The role of e-SAF in reaching Net Zero

Key findings of the study carried out by our Working Group dedicated to aviation

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In collaboration with

ERM

NEW ENERGIES

The energies coalition for transport & logistics

Preamble

The need to **tackle climate change** will require **wide-scale emissions reduction** in all sectors of the economy including **air travel**. There are **multiple activities** underway in the aviation sector to drive this reduction, and a **wide range of enabling technologies**. In particular, the **International Civil Aviation Organization** (ICAO) has developed the **Carbon Offsetting and Reduction Scheme** for **International Aviation** (CORSIA), which make it possible for participating parties to reduce emissions through **offsetting** or the use of **Sustainable Aviation Fuels** (SAF).

Among the different SAF pathway options, **e-fuels, produced** from captured carbon dioxide and green hydrogen[1] will have near zero life-cycle emissions, **could play an important role** in the aerospace industry's decarbonisation roadmap set out by ATAG, IATA and ICAO given their potential scalability. These leading aviation authorities and regulatory bodies consider SAF as a **key contributor to reach 'net-zero carbon emissions' by 2050**.

For reasons of technical suitability, all SAF pathways today are limited to a maximum of 50% blend ratio with fossil fuel within the controlling ASTM fuel specification. As a result, there is a need to understand how to enable the use of 100% SAF – thereby removing the need to blend with fossil fuels at all. There is an interest in e-fuels in particular, the production of which is not subject to the availability of biomass feedstocks. Understanding the technical feasibility, costs, deployment, potential constraints as well as the social and environmental impacts of e-fuels (including greenhouse gas (GHG) emissions reduction) is the subject of ongoing research across multiple sectors.

This report highlights the work on the subject done by the New Energies Coalition through one of its working groups led by **Rolls Royce** with the significant contribution of **Airbus, CMA CGM, TotalEnergies**, with analysis conducted by the consultancy firm ERM.

[1] Green hydrogen (GH2 or GH_2) is **hydrogen produced by the electrolysis of water, using renewable electricity**. Source Wikipedia

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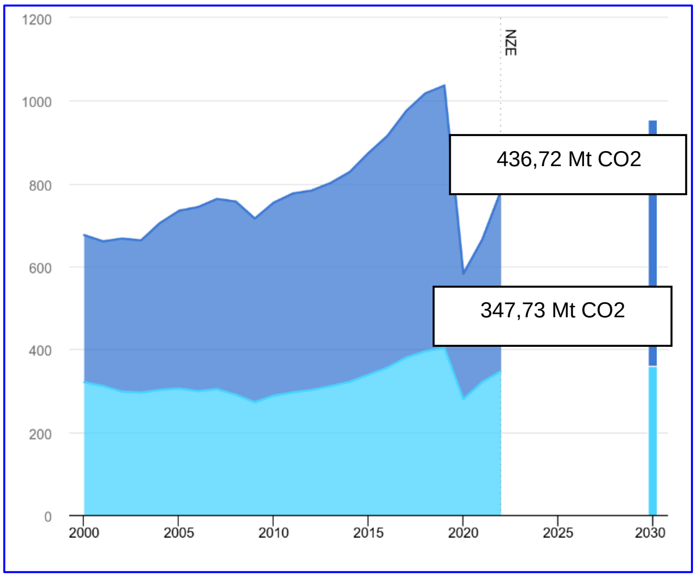
SAF will play a crucial role in the decarbonization of the aviation sector (particularly to 2050) but faces several challenges

According to the International Energy Agency (IEA), air transportation is responsible for ~800Mt of CO_2 emissions (2022), representing approximately **2 to 3% of global human-induced greenhouse gas** (GHG) emissions.



It is important to highlight that **domestic aviation traffic has multiplied by 4 since 1990**, **however aviation emissions have only doubled due to a 50% improvement in the fleet fuel efficiency.**

Figure 1: CO_2 emissions in aviation in the Net Zero Scenario, 2000-2030, in million tons per year
Source: IEA (2023)
https://www.iea.org/data-and-statistics/charts/co2-emissions-in-aviation-in-the-net-zero-scenario-2000-2030
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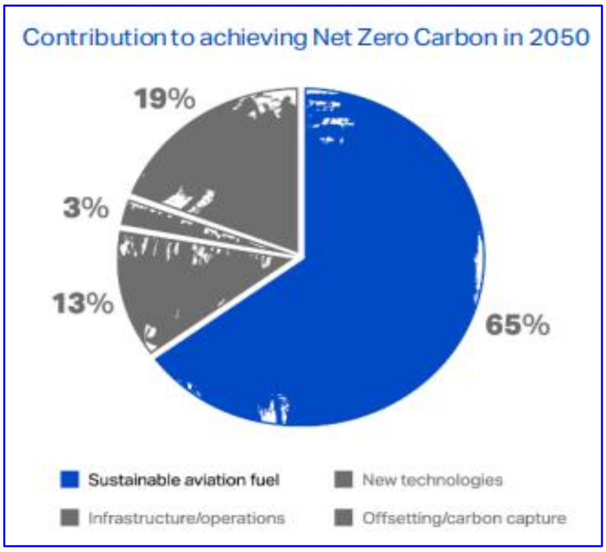
Domestic aviation International aviation

The International Civil Aviation Organization (ICAO) expects aviation CO_2 emissions to grow in the next decades due to increased air travel demand.

To address this challenge and **meet the aviation industry's objective for 'net-zero** carbon emissions' **by 2050**, several complementary levers are being explored: renewal of the current fleet with latest generation aircraft, improvements in operational efficiency, technological innovations for next generation aircraft, carbon offsetting & removal, and... Sustainable Aviation Fuels (SAF). It is widely recognized that SAF will have to play an essential role in this decarbonization journey of the sector, in the short and long term.

IATA estimates that SAF could contribute around 65% of the reduction emissions needed by aviation to reach net-zero in 2050, however, this will require a massive increase in production.

The largest acceleration is expected in the 2030s as policy support becomes global, SAF becomes more economically competitive with fossil kerosene and credible offsets become more scarce.



