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The e-SAF market: Europe’s head start and the road ahead

Can Europe deliver on its e-kerosene ambitions?

The e-SAF market: Europe’s head start and the road ahead

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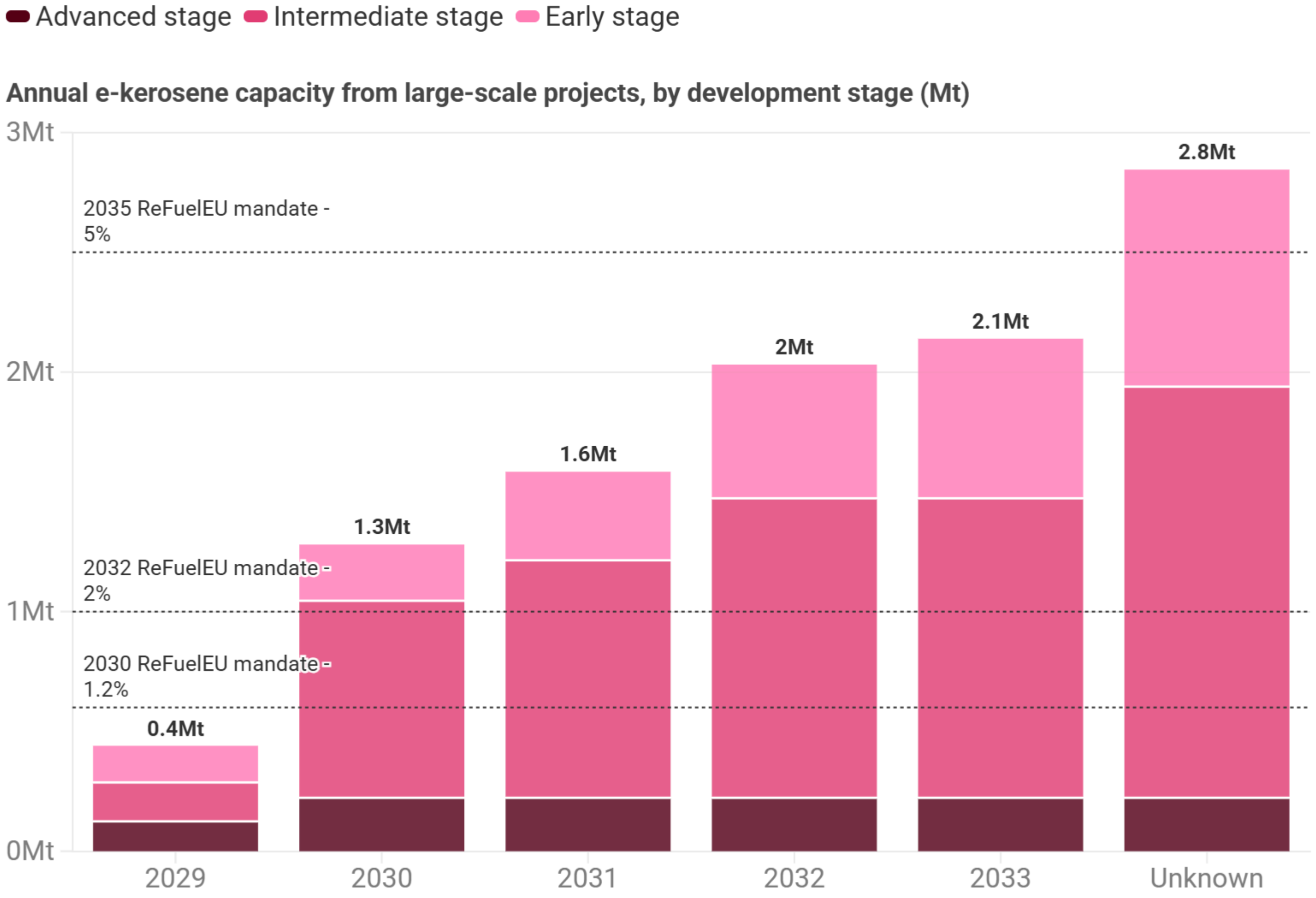
Executive summary

Sustainable Aviation Fuels (SAFs) are expected to play a critical role in aviation's decarbonisation. In 2023, **the EU adopted the world's most ambitious SAF mandate (ReFuelEU), including sub-targets for synthetic fuels produced from renewable hydrogen and carbon.** These e-fuels — referred to interchangeably as **e-SAF** or **e-kerosene** in this report — are the most scalable and sustainable form of SAF. Under the ReFuelEU mandate, at least 1.2% of all jet fuel supplied to EU airports must be e-kerosene by 2030, increasing to 35% by 2050.

No large-scale e-SAF facility — with a production capacity above 10,000 tonnes of e-kerosene per year — is operational yet, but ReFuelEU has successfully triggered a wave of project announcements. As of May 2025, **41 large-scale e-SAF projects are under development in Europe** (up from 27 in January 2024), making it the region with the most projects in the world. These 41 projects have a potential combined production capacity of **2.8 million tonnes per year**, close to three times the annual volume required by ReFuelEU by 2032.

ReFuelEU targets achievable with announced production, but time is running out for FIDs



Source: T&E (2025) • Mt = million tonnes. Early stage (conceptualisation, feasibility), Intermediate stage (pre-FEED), Advanced stage (FEED, pending FID). Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025. 2030-2035 ReFuelEU targets have flexibility mechanisms.

However, these projects are maturing rather slowly: most are still in intermediate stages of development, and **none have reached a Final Investment Decision (FID)** — a crucial milestone in shifting these projects from paper to reality. Although it is still feasible to meet ReFuelEU's 2030 target with these 41 projects, this is dependent on more FIDs being secured within the next 12 to 18 months.

While **Europe accounts for more than half of the world's announced e-SAF production capacity,** other regions are also stepping up — particularly China, where 11 large-scale plants are in development, mainly led by state-owned energy companies. Although the United States has far fewer projects on the cards, the world's largest e-SAF offtake agreement to date and the first FID for a large-scale project were secured by US start-ups.

A number of factors make Europe a favourable location for e-kerosene production: a unique and binding e-SAF mandate that creates strong demand, and **one of the cleanest electricity grids in the world,** which gives European projects a cost advantage under the current regulatory framework.

However, European projects face multiple hurdles, which have so far kept most of them confined to the planning stages. These include perceived **regulatory uncertainties**, particularly around enforcement mechanisms and the upcoming 2027 review of ReFuelEU, which is seen as vulnerable to industry pressure to weaken or delay SAF targets. Additional barriers include renewable energy and CO_2 bottlenecks, as well as structural challenges linked to historical fuel suppliers controlling the existing jet fuel infrastructure.

Financing remains the most significant hurdle, with each plant requiring **€1-2 billion in capital**. Start-ups have taken the lead in project development, stepping into a role that should have logically been held by incumbent fuel suppliers. This developer profile, combined with the lack of binding offtake agreements from airlines, makes these projects appear high-risk to banks and other potential investors.

To unlock FIDs in time and preserve its head start on e-SAF, the EU should focus on establishing targeted public funding mechanisms that facilitate offtake agreements, reduce risks, and lower project costs. The **Sustainable Transport Investment Plan (STIP)** is the perfect opportunity to design such mechanisms, which could take the form of **a market intermediary using double-sided auctions**, funded by revenues from the EU Emissions Trading System (ETS). Lastly, in light of the upcoming review of ReFuelEU, it is essential that policymakers **maintain the existing ambition of the e-SAF mandate** and avoid losing precious time by reopening settled debates.

With targeted action such as this, the EU will be well positioned to meet its 2030 target and build a globally competitive e-kerosene industry, delivering climate, industrial, and energy security benefits.

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Introduction

Sustainable aviation fuels (SAFs) are essential to cutting emissions from aviation, one of the most carbon-intensive and fastest-growing forms of transport. **But not all SAFs are equally sustainable.** E-kerosene (referred to interchangeably as e-SAF throughout this report) offers the greatest potential. If made with additional renewable electricity and CO_2 captured directly from the atmosphere, it can be highly scalable. It avoids the land-use impacts, indirect emissions, and feedstock constraints associated with other types of SAFs, such as biofuels, and can reduce lifecycle emissions by over 90%.

In addition to its sustainability credentials, e-kerosene presents a compelling industrial case for Europe. Its production relies on green hydrogen and captured CO_2, making it **a key driver for the continent's growing hydrogen economy** and a catalyst for scaling electrolysis capacity and carbon capture infrastructure. At the same time, by enabling domestic fuel production, it supports Europe's goal of reducing dependency on imported fossil fuels and **strengthening its energy independence.**

The global market for e-kerosene is developing rapidly. Following the adoption of the ReFuelEU Aviation regulation, which mandates jet fuel suppliers to deliver growing shares of SAF (including a binding sub-target for e-SAF) to EU airports, a wave of projects were announced across Europe. However, other markets are catching up. Some of the world's largest announced projects are located in China, and the first FID for a large-scale e-SAF plant as well as the largest e-SAF offtake agreement to date were secured by US-based start-ups. Meanwhile, several early European projects have encountered delays or been cancelled.

2025 and 2026 will be critical years for Europe's e-kerosene ambitions. While the European SAF mandate has only been in place for a few months, pushback from airlines and fuel suppliers is already mounting based on claims that there will not be enough e-SAF (and SAF more generally) to comply with the mandate in 2030. However, in last year's edition of this report, T&E modelling demonstrated the feasibility of reaching the required volumes by 2030, if all planned projects in Europe went ahead. The challenge was not a lack of announced projects, but the difficulty in getting them to Final Investment Decision (FID) in the face of financing hurdles, and difficulties to secure offtakes. One year later, that same assessment still stands.

This report provides **an updated overview of the European e-kerosene market, now complemented by a broader global perspective** to offer a comparative lens on where Europe stands. In an attempt to deliver one of the most comprehensive overviews of e-kerosene projects currently available, the analysis draws on multiple data sources, including insights gathered from interviews with industry stakeholders, public announcements, as well as existing databases like BloombergNEF, Argus Media, and T&E's previous report on e-kerosene projects.

The report identifies key bottlenecks across regulation, finance, and infrastructure, and evaluates whether existing support mechanisms are sufficient to unlock the investments needed. It offers policy recommendations to ensure Europe harnesses the full potential of e-kerosene as a pillar of its sustainable aviation and industrial strategy.

Section 1

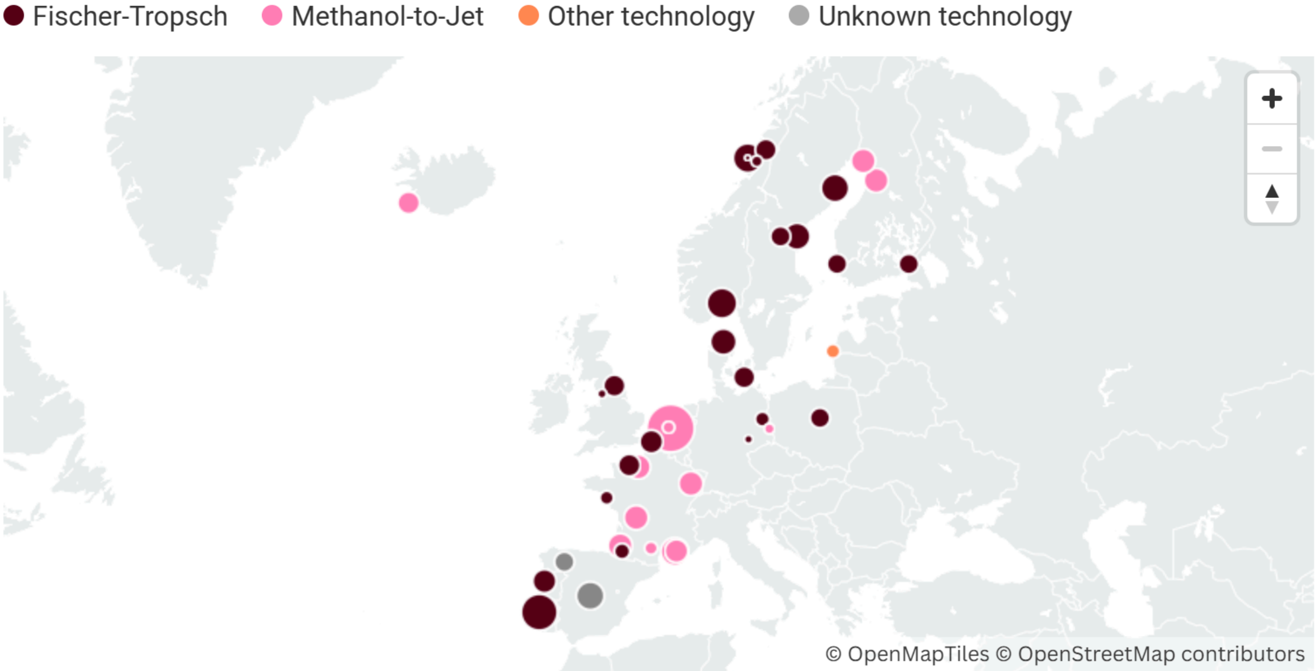
Global market overview and trends

1. Europe’s e-kerosene project landscape

1.1. Despite cancellations and delays, Europe’s e-kerosene project pipeline keeps expanding

Europe’s e-kerosene project pipeline keeps expanding

Large-scale e-kerosene projects where dot sizes represent annual production capacity



Source: T&E (2025), based on Bloomberg (2025), BNEF (2024), Argus (2024), Stratas (2024) and conversations with producers • Locations approximative and estimated for projects with unknown site. Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025.

Between 2024 and early 2025, **16 large-scale e-SAF projects — with a production capacity above 10,000 tonnes of e-kerosene per year — were paused or cancelled,** among them several flagship initiatives like the Hyskies project led by Shell and Vattenfall, or Orsted’s Green Fuels for Denmark. However, that setback was offset by the announcement of **new projects**, bringing the total number of large-scale projects in Europe to **41,** compared to 27 in our previous analysis (including UK-based projects). In addition, we identified 14 smaller commercial-scale plants (capacity of more than 100 and up to 10,000 tonnes of e-kerosene per year), among them Solarbelt’s and Ineratec’s operational plants in Germany, as well as 12 ongoing research projects, bringing the total project count to **67 projects**.

As a result, **the total announced production capacity of Europe’s e-kerosene pipeline has increased by 60%** from 1.8 Mt in the previous edition (with an additional 0.06 Mt/yr of capacity from ORLEN's project that we missed in last year's tracker) to 2.8 Mt. The average project size now reaches a projected **70,000 tonnes of e-kerosene capacity per year,** reflecting a trend towards larger facilities.

Of the 41 announced projects, **19 aim to be operational by 2030**, with a combined output of 1.3 Mt per year. This potential 2030 output has decreased by **25% compared to last year's estimate,** reflecting delays in project development and more realistic timelines. While delays are rarely officially communicated, it is now clear that most projects aim for a production start from 2030 onwards, once the ReFuelEU e-kerosene sub-mandate kicks in — not before.

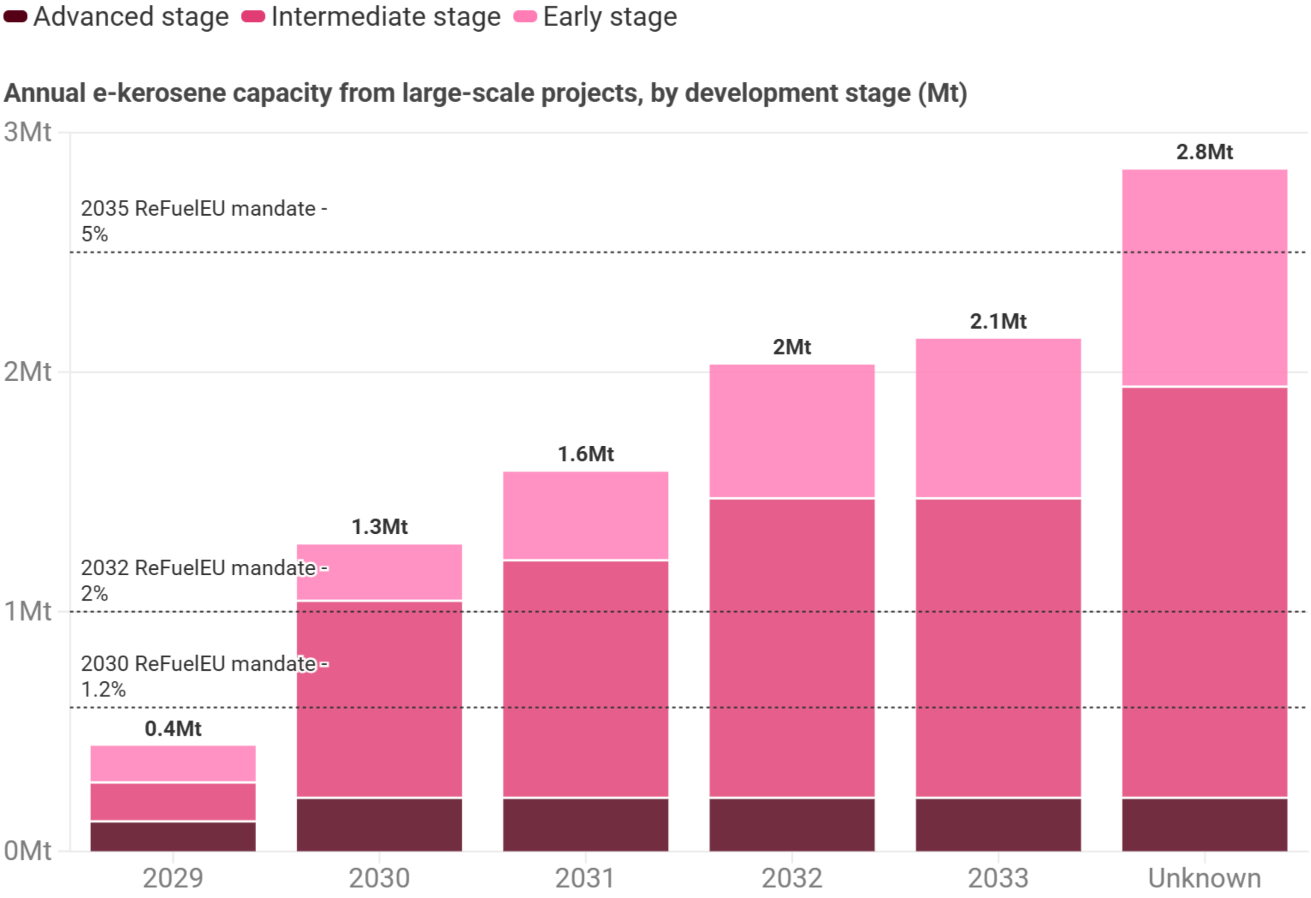
1.2. With only four European large-scale projects at advanced stage, Europe risks missing the ambition set by the ReFuelEU and UK SAF mandates

With 41 large-scale projects aiming to produce up to 1.3 Mt of e-kerosene by 2030, and 2.0 Mt by 2032, Europe could, in theory, largely meet the ReFuelEU mandate (0.6 Mt/yr by 2030 and 1 Mt by 2032) as well as the 2030 UK SAF mandate (<0.1 Mt/yr through 2032). However, a significant challenge persists: **none of these projects has reached a Final Investment Decision (FID),** a critical milestone for moving from planning to construction. Without FIDs within the next 12-18 months, the targets will be missed.

More than 30% (0.9 Mt) of the total volumes announced are still in early stages of development, with projects either in pre-feasibility or feasibility phases. The majority of projects are at an intermediate stage of development, particularly the pre-FEED (Front-End Engineering Design) phase. **Only four large-scale projects, representing just 0.2 Mt of e-kerosene, are in the advanced stages,** either undergoing the FEED phase (Verso Energy's project DéZiR, Norsk e-Fuel's project Mosjøen, Elyse Energy's project BioTJet) or pending FID after completing their FEED (Arcadia eFuels' project ENDOR).

