in the EU, supplemented by co-processing volumes. The Operational and Realistic scenarios are

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[67] (Henderson, 2023)
[68] (ENI, 2021)
[69] (Exxon Mobil, 2023)

driven exclusively by these two pathways. The Optimistic scenario includes more variety insofar as other production pathways are also included; however, there is currently no commercial-scale operational or under-construction facility relying on other RFEUA eligible pathways other than HEFA in the EU. In the Optimistic scenario, 1.1 MT PtL SAF is expected by 2030, but such facilities were not accounted for in the Realistic scenario due to lower project maturity score at present.

Co-processing may play an important role during the ramp-up phase of SAF production, as it can oftentimes be implemented comparatively quickly in conventional refineries. While it currently contributes significantly to SAF production in the EU, exact output volumes are unknown. To overcome this data limitation, three scenarios were analysed, with gradually increasing SAF output from 10 kilotons to 20 kilotons per facility (co-processing facilities listed in Appendix). This analysis resulted in projected 0.2 MT SAF coming from co-processing in the Realistic scenario. However, it is important to underline that significant uncertainty remains due to limited public disclosure from producers.

While the SAF production capacity based on announced projects is projected to be enough to meet the RFEUA 2030 targets, the actual SAF volumes produced may end up to be lower than expected due to potential project delays or failures, though partial or full substitution via imports from other markets is a possibility. In addition, even if the current facilities and projects manage to deliver the required SAF quantities by 2030, the need to comply with the ramp-up of the minimum SAF share required under RFEUA beyond 2030 (from 6% in 2030 to 20% in 2035) is likely to further increase pressures to rapidly expand production capacity.

4.4 Emerging trends in the EU SAF production market

This section briefly summarises major trends that emerged during the analysis and highlights key points concerning the SAF production market in the EU.

4.4.1 Oil and gas companies to play a key role

In the early stages of SAF scale-up, the EU landscape is likely to feature substantial contributions from conventional oil and gas companies with existing refineries. Many of these companies are already actively participating in SAF supply chains, leveraging their existing crude oil refineries through the co-processing pathway.

A substantial portion of oil and gas companies in the EU are already in the process of constructing HEFA-dedicated units or have publicly announced such plans. These units are expected to come into operation prior to 2030. Their comparatively lower complexity and capital requirements make them an attractive choice for increasing SAF production volumes within the EU. This trend is most prominent in France with TotalEnergies, in Spain with Repsol, Cepsa and BP, as well as in Italy with Eni. Other countries such as Austria, Germany, Poland, Sweden and Portugal also have oil and gas companies in a favourable position for future domestic SAF supply.

At the same time, recent announcements from Shell and BP on pausing several SAF projects in the EU may put pressure on short-term supply[70]. Shell and BP pointed to recent market dynamics as the reason for their decision. However, both organisations highlighted their continued commitment to scaling up SAF and meeting long-term decarbonisation targets.

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[70] (Shell, 2024); (Hussain, ‘Refocusing plans’: bp pauses work on SAF plants, 2024) Shell Rotterdam facility has been excluded from the quantitative analysis in this study due to uncertainty of its future. The plant with a total announced capacity of 0.82 MT biofuels per annum, could result in additional ~0.3 MT/y SAF in the EU dependent on the SAF yield and operational conditions if constructed and commissioned .

4.4.2 The Nordics emerging as a synthetic aviation fuel (PtL) hub

The production of synthetic aviation fuels (PtL) requires significant quantities of renewable electricity to be able to secure production at a commercial scale. Renewable electricity serves as fundamental input for both renewable hydrogen manufactured through electrolysis and the carbon capture process. This renewable energy requirement is the primary driver behind the growing focus on the production of synthetic aviation fuels in Nordic countries[71], which have been successfully increasing the share of renewable electricity generation to a very high level. In addition to the high share of renewable electricity, these countries also benefit from abundantly available biogenic CO_2 that is suitable for the production of PtL SAF.

All the announced SAF projects in Norway, Denmark and Iceland are set to produce synthetic aviation fuels. In addition, there are synthetic aviation fuels projects announced in Sweden as well. These initiatives are expected to supply a considerable portion of synthetic aviation fuels contributing to meeting the synthetic aviation fuels minimum share, potentially making the Nordics the main PtL hub in the EU.

Besides the Nordics, Germany, Spain and France are also actively pursuing synthetic aviation fuel projects. Although the synthetic aviation fuels production pathway is still an emerging technology and CAPEX is comparatively high, the EU is well-positioned to capture a large share of the synthetic fuel produced globally in the future, given 2/3 of the announced PtL capacity is estimated to be in Europe[72].

4.4.3 Limited activity in other pathways

Another noteworthy point emerging from the analysis conducted is that, apart from coprocessing, HEFA and PtL, there is only a limited number of projects in the EU targeting other production pathways such as AtJ and FT.

There are currently only three announcements for facilities attempting to commercialise the AtJ pathway within the EU. The relatively low interest in AtJ plants in the EU, as opposed to other regions globally, could be attributed to the limited commercial feasibility of the eligible feedstock. All three facilities have announced their reliance on wood residues as the primary feedstock, an abundant but very low energy dense material.

There is also only a limited number of FT facilities announced in the EU. At the time of publication of this report, there have been three project announcements using this technology, however with no recent updates on their progress, and with high associated uncertainty. Two of these projects are exploring the use of forest residues as feedstock, whereas the third project located in the Netherlands is investigating the potential of utilising MSW. However, the high capital and operating costs associated with such projects may lead to reduced interest in developing such facilities.

Other routes, such as Sun-to-Liquid (StL)[73] and HtL are also under development. However, they remain immature, with only a couple of pilot plants announced, and their contribution to commercial SAF volumes is projected to be negligible by 2030.

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[71] Nordic countries refer to: Denmark, Norway, Sweden, Finland and Iceland

[72] (Project SkyPower, 2024). Global assessment has not been performed in the current analysis.

[73] Sun-to-Liquid is a process, which uses solar energy to convert CO_2 into renewable fuels. Solar energy is converted into high-temperature process heat, which is subsequently fed into a thermochemical reactor to produce syngas. The syngas is then processed into fuels, such as jet fuel and diesel. - (Synhelion, n.d.)

5. SAF activity in the EU

This chapter presents an overview of the currently operating as well as announced SAF production facilities in the EU Member States as well as EFTA Member States.

Note: This analysis was conducted to the best of EASA's knowledge, based on publicly available data as well as inputs EU Member States' authorities. It is recognised that some projects may have been missed and have thus not been featured in this analysis. Stakeholders are encouraged to contact EASA and provide information to ensure any missing information is incorporated into future reports.

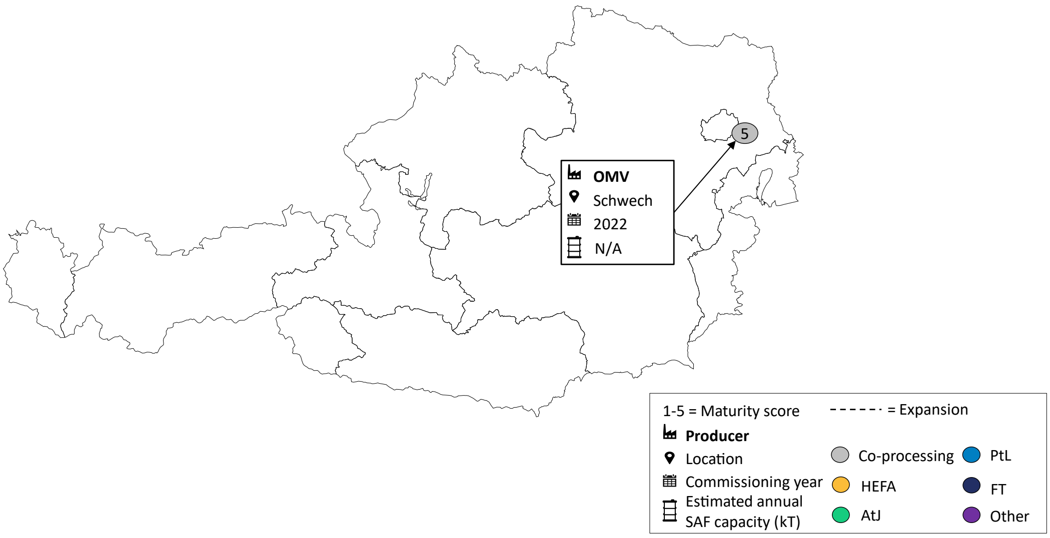
5.1 SAF activity per EU Member State

5.1.1 Austria

In Austria, SAF is currently produced by the country's largest oil and gas company, OMV. The SAF volumes are derived through co-processing biogenic waste feedstock such as UCO at the company's Schwechat refinery. Initial batches of SAF were produced in March 2022 and delivered to Austrian Airlines in Vienna Airport, highlighting the country's potential for well-established SAF supply chains. OMV has also signed offtake agreements with Europe's largest low-cost carriers (LCCs), WizzAir and Ryanair, as well as Lufthansa, for the delivery of SAF by 2030[74].

OMV is producing limited volumes of SAF at present (disclosed SAF production of 1.5 kT/yr in 2022[75]), but the company has announced plans to expand its capacity to 0.7 MT of SAF by 2030. However, the stated amount might not come fully from the Schwechat refinery as OMV operates plants in Romania and Germany.

Figure 12: Operating and announced SAF facilities in Austria



Overall, SAF production is currently limited in Austria. However, a company targeting synthetic aviation fuel production is exploring a demonstration facility. To date no further information has been publicly announced.

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[74] (ICAO Environment, n.d.)

[75] (Henderson, 2023)

5.1.2 Denmark

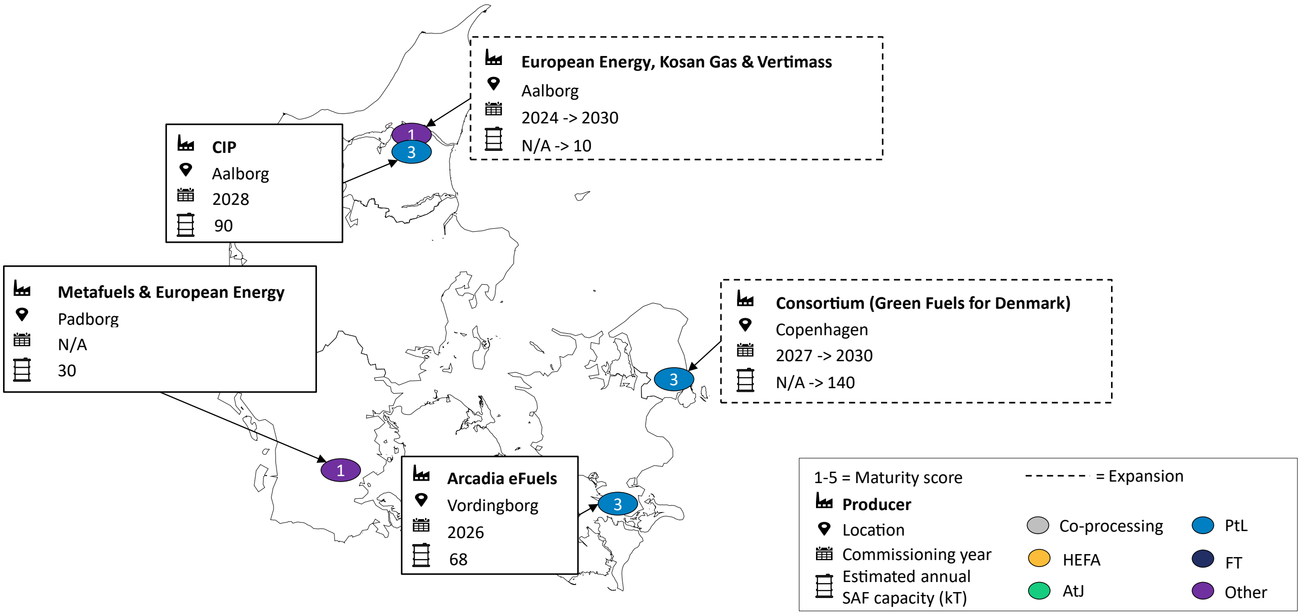
Denmark is rapidly expanding its renewable energy capacity. Having produced 81% of its electricity from renewables in 2022[76], the country aims to reach 100% by 2030. Denmark's abundant renewable energy resources make it an ideal candidate for synthetic aviation fuel projects, which require substantial amounts of renewable electricity for processes such as renewable hydrogen production through electrolysis and carbon capture.

Although currently lacking any SAF production capacity, Denmark stands out as a leading country in terms of announced synthetic kerosene production volumes within the EU. All SAF produced in the country is expected to follow some form of the PtL pathway. There are currently three announced projects utilising a conventional FT reactor and two following a pathway not yet ASTM-approved, which involves methanol as an intermediate step before producing the final synthetic fuel. This includes a demonstration plant in Aalborg, set to commence operations this year.

Another noticeable project is Green Fuels for Denmark, which is a consortium between companies covering all aspects of the SAF value chain – from renewable electricity generation to airlines using the final product. The project is expected to unfold in three stages, with synthetic kerosene beginning production in 2027 and 0.25 MT of e-fuels (translating to c. 0.14 MT of SAF depending on the yield and conversion efficiency) expected by 2030.

The government has also been active in promoting SAF and other green initiatives targeting the aviation industry. It introduced a plan to ensure all domestic flights will be using e-fuel by 2030[77]. This is complemented by a tax on air passengers, approved in December 2023 to come into effect from 2025[78], which will be used to fund green jet fuel projects, with the potential to help support domestic SAF production capacity.

Figure 13: Operating and announced SAF facilities in Denmark



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[76] (Tisheva, 2023)
[77] (TOPSOE, 2024)
[78] (Etias, 2023)

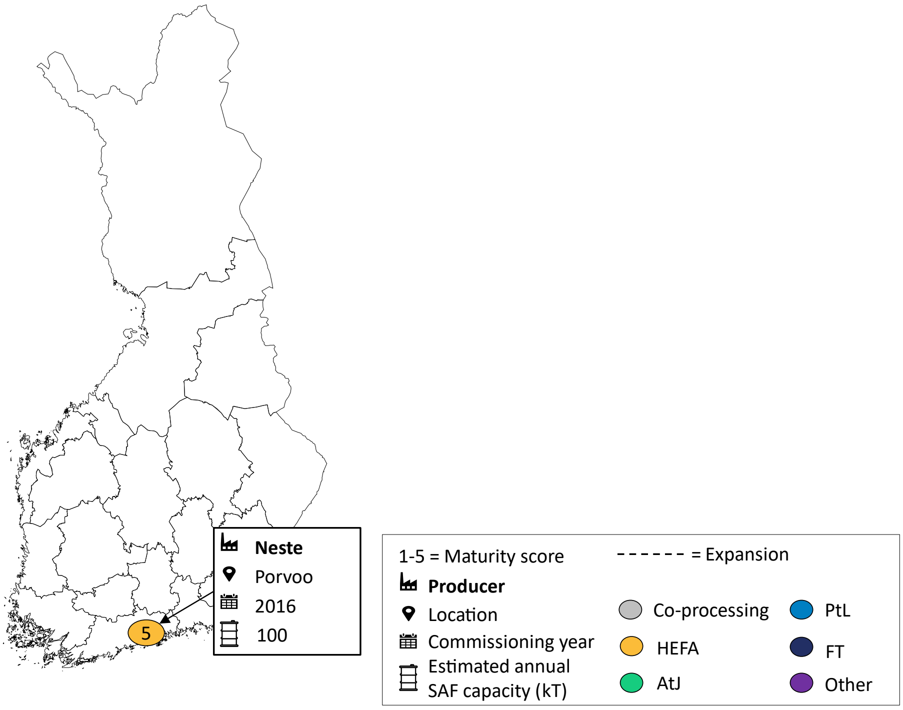
5.1.3 Finland

Finland hosts Neste as one of the first SAF producers globally. The company's SAF production relies on the HEFA pathway, using UCO and waste animal fats as feedstock. Neste began producing renewable products at its Porvoo refinery in 2007, with initial SAF volumes delivered in 2016[79]. Currently, the annual SAF production capacity at the facility stands at 0.1 MT.

