European Union Aviation Safety Agency

METHODOLOGY DOCUMENT

EASA Reference Prices for RFEUA Eligible Aviation Fuels

Acknowledgements

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Photocredits

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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
KTA	Kilo Tonne per Annum
LCOE	Levelized Cost of Energy
LPG	Liquified Petroleum Gas
MED	Mediterranean
MtJ	Methanol-to-Jet
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
Mt	Million 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
RED	Renewable Energy Directive
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

Table of figures and tables

1 Introduction

This methodology document was developed by EASA as a supplementary resource to provide a more detailed explanation of how reference prices are determined for aviation fuels eligible under the ReFuelEU Aviation Regulation (Regulation (EU) 2023/2405, "RFEUA")[1].

Establishing these reference prices forms a key part of EASA's work for its Annual Technical Report, which EASA is required to prepare and publish each year in accordance with Article 13 of RFEUA. In addition to being included in the Annual Report, typically released in the third quarter, the same reference prices are also published earlier in the year through a dedicated EASA briefing note[2].

The reference prices are intended to serve as reference for EU Member States in the determination of penalties under RFEUA as well as for the support mechanism for the use of eligible aviation fuels under the EU ETS Directive (FEETS)[3].

This methodology document is maintained as a standalone resource and will be updated as needed to reflect any changes in the approach used to calculate EASA's reference prices.

The document starts with an overview of the basics of the methodology, followed by detailed sections outlining how the reference prices are calculated for the different subcategories of RFEUA eligible aviation fuels, depending on the fuel's market availability.

[1] ReFuelEU Aviation – Regulation (EU) 2023/2405
[2] *EASA Briefing Note* 2024 Aviation Fuels Reference Prices for ReFuelEU Aviation
[3] Delegated Regulation supplementing Directive 2003/87/EC of the European Parliament and of the Council by laying down detailed rules for the yearly calculation of price differences between eligible aviation fuels and fossil kerosene and for the EU ETS allocation of allowances for the use of eligible aviation fuels

2 Methodology - Basics

2.1 Real index pricing vs back up pricing

EASA determines reference prices for all aviation fuels eligible under RFEUA (“RFEUA eligible aviation fuels”). To determine the reference prices, EASA developed a methodology based on the market availability of a given RFEUA eligible aviation fuel in the reference year. The reference year is the year *n-1*, with *n* being the year of publication of the EASA Annual Technical report as per Article 13 RFEUA. For instance, the reference prices included in the EASA Annual Technical Report published in 2025 *(n)* therefore relate to the reference year 2024 *(n-1).*

If a given RFEUA eligible aviation fuel is publicly traded in sufficient quantities in the reference year *(n-1)*, then a **real index pricing** approach is used to determine the reference price for that RFEUA eligible aviation fuel for the year *n-1*. Real index pricing uses price data published via price indices provided by PRAs.

On the other hand, if a given RFEUA eligible aviation fuel is **not** publicly traded in sufficient quantities in the reference year *(n-1)*, and thus no real index price via PRA data can be determined, a **back up pricing** approach is used to calculate the reference price for that RFEUA eligible aviation fuel for the year *n-1*. Back up pricing consists of a bottom-up production cost estimation, leveraging price data published via PRAs (e.g., on feedstocks) and relevant EU databases[4], where available.

EASA also determines a reference price for conventional aviation fuel (CAF), given its fundamental reference role in the implementation of RFEUA and the FEETS mechanism.

In line with what is required for both RFEUA and the FEETS mechanism, the reference prices for RFEUA eligible aviation fuels represent average annual prices for the reference year, thereby providing a single data point as reference.

2.2 Subcategories of RFEUA eligible aviation fuels

Table 1 lists all subcategories of RFEUA eligible aviation fuels for which EASA determines reference prices, including their respective definitions as per Article 3 RFEUA. It also provides information on the approach used – either real index pricing or back up pricing – to establish the corresponding reference price.

RFEUA AVIATION FUELS SUBCATEGORY	DEFINITION AS PER ARTICLE 3 RFEUA	APPROACH USED FOR REFERENCE PRICE
Sustainable aviation fuels (SAF)		
Synthetic aviation fuels	**Art 3(12).** Renewable fuels of non-biological origin (RFNBOs) as defined in the Renewable Energy Directive (RED)[5].	Back up pricing
Advanced aviation biofuels	**Art 3(8)(a).** Biofuels produced from feedstock listed in Part A of Annex IX of RED.	Back up pricing
Aviation biofuels	**Art 3(8)(b).** Biofuels produced from feedstock listed in Part B of Annex IX of RED.	Real index pricing

[4] Such as Eurostat data for electricity and natural gas prices.
[5] Renewable Energy Directive (EU RED).

RFEUA AVIATION FUELS SUBCATEGORY	DEFINITION AS PER ARTICLE 3 RFEUA	APPROACH USED FOR REFERENCE PRICE
Other aviation biofuels	**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.	*Real index pricing (currently excluded due to lack of liquidity)*[6]
Recycled carbon aviation fuels	**Art 3(9).** Recycled carbon fuels as defined in RED.	Back up pricing
Other eligible renewable and low-carbon aviation fuels		
Renewable hydrogen for aviation	Art 3(16). Hydrogen for use in aircraft that qualifies as renewable fuel of non-biological origin (RFNBO) as defined in RED.	Back up pricing
Low-carbon hydrogen for aviation	Art 3(15). Hydrogen for use in aircraft the energy content of which is derived from non-fossil, non-renewable sources.	Back up pricing
Synthetic low-carbon aviation fuels	Art 3(13). Aviation fuels of non-biological origin, the energy content of which is derived from non-fossil, low-carbon hydrogen.	Back up pricing
Other aviation fuels		
Conventional aviation fuels	Art 3(14). Aviation fuels produced from fossil non-renewable sources of hydrocarbon fuels.	Real index pricing

Table 1: RFEUA aviation fuels subcategories – respective definitions as per RFEUA and approach used for determining reference prices.

The aviation fuels subcategories under RFEUA generally align with the eligible aviation fuel subcategories outlined in the Annex of the Delegated Regulation on FEETS, with the following differences:

- recycled carbon aviation fuels are not eligible for support as FEETS; and
- FEETS additionally includes several co-processing-based aviation fuels subcategories. For the RFEUA eligible aviation fuels reference prices, co-processed fuels are included in their respective aviation fuels subcategory.

2.3 USD to EUR exchange rate

Given the global nature of the fuels industry, the US dollar (USD) is the standard currency used for price assessments. However, EASA reports its findings in euros (EUR), requiring the conversion of all prices from USD to EUR using an average exchange applicable to the reference year. This rate is calculated as the arithmetic average of the European Central Bank's (ECB) daily EUR/USD exchange rates for the year.

[6] "Other aviation biofuels" are produced from biomass feedstocks not listed in Annex IX of the RED. Currently very limited SAF quantities belonging to this subcategory were identified. As a result, "other aviation biofuels" are excluded from reference price determination for the time being.

3 Real index pricing

If a given RFEUA eligible aviation fuel is publicly traded in sufficient quantities in the reference year *(n-1)*, then a real index pricing approach is used to determine the reference price for that RFEUA eligible aviation fuel for the year *n-1*. Real index pricing involves calculating an arithmetic average[7] of historical spot market prices for SAF and CAF, through the data provided by PRAs for the reference year.

This chapter first provides a brief overview of the PRA selection process, followed by an explanation of how the real index pricing approach is applied to both CAF and SAF.

3.1 PRA selection process

Before each price determination exercise, EASA reviews the PRA market to identify relevant providers of CAF and SAF price data. The selection of PRAs is based on their capacity to provide both CAF and SAF data. PRAs that offer only CAF or only SAF data are excluded from the assessment.