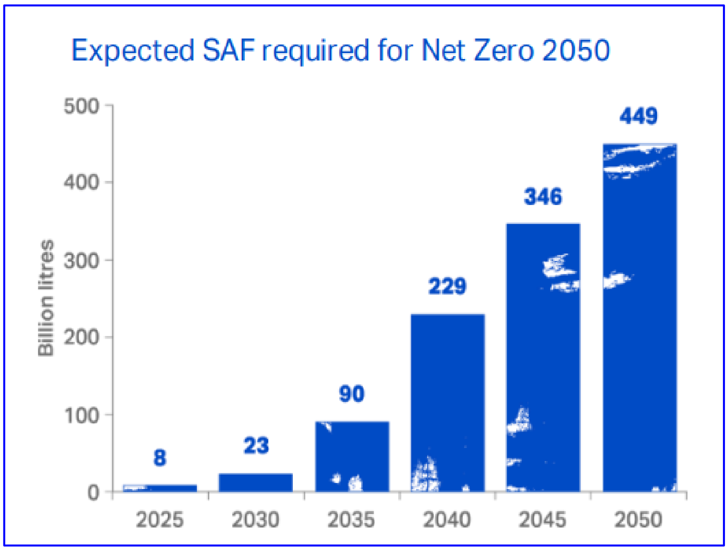


Figure 2 & 3: SAF contribution to achieving Net Zero Carbon in 2050
Source: IATA (2024) https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---alternative-fuels

In 2023, **SAF volumes doubled and reached over 600 million liters** (0,5 MT) up from 300 million liters (0,25 MT) in 2022, but still **only amounting to less than 0,2 % of aviation fuel consumption** for the year.

What is SAF?

Sustainable Aviation Fuel, often abbreviated by SAF, is generally defined as a renewable **fuel** designed for aviation. Current SAF supplies can reduce lifecycle CO_2 emissions by 80% on average compared with fossil-derived jet fuels.

SAF can be produced from **renewable feedstocks,** such as bio wastes (from other industries like agriculture, food, used cooking oil and animal fats, etc…) **("bio-SAF")**. It can also be **produced by capturing carbon dioxide** (from point source or directly from the air) **and combining it with green hydrogen to produce hydrocarbons ("e-SAF").** SAF blended up with a certain % volumes with fossil-derived jet fuel can be directly used in current aircraft without requiring any modifications – the resulting blend is a "drop-in" low carbon fuel (compliant with JET A/A-1 specifications, e.g. qualified under from ASTM D1655 and Def Stan 91-091).

To comply with CORSIA or local regulations (e.g. ReFuelEU Aviation in Europe), SAF must meet certain "sustainability criteria", which aim to ensure that SAF:

- generates lower GHG emissions on a lifecycle basis (at least 10 % compared to a fossil fuel baseline of 89 grams of CO2 equivalent per megajoule (g CO2e/MJ) under CORSIA, or at least 70% compared to 94 gCO2e/MJ under ReFuelEU Aviation
- is produced from feedstocks that are not food crops, and that do not promote land clearing/deforestation, soil productivity loss or biodiversity loss.

To **be considered as "Aviation Fuels"**, SAF must meet the fuel compliance testing requirements specified under ASTM D7566. In addition, the blended SAF fuel mix must satisfy the quality assurance testing based on ASTM D1655/DEF STAN 91-091.

In the context of Sustainable Aviation Fuels (SAF), ASTM International plays a **crucial role** in **establishing standards** and **specifications for the production, blending**, and use of SAF in commercial aviation.

The organization provides a **clear framework** for producers to **develop and scale up** their production processes while **ensuring the fuels** meet **stringent quality** and **performance standards** to ensure **compatibility** with **existing aircraft, engines, and fuel infrastructure.**

ASTM has qualified several pathways to produce SAF, the main ones are (exhaustive list here):

- **Hydroprocessed Esters and Fatty Acids (HEFA-SPK):** This pathway involves the hydroprocessing of feedstocks such as waste oils, animal fats, and vegetable oils to produce jet fuel components. As of today, it is the most mature pathway with production sites up and running in the US, Europe and Asia.
- **Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)**: ATJ-SPK is produced through the conversion of alcohols, such as ethanol or iso-butanol, into jet fuel using a series of chemical processes. These alcohols can be produced from fermentation of sugars obtained from glucose-rich agricultural resources (sugarcane, maize, etc. …) where allowed by the regulation, or from biogenic wastes and residues. The first commercial Alcohol-to-Jet plants have recently started operations.
- **Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)**: FT-SPK is produced using the Fischer-Tropsch synthesis process, which involves converting synthesis gas (mostly a mixture of CO and H2) into liquid hydrocarbons. Synthesis gas ("syngas") is often derived via gasification of biomass and wastes but can also be catalytically generated from CO2 and H2. There is currently very limited production capacity globally for this pathway.

Focus on e-SAF

e-SAF is a **type of sustainable aviation fuel produced through synthetic processes combining carbon dioxide** (CO2) captured from the atmosphere or industrial point sources with hydrogen (H2) obtained from **renewable or low-carbon electricity**.

The main e-SAF production processes are summarized in Figure 4 below.