In December 2023, Neste unveiled plans to increase SAF output from its Finland refinery to 1.5 MT by the mid-2030s[80]. This expansion could contribute to the overall SAF production capacity within the EU post-2035 if realised. However, given the decade-long timeline for implementation, considerable uncertainty surrounds this projection.

Besides its Porvoo refinery, Neste also operates SAF facilities in Rotterdam and Singapore, contributing to the company's global SAF presence and capacity[81, 82].

➨ **Figure 14:** Operating and announced SAF facilities in Finland



5.1.4 France

Currently, France ranks as the third-largest Member State in announced SAF production volume by 2030, projected at 0.7 MT per year. All existing domestic SAF in France is produced by major oil and gas companies, including TotalEnergies and ExxonMobil. These companies leverage their existing refineries to co-process biogenic feedstock with petroleum feedstock. TotalEnergies is the most active player in the field, operating four

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[79] (SAF Investor, 2022)

[80] (Kauranen, 2023)

[81] Expansion not included in the map as beyond 2030

[82] Recent announcement (October 2024) for a synthetic aviation fuel facility in Finland by Norsk e-Fuel ((Fayaz, Fortum, Norsk e-Fuel announce eSAF project in Finland, 2024)). Facility not included in the present analysis as the study does not cover announcements after the consultation with Member States in April 2024

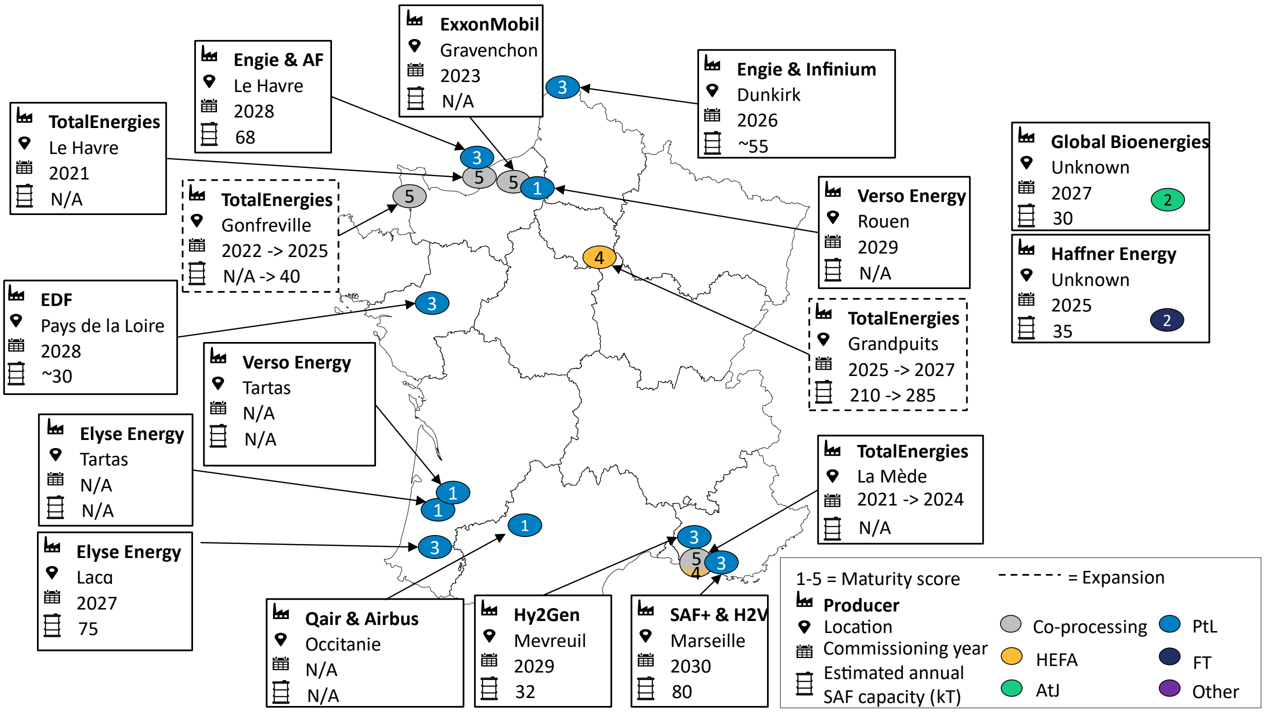
refineries with SAF production capacity. Even though current volumes are limited, the company is progressing with its expansion plans, which are expected to be realised within the next three years[83].

ExxonMobil has also entered the SAF market in France, producing initial SAF batches at its Gravenchon refinery through co-processing in late 2023[84]. The company aims to increase its total biofuels capacity to 0.14 MT at its French refinery by 2025, also expanding the SAF volumes.

France is strategically positioned to diversify its SAF production capacities beyond co-processed and HEFA-derived SAF. Given the constrained availability of feedstock and expected global competition, the country is exploring more advanced pathways, including the announcement of AtJ, PtL and FT projects.

France is also emerging as a promising hub for PtL SAF, alongside Germany, Spain and the Nordics. Numerous synthetic aviation fuel projects have been announced, collectively contributing to a projected annual volume of c. 0.35 MT by 2030. While not all of these projects may materialise into operational units, even some of them coming into operation could elevate France's synthetic aviation fuel capacity.

Figure 15: Operating and announced SAF facilities in France



5.1.5 Germany

While Germany boasts the largest number of announced SAF production facilities, a significant proportion of these are early stage, including feasibility studies, pilot plants and research projects aimed at promoting the viability of more advanced pathways.
Currently, the country's only operating plant producing SAF is the BP refinery in Lingen, which started production in 2022[85]. UCO is the primary feedstock, processed in a co-processing unit. The company has also undergone trials using carinata oil at the facility[86].

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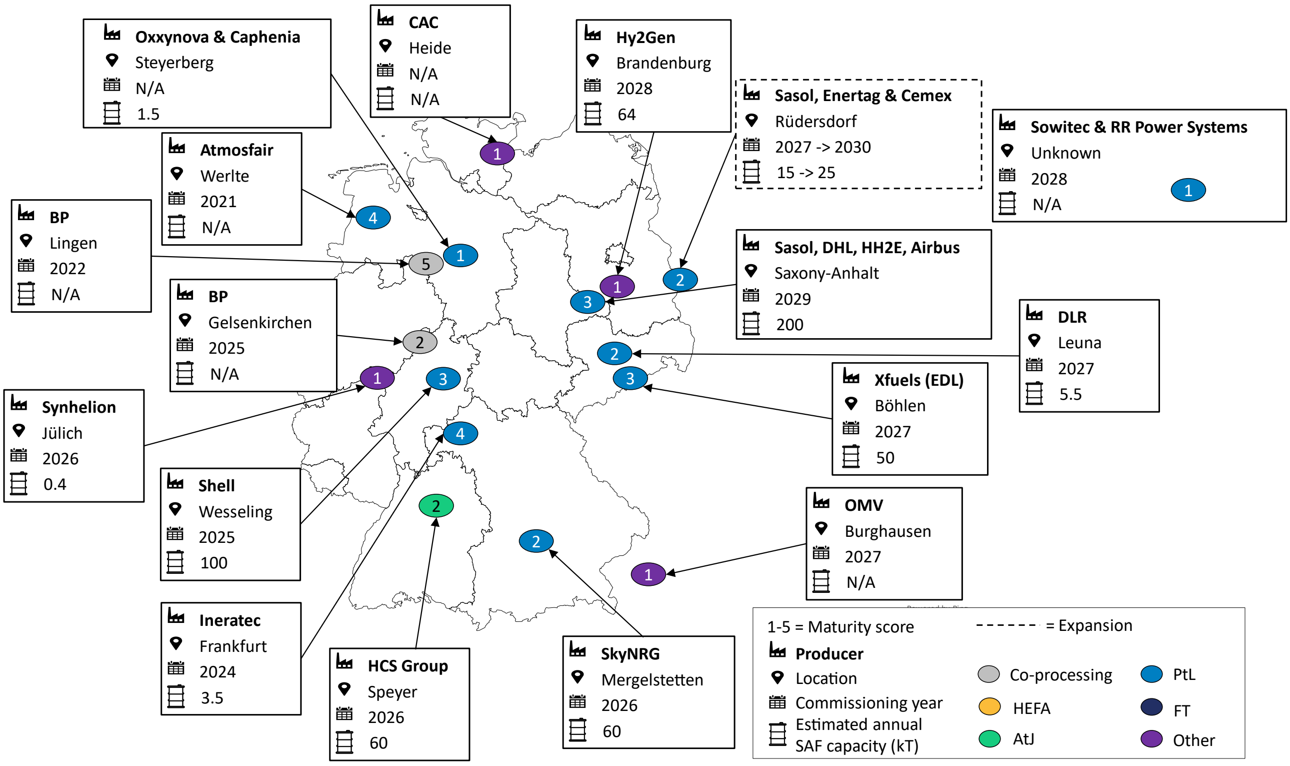
[83] (Total Energies, 2023)
[84] (ExxonMobil, 2023)
[85] (BP, 2022)
[86] (Washington & Burgin, 2023)

The country is aiming to establish PtL as a dominant pathway for producing SAF domestically, with the announcement of a number of facilities relying on renewable hydrogen and CO_2 as inputs to produce SAF. However, many of these projects plan with an expected output of less than 10 kT of SAF per year, requiring a significant scale-up if a large proportion of flights are to be powered by domestically produced SAF.

Nevertheless, there are projects which aim at commercial production of PtL SAF volumes of PtL SAF. For example, NetZeroLEJ, a collaboration between Sasol, DHL, HH2E and Airbus, is the largest facility that has been announced in Germany. It targets 0.2 MT of PtL SAF produced annually starting in 2029, with future upscaling most likely beyond the 2030 horizon to 0.5 MT of SAF per year[87].

Another project of note is the Synhelion facility in Jülich. The project, named DAWN, is expected to be the first demonstration plant producing synthetic fuels using solar heat. This is an innovative pathway which could provide a further diversification of SAF manufacturing, if proved viable at commercial scale. The pilot facility is expected to come online by 2026 with an initial capacity of 4 kT per annum[88].

Figure 16: Operating and announced SAF facilities in Germany



[89]

5.1.6 Italy

For domestic SAF production, Italy currently depends exclusively on Eni, its largest national oil and gas producer. Eni operates several refineries that can process both renewable and fossil feedstock:

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[87] (HH2E, 2023)

[88] (Synhelion, 2022)

[89] Project NetZeroLEJ (Sasol, HH2E, DHL & Airbus) potential expansion not included in the map as beyond 2030

- **Taranto refinery –** Eni initiated production of SAF at its Taranto refinery in 2021 through co-processing UCO. The exact annual SAF production capacity has not been announced publicly[90].
- **Livorno refinery –** The Livorno refinery commenced SAF production in 2022 through co-processing UCO. Eni announced annual production volumes of 10 kT of SAF, but there is potential for greater volumes if SAF yield is maximised. Additionally, in January 2024, Eni reported progress on its plans to convert the Livorno plant into a dedicated biofuels platform, making it the third such facility in the company's portfolio - alongside Gela and Venice[91]. Though the refinery will be optimised for Hydrotreated Vegetable Oil (HVO) production, SAF volumes may also increase.
- **Gela refinery –** In 2019, this facility was converted into a dedicated biofuel platform focused on HVO production. Recognising the significance of SAF and the increasing demand for production, Eni is constructing a dedicated HEFA unit at the Gela facility. This unit is expected to begin operations later in 2024, having an annual output of 0.15 MT of SAF[92].
- **Venice biorefinery –** Eni's dedicated biorefinery in Venice, which is currently supplying HVO to the market, is in the position to significantly contribute towards the overall SAF volumes produced by the company. By the end of 2024, the Venice biorefinery is expected to have a total biofuel refining capacity of 0.6 MT[93]. Even if only a fraction of this capacity were dedicated to SAF production, it would result in a substantial boost in available SAF volumes. Eni is actively considering the establishment of a dedicated SAF unit at this facility and is awaiting the necessary permits[94].

Eni has set a target of producing 0.5 MT of SAF by 2030, contributing to Italy's domestic production capacity[95]. However, as of now, no other company has publicly announced plans to enter the SAF market in the country.

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[90] (Brelsford, 2021)

[91] Livorno refinery (ENI, 2024)

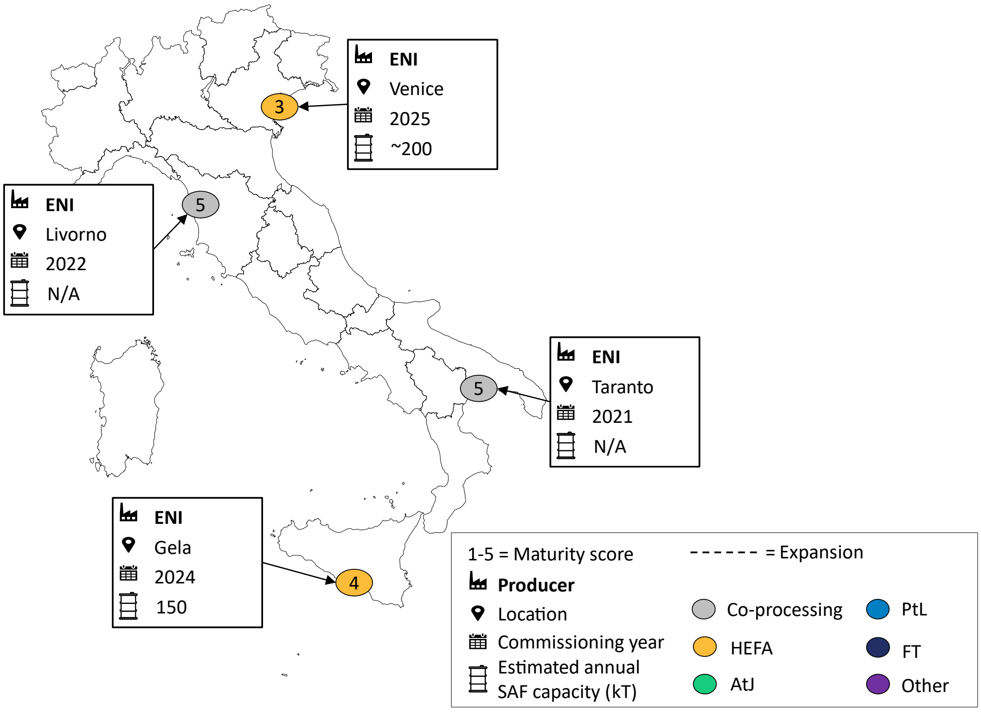
[92] (ENI, 2021)

[93] Venice refinery annual SAF capacity is estimated based on total biofuel production capacity of 0.6 MT and yields presented in Appendix 6.5

[94] (ENI, n.d.)l

[95] (ENI, 2021)

Figure 17: Operating and announced SAF facilities in Italy



5.1.7 Netherlands

The Netherlands is emerging as an attractive destination for SAF projects, with the largest announced production capacity by 2030 of all EU Member States at 1.6 MT per year. Additionally, the country already hosts two operational facilities that actively contribute to domestic SAF volumes.