To ensure accuracy and market relevance, the PRA selection process also incorporates a maximum standard deviation threshold to assess consistency of data provided by the different PRAs and filter out outliers.

Currently, indices from three different PRAs are used, each of which provided CAF and SAF price data covering European activity[8]:

- Argus Media (Argus)
- S&P Global Commodity Insights (Platts)
- General Index (GX)

Consideration of other PRAs by EASA

To account for market developments and ensure access to the broadest possible tool of credible data, EASA conducts a regular review of the PRA market to identify relevant (additional) providers of CAF and SAF price data.

EASA invites proactive expressions of interest by other PRAs that provide CAF and SAF price data relevant to European activity and to the reference year under consideration.

3.2 Conventional aviation fuels

While CAF is not a RFEUA eligible aviation fuel, EASA also determines a reference price for it, given its fundamental reference role in the implementation of RFEUA and the FEETS mechanism.

[7] The arithmetic mean assigns equal weight to all items, making it appropriate when no single item should disproportionately influence the index. In addition to its use in widely recognised economic indicators such as the Consumer Price Index (CPI) and Producer Price Index (PPI), global PRAs also apply the arithmetic mean in the development of their pricing indices.

[8] Methodology documents: Argus Fuels and Octane methodology, Argus Biofuels methodology, https://www.spglobal.com/platts/plattscontent/_assets/_files/en/our-methodology/methodology-specifications/world_jet_indexes.pdf, Specifications Guide Global Jet Indices, Specifications Guide Global Biofuels, General Index SAF, General Index CAF

CAF price indices have been widely used in the aviation industry for decades. Owing to the high volume of transactions and strong market liquidity, PRAs are well positioned to accurately reflect CAF price dynamics.

CAF price indices are developed based on two primary factors: The location of the transaction and the international commercial terms.

Within the EU, most transactions take place in Northwest Europe (NWE) and the Mediterranean (MED). Therefore these two locations are considered as the benchmark hubs for most of the commodity activities.

In addition, the International commercial terms ("Incoterms") play a key role in pricing. "Free On Board" (FOB) excludes shipping, insurance, and other costs beyond the port of origin, which are borne by the buyer. In contrast, "Cost, Insurance and Freight" (CIF) includes shipping, insurance, and other costs up to the destination. The CIF price is typically higher than the FOB price and more accurately reflects the actual costs incurred by aircraft operators. The CIF price is therefore used as the basis for assessment. It is important to note that in all PRA assessments on CIF basis, downstream costs, such as blending and transport, are either excluded or only partially included. Given the variability of these costs across assessments, and to ensure a level playing field, only upstream costs up to the hub price are considered under the real index pricing approach.

Currently, the following PRA indices are used for CAF:

- Argus: Jet/kerosine NWE cif prompt, London close, midpoint, USD/t, cif
- GX: Jet Fuel NWE CIF Cargoes EUR
- Platts: Platts Jet CIF NWE Cargo

The reference price for CAF for a given reference year is calculated as follows:

- At the beginning of each year, prior to a new price determination exercise, EASA receives a compiled table from the selected PRAs containing daily CAF price data for the reference year (year n–1).
- The dataset then undergoes a thorough review to identify any outliers. To date, the CAF data provided by the selected PRAs has shown minimal variation, with no outliers detected.
- Daily arithmetic averages are derived from these data points, followed by the calculation of an annual average to establish a single reference price for CAF.

The price difference between the NWE and MED locations is mainly due to transportation costs for crude and refined oil from the Middle East to each hub, although this difference is considered minimal (less than 1%). Over the two reference years for which EASA has calculated reference prices so far (2023 and 2024), CIF NWE jet fuel price data from the three PRAs – Argus, Platts, and GX – has shown to be very similar.

3.3 Aviation biofuels

SAF is an emerging commodity that PRAs have only begun to assess in recent years. A PRA's ability to determine prices generally depends on the volume, frequency, and transparency of market transactions. Although the SAF market remains relatively small and fragmented to-date, several PRAs have already initiated the development of pricing indices. For instance, Argus, Platts, and GX have established spot price indices for SAF. It is important to note that SAF is not a uniform commodity; differences in carbon intensity and feedstock types result in notable price variations.

So far, PRAs have focused on specific SAF subcategories – particularly HEFA SAF produced from waste fats, oils and greases (“FOGs”) – but these indices are expected to grow in complexity over time to reflect the diversity of SAF attributes.

Argus began publishing SAF price indices in 2021, followed by Platts in September 2023. Prior to that, Platts had only provided estimates of SAF production costs. For the years 2023 and 2024, Argus, Platts, and GX each released SAF spot price indices for SAF produced from feedstock eligible under RED Annex IX Part B; thus considered “aviation biofuels” under RFEUA.

Currently, the following PRA indices are used for SAF:

- Argus: RED SAF cif NWE range USD/t prompt, London close, midpoint, USD/t,
- GX: SAF Neat HEFA NWE FOB Barges Spot Market Value EUR
- Platts: Sustainable Aviation Fuel CIF NWE $/mt

So far, none of the PRAs provide price data for SAF other than for “aviation biofuels”. The reference price for “aviation biofuels” is determined in a way that closely mirrors the approach applied for CAF:

- At the beginning of each year, prior to a new price determination exercise, EASA receives a compiled table from the selected PRAs containing daily SAF (“aviation biofuels”) price data for the reference year (year n–1).
- The dataset then undergoes a thorough review to identify any outliers. SAF data is still evolving and PRAs are still improiving their established approach. For the first half of 2024, some variation was observed between prices reported by PRAs, due to volatile market conditions. However the price trend was identical. The prices reported for the second half of 2024 were very close to each other with limited difference.
- Daily arithmetic averages are derived from these data points, followed by the calculation of an annual average to establish a single reference price for “aviation biofuels”.

The “real index pricing” result for “aviation biofuels” is calculated by price reporting agencies for the Northwest European (NWE) hub. Liquidity is currently strongest at the NWE hub, making it a suitable benchmark for establishing a reference price that supports a level playing field. Beyond this hub, SAF prices vary considerably due to the factors outlined above.

As illustrated in Figure 1, this price reflects the costs associated with feedstock production, upstream logistics, production at the refinery and sustainability certification. However, it does not capture downstream components, such as costs associated with blending, distribution, and downstream actors’ (such as aviation fuel suppliers’) profit margins. Additionally, PRA assessments are typically based on larger trade volumes, whereas airlines often procure smaller quantities, resulting in potentially higher unit costs.

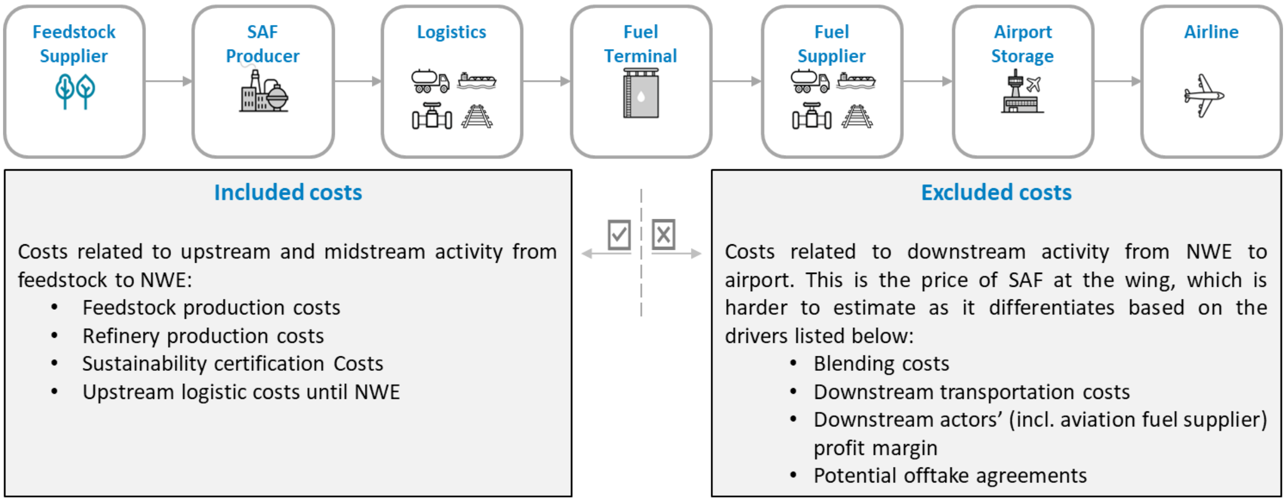


Figure 1: Overview of included and excluded costs of PRA assessments.