While the pipeline of projects in the advanced and intermediate stages could, in theory, meet these mandates, **it is essential that first FIDs occur in 2025 or early 2026 at the latest.** Since commercial-scale e-fuel plants typically require three to four years to build and commission after FID, delays beyond this timeline could result in a significant shortfall in production capacity, making the achievement of the 2030 target increasingly uncertain unless targeted support mechanisms are deployed.

ReFuelEU targets achievable with announced production, but time is running out for FIDs



Source: T&E (2025) • Mt = million tonnes. Early stage (conceptualisation, feasibility), Intermediate stage (pre-FEED), Advanced stage (FEED, pending FID). Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025. 2030-2035 ReFuelEU targets have flexibility mechanisms.

Infobox: Project development milestones

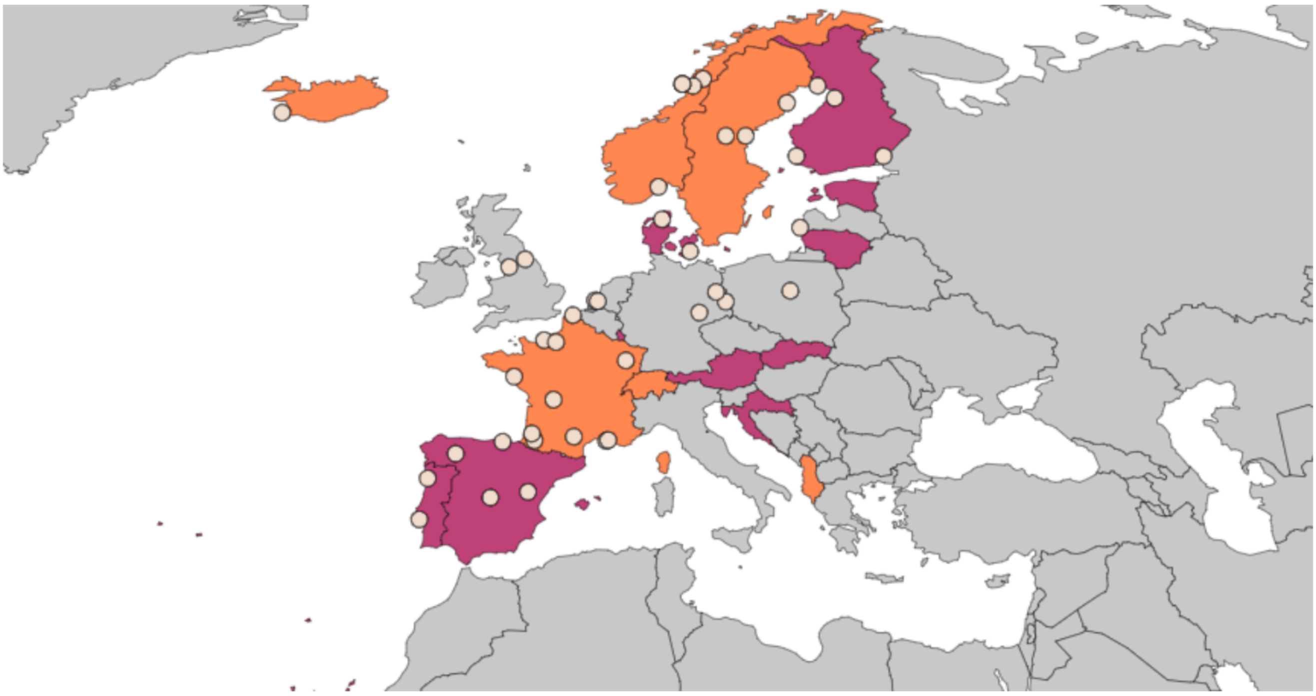
- **Feasibility study** (~1 year)**:** Assessment of whether a project is technically and economically viable (assess feedstock availability, conversion technology, market demand, policy/regulatory framework, and high-level cost estimates).
- **Pre-FEED (Pre-Front End Engineering Design)** (1-2 years)**:** Covers preliminary engineering, site selection, stakeholder consultations, permitting strategy, environmental assessments, and early cost estimates.
- **FEED (Front End Engineering Design)** (~1 year)**:** Detailed engineering and design work that reduces technical and financial uncertainties.
- **FID (Final Investment Decision):** The formal decision to invest into and build the project. There is no set duration, but **reaching FID can take at least 3-4 years from the feasibility study**. Once an FID is made, **construction begins and takes another 3-4 years**. This explains the urgency of securing FIDs by 2026 if the first European drops of e-kerosene are to reach the European market by 2030.

1.3. Project announcements are concentrated in countries with access to cheap, low-carbon electricity

European large-scale e-kerosene projects are primarily located in countries with low grid carbon intensity

Countries: 🟧 Has low-carbon grid in 2025 🟪 Expected to have low-carbon grid by 2030

Projects: ○ Location of large-scale e-kerosene project



Source: T&E (2025), based on Ember (2025) for CI values and Hydrogen Europe for 2030 projections • Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025.

The location of e-kerosene projects across Europe is closely tied to the availability of low-carbon and affordable renewable electricity. Under the EU's Delegated Acts on Renewable Fuels of Non-Biological Origin (RFNBOs), regulatory requirements vary based on the carbon intensity and composition of the electricity grid. These rules apply to Europe as well as to the rest of the world.

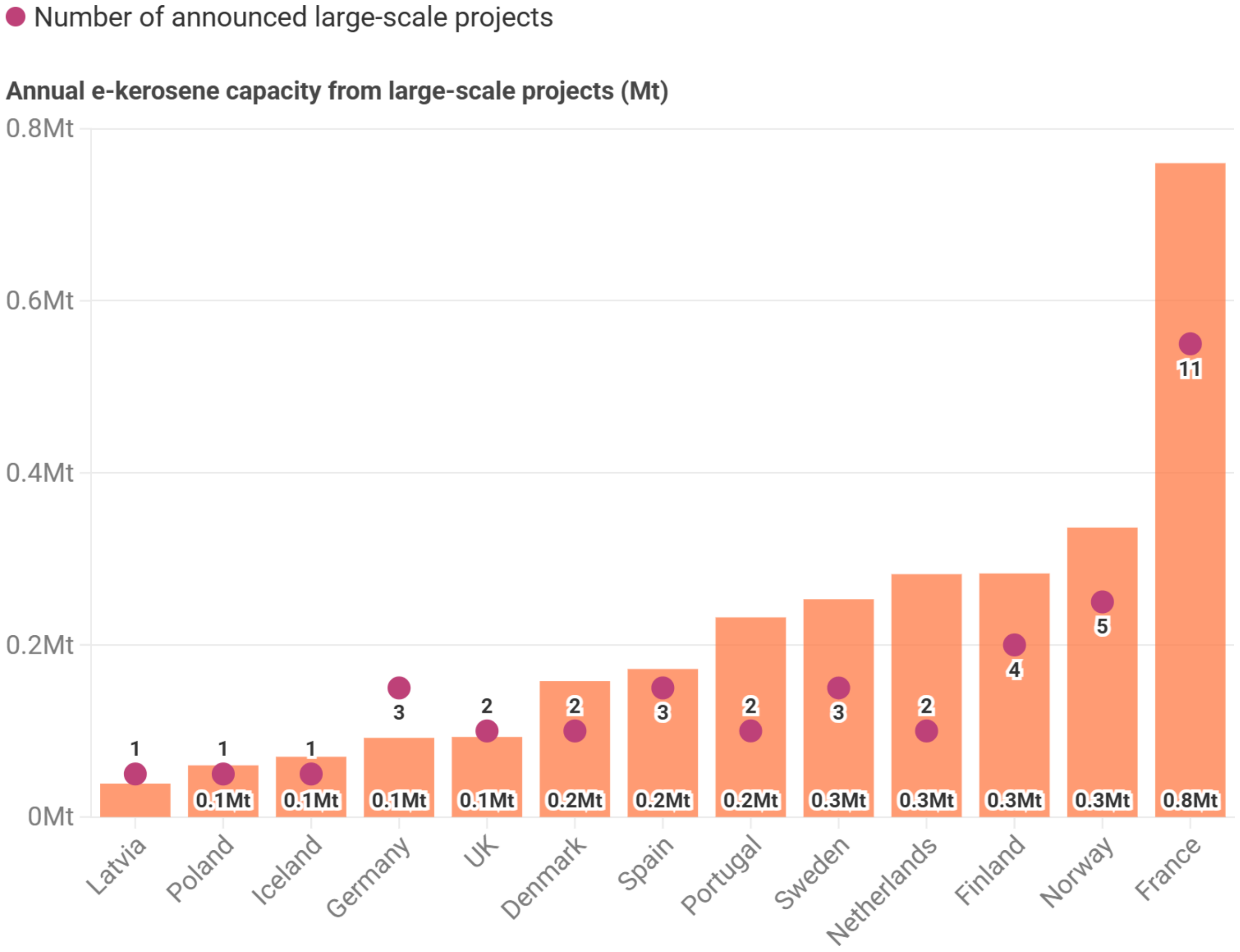
- Projects in countries with **low-carbon grids** (emitting less than 18 gCO$_2$eq/MJ electricity) – such as Norway, Sweden and France – are exempt from **additionality rules**, meaning they do not need to source electricity from *new* renewable capacity. However, they must still sign **Power Purchase Agreements (PPAs)** – long-term contracts that guarantee the supply of renewable electricity at agreed prices – with existing renewable facilities to qualify as RFNBOs.
- Alternatively, projects located in countries with low-carbon grids can operate fully on-grid without renewable PPAs but will then qualify only as **Low-Carbon Fuels (LCFs)**, not

RFNBOs. LCFs can be used to meet the ReFuelEU sub-mandate. According to the EU Aviation Safety Agency (EASA), these fuels could on average be 30% cheaper to produce than standard RFNBOs, further reinforcing the competitive edge of countries with low-carbon electricity.
- Projects in countries with **over 90% renewable electricity** (such as Norway) benefit from the most flexible conditions: they can use grid electricity without PPAs and still be considered RFNBO-compliant.

These regulatory flexibilities significantly reduce complexity and cost, making certain locations far more attractive for e-kerosene project developers.

France leads the way for e-kerosene production in Europe

European countries by announced annual e-kerosene production capacity



Source: T&E (2025) • Mt = million tonnes. Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025.

France is attracting by far the largest number of projects in Europe, with enough e-SAF production capacity to meet the EU's 2030 e-SAF mandate alone. In just one year, the number of French projects and their combined output have doubled. One third of the projects developed in

France are led by a single company – Verso Energy. This surge is driven by structural advantages: a low-carbon electricity mix that bypasses additionality requirements, good biogenic CO_2 availability, open jet fuel infrastructure (see section 2.5), and government support, including a €100 million funding program targeting FEED studies.

The Nordic countries remain very attractive for e-SAF project developers. **Norway** is still a key player, with some of the continent's most mature projects led by Norsk e-Fuel. Its nearly fully renewable grid (>90%) is a major asset, removing the need for PPAs, but project progress is increasingly hindered by grid congestion and rather restricted access to existing jet fuel infrastructure. **Finland**, which was not on the map one year ago, has entered the scene as an attractive location, supported by a grid projected to be low-carbon by 2030. **Sweden** saw the cancellation of three flagship projects: HySkies (Shell & Vattenfall), SkyFuelH2 (Sasol & Uniper), and the St1/Vattenfall venture. Yet new initiatives by Norsk e-Fuel and SkyNRG show continued interest in Sweden as its core strengths (a renewable-heavy grid and cheap electricity) still make it attractive for project developers.

Denmark, though impacted by the cancellation of Ørsted's "Green Fuels for Denmark" initiative, remains a key location with two major projects, including Arcadia eFuels' ENDOR project, one of the only projects in Europe to have completed FEED. The Danish grid is expected to become over 90% renewable within the next few years. Meanwhile, despite some cancellations linked to grid congestion issues, **the Netherlands** are hosting a new project jointly developed by Power2X and Advario that plans to transform imported e-methanol into e-SAF.

Portugal is home to a couple of large-scale projects from Smartenergy. The Portuguese grid is on track to be more than 90% renewable by 2030, and the country already benefits from some of the continent's lowest solar energy costs, making it highly attractive for developers aiming to minimise production costs and regulatory hurdles.

Germany's production capacity is impacted by the uncertain future of the joint project between DHL, HH2E and Sasol due to the bankruptcy of HH2E. Only three large-scale projects remain, including Concrete Chemicals, which received a €300 million government subsidy. This lack of large-scale projects can be explained by several factors including high electricity prices, restricted infrastructure access in parts of the country (see section 2.5), and inconsistent policy signals, including the cancellation of national Power-to-Liquid (PtL) quotas and €2 billion in subsidy cuts.

However, Germany is a leader in Europe when it comes to the first commercial-scale e-SAF plants as well as research and demonstration projects. For example, one of the first commercial-scale e-SAF plants in Europe was built by Solarbelt in 2023 and started operating in June 2024. It aims to reach its full capacity with around 300 tonnes of e-fuel per year from 2026. In June 2025, Ineratec inaugurated **the largest e-SAF plant to date in Frankfurt**, with the capacity to produce up to 2,500 tonnes of e-fuel, including a large share of e-SAF. The German Aerospace Center (DLR) is currently building a Technology Platform for Power-to-Liquid Fuels

(TPP) in Leuna, with a capacity of 2,500 tonnes of e-fuel per year. DLR received €130 million in public funding for the construction of the facility.

Spain is gaining interest from project developers, but grid congestion is reported to be a major issue. Developers like Solarig are tapping into the Spanish agricultural residue potential, launching two SAF projects combining biomethane with green hydrogen. **Italy** remains absent from the map, likely because of a high cost of renewable energy and a lack of government support.

A few projects are developed in Eastern Europe. In **Latvia,** Avia Solutions Group plans to produce e-SAF via the Alcohol-to-Jet pathway. In **Poland**, ORLEN's HyFly project will make e-SAF via the Fischer-Tropsch pathway, enabling both companies—already jet-fuel suppliers—to cover part of their ReFuelEU Aviation SAF mandate. In **Estonia**, the Port of Tallinn and Protio have formed a joint venture that is assessing the feasibility of local e-SAF production.

Focus: can the UK fulfill its PtL mandate with domestic production?

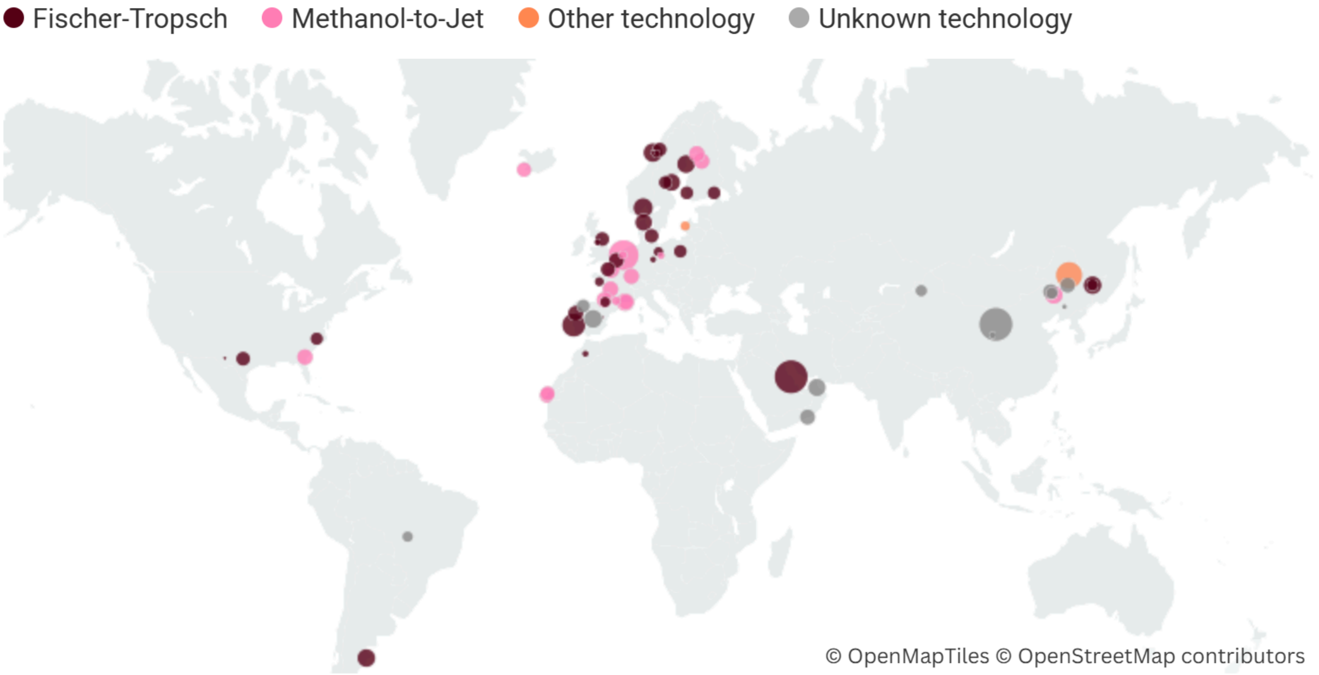
With only two large-scale projects – one led by Carbon Neutral Fuels targeting 25,000 tonnes of e-kerosene by 2031, the other led by Arcadia eFuels targeting 70,000 tonnes of e-kerosene in the early 2030s, the UK's e-SAF targets (0.2% or around 25,000 tonnes annually starting in 2028, reaching 0.6% or around 65,000 tonnes as of 2030) seem impossible to achieve with domestic production alone. Even if these two projects come online, additional capacity will be required to meet the UK's steadily increasing e-SAF mandate, which rises to around 150,000 tonnes per year by 2034.

At the same time, the British airline group IAG has concluded offtake agreements with US-based e-fuels startups Twelve and Infinium set to start before 2028, with an average annual offtake volume of 63,500 tonnes per year. This is likely enough to largely meet the UK SAF mandate's PtL obligation from 2028 to 2030, provided the e-SAF produced by these companies is imported to the UK.

2. Global perspective: driven by the EU and UK mandates, Europe has positioned itself as a frontrunner for e-kerosene development

Announced e-kerosene production primarily in Europe and China

Large-scale e-kerosene projects where dot sizes represent annual production capacity



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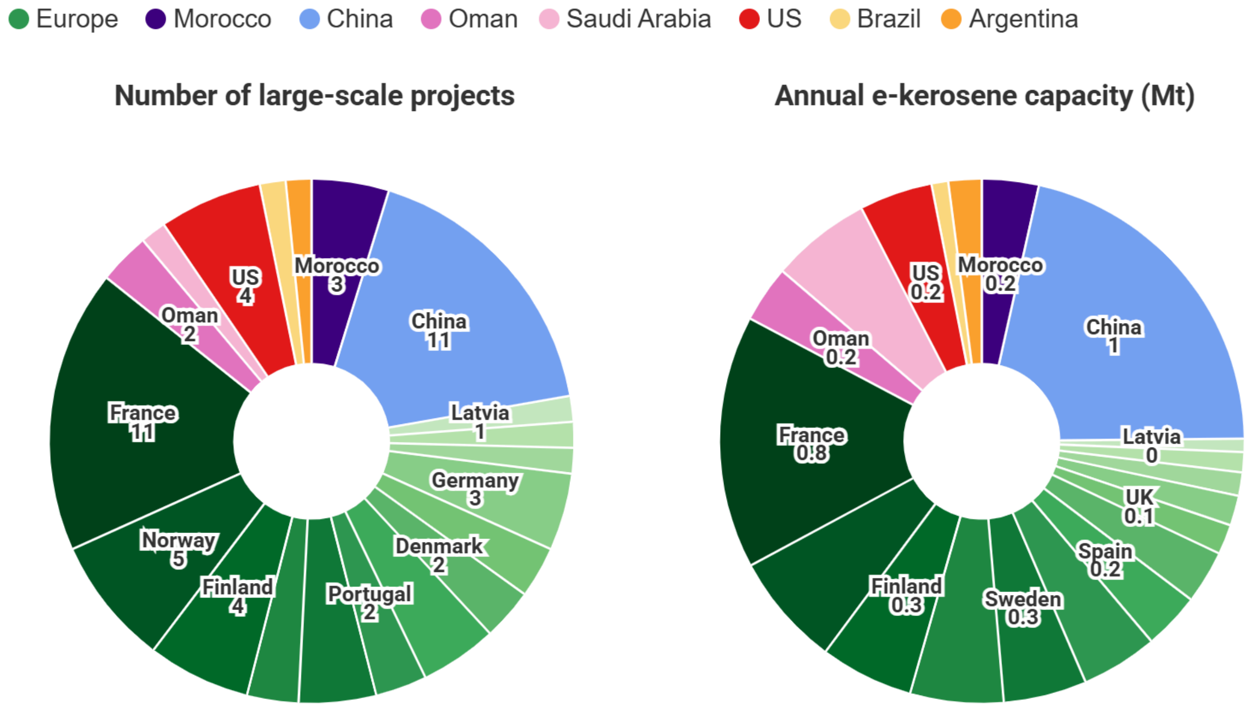
We identified 23 large-scale e-SAF projects under development outside of Europe, bringing the global number of announced projects to **64**. Seven extra-European projects are due to be operational by 2030 – bringing the total number of projects due to be operational by 2030 to 26 (including European projects). Driven by ReFuelEU and the UK SAF mandate, **European projects account for more than half of the global announced production capacity.** China follows as the second-largest hub, representing around 20% of global capacity.

