The challenges of scaling up e-kerosene production in Europe

After ReFuelEU, what is the state of play of e-kerosene projects in Europe?

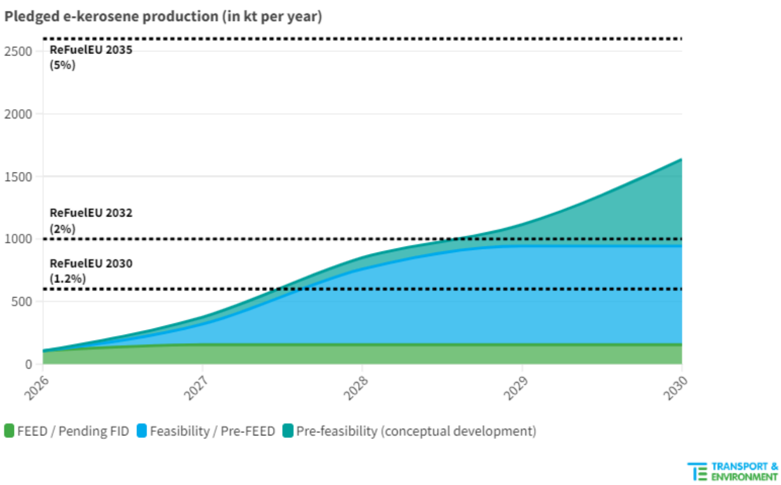
January 2024

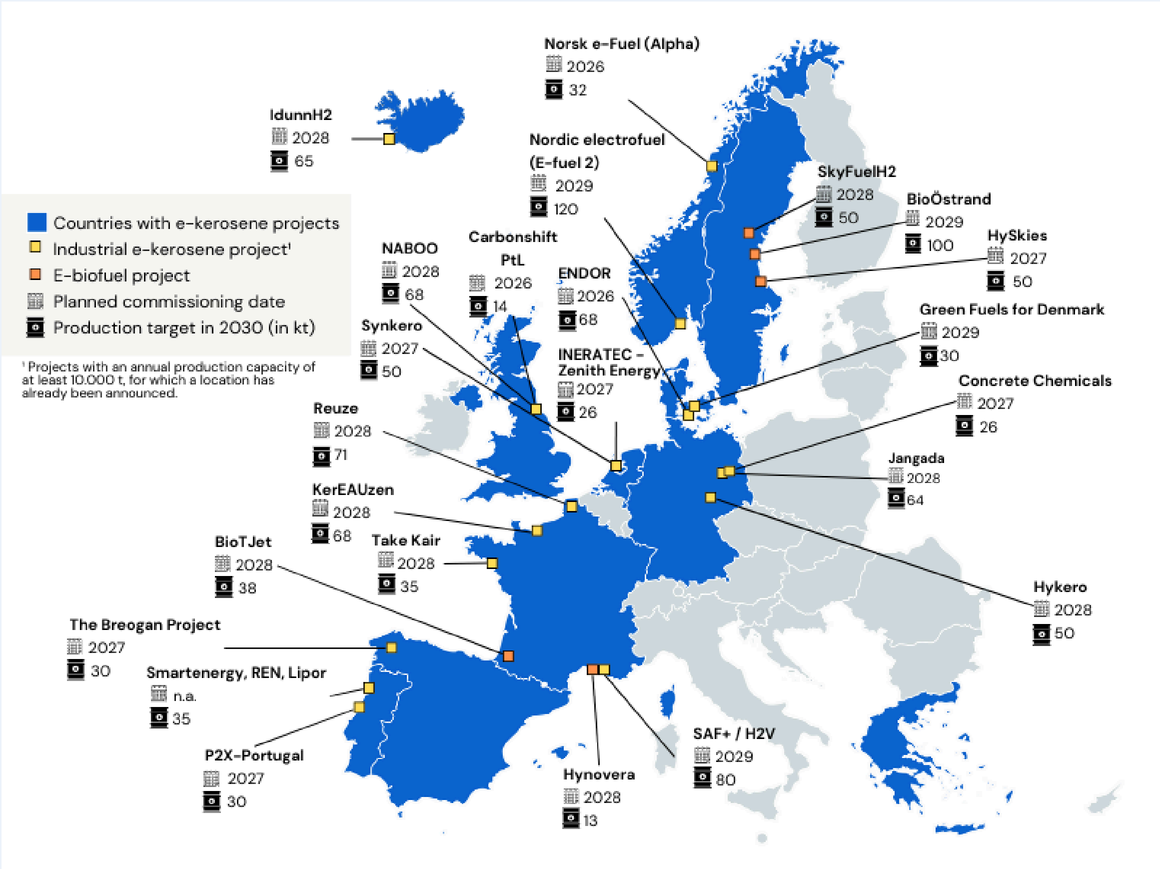
Summary

The EU has recently adopted its first-ever blending obligation for Sustainable Aviation Fuels (SAF) used in aircraft departing from the bloc through its ReFuelEU regulation. The text includes a sub-target for synthetic aviation fuels, thus creating long-term predictable demand which should de-risk investments in the e-kerosene supply chain. In this updated study, we quantify the projected total e-kerosene production capacity in the European Economic Area (EEA) in order to assess whether the EU is on track with its objectives.