4 Back up pricing

If a given RFEUA eligible aviation fuel is not publicly traded in sufficient quantities in the reference year *(n-1)*, and thus no real index price via PRA data can be determined, a back up pricing approach is used to calculate the reference price for that RFEUA eligible aviation fuel for the year *n-1*.

Back up pricing consists of a bottom-up production cost estimation, leveraging price data published via PRAs (e.g., on feedstocks) and relevant EU databases[9], where available. Reference prices determined via back up pricing, being production cost estimates only, do not factor in additional costs such as transportation or commercial margins applied by actors along the value chain. These costs can vary largely based on the characteristics of each transaction, further complicated by the lack of market availability for those RFEUA eligible aviation fuel subcategories for whick back up pricing is applied. As a consequence, it was decided that back up pricing should focus solely on production cost estimates.

Currently, a back up pricing approach is being used for all RFEUA eligible aviation fuel subcategories except “aviation biofuels”.

Naturally, a wide range of variables can influence the bottom-up production cost of any RFEUA eligible aviation fuel, including feedstock and technology combinations, or differences in feedstock and utility prices. In light of this complexity, the analysis for the production cost estimate has been focused on the characteristics of production facilities for that type of SAF announced to date.

The resulting estimates indicated for each RFEUA eligible aviation fuel determined via back up pricing reflect the lower and upper bounds of calculations, aiming to capture these variations. Both RFEUA and the FEETS mechanism require a single reference data point for the calculation of penalties or incentives in the form of “SAF allowances”. Therefore, average reference prices are calculated for each RFEUA eligible aviation fuel subcategory. The averages reflect production cost estimates within the given range.

This chapter outlines the process for selecting technology pathways, defining related assumptions, and identifying key considerations used in estimating production costs.

[9] Such as Eurostat data for electricity and natural gas prices.

4.1 Process selection

The determination of a realistic production cost estimate for a RFEUA eligible aviation fuel via back up pricing requires selecting specific feedstock and technology pathways that reflect SAF production facility announcements made to date. Accordingly, the considerations outlined below were prioritized in identifying and selecting appropriate processes for the back up pricing assessment:

- **Technology maturity:** The Technology Readiness Level (TRL) indicates the development stage of SAF technologies, ranging from 1 (basic principles) to 9 (operational environment). In commercial aviation, only SAF approved under ASTM standards is permitted, which limits the range of eligible technologies. Although Methanol-to-Jet (MtJ) and Hydrothermal Liquefaction (HtL) are considered technically viable, they have not yet received ASTM D4054 certification and are therefore excluded from this analysis.
- **Market dynamics:** Market readiness is assessed based on the number of facilities and projects announced within the EU that utilize a specific technology pathway. This serves as an indicator of current market interest and willingness to adopt particular technology and feedstock combinations. For instance, certain advanced aviation biofuel production routes – such as the use of waste biomass with AtJ or FT processes – have seen greater activity compared to other alternatives, based on announced facilities.

For each feedstock and technology combination, a range of variables influences the production cost. These include location, technology type, license fees, labour rates, specific technology process guarantees, the trade-off between capital cost and equipment efficiency, cost escalation factors, required investment returns, proximity to feedstock sources, contractual terms, feedstock type and quality, as well as the source of energy used.

For this analysis, the RFEUA eligible fuel subcategories were disaggregated into technology and feedstock combinations, providing a comprehensive overview of the production process, CO_2 capture methods, and cost factors for each type of SAF. This detailed breakdown is used for identifying the production cost of the SAF combinations selected. The combinations presented in the table below were selected based on their potential for scale-up – either due to production facilities already announced in Europe or because the technology involved is promoted by regulators ("synthetic aviation fuels" and hydrogen)[10].

TYPE OF RFEUA ELIGIBLE AVIATION FUEL	PRODUCTION PATHWAY	FEEDSTOCK
Synthetic aviation fuels	FT (PtL)	Biogenic and industrial CO_2 from Point Source Capture (PSC) and hydrogen from electrolysis using renewable electricity
		Atmospheric CO_2 from Direct Air Capture (DAC) and hydrogen from electrolysis using renewable electricity
Advanced aviation biofuels	Gasification FT	MSW (biomass fraction, compliant with Annex IX.A)
		Forest residues
	AtJ	Bioethanol from feedstock listed in Annex IX.A
Recycled carbon aviation fuels	AtJ	Fossil CO_2 from PSC, fermentation to ethanol
Renewable hydrogen for aviation	Alkaline and proton exchange	Green hydrogen from electrolysis using renewable electricity

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

TYPE OF RFEUA ELIGIBLE AVIATION FUEL	PRODUCTION PATHWAY	FEEDSTOCK
	membrane (PEM) electrolysis	
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 nuclear electricity
		Atmospheric CO_2 from DAC and hydrogen from electrolysis using nuclear electricity

Table 2: Selected production pathway and feedstock combinations per RFEUA eligible aviation fuel subcategory

4.2 Production cost estimation model and assumptions

A production cost estimate represents the total of all costs incurred throughout the SAF production process. It is primarily driven by two components: operating expenditures (OPEX) and capital expenditures (CAPEX). These cost elements are aggregated and adjusted for by subtracting the value attributed to co-products. Accounting for the share of co-product revenues within the facility's total valuable output enables a more comprehensive assessment of net production costs.

Two main types of data sources for relevant material or energy inputs are used for the assessment of the production cost estimations: PRA data and publicly available data published by European institutions. Where these are not available, internally developed assumptions and models based on industry knowledge and experience are used.

Two primary types of data sources are used for relevant material and energy inputs: data from PRAs and publicly available information published by European institutions. In cases where such data is unavailable, internally developed assumptions and models based on industry knowledge and experience are used.

4.2.1 OPEX

OPEX refers to the expenses associated with operating the facility and encompasses both variable and fixed costs. Variable costs include utilities such as electricity, natural gas, process water, wastewater disposal, and chemical inputs, as well as feedstock. These are calculated based on feedstock and utility price data, process energy needs, chemical usage, and feedstock requirements specific to the facility. The values can vary significantly depending on the chosen production pathway. Fixed costs typically cover maintenance, labor, insurance, and permitting. Further details on both variable costs (including utilities and feedstock) and fixed costs are provided in the following sections.

4.2.1.1 Utility costs

Utility costs refer to the essential services and resources required during SAF production, including water, electricity, and heat. These costs are highly dependent on the chosen technology pathway and feedstock. Utility prices and consumption rates are derived from PRA responses, publicly available data from EU databases, and internal resources. This report prioritizes PRA data where available to maintain consistency with other cost components and ensure alignment with the most recent market information, as shown in the table below.