If all the announced projects became operational, global production capacity could reach **2.1 Mt by 2030,** and **5.0 Mt in total** (i.e. roughly 10% of EU jet fuel demand)**.** However, to T&E's knowledge, except for Infinium's Project Roadrunner in the US, none of these projects, be that in Europe or abroad, has reached a FID, and timelines remain uncertain.

Global announced e-kerosene production capacity reaches 10% of European jet fuel demand



Source: T&E (2025) • Mt = million tonnes. Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025.

In Asia, **China is emerging as a key country for e-SAF production** with a growing number of large-scale projects, mainly led by state-owned enterprises. For example, China's State Power Investment Corporation (SPIC), one of China's largest state-owned energy companies, aims to invest nearly $6 billion to produce up to 400,000 tonnes of SAF and methanol, including a large share of e-SAF, in Qiqihar in the Heilongjiang Province. To lay the groundwork for this, a smaller demonstration plant with 10,000 tonnes of SAF capacity using a novel conversion pathway is under construction.

A number of Chinese projects are likely Power-and-Biomass-to-Liquids (PBtL) projects aiming to gasify solid biomass such as straw, with the added benefit of providing biogenic carbon for the process. China's e-SAF scale-up coincides with national programs like **the Green Low-Carbon Advanced Technology Demonstration (GLATD) initiative,** through which the central government is assigning to state-owned companies the task of building large hydrogen demonstration plants (including a number of HEFA SAF plants using green hydrogen).

The United States hosts a comparatively much lower number of projects, highlighting the effectiveness of the EU's mandate-based approach in driving early market development. While the Inflation Reduction Act (IRA) provides significant tax credits (such as hydrogen credits worth up to €850 per tonne of e-fuel and carbon capture credits worth up to €150 per tonne), these incentives are insufficient to make the cost of e-kerosene competitive with cheaper biofuels or fossil jet fuel.

Without a binding mandate, e-SAF consumption in the US depends on uncertain voluntary demand from airlines and corporate buyers. Moreover, the future of the IRA subsidies is uncertain, as the US House of Representatives passed a bill which will end the hydrogen tax credits as of 1 January 2026. This demonstrates how stable mandates are key to complement subsidies and/or tax credits.

That said, the IRA subsidies improve(d) the competitiveness of US-based projects compared to their European counterparts. **Some of the largest e-SAF offtake agreements to date were concluded by US-based start-ups Twelve and Infinium**. Two of these deals were signed with the European airline group IAG and were at least in part driven by European demand-side mandates. In May 2025, Infinium announced a FID for its Project Roadrunner in Texas, scheduled to start operation in 2027. With 23,000 tonnes of e-fuels capacity per year, it is one of the first large-scale projects in the world to reach this stage, marking a significant milestone for the e-kerosene market.

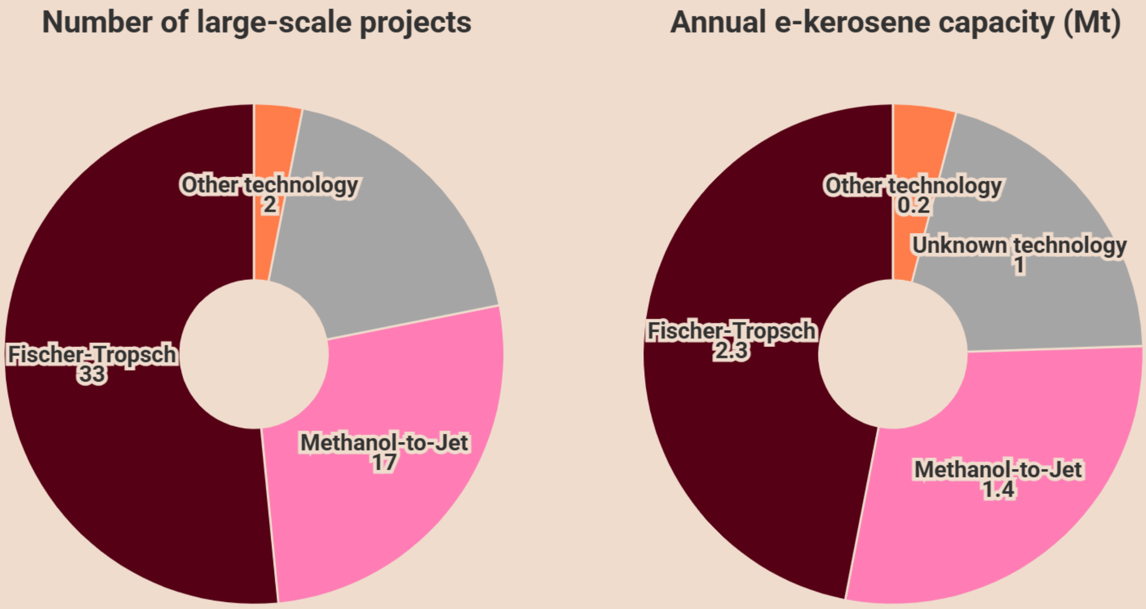
The Middle East is emerging as another potential e-SAF production hub, with at least three projects under development in Oman and Saudi Arabia, not accounting for MoUs which are too uncertain for the time being. For example, the OSCAR consortium, which is composed of six companies including Airbus, is assessing the feasibility of producing e-gasoline and e-SAF in Oman. While the Middle East offers lower renewable energy prices, significant challenges remain for e-SAF projects in this region, including the relatively low availability of biogenic carbon, which is key to complying with ReFuelEU. Moreover, because electricity grids there are fossil-dependent, projects located in the Middle East also need to comply with rules on additionality and temporal correlation.

We identified two large-scale e-SAF projects **in South America**: Sempen's project Grosso in Brazil as well as GreenSinnergy's project Eco-Refinerías del Sur in Argentina.

Infobox: E-kerosene projects broken down by technology

On the technological front, most projects use the **Fischer-Tropsch (FT)** pathway. It converts syngas – a mix of carbon monoxide and hydrogen, typically derived from captured CO_2 and green hydrogen – into liquid hydrocarbons. It is the most established conversion pathway – developed 100 years ago and first commercialised in 1936 – but comes with trade-offs: for example, it typically yields more co-products (like e-diesel and e-naphtha) than other pathways, although some technology providers now license technology with 100% e-SAF selectivity.

Most projects still planning to use Fischer-Tropsch, but Methanol-to-Jet is gaining traction



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Seven large-scale Fischer-Tropsch projects pursue the **Power-and-Biomass-to-Liquids (PBtL)** pathway: they use the same Fischer-Tropsch technology but instead of purely relying on green hydrogen from electrolysis they mix green hydrogen with biomass-derived hydrogen and carbon. This enhances carbon conversion efficiency compared to a process without green hydrogen input, but biomass supply constraints will likely limit its broader deployment. This process produces a mix of biofuels and e-fuels.

At the same time, the **Methanol-to-Jet (MtJ)** pathway is gaining traction. It involves converting e-methanol into synthetic jet fuel through a series of catalytic reactions. The MtJ pathway offers broader offtake opportunities, as the e-methanol intermediate can be diverted to the shipping and chemicals industry. However, MtJ is not yet certified under ASTM standards for aviation fuel – a gap that should be addressed to enable its deployment at scale.

ReFuelEU and the UK SAF mandate are technology-neutral when it comes to e-fuels: all these technologies are eligible under European regulations.

Section 2

Challenges and opportunities for e-kerosene production in Europe

This section draws conclusions from a series of interviews conducted by T&E with a number of project developers. It provides an overview of the main technical, political and financial challenges currently facing the development of e-kerosene projects in Europe. Despite these hurdles, the section also highlights significant opportunities for a domestic production of e-kerosene, including Europe's strong policy framework and renewable energy potential.

1. An ambitious regulatory framework, weakened by rumours of revision, implementation delays, and grey areas

1.1. The e-kerosene submandate creates crucial market demand but the 2027 review introduces perceived uncertainty

Europe has built a world-leading regulatory framework for e-SAF. The EU's ReFuelEU Aviation Regulation and the UK's SAF mandate stand out as unique globally in that they establish specific targets for e-SAF, unlike other SAF mandates, which generally encompass all types of alternatives to fossil fuels and no specific provision for e-SAF. These subtargets are crucial, as they guarantee a minimum level of demand for e-kerosene, which is significantly more expensive to produce than bio-SAF and would otherwise struggle to compete.

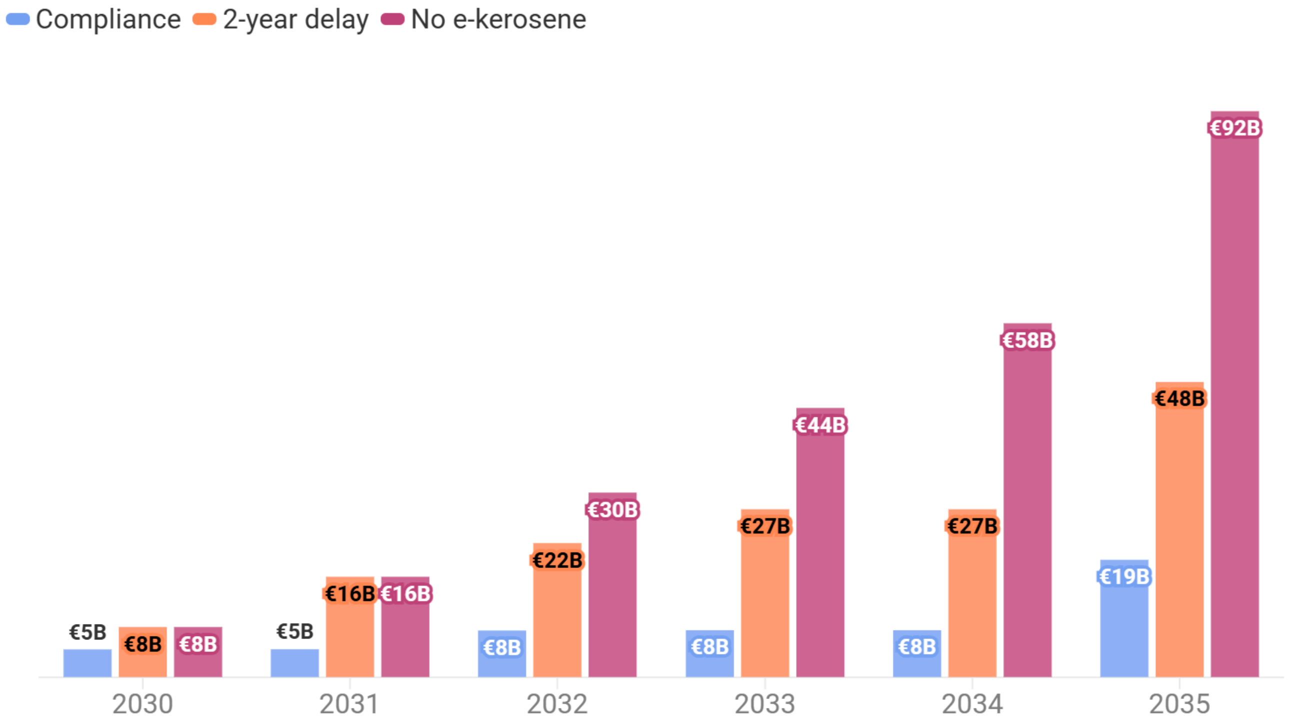
The early impact of these policies is already visible: as shown in section 1 of this report, around half of global e-kerosene production volumes are located in Europe. Maintaining the level of ambition of the mandate is vital to cementing Europe's leadership in this nascent market.

However, ReFuelEU is scheduled for a review in 2027 – a very common practice for EU legislation. While **a review does not automatically imply a revision,** the mere possibility is perceived as a source of uncertainty among stakeholders. The European Commission has, in several instances, publicly stressed that the review will focus on measures to support the SAF market, rather than adjusting the targets. To bolster market confidence and dissuade attempts to weaken the mandate, European decision-makers should continue to publicly reaffirm their commitment to the current targets and ensure consistent messaging ahead of the 2027 review.

1.2. The ReFuelEU penalties are a strong enforcement mechanism, but patchy national implementation undermines their impact

From a design standpoint, **ReFuelEU stands out for its strong enforcement mechanism.** It includes high penalties for non-compliance, set at a minimum of twice the price gap between e-kerosene and fossil jet fuel, and **a follow-up obligation** that requires suppliers to compensate for any shortfall in delivery in the following year. For example, if a fuel supplier fails to meet their annual average requirement of 1.2% for the 2030–2031 period, they must compensate for the shortfall during the next reporting period (2032–2034) *on top of* the regular annual average requirement of 2% for that period.

These provisions make non-compliance with the submandate a very costly option, potentially amounting to several billion euros in fines across the EU, substantially higher than the cost of producing e-kerosene in line with the mandate.



Compliance with ReFuelEU is much cheaper than penalties

Comparison of total annual e-kerosene compliance cost and penalties

Source: T&E (2025), based on T&E's briefing "Implementing the EU's e-SAF mandate" (10/2024) updated with EASA's 2024 reference prices

In contrast, **the newly adopted UK SAF mandate is less stringent.** Its enforcement relies on a buy-out mechanism and does not include a follow-up requirement, reducing the financial risks of under-compliance for fuel suppliers. Additionally, the UK's PtL targets are relatively modest, starting at 0.2% of total jet fuel demand in 2028 and reaching only 3.5% by 2040.

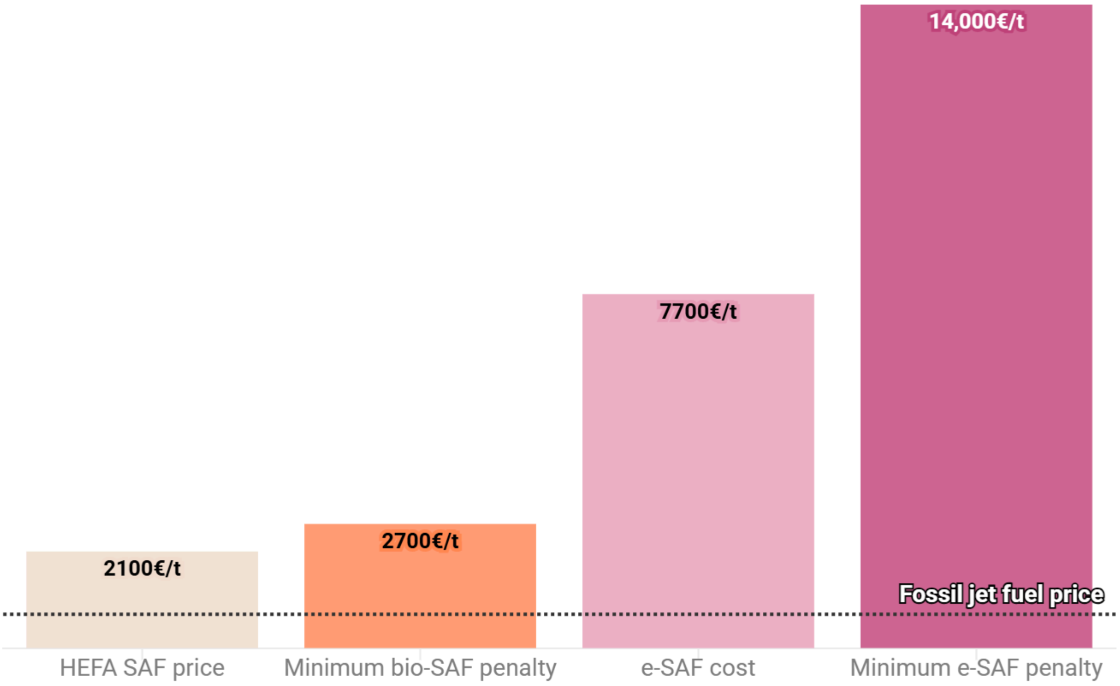
However, a key implementation challenge of the EU's SAF mandate lies in **the Member State-led enforcement of its penalties.** While article 12 of RefuelEU sets the general framework for the fines, it is up to Member States to individually transpose and apply these provisions.

Member States were expected to adopt implementing legislation by the end of 2024, yet as of the time of writing, most have not completed this process. A few, such as Denmark, France and Finland, have translated Article 12 into national law, but they have not yet assigned specific monetary values to the fines. In France, the law refers to a forthcoming decree to define the calculation method, while Danish authorities do not intend to set predetermined monetary values.

This lack of defined penalties weakens the transparency and predictability of non-compliance costs, despite indications that most countries intend to use EASA’s price references as a benchmark. EASA estimates that RFNBO-grade e-SAF would cost around €7,700 per tonne, resulting in penalties of close to **€14,000 per tonne**. At that level, EU jet fuel suppliers could be fined a total of **€8 billion** if they fail to deliver the first drops of e-kerosene by 2030. A fuel supplier like Air bp that supplies around 25% of European jet fuel would face a €2 billion fine for its 2030 obligation alone.

The minimum e-SAF penalty will be around 14,000 €/t based on EASA's reference prices

ReFuelEU (e-)SAF penalty estimates based on EASA's 2024 price references



Sources: T&E (2025), based on EASA (2025)

Despite the high penalties foreseen under ReFuelEU, investment in e-SAF remains limited. One reason could be that suppliers are not yet internalising the financial risks of non-compliance in their investment planning. To address this, the European Commission, in coordination with national financial regulators, should clarify that **expected penalties under ReFuelEU are to be treated as contingent liabilities on corporate balance sheets**, in line with existing accounting standards.

1.3. Strict production criteria support EU-based production, but loopholes like the eligibility of green hydrogen in biofuel production processes could weaken the mandate

Under ReFuelEU, e-kerosene must meet the production criteria defined in the RFNBO Delegated Acts. This includes compliance with additionality rules, as well as geographical and temporal correlation requirements for renewable electricity sourcing (see infobox below). On the carbon side, industrial point-source CO_2 – captured from major emitters of CO_2 covered by the EU Emissions Trading System (ETS), typically big coal or gas-fired power plants, refineries, steel or cement plants, etc. – is not allowed as of 2041. Synthetic low-carbon aviation fuels can also count towards the e-kerosene sub-target, but only if their hydrogen component is of non-fossil origin, effectively excluding fuels made from blue hydrogen. While these criteria have been criticised for their stringency, **they are designed to ensure high environmental integrity.**

Infobox: Key energy requirements for renewable hydrogen production under the RFNBO Delegated Acts

- **Additionality:** Renewable electricity used for hydrogen production must come from installations that:
    - Began operation no earlier than 36 months before the hydrogen production facility starts operating.
    - Have not received any public financial support, such as operating aid or investment aid, unless such support has been fully repaid.