More than half of the anticipated SAF production volume by 2030 is associated with Neste's Rotterdam plant. The Finnish producer constructed the Netherland's refinery following its global expansion plans and commenced SAF production in 2024. Estimated production in 2024 is 0.35 to 0.55 MT HEFA SAF[96]. Further expansion plans are underway, with additional 0.7 MT of SAF output expected to become available by 2026[97]. This substantial growth would position the facility as the largest SAF platform in the EU if realised.

Other large projects anticipated to bolster the local SAF market growth include Varo Energy's and Chane Terminals facilities in Rotterdam. Varo Energy has anticipated capacity of 0.25 MT SAF per annum commissioning in 2026, while Chane Terminals is progressing on its expansions plans to increase current SAF production volumes by 2025[98]. Additional projects aiming to increase the SAF production capacity in the Netherlands are SkyNRG's, Delfzjil HEFA-based facility, which is set to commence production in 2027 and BP's Rotterdam platform.

While 95% of the announced capacity is projected to come from HEFA plants that use waste biogenic feedstock, companies in the Netherlands are actively investigating alternative pathways for SAF production. These efforts aim to diversify the technology mix, reducing dependency on a single group of feedstocks.

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[96] (Neste, 2024)
[97] (Neste, n.d.)
[98] (Fayaz, Chane's SAF Unit 4 to begin operations in 2025, 2023)

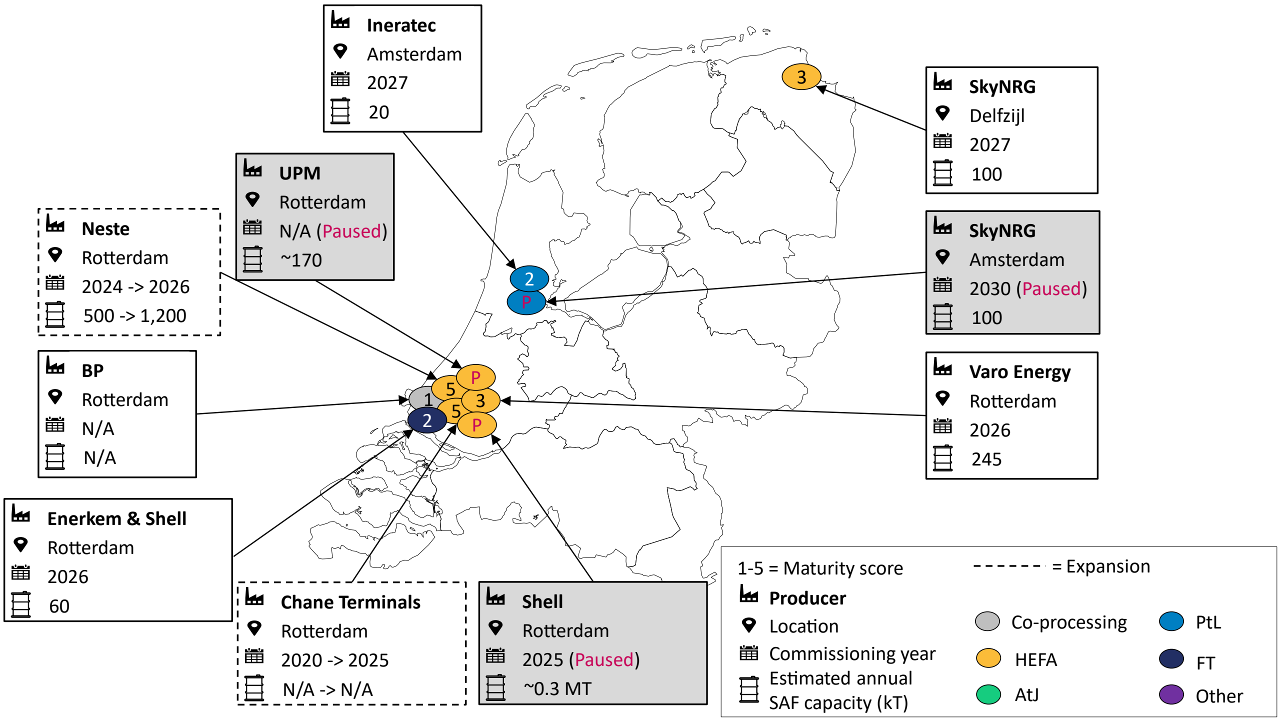
A project worth highlighting is the collaboration between Shell and Enerkem. The facility in Rotterdam will rely on the FT technology, using recycled MSW as the primary feedstock. Anticipated to achieve a capacity of up to 80 kT of renewable products per year with approximately 75% of that being SAF, the initiative is slated for a three-year construction period. Production is expected to commence in 2026[99]. However, there have been no updates since initial plans for the construction of this facility were announced.

Additionally, Ineratec, a German-based provider of e-fuel solutions is targeting the production of synthetic aviation fuel in Amsterdam. The pilot facility is anticipated to commence operations in 2027, with a total annual output of 35 kT of fuels, translating into c. 20 kT of SAF[100].

There have been recent announcements regarding SAF projects being paused, three of which based in the Netherlands. All three projects – Shell facility in Rotterdam[101], SkyNRG Synkero project in Amsterdam[102] and UPM facility in Rotterdam[103] , have pointed out market conditions as the main cause for the decision to pause further progress. Due to the uncertainty of the future of these facilities, they have been excluded from the quantitative analysis and scenarios presented in this report.

Overall, the Netherlands are in a favourable position to emerge as a significant SAF production hub in the coming decade.

Figure 18: Operating and announced SAF facilities in the Netherlands



[104]

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[99] (Enerkem, 2021)v

[100] (Ineratec, 2023)

[101] (Shell, 2024)

[102] (SkyNRG, n.d.)

[103] (Fayaz, Finland's UPM delays work on SAF/HVO site, 2023)

[104] Recent announcement (October 2024) for a synthetic aviation fuel facility in Finland by Power2X ((Power2X, n.d.)). Facility not included in the present analysis as the study does not cover announcements after the consultation with Member States in April 2024

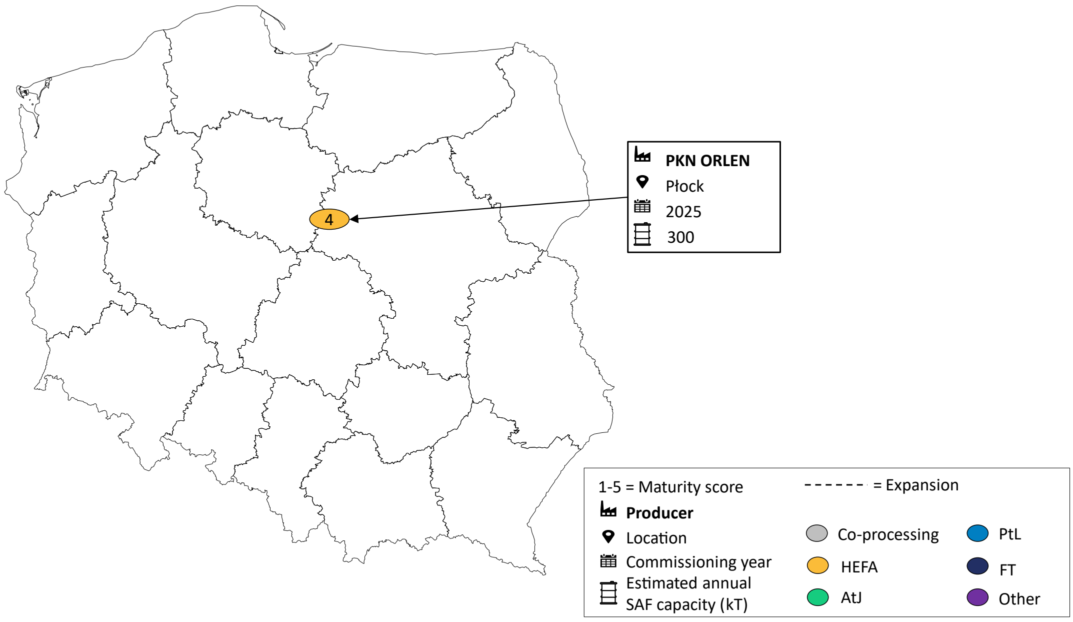
5.1.8 Poland

While Poland currently lacks SAF production, it stands out as one of the first Eastern EU Member States with an announcement regarding a future SAF plant. PKN Orlen, a prominent Polish oil and gas company, is spearheading efforts to establish SAF production capability within the country.

A renewable fuels facility, currently under construction in Płock, is poised to commence SAF production by 2025. The fuel will be produced using the HEFA pathway, with UCO as the primary feedstock. The projected capacity of this plant is 0.3 MT of SAF annually.

Part of this domestically produced SAF will be allocated to Poland's flag carrier LOT Polish Airlines. In 2022, the airline signed an agreement with Orlen for the delivery of SAF once the plant is operational[105].

➨ **Figure 19:** Operating and announced SAF facilities in Poland



5.1.9 Portugal

Portugal is currently lacking domestic SAF production, but efforts to grow such capacity are led by the country's largest energy company, Galp. In late 2023, Galp announced a joint venture with Mitsui for the construction and operation of a SAF facility located in Sines[106]. The project focuses on a HEFA-based plant, with a targeted commissioning date in 2026. The total expected capacity of this facility is c. 0.27 MT per year, producing both renewable diesel and SAF. A large share of the required feedstock – UCO and animal fats – is anticipated to come from Asia. If successfully realised, this project will serve as a crucial stepping stone for domestic SAF production in Portugal, potentially paving the way for future expansion.

In addition to the HEFA project, Portugal has three announced facilities focusing on the PtL pathway. LIPOR, a Portuguese company specialising in municipal waste treatment, is involved with two of these projects, and could serve as the source of CO_2 feedstock required for the PtL process[107][108]. The targeted location for both facilities is Porto. However, it is important to note that these announcements provide limited information,

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[105] (Ahlgren, 2022)

[106] (Mitsui&Co, 2023)

[107] (Veolia, 2022)

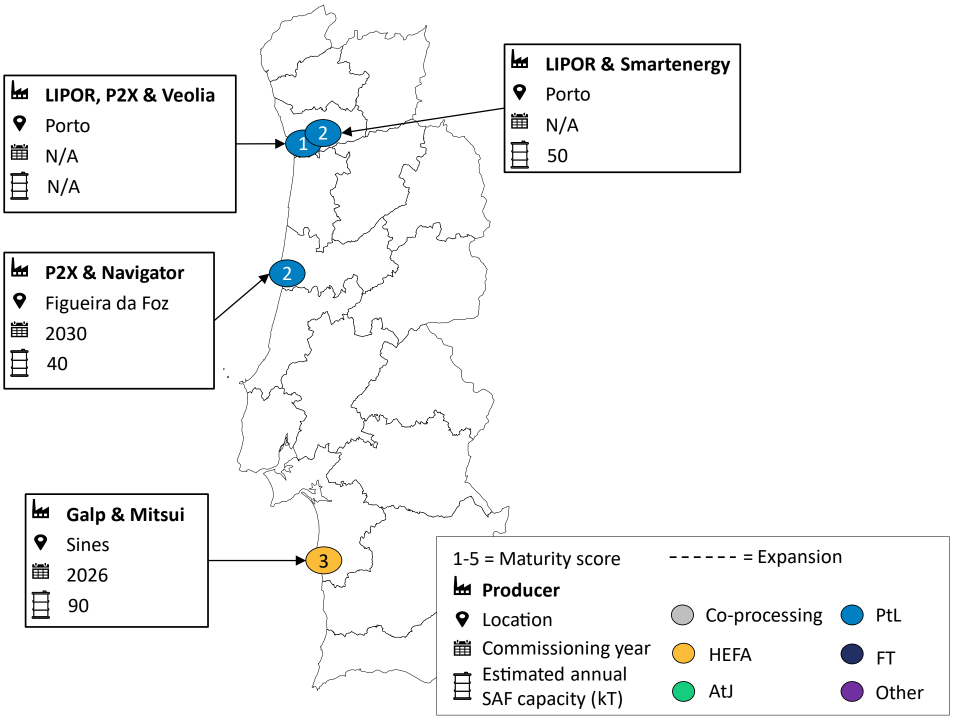
[108] (TPN, 2023)

lacking crucial details such as the anticipated commissioning year and projected production capacity. As a result, the progress toward completion remains highly uncertain.

The third PtL project in Portugal, known as P2X-Portugal, is a partnership between two companies. It brings together the Portuguese company Navigator, which will supply the necessary biogenic CO_2 from its pulp and paper production facility, and P2X-Europe, a pioneer in the PtL technology. The primary goal of this joint venture is to produce non-fossil synthetic e-fuels and scale up the PtL technology. The project aims to deliver approximately 40 kT of SAF per year with an anticipated start date of 2030[109].

The announced projects in Portugal represent a promising first step toward establishing domestic SAF production capacity. However, to fully meet the Member State's aviation fuel demands, further expansion and investment will be necessary.

➨ **Figure 20:** Operating and announced SAF facilities in Portugal



5.1.10 Romania

Romania's domestic SAF production capacity is limited to the volumes produced by the Austrian oil and gas company OMV at its Petrobrazi refinery. Initial batches of SAF were produced in 2020 using rapeseed oil as the biogenic feedstock in a co-processing unit[110].

The current SAF co-processing capacity is not publicly available. Relying on the crude oil refining capacity of 4.5 MT per year[111] and the process explained in the methodology section, the Petrobrazi refinery could deliver approximately 50 kT of SAF, potentially by 2030[112].

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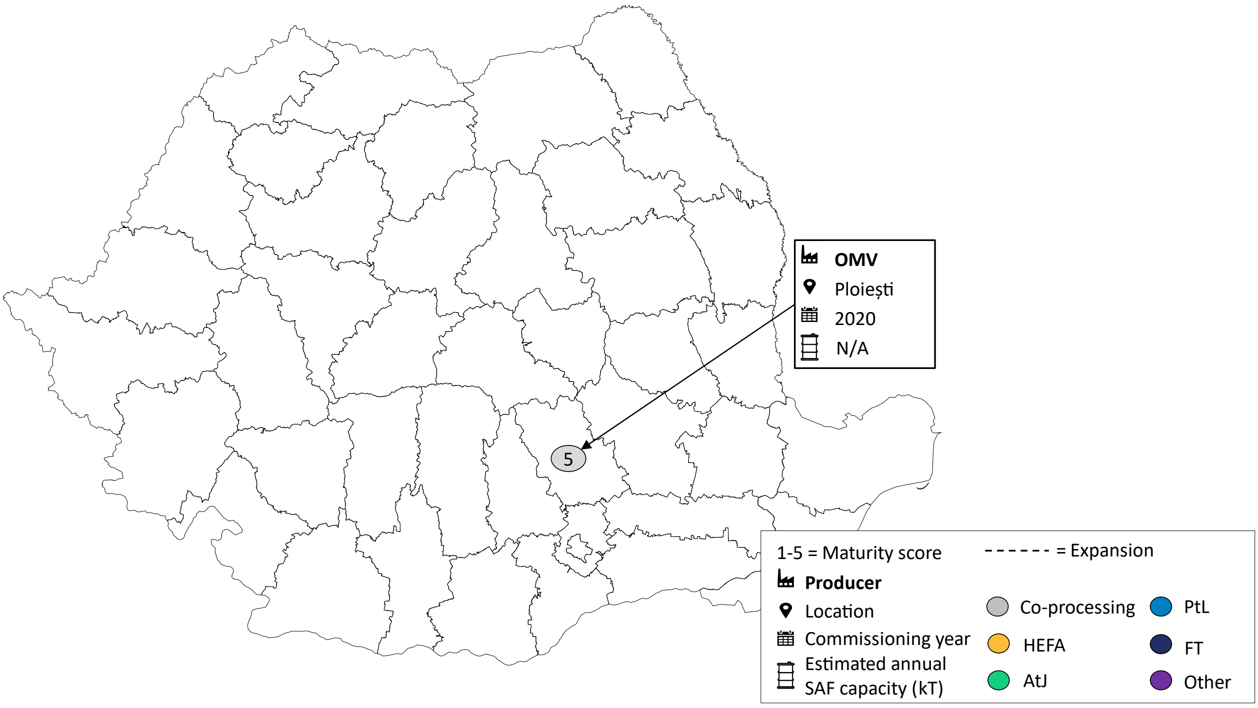
[109] (Franke, 2022)
[110] (Banila, 2022)
[111] (OMV, 2024)
[112] Recent announcement (June 2024) for the expansion of the SAF production capacity at the Petrobrazi refinery ((OMV Petrom, 2024)). Facility not included in the present analysis as the study does not cover announcements after the consultation with Member States in April 2024

In 2024, the company also announced plans to construct electrolysers and produce green hydrogen at the refinery, which might be utilised in the SAF production process[113].