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION OR SOURCE
Nuclear electricity price	French Energy Regulation Commission	French Energy Regulation Commission
Eurostat electricity pricing	Electricity prices for non-household consumers – bi-annual data (from 2007 onwards) (Statistics | Eurostat)	2024-S1 data for the EU 27 countries (excluding VAT)
Eurostat natural gas pricing	Gas prices for non-household consumers – bi-annual data (from 2007 onwards) (Statistics | Eurostat)	2024-S1 data for the EU 27 countries (excluding VAT)
Process water and wastewater disposal	EurEau, 2021[11]	EU average industrial process water and wastewater disposal price information Reference years are 2017-2019, varying by country based on frequency of data collected.
Oxygen	(1) Index Box[12] (2) NREL, 2010[13] (3) Lee et al., 2022[14]	(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

Table 3: Utilities – main assumptions and data sources

4.2.1.2 Feedstock costs

Different SAF subcategories require different feedstocks, and feedstock costs directly influence the base price of the fuel. By analysing market prices and availability of various feedstocks, more accurate cost estimates can be developed. This approach aims to ensure that estimates reflect current market conditions and resource accessibility, using data inputs from PRAs wherever possible. Specifically, feedstock prices are derived from PRA responses, publicly available sources, and internal modelling. Where available, sources providing average prices across all EU countries for the reference year are prioritised. Some prices are based on specific countries or data from earlier years where data for the reference year is not available. Bioethanol, forest residue, MSW, and renewable hydrogen prices have multiple price points based on differing assumptions or price availability, so multiple production costs were calculated to reflect the range in potential production costs.

Currently, hydrogen price assumptions are based on market data collected from PRAs. These figures are broadly consistent with the outcomes of the first EU-wide pilot auction for renewable hydrogen (IF 23)[15], launched in November 2023. Further details on feedstock-related inputs and assumptions are provided in the table below.

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION
Bioethanol	(1) Platt's FOB Rdam (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

[11] (EurEau, 2022)
[12] (Index Box, 2022)
[13] (Ryan M. Swanson, 2010)
[14] (Kyuha Lee, 2022)
[15] Results of the IF23 pilot auction for renewable hydrogen production (European Commission, 2023)

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION
Waste gas ethanol	(1) Potential solution to the sustainable ethanol production from industrial tail gas: An integrated life cycle and techno-economic analysis[16] (2) Internal modelling (low) (3) 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[17] and process modelling inputs from Life Cycle Assessments of Ethanol production via gas fermentation: anticipated GHG emissions for cellulosic and waste gas[18] 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.
Forest residue	Argus Media	Argus Media provided average 2024 wood chip price within a 750 km radius of Rotterdam
MSW	(1) Techno-economic and life cycle assessment of standalone Single-Stream material recovery facilities in the United States[19] (2) European Environment Agency tipping fee (Typical charge (gate fee and landfill tax) for legal landfilling of non-hazardous municipal waste in EU Member States and regions | European Environment Agency's home page)	(1) Provided methodology used to estimate cost of operating a MRF which is scaled and updated to use EU electricity price (2) 2024 average tipping fee in Europe
PSC CO_2	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 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	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.
Renewable hydrogen	Argus Media and Platts, S&P Global Commodity Insights	2024 average hydrogen price for six cases: (1) Argus Media Hydrogen no-C offshore wind+PEM Germany EUR/kg, ex-works

[16] (Zhang, 2024)
[17] (LanzaTech, 2023))
[18] (Handler, 2015)
[19] (Olafasakin, et al., 2023)

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION
		(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

Table 4: Feedstock assumptions and data sources

4.2.1.3 Fixed costs

Fixed costs encompass labour, maintenance, insurance, permitting, and general and administrative (G&A) expenses. These costs may vary depending on the facility's complexity and the specific requirements of its owner. Infrequent, high-cost maintenance activities, referred to as major maintenance (e.g., catalyst replacement), are typically included within fixed costs. For high-level estimates such as this, it is standard practice to express fixed costs as a percentage of CAPEX. The table below provides a detailed breakdown of the fixed cost components used in this assessment.

ITEM	GASIFICATION FT (% OF CAPEX)	ATJ (% OF CAPEX)	PTL (% OF CAPEX)
Maintenance	2.00%	1.50%	0.20%
Labor	1.50%	1.50%	1.50%
SG&A	0.15%	0.15%	0.15%
Insurance	0.75%	0.75%	0.75%
Property taxes	1.00%	1.00%	1.00%
Major maintenance	1.00%	1.00%	1.00%
Total	**6.40%**	**5.90%**	**4.60%**

Table 5: Fixed cost assumptions as share of CAPEX

4.2.2 CAPEX

CAPEX refers to the upfront investment required for the equipment and infrastructure necessary to implement the project. It includes direct costs, such as equipment and labour for facility construction, and indirect costs, including support infrastructure (e.g., offices), taxes, and related expenses. Additionally, owner's costs are accounted for, covering project financing, engineering, and permitting activities.

Equipment costs are subcategorised 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. Assumptions are applied to evaluate both equipment costs.

The production cost estimates are derived from a capital cost estimating tool[20] at an AACE Class 5 level. The total CAPEX cost is then annualised based on assumptions of how the project is financed

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

and the definition of the loan term and interest rate. To achieve more precise cost estimates, project-specific information and vendor quotes are required. Costs are initially estimated in USD for the reference year, updated as necessary using the Chemical Engineering Plant Cost Index (CEPCI)[21]. Other CAPEX assumptions are listed below:

- Construction labour and material costs are adjusted to reflect European standards.
  - Labour costs are set at 94% of the US Gulf Coast (USGC)[22] 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.
  - This subcategory encompasses costs for equipment, bulk materials, labour, detailed engineering, 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.

The total CAPEX, including ISBL and OSBL equipment, indirect costs, EPC costs, owner's costs, and financing costs are included for each pathway and converted from USD to EUR using the ECB exchange rate explained in chapter 2. The resulting CAPEX is then annualized and incorporated in the production cost estimate.

4.2.3 Co-product prices

Co-products are the valuable products generated alongside SAF during production. These can include gases, chemicals, or other materials that have their own market value. In the cost estimation model, the impact[23] of co-products is 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.

Selling prices for renewable diesel and naphtha co-products were available for the most recent price determination exercise, covering the previous reference year. The remaining costs are attributed to the SAF product to better reflect the production cost impact of new SAF development.

For all pathways, the process is modelled to maximise SAF production. Co-product selling price is calculated using the average price information for the reference year provided by the selected PRAs. The formulas below illustrate how the production cost estimation for SAF incorporates co-product values. This is followed by a table outlining the relevant assumptions and input parameters.

$$SAF\ production\ costs\ = Total\ production\ costs - \ Value\ of\ coproducts$$

$$Value\ of\ coproducts\ = Seling\ price\ of\ coproducts\ \times\ Volume\ of\ coproducts\ produced$$

[21] (CEPCI)

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

[23] 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 EUR/tonne SAF.