  For RFNBO installations operational before 1 January 2028, these additionality requirements apply from 1 January 2038. For installations operational on or after 1 January 2028, the requirements apply immediately.
  Why? To ensure that hydrogen production stimulates new renewable energy capacity, rather than diverting existing renewable resources.

- **Geographical correlation:** The renewable electricity used must be generated in the same bidding zone as the hydrogen production facility.
  Why? By requiring production and consumption within the same bidding zone, the regulation ensures that hydrogen production contributes to regional grid decarbonization and reflects the constraints of the local electricity system.

- **Temporal correlation:** The renewable electricity must be consumed at (almost) the same time it is produced.
    - **Monthly correlation** is acceptable until 2030. If an electrolyzer is connected to a renewable energy source (RES) via the grid, and with a PPA in place, the electricity it consumes is considered to come from the RES as long as it is generated within the same month.
    - **Hourly matching** becomes mandatory from 2030, i.e. the electricity used for hydrogen production must be generated from the RES during the same hour that the hydrogen is produced.

  Why? To ensure that hydrogen production is directly tied to periods of renewable energy availability, preventing the use of renewable certificates to offset fossil-based electricity consumption.

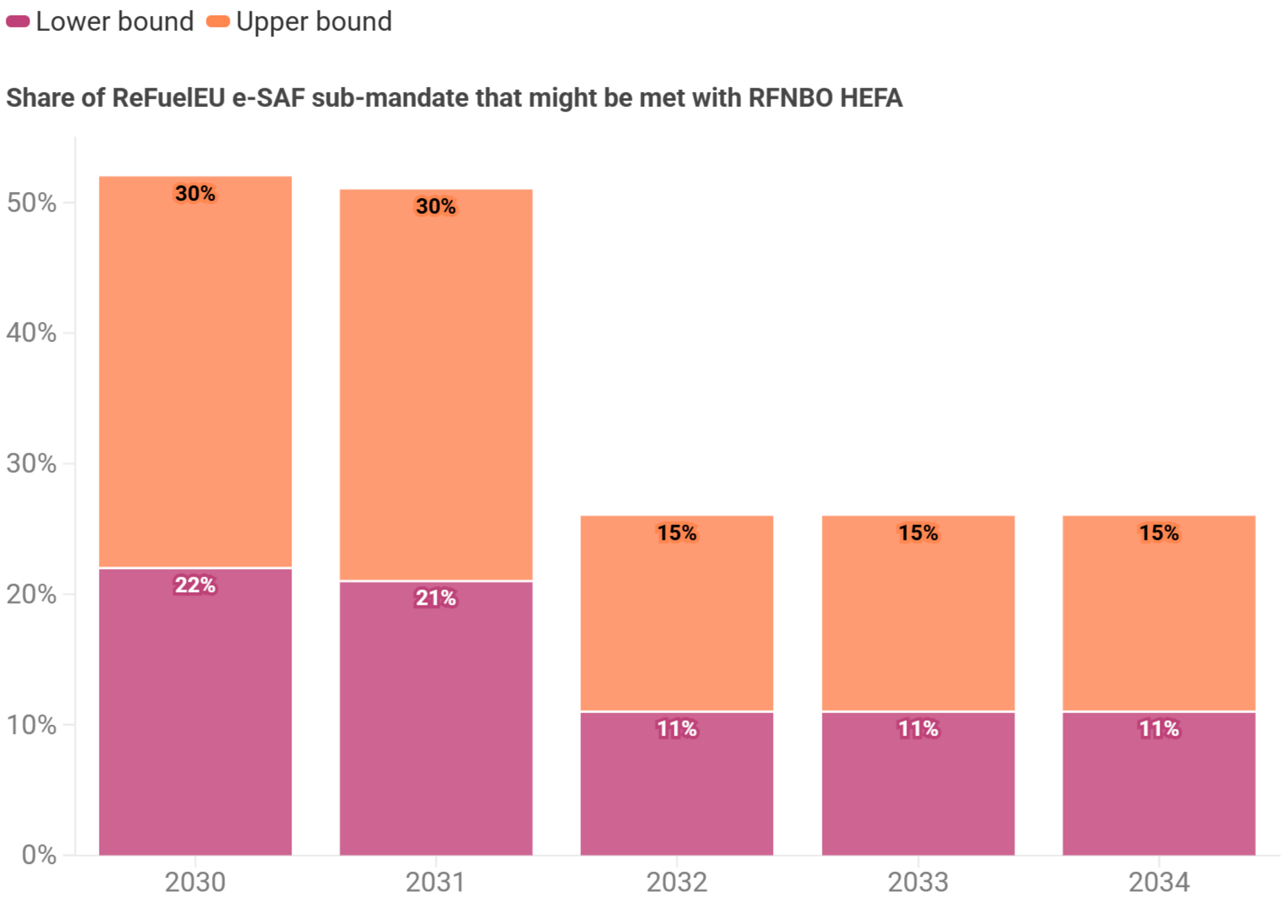
At the same time, **these criteria may have the additional effect of supporting EU-based production**. For instance, certain US-based projects from companies like DG Fuels, are excluded from compliance due to their reliance on blue hydrogen (encouraged by the IRA set-up). Additionally, while the use of fossil-derived carbon will be prohibited within the EU from 2041 onward, projects located outside the EU face this restriction immediately, due to their lack of effective carbon pricing systems (see section 2.2). This complicates compliance for producers in regions which may benefit from abundant renewable electricity but lack access to biogenic CO_2. Moreover, exemptions granted for renewable and/or low-carbon grids (allowing some flexibility under the additionality and correlation rules) tend to benefit European projects, as several EU Member States operate power systems with significantly lower carbon intensity compared to most other regions globally (see section 2.1).

However, some regulatory grey zones could weaken the mandate. One is about **the link between the HEFA (Hydroprocessed Esters and Fatty Acids) pathway and the e-SAF mandate.** HEFA is currently the most commercially mature SAF pathway and involves refining renewable oils (like used cooking oil or animal fats) into jet fuel using an external hydrogen input. A share of the hydrogen that enters the process cleans up the renewable oils and is not chemically incorporated into the fuel. A fraction, however, ends up in the final fuel. T&E estimates that if the grey hydrogen currently used in this process were replaced with RFNBO hydrogen, around 5%-12% of the SAF output could potentially qualify as RFNBO depending on how the legislation is interpreted.

This potential loophole risks undermining the investment case for dedicated e-SAF plants. **Interpreting a share of the HEFA output as a possible e-SAF compliance option would be misaligned with the legislators' intention to promote genuine e-fuels**, made from renewable electricity and captured CO_2, through the ReFuelEU sub-mandate. If certification schemes were to interpret green hydrogen used in HEFA production as a compliance option with the e-SAF sub-mandate, we estimate that **between 20% and 50% of the ReFuelEU e-SAF sub-mandate could be met via the HEFA pathway**.

To preserve the integrity of the e-SAF target, the European Commission should clarify that it is not possible to meet the ReFuelEU e-SAF target through the HEFA pathway, e.g. by updating its FAQ on ReFuelEU, and **refuse to endorse certification schemes that adopt a different interpretation.**

RFNBO SAF produced from waste oil refining could meet between 20% and 50% of ReFuelEU e-SAF mandate in 2030



Source: T&E (2025) • HEFA = Hydroprocessed Esters and Fatty Acids = Waste-oil refining into SAF. Assume that ReFuelEU bio-SAF mandate is met via HEFA pathway until 2034 using external RFNBO hydrogen input. Lower bound corresponds to 5.1% HEFA RFNBO share and upper bound corresponds to 12.2% HEFA RNBO share.

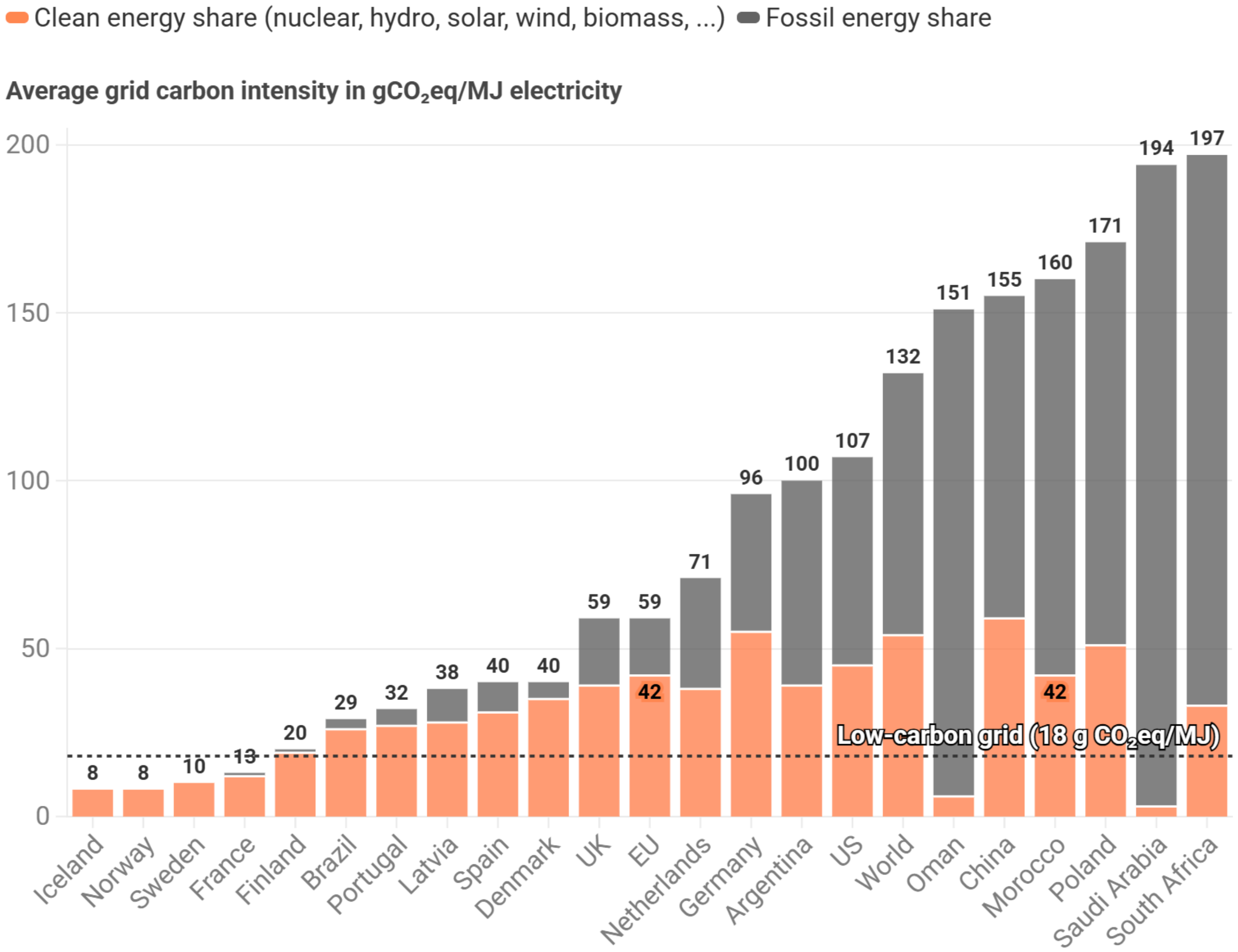
2. Energy and CO_2 sourcing: opportunities and bottlenecks

Europe's ambition to lead in e-kerosene production is supported by its relatively clean electricity grid and steady renewable energy deployment. However, challenges related to energy costs, infrastructure limitations, and CO_2 sourcing complexities pose significant hurdles.

2.1. Europe’s clean electricity grid supports e-SAF deployment, but high energy costs and grid congestion remain major barriers

Europe's electricity generation is among the cleanest globally. In 2024, the EU’s grid carbon intensity was significantly below the global average. Within Europe, several countries have achieved extremely low carbon intensities below or close to the low-carbon grid threshold of around 18 gCO_2eq/MJ electricity, like Iceland, Norway, Sweden or France. This cleaner grid provides a favorable environment for producing green hydrogen, as projects located in such countries can operate fully on-grid without renewable PPAs to produce **low-carbon fuels that**

comply with the ReFuel EU e-SAF submandate. According to EASA, low-carbon aviation fuels produced using grid electricity in these countries would cost around 5,500€/t and could therefore be up to 30% cheaper than RFNBO e-SAF estimated to cost around 7,700€/t. This difference is due to avoided costs associated with the additionality and temporal correlation criteria that lead to lower load factors.



Green hydrogen will require additionality and temporal correlation in most countries outside of Europe

Grid carbon intensity by selected region in 2024*

Source: T&E (2025), based on EMBER (2025) • Assume 66% electrolyser efficiency for the low-carbon grid threshold. * Use 2023 data for Saudi Arabia and Iceland as 2024 data was not available.

Unlike European countries with clean grids, **most hydrogen and e-fuel producers outside Europe must meet EU rules on additionality, temporal alignment, and geographic correlation.** These requirements mandate the use of dedicated renewable energy sources closely matched in time and location with fuel production, often increasing production complexity and costs. As a result, the ability to use grid electricity in countries with low-carbon grids could lead to a cost advantage for European projects relative to competitors in regions with cheaper renewable resources, but high-carbon grids.

However, low-carbon synthetic aviation fuels produced from grid electricity, even in Europe, are generally less sustainable than RFNBOs. Their reliance on grid power can indirectly displace clean electricity that might otherwise be exported to neighboring countries with more carbon-intensive grids.

Infobox: Electricity requirements to meet the ReFuelEU e-SAF mandate

Looking ahead five years, by 2030, meeting the ReFuelEU e-fuels mandate (1.2%) will already require around 15 TWh of renewable and/or low-carbon electricity, which is equivalent to the annual output of two large 1GW nuclear reactors, or Denmark's current electricity production from wind farms. ReFuelEU requires a 35% blend of e-fuels in the EU's aviation fuel mix by 2050. If the aviation sector grows as projected by the industry (~ 3% annually), this will translate to around 25 Mt of e-kerosene, which would require around **600 TWh of renewable electricity.** This is the equivalent of **about 10% of the EU's total projected wind and solar power generation by 2050.** These figures confront us with a reality: without growth mitigation, decarbonising the aviation sector with e-fuels will put significant pressure on Europe's clean electricity supply.

Despite the strategic advantages provided by its relatively cleaner power grid, **Europe's higher renewable electricity prices** (due to a combination of natural factors, limited grid capacity, high capital costs, and slow permitting) **continue to result in higher costs for green hydrogen production,** the largest cost component of e-kerosene production. According to BNEF's 2025 Hydrogen Levelized Cost Outlook and the Project SkyPower model, **hydrogen** produced via electrolysis in advantageous locations in Europe like **Spain and Norway costs between 5-6€/kg**. These costs are significantly higher than those in regions with cheaper renewable electricity prices. For example, **in China**, where large-scale renewable projects are rapidly expanding, BNEF estimates production slightly above **3€/kg**, largely due to significantly lower alkaline electrolyser costs in China. **In the US**, the IRA offers a tax credit of up to around €3 per kilogram of hydrogen produced, bringing costs down to **€3-4 per kg** in locations like Texas, but these incentives are expected to end soon.

On top of energy prices, European projects are often struggling to secure grid connections and PPAs. In interviews with T&E, project developers reported difficulties securing grid connections in countries like the Netherlands, Spain or Norway. Such infrastructure limitations can delay or hinder e-kerosene projects dependent on adequate grid capacity to support multi-hundred-MW electrolyzers.

The situation is equally challenging when it comes to PPAs. In many European countries, the development of renewable electricity capacity is still primarily driven by government-organized tenders, which offer developers long-term price stability through Contracts for Difference (CfD) schemes, like the French Contrats de Rémunération (CdR). These mechanisms are crucial for renewable energy providers to secure project financing. However, **they also reduce the incentive for renewable energy providers to pursue private PPAs with industrial consumers like e-fuel developers,** who are often reluctant or unable to commit to the long-term contracts (e.g., 15–20 years) needed by renewable energy providers.

A potential solution to address the limited availability of PPAs in Europe would be **to introduce greater flexibility within existing support schemes,** such as the Contrat de Rémunération or similar mechanisms used across Member States. Auction-winning renewable projects could be allowed to temporarily suspend their support contracts in order to sign private PPAs with consumers, for a minimum duration, without incurring penalties. This would give renewable energy developers the ability to tap into market-based revenue opportunities while preserving the financial security of the public support framework as a fallback.

2.2. Securing CO_2 already comes with challenges and is likely to become a growing bottleneck unless DAC scales up to complement limited biogenic sources

The RFNBO Delegated Acts stipulate that the CO_2 used to produce e-kerosene must originate either from biogenic sources or be captured directly from the atmosphere through Direct Air Capture (DAC). CO_2 from industrial point sources is also temporarily eligible until 2041 for most industrial processes. Because industrial CO_2 lacks long-term regulatory certainty and DAC remains both costly and commercially limited (see Infobox below), **most e-kerosene project developers worldwide are currently relying on biogenic CO_2.**

Infobox: CO_2 sources for e-kerosene production

To qualify as RFNBO under EU rules, the CO_2 used in e-kerosene production must meet several criteria. The main eligible CO_2 sources are:

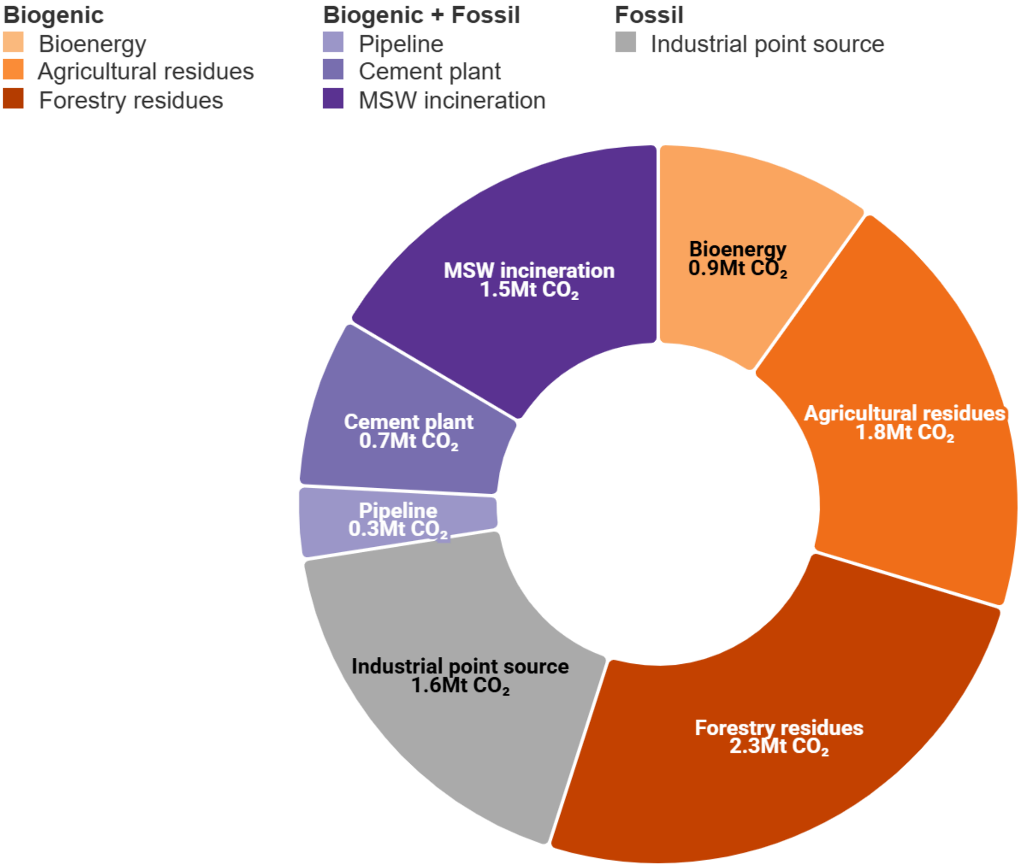
- **Biogenic Sources**: Refers to CO_2 released from the processing or combustion of biomass. Main sources include bioethanol fermentation (currently the main commercial source of biogenic CO_2), biogas upgrading, biomass-fired power plants, the pulp and paper industry, and waste incinerators. Under EU rules, this CO_2 is fully eligible, provided the biomass feedstock meets the sustainability and GHG saving criteria outlined in the Renewable Energy Directive (RED). The cost of capturing biogenic CO_2 is under €100 per tonne.