Figure 21: Operating and announced SAF facilities in Romania



5.1.11 Spain

Spain is making significant strides in scaling-up domestic SAF production capacity. The push is primarily driven by large oil and gas companies such as Repsol, Cepsa and BP. These have started producing SAF in the country through co-processing, but are also targeting construction of dedicated HEFA units, which would further expand the production capacity.

In 2020, Repsol initiated SAF production at its Puertollano refinery. This facility, along with two other refineries in Tarragona and Bilbao, which commissioned SAF production in 2021, manufacture SAF through co-processing UCO. The initial batches from these facilities combine to approximately 25 kT of SAF[114]. However, the exact SAF volumes produced through co-processing per year has not been officially announced yet and remains based on estimates.

In 2024, Repsol expanded its SAF production capabilities by launching a dedicated HEFA unit at its Cartagena refinery. The primary feedstock used in this unit would be UCO. The Cartagena refinery largely enhances Repsol's renewable fuels production capacity, with a total annual output of 0.25 MT[115]. Repsol has stated that it is aiming to maximise the SAF output of this refinery.

Cepsa, another prominent national oil and gas company, is actively working to transform its operations towards sustainable fuel production. In 2023, the company introduced SAF co-processing at its Huelva refinery, utilising UCO as a feedstock. The SAF produced at this facility was subsequently supplied to major Spanish airports,

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[113] (Collins, 2024)

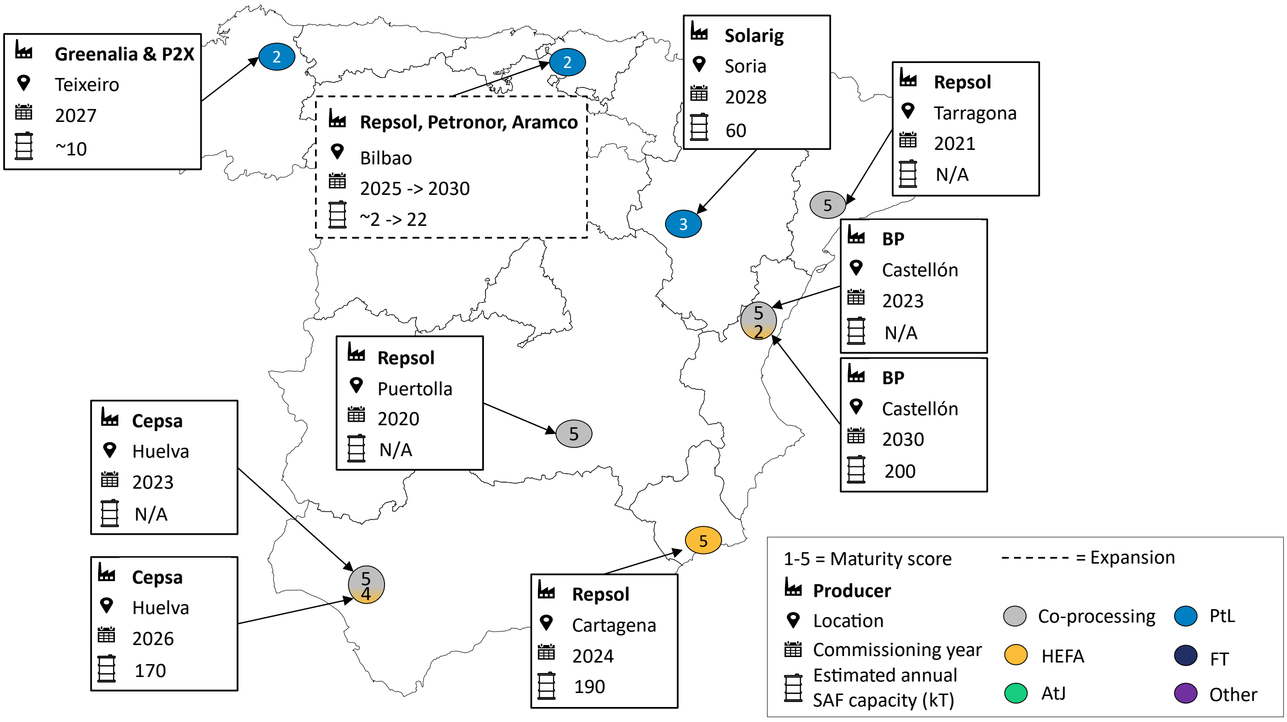
[114] (Repsol, 2021)

[115] (Fayaz, Repsol to begin SAF production at Cartagena plant in few weeks, 2023)/

including Madrid, Barcelona, Palma de Mallorca and Seville[116]. Cepsa aims to further enhance its SAF production capacity. To achieve this, the company is constructing a dedicated HEFA unit at its Huelva refinery. The construction began in 2024, with a planned commissioning date in 2026. Once operational, this facility is expected to contribute 0.5 MT per year to Cepsa's renewable fuels capacity[117]. The company has goals to further expand its SAF production volumes in the future. It has announced plans to increase SAF output to 0.8 MT per year by 2030[118]. No further details have been publicly disclosed linking these plans to specific location or technology.

BP is the third oil and gas company which has joined the ranks of SAF producers in the country. Their Castellón refinery commenced co-processing SAF in 2023, with initial batches delivered to Zaragoza airport[119]. BP is expanding its operations by establishing a dedicated HEFA plant at the Castellón refinery. This move aims to enhance biofuels production capacity, including SAF, with a target of reaching 0.65 MT by 2030. Although the plant is expected to commission in 2027, the FID stage remains pending[120].

➡ **Figure 22:** Operating and announced SAF facilities in Spain



Despite the dominance of oil and gas companies in Spain's SAF production landscape through the HEFA pathway, several PtL projects are also being developed. The following three initiatives aim to boost the country's synthetic aviation fuel output:

- **Numatia SAF** - In 2024, Solarig announced plans to construct a PtL facility in Soria with capacity of 60 kT of SAF per year. The project is expected to start producing renewable fuels in 2028[121].

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[116] (CEPSA, 2023)
[117] (MOEVE, n.d.)
[118] (Cepsa / Moeve, n.d.)a
[119] (BP, 2023)
[120] BP Castellon refinery potential annual SAF capacity, as well as Cepsa's Huelva refinery have been estimated from total announced biofuel capacity and SAF yields in the Appendix 6.5
[121] (R., 2024)

- **Breogan** – A project led by Greenalia in collaboration with P2X-Europe. Located in Teixeiro, this facility anticipates commencing SAF production in 2027, with an annual output of 10 kT. Greenalia would be responsible for supplying the required biogenic captured CO_2 feedstock from its production facility[122].
- **Bilbao plant** - Repsol, together with Petronor and Aramco, is spearheading an effort to establish a PtL SAF production capability alongside its more conventional HEFA-based operations. Currently, this project aims to create a pilot plant to prove the feasibility, with a capacity of 2 kT of synthetic aviation fuel per year by 2025. Future expansion plans include a demonstration facility with 20 kT of SAF output per year[123].

If all the aforementioned projects come to fruition and achieve their anticipated capacities, Spain could emerge as a significant SAF production hub by the end of the decade. The multifaceted approach adopted by major oil and gas companies – leveraging co-processing while concurrently developing dedicated HEFA capabilities – contributes significantly to Spain's ambition of becoming a key player in the global effort to scale-up the SAF industry. Additionally, companies in Spain are actively exploring alternative pathways to diversify SAF production technology and feedstock.

5.1.12 Sweden

Currently, there is one operational facility producing SAF in Sweeden, located in Gothenburg and owned by the Finnish oil and gas company St1. The initial SAF production began in 2024 with the fuel produced through the HEFA pathway using UCO and tall oil as feedstock. The announced total renewable fuel annual capacity of this facility is 200 kT[124]. A portion of that would be SAF, with estimations based on yields provided in the Appendix.

Preem, a major player in the oil and gas industry, is expected to contribute the largest share of domestically produced SAF volumes by the end of the decade. Currently, Preem is in the process of converting its Lysekil refinery into a biofuel platform, with an expected start date for SAF production in 2027[125]. Tall oil and animal fat are anticipated to be used as feedstock in the HEFA process. The Lyskeil biorefinery is projected to contribute close to 0.5 MT of SAF per year.

Additionally, Preem is targeting another facility for conversion into a biofuel plant, known as "Project Viking"[126]. The Gothenburg refinery is expected to start HEFA SAF production by 2027, with an announced capacity of 0.8 MT of biofuels resulting in c. 0.3 MT of SAF. Although this project is at an earlier stage compared to Lysekil facility development, the combined impact of these two facilities will be contribute c. 0.75 MT of domestic annual SAF production by 2030 if successful. This volume might increase if the two platforms are operated for maximised SAF output.

Sweden benefits from a diversified feedstock pool, with abundant availability of woody biomass. Sweden's already high and further increasing share of renewable electricity further enhances its advantageous position for diversification of SAF production. This advantage is underscored by the technology mix of announced projects within the country. In addition to HEFA projects described above, there are also facilities targeting the AtJ, PtL and FT pathways.

Swedish Biofuels has been active in AtJ technology development. The company utilises woody biomass-derived alcohols to produce biofuels, including SAF. While a pilot plant has already been operated, an upscale facility is

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[122] (P2X Europe, 2023)/
[123] (REPSOL, n.d.)
[124] (ST1, 2024)n
[125] (Preem, n.d.)
[126] (Preem, n.d.)

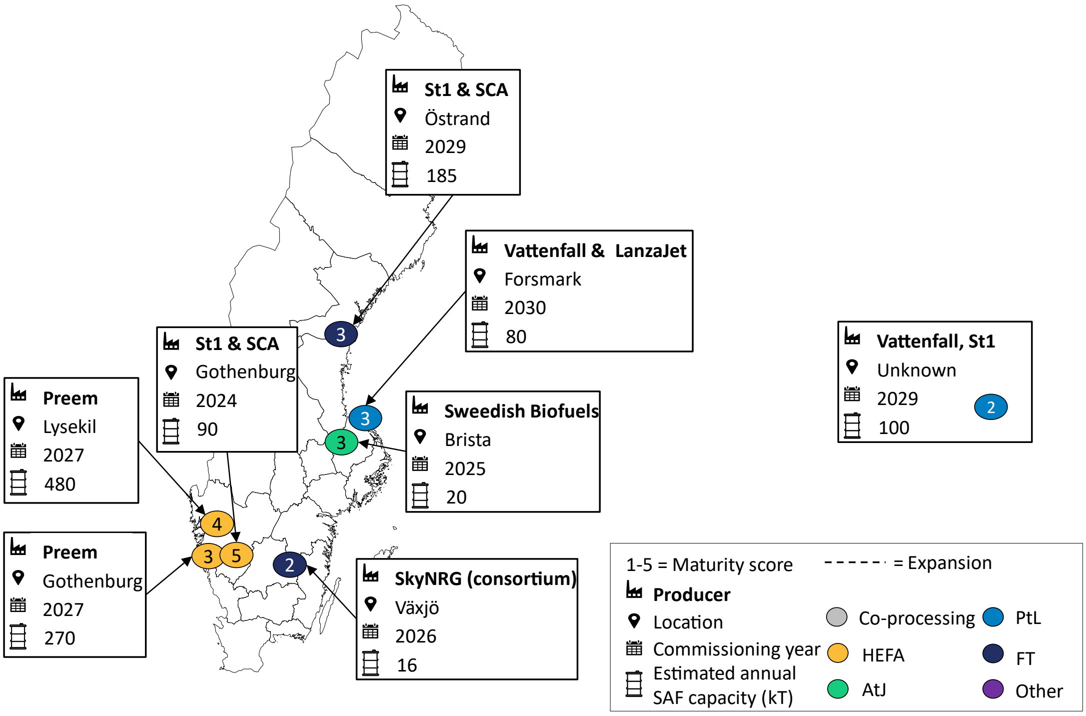
planned for commissioning in 2025 with capacity of 20 kT per year at Brista[127]. If successful, this demonstration facility could serve as the foundation for further expansion.

While not as reliant on PtL technology as other Scandinavian countries like Denmark and Norway, Sweden has two announced projects expected to utilise this pathway for producing SAF. Notably, both projects are led by Vattenfall, a Swedish power company. However, it is important to note that these two projects are not expected to come online prior to 2029. If they are successful, they will contribute c. 0.2 MT of domestically produced PtL SAF per year.

Adding to the technology mix is a demonstration project for SAF production relying on the FT technology. This innovative project utilises forestry residues as feedstock. The consortium leading this effort includes companies such as SkyNRG, Södra and Växjö Energi. The envisioned facility is to be deployed in Småland with expected production capacity of 16 kT SAF annually by 2026[128]. However, there have not been any recent updates regarding this facility since the initial announcement.

Overall, Sweden emerges as an attractive location for SAF production due to its diverse feedstock options. The country's commitment to utilising various SAF production pathways reflects an ambitious approach to meeting aviation fuel demands while minimising environmental impact.

➨ **Figure 23:** Operating and announced SAF facilities in Sweden



5.2 EFTA SAF activity per country

5.2.1 Iceland

Iceland-based hydrogen development company IðunnH₂ is pioneering the establishment of the country's first SAF manufacturing plant. This commercial-scale synthetic aviation fuel facility will be strategically located in

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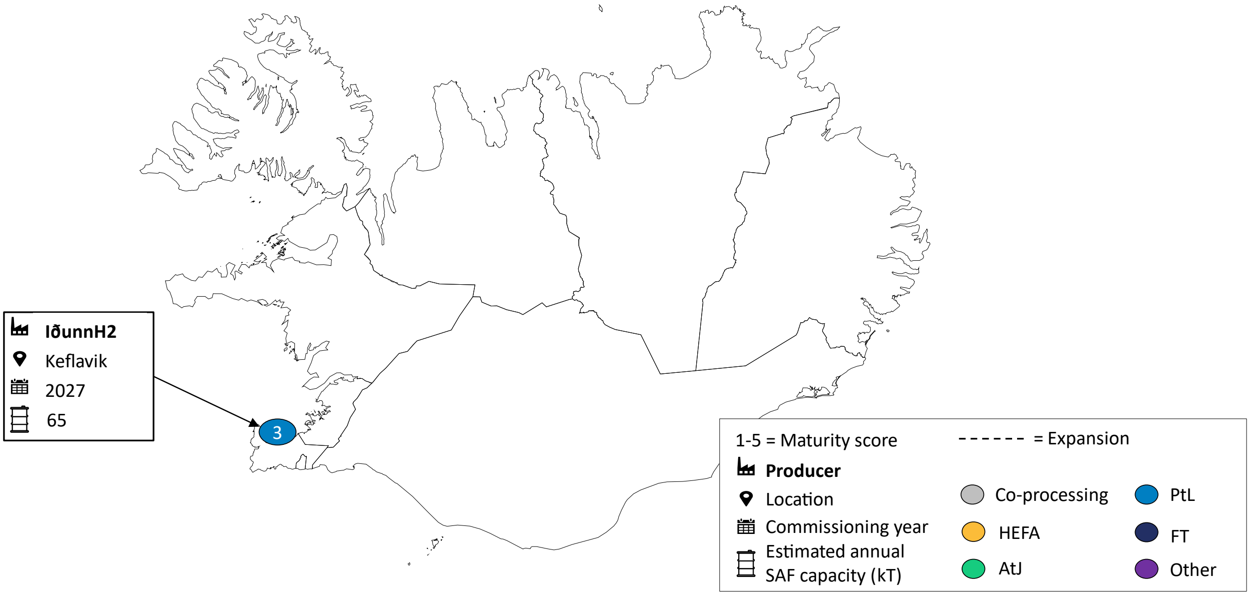
[127] (Swedish Biofuels, n.d.)
[128] (SkyNRG, n.d.)