As of 2023, we have identified a total of **45 e-kerosene projects** in the EEA, including 25 large-scale industrial projects and 20 smaller pilot projects. This update adds 17 projects compared to our last analysis published in November 2022, including eight new major announcements. In total, the large-scale industrial projects identified in this study amount to a potential production capacity of **1.7 Mt in 2030**, which is well above the target of 1.2% (translating into 0.6 Mt) mandated by ReFuelEU for that same year (rising to 2% or 1.0 Mt in 2032). While this seems to indicate that the EU is on the right track to achieve its targets, it should be noted that **none of the major projects have reached final investment decision (FID) yet,** and many projects are still running feasibility studies. **Until FIDs are taken, the projects' capacity referenced in this analysis should be considered as hypothetical until they actually materialise.**

Forecasted e-kerosene production capacity in the EEA per advancement stage compared with ReFuelEU blending mandates





From a geographical perspective, **Norway, France, Germany and Sweden are attracting most of the investments**, with up to 80% of potential e-kerosene production likely to be located in these four countries, whereas Italy, Poland, Belgium, and, more broadly, Eastern European states, are nowhere to be seen on the map. Our analysis also looked at CO_2 sources and revealed that **all projects listed are planning to use biogenic carbon sources**, with a shift away from carbon stemming from existing industrial emission streams, and a stall in the deployment of direct air capture (DAC) technologies that draw carbon dioxide from ambient air to produce e-fuels.

While ReFuelEU seems to have triggered a lot of ambitious announcements, many challenges still stand in the way of the scaling up of e-kerosene production in Europe :

- Some regulatory loopholes, including a lack of incentives to supply e-kerosene before 2030, looming regulatory incentives to use e-fuels in the road sector, and the possible non-inclusion of e-fuels for aviation and shipping as a strategic technology in the Net Zero Industrial Act (NZIA).
- The limited availability of renewable hydrogen and sustainable carbon sources risks creating a bottleneck on the market.
- High production costs remain a significant barrier to secure offtake agreements with airlines, although ReFuelEU financial penalties, the SAF allowances and Contracts for Difference (CfD) schemes should contribute to solving that issue.

- EU-funding is insufficiently targeted towards hydrogen use in hard-to-electrify sectors like aviation and shipping, and too few Member States are proactively seeking to develop local e-kerosene production.
- The control oil majors retain over the downstream jet fuel supply chain could turn them into gatekeepers, making it harder for new players to enter the market.
- Social acceptability is emerging as a new topic for e-fuels projects launching public consultations to secure environmental permits.

In order to address these challenges, T&E recommends:

- To prioritise the use of e-fuels in hard-to-abate sectors like aviation and shipping, instead of incentivizing their use in the road sector.
- To include e-kerosene projects in the list of strategic net-zero technologies of the Net Zero Industrial Act.
- To ensure more effective pricing of emissions linked to fossil jet fuel usage in aviation, to reduce the cost gap with e-fuels and encourage their deployment.
- For Member States to boost early supply of e-kerosene by setting pre-2030 targets, and to earmark a percentage of national revenues from the carbon market for aviation (known as EU ETS) to support local production of e-fuels.
- For EU funding to focus more on hydrogen applications for aviation and shipping, through auctioning or competitive bidding schemes in the Innovation Fund.
- To develop meaningful DAC policy incentives, such as future mandates for DAC use within fuels policies, and funding for research and project development.
- To guarantee fair and unrestricted access to existing and future jet fuel infrastructure.

1. Introduction

1.1. Scope and methodology

This study is meant to update T&E's analysis of green jet fuel production in Europe, which was initially published in June 2022 (and updated for the first time in November 2022). Since then, EU negotiators have come to an agreement on a sustainable fuels mandate for aviation (see section 1.3). While our previous analysis focused on quantifying the total e-kerosene production plans in Europe, this new version also takes stock of the challenges e-kerosene producers have to overcome to develop their projects.

E-kerosene is generated from hydrogen (H_2) and carbon dioxide (CO_2). In accordance with EU legislation, in order to fall within the scope of our analysis, e-kerosene projects must comply with the following criteria :

- The energy content of the fuel produced must come from renewable electricity;
- The hydrogen must be produced by electrolysis of water powered by renewable or nuclear electricity;

- The CO_2 can be recycled from bioenergy (so called biogenic carbon), industrial emissions or captured from the air (through Direct Air Capture).