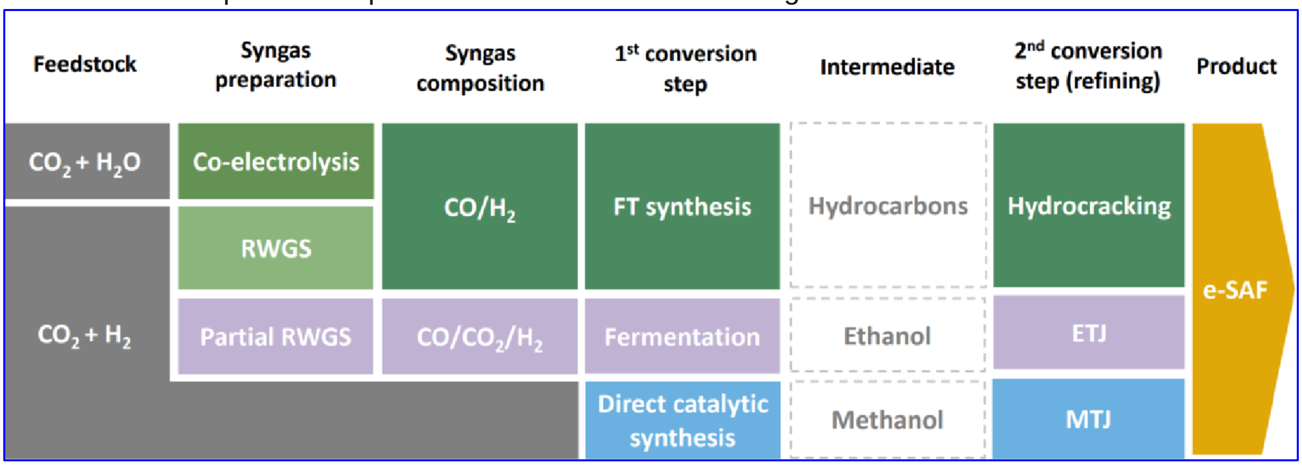


Figure 4: The 4 main pathways to produce e-SAF.
Source: ERM study for the New Energies Coalition (2023)

SAF: main benefits & challenges

Sustainable Aviation Fuels are crucial for reducing greenhouse gas emissions in the aviation sector, diversifying energy sources, supporting a circular economy, and helping the industry meet environmental targets. However, challenges such as feedstock availability, production cost, and policy support need to be addressed for widespread adoption. Research and development are ongoing to make SAF a more viable solution for the industry, via improved availability and lower costs.

Benefits	Challenges
Environment	
Reduced GHG emissions On average, current SAF supplies release 80% [2]less CO_2 than conventional fuels throughout their life cycle **Support for a circular economy** Some SAF production pathways utilize waste materials or by-products as feedstocks	**Feedstock sustainability** Must be sourced responsibly to avoid competition with food production & avoid negative impacts on induced land use change or deforestation.
Production	
Diversification of energy sources Can be produced from a variety of sustainable resources (waste oils, agricultural residues, algae, municipal solid waste…)	**Production** Requires very large investments in new plants. **Feedstock availability** Must be collected in sufficient quantities to produce the volume needed to meet industry decarbonization objectives. **Electrical energy** Very large amounts of green electricity [3]will be required
Aircraft & Infrastructure	
Compatibility with existing aircraft & infrastructure For Drop-in fuels, up to 50% blend with conventional fossil fuels	**Infrastructure development** Blending facilities, fuel distribution from new production location
Regulation	
Compliance with regulations & sustainability targets As international & national policies increasingly focus on reducing GHG emissions, regulations supporting SAF deployment send a "demand certainty" signal to the investors	**Regulatory framework** Lack of consistency and/or stability can create uncertainty for investors and hinder the growth of the SAF industry
Techno- economics	
Job creation and economic benefits New job opportunity in feedstock production, fuel processing, & other related industries	**Production cost** Significantly more expensive than conventional jet fuel **Technology development** To improve efficiency, reduce costs & increase scalability **Competition for resources** Potential for competition around feedstocks, access to low carbon electricity, etc, some of which will be policy driven

[2] Number used by Airbus, based on current production pathways being nominated by HEFA.

[3] Electricity produced from renewable resources such as solar, wind, geothermal, hydroelectric.

All SAF pathways today are limited to a maximum 50% blend ratio with fossil jet fuel, as defined within the relevant ASTM standards. To meet the industry decarbonization objective, this limit will have to be overcome in the future. There is a need to understand how to reach 100% SAF, including e-SAF.

To be fully compatible with existing aircraft and infrastructure ("drop-in"), SAF must be chemically comparable to conventional fossil fuel.

Today, SAF blend components are mainly paraffinic hydrocarbons via the HEFA-SPK pathway, and the aromatic hydrocarbon requirement (8% volume minimum) that is required in the ASTM jet fuel specification comes from the fossil component of the blend. Depending on the properties of the fossil blend component, actually achieving a 50% SAF blend ratio can be challenging. Both density and aromatic content are examples of potential limiting properties.

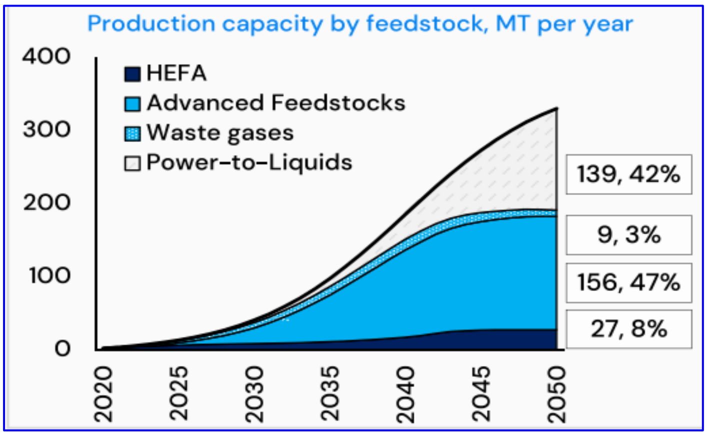
To overcome this limit and ultimately reach fully synthetic sustainable fuel ("100% SAF"), two approaches are possible:

- "sustainable" aromatics will be synthesized (separately or simultaneously with the paraffins) to produce a "100% drop-in SAF"

- aircraft and refueling infrastructure will be adapted to be compatible with fuels with low or no aromatics ("100% non-drop-in SAF" as it requires a new fuel specification).

The industry is currently exploring both options in parallel.

As suggested by most SAF production scenarios, bio-SAF availability will be limited by the availability of sustainable feedstocks, and e-SAF will be needed to supplement bio-SAF industry objectives.