Helguvík Harbour due to proximity to Keflavík International Airport, with planned commissioning set for 2027[129].

The plant aims to produce 65 kT of SAF annually through the PtL pathway, which involves combining renewable hydrogen and captured CO_2. Notably, some of the SAF produced at this facility will be consumed domestically as IðunnH$_2$ has inked an agreement with Icelandair, the national carrier, for the delivery of 45kT of SAF starting in 2028[130]. This milestone represents a significant leap towards establishing SAF production capacity within Iceland.

➡ **Figure 24:** Operating and announced SAF facilities in Iceland



5.2.2 Norway

Norway introduced a national mandate in 2020 that obliged aviation fuel suppliers to ensure that 0.5% of all the aviation fuel delivered at domestic airports annually was SAF, with a progressive scaling toward a higher share. This mandate provided a clear market signal underscoring the demand for SAF in the country and emphasised the government's ambition to establish a robust domestic SAF production capacity.

Norway has been actively working to decarbonise, with the country standing as the global leader in energy share generated through renewable sources (98.5% in 2022)[131]. The successful decoupling of electricity generation from fossil fuels and the large availability of renewable electricity has sparked interest in synthetic aviation fuel projects in the region. Approximately 0.3 MT of synthetic aviation fuel annual production capacity by 2030 has been announced, constituting close to 100% of the SAF portfolio in the country announced to date. While most of these projects are still in early stages of development, the potential for future expansion is substantial.

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[129] (IDUNN H2, n.d.)

[130] (CJI Team, 2023)

[131] (Be the story, 2023)

The two most notable projects in the country, led by Nordic Electrofuel and Norsk e-Fuel, are both targeting a ramp-up approach, with initial pilot units demonstrating the feasibility and economic viability of these facilities, then followed by an expansion to increase the SAF capacity.

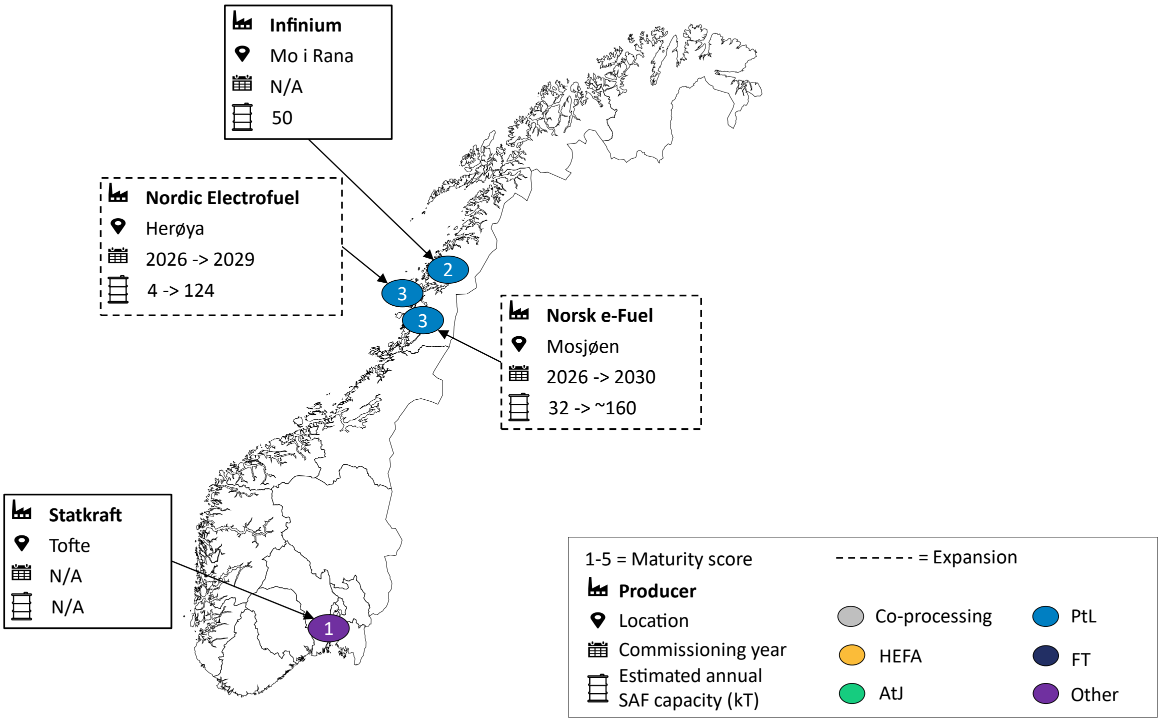
Nordic Electrofuel aims to construct a pilot plant in Herøya, with an initial SAF production capacity of 4 kT per year by 2026. This facility would serve as a stepping stone, and if successful, the company has announced plans for further expansion to reach 120 kT of SAF per year by 2029. Additionally, Nordic Electrofuel has disclosed intentions to ramp-up e-fuel production until 2050[132]. However, its long-term horizon, technology lack of proof at commercial scale, and substantial requirement of CAPEX introduce significant uncertainty to these plans.

Following a similar strategy, Norsk e-fuel, supported by Scandinavia's second-largest airline, Norwegian[133], aims to deploy its inaugural PtL facility in Mosjøen. The plant is designed with a capacity of 32 kT of SAF per year (derived from total announced fuel output of 40 kT and yields presented in Appendix). The platform is planned to start production in 2026, and the required CO_2 would be Point Source (PS) captured from an aluminium production plant adjacent to the facility[134].

If the initial project proves successful, Norsk has plans to expand its PtL derived products capacity. Specifically, the company envisions deploying two additional plants, each capable of supplying c. 65 kT of e-SAF per year.

Overall, Norway is strategically positioned to seize the opportunity of developing a strong slate of PtL projects, thanks to its abundant renewable electricity resources – a critical requirement for the synthetic fuel production process, encompassing both renewable hydrogen production and carbon capture. If the developing projects prove successful, it is highly likely that more similar initiatives will emerge in the region.

Figure 25: Operating and announced SAF facilities in Norway



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[132] (Nordic Electrofuel, n.d.)
[133] (Norwegian, 2024)
[134] (Norsk e-fuel, n.d.)

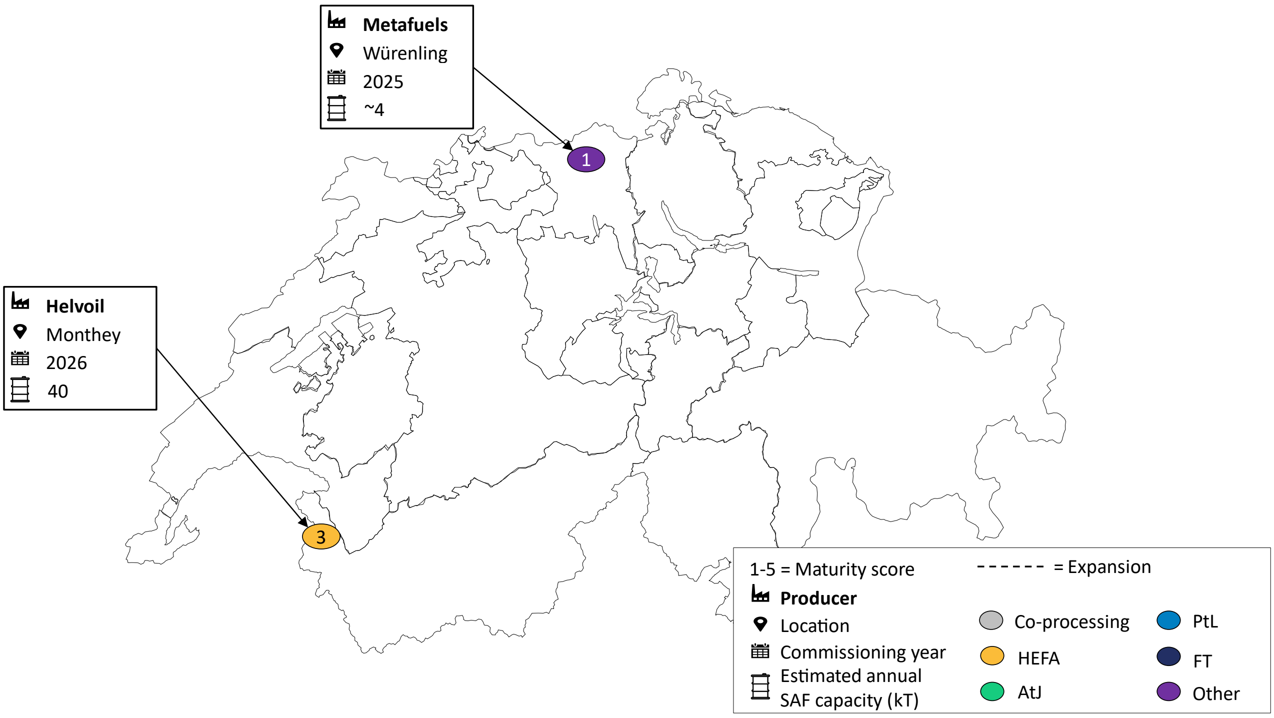
5.2.3 Switzerland

Switzerland currently lacks domestic SAF production capacity, though this is set to change in the coming years. While the number of announced facilities remains limited, two notable players are making strides:

- **Helvoil** aims to become Switzerland's pioneer SAF manufacturer. The company is developing a facility in Monthey, where it plans to produce SAF by utilising UCO and waste fats in a HEFA unit. Expected to commence production in 2026, this facility targets an annual SAF output of 40 kT[135]. If successful, Helvoil's project would contribute to the domestically produced SAF.

- **Metafuels**, an emerging company, is taking an innovative approach to SAF production. The MtJ pathway is not yet ASTM-approved, though it is currently being assessed and moving closer to approval as growing number of companies are going through feasibility studies[136]. Metafuels is planning to establish a pilot facility in Würenlingen capable of producing approximately 4 kT of SAF per year in 2025[137]. This initial step will help prove the concept and pave the way for potential future scale-up. Besides their pilot plant, Metafuels has also signed a partnership with European Energy for an MtJ facility in Denmark[138].

Figure 26: Operating and announced SAF facilities in Switzerland



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[135] (Helvoil, n.d.)

[136] (ICAO SAF conversion processes, 2024)

[137] (Kapoor, 2024)

[138] (Fayaz, e-SAF startup Metafuels raises $8m, 2023)

6. Appendix

6.1 ASTM approved SAF pathways

For SAF to be eligible for use in an aircraft engine, it must meet stringent certification standards set by ASTM, or equivalent standards accepted by the manufacturer, to ensure the safety and reliability of the aircraft. This section provides an overview of the various SAF production technology pathways, and how they relate to the different RFEUA aviation fuel categories. ASTM D4054 outlines the evaluation process for new fuels, including SAF, detailing the required fuel properties and the necessary engine testing to confirm the fuel's suitability for commercial aviation. Only SAF produced through the technology pathways detailed in ASTM D4054 are eligible for certification under ASTM D7566. These pathways detail the eligible feedstock, conversion process and maximum permitted blending limit with CAF. There are currently eight approved SAF pathways detailed in ASTM D7566, as shown in Table 11 below.

Table 11: ASTM approved pathways (2024) [139]

PATHWAY NAME	FEEDSTOCK*	CONVERSION PROCESS	RFEUA SAF CATEGORY	BLEND PERCENTAGE
FT-SPK	Biomass or waste (syngas)	Fischer-Tropsch synthesis	• Synthetic aviation fuel • Advanced aviation biofuel • Recycled carbon aviation fuel • Synthetic low-carbon aviation fuel	50%
HEFA-SPK	Fats, oils and greases	Hydroprocessing	• Advanced aviation biofuel • Aviation biofuel • Other aviation biofuel	50%
SIP	Sugars	Hydroprocessing	*Likely not eligible due to food crop processing*	10%
FT-SPK/A	Biomass or waste (syngas)	Fischer-Tropsch synthesis	• Synthetic aviation fuel • Advanced aviation biofuel • Recycled carbon aviation fuel • Synthetic low-carbon aviation fuel	50%
ATJ-SPK	Alcohols	Dehydration and oligomerisation	• Advanced biofuel • Aviation biofuel • Other aviation biofuel • Recycled carbon aviation fuel	50%
CHJ	Fats, oils and greases	Catalytic Hydrothermolysis	• Advanced aviation biofuel • Aviation biofuel • Other aviation biofuel	50%
HEFA-SPK/A	Fats, oils, greases and specific algae	Hydroprocessing	• Advanced aviation biofuel • Aviation biofuel • Other aviation biofuel	10%
ATJ-SKA	Alcohols	Dehydration and oligomerisation	• Advanced biofuel • Aviation biofuel • Other aviation biofuel • Recycled carbon aviation fuel	50%

* While the ASTM pathways are based on the conversion technology, the REFUA aviation fuel categories are determined on the basis of the feedstock and energy inputs, with strict eligibility criteria. Additionally, three SAF production pathways are approved under ASTM D1655 and therefore do not require any further blending. These pathways involve the co-processing of lipids, FT hydrocarbons, and hydrotreated biomass with CAF feedstock (typically crude oil) at up to 5% for the first two and up to 24% for the third one.

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[139] (ICAO SAF conversion processes, 2024)

Several pathways are currently under evaluation or revision, including the consideration of whether to increase the maximum rates of co-processing up to 30%. SAF produced through an ASTM D4054-approved pathway can be blended with CAF, if adhering to the maximum blend limits for each pathway and then certified to ASTM D7566. Once blended, the fuel is recognised as an ASTM D1655 aviation fuel, making it suitable for use in existing aircraft engines, or fuel infrastructures, without requiring any modifications nor separated logistics.

6.2 RFEUA eligible aviation fuels feedstock eligibility

➨ **Table 12:** description of RFEUA eligible fuels and possible feedstocks used to produce them

TYPE OF RFEUA ELIGIBLE AVIATION FUEL	REGULATORY BACKGROUND / GHG SAVING THRESHOLD	DESCRIPTION/DEFINITION
Synthetic aviation fuels	Art 3(12) RFEUA **(70%)**	*means aviation fuels that are 'renewable fuels of non-biological origin' as defined in Article 2, second paragraph, point (36), of Directive (EU) 2018/2001 'renewable liquid and gaseous transport fuels of non-biological origin' means liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass;*
Advanced aviation biofuels	Art 3(8)(a) RFEUA **(65%)**[140]	*means biofuels that are produced from the feedstock listed in Part A of Annex IX* a) *Algae if cultivated on land in ponds or photobioreactors* b) *Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC* c) *Biowaste as defined in point (4) of Article 3 of Directive 2008/98/EC from private households subject to separate collection as defined in point (11) of Article 3 of that Directive* d) *Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex* e) *Straw* f) *Animal manure and sewage sludge* g) *Palm oil mill effluent and empty palm fruit bunches* h) *Tall oil pitch* i) *Crude glycerine* j) *Bagasse* k) *Grape marcs and wine lees* l) *Nut shells*

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[140] Article 29 (10) RED, for production facilities that started operation at an earlier date, a lower GHG threshold is set.