- **Industrial Point Sources**: Fossil CO_2 captured from industrial emissions, such as cement plants, steel mills, or chemical production facilities. It is allowed temporarily under RFNBO rules (until 2036 for power generation sources, and until 2041 for other industrial processes), provided the CO_2 emissions have been accounted for upstream in "an effective carbon pricing system". Only the EU ETS, the UK ETS and the Swiss ETS are considered effective systems according to a Commission Q&A for the certification of RFNBOs. Therefore, this provision makes it virtually impossible to produce EU-compliant e-fuels using industrial point sources outside Europe.

- **Direct Air Capture (DAC)**: CO_2 extracted directly from the atmosphere. It is fully eligible under RFNBO rules. While DAC faces high energy requirements, high costs ($600-$1,000 per ton of CO_2 captured) and limited commercial availability, it is considered the most sustainable method for sourcing CO_2. That is because, unlike point sources that are limited and will phase out with decarbonization, DAC is infinitely scalable.

E-kerosene projects are mainly betting on biogenic CO_2

Expected annual CO_2 demand by source for large-scale e-kerosene projects with known inputs (Mt)



Source: T&E (2025) • Mt = million tonnes. Assume 4t CO_2 for every tonne of e-SAF. Ignore co-products and biofuel share in co-production of e- and biofuels. CO_2 sources unknown for around half of announced production; Based on project announcements until May 2025

Europe has a substantial theoretical supply of biogenic CO_2, estimated at around **334 Mt** annually by 2050 in a study commissioned by T&E to Ricardo. In theory, this could be sufficient to meet the projected demand from the ReFuelEU e-kerosene mandate, which is expected to require approximately **120 Mt of CO_2**. However, **biogenic CO_2 is also in demand from other sectors,** including for the production of e-methanol and e-ammonia. According to the Ricardo study, total market demand across all sectors is projected to reach **between 430 and 600 Mt** by mid-century.

Moreover, **Carbon Capture and Storage (CCS)** competes with Carbon Capture and Utilisation (CCU) for the same sources of CO_2 and is expected to further reduce the volume of biogenic CO_2 available for utilization. Today, emitters that capture their CO_2 can either sell it to e-fuel producers (CCU) or store it underground (CCS). While there is currently little financial incentive to store CO_2, this could change if the EU ETS begins crediting negative emissions, a possibility that is currently assessed by the Commission as part of a report due by 31 July 2026. E-fuel producers would then need to offer emitters a higher price for their captured CO_2 in order to compete with the financial incentives of storage. To maximise the synergies between CCU and CCS, e-SAF projects should be located at sites where CCS is not an option, for instance due to a lack of suitable geological carbon storage sites.

The Ricardo study expects CCS to reduce the volume of biogenic CO_2 available for utilization to around **156 Mt**. If only biogenic CO_2 from sustainable feedstocks is considered (excluding sources like forestry residues and crops), the available supply drops sharply to just 26 Mt.

This shortfall highlights the need to manage traffic growth and **accelerate the deployment of DAC technologies** to ensure a scalable, long-term source of CO_2 for e-kerosene production. Ricardo estimates the total gap to be filled by DAC by 2050 is between 300 and 450 Mt.

However, DAC technology is still in its infancy, with only a few large facilities worldwide and high operational costs. For example, Climeworks operates a plant in Iceland that currently captures CO_2 at a cost of between $1,000 and $1,300 per tonne. In the absence of specific policy targets or incentives, there is currently little economic rationale for using DAC-derived CO_2 to produce e-fuels. To create a viable market for DAC, the EU could introduce sub-targets under ReFuelEU, FuelEU Maritime and the RED for e-fuels made with atmospheric CO_2. In parallel, measures are needed to lower DAC costs, such as scaling up support through the EU Innovation Fund, and to invest in CO_2 transport infrastructure that can connect future DAC hubs with e-fuel production sites.

Accessing CO_2 is not just a future theoretical challenge. It is **a very pressing logistical challenge.** Many e-kerosene projects are currently dependent on single sources, such as paper mills or waste incinerators, for their CO_2 supply. This comes with inherent risks: should any of these facilities shut down or face operational issues, the CO_2 supply could be disrupted. To mitigate this risk, projects are exploring **diversification strategies,** including establishing multiple MoUs with various emitters or connecting to **long-distance CO_2 pipelines** that aggregate emissions from multiple sources and deliver them to production hubs. For example, several e-fuel producers are eyeing the Rhône CO2 project in France.

However, **transporting CO_2 from multiple emitters presents logistical complexities.** Truck transport is a fallback option for small plants but requires CO_2 to be liquefied first, adding substantial costs. Building short pipelines between the emission points and the production sites is another option, but it also comes at a cost (both financial and administrative). As for long-distance CO_2 pipelines, their availability is currently limited. As a matter of fact, there are currently no long-distance pipelines dedicated to CO_2 transport in Europe (unlike in the US, where there are already over 8,000 km of CO_2 pipeline – used for enhanced oil recovery).

Several projects are in development in Belgium, the Netherlands, France, Germany, and Italy, allowing for a European CO_2 transport network to start taking shape.

3. E-kerosene offtake agreements remain scarce due to high costs and first-mover risks

Despite the demand certainty provided by ReFuelEU, the number of firm offtake agreements announced so far remains very limited, although three new large offtake deals were announced in 2024, all from European airlines:

- **Norsk e-Fuel, Norwegian and Cargolux:** In January 2024, Norwegian airlines and Cargolux signed a deal with Norwegian start-up Norsk e-Fuel for the joint purchase of 140,000 tonnes of e-fuel spanning over ten years from 2026 to 2035 (14,000 t/yr).
- **IAG and Twelve**: In February 2024, International Airlines Group (IAG) signed an agreement with US-based start-up Twelve for the supply of 785,000 tonnes of e-kerosene over 14 years (corresponding to ~56,000 t/yr), with first deliveries supposed to start in 2025.
- **Infinium and IAG:** In November 2024, Infinium announced a purchase deal with IAG for 7,500 t/yr of e-SAF for a period of 10 years, starting in 2026. The e-fuel will be produced at Infinium's Project Roadrunner facility, located in the United States in West Texas.

New Memoranda of Understanding (MoUs) were also announced by easyJet with Renavia and WFS as well as by SAS group with Copenhagen Infrastructure Partners.

A number of American airlines have signed offtakes with e-SAF producers, such as JetBlue, Virgin Atlantic and Boom Supersonic with Air Company in 2022, United Airlines with Dimensional Energy in 2022, Alaska Airlines and Microsoft with Twelve in 2022, and American Airlines with Infinium in 2023. In Asia, Cathay Pacific signed a MoU with SPIC in 2023.

Still, there are too few firm long-term e-SAF offtake agreements. This can be explained via two main factors:

- **High costs:** E-kerosene is estimated to be up to 10 times as expensive as fossil kerosene and 2-3 times as expensive as other types of SAF. Still, **the projected impact of e-kerosene on average ticket costs remains modest in the first years of the mandate:** around 3% by 2030, and 6% by 2032 according to T&E's estimates. Moreover, e-SAF production costs are expected to decrease by 40–50% in the long-term, as technologies mature and economies of scale kick in.

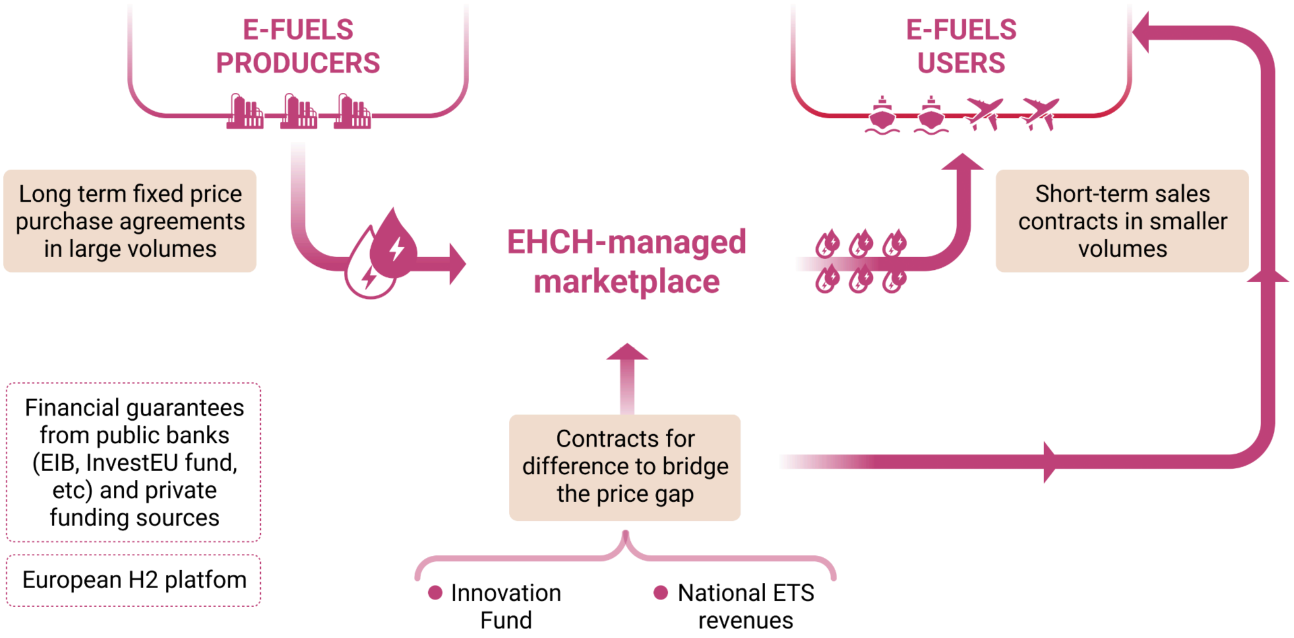
  In any case, the cost of compliance with the mandate will likely remain lower than the penalties for non-compliance with ReFuelEU (as seen in section 1.2), so the cost of e-kerosene shouldn't be such a problem. However, a key issue is that these penalties apply to fuel suppliers, not directly to airlines, making it uncertain how much of that cost will ultimately be passed through. This ambiguity and the prospect of a potential revision of ReFuelEU are prompting potential offtakers to adopt a wait-and-see approach.

- **First-mover risk and offtake duration mismatch:** Beyond fuel costs, airlines are also concerned about first-mover risk. E-kerosene producers require long-term offtake agreements, typically spanning 10 to 20 years, in order to secure financing for new production facilities. However, airlines are traditionally used to sourcing fuel on the spot market or on short-term annual contracts.

  As a result, **they are hesitant to lock themselves into long-term supply deals with individual producers,** especially in a market where new entrants could eventually offer lower prices. Committing to a high-cost, long-term contract today could leave early movers at a significant competitive disadvantage if production costs fall or alternative suppliers emerge.

A solution to this double problem could be the creation of a **European Hydrogen Clearing House**, as proposed by T&E as a cornerstone of the Sustainable Transport Investment Plan (STIP) that was announced by the Commission in its Clean Industrial Deal communication in February 2025.

European Hydrogen Clearing House: igniting the e-fuels market



Source: T&E

The EHCH, drawing inspiration from the already functioning H2 Global initiative, would act as a market intermediary, using double-sided auctions to bridge the gap between the price producers are willing to offer and what airlines are willing to pay.

The Clearing House would sign long-term contracts with e-fuel producers to provide revenue certainty, and then resell the fuel to airlines through shorter agreements more aligned with their procurement habits. Backed by the Innovation Fund and ETS revenues, the EHCH would help kick-start the e-kerosene market by facilitating offtake agreements and providing.

4. The funding challenge

One of the most pressing barriers to scaling e-kerosene production in Europe is **the high capital investment required to build new facilities.** Project SkyPower's cost model indicates that a single commercial-scale e-kerosene plant (producing around 70,000 tonnes of e-SAF per year) requires an upfront investment of around **€1-2 billion**.

Most plants are greenfield projects, i.e. built with little existing infrastructure. This is because **there are few industrial installations that could be repurposed and are dedicated to fuel production.** On the Fischer-Tropsch side, notable plants include the Pearl Gas-to-Liquids (GTL) plant and the ORYX GTL plant in Qatar; the Escravos GTL plant in Nigeria; the Shell Middle Distillate Synthesis plant in Malaysia; the Uzbekistan GTL plant in Uzbekistan; and Sasol's Sasolburg and Secunda plants in South Africa. For the latter, Sasol and Linde had launched the HyShift project, which aimed to progressively replace fossil hydrogen with green hydrogen in the existing Fischer-Tropsch plant. However, the project is currently on hold due to issues with GHG savings allocation rules in the EU.

On the Methanol-to-Jet side, there is the option to repurpose existing Methanol-to-Olefin (MtO) plants. Olefins are an intermediate product in the production of SAF in the Methanol-to-Jet pathway. Yet, most MtO assets are in active use. One exception is Mongolia Jiutai Group's MtO plant in Ordos City, Inner Mongolia, China that consumes 1.8 Mt of coal-derived methanol per year to produce feedstocks for petrochemical products. Mongolia Jiutai Group plans to repurpose some of its excess capacity to produce 100,000 tonnes of jet fuel per year.

To meet the ReFuelEU Aviation targets, approximately ten plants must be operational by 2030 and 17 by 2032. This implies **a total capital requirement of €10-€20 billion by 2030, and €17-€34 billion by 2032**.

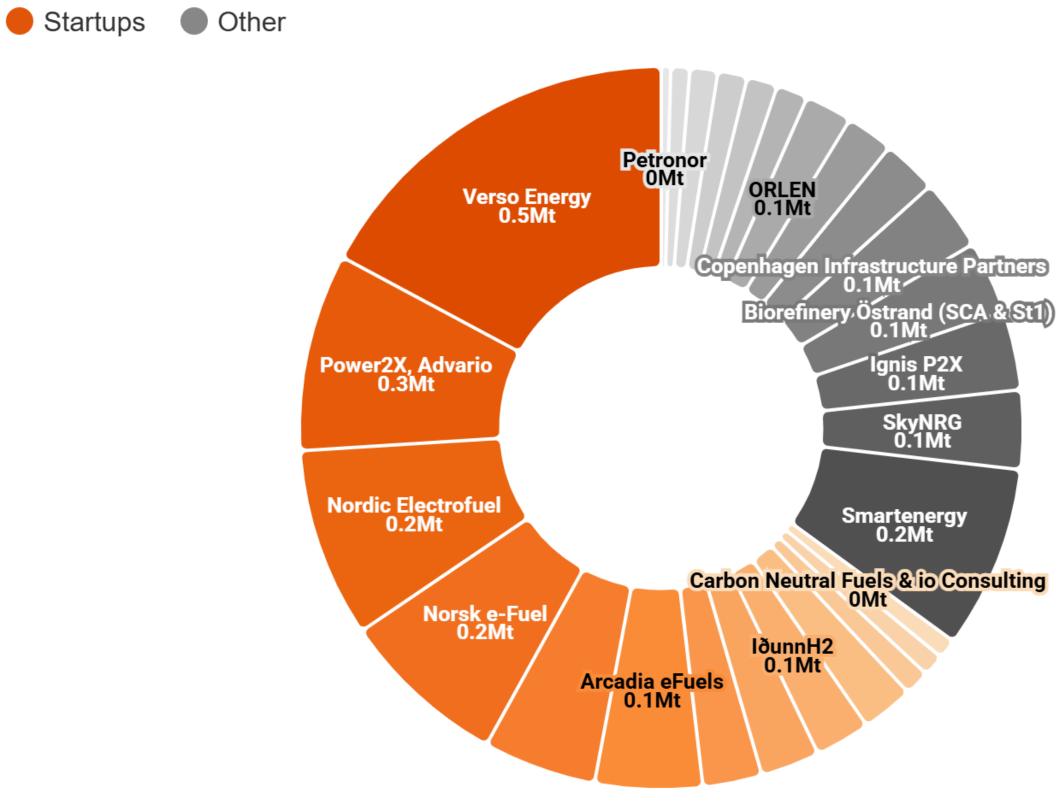
4.1. Mobilizing private capital remains a major challenge, particularly in Europe

Despite their considerable financial capacity, and while they are the main target of the ReFuelEU quotas, **major oil companies remain largely absent from the emerging e-kerosene market.** This is particularly striking given the substantial capital expenditures they plan for the next few years: an estimated €130–150 billion between 2025 and 2027 across Shell, bp, and TotalEnergies, for instance. Yet, the involvement of these players in e-kerosene remains negligible. Shell's withdrawal from the HySkies project in July 2024 reflects the passive attitude of traditional energy majors on this market.

In their absence, **start-ups have taken the lead in e-kerosene project development in Europe and the United States.** However, they lack the internal resources to finance capital-intensive infrastructure and must rely on a mix of equity and debt funding, with equity typically covering around 40% of total project funding. Access to debt financing is challenging, as banks perceive e-kerosene projects as high-risk due to the start-up profile of developers, very high CAPEX requirements, technological risks (inherent to first-of-a-kind projects), and lack of offtake agreements.

Startups develop most of Europe's e-kerosene capacity

Annual European e-kerosene capacity from large-scale projects by developer type (Mt)



Source: T&E (2025) • Mt = million tonnes. Large-scale: > 10 kt annual e-kerosene production capacity. Based on project announcements until May 2025.

Investors seem to be showing more and more interest in e-fuels. According to BloombergNEF, 70% of equity raised by renewable fuels companies in the first three quarters of 2024 went to e-fuel ventures, a notable shift from 2023 when biofuels dominated. **American e-fuels start-ups raised over $1 billion in private capital in 2024,** with standout companies including Twelve ($645M), Air Company ($69M), and Infinium ($1.1B from Brookfield Asset Management). However, current financial flows are not yet matching the required pace.

In Europe, the private investment environment seems comparatively sluggish. Ineratec secured a significant private grant (€30 million from Breakthrough Energy Catalyst in March 2025, complemented by a €40m venture debt loan with the European Investment Bank). Elyse Energy raised approximately €120 million to advance its e-methanol and e-SAF projects in France and Spain, backed by investors including Hy24, Bpifrance, and PGGM. However, these examples remain the exception, and European start-ups still face significant hurdles in accessing the scale of funding required to bring commercial plants online.

4.2. Existing public funding instruments have failed to unlock e-kerosene production so far

On the public funding side, existing EU-level instruments – the Innovation Fund, the SAF allowances, and the Hydrogen Bank – fall short of unlocking the situation.

- **The Innovation Fund**, funded through ETS revenues, awards grants to projects deploying low-carbon technologies to support their capital expenditures. While e-kerosene is eligible for support under this scheme, **it competes with a wide range of technologies that better fit into the Fund's awarding criteria**. Notably, the Fund's emphasis on GHG emissions avoidance efficiency, cost efficiency and financial maturity in project selection disadvantages FOAK large-scale e-SAF plants.