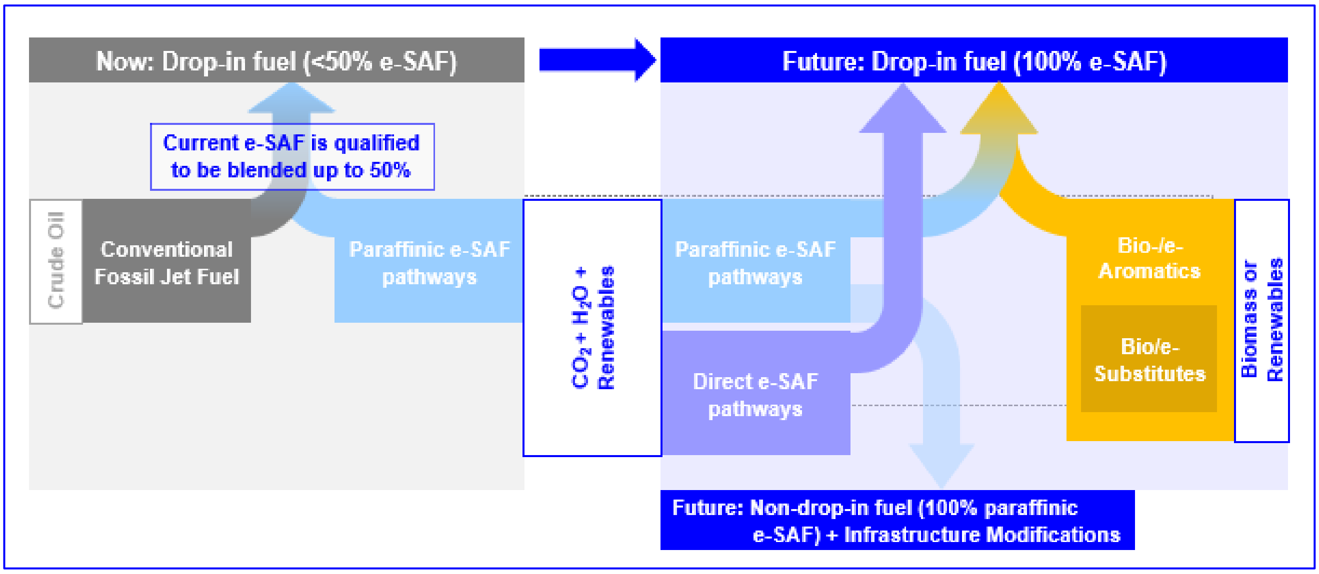
HEFA: 27 MT (8%), Advanced Feedstocks: 156 MT (47%); Waste gases: 9 MT (3%); Power-To-Liquids: 139 MT (42%)

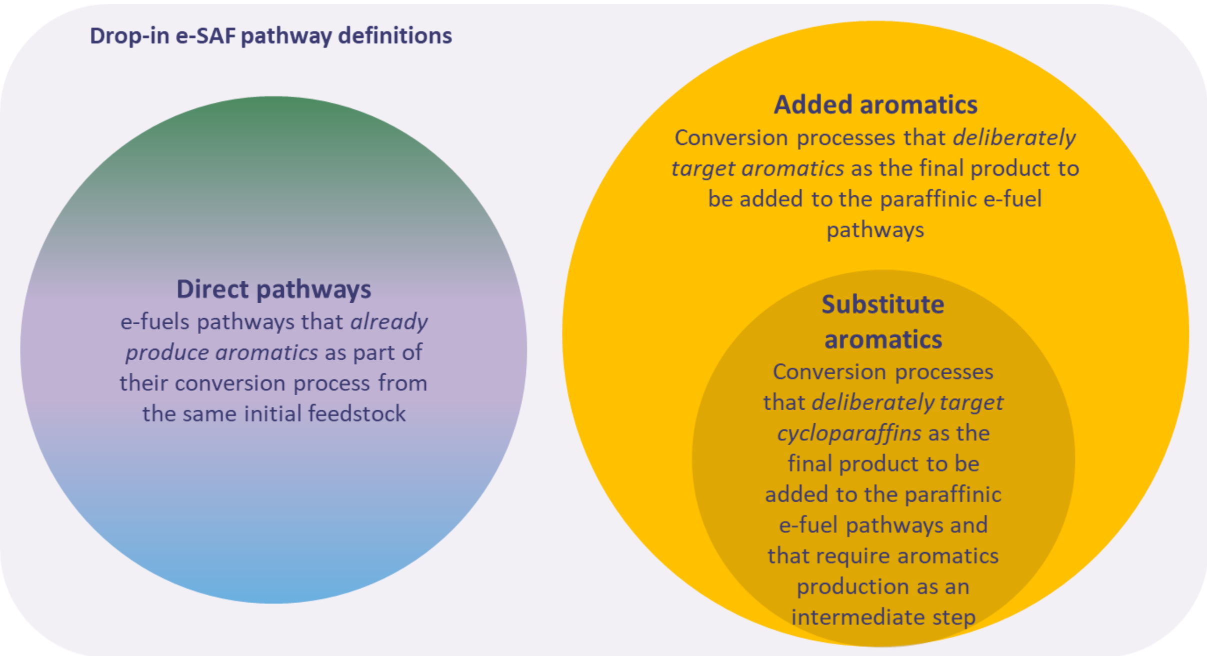
Figure 5: Aspirational & aggressive technology perspective.
Source: ATAG & ICF Scenario 3 https://atag.org/industry-topics/climate-action - https://aviationbenefits.org/media/167495/fueling-net-zero_september-2021.pdf

In this context, and recognizing the limitations, the Coalition study focused on understanding the feasibility and potential of 100% drop-in e-SAF.

100% drop-in e-SAF feasibility

Our study has identified 3 routes to produce 100% drop-in e-SAF - Direct, added aromatics, or Substitute aromatics* – detailed on the figure below:





Figures 6 & 7: 3 groupings of pathways to produce 100% drop-in e-SAF
Source: ERM study for the New Energies Coalition (2023)

Production

Among these 3 main groupings, our study identified several promising pathways for producing 100% drop-in e-SAF, that stood out in terms of technology readiness and level of developer activity – see table below. For each pathway, the levelized production cost and GHG emissions were assessed by ERM using their in-house techno-economic model.