TYPE OF RFEUA ELIGIBLE AVIATION FUEL	REGULATORY BACKGROUND / GHG SAVING THRESHOLD	DESCRIPTION/DEFINITION
		m) *Husks* n) *Cobs cleaned of kernels of corn* o) *Biomass fraction of wastes and residues from forestry and forest-based industries, namely, bark, branches, pre- commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil* p) *Other non-food cellulosic material* *q) Other ligno-cellulosic material except saw logs and veneer logs.* *r) Fusel oils from alcoholic distillation;* *s) Raw methanol from kraft pulping stemming from the production of wood pulp;* *t) Intermediate crops, such as catch crops and cover crops that are grown in areas where due to a short vegetation period the production of food and feed crops is limited to one harvest and provided their use does not trigger demand for additional land, and provided the soil organic matter content is maintained, where used for the production of biofuel for the aviation sector;* u) *Crops grown on severely degraded land, except food and feed crops, where used for the production of biofuel for the aviation sector;* v) *Cyanobacteri*a
Aviation biofuels	Art 3(8)(b) RFEUA **(65%)**[141]	*means liquid fuel for transport produced from the feedstock listed in Part B of Annex IX:* a) *Used cooking oil* *b) Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009.* *c) Damaged crops that are not fit for use in the food or feed chain, excluding substances that have been intentionally modified or contaminated in order to meet this definition;* *d) Municipal wastewater and derivatives other than sewage sludge;* *e) Crops grown on severely degraded land excluding food and feed crops and feedstocks listed in Part A of this Annex, where not used for the production of biofuel for the aviation sector;*

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[141] For facilities starting operations after 2021, Article 29 (10) RED. for production facilities that started operation at an earlier date, a lower GHG threshold is set.

TYPE OF RFEUA ELIGIBLE AVIATION FUEL	REGULATORY BACKGROUND / GHG SAVING THRESHOLD	DESCRIPTION/DEFINITION
		Intermediate crops, such as catch crops and cover crops, and excluding feedstocks listed in Part A of this Annex, that are grown in areas where due to a short vegetation period the production of food and feed crops is limited to one harvest and provided their use does not trigger demand for additional land and provided the soil organic matter content is maintained, where not used for the production of biofuel for the aviation sector.
Other aviation biofuels	Art 3(8)(c) RFEUA **(65%)**[142]	*as defined in Article 2, second paragraph, point (33), of Directive (EU) 2018/2001, with the exception of biofuels produced from 'food and feed crops' as defined in Article 2, second paragraph, point (40), of that Directive,* *'food and feed crops' means starch-rich crops, sugar crops or oil crops produced on agricultural land as a main crop excluding residues, waste or ligno-cellulosic material and intermediate crops, such as catch crops and cover crops, provided that the use of such intermediate crops does not trigger demand for additional land;*
Recycled carbon aviation fuels	Art 3(9) RFEUA **(70%)**	*means liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations;*
Renewable hydrogen for aviation	EU Art 3(16) RFEUA **(70%)**	*means hydrogen for use in aircraft that qualifies as a 'renewable fuel of non- biological origin', as defined in Article 2, second paragraph, point (36), of Directive (EU) 2018/2001, where* *'renewable liquid and gaseous transport fuels of non-biological origin' means liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass;*
Low-carbon hydrogen for aviation	Art 3(15) RFEUA **(70%)**	*means hydrogen for use in aircraft the energy content of which is derived from non-fossil non-renewable sources, which meets a lifecycle emissions savings threshold of 70 % and the methodologies for assessing such lifecycle emissions savings pursuant to relevant Union law;*

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[142] Article 29 (10) RED, for production facilities that started operation at an earlier date, a lower GHG threshold is set.

TYPE OF RFEUA ELIGIBLE AVIATION FUEL	REGULATORY BACKGROUND / GHG SAVING THRESHOLD	DESCRIPTION/DEFINITION
Synthetic low-carbon aviation fuels	Art 3(13) RFEUA **(70%)**	*means aviation fuels that are of non-biological origin, the energy content of which is derived from non-fossil low-carbon hydrogen, which meet lifecycle emissions savings threshold of 70 % and the methodologies for assessing such lifecycle emissions savings pursuant to relevant Union law;*

6.3 2023 production cost estimations for RFEUA aviation fuel categories

➨ **Table 13:** Production cost estimations for aviation fuel categories under RFEUA including feedstock and utility scenarios

FUEL CATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA FUEL PRODUCED)	TOTAL COST €/TONNE SAF OR HYDROGEN	CAPEX	FEEDSTOCK / HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
Synthetic aviation fuels	Power to Liquids (FT)	Biogenic point source carbon and Renewable hydrogen price 1 from Argus Media	-	30	€ 7,600	14%	77%	0%	1%	8%
		Biogenic point source carbon and Renewable hydrogen price 2 from Argus Media	-	30	€ 6,600	16%	74%	0%	1%	9%
		Biogenic point source carbon and Renewable hydrogen price 1 from Platts	-	30	€ 7,600	14%	77%	0%	1%	8%
		Biogenic point source carbon and Renewable hydrogen price 2 from Platts	-	30	€ 7,550	14%	77%	0%	1%	8%
		Biogenic point source carbon and Renewable hydrogen price 3 from Platts	-	30	€ 7,650	14%	77%	0%	1%	8%
		Biogenic point source carbon and Renewable hydrogen price 4 from Platts	-	30	€ 7,975	14%	77%	0%	1%	8%
		Atmospheric carbon Renewable hydrogen price 1 from Argus Media	-	30	€ 8,300	17%	70%	0%	3%	10%
		Atmospheric carbon Renewable hydrogen price 2 from Argus Media	-	30	€ 7,300	19%	67%	0%	3%	11%
		Atmospheric carbon Renewable hydrogen price 1 from Platts	-	30	€ 8,325	17%	71%	0%	3%	9%
		Atmospheric carbon Renewable hydrogen price 2 from Platts	-	30	€ 8,275	17%	70%	0%	3%	10%
		Atmospheric carbon Renewable hydrogen price 3 from Platts	-	30	€ 8,375	17%	71%	0%	3%	9%
		Atmospheric carbon Renewable hydrogen price 4 from Platts	-	30	€ 8,700	16%	72%	0%	3%	9%

FUEL CATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA FUEL PRODUCED)	TOTAL COST €/TONNE SAF OR HYDROGEN	CAPEX	FEEDSTOCK / HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
		Industrial point source carbon and Renewable hydrogen price 1 from Argus Media	-	30	€ 7,600	14%	77%	0%	1%	8%
		Industrial point source carbon and Renewable hydrogen price 2 from Argus Media	-	30	€ 6,600	16%	74%	0%	1%	9%
		Industrial point source carbon and Renewable hydrogen price 1 from Platts	-	30	€ 7,600	14%	77%	0%	1%	8%
		Industrial point source carbon and Renewable hydrogen price 2 from Platts	-	30	€ 7,550	14%	77%	0%	1%	8%
		Industrial point source carbon and Renewable hydrogen price 3 from Platts	-	30	€ 7,650	14%	77%	0%	1%	8%
		Industrial point source carbon and Renewable hydrogen price 4 from Platts	-	30	€ 7,975	14%	77%	0%	1%	8%
Advanced aviation biofuel	Gasification FT	(1) Feedstock price from Material Recovery Facility (MRF) operating costs	(1) Import O_2	60	€ 2,525	34%	24%	19%	4%	20%
			(2) Low end ASU onsite O_2 production		€ 2,250	37%	26%	11%	5%	22%
			(3) high end ASU onsite O_2 production		€ 2,475	35%	24%	17%	4%	20%
		(2) Feedstock price subtracting the European Average tipping fee	(1) Import O_2		€ 1,900	42%	5%	23%	5%	24%
			(2) Low end ASU onsite O_2 production		€ 1,625	47%	6%	13%	6%	27%
			(3) high end ASU onsite O_2 production		€ 1,850	43%	6%	21%	5%	25%
	Gasification FT	(1) Forest residue price from North SAF Raw Material presentation	(1) Import O_2	90	€ 2,950	33%	27%	17%	4%	19%
			(2) Low end ASU onsite O_2 production		€ 2,600	37%	30%	8%	4%	21%

FUEL CATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA FUEL PRODUCED)	TOTAL COST €/TONNE SAF OR HYDROGEN	CAPEX	FEEDSTOCK / HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
			(3) high end ASU onsite O_2 production		€ 2,775	35%	29%	13%	4%	20%
		(2) Forest residue price from Argus Media	(1) Import O_2		€ 3,675	28%	39%	14%	3%	16%
			(2) Low end ASU onsite O_2 production		€ 3,325	30%	43%	7%	3%	17%
			(3) high end ASU onsite O_2 production		€ 3,500	29%	41%	10%	3%	17%
	Ethanol to Jet	(1) Platt's ethanol price	-	30	€ 2,400	23%	61%	0%	4%	13%
		(2) Argus Media's ethanol price	-		€ 2,925	19%	67%	0%	3%	11%
Recycled carbon aviation fuels	Ethanol to Jet	(1) Zhang 2024 ethanol feedstock price (low)	-	30	€ 1,800	29%	50%	0%	4%	17%
		(2) Calculated waste ethanol feedstock price based on announced facility (medium)	-	30	€ 2,150	25%	56%	0%	4%	15%
		(3) Calculated waste ethanol feedstock price based on announced facility (high)	-	30	€ 2,450	23%	61%	0%	3%	13%
Renewable hydrogen for aviation	Alkaline and PEM electrolysis	Renewable hydrogen price 1 from Argus Media	-	300 MW	€ 7,025	Breakdown not provided				
		Renewable hydrogen price 2 from Argus Media	-	300 MW	€ 5,925	Breakdown not provided				
		Renewable hydrogen price 1 from Platts	-	300 MW	€ 7,050	Breakdown not provided				
		Renewable hydrogen price 2 from Platts	-	300 MW	€ 6,975	Breakdown not provided				
		Renewable hydrogen price 3 from Platts	-	300 MW	€ 7,100	Breakdown not provided				
		Renewable hydrogen price 4 from Platts	-	300 MW	€ 7,450	Breakdown not provided				
Low-carbon hydrogen for aviation	Alkaline electrolysis	Hydrogen from electrolysis using nuclear electricity	-	300 MW	€ 4,700	30%	0%	0%	52%	18%
Synthetic low-carbon aviation fuels	Power to Liquids	Biogenic/Industrial point source carbon and hydrogen from electrolysis using nuclear electricity	-	30	€ 5,300	44%	0%	0%	31%	25%

FUEL CATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA FUEL PRODUCED)	TOTAL COST €/TONNE SAF OR HYDROGEN	CAPEX	FEEDSTOCK / HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
		Atmospheric carbon and hydrogen from electrolysis using nuclear electricity	-	30	€ 6,025	44%	0%	0%	31%	25%

6.4 Assumptions

6.4.1 Utilities

Table 14: Utilities – main assumptions and data sources

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION OR SOURCE	PRICE RANGES
Nuclear electricity price	French Energy Regulation Commission (2023)	French Energy Regulation Commission	42 €/MWh
(1) Electricity price in EU (and by country) (2) Electricity price in Germany[143]	(1) Study on energy prices and costs - Publications Office of the EU (europa.eu)[144] (2) Argus Media	(1) European Commission 2023 electricity costs (2) 2023 average for base load price for electricity in Germany	EU Average: 122 €/MWh Argus Media Germany price: 116 €/MWh
Natural Gas price in EU (and by country) Natural gas price in London[145]	(1) Study on energy prices and costs - Publications Office of the EU (europa.eu) (2) Argus Media	(1) European Commission 2023 industrial use natural gas costs (2) 2023 average price for natural gas in London	EU Average: 42 €/MWh Argus Media London price: 40.86 €/MWh
Process water and wastewater disposal	EurEau, 2021[146]	EU average industrial process water and wastewater disposal price information Reference years are 2017-2019, varying by country based on frequency of data collected.	1.77 €/m3
Oxygen	(1) Index Box[147] (2) NREL, 2010[148] (3) Lee et al., 2022[149]	(1)2023 import price of oxygen to the EU (2) and (3) were used to provide a range of air separation unit capital and operating costs	131 €/tonne 108 €/tonne 68 €/tonne

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[143] Given the limited availability of utility data points, PRA data were prioritised with, in some cases, only some countries available

[144] (European Union, 2024)

[145] Natural gas is a process input for pathways where additional heating is required, exceeding what is available through plant operations, as in the PtL with DAC case. The natural gas is used to produce onsite hydrogen for the ethanol to jet cases.

[146] (EurEau, 2022)

[147] (Index Box, 2022)

[148] (Ryan M. Swanson, 2010)

[149] (Kyuha Lee, 2022)

6.4.2 Feedstock

Table 15: Feedstock assumptions and data sources

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION	PRICE RANGES
Bioethanol	(1) Platt's ethanol price[150] (2) Argus Media (RED double counting ethanol for Feb – May 2024)	Argus Media bioethanol price based on an average price for RED double counting (advanced) ethanol from February to May 2024	(1) 0.672 €/L (2) 0.872 €/L
Waste gas ethanol	(1) Potential solution to the sustainable ethanol production from industrial tail gas: An integrated life cycle and techno-economic analysis[151] (2) ICF internal modelling (low) (3) ICF internal modelling (high)	(1) Used average minimum selling price of ethanol from baseline steel mill tail gas scenario. (2) Used capital cost from a facility announcement in Ghent, Belgium[152] and process modelling inputs from Life Cycle Assessments of Ethanol Production via Gas Fermentation: Anticipated Greenhouse Gas Emissions for Cellulosic and Waste Gas[153] to calculate waste gas ethanol production cost. (3) Updated feedstock price assumption 2 to include additional 30% escalation of CAPEX to include any contingency, escalation, additional costs that may not have been captured in the initial investment.	(1) 0.433 €/L (2) 0.565 €/L (3) 0.683 €/L
Forest Residue	(1) North SAF Raw Material presentation[154] (2) Argus Media Information	The North SAF Raw Material presentation provided Fastmarket's price for wood chips in Finland used in the bioenergy sector. The most recent information from 2022 was included in the analysis. Argus Media provided average 2023 wood chip price within a 750 km radius of Rotterdam	(1) 23 €/MWh (2) 39.76 €/MWh
MSW	(1)Techno-Economic and life cycle assessment of standalone Single-Stream material recovery facilities in the United States[155] (2) European Environment Agency's Overview of landfill taxes on municipal waste used in EU Member States 2023[156]	(1) Provided methodology used to estimate cost of operating a MRF which was scaled and updated to use EU electricity price (2) 2023 Average tipping fee in Europe	(1) 60 €/tonne based on size of facility to meet fuels plant needs (2) Including tipping fee: 11 €/tonne
Point Source Capture CO_2	ICF internal modelling	Cost of PSC CO_2 is based on the cost of the equipment and energy requirements to capture the CO_2. In the production cost results, the PSC CO_2 cost is included in the overall CAPEX and OPEX of the fuels plant. PSC has minimal operating cost when incorporated into the fuels plant since the energy requirements are fulfilled using the energy	~43 €/tonne