ITEM	CURRENT DATABASE / ASSUMPTION	DESCRIPTION
Renewable diesel	(1) & (2) Argus Media (3) & (4) S&P Platts	(1) Argus Media HVO (hydrotreated vegetable oil) FOB ARA range (Class II) USD/t prompt, London close, midpoint, EUR/t, FOB (2) Argus Media HVO (hydrotreated vegetable oil) FOB ARA range (Class IV) USD/t prompt, London close, midpoint, EUR/t, FOB (3) S&P Platts RD-B assessments reflect renewable diesel produced from feedstocks in Annex IX-B of RED. (4) S&P Platts RD-A assessments reflect renewable diesel produced from RED Annex IX-A waste and residue feedstocks, as listed in the Netherlands Energy for Transport register.
Bionaphtha	(1) Argus Media (2) S&P Platts	(1) Average price Bionaphtha FOB ARA over 2024 Converted from $/tonne to EUR/t (2) S&P Platt's Bio-Naphtha FOB NEW Converted from $/t to EUR/t

Table 6: Co-product historical prices from PRAs

4.2.4 Process level assumptions

Due to the widespread acceptance and industry recognition of PRA indices, along with the ease of replicating such data in future years, PRA data is prioritised wherever available. In cases where PRA data is not accessible, publicly available sources are used, with a focus on average European prices from official EU databases, for the reference year. The following assumptions guided this process:

- **Production capacity assumptions:**
  - The production capacity of a SAF facility can vary significantly. Given that these pathways for which back up pricing is applied are not yet widely deployed, the production cost estimates are based on a hypothetical first-of-a-kind facility assumed to be operational in that year.
- **Process design assumptions:**
  - Co-product naphtha will be used in-plant for hydrogen production, if required.
  - 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 the 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.

It is also assumed that all cases will maximise SAF production. More details on how the process was designed for each pathway can be found in the following sections, with the order listed below:

- Power to Liquid (PtL) fuels
- Gasification FT
- Alcohol to Jet (AtJ)

- Renewable and low carbon hydrogen

4.2.4.1 Power to Liquid (PtL) fuels

PtL is an advanced SAF production technology enabling the use of water and electricity for SAF production. The figure below shows the exemplary 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 fed to FT reactor.

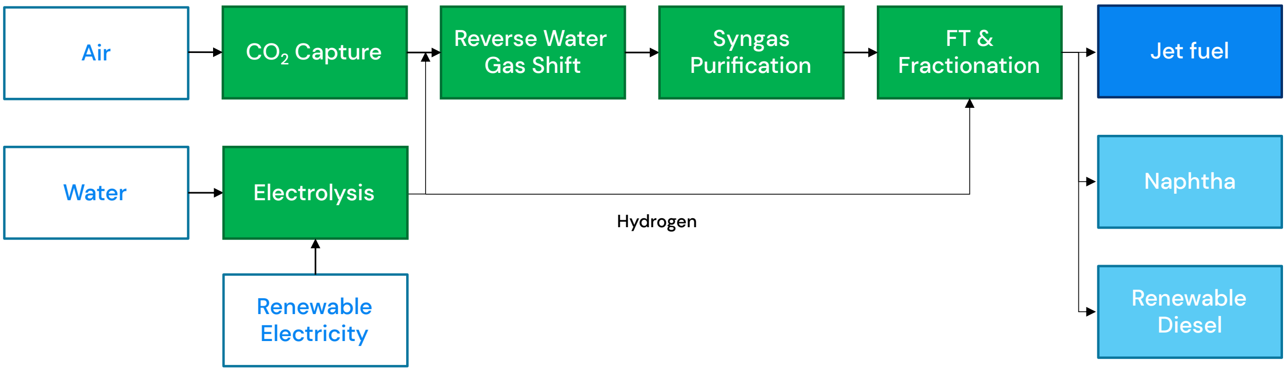


Figure 2: Exemplar process flow of "synthetic aviation fuel" production through FT (DAC

RFEUA subcategories of "Synthetic aviation fuels" and "Synthetic low-carbon aviation fuel" can be produced using this technology. The assumptions used for each subcategory can be seen in the following sections.

Synthetic aviation fuels

"Synthetic aviation fuels" are produced using PSC or DAC technology plus hydrogen production using renewable electricity. For PSC, biological and industrial CO_2 sources are assumed. More details on the assumptions can be found below:

<u>Assumptions for the biological and industrial Point Source CO_2</u>

- Production capacity: 40 kt per year fuel based on a FOAK facility
- 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. The 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[24,25].

<u>Assumptions for the DAC CO_2</u>

- Production capacity: 30 kt per year fuel based on a FOAK facility

[24] (National Energy Technology Laboratory)
[25] (Hughes, et al., 2022)

- 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[26]. The CO_2 capture energy requirements are met through utilising onsite electricity generated in the steam turbine and waste heat. Additional utility electricity and natural gas are required.

For all three CO_2 cases, the CO_2 capture facility is assumed co-located with the fuels facility. The production capacity of PSC CO_2 is higher than the case using DAC, since PSC capacity is based on announced facility sizes and since PSC has higher TRL than DAC. Biological and industrial PSC cases have different assumptions based on the purity of the CO_2 stream.

Synthetic low-carbon aviation fuel

Synthetic low-carbon aviation fuels are similar to the previous subcategory but are derived from hydrogen using non-fossil low-carbon energy, namely, nuclear electricity. Similar to "Synthetic aviation fuels" cost estimation, PSC and DAC variations are considered, as presented below:

<u>Assumptions for the Point Source CO_2</u>

- Capacity: 40 kt per year fuel
- Hydrogen is produced using an Alkaline electrolysis system and using nuclear electricity. The hydrogen facility is assumed to be co-located with the SAF facility.
- Biogenic CO_2 is captured and compressed from an ethanol production facility. The ethanol facility is assumed to be co-located with the SAF facility, so there are no transportation costs considered.

<u>Assumptions for the DAC CO_2</u>

- Capacity: 30 kt per year fuel
- 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[27]. The CO_2 capture energy requirements are met through utilizing onsite electricity generated in the steam turbine and waste heat. Additional utility electricity and natural gas are required.

All of the PtL pathways require a significant amount of electricity, both for hydrogen production from electrolysis and CO_2 capture. The amount of electricity required varies mainly due to the hydrogen production pathway, whether alkaline or PEM electrolysis is used, and the CO_2 capture system used. In all of the PtL cases included above, we have assumed the hydrogen and CO_2 facilities are co-located. In cases where the facilities are not co-located, CO_2 and hydrogen transport would increase the SAF production cost.

4.2.4.2 Gasification FT

The FT process is a method used for producing liquid fuels from gas. In this process, syngas, composed of primarily carbon monoxide (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

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

Waste (MSW), as the feedstock. The following assumptions were used:

Gasification FT, wood waste as feedstock

- Capacity: 90 kt per year fuel
- Feedstock moisture content: 45wt%
    - Used to calculate 97 EUR/wet tonne feedstock from woodchips price option 2 from Argus Media
    - Feedstock is dried before entering the gasifier
- Oxygen cost
    - Option 1 is 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.
- The plant is assumed power balanced since electricity requirement met with electricity generated from steam turbine utilising steam generated throughout process and fuel gas boiler. Off-gas from the process is used in the fuel gas boiler to meet steam and electricity demand.
- No natural gas is required, as Fischer-Tropsch reaction is exoterhmic and FT reactor tail gas is recycled to meet gasification heat requirement.

Gasification FT, MSW as feedstock

- Capacity: 60 kt per year fuel
- Feedstock options:
    - Option 1 is estimated based on the cost to operate a Materials Recovery Facility (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"[28]. The cost is updated to reflect the size of MRF required to meet the fuel plant's feedstock requirement and use EU average electricity pricing. The feedstock price is estimated to be approximately 80 EUR/tonne.
    - Option 2 includes average EU tipping fee[29], lowering the cost to ~21 EUR/tonne.
- Oxygen is needed in the gasifier and the cost of oxygen was modelled considering the use of imported oxygen or onsite generation. Options considered were:
    - 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 are considered since electricity usage of air separation unit varies.
- Plant is assumed power balanced as 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.