  As a result, **only three projects** (Nordic Electrofuels, HySkies and BioÖstrand) have received support from the Innovation Fund – in six calls since 2020. While the Innovation Fund is meant to support up to 60% of the CAPEX and OPEX of the projects selected, the grants received by the three selected e-kerosene projects amounted to €40M, €80M and €167M respectively. This is substantial, but still leaves very high amounts of CAPEX (and OPEX) to fund, and, consequently, **cannot significantly reduce the price of e-kerosene.**

  Therefore, the cost support provided by the Innovation Fund is not enough to facilitate the long-term offtake agreements which e-kerosene producers need to secure revenue certainty and unlock funding. As a proof of this, none of the e-kerosene projects selected under the Innovation Fund has reached FID yet and one of the projects (Hyskies) was even cancelled.

  Having **a dedicated basket for e-fuels for aviation**, as was the case for the maritime sector in the third large-scale Innovation Fund call, could be a way to improve the accessibility of the scheme for e-kerosene projects.

- **The Hydrogen Bank,** primarily funded through the EU Innovation Fund, supports the scale-up of green hydrogen and its derivatives through OPEX support via competitive auctions. This support comes in the form of **a fixed premium per kilogram of renewable hydrogen produced,** aiming to provide revenue certainty to project developers. The premium is awarded only upon production of renewable hydrogen and is paid over a period of up to ten years. It is not cumulative with other EU funding (Innovation Fund, CEF, IPCEI, etc.) and national state aid, except if the aid was received for early project development phases (e.g. feasibility, FEED studies).

  While e-kerosene projects can apply for the scheme, the fact that funding is awarded primarily on a cost efficiency basis makes it very hard for e-kerosene projects to compete. There was no e-SAF project among the winners of the first auction. Besides, **the subsidies delivered were quite low, below €500/t of hydrogen.** This is far less than what would be needed to significantly bridge the price gap between e-kerosene and conventional jet fuel.

- **The SAF allowances** (deployed under the ETS) are designed to incentivize airlines to use SAF by bridging the price gap between SAF and conventional kerosene, but they fail to facilitate the long-term offtake agreements and revenue certainty that e-kerosene projects need.

  SAF is already zero-rated under the ETS, meaning airlines don't have to surrender emissions for the use of SAF. On top of that, a dedicated pool of 20 million "SAF allowances" was put in place to reward the use of SAF between 2024 and 2030. These 20 million allowances translate to a subsidy of €1.6 billion over seven years, i.e. ~ €230 million per year (assuming an optimistic carbon price of €80/t). They are intended to cover part of the price difference between SAF and conventional jet fuel. The coverage varies based on the type of SAF used. For e-kerosene, that coverage reaches **95% of the price differential** (50% in the case of synthetic low-carbon fuels).

  While this is a very strong incentive to use e-SAF, the fact that e-SAF will most likely not be available on the market before 2030 considerably reduces the potential subsidies for this fuel. **All the subsidies available between 2024 and 2029 will support bio-SAF,** as this will be the only type of SAF commercially available. As for 2030, even if the €230 million went exclusively to support e-kerosene that year, it would cover less than a third of the mandated volume (based on EASA cost estimate).

  In any case, this is unlikely to happen given **the lack of earmarking of allowances for e-SAF**: airlines might prefer larger volumes of subsidised biofuels (even if only 50–70% of the price gap is covered) rather than getting nearly full support for e-SAF but in much smaller quantities.

  Furthermore, the way allowances are distributed does not provide airlines with enough visibility on whether they will receive support for their use of SAF. This is because allowances are distributed **ex-post** (the airline needs first to buy and use the SAF to receive the support), **on an annual and first-come-first-served basis.**

Beyond these funding mechanisms, the role of public financial institutions is also critical to unlock private capital for e-SAF. In this regard, the limited engagement of the **European Investment Bank (EIB)** is particularly striking.

The EIB uses public money to finance projects that support the EU's goals, like clean energy, innovation, and infrastructure. It mostly provides **low-interest loans** that help reduce risk and attract other investors, making it easier for important projects to get off the ground. **To date, the EIB has supported only one e-SAF project, compared to six biofuels projects.** While this can be explained by the EIB's tendency to finance more mature or lower-risk technologies, it should rather be prioritising fuels that have the best long-term potential of scalability (i.e. e-SAF).

Infobox: Overview of national support schemes across Europe

National governments have started stepping in with targeted support schemes. **France**, for instance, allocated €100M in direct grants to four e-SAF projects as part of the France 2030 investment plan, covering up to 80% of FEED study costs. This targeted FEED support is a good measure that could be replicated by more countries across Europe, as conducting feasibility and FEED studies are significant investments (in the order of €40-60 million) and equity is difficult to secure at this stage.

In **Germany**, the Federal Ministry for Digital and Transport Affairs (BMDV) is funding the construction of a semi-industrial demonstration plant, the Power-to-Liquid Fuels Technology Platform (TPP), operated by the German Aerospace Centre (DLR), with around 130 million euros. In December 2024, the Commission approved two German state aid schemes: a direct grant of €350 million for the Concrete Chemicals project in Rüdersdorf, and a €3 billion German-Dutch scheme to support the production of RFNBOs throughout the world through double-sided auctions. While the double-sided auction system is an interesting choice, the tenders do not target e-SAF specifically, and most RFNBO producers are expected to come from non-EU countries. As part of its coalition agreement, the new government has committed to dedicate half of national aviation ETS revenues to promote SAF.

Spain awarded €81 million to an e-SAF project developed by RIC Energy as part of its Hydrogen Valley programme, a €1.2 billion package funded through the EU's Recovery and Resilience Facility (RRF). **Portugal** earmarked €40 million for SAF tenders. While the scheme does not target e-SAF specifically and the funding volume is limited, its financing structure, drawing from national ETS revenues and aviation carbon tax, can be regarded as a good practice.

A promising development is the **UK's Revenue Certainty Mechanism** (RCM) aimed at supporting non-HEFA SAF. The draft bill was published recently, and all required legislation for the mechanism is expected to be in place by the end of 2026. Under the RCM's contracts for difference (CfD) type scheme, a guaranteed strike price is set for SAF. If the market price falls below this strike price, the SAF producer receives a top-up payment to cover the difference. Conversely, if the market price exceeds the strike price, the producer pays back the difference. This approach mirrors the CfD model used in offshore wind production, and is intended to enhance investor confidence, ensure revenue stability for producers and reduce financing costs for SAF projects.

One of the most positive features of the scheme is that it will be industry-funded, primarily through **a levy on aviation fuel suppliers,** in line with the 'polluter pays' principle. While it is also positive that HEFA SAF is excluded from the mechanism, other types of biofuels are eligible in the same way as e-fuels, which could undermine the efficacy of the RCM for e-SAF. To ensure that the mechanism is effective at supporting e-SAF it is crucial that the bill is amended to earmark part of the RCM support to e-SAF and run dedicated auctions, also accounting for the higher price of e-SAF compared to biofuels. Otherwise the mechanism risks being effective at supporting biofuel based SAF only.

5. The ultimate challenge: getting e-kerosene to the market, in a supply chain largely controlled by oil majors

E-fuel producers have three main options to get their fuel to the market:

- **They may opt to sell their fuel at the production site to oil majors or intermediaries,** who handle blending and logistics. This path is straightforward but offers minimal control or margin, and oil majors have so far shown very limited willingness to purchase e-SAF.
- **A currently predominant route involves selling directly to large hub airlines capable of managing their own logistics.** European hub airlines and airline groups, such as the Air France-KLM Group, IAG, the Lufthansa Group and SAS, have been expanding the classic model of into-plane purchasing and are introducing self-supply systems at their hubs. This means they take care of the purchasing and logistics of jet fuel themselves in order to reduce their dependence on fuel suppliers and optimize costs. Their access to fossil fuel and fuel infrastructure, including blending options, make them supposedly good partners for the purchase of neat SAF.
- **The most challenging path is to act as a direct supplier at the airport selling directly to customer airlines,** which requires e-SAF producers to navigate the full chain of custody: sourcing Jet A-1 for blending, accessing and paying for infrastructure, meeting technical stock-keeping and insurance requirements, and securing airline buyers through competitive tenders. This approach remains prohibitively complex for most new entrants.

Given the limited willingness shown by oil majors to purchase e-SAF so far, most e-SAF developers are looking to bypass traditional suppliers and engage directly with end-users, particularly airlines (i.e. second and third models described above). However, even when airlines are open to purchasing e-fuels, the full logistics chain — blending, transport, storage, and delivery — must usually be in place before any tender or contract can be finalized. **This is where jet fuel infrastructure ownership becomes a critical and often problematic factor.**

A largely overlooked bottleneck to scaling European e-kerosene production lies in accessing the physical jet fuel infrastructure needed to bring the product to market. **Much of this supply chain is controlled by incumbent jet fuel suppliers,** typically large oil and gas companies.

This infrastructure dependency creates a structural barrier that restricts entry for new players like e-SAF producers. Based on a briefing by IATA, T&E commissioned a study to Pro Aviation to further assess the scale of this problem with a focus on the European market, the findings of which are laid down below.

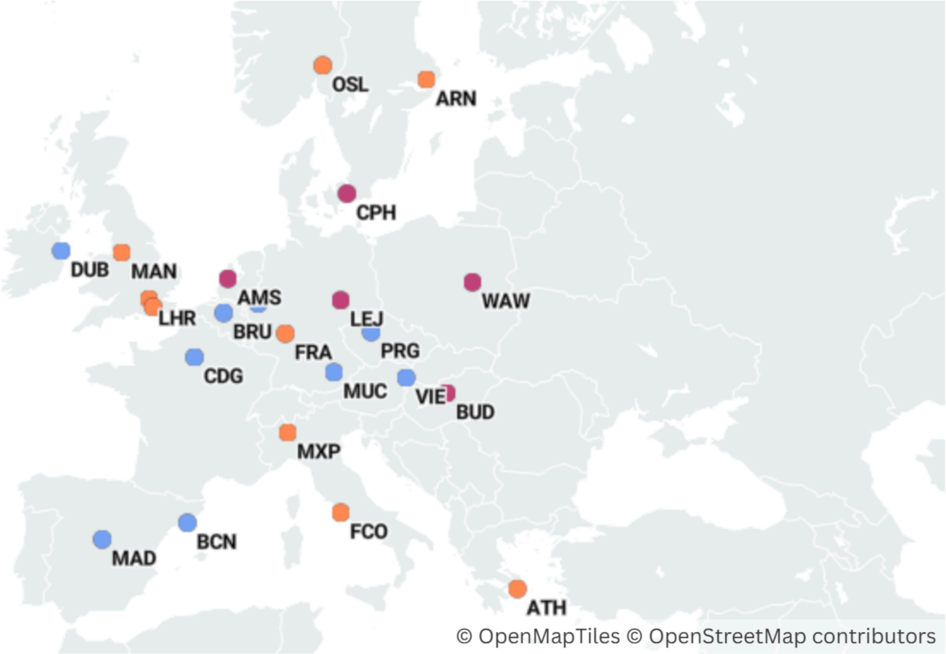
The study confirmed that access to jet fuel infrastructure in Europe — both **on-airport** (like fuel storage facilities) and **off-airport** (such as blending sites, pipelines, trucks, and railcars) — is uneven and predominantly exclusive.

Access to jet fuel infrastructure is difficult at many airports

🔵 **Open-access airport:** All suppliers can use the infrastructure on equal and transparent terms.

🟠 **Semi-open access airport:** Either on- or off-airport infrastructure access is restricted.

🟣 **Restricted access airport:** Both on- and off-airport infrastructure access are restricted.



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Source: T&E (2025), based on ProAviation (2025)

Whether access to airport fuel infrastructure is open (all suppliers can use the infrastructure on equal and transparent terms), semi-open (either on- or off-airport infrastructure access is restricted), or fully restricted (both on- and off-airport infrastructure access are restricted) largely depends on how the ownership of the infrastructure is structured. There are three main models of ownership to distinguish in Europe:

- **Ownership by a single supplier or a joint venture of suppliers,** typically big oil companies, potentially together with the hub airline. In this model, access to the jet fuel infrastructure by third party companies tends to be **restricted**, as owning entities can freely decide access fees and how storage is allocated within its facilities. This model tends to restrict competition, as owner(s) can deny access to new suppliers, or make access too expensive for them, e.g. by requiring them to buy a share in the joint venture. According to IATA, the owner(s) of the fuel infrastructure may also impose very high fees to help them lower the costs of their own fuel business, basically using the money from competitors to make their own fuel cheaper.
- **Ownership by airport operators** who actively decided to tender the operation of their fueling facilities to third parties (example: Munich, Paris CDG, Brussels, Prague airports).

This model generally allows for **open access** to the infrastructure since the conflicts of interest described above do not apply.

- **Ownership by a third party** (typically an independent private party that does not engage in fuel sales) (example: Exolum at Madrid airport). This model also generally allows for **open access** to the airport infrastructure.

Many on-airport storage and hydrant systems in Europe are owned and operated by a single supplier or a joint venture of oil companies (and the local hub airlines). That is notably the case at Oslo (OSL), Stockholm (ARN), Copenhagen (CPH), Amsterdam Schiphol (AMS), Frankfurt (FRA) and most German airports (with notable exceptions like Munich and Stuttgart). Unless airport authorities intervene, the joint ventures of oil majors who own on-airport storage facilities are not obliged to guarantee open access to third parties nor to disclose their access fees. In some cases, access to the fuel farm even requires purchasing equity in the joint venture, with the size of the stake determining the proportion of fuel a supplier is allowed to sell at the airport. It is still the system in place at Amsterdam (AMS) and Copenhagen (CPH) airports.

One way to address this issue is for airports to declare fueling facilities as **centralized infrastructure**, i.e. “facilities required for the provision of ground handling services that cannot be shared or duplicated due to their complexity or for cost or environmental reasons” (EU Directive 96/67/EC). When doing so, **airport operators may gain control in terms of cost structure by determining and publishing throughput rates.** This was successfully done in Frankfurt and Vienna airports, for example. However, this doesn’t lift all obstacles for newcomers on the market.

When it comes to off-airport logistics, the situation is a bit different. Most of Europe’s major fuel pipelines are owned and/or operated by third parties — public or private — and offer fair and transparent third-party access. For example, all the French pipelines (e.g. CEPS, Trapil, PMR, etc.) offer open access for third parties.

However, there are two major exceptions. In the United Kingdom, the pipeline network — key to access Heathrow, Gatwick and Manchester airports — is largely under the control of oil majors, with limited transparency on fees for third-party access. The **Rhein-Main Pipeline (RMR)** in Germany represents another major bottleneck. This pipeline is owned by oil majors. It is one of the main supply routes for Frankfurt Airport (FRA), one of Europe's busiest hubs, but open access has been historically denied there.

There seems to be a strong case for competition authorities, both at EU and national levels, **to re-examine the competitive conditions governing jet fuel infrastructure.** This includes scrutinizing ownership models that restrict third-party access and assessing potential abuse of dominant position by incumbent jet fuel suppliers through pricing or allocation practices. The European Commission — led by DG COMP, in coordination with DG MOVE and national competition authorities — should initiate **a sector-wide review of jet fuel infrastructure access** with a particular focus on anti-competitive behaviors and transparency obligations.

Recommendations

1

Preserve the ambition of ReFuelEU and implement it via the Sustainable Transport Investment Plan (STIP)

Maintain the integrity of the SAF mandate, in particular the e-SAF submandate. Policymakers must reaffirm their commitment to ReFuelEU's current targets, especially in the context of the 2027 review of the legislation, in order to ensure policy and market stability, which helped establish the EU as a leader in e-kerosene. Any revision proposal (if any, as review does not equate revision) from the Commission should be focused on ensuring enabling conditions for e-kerosene uptake and investment.

Make the STIP an enabler of the EU e-kerosene value-chain. The European Commission must prioritise e-SAF in the STIP and set a comprehensive and robust strategy to de-risk production and offtake.

2

Improve public funding mechanisms to ensure long-term revenue certainty and trigger offtake agreements

Establish a European Hydrogen Clearing House for maritime and aviation e-fuels. The EU should create a dedicated public entity, inspired by the H2Global model, to act as a market intermediary for e-kerosene. This intermediary would run double-sided auctions: on one side, buying e-kerosene from producers through long-term contracts at the lowest possible price; on the other side, selling that fuel to obligated parties (such as fuel suppliers or airlines) via short-term auctions at the highest achievable market price. The difference between the purchase and resale price would be covered by public funds.

Fund the intermediary through aviation ETS revenues. According to T&E calculations, earmarking just 25% of aviation-related EU ETS revenues (i.e. **€2.5 billion** from 2025 to 2034) would be enough to cover around 87% of the mandated e-kerosene volumes from 2030 to 2034, assuming the CfD bridges 20% of the price gap between e-kerosene and fossil kerosene (approx. €1,000/tonne). If the ETS scope is expanded to include all departing flights from the EEA, the same 25% share of ETS revenues could cover 100% of mandated volumes.

Tailor existing tools (Innovation Fund, Hydrogen Bank and SAF allowances) to support e-kerosene. If existing mechanisms are retained as complementary or transitional instruments, they must be adapted to the specific needs of e-SAF production:

- **Introduce e-kerosene-dedicated baskets in the Innovation Fund and**

Hydrogen Bank to prevent synthetic fuels from being completely crowded out by lower-cost alternatives, similar to the maritime basket that was introduced as part of the second Hydrogen Bank auction.
- **Earmark a significant share of the SAF allowances (e.g. 50%) for e-kerosene,** to avoid full allocation to biofuels.

Scale up national support using aviation-derived revenues. Member States should ramp up targeted support for e-kerosene, particularly for early-stage project development such as FEED studies, where equity is often difficult to secure. Any national funding scheme should be grounded in the "polluter pays" principle and financed through aviation-derived revenues, including levies on fuel suppliers, carbon or ticket taxes, and/or national aviation ETS revenues.

In addition, **national ETS revenues should be mobilised to support the launch of the European market intermediary,** including a potential initial pilot auction in 2026, in case EU-level Innovation Fund resources cannot be unlocked in time.

3

Mobilise public financial institutions to de-risk investment

Multilateral development banks (MDBs), notably the European Investment Bank (EIB), national promotional banks, and export credit agencies, **must play a much greater role in unlocking capital for e-kerosene projects.** Their participation is essential to mitigate the high financing risks associated with first-of-a-kind facilities typically developed by small and medium companies with limited access to capital.

Public banks should provide **accessible and affordable long-term loans** to reduce reliance on commercial debt. Their involvement offers a powerful de-risking signal to private investors by providing a "stamp of approval." In parallel, **loan guarantees from InvestEU or national export credit agencies** should be expanded to lower credit risk and facilitate larger loan sizes from commercial banks. These tools are critical to bridging the €1–2 billion capital needs per project.

4

Unlock renewable energy and CO_2 resources for project developers

Accelerate the deployment of Direct Air Capture (DAC). As industrial CO_2 sources are supposed to stop emitting after 2040 due to EU climate rules, and biogenic CO_2 sources are limited, DAC is the only sustainable, long-term CO_2 source compatible with e-fuel production. The EU should adopt DAC-specific incentives, such as sub-targets under ReFuelEU, FuelEU and the RED for e-fuels made with DAC, to speed up deployment, reduce costs, and ensure future-proof CO_2 supply for aviation e-fuels.

Facilitate the deployment of a CO_2 transport and collection network. The EU should develop a coordinated strategy to connect key industrial CO_2 emitters, DAC hubs, and e-fuel production sites. This effort should be anchored in existing legislative frameworks, like the TEN-E Regulation (Trans-European Networks for Energy) and the Connecting Europe Facility (CEF).

Facilitate access to long-term PPAs by introducing flexibility in national renewable support schemes to help unlock renewable electricity sourcing for e-fuel projects while maintaining financial stability for renewable developers. Member States should allow renewable electricity projects that win auctions or benefit from support contracts (e.g., CfD schemes) to temporarily suspend these contracts in order to enter long-term PPAs with e-fuel producers.