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[150] Ethanol FOB
[151] (Zhang, 2024)
[152] (LanzaTech, 2023))
[153] (Handler, 2015)
[154] (North, 2021)
[155] (Olafasakin, et al., 2023)
[156] (European Environment Agency, 2024)

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION	PRICE RANGES
		generated in the facility. It is assumed the CO_2 source is co-located with the fuels plant. To note, only the equipment and operating costs are considered for PSC CO_2. Once CO_2 is a more established feedstock, the price of PSC CO_2 may increase.	
DAC CO_2	ICF internal modelling	Cost of DAC CO_2 is based on the cost of equipment and energy requirements to capture atmospheric CO_2. In the production cost results, the DAC cost is included in the overall CAPEX and OPEX of the fuels plant. Operating costs are lower when considered as part of the fuels plant since heat and electricity generated within the fuels facility are used to offset utility cost.	~132 €/tonne
Renewable hydrogen	Argus Media and Platts, S&P Global Commodity Insights	2023 average hydrogen price for six cases: (1) Argus Media Hydrogen no-C offshore wind+PEM Germany EUR/kg, ex-works (2) Argus Media Hydrogen no-C offshore wind+PEM Netherlands EUR/kg, ex-works (3) Platts Spain Alkaline Renewable PPA Derived Hydrogen (4) Platts France Alkaline Renewable PPA Derived Hydrogen (5) Platts The Netherlands Alkaline Renewable PPA Derived Hydrogen (6) Platts Germany Alkaline Renewable PPA Derived Hydrogen	(1) 7.03 €/kg (2) 5.92 €/kg (3) 7.05 €/kg (4) 6.99 €/kg (5) 7.09 €/kg (6) 7.45 €/kg

6.4.3 Co-products

➨ **Table 16**: Co-product historical prices from PRAs

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION	PRICE RANGE
Renewable diesel	Argus Media	Average of HVO class II FOB Amsterdam -Rotterdam-Antwerp (ARA) range for 2023 Converted from \$/tonne to €/tonne	1,986 €/tonne
Bionaphtha	Argus Media	Average price Bionaphtha FOB ARA over 2023 Converted from \$/tonne to €/tonne	1,459 €/tonne

6.4.4 CAPEX and Fixed Costs

6.4.4.1 CAPEX

CAPEX refers to the funds used by a company to build a facility. The initial cost estimation relies on Class 5 capital cost model. Costs are in 2023 US dollars, updated as necessary using the Chemical Engineering Plant Cost Index (CEPCI)[157].

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[157] (Chemical Engineering)

- Construction labour and material costs are adjusted to reflect European standards.
    - Labour costs are set at 94% of the US Gulf Coast (USGC)[158] average, based on data from France, Germany, and the Netherlands.
    - Bulk construction material costs are set at 110% of the USGC, reflecting the lowest cost among the three EU cities in the report.
    - It encompasses costs for equipment, bulk materials, labour, detailed engineering, and miscellaneous items such as spare parts, commissioning, and startup costs.
- EPC costs, which include EPC contingency and profit, account for 30% of the bare installed cost.
- Owner's costs, including land, project development, Front End Loading (FEL) engineering, permitting, etc., add an additional 22.5% to the total EPC capital cost.
- Financial costs contribute an extra 6% to the total EPC capital cost.

6.4.4.2 Fixed Costs

Fixed costs include assumptions for maintenance, labour, general and administrative, insurance, property tax and major maintenance costs. In high-level estimates such as this one, it is common practice to calculate the fixed costs of a facility as a percentage of the CAPEX. The table below shows the breakdown of the fixed cost used for each case.

Table 17: Fixed cost assumptions as share of CAPEX

ITEM	VALUE (% OF CAPEX)
Maintenance	1.50%
Labor	1.00%
G&A	0.50%
Insurance	0.75%
Property Taxes	1.00%
Major Maintenance	1.00%
Total	**5.75%**

6.4.5 Main assumptions per process

Given the broad acceptance and recognition of PRA indexes across the industry, and ease of replicability of data in following years, PRA data was prioritised whre possible. If PRA data was not available, publicly available information was utilised, with an emphasis on average 2023 European prices. The following assumptions were used in this process:

- Production capacity assumptions
    - Production capacity of a SAF facility can vary substantially. This study focused on 2023 production activity for SAF and hydrogen, utilising advanced technologies. Considering these technologies were not widely available in 2023, production cost estimations were based on estimating a first of a kind facility, which would hypothetically operate in 2023. Therefore, production capacities were based on announced facilities expected to be operational by 2027 and stayed at the lower end of capacity ranges.
- Process design assumptions
    - Byproduct naphtha and Liquified Petroleum Gas (LPG) production will be used in-plant for hydrogen production, if required.

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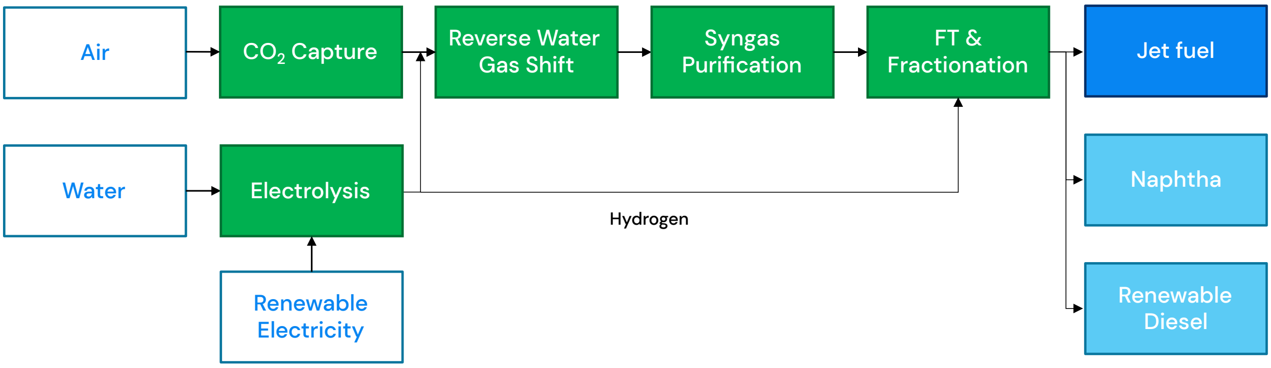
[158] (Global construction market outlook Headwinds forming on multiple fronts, 2022)

- Each plant design will incorporate all the required OSBL and utility systems necessary for SAF production.
    - If the plant generated fuel gas is insufficient for the required plant fuel demands, natural gas may be imported.
    - If the power generation in the plant is insufficient for the parasitic power demand, the plant will import electricity from grid.
    - Water required for plant operations will be imported from local water supply systems.
    - Wastewater generated by plant operations will be pretreated and disposed of offsite in local municipal water treatment plants.
    - Equipment necessary for feedstock, product and byproduct logistics will be included in the plant design for each case.
- All cases will maximise SAF production.

6.4.5.1 Power to Liquid (PtL) fuels

Figure 27 below shows the exemplar case of CO_2 from DAC and hydrogen from water electrolysis using renewable electricity. The captured CO_2 is reduced to CO by the reverse gas shift reaction. Hydrogen is combined with the CO stream to produce syngas. This syngas is purified and undergoes the FT process.

➨ **Figure 27:** Simplified process flow of renewable Synthetic Aviation fuel (RFNBO) production through FT for the exemplar case of DAC and water electrolysis



6.4.5.1.1 Synthetic aviation fuels

Synthetic aviation fuels, also known as renewable Power-to-Liquid SAFs, are produced using PSC or DAC technology plus hydrogen production using renewable electricity.

Biological and industrial Point Source CO_2

- Capacity: 30 kTPY
- Hydrogen feedstock is based on the six hydrogen scenarios and prices provided by Argus Media and Platts, S&P Global Commodity Insights. The hydrogen facility is assumed to be co-located with SAF facility.
- Biogenic CO_2 is captured and compressed from an ethanol production facility. Th ethanol facility is assumed to be co-located with the SAF facility, so there are no transportation costs considered.
- Fossil CO_2 is captured and compressed using the off-gas from a steel mill. The steel mill is assumed to be co-located with the SAF facility, so there are no transportation costs considered.

  - CO_2 capture based on adsorption process using amines to capture the CO_2. This process is used for dilute CO_2 streams. The cost of capture is based off on the Shell CANSOLV process[159,160]

DAC CO_2

- Capacity: 30 kTPY
- Hydrogen feedstock is based on the six hydrogen scenarios and prices provided by Argus Media and Platts, S&P Global Commodity Insights. The hydrogen facility is assumed to be co-located with SAF facility.
- A low temperature DAC system is used to capture CO_2 from the atmosphere. The CO_2 capture energy requirements are based on the Climeworks system[161].

6.4.5.1.2 Synthetic low-carbon aviation fuel

Synthetic low-carbon aviation fuels are similar to the previous categories but are derived from hydrogen using non-fossil low-carbon energy, namely, nuclear electricity. Nuclear electricity is assumed in the production cost estimation.

Point Source CO_2

- Capacity: 30 kTPY
- Hydrogen is producing using an Alkaline electrolysis system and using nuclear electricity. The hydrogen facility is assumed to be co-located with SAF facility.
- Biogenic CO_2 is captured and compressed from an ethanol production facility. Th ethanol facility is assumed to be co-located with the SAF facility, so there are no transportation costs considered.

DAC CO_2

- Capacity: 30 kTPY
- Hydrogen is produced using an Alkaline electrolysis system and using nuclear electricity. The hydrogen facility is assumed to be co-located with SAF facility.
- A low temperature DAC system is used to capture CO_2 from the atmosphere. The CO_2 capture energy requirements are based on the Climeworks system[162].

6.4.5.2 Gasification FT

The FT process is a method used for producing liquid fuels from gas. In this process, syngas, composed of primarily CO and Hydrogen (H_2), is converted into liquid hydrocarbons through a series of chemical reactions facilitated by a metal catalyst. This syngas is typically produced by the gasification of solid materials. The gasification FT process can be used to produce SAF by using organic material such as biomass or waste streams, such as Municipal Solid Waste (MSW), as the feedstock.

Gasification FT of wood waste

- Capacity: 90 kTPY SAF
- Feedstock moisture content 45wt%

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[159] (National Energy Technology Laboratory)

[160] (Hughes, et al., 2022)

[161] (Fasihi, Bogdanov, & Breyer, 2016) https://doi.org/10.1016/j.egypro.2016.10.115

[162] (Fasihi, Bogdanov, & Breyer, 2016)

    - Used to calculate 65 €/wet tonne feedstock from woodchips price option 1 from the North SAF Raw Material presentation
    - Used to calculate 122 €/wet tonne feedstock from woodchips price option 2 from Argus Media
    - Feedstock is dried before entering the gasifier
- Oxygen cost
    - Option 1 to import oxygen
    - Options 2 and 3 consider the CAPEX and OPEX of operating an onsite air separation unit to produce oxygen. Two cases considered since electricity usage of air separation unit varies.
- Plant is assumed power balanced since electricity requirement met with electricity generated from stream turbine utilising steam generated throughout process and fuel gas boiler. Off-gas from process is used in the fuel gas boiler to meet steam and electricity demand.
- No natural gas required since Fischer Tropsch reactor tailgas is recycled to meet gasification heat requirement.

<u>Gasification FT of MSW</u>

- Capacity: 60 kTPY SAF
- Feedstock
    - Feedstock option 1 estimated based on the cost to operate a MRF based on the methodology provided in the- "*Techno-Economic and life cycle assessment of standalone Single-Stream material recovery facilities in the United States"*[163]*. The cost was updated to reflect the size of MRF required to meet the fuels plant feedstock requirement and use EU average electricity pricing. The feedstock price was estimated to be approximately 60 €/tonne.*
    - Feedstock option 2 includes average EU tipping fee[164], lowering the cost to ~11 EUR/tonne
- Oxygen cost
    - Option 1 to import oxygen
    - Options 2 and 3 consider the CAPEX and OPEX of operating an onsite air separation unit to produce oxygen. Two cases considered since electricity usage of air separation unit varies.
- Plant is assumed power balanced since electricity requirement met with electricity generated from stream turbine utilising steam generated throughout process and fuel gas boiler. Off-gas from process is used in the fuel gas boiler to meet steam and electricity demand.
- No natural gas required since Fischer Tropsch reactor tail gas is recycled to meet gasification heat requirement.

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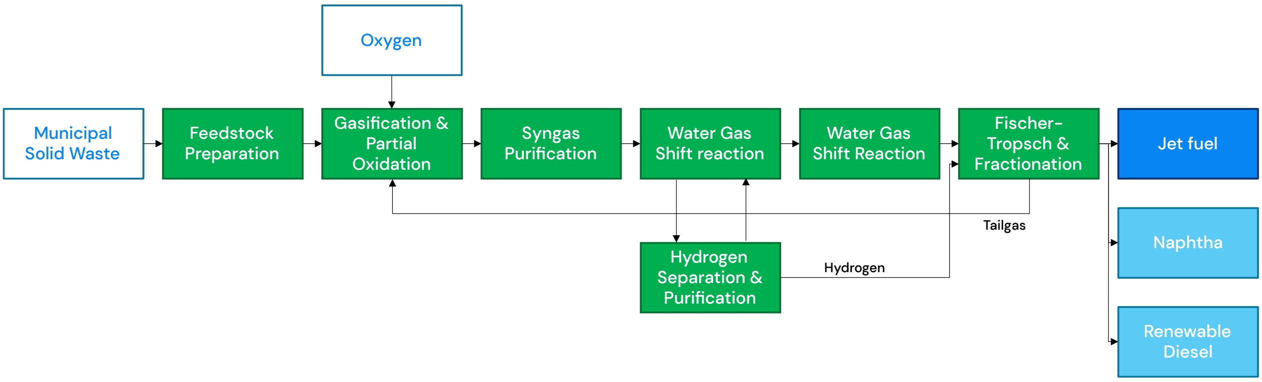
[163] (Olafasakin, et al., 2023)

[164] (European Environment Agency, 2024)

Figure 28: Simplified process flow of a Gasification-FT process for Advanced Biofuel production for the exemplar case of MSW feedstock (biogenic fraction complying with Annex IX B of RED only)



6.4.5.3 Alcohol to Jet (AtJ)

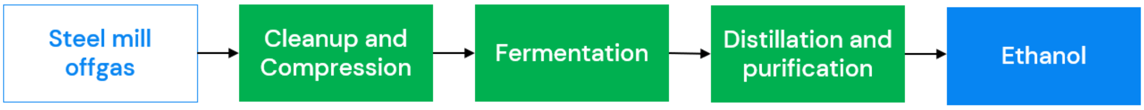
6.4.5.3.1 Recycled Carbon Aviation Fuels

Recycled carbon aviation fuels can use a combination off-gas from heavy industries like Steel or Cement, or non-recuperable non-bio wastes (such as waste plastics, tires or MSW that contains a non-biogenic fraction) a as input to produce low carbon intensive SAF. The carbon feedstock can then be used to produce ethanol through gas fermentation. The ethanol from gas fermentation is then used to produce SAF using an Alcohol to Jet (AtJ) pathway.

<u>Steel mill offgas to ethanol</u>

- Three feedstock prices considered.
  - Feedstock 1 based on steel mill tail gas stream gas fermentation[165].
  - Feedstock 2
    - Capacity and capital cost based on announced facility in Ghent, Belgium[166]
      - Capacity: 80 million Liters
      - Capital cost: 200 million euro
    - Process inputs include electricity, water, wastewater treatment, and chemical inputs from literature[167].
  - Feedstock 3
    - Capacity and process inputs consistent with feedstock case 2.
    - Increased capital cost by 30% to include potential need for additional escalation, contingency, and outside battery limits (OSBL) considerations that may not be included in the initial investment.