[28] (Olafasakin, et al., 2023)
[29] (European Environment Agency, 2024)

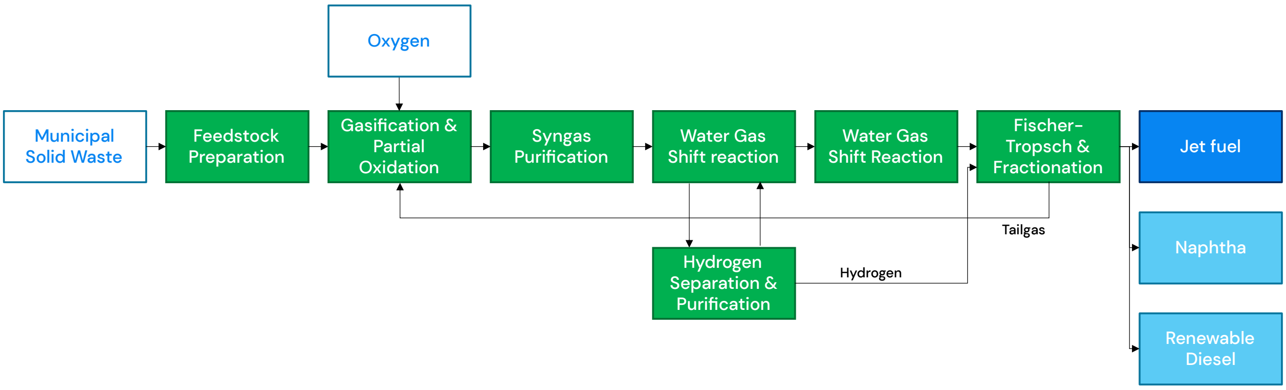


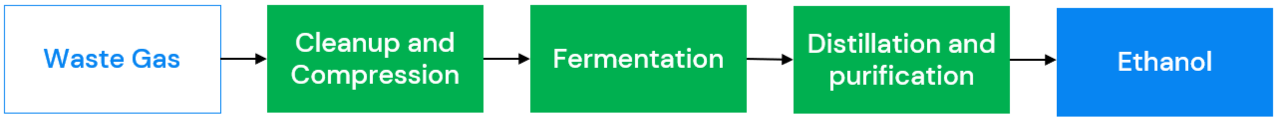
Figure 3: Exemplar process flow of a Gasification-FT process for "advanced biofuel" production (MSW)

Since all gasification FT cases modelled are energy balanced, there are no electricity and natural gas costs for fuel production included in the production cost estimate. Different cases include different feedstock and oxygen pricing, driving differences in the production cost results.

4.2.4.3 Alcohol to Jet (AtJ)

Recycled Carbon Aviation Fuels

Recycled carbon aviation fuels can use a combination of off-gases 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) as inputs to produce low-carbon-intensity 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. The following assumptions were used for the steel mill offgas to ethanol case and the alcohol to jet pathways:

Figure 4: Exemplar process flow diagram of recycled carbon aviation fuel from waste gas to ethanol

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

- Three feedstock prices considered:
  - Feedstock 1 is based on steel mill tail gas stream gas fermentation[30].
  - Feedstock 2
    - Production capacity and CAPEX based on an announced facility in Ghent[31]
    - Process inputs include electricity, water, wastewater treatment, and chemical inputs from literature[32].
  - Feedstock 3
    - Production capacity and process inputs consistent with feedstock case 2.
    - Increased capital cost by 30% to include potential need for potential escalation, contingency, and outside battery limits (OSBL) considerations that may not be included in the initial investment.

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[30] (Zhang, 2024)
[31] (LanzaTech, 2023)
[32] (Handler, 2015)

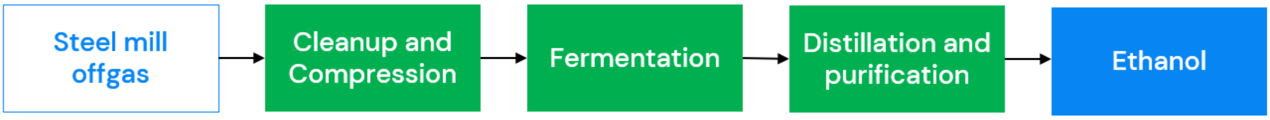


Figure 5: Exemplar process flow diagram of steel mill offgas to ethanol process

Alcohol to Jet with ethanol feedstock

- Production capacity: 30 kt per year fuel based on a FOAK facility.
- Steam generated throughout the process is used in a steam turbine to generate electricity.
- Process off-gas is 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.

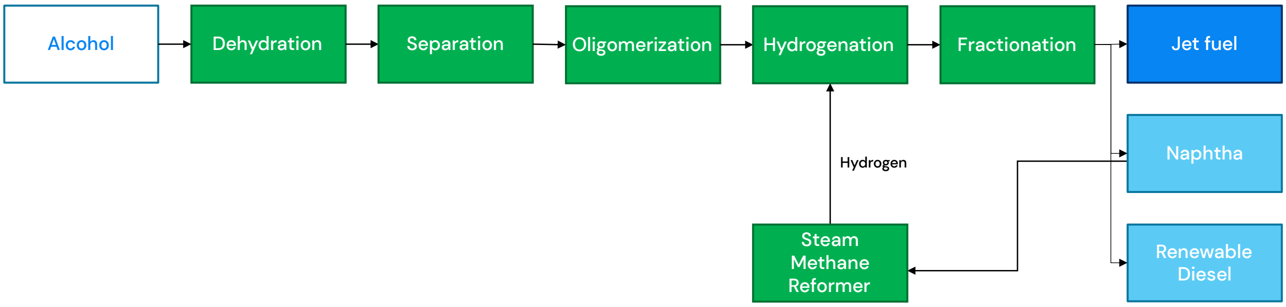


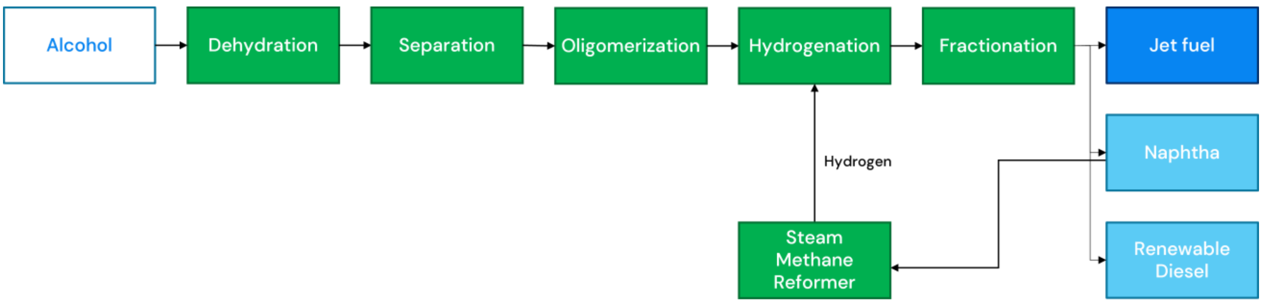
Figure 6: Exemplar process flow diagram of Alcohol to Jet with steel offgas ethanol feedstock (RCF)

Unlike other ethanol feedstock, it was not possible to identify PRA pricing for ethanol captured from steel mills. For this pathway, various ethanol production cost scenarios from steel mill offgas are provided based on available information in literature and the publicly announced cost of the facility in Ghent.

Advanced Biofuels

Alcohol to Jet with ethanol feedstock

- Production capacity: 100 kt per year fuel based on FOAK facilities
- Two ethanol feedstock options for bioethanol using PRA data.
- Steam generated throughout the process is used in a steam turbine to generate electricity.
- Process off-gas is used to offset natural gas required.
- Some of the naphtha co-product is sent to a steam methane reformer to produce the hydrogen needed for hydrogenation.