Fuel pathway	Feedstock/main input	Fuel products	Non-fuel co-products	TRL ERM
Direct FT	Renewable electricity via grid	Jet, naphtha, diesel (only MTJ)	Steam	5
Methanol (MEOH) to jet (via MTO)				5-6
Paraffinic FT via RWGS				6
Catalytic reforming of Naphtha (with Capex)	Bio-naphtha from HVO production	Naphtha reformate, LPG	Gaseous hydrogen	7-9
Catalytic reforming of Naphtha (w/o Capex)	e-naphtha as a byproduct of FT synthesis			6-9
Bioethanol to aromatics	2G bioethanol	Liquid hydrocarbon product		6
Hydropyrolysis	Wood chips (50% moisture)		Char, ammonia, steam	5
APR (imported hydrogen)	Lignocellulosic biomass		Steam, electricity	5
APR (hydrogen in situ)			Steam	5

Figure 8: Promising pathways for producing 100% drop-in e-SAF.
Source: ERM study for the New Energies Coalition (2023)

Distribution Infrastructure

The costs and GHG emissions of transporting, storing and distributing SAF or SAF components were compared for the Direct pathways ("D"), the blend of paraffinic and Aromatic (or Aromatics Substitutes) components ("AS"), and Paraffinic-only fuels ("P"), considering waterborne or pipeline modes. The infrastructure steps modelled in ERM's study for these options are illustrated in the figure below:

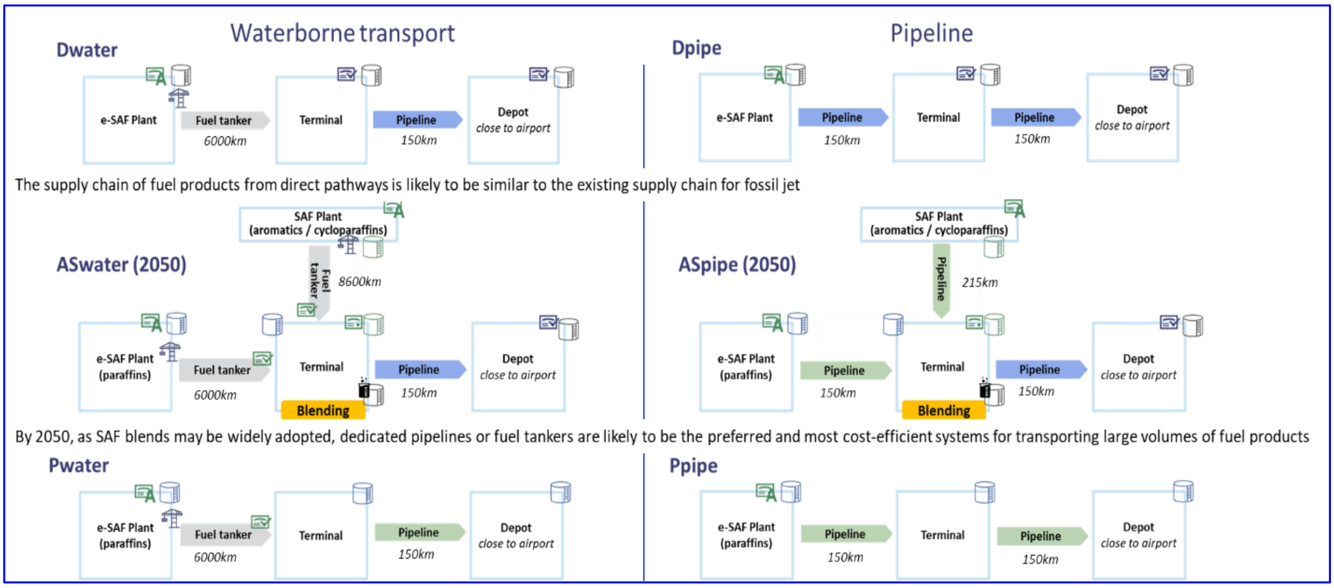


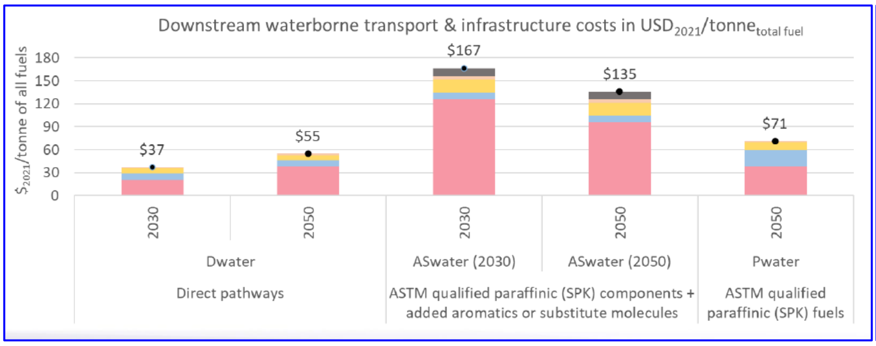
Figure 9: SAF Distribution infrastructure from production to airport depot
Source: ERM study for the New Energies Coalition (2023)

These scenarios were assessed in the years 2030 and 2050, accounting for the costs and GHG intensity of inputs to the transportation and distribution infrastructure expected at these horizons. As the uptake of non-drop-in paraffinic-only fuels is expected to be limited by technical and regulatory readiness, dedicated infrastructure for these pathways is likely to only be developed after 2030, so the Pwater and Ppipe distribution options were only assessed in 2050.

Note that the infrastructure presented here finishes at the depot where the fuel is stored near the airport. Considerable further efforts would be needed for supply chains transporting 100% non-drop-in paraffinic fuels from the depot to the aircraft, whereas the drop-in fuels will be able to use the existing infrastructure between the depot and aircraft.