Figure 29: Simplified block flow diagram of steel mill offgas to ethanol process



<u>Alcohol to Jet with ethanol feedstock</u>

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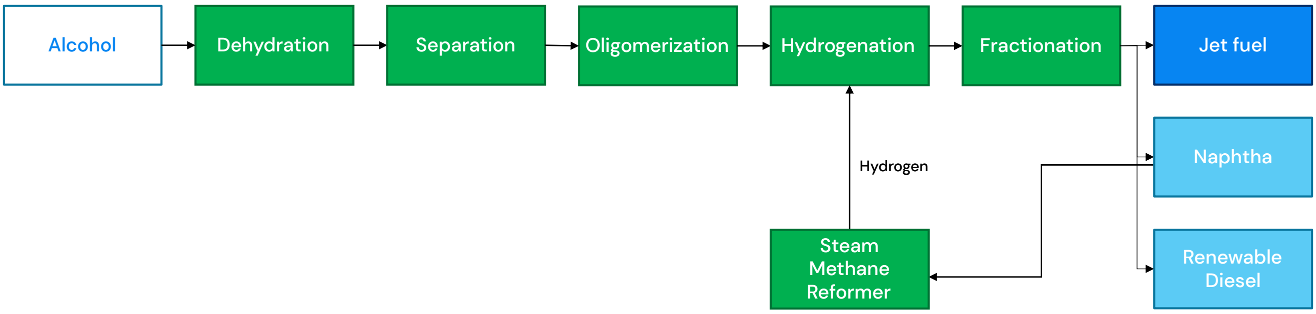
[165] (Zhang, 2024)

[166] (LanzaTech, 2023)

[167] (Handler, 2015)

- Capacity 30 kTPY
- Steam generated throughout the process is used in steam turbine to generate electricity.
- Process off-gas used to offset natural gas required.
- Some of the naphtha product is sent to a steam methane reformer to produce the hydrogen needed for hydrogenation.

➨ **Figure 30:** Simplified block flow diagram of Alcohol to Jet with steel offgas ethanol feedstock used in Recycled Carbon Aviation Fuels production

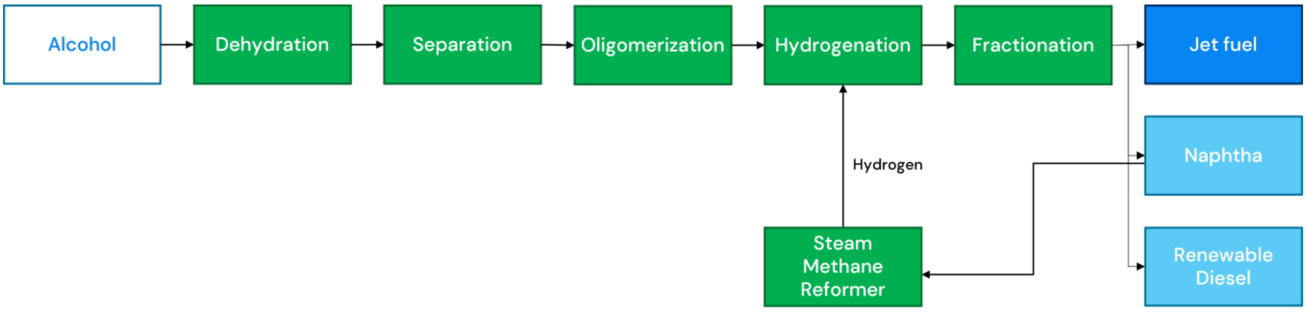


6.4.5.3.2 *Advanced Biofuels*

<u>Alcohol to Jet with ethanol feedstock</u>

- Capacity: 30 kTPY
- Two ethanol feedstock options for bioethanol.
- Steam generated throughout the process is used in steam turbine to generate electricity.
- Process off-gas used to offset natural gas required.
- Some of the naphtha product is sent to a steam methane reformer to produce the hydrogen needed for hydrogenation.

➨ **Figure 31:** Simplified process flow of an Alcohol-to-Jet pathway for Advanced Biofuel production



6.4.5.4 Renewable and low carbon hydrogen

Argus Media and Platts, S&P Global Commodity Insights Platts 2023 average hydrogen pricing was used for renewable hydrogen. In all cases, the capacity of the system was listed as a 300 MW electrolyser system.

- Hydrogen pricing from Argus included two cases of hydrogen production using Proton Membrane Exchange (PEM) electrolysis using offshore wind to power the hydrogen facility and without grid electricity connection. The two cases are based on hydrogen pricing in (1) Germany and (2) The Netherlands. The list of hydrogen prices used from Argus Media is:

  - Hydrogen no-C offshore wind+PEM Germany EUR/kg, Ex-Works (EXW)
  - Hydrogen no-C offshore wind+PEM Netherlands EUR/kg, EXW
- Hydrogen pricing from Platts included four cases of hydrogen production from alkaline electrolysis using Power Purchase Agreements (PPA) to purchase the electricity for electrolysis and the associated renewable electricity credits. The list of hydrogen prices used from Platts is:
  - Spain Alkaline Renewable PPA Derived Hydrogen
  - France Alkaline Renewable PPA Derived Hydrogen
  - The Netherlands Alkaline Renewable PPA Derived Hydrogen
  - Germany Alkaline Renewable PPA Derived Hydrogen
- Hydrogen pricing includes cost of producing hydrogen to the hydrogen facility gate
- For all six cases, the plant design capacity is assumed to be 300 Megawatts (MW) electrolyser.

The following assumptions were used to calculate low carbon hydrogen:
- 300 MW Alkaline electrolyser with electricity from power purchase agreements.
- 57 kWh/ kg hydrogen electricity requirement for electrolyser and balance of plant.
- Low carbon hydrogen includes nuclear electricity prices based on the French Energy commission.

6.5 SAF conversion assumptions

➨ **Table 18:** Production performance information for respective types of SAF (mass basis)

PATHWAY	FUEL CONVERSION (%)	SAF SELECTIVITY (%)
HEFA	85	40
AtJ	60	83
FT (biomass)	20	70

To produce a tonne of synthetic aviation fuel, it is estimated that 6.77 tonne CO_2 and 0.79 tonne H_2 (including for upgrading) would be required.

6.6 Co-processing facilities

➨ **Table 19:** Operating/announced co-processing facilities

COUNTRY	PRODUCER	FACILITY	CRUDE OIL CAPACITY (MT)	REFERENCES
Austria	OMV	Schwechat	9.6	[LINK]
France	ExxonMobil	Gravenchon	11.5	[LINK]
	TotalEnergies	Gonfreville	12	[LINK]
	TotalEnergies	Le Havre	N/A	[LINK]
Germany	BP	Lingen	4.3	[LINK]
	BP	Gelsenkirchen	12	[LINK]
Italy	Eni	Taranto	6.5	[LINK]
	Eni	Livorno	4.9	[LINK]
Romania	OMV	Petrobrazi	4.5	[LINK]
Spain	Repsol	Tarragona	9.4	[LINK]

COUNTRY	PRODUCER	FACILITY	CRUDE OIL CAPACITY (MT)	REFERENCES
	Repsol	Puertollano	7.5	[LINK]
	Repsol	Petronor	10.2	[LINK]
	BP	Castellón	5.1	[LINK]
	Cepsa	Huelva	9.5	[LINK]

6.7 List of EU/EFTA based SAF projects[168]

Table 20: EU SAF production projects

COUNTRY	PRODUCER	PROJECT/FACILITY	TECHNOLOGY	COMMISSIONING YEAR	REFERENCE
Denmark	Arcadia eFuels	Endor	PtL	2026	[LINK]
	Consortium	Green Fuels for Denmark	PtL	2027	[LINK]
	Consortium	Green Fuels for Denmark – Expansion	PtL	2030	[LINK]
	Kosan Gas, European Energy, Vertimass	MeSAF pilot plant	MtJ	2024	[LINK]
	Kosan Gas, European Energy, Vertimass	MeSAF – Expansion	MtJ	N/A	[LINK]
	Metafuels, European Energy	Metafuels plant	MtJ	N/A	[LINK]
	CIP	FjordPtX	PtL	2028	[LINK]
Finland	Neste	Porvoo	HEFA	2016	[LINK]
	Neste	Porvoo – Expansion	HEFA	2035	[LINK]
France	TotalEnergies	La Mède	HEFA	2024	[LINK]
	TotalEnergies	Grandpuits	HEFA	2025	[LINK]
	TotalEnergies	Grandpuits – Expansion	HEFA	2027	[LINK]
	Global Bioenergies	Global Bioenergies plant	AtJ	2027	[LINK]
	Elyse Energy	BioTJet	PtL	2027	[LINK]
	Elyse Energy & Khimod Greentech	Avebio	PtL	N/A	[LINK]
	EDF	Take Kair	PtL	2028	[LINK]
	Engie & Air France	France KerEAUzen	PtL	2028	[LINK]
	Engie & Infinium	Reuze	PtL	2026	[LINK]

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[168] Apart from the co-processing facilities

COUNTRY	PRODUCER	PROJECT/FACILITY	TECHNOLOGY	COMMISSIONING YEAR	REFERENCE
	Hy2Gen	Hynovera	PtL	2029	[LINK]
	SAF+ & H2V	Marsille Fos	PtL	2030	[LINK]
	Verso Energy & RYAM	Verso Tartas plant	PtL	N/A	[LINK]
	Verso Energy	Project Rouen	PtL	2029	[LINK]
	Qair & Airbus	Qair e-SAF plant	PtL	N/A	[LINK]
	Haffner Energy	Haffner Energy facility	PtL	2025	[LINK]
Germany	HCS Group	Speyer plant	AtJ	2026	[LINK]
	Oxxynova & Caphenia	EnZaH2	PtL	N/A	[LINK]
	DLR	Technology Platform PtL	PtL	2027	[LINK]
	Hy2Gen	Jangada	MtJ	2028	[LINK]
	Ineratec	Frankfurt Hochst plant	PtL	2024	[LINK]
	PtX Lab Lausitz	PtX Lab pilot plant	PtL	N/A	[LINK]
	Sasol ecoFT, Enertag & Cemex	Concrete Chemicals	PtL	2027	[LINK]
	Sasol ecoFT, Enertag & Cemex	Concrete Chemicals - Expansion	PtL	N/A	[LINK]
	Sasol, DHL, HH2E & Airbus	NetZeroLEJ	PtL	2029	[LINK]
	Sasol, DHL, HH2E & Airbus	NetZeroLEJ – Expansion	PtL	N/A	[LINK]
	SkyNRG & SCHWENK Zement	SkyNRG Germany	PtL	2028	[LINK]
	Atmosfair	Atmosfair Germany	PtL	2021	[LINK]
	Xfuels (EDL)	Hykero	PtL	2027	[LINK]
	Shell	Wesseling PtL project	PtL	2025	[LINK]
	Synhelion	DAWN	StL	2026	[LINK]
	Frauenhofer ISE	SAFari	MtJ	2026	[LINK]
	Sowitec & RR Power Systems	Sowitec pilot plant	PtL	2028	[LINK]
	Spark e-fuels	Spark e-fuels Germany	PtL	2025	[LINK]
	CAC	KEROSyN100	MtJ	N/A	[LINK]
	Consortium	TAKE OFF	PtL	N/A	[LINK]
	OMV	M2SAF	MtJ	2027	[LINK]
	KIT	reFuel	PtL	N/A	[LINK]

COUNTRY	PRODUCER	PROJECT/FACILITY	TECHNOLOGY	COMMISSIONING YEAR	REFERENCE
	Bayernoil (Varo Energy)	Bayosine	HtL	N/A	[LINK]
Italy	ENI	Gela	HEFA	2024	[LINK]
	ENI	Venice	HEFA	2025	[LINK]
Netherlands	BP	Rotterdam refinery	HEFA	N/A	[LINK]
	Chane Terminals	Chane Tankstorage Botlek	HEFA	2020	[LINK]
	Chane Terminals	Chane Tankstorage Botlek - Expansion	HEFA	2025	[LINK]
	Neste	Neste Rotterdam	HEFA	2023	[LINK]
	Neste	Neste Rotterdam – Expansion	HEFA	2026	[LINK]
	Shell	Shell Rotterdam	HEFA	*Paused*	[LINK]
	SkyNRG	SkyNRG Delfzijl (DSL-01)	HEFA	2027	[LINK]
	UPM Biofuels	UPM Rotterdam plant	HEFA	*Paused*	[LINK]
	Varo Energy & Gunvor	Varo Rotterdam	HEFA	2026	[LINK]
	Enerkem & Shell	Enerkem Rotterdam	FT	2026	[LINK]
	Ineratec & Zenith Energy	Ineratec Amsterdam	PtL	2027	[LINK]
	SkyNRG	SkyNRG Synkero	PtL	*Paused*	[LINK]
Poland	PKN ORLEN	Płock plant	HEFA	2025	[LINK]
Portugal	Galp & Mitsui	Sines plant	HEFA	2026	[LINK]
	LIPOR, P2X Europe & Veolia	LIPOR & Veolia PtL plant	PtL	N/A	[LINK]
	LIPOR & Smartenergy	LIPOR & Smartenergy PtL plant	PtL	N/A	[LINK]
	P2X Europe & Navigator	P2X-Portugal	PtL	2030	[LINK]
Spain	BP	Castellón refinery - Expansion (HEFA unit)	HEFA	2030	[LINK]
	Cepsa	Huelva refinery - Expansion (HEFA unit)	HEFA	2026	[LINK]
	Repsol	Cartagena refinery	HEFA	2024	[LINK]
	Greenalia & P2X	Breogan	PtL	2027	[LINK]
	Repsol, Petronor, Aramco	Bilbao pilot plant	PtL	2025	[LINK]
	Solarig	Numantia SAF	PtL	2028	[LINK]
Sweden	Preem	ICR project	HEFA	2027	[LINK]
	Preem	Viking	HEFA	2027	[LINK]

COUNTRY	PRODUCER	PROJECT/FACILITY	TECHNOLOGY	COMMISSIONING YEAR	REFERENCE
	St1 & SCA	St1 Oy Gothenburg	HEFA	2024	[LINK]
	Swedish Biofuels	Brista plant	AtJ	2025	[LINK]
	SkyNRG (consortium)	Smaland pilot plant	FT	2026	[LINK]
	BiorefineryÖstrandAB (St1 & SCA)	BioÖstrand	FT	2029	[LINK]
	Vattenfall & LanzaJet	HySkies	PtL	2030	[LINK]
	Vattenfall & St1	Hy X	PtL	2029	[LINK]

➨ **Table 21:** EFTA SAF production projects

COUNTRY	PRODUCER	PROJECT/FACILITY	TECHNOLOGY	COMMISSIONING YEAR	REFERENCE
Iceland	IðunnH2	Helguvik plant	PtL	2027	[LINK]
Norway	Nordic Electrofuel	E-fuel 1 (Pilot)	PtL	2026	[LINK]
	Nordic Electrofuel	E-fuel 2	PtL	2029	[LINK]
	Norsk	Norsk e-fuel Mosjoen plant	PtL	2026	[LINK]
	Norsk	Norsk e-fuel – Expansion	PtL	2030	[LINK]
	Infinium & Mo i Rana	Infinium Norway plant	PtL	N/A	[LINK]
	Statkraft	Silva Green Fuels	HtL	N/A	[LINK]
Switzerland	Metafuels	Metafuels pilot facility	MtJ	2025	[LINK]
	Helvoil	Monthey plant	HEFA	2026	[LINK]

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