➡ **Figure 7:** Exemplar process flow of an Alcohol-to-Jet pathway for advanced biofuel production

4.2.4.4 Renewable and low carbon hydrogen

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

Hydrogen pricing from Argus included two cases of hydrogen production using Proton Exchange Membrane (PEM) electrolysis using offshore wind to power the hydrogen facility and without a 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 capital and operating costs of hydrogen production to the hydrogen facility gate

The following assumptions were used for the 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.
- Nuclear electricity prices based on the French Energy Commission.

The hydrogen production cost values used for renewable and low carbon hydrogen were also included in the production cost calculations for synthetic aviation fuel and synthetic low carbon aviation fuel. Hydrogen product costs vary mainly due to electricity pricing and hydrogen technology.

4.3 Interpretation of results

The SAF facilities assessed under the back up pricing approach utilize emerging technologies and are classified as small-scale, first-of-a-kind projects. While this analysis highlights the most promising technological pathways, it does not incorporate potential future cost reductions resulting from economies of scale or advancements in technology.

Production cost estimation serves as the foundation for determining the minimum fuel selling price. Due to the complexities associated with developing SAF facilities, accurately estimating production costs is particularly challenging, especially for technology pathways that were not yet operational in the year preceding the assessment (year *n-1*). The estimates presented here are based on high-level Class 5 CAPEX evaluations, following the AACE cost classification system, and carry an expected accuracy range of -30% to +50%. Achieving more precise cost predictions would require detailed, project-specific and site-specific data. While the production cost estimates are broadly applicable across the EU, it is important to recognise that variable costs, such as utilities, feedstock, labour, and materials, can vary significantly by location.

4.4 Other considerations

4.4.1 SAF conversion assumptions

Fuel conversion refers to the proportion of feedstock transformed into fuel during the production process. For instance, if 100 units of feedstock are processed and 85 units result in usable fuel, the conversion rate is 85%. Selectivity indicates the share of final products that specifically constitutes SAF, as opposed to other co-products. For example, if 40% of the total output is SAF, the SAF selectivity is 40%. Selectivity can vary depending on the production pathway and may evolve as technologies advance and market conditions shift. Although literature provides reference values for SAF selectivity, ongoing technological improvements aim to enhance SAF yields. Moreover, selectivity is influenced by the targeted product split, such as whether a facility prioritizes SAF production or focuses on renewable diesel. The assumptions used in the backup pricing assessment are detailed in the table below.

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

Table 7: Production performance information for respective types of SAF (mass basis)

To produce a tonne of synthetic aviation fuel, it is estimated that 5.89 tonne CO_2 and 0.79 tonne H_2 (including for upgrading) are required.

4.4.2 EU SAF production capacity weighting

EASA is required to establish a single reference price point for each subcategory of RFEUA eligible aviation fuel. This necessitates calculating weighted averages of production cost estimates across various process and feedstock combinations. To ensure feasibility, the analysis uses the characteristics of announced SAF facilities within the EU as the baseline for selecting relevant process and feedstock configurations.

The EU SAF production capacity outlook, prepared annually by EASA, serves as the basis for calculating the weighted average price for each fuel subcategory defined under RFEUA. This outlook relies on announced production facilities within EU Member States that are scheduled for commissioning before 2030. Data collection is carried out through desk research and subsequently verified with national authorities in each Member State. Projects that are paused but not officially cancelled are excluded from the weighted average calculation.[33]

Each subcategory of RFEUA eligible aviation fuel can be produced using different combinations of technologies and feedstocks. However, to determine a single price point, the production cost estimate for each combination is weighted according to its share in the total announced production capacity. Consider, for example, the “synthetic aviation fuel” reference price (P_{syn}):

[33] For more information, please refer to the dedicated methodology document on EASA’s SAF production capacity assessment, which is available on the EASA website.

$$P_{syn} = P_{ind} \times w_{ind} + P_{bio} \times w_{bio} + P_{DAC} \times w_{DAC}$$

Where P_{ind} is the price of synthetic aviation fuels from industrial CO_2, P_{bio} is the price of synthetic aviation fuels from biogenic CO_2, and P_{DAC} is the price of synthetic aviation fuels from atmospheric CO_2 capture.

Currently, all these represent estimated production costs rather than actual index prices. The weightings (w), expressed as percentages (%), are derived from the projected production capacity outlook through 2030.

For instance the weighting of the industrial CO_2 capture to SAF projects (w_{ind}) would be:

$$w_{ind} = \frac{C_{ind}}{(C_{ind} + C_{bio} + C_{DAC})}$$

C_{ind}, C_{bio} and C_{DAC} represent the announced production capacity of industrial, biogenic and atmospheric CO_2 capture to SAF projects in th EU respectively, in million tonnes (Mt) based on the feedstock source, coming online by 2030. Based on the new announcements each year, the weighting might change. For example, currently the weighting for “synthetic aviation fuel” from atmospheric CO_2 is close to zero due to the very limited volume of potential fuel production announced using atmospheric CO_2 as input. However, as the technology matures with time, more facilities may use DAC route and the weighting could increase, affecting the reference price of synthetic fuels.

A similar approach is applied to determine the weighted average production cost for the “advanced aviation biofuel” subcategory, which encompasses a range of production technologies and feedstocks. For instance, processes such as the gasification of MSW or forest residues, and the conversion of ethanol into jet fuel, all fall within this RFEUA category, each with distinct production costs.

5 Application of reference prices under RFEUA

Using the reference prices from the different RFEUA eligible aviation fuels *subcategories*, EASA also determines reference prices for RFEUA eligible aviation fuels *categories*. These are provided to support EU Member States in the determination of penalties under RFEUA, in line with Article 12 of the Regulation.

To determine the reference prices for RFEUA eligible aviation fuels *categories*, the following calculations are applied to the reference prices for RFEUA eligible aviation fuels *subcategories*:

I. The **reference price of CAF (P_{conv})** is the reference price of CAF.

II. The **reference price of SAF[34] (P_{SAF})** is the weighted average price across (1) “advanced aviation biofuels”, (2) “aviation biofuels”, (3) “other aviation biofuels”, and (4) “recycled carbon aviation fuels”, based on the availability of each fuel subcategory in the market during the reference year.”

[34] Note that this excludes synthetic aviation fuels for the purpose of determining penalties under RFEUA

III. The **reference price of synthetic aviation fuels (P_{syn})** is the weighted average price across "synthetic aviation fuels from industrial CO_2", "synthetic aviation fuels from biogenic CO_2" and "synthetic aviation fuels from atmospheric CO_2".

IV. The **reference price of aviation fuels[35] (P_{af})** is the weighted average price of CAF, SAF and synthetic aviation fuels corresponding to the minimum shares of SAF and synthetic aviation fuels outlined in Annex I of RFEUA. The price of aviation fuels is calculated as follows:

$$P_{af} = \frac{(P_{conv} \times V_{conv}) + (P_{SAF} \times V_{SAF}) + (P_{syn} \times V_{syn})}{V_{conv} + V_{SAF} + V_{syn}}$$

where V_{conv} is the fraction of the aviation fuels supplied which is neither SAF (V_{SAF}, the minimum share of SAF from Annex I, in %) nor synthetic aviation fuels (V_{syn}, the minimum share of synthetic aviation fuels from Annex I, in %).

For example, for 2024, V_{conv} is 100%, which corresponds to the total (100%) minus the minimum mandated share of SAF (0%) and the share of synthetic aviation fuels (0%):

$$P_{af\_2024} = P_{conv\_2024} \times 100\% + P_{SAF\_2024} \times 0\% + P_{syn\_2024} \times 0\%$$

For 2025, V_{conv} is 98%, as the minimum mandated share of SAF increases to 2%.

[35] "Aviation fuel" means drop-in fuel manufactured for direct use by aircraft (definition as per RFEUA Article 3(6)).