5

Guarantee fair and open access to jet fuel infrastructure

Review competition barriers. EU and national competition authorities should investigate whether current ownership and access conditions for jet fuel infrastructure restrict competition. A coordinated review led by the European Commission should examine potential abuses of dominant position by incumbent fuel suppliers, focusing on barriers to entry, pricing practices, and transparency of access terms.

Mandate open access across the supply chain. Reinforce ReFuelEU's airport provisions to ensure SAF producers can access critical infrastructure, such as pipelines, blending facilities, and storage terminals, on fair and non-discriminatory terms.

Declare airport fuel farms as centralized infrastructure (CI), as allowed under Directive 96/67/EC**.** Member States and airport operators should require that storage and hydrant systems be designated as CI, ensuring non-discriminatory access and fair pricing for SAF suppliers.

Ensure open access to strategic pipelines. EU and national competition authorities should ensure fair third-party access to key off-airport infrastructure, especially major pipelines like the Rhein-Main Pipeline (RMR) that serve strategic hubs such as Frankfurt.

6

Clarify definitions and enforcement mechanisms for e-SAF (non-)compliance

Exclude renewable hydrogen used in HEFA from compliance. The Commission should refuse to endorse certification schemes that consider that green hydrogen added during bio-refining processes (e.g. HEFA upgrading) can qualify towards the e-SAF mandate. This interpretation, if allowed, would divert compliance volumes away from genuine e-fuels and weaken the investment case for new synthetic fuel plants.

Make financial penalties for non-compliance enforceable and clearly defined. All Member States must urgently embed ReFuelEU penalties into national legislation and, preferably, assign specific monetary values to them. For consistency, values should be benchmarked to EASA price references (e.g. €14,000/tonne).

Treat non-compliance penalties as accounting liabilities. Regulatory authorities and auditors should recognise expected non-compliance costs as financial liabilities on obligated parties' balance sheets. This would ensure fuel suppliers are held accountable by their shareholders if they fail to sign long-term offtake agreements or bring e-kerosene production online.

Sources

The analysis heavily relies on information from conversations with project developers, press releases and company announcements. The data and analysis reflects announced projects up to April 2025, as data collection concluded then. In addition, we used the following sources for the analysis:

- Legislation
    - ReFuelEU Aviation Regulation
    - RFNBO Delegated Acts, as required under Article 27(3) of the Renewable Energy Directive (2018/2001)
        - First Delegated Act
        - Second Delegated Act
        - Q&A
    - Guidance on RFNBOs in conventional and biorefineries
    - UK SAF mandate
- SAF producers
    - Bloomberg NEF - Global Renewable Fuel Projects Tracker
    - Stratas Advisors - Renewable Fuel Project Tracker
    - Argus - Renewable Fuel Project Tracker
    - EASA - State of the EU SAF Market
    - SIA-Partners - Observatoire international des e-fuels
    - NIA
    - E-fuel alliance - e-fuels production map
    - RLCF alliance - pipeline
    - Sohu article
    - CENA - SAF monitor
- Electricity grids
    - Ember - Yearly electricity data
    - Hydrogen Europe - Impact Assessment on the RED II DAs
- SAF prices
    - EASA - 2024 Aviation Fuels Reference Prices ReFuelEU Aviation
    - Project SkyPower - Open-source cost model
- HEFA pathway
    - Studio GearUp - Options for the deployment of UCO

Annex 1: Methodology

Introduction

This methodological annex provides a detailed explanation of the data collection, assumptions, limitations, and calculations used in this report.

The report is based on information retrieved from fuel producer's financial and environmental reports, articles and press-releases as well as 29 bilateral conversations. The data was provided to 66 project developers for review; however, only not all responded, introducing potential gaps in the data. Consequently, we cannot guarantee the completeness or correctness of the information provided.

Project Selection Criteria

- **Minimum production threshold**: Only includes projects with a planned or confirmed **e-kerosene production capacity above 10 kilotonnes per year (kt/yr)**. This threshold distinguishes **large-scale projects** from smaller commercial- or research-scale efforts.
- **Known or stated capacity**: Projects are listed **only if**:
    - The production capacity is publicly known, **or**
    - It is explicitly stated (e.g., in a Memorandum of Understanding) that the target capacity exceeds **10 kt/yr**.
- **Hydrogen made from electricity**: For large-scale projects, only those using hydrogen made from electric energy are included. Projects relying **exclusively on biogenic or grey hydrogen** are excluded.
- **CO_2 input assumptions**: Projects are included even if they do not specify the **source of CO_2**, assuming standard process requirements apply.
- **Project counting**: If a project developed at a single site with different development states, we only count the additional e-kerosene production capacity at each stage and count the different stages as separate projects since they will require more financing and development. Furthermore, earlier development stages will likely proceed independently from later plans.

Technical and Process Assumptions

- **E-kerosene density**: Assumed at **0.757 kg/l**, used to convert between mass and volume.
- **Energy content**: Assumed at **44 MJ/kg** (Lower Heating Value), used to calculate energy output from mass.
- **CO_2 input requirement**: Assumed that **4 tonnes of CO_2** are required to produce **1 tonne of e-kerosene**, accounting for losses in processes such as Reverse Water-Gas Shift (RWGS).

- **Electrolysers:** Assumed that the **electrolyser capacities refer to input electrical power** unless stated otherwise and estimate the output assuming **85% full load hours** and **66% efficiency**. Assume that 0.5 tonnes of hydrogen are required for the production of 1 tonne of e-crude, accounting for losses in processes such as Reverse Water-Gas Shift (RWGS). This means that **100 MW of input electrolyser capacity imply an e-crude production capacity of 29kt.**
- **PBtL fuel split**: For Power-and-Biomass-to-Liquid (PBtL) projects using gasifiers, a default **50:50 split** between e-fuels and biofuels is assumed unless more specific information is available.
- **Fischer-Tropsch kerosene yield**: Assumed **75% kerosene selectivity** from total output unless project-specific data indicates otherwise.
- **Methanol-to-Jet kerosene yield**: Assumed **95% kerosene selectivity** unless more accurate project-specific information is provided.
- **Production capacity assumptions**: Capacities are listed even though **load factors below 100%** are likely, meaning real output may be lower than nameplate capacity.
- **E-SAF investment needs**: We assume a model plant with 85% full load hours capacity of and a capacity of 70,000 tonnes of e-SAF production. This implies 59,000 tonnes of e-SAF output per year. Therefore, ten plants could meet the ReFuelEU 2030 mandate. Assuming €1-2 billion of CAPEX per plant, this leads to investment needs of €10-20B by 2030.

Future fuel consumption and SAF mandates

The analysis of the fuel and SAF consumption of airlines/airline groups requires a range of assumptions that are explained in the following:

- **EU**: Estimate EU jet fuel consumption in 2023 using OAG flight schedule data and extrapolate with a 1.1% annual fuel consumption growth rate leading to around 50 Mt of fuel consumption by EU civil aviation in 2030
- **UK:** Based on **RTFO and SAF Mandate standard data** projecting around 12 Mt of UK jet fuel consumption in 2030

Ticket price increase

Ticket price increases were estimated based on the following assumptions:

- **Fuel cost share**: Jet fuel accounts for **33% of the total ticket price**.
- **Fossil jet fuel price**: Assumed at **€750 per tonne**.
- **e-SAF price**: Based on the **EASA reference price for RFNBO e-kerosene of €7,700 per tonne**.
- **Blending mandates**: A **1.2% e-SAF blending requirement by 2030**, increasing to **2% by 2032** under the ReFuelEU Aviation Regulation.

Hydrogen costs

Hydrogen costs are based on **Project SkyPower's open-source e-SAF cost and BNEF's 2025 LCOH cost model**. LCOH costs are estimated as:

- **China:** 3.21 $/kg (in 2025 in real 2023 $)
- **Spain:** 5.95 $/kg (in 2025 in real 2023 $)
- **Texas:** 6.24 $/kg (in 2025 in real 2023 $)
- **Utah:** 7.81 $/kg (in 2025 in real 2023 $)
- **Germany:** 7.93 $/kg (in 2025 in real 2023 $)
- **Norway:** 5.61 €/kg (for e-SAF plant with FID in 2030 in 2024 €)
- Assume 3% annual inflation and 1.1 $/€ in 2023

E-SAF costs

E-SAF costs are based on **Project SkyPower's** **open-source e-SAF cost model** and **EASA's** **2024 Aviation Fuels Reference Prices for ReFuelEU Aviation.** We use the following production cost estimates from EASA's report:

- Synthetic aviation fuels (weighted average between industrial, biogenic and DAC CO_2): €7,695 per tonne
- Synthetic low-carbon aviation fuels: €5,525 per tonne
- Therefore, synthetic low-carbon aviation fuels are expected to be on average 30% cheaper than synthetic aviation fuels due to the stricter RFNBO requirements for electricity sourcing

Maps

- **Location estimation**: Project coordinates were estimated using the **Python Geopy** library based on available geographic references such as city names or industrial zones.
- **Representative locations**: For projects with **unclear or missing location data**, approximate coordinates were identified using **ChatGPT**, relying on contextual information such as company headquarters, project partners, or regional mentions in public sources.
- **Map boundaries disclaimer**: Country and region boundaries displayed on the maps are based on **World Bank standard shapefiles**. Their inclusion does **not imply any endorsement or political stance** regarding the status or borders of any territory.

Annex 2: HEFA and RFNBOs

Context and Objective

This section outlines the rationale and methodology we use to estimate the share of a typical HEFA (Hydroprocessed Esters and Fatty Acids) process output that can be classified as Renewable Fuels of Non-Biological Origin (RFNBO).

Under the ReFuelEU Aviation Regulation, e-SAF is defined as "*aviation fuels that are RFNBOs*", in line with the Renewable Energy Directive (RED). The RED defines RFNBOs as "*liquid or gaseous fuels... the energy content of which is derived from renewable sources other than biomass.*"

In the HEFA production process, a portion of the energy content in the final aviation fuel stems from the hydrogen introduced during hydrotreatment. When this hydrogen is derived from renewable electricity (i.e. green hydrogen), *a part of the HEFA product may technically meet the RFNBO criteria*, despite the process itself being bio-based.

This overlap has triggered debate about whether the renewable hydrogen input in HEFA fuels can justifiably count towards the e-SAF sub-mandate under ReFuelEU. Critics refer to Annex A10 of the second delegated act on RFNBOs, which could be interpreted to require that the carbon in RFNBOs originate from captured CO_2—implicitly excluding biofuel pathways like HEFA.

Regardless, interpreting the green hydrogen fraction of a HEFA fuel as e-SAF-compliant (like some certification schemes are proposing) goes against the legislators' intention to promote genuine e-fuels made from renewable electricity and captured CO_2 through the ReFuelEU sub-mandate, which is reflected in the regulation's recitals (such as recital 25).

We highlight the risk of double counting or regulatory loopholes if a portion of HEFA aviation fuel is credited under the e-SAF mandate merely due to RFNBO hydrogen input. To bring clarity to this issue, we proceed to quantify the share of HEFA fuel output that could be considered RFNBO under current regulatory interpretations.

Methodology

RFNBO attribution is calculated following the general energy-based rule:

> *"If the output of a process does not fully qualify as renewable liquid and gaseous transport fuels of non-biological origin or recycled carbon fuel, their respective shares in the total output shall be determined by dividing the relevant renewable energy input into the process by the total relevant energy inputs."*

Here, the **relevant energy** is the **lower heating value (LHV)** of the material inputs that end up in the **molecular structure of the fuel**.

The HEFA (or HVO) process involves hydrotreating triglycerides and free fatty acids derived from vegetable oils or waste oils (e.g., used cooking oil, UCO). The pathway broadly includes:

- **Saturation** of double bonds in fatty acids
- **Hydrocracking** of triglycerides into free fatty acids
- **Hydrodeoxygenation** to remove oxygen as water
- **Decarbonylation** to remove oxygen as carbon monoxide
- **Decarboxylation** to remove oxygen as carbon dioxide
- **Hydrocracking** of hydrocarbons into shorter hydrocarbon chains
- **Isomerisation** (primarily for aviation fuels) to enhance cold-flow properties

These reaction steps require the input of hydrogen that is currently produced from natural gas (grey hydrogen) in most biorefineries. A share of the hydrogen used in the saturation, cracking, hydrodeoxygenation and decarbonylation and cracking steps ends up in the molecular structure of the final fuel. Therefore, a share of the output of the HEFA/HVO process qualifies as RFNBO if the input hydrogen qualifies as RFNBO.

We modelled the process using a molecular-level approach in Python to track **how much hydrogen contributes energy to the final fuel molecules**, and thus how much of the HEFA output can be considered RFNBO.

Three approaches were considered:

Approach 1: Gross Energy Input Method

This method uses the ratio:

$$\mathbf{LHV\_H_2 / (LHV\_H_2 + LHV\_UCO)}$$

It assumes all hydrogen ends up in the fuel, and estimates RFNBO share based on energy inputs. However, it may **overestimate RFNBO share**, as not all hydrogen atoms are incorporated in final fuel molecules (e.g., some are lost as water or leave in by-products like propane).

Approach 2: Net Hydrogen Retention Method

This approach improves on the first by accounting **only for the hydrogen that ends up in the final hydrocarbon molecules**. This approach modifies the numerator accordingly, but still treats the process as a black box. It neglects the energy that the hydrogen contributes to the final molecule by reducing oxygen and making it more reactive.

Approach 3: Step-by-Step Attribution

This approach models each chemical reaction step and tracking:

1. The **hydrogen input** at each stage (saturation, hydrodeoxygenation, cracking, etc.)
   The **retention rate**—how much of the hydrogen's energy is embedded in the final hydrocarbon product
2. The cumulative **RFNBO share of energy** at each step, combining fossil and non-fossil contributions

Molecular compositions and LHVs were calculated using **Boie's equation after each reaction.** Again, this approach neglects the energy that the hydrogen contributes to the final molecule by reducing oxygen and making it more reactive.

Key Modelling Assumptions

- For the process assumptions, we follow the Studio GearUp report Conversion efficiencies of fuel pathways for Used Cooking Oil that models
  - **Feedstock composition**: 90% triglycerides (TAG), 10% free fatty acids (FFA)
  - Equal mix of rapeseed, soy oil and palm oil FFA
  - Free fatty acids with an average 17.6 C atoms, 32.6 H atoms, 2 O atoms
  - The process configuration studies in the report yields
    - 778 kg HEFA fuel, 36 kg propane, 61.9 kg naphtha and 30.9 kg fuel gas **for 1000 kg of pre-treated UCO input**
  - We assume 100% hydrodeoxygenation of the free fatty acids and a single cracking step
- **Energy values**:
  - Hydrogen: **120 MJ/kg**
  - The higher heating value (HHV) is estimated for each molecule step using atomic composition (C, H, O) using Boies equation HHV = 34.8 * c + 93.9 * h - 10.8 * o where c + h + o = 1 respect the mass shares of the carbon, hydrogen and oxygen atoms in the molecules. This assumes zero nitrogen and sulfur content of the input vegetable oils.
  - The lower heating value (LHV) relevant for the calculation of the RFNBO share is estimated using the HHV. Every kg of hydrogen produces approximately 9 kg of water and water requires a latent heat of 2.442 MJ/kg to vaporise. As a first approximation, the LHV therefore reads LHV = HHV - 2.442 * 9 * h with the respective hydrogen mass share h.
  - For the input triglyceride, this yields: LHV = 36.9 MJ/kg

- **Retention rates**:
  - Full retention for saturation where each double bond is saturated with one hydrogen molecule ($R{-}CH{=}CH{-}R' + H_2 \rightarrow R{-}CH_2{-}CH_2{-}R'$) and isomerisation
  - 50% retention during propane splitting ($C_3H_5(OOCR)_3 + 3\ H_2 \rightarrow 3\ R{-}COOH + C_3H_8$) since have of the hydrogen input ends up in the propane and the other half in the liquid fuel

    - One-third retention during hydrodeoxygenation ($R{-}COOH + 3\ H_2 \rightarrow R{-}CH_3 + 2\ H_2O$) since two thirds of the hydrogen atoms end up in two water molecules created per FFA
    - Full retention for cracking (a hydrogen molecule breaks a hydrocarbon chain into two shorter hydrocarbon chains)
- Assume that RFNBO hydrogen is evenly distributed across the hydrocarbon output range in the final fuel molecules

Results

- **In the example process for the hydrotreatment of 1t of pre-treated UCO**
    - A total of 42.5 kg hydrogen are consumed based on stoichiometric calculations assuming oxygen removal through 100% **hydrodeoxygenation**
        - The Studio GearUp report finds a slightly lower H2 consumption of 41 kg hydrogen taking into account a small share of decarbonylation and decarboxylation
    - A total of 25.4 kg of hydrogen are retained in the chemical structure of the final fuel with the above retention rates
- Gross input energy (Approach 1):
    - 5101 MJ H2 input
    - 36609 MJ UCO input
    - Share of hydrogen energy input as percentage of total energy input
    - **12.2% RFNBO share in final fuel**
- Net hydrogen retained (Approach 2)
    - 3043 MJ H2 input
    - 36609 MJ UCO input
    - Consider only the hydrogen that ultimately remains within the liquid hydrocarbon products, excluding hydrogen lost as water or in by-products (e.g., propane).
    - For each free fatty acid (FFA), count only one-third of the hydrogen used for hydrodeoxygenation, since two-thirds convert to water.
    - For each triglyceride (TAG), assume half of the hydrogen used during cracking is incorporated into propane and the remainder into FFAs.
    - Converts the retained hydrogen mass to its lower heating value (LHV) and compares this energy to the UCO feedstock's LHV to determine the RFNBO fraction.
    - Produce a single "black-box" RFNBO share without explicit stepwise reaction tracking.
    - **7.6% RFNBO share in final fuel (see Python model for details)**
- Stepwise attribution (Approach 3)
    - Model each reaction sequentially: saturation, HDO, cracking.
    - At each stage, calculate the energy input from hydrogen and apply the retention factors.
    - Updates the cumulative RFNBO share by accounting only for the hydrogen energy that remains in the evolving fuel molecules at each intermediate step.

- Compare retained hydrogen energy to the total input energy after each reaction to track how the RFNBO share evolves.
- **5.1% RFNBO share in final fuel (see Python model for details)**

Annex 3: E-SAF projects

Introduction

This annex lists all the e-SAF projects considered in this report that are ongoing as of May 2025 according to the authors' knowledge. We distinguish between large-scale projects (production capacity >10,000 tonnes/year of e-kerosene), commercial-scale projects (100-10,000 tonnes/year) and research-scale projects.