Economics

For the studied scenarios and the assumptions considered by the study, the costs associated with the transport and distribution infrastructure are small relative to their production costs- see example below for the waterborne transport.



Assumptions	Unit	Value
Distance SAF (paraffins) plant – terminal	km	6000
Distance SAF (aromatics/cycloparaffins) plant – terminal	km	8600
Transport terminal-depot (pipeline)	km	150
HFO price (2030)	$$_{2021}$/t	826
e-methanol price (2050)*	$$_{2021}$/t	1046

Figure 10: Downstream waterborne transport & infrastructure costs.
Source: ERM study for the New Energies Coalition (2023)

These distribution costs were added to the fuel production cost of the selected pathways to determine the fuel "delivered cost", i.e., the cost of the SAF at the airport fuel depot. In the case of non-drop-in paraffinic cost, the additional cost of segregated distribution infrastructure within the airport would need to be added that might have also an impact on GHG reduction and acceptability.

The chart below shows the results for waterborne transport, considering bio-aromatics for the "added aromatics" route.

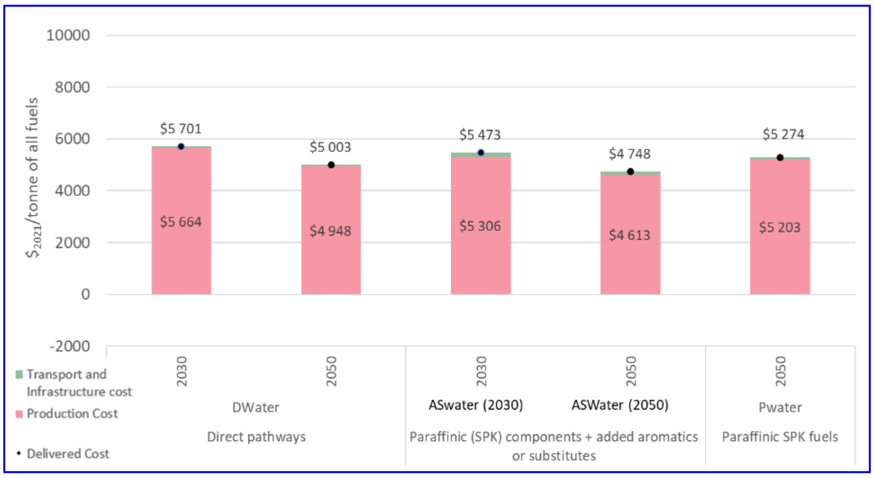


Figure 11: Delivered e-SAF costs via waterborne modes in 2030 and 2050 for the direct, added aromatics and non-drop in paraffinic routes *Source: ERM study for the New Energies Coalition (2023)*

- The transport & infrastructure costs (in green) are small compared to the fuel production cost (in pink).
- Overall within a year, the delivered cost across all pathways is similar with differences that fall within the margin of error.
- Along with the 'direct pathways', another option is to blend aromatics with paraffinic e-SAF. However, when e-aromatics are used instead of bio-aromatics then the blended production cost will be higher than given above. Therefore, the incorporation of bio-aromatics would be a likely first step before the industry aims to develop more sophisticated solutions such as e-aromatics.
- Indeed, projections of aromatics production performed in the frame of this study suggest that if both bio-SPK and e-SPK (paraffinic) routes require external aromatics for blending, there may not be sufficient global supply of renewable aromatics in 2050 to meet industry objectives. There may be a need for more use of Direct pathways, or of aromatic substitutes such as cycloalkanes, or use of non-drop-in fully paraffinic solutions. Competition with other uses of renewable aromatics (e.g. in the chemicals industry) is also likely to occur.