6 Appendix – Production cost estimation breakdown

The table below provides a cost breakdown of each driver being largely impacted by the technology/feedstock combination

Table 8: Production cost estimations for RFEUA aviation fuel subcategories (feedstock & utility scenarios)

FUEL SUBCATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA[36] FUEL PRODUCED)	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	-	40	12%	82%	0%	1%	6%
		Biogenic point source carbon and Renewable hydrogen price 2 from Argus Media	-	40	13%	80%	0%	1%	6%
		Biogenic point source carbon and Renewable hydrogen price 1 from Platts	-	40	12%	82%	0%	1%	6%
		Biogenic point source carbon and Renewable hydrogen price 2 from Platts	-	40	13%	80%	0%	1%	6%
		Biogenic point source carbon and Renewable hydrogen price 3 from Platts	-	40	11%	83%	0%	1%	5%
		Biogenic point source carbon and Renewable hydrogen price 4 from Platts	-	40	11%	83%	0%	1%	5%
		Atmospheric carbon Renewable hydrogen price 1 from Argus Media	Grid electricity from Eurostat	30	15%	73%	0%	3%	9%
		Atmospheric carbon Renewable hydrogen price 2 from Argus Media	Grid electricity from Eurostat	30	17%	70%	0%	4%	9%
		Atmospheric carbon Renewable hydrogen price 1 from Platts	Grid electricity from Eurostat	30	15%	73%	0%	3%	9%
		Atmospheric carbon Renewable hydrogen price 2 from Platts	Grid electricity from Eurostat	30	16%	71%	0%	4%	9%

[36] KTA= Kilo Tonne per Annum

FUEL SUBCATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA[36] FUEL PRODUCED)	CAPEX	FEEDSTOCK/ HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
		Atmospheric carbon Renewable hydrogen price 3 from Platts	Grid electricity from Eurostat	30	14%	74%	0%	4%	8%
		Atmospheric carbon Renewable hydrogen price 4 from Platts	Grid electricity from Eurostat	30	14%	75%	0%	3%	8%
		Atmospheric carbon Renewable hydrogen price 1 from Argus Media	LCOE electricity price from Argus (the Netherlands)	30	15%	73%	0%	3%	9%
		Atmospheric carbon Renewable hydrogen price 2 from Argus Media	LCOE electricity price from Argus (the Netherlands)	30	17%	70%	0%	4%	9%
		Atmospheric carbon Renewable hydrogen price 1 from Platts	LCOE electricity price from Argus (the Netherlands)	30	15%	73%	0%	3%	9%
		Atmospheric carbon Renewable hydrogen price 2 from Platts	LCOE electricity price from Argus (the Netherlands)	30	16%	71%	0%	4%	9%
		Atmospheric carbon Renewable hydrogen price 3 from Platts	LCOE electricity price from Argus (the Netherlands)	30	14%	74%	0%	4%	8%
		Atmospheric carbon Renewable hydrogen price 4 from Platts	LCOE electricity price from Argus (the Netherlands)	30	14%	75%	0%	3%	8%
		Atmospheric carbon Renewable hydrogen price 1 from Argus Media	LCOE electricity price from Argus (Germany)	30	15%	75%	0%	3%	7%
		Atmospheric carbon Renewable hydrogen price 2 from Argus Media	LCOE electricity price from Argus (Germany)	30	17%	72%	0%	3%	8%

FUEL SUBCATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA[36] FUEL PRODUCED)	CAPEX	FEEDSTOCK/ HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
		Atmospheric carbon Renewable hydrogen price 1 from Platts	LCOE electricity price from Argus (Germany)	30	15%	75%	0%	3%	7%
		Atmospheric carbon Renewable hydrogen price 2 from Platts	LCOE electricity price from Argus (Germany)	30	16%	73%	0%	3%	8%
		Atmospheric carbon Renewable hydrogen price 3 from Platts	LCOE electricity price from Argus (Germany)	30	14%	76%	0%	3%	7%
		Atmospheric carbon Renewable hydrogen price 4 from Platts	LCOE electricity price from Argus (Germany)	30	14%	77%	0%	3%	6%
		Industrial point source carbon and Renewable hydrogen price 1 from Argus Media	-	40	12%	80%	0%	1%	7%
		Industrial point source carbon and Renewable hydrogen price 2 from Argus Media	-	40	13%	78%	0%	1%	8%
		Industrial point source carbon and Renewable hydrogen price 1 from Platts	-	40	12%	80%	0%	1%	7%
		Industrial point source carbon and Renewable hydrogen price 2 from Platts	-	40	13%	79%	0%	1%	7%
		Industrial point source carbon and Renewable hydrogen price 3 from Platts	-	40	11%	81%	0%	1%	6%
		Industrial point source carbon and Renewable hydrogen price 4 from Platts	-	40	11%	82%	0%	1%	6%
		(1) Feedstock price from Material Recovery Facility (MRF) operating costs	(1) Import O_2		31%	29%	17%	4%	19%
			(2) Low end ASU onsite O_2 production		33%	32%	10%	4%	21%
Advanced aviation biofuel	Gasification FT		(3) high end ASU onsite O_2 production	60	35%	24%	17%	4%	20%
		(2) Feedstock price subtracting the European Average tipping fee	(1) Import O_2		39%	10%	21%	5%	25%
			(2) Low end ASU onsite O_2 production		43%	11%	13%	5%	28%

FUEL SUBCATEGORY	PROCESS	FEEDSTOCK SCENARIO	UTILITIES SCENARIO	CAPACITY (KTA[36] FUEL PRODUCED)	CAPEX	FEEDSTOCK/ HYDROGEN	OXYGEN	OTHER OPERATING COSTS	FIXED COSTS
			(3) high end ASU onsite O_2 production		38%	9%	23%	5%	25%
		Forest residue price from Argus Media	(1) Import O_2	90	29%	35%	14%	3%	19%
			(2) Low end ASU onsite O_2 production		32%	38%	7%	3%	20%
			(3) high end ASU onsite O_2 production		30%	36%	12%	3%	19%
	Ethanol to Jet	(1) Platt's ethanol price	-	100	15%	71%	0%	5%	9%
		(2) Argus Media's ethanol price	-		12%	76%	0%	5%	7%
Recycled carbon aviation fuels	Ethanol to Jet	(1) Zhang 2024 ethanol feedstock price (low)	-	30	28%	49%	0%	6%	17%
		(2) Calculated waste ethanol feedstock price based on announced facility (medium)	-		24%	56%	0%	6%	14%
		(3) Calculated waste ethanol feedstock price based on announced facility (high)	-		22%	60%	0%	5%	13%
Renewable hydrogen for aviation	Alkaline and PEM electrolysis	Renewable hydrogen price 1 from Argus Media	-	300 MW			Breakdown not provided		
		Renewable hydrogen price 2 from Argus Media	-	300 MW			Breakdown not provided		
		Renewable hydrogen price 1 from Platts	-	300 MW			Breakdown not provided		
		Renewable hydrogen price 2 from Platts	-	300 MW			Breakdown not provided		
		Renewable hydrogen price 3 from Platts	-	300 MW			Breakdown not provided		
		Renewable hydrogen price 4 from Platts	-	300 MW			Breakdown not provided		
Low-carbon hydrogen for aviation	Alkaline electrolysis	Hydrogen from electrolysis using nuclear electricity	-	300 MW	31%	0%	0%	52%	17%
Synthetic low-carbon aviation fuels	Power to Liquids	Biogenic/Industrial point source carbon and hydrogen from electrolysis using nuclear electricity	-	40	39%	0%	0%	40%	21%
		Atmospheric carbon and hydrogen from electrolysis using nuclear electricity	-	30	41%	0%	0%	38%	21%

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