Large-scale projects

Project developers	Country	Location	E-kerosene capacity in kt per year	Planned commissioning year	Note
Elion Resources Group (亿利集团)	China	Alxa league, Wulan County, Inner Mongolia (阿拉善乌兰布)	300	Unknown	Announcement includes 3.5 GW combined wind and solar capacity. Assuming 30% full load hours, this corresponds to 310 kt/yr of e-crude. With a process that recycles co-products, it is possible that this project aims for 300 kt/yr of e-SAF.
Nordic Electrofuel	Saudi Arabia	Jubail	300	2029	Assume 75% kerosene share out of 400 kt e-crude output.
Power2X, Advario	Netherlands	Port of Rotterdam	250	2030	Assume 5% co-products
SPIC (国电投集团)	China	Nehe Laha Biotechnology and Chemical Pharmaceutical Industrial Park, Qiqihaer, Heilongjiang (黑龙江齐齐哈尔)	195	2030	Announcement talks about 390kt e-SAF and 400 kt of e-methanol as well as 164 kt/yr hydrogen capacity. 164 kt/yr hydrogen capacity. Methanol synthesis requires roughly 0.2 kg H2/kg hydrogen, so the 400 kt e-methanol would consume around of the hydrogen leaving 80 kt/yr of hydrogen or 160 kt/yr of e-crude. Assuming that this project uses 50% biogenic hydrogen from solid biomass, we find 40 kt hydrogen demand for 200 kt e-methanol and ~100 kt hydrogen demand for ~200 kt of e-SAF which is more consistent with 164 kt/yr hydrogen capacity. The paper published on the CO2AF conversion technology (https://www.tsinghua.edu.cn/info/1175/91107.htm)

					developed by Beijing University also shows a figure combining syngas from solid biomass gasification with electrolytic hydrogen for this process supporting the assumption that a share of this SAF is actually bio-SAF. Therefore, assume 50% e-SAF share.
Smartenergy	Portugal	Lisbon	155	2030+	No co-products since naphtha is recycled.
Nordic Electrofuel	Norway	Herøya	114	2032	200M litres of e-crude assuming 0.76 kg/l density. Assume 75% kerosene share.
Nordic Electrofuel	Norway	Unknown	108	2033	190M litres of e-crude assuming 0.76 kg/l density. Assume 75% kerosene share.
GreenSinnergy	Argentina	Chubut	100	2032	
Elyse Energy	France	Fos-sur-Mer (Industrial port zone)	100	2032	Initially 50 kt/yr e-kerosene, later 75 kt/yr, up to 100 kt/yr capacity with 50 kt/yr on-site production.
SkyNRG	Sweden	Port of Skellefteå	100	2030	
China Energy (中国能建中电工程)	China	Shuangyashan City, Heilongjiang Province (黑龙江双鸭山)	100	Unknown	Assume 50:50 e-biofuel split out of the difference of 200 kt/yr of SAF output between phase 1 and phase 2 of the project. At that point, they plan on using 1.6 Mt of straw.
Ignis P2X	Spain	Villaluenga de la Sagra (Holcim's existing cement plant south of Madrid)	100	2031	
Mongolia Jiutai Group (内蒙古久泰集团)	China	Zharut Banner, Inner Mongolia (扎鲁特旗, 内蒙古)	100	Unknown	Conversion of excess capacity at Jiutai Group's existing MtO refinery.
Wakud	Oman	Port of Sohar	95	Unknown	125 million litres of e-SAF in addition to 250 million litres of HEFA SAF. Assume 0.76 kg/l SAF density.

Biorefinery Östrand (SCA & St1)	Sweden	Östrand	93	2029	Assume 50:50 e-biofuel split out of 235 kt of crude and 185 kt/yr of SAF.
Copenhagen Infrastructure Partners	Denmark	Aalborg	90	2030	
Verso Energy	France	Chavelot (Grand-Est)	81	2030+	85 kt/yr e-crude and 81 kt/yr e-SAF.
Verso Energy	US	Jesup, Georgia	81	2030+	85 kt/yr e-crude and 81 kt/yr e-SAF.
Verso Energy	Finland	Oulu	81	2030+	85 kt/yr e-crude and 81 kt/yr e-SAF.
Verso Energy	France	Rouen / Petite Couronne	81	2029	85 kt/yr e-crude and 81 kt/yr e-SAF.
Verso Energy	France	Saillat-sur-Vienne et Etagnac (Limousin)	81	2030+	85 kt/yr e-crude and 81 kt/yr e-SAF in phase 1. Ramp-up to 150 kt of e-SAF in phase 2.
Verso Energy	France	Tartas (RYAM site)	81	2030+	85 kt/yr e-crude and 81 kt/yr e-SAF.
Verso Energy	Finland	Tornio (Arctio North industrial site)	81	2029	85 kt/yr e-crude and 81 kt/yr e-SAF.
Smartenergy	Portugal	Porto	77	2030	No co-products since naphtha is recycled.
Wakud	Oman	Port of Salalah	76	Unknown	100 million litres of e-SAF in addition to 200 million litres of HEFA SAF. Assume 0.76 kg/l SAF density.
Xiangrui Energy (祥睿能源), Beijing Energy International (北京能源国际控股有限公司)	China	Dorbod Mongol Autonomous County, Heilongjiang Province (黑龙江省杜尔伯特)	75	Unknown	Assume that this is a project co-producing 50% e-SAF and 50% bio-SAF out of 150 kt/yr SAF output.
H2V	France	Dunkerque	75	2032	Start date: 2031 or 2032. Assume 2032. Assume 75% e-kerosene share out of 100 kt/year e-crude.
H2V, Hy2gen	France	Fos-sur-Mer (Industrial	75	2030	

		port zone)			
Shanxi International Energy Group (山西国际新能源)	China	Zharut Banner, Inner Mongolia (扎鲁特旗, 内蒙古)	75	Unknown	Source talks about 700 MW of wind power capacity with battery buffering in the first phase. Assuming 50% full load hours, this corresponds to 350 MW and only around 100 kt/yr of e-crude. Therefore, assume that this is a project co-producing e-fuels and biofuels with 50:50 split.
MGH Energy	Morocco	Dakhla-Oued Ed-Dahab region	70	2030	Output of first stage is 70kty of e-jet (2030), output of the second stage: 140kty of e-jet, 190kty of e-methanol
MGH Energy	Morocco	Dakhla-Oued Ed-Dahab region	70	Unknown	Output of first stage is 70kty of e-jet (2030), output of the second stage: 140kty of e-jet, 190kty of e-methanol. Only list difference for stage 2.
IðunnH2	Iceland	Helguvík Harbour	70	2029	
Engie	France	Le Havre	70	2031	70 kt/yr e-kerosene out of around 86.5 kt/yr of e-crude.
Arcadia eFuels	UK	Teesside	68	2030+	68 kt e-SAF out of 80 kt output.
Arcadia eFuels	US	Texas	68	2030+	68 kt e-SAF out of 80 kt output.
Arcadia eFuels	Denmark	Vordingborg	68	2030	68 kt e-SAF out of 80 kt output. FEED completed.
Infinium	Norway	Mo i Rana	66	Unknown	Up to 2000 barrels/per day translating to up to 88 kt of e-crude per year assuming 0.76 kg/l density. Assume 75% kerosene share.
Norsk e-Fuel	Sweden	Ånge	61	2032	Norsk has goal of one operational plant by 2030 and three operational plants by 2032. Assume that Project Mosjoen will be operational in 2030 and Project Rauma and Alby operational by 2032 since they are the most advanced according to the project website https://www.norsk-e-fuel.com/projects as of 04/2025.
Norsk e-Fuel	Finland	Pelkola, Imatra Municipality	61	Unknown	Norsk has goal of one operational plant by 2030 and three operational plants by 2032. Assume that Project Mosjoen will be operational in 2030 and Project Rauma and Alby operational by 2032 since they are the most advanced according to the project website https://www.norsk-e-fuel.com/projects as of 04/2025.
Norsk e-Fuel	Finland	Rauma	61	2032	Norsk has goal of one operational plant by 2030 and three operational plants by 2032. Assume that Project Mosjoen will be operational in 2030 and Project Rauma and Alby operational by 2032 since they are the most advanced according to the project website https://www.norsk-e-fuel.com/projects as of 04/2025.

RIC Energy	Spain	Cubillos del Sil (Castilla y León)	60	2029	Assume that 250 MW_e correspond to 80 kt e-crude. Assume 75% kerosene share.
ORLEN	Poland	ORLEN refinery	60	2031	60 kt e-SAF out of 70 kt e-crude.
Lydian	US	Unknown	57	2030	20 million gallons of e-SAF per year assuming 0.76 kg/l SAF density.
China Energy (中国能建中电工程)	China	Karamay, Xinjiang province (新疆克拉玛依)	50	Unknown	1 GW wind and PV installations - suggesting a maximum capacity of around 70 kt of e-crude depending with 25% load factor. The article also mentions goals to produce 10 kt of hydrogen which would bring this amount down by 20 kt. Subtract the separate hydrogen production to arrive at 50 kt/year. This is also consistent with China Energy's Shuangyashang project where the announcements explicitly mention 50 kt of e-SAF and 50 kt of bio-SAF.
China Energy (中国能建中电工程)	China	Shuangyashan City, Heilongjiang Province (黑龙江双鸭山)	50	2027	Assume 50:50 e-biofuel split out of 100 kt announced SAF capacity. "Once the project begins full production, nearly 900,000 tons of crop stalk raw materials will be used annually."
Shanxi International Energy Group (山西国际新能源)	China	Zharut Banner, Inner Mongolia (扎鲁特旗, 内蒙古)	50	2027	Source talks about 300 MW of wind power capacity with battery buffering in the first phase. Assuming 50% full load hours, this corresponds to 150 MW and only around 45 kt/yr of e-crude. Therefore, assume that this is a project co-producing e-fuels and biofuels with 50:50 split. This is also consistent with the second source showing the project approval: It states a total hydrolysis capacity of 32,000Nm3/h that corresponds to 25 kt/yr of hydrogen which matches 50 kt/yr of e-crude.
Sempen	Brazil	Unknown	45	Unknown	Estimate based on 200 MW_e electrolyser producing 60 kt of e-crude per year. Assume 75% kerosene output.
Elyse Energy	France	Bassin de Lacq	44	2029	Assume 50% e-fuel and biofuel split out of 110 kt/yr crude containing 87 kt SAF.
Concrete Chemicals	Germany	Rüdersdorf	40	2030	
Norsaf	Latvia	Liepaja Special Economic Zone	39	2030	Assume 60:40 bio-SAF and e-SAF split with 100 kt/yr of SAF output. AtJ-SKA pathway producing 100% drop-in SAF with a share of e-ethanol.
EDF	France	Saint-Nazaire	38	2032	
MGH Energy	France	Occitanie	35	2031	
Metafuels,	Netherla	Port of	32	Unkno	120 kl per day in second phase assuming 0.76 kg/l SAF

Evos	nds	Rotterdam		wn	density. Only show difference with phase 1.
Norsk e-Fuel	Norway	Nesbruket	30	2030	50M liters of e-crude of which up to 80 % will be upgraded to sustainable aviation fuel. Assume 0.76 kg/l SAF density.
Hy2gen Deutschland GmbH	Germany	Brandenburg	28	2030	Design: At least 16kt/yr. Options with potential offtakers to increase it to 28 kta. Assume 95% kerosene share.
Unknown	China	Baiyin City, Gangsu Province	25	Unknown	The source talks about the production of 50 kt/yr of SAF through green hydrogen produced with wind and solar energy. Like other Chinese projects, this could refer to a project co-producing e-SAF and bio-SAF. To err on the side of caution, we assume that 50% of the SAF qualifies as e-SAF.
Carbon Neutral Fuels & io Consulting	UK	North West, UK	25	2031	
Synhelion	Morocco		25	Unknown	Generates syngas from bio-methane using solar heat. Assume that 1/3 of the output of 100 kt/yr qualifies as e-crude. Assume 75% kerosene selectivity.
XFuels	Germany	Bohlen-Lippendorf (DOW's industrial park)	24	2030	Assume 50:50 e-biofuel ratio and 75% kerosene share.
China Energy (中国能建中电工程)	China	Diaobingshan District, Tieling City (铁岭调兵山), Liaoning	20	Unknown	Phase I will have an annual output of 100,000 tonnes of green methanol and 20,000 tonnes of green aviation fuel, with a total investment of approximately 4.2 billion RMB. Supporting facilities such as centralized wind farms and photovoltaic power stations will be constructed. This project will leverage the locally abundant wind and solar resources, applying a CO_2-coupled, new-energy hydrogen-to-methanol process and extending it to produce green aviation fuel.
Nordic Electrofuel	Norway	Unknown	19	2030	33M litres of e-crude assuming 0.76 kg/l density. Assume 75% kerosene share.
Infinium	US	Pecos, Texas	16	2027	7M gallons of e-crude per year correspond to 22 kt / year assuming 0.76 kg/l SAF density. Assume 75% kerosene share.
Solarig	Spain	Teruel	14	2031	Assume 13%-87% e-fuel and biofuel split out of 105 kt of crude. Assume 100% kerosene share.

Enagás Renovable, EVE, Petronor	Spain	Bilbao	12	2029	Assume 50% kerosene share out of 21 kt/yr e-crude. Therefore, assume 10x the output of pilot plant since the electrolyser is 10x the size.

Commercial-scale projects

Project developers	Country	Location	E-kerosene capacity in kt per year	Planned commissioning year	Note
SPIC (国电投集团)	China	Nehe Laha Biotechnology and Chemical Pharmaceutical Industrial Park, Qiqihaer, Heilongjiang (黑龙江齐齐哈尔)	10	2025	Announcement actually talks about 100% electrolytic H2 + CO2 from corn ethanol production for the first phase. So, assume 100% e-SAF out of 10 kt/yr announced SAF production capacity for the first phase
SPIC (国电投集团)	China	Toli county, Dacheng area, Xinjiang province (新疆塔城地区托里县)	10	Unknown	Based on 1.2 GW off-grid windpower, assuming 25% full load hours, it could produce 88 kt of e-crude per year. But sources explicitly talk about 10 kt/yr of e-SAF.
CAC ENGINEERING GmbH, TU Bergakademie Freiberg	Germany	Unknown	9.6	2030	Currently not a formal project, but a plan for further activities. Concept phase. Goal of kerosene selectivity greater than 80%. This would not be a commercial project but a development project.
Solariq	Spain	Garray, Soria	9	2033	Assume 15%-85% e-fuel and biofuel split out of 60 kt/yr crude. Assume 100% kerosene selectivity.

Zero Petroleum	UK	Orkney	6.1	2026	
Nordic Electrofuel	Norway	Herøya	5.68	2029	10M litres of e-crude assuming 0.76 kg/l density. Assume 75% kerosene share.
Zero Petroleum	Australia	South Australia's Upper Spencer Gulf	5.68	Unknown	Assume 75% kerosene output out of 8 kt of e-crude
Caphenia	Germany	Gendorf (Chemicals park)	5	2027	PBtL process that creates syngas from biomethane using electric energy input. Assume 1/3 e-SAF and 2/3 bio-SAF output. Stage 1 until Q4/2027 15 kt-year SAF capacity Stage 2 until 2030 up to 100 kt-year SAF capacity
Hydrogen Refinery	UK	Farnborough	3.33	2028	Plasma electrolysis system that generates syngas from MSW using electric energy input. No external hydrogen input. Assume that 1/3 of the output qualifies as e-SAF.
Metafuels, Evos	Netherlands	Port of Rotterdam	3.32	Unknown	12 kl per day in first phase assuming 0.76 kg/l SAF density.
European Energy, Metafuels	Denmark	Padborg	3.23	Unknown	12 kl/day of e-SAF per day assuming 0.76 kg/l SAF density.
Dimensional Energy, Seneca Holdings	US	Niagara Falls	2	2027	200-barrel-per-day facility yielding 8 kt e-crude per year. Assume 25% kerosene share.
Ineratec	Germany	Frankfurt Höchst	1.88	2025	77% kerosene output out of 2.5 kt/e-fuels per year. Goal to increase share to 85%.
DLR	Germany	Leuna	1.88	2026	Assume 75% e-SAF output. Later, target capacity of up to 10 kt/year.
Vast, GGS Energy	US	Southwest United States	1.88	Unknown	7.5 kt/year methanol. Assume 75% MtJ conversion efficiency.
Enagás Renovable, EVE, Petronor	Spain	Bilbao	1.15	2026	Assume 50% kerosene share out of 2.1 kt/yr e-crude.

Solarbelt	Germany	Werlte	0.27	2024	Assume 75% e-kerosene selectivity out of 0.3 kt e-crude per year.
Synhelion	Spain	Mostoles	0.25	2027	Generates syngas from bio-methane using solar heat. Assume that 1/3 of the output of 1 kt/yr qualifies as e-crude. Assume 75% kerosene selectivity.
Twelve	US	Moses Lake	0.19	2025	Commercial-demonstration plant. 5 barrels per day/67650 gallons per year means around 0.2 kt e-crude per year assuming 0.76 kg/l density. Assume 80% kerosene share
Caphenia	Germany	Frankfurt Höchst	0.15	2025	PBtL process that creates syngas from biomethane using electric energy input. Assume 1/3 e-SAF and 2/3 bio-SAF. 0.5 kt-year SAF capacity

Research-scale projects

Project developers	**Country**	**Location**	**E-kerosene capacity in kt per year**	**Planned commissioning year**	**Note**
P2X-Europe	Italy	Sarroch, Sardinia	0.1	2025	0.15 kt / year of e-crude with a share of e-SAF.
ENEOS	Japan	Yokohama City, Kanagawa Prefecture, ENEOS research centre	0.04	2024	1 barrel per day. Assume 75% e-SAF.
Dimensional Energy	Canada	Richmond, British Columbia	0.03	2024	10x scale-up from Tucson facility. Tucson facility produces 19 l/synthetic crude oil per day translating to around 5 tonnes of e-fuel per year. This means

					0.05 kt e-crude/year for this plant.
CAC ENGINEERING GmbH, TU Bergakademie Freiberg	Germany	Freiberg (Institute of Energy Process Engineering and Chemical Engineering (IEC))	<0.01	2025	9.2 tones per year. Goal of kerosene selectivity greater than 80%.
Dimensional Energy	US	Tucson, Arizona	<0.01	2022	19 l/synthetic crude oil per day translating to around 5 tonnes of e-fuel per year.
Synhelion	Germany	Jülich	<0.01	2024	10 thousand liters of fuel per year. Generates syngas from bio-methane using solar heat. Assume that 1/3 of the output qualifies as e-crude. Assume 75% kerosene selectivity.
National Institute of Advanced Industrial Science and Technology (AIST)	Japan	Koto City, AIST research centre	<0.01	2024	200 ml/h with SOEC that co-electrolyses CO2 and water into syngas.
OXCCU	UK	London Oxford Airport, Oxford	<0.01	2026	Updated wr.t. to public announcement. 10-30 liters of fuels per day. Facility will be fully closed recycle loops and produce a finished Synthetic Blend Component using representative feedstocks. TRL7-8.
IHI Corporation, A*STAR ISCE2 (Institute of Sustainability for Chemicals, Energy and Environment)	Singapore	Singapore (Agency for Science, Technology and Research, Institute of Sustainability for Chemicals, Energy and Environment)	<0.01	2025	Direct Fischer-Tropsch process (or Modified FT, which will use CO2 and H2 as the source to directly convert to hydrocarbon without reverse water gas shift process). Target capacity of 1t of e-SAF per year if the test rig is fully operated.

OXCCU	UK	London Oxford Airport, Oxford	<0.01	2024	1.2kg of liquid fuel per day, assume 75% e-kerosene yields less than 1 t/yr of e-SAF.
Zero Petroleum	UK	Bicester	<0.01	2023	
Air Company	US	Bushwick, Brooklyn	<0.01	2021	1 l/h pilot plant results in 0.006 kt e-crude per year assuming 0.76 kg/l.
Infinium	US	Corpus Christi	<0.01	2024	8300 litres per day, main offtaker is Amazon for trucks, likely small kerosene share below 1 kt per year.
Topsoe	Denmark	Foulum, Denmark	<0.01	2024	Energy from biogas input in first stage
Fraunhofer ISE	Germany	Freiburg	<0.01	2028	
SAF + Consortium	Canada	Montreal (ParaChem Industrial site)	<0.01	2021	Assume less than 0.5 kta e-SAF
Metafuels	Switzerland	Paul-Scherrer-Institut	<0.01	Unknown	Assume less than 0.5 kta e-SAF.
Lydian	US	Research Triangle Park (RTI International) in North Carolina	<0.01	2025	25 gallons of fuel per day implies 0.03 kt of e-crude per year assuming 0.76 kg/l SAF density and therefore less than 1kt of e-SAF.
OXCCU	UK	Sheffield Translational Energy Research Centre	<0.01	Unknown	Assume less than 0.5 kta e-sAF.
University of Stuttgart IPV	Germany	Stuttgart	<0.01	2027	
Liquid Sun	Finland	Tampere	<0.01	2026	Less than 0.5 kt/yr e-SAF output.