GHG emissions

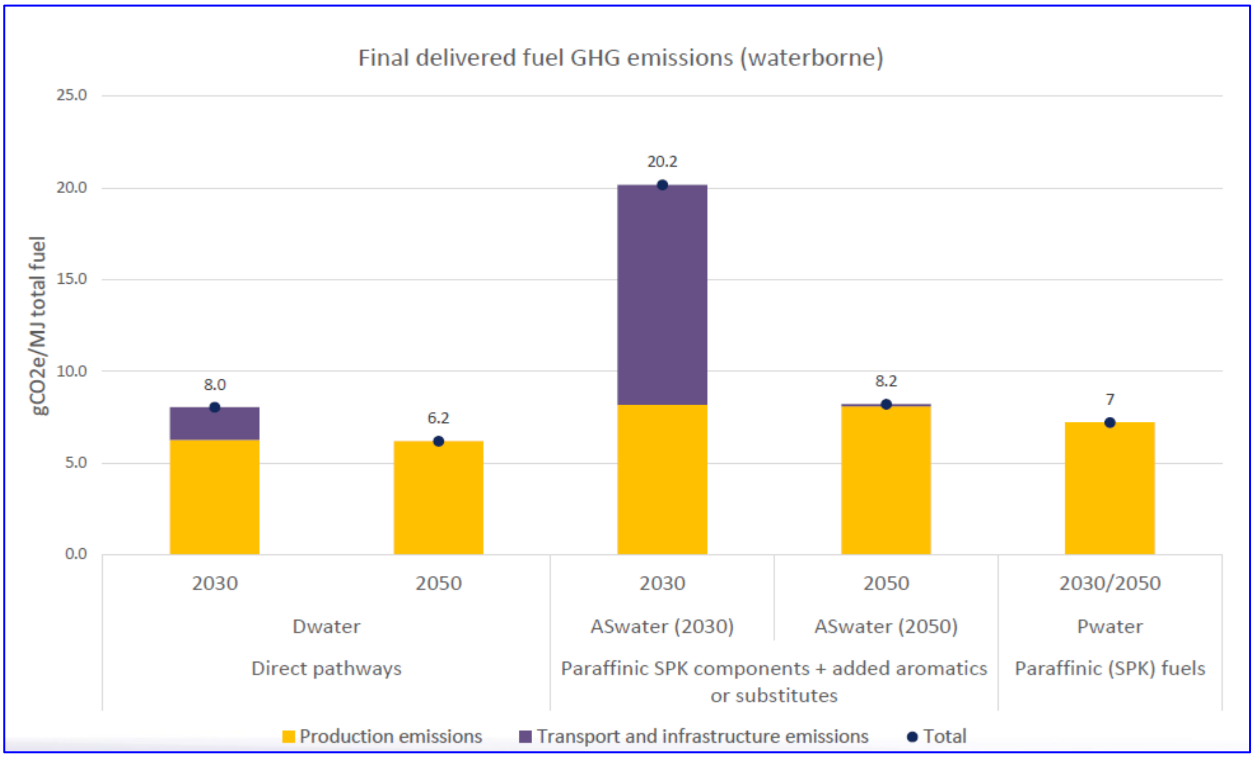


Figure 12: Delivered e-SAF GHG emissions via waterborne modes in 2030 and 2050 for the direct, added aromatics and non-drop in paraffinic routes

Source: ERM study for the New Energies Coalition (2023)

- The aromatics modelled in Figure 12 are produced from biomass feedstocks and may have slightly higher GHG emissions than the e-SAF. For example, bio-aromatics from bio-naphtha via CNR (Catalytic Naphtha Reforming) and 2G bioethanol have ~15 and 14 gCO_2e/MJ_{LHV} respectively (still very low).
- Based on these assumptions, blending bio-aromatics with paraffinic e-SAF may slightly increase GHG emissions compared to drop-in SAF produced via direct pathways. E-aromatics would likely have lower GHG emissions than bio-aromatics, which would slightly reduce the overall production emissions.
- Emissions from distribution are higher for the “added aromatics” route compared to the Direct pathways. This is due to the additional need to transport the blending components to a blending facility before distribution of the final 100% drop-in product. This might be quite penalizing for the “added aromatics” route in 2030 but becomes negligible by 2050 as transportation is assumed to decarbonize as well.

Overview of e-fuels categories

The two tables below summarise the key findings of the study in terms of Technology Readiness Level (TRL), feedstock constraints and ASTM status (Figure 14) as well as fuel production / infrastructure costs, GHG reduction potential and further considerations (Figure 15).

Direct pathways are less mature, but blending aromatics with paraffinic components relies on feedstocks which may have competing demands. In addition, ASTM has a key role, working with engine and airframe OEMs to qualify new SAF pathways.

	e-fuel category	TRL / Level of activity	Feedstock constraints	ASTM Qualification status
		TRL 8-9 and high activity *TRL 5-7 and mid activity* *TRL 1-4 and low activity*	*Low constraints* *Medium constraints* *High constraints*	*Many qualified* *Few qualified/ in progress* *None qualified*
Drop-in	Direct pathways	**TRL5-6**: still at a relatively early stage, with some developers pursuing this space. Projected rate of supply ramp up is expected to be slower.	Do not rely on external feedstocks to obtain aromatic content. Depend on CO_2 and renewable electricity availability.	One ASTM qualified pathway (ATJ-SKA) but limited to <50% blend, others in the process of obtaining qualification
Drop-in	Paraffinic pathways + Added aromatics (A) or substitutes (S)	**(A)** Could utilize technologies present in existing refineries (e.g. CNRs) with feedstock from mature (e.g. HEFA) or maturing (Gasification + FT) routes **(S)** Currently, all pilot/demo stage routes to cycloparaffins have aromatic intermediate products, whilst routes without prior aromatic hydrotreatment are at R&D/lab scale. There still remains significant uncertainty over level of cycloparaffins needed to replace aromatics for seal swelling as well.	**Aromatics & Substitutes** Rely on obtaining feedstocks (e.g. bio or e-naphtha, 2G bioethanol) from other low carbon fuel pathways, which might imply competition for feedstock (and bio-SAF pathways may also need aromatics)	**Aromatics & Substitutes** One 50% ASTM qualified pathway (CHJ), several others in the process of certification **Paraffinic components** Multiple ASTM qualified pathways (max 50%)
Non drop-in	Paraffinic (SPK) fuels	**Paraffinic components** Similar TRL to Direct pathways (5-6), but higher level of developer activity	**Paraffinic components** Same as for Direct pathways	**100% paraffinic fuels:** (due to non drop in nature)

Figure 14: Overview of e-fuels categories: Technology readiness, Feedstock constraints and ASTM Qualifications status.
Source: ERM study for the New Energies Coalition (2023)

All e-SAF are expected to have similar costs and GHG reduction potential, but the direct pathways will have an advantage in terms of ease of fuel transportation and handling.

	e-fuel category	Fuel production costs	Infrastructure costs	GHG emissions reduction potential	Wider sustainability considerations
		Medium production costs *High production costs* *Higher production costs*	*Lower infrastructure costs* *Medium infrastructure costs* *Higher infrastructure costs*	*High reduction potential* *Medium reduction potential* *Low reduction potential*	*Low risks* *Medium risks* *High risks*
Drop-in	Direct pathways	Potentially slightly higher than blending, but within uncertainty margin	Lowest as fewest changes expected to infrastructure	As per paraffinic component below. May have slight benefit in terms of transportation GHGs as only one 'set' of molecules needs to be transported	No high risks identified for any pathways – but there are some considerations related to water and land needs, and usage of mined resources
Drop-in	Paraffinic pathways + Added aromatics (A) or substitutes (S)	Expected to be slightly lower than other two categories as can benefit from use of cheaper bio-based feedstock (but note future competition for bio-based feedstock from bio-SAF and chemicals)	Highest as essentially two 'sets' of molecules need to be transported and stored then blended	**Aromatics & Substitutes** Very good if waste-based biomass used, and renewable hydrogen used for upgrading	For bio-aromatics, impact on water and land usage is highly dependent on feedstock (crop-based vs. waste-based)
Non drop-in	Paraffinic (SPK) fuels	Expected to be similar to Direct Pathways	Higher than Direct but lower than blending	**Paraffinic components** Can be very good if renewable heat used for processing and renewable electricity is used to produce hydrogen and capture CO_2	0 aromatic content potentially beneficial regarding non-CO_2 effects and local air quality

Figure 15: Assessment of e-fuel categories: Production costs, Infrastructure requirements, Emissions reduction potential and Sustainability considerations.
Source: ERM study for the New Energies Coalition (2023)

Conclusions

The quantity of SAF needed to reach net zero globally by 2050 is large, from 330 to 440 Mtonnes per annum depending on the scenario (Source: ATAG/ICF Fuelling Net Zero report).

In the short to medium term **the primary focus will be on bio-SAF** due to its existing technology readiness and emerging commercial scale.

e-SAF is expected to mature at the earliest in the **mid-2030s** and may represent **up to 25%** of total SAF production in 2050.

Based on the current developers and focus of their activities, by 2050, **20%** of e-SAF could be from **direct drop-in pathways**. **Direct drop-in pathways** may become the **preferred choice** as they do not compete for aromatics and are fully compatible with existing infrastructure, but they are not technically mature yet and no industrial scale commercial production is foreseeable in the near future.

The projected supply of aromatics may be enough to enable paraffinic e-SAF to become 100% drop in – however, bio-based aromatics may also be needed for paraffinic bio-derived SAF to become drop-in **and there might be competition for renewable aromatics from other sectors** e.g., chemicals.

The complexity in developing additional infrastructure to use paraffinic/aromatic blends or pure paraffinic fuels is significant, with higher transport and infrastructure costs and GHG emissions expected.

Added aromatics/substitutes will be needed to enable established paraffinic routes **to go beyond current blend levels,** but global production of low carbon aromatics/substitutes may not be sufficient.

For the **fully paraffinic** (non-drop-in) route, uncertainties remain regarding **infrastructure considerations**.

Ultimately **all 3 categories (direct drop-in, added aromatics/substitutes and fully paraffinic non-drop-in) will likely be needed to reach the industry decarbonization objective**, and further development efforts are needed to better understand key uncertainties and accelerate their deployment.

Glossary

- APR**: Aqueous-Phase Reforming** (APR) is a high temperature reforming process using a chemical catalyst to convert sugars (which can be derived from hydrolysis of biomass and wastes) into a mixture of oxygenated compounds, including acids, ketones, aromatics and cyclic hydrocarbons. This intermediate product can then be upgraded to make a range of hydrocarbon products including jet fuel paraffins, aromatics and/or cycloparaffins.
- ASTM International: **ASTM International**, formerly known as American Society for Testing and Materials, is a standards organization that develops and publishes voluntary consensus technical international standards for a wide range of materials, products, systems and services.
- CORSIA: The **Carbon Offsetting and Reduction Scheme for International Aviation** (CORSIA) is a carbon offset and carbon reduction scheme to lower CO_2 emissions for international flights, to curb the aviation impact on climate change. It was developed by the International Civil Aviation Organization (ICAO) and adopted in October 2016.
- CNR*:* **Catalytic Naphtha Reforming** (CNR) is a process used to convert low octane naphthas into high-octane gasoline blending components called reformates. Reforming is the total effect of several reactions that occur simultaneously including cracking, polymerization, dehydrogenation, and isomerization.
- ETJ: **Ethanol-to-Jet** is a catalytic process for dehydration of ethanol (typically derived from feedstocks such as corn, sugarcane or wastes) into ethylene, followed by oligomerisation and hydrotreating to produce jet fuel.
- MTJ: **Methanol-to-Jet** s a catalytic process that converts methanol (a simple alcohol that can be derived from various biomass sources, natural gas or renewable electricity and CO2) into short-chain olefins (such as propylene and ethylene), followed by oligomerisation and hydrotreating to produce jet fuel.
- FT: **Fischer-Tropsch** (FT) synthesis is a catalytic process used to produce hydrocarbons from synthesis gas, a mixture of carbon monoxide and hydrogen. Any FT waxes generated are hydrotreated to produce shorter-chain hydrocarbons, such as jet fuel.
- GHG: **Greenhouse Gas Emissions** (GHG) emissions from human activities intensify the greenhouse effect. This contributes to climate change. Carbon dioxide (CO_2), from burning fossil fuels such as coal, oil, and natural gas, is one of the most important factors in causing climate change.
- IATA: The **International Air Transport Association** (IATA) is a trade association of the world's airlines founded in 1945. In addition to setting technical standards for airlines, IATA also organized tariff conferences that served as a forum for price fixing.
- ICAO: The **International Civil Aviation Organization** (ICAO) is a specialized agency of the United Nations that coordinates the principles and techniques of international air navigation and fosters the planning and development of international air transport to ensure safe and orderly growth.
- LPG: **Liquefied Petroleum Gas** (LPG) is a mixture of butane and propane, proportions of which are dependent on the season.
- MTO: **Methanol To Olefins** (MTO) is an intermediate process step to produce jet from methanol (see MTJ definition).
- RWGS: The **Reverse Water-Gas Shift** (RWGS) reaction is a chemical process that converts carbon dioxide (CO_2) and Hydrogen (H_2) into carbon monoxide (CO) and water (H_2O).
- SAF: **Sustainable Aviation Fuel** (SAF) is a type of fuel designed to power aircraft with a reduced carbon footprint compared to conventional fossil-based aviation fuels.
- SPK*:* **Synthetic Paraffinic Kerosene** (SPK) is a type of Sustainable Aviation Fuel produced through various chemical processes to create a high quality, renewable jet fuel. SPK is designed to be compatible with conventional jet fuel and when blended, can be used in existing aircraft engines and infrastructure without modifications.
- TRL: **Technology Readiness Levels (TRL)** is a metric used to assess the maturity level of a particular technology. Each pathway is evaluated against the parameters for each TRL and is then assigned a TRL rating. There are nine technology readiness levels, with TRL 1 as the lowest (theoretical concept) and TRL 9 (fully commercialised) the highest. More info here

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