We have also decided to include within the scope of our analysis the e-fuel share of so-called "e-biofuels" (sometimes referred to as Power-and-Biomass-to-Liquid (PBtL) fuels). These fuels come from the co-processing of a synthetic gas derived from biomass gasification and hydrogen from renewable electricity, which results in co-production of biofuel and e-fuel, as recently confirmed by the European Commission (EC) in a Q&A (question 45).[1]

ReFuelEU is a text with European Economic Area (EEA) relevance, which means it should be considered for incorporation into the EEA agreement and apply in EEA countries. Therefore, we include projects located in Norway and Iceland in the scope of the study. The United Kingdom (UK) is expected to have its own SAF mandate, which is why it is analysed separately (see Info Box pp. 7-8).

We used the projects listed in our previous analysis as a basis for this update. We checked the status and technological pathways of each project previously referenced, in order to filter out those which were abandoned and those which do not comply with production criteria defined by the new regulatory framework (see section 1.3). Production capacity estimations were refined, especially for e-biofuels projects (differentiating the bio-share from the e-share of the final product). We decided to base our production capacity estimations on concrete plant announcements rather than on upscaling targets, which has led us to downscale our production estimations for some projects[2]. This is why our total production capacity estimation is slightly lower than previously calculated (from 1.85 Mt to 1.7 Mt) despite having identified more projects. Finally, we tracked all public updates about already announced projects as well as new project announcements. Personal communications were established with most of the projects analysed in order to cross-check the information publicly available online, and to identify the main hurdles detailed in Section 3 of this briefing. More details can be found about the methodology of the analysis in Annex.

1.2. General context: the role of e-kerosene to decarbonise aviation

In order to decarbonize, the aviation sector requires an alternative to fossil kerosene which can be scaled up to meet the fuel demands of the sector. Unlike the biomass feedstocks used for biofuels[3], e-kerosene uses a more scalable source of feedstock: renewable energy. **If produced using additional renewable electricity and carbon dioxide captured from the atmosphere, the combustion of e-kerosene can be close to CO_2 neutral,** apart from some residual emissions due to the production and distribution of the fuel.

[1] The e-fuel to biofuel ratio is determined by the energetic ratio of electrolysed to biogenic hydrogen that ends up in the hydrocarbon. Only the share of final energy in e-biofuels derived from the injection of hydrogen produced by water electrolysis can count towards the RED and ReFuelEU RFNBO subtargets.

[2] Downscaled projects mainly include Synhelion (from 464 kt to 354 t, pending more concrete upscaling announcements), Green Fuels for Denmark (from 250 kt to 30 kt), and Arcadia e-Fuels (from 325 kt to 67 kt).

[3] The potential supply of advanced biofuels is limited to 11.4% of the remaining 2050 fuel demand (T&E, 2018).

Zero-emission aircraft (hydrogen or electric) could also play a significant role in reducing aviation emissions. However, such aircraft are not expected to be in operation in significant numbers until the late 2030s or 2040s, and it will be especially challenging to replace conventional aircraft for long-haul flights due to the fundamentally limited gravimetric energy density of batteries and low volumetric energy density of liquid hydrogen. Reduced flying by shifting to rail or removing fossil fuel subsidies enjoyed by the sector will also play an important role, especially in light of the high energy requirements to produce e-kerosene.

1.3. A brand new regulatory framework

Several texts now regulate the deployment of e-kerosene in the European market:

- Most importantly, **ReFuelEU Aviation** (2023) makes it compulsory for all jet fuel suppliers to blend a certain proportion of e-kerosene into the jet fuel they deliver to EU airports, starting at 1.2% in 2030 and progressively rising to 35% in 2050 **(Table 1)**.
    - According to article 3(8), '**synthetic aviation fuels**' are "*aviation fuels that are renewable fuels of non-biological origin*" (RFNBOs), as defined in the directive RED II (EU) 2018/2001, which comply with a lifecycle emissions savings threshold of 70%, in accordance with that same directive.
    - According to article 4(1), low-carbon synthetic aviation fuels (i.e. e-kerosene produced from nuclear energy) can count towards the synthetic aviation fuels blending mandate.

Effective dates	Minimum volume share of synthetic aviation fuels	Corresponding annual e-kerosene uptake in the EEA [4] (in Mt)
January 1, 2030 – December 31, 2031	Average share of 1.2%, with a minimum share of 0.7% in each year	0.6 (2030)
January 1, 2032 – December 31, 2034	Average share of 2%, with minimum shares each year of 1.2% from January 1, 2032, until December 31, 2033, and 2% from January 1, 2034, to December 31, 2034	1.0 (2032)
January 1, 2035	5%	2.6
January 1, 2040	10%	5.2
January 1, 2045	15%	8.2
January 1, 2050	35%	18.8

Table 1: E-kerosene blending mandates in ReFuelEU

[4] Total fuel burnt in a "no action scenario" is calculated based on a yearly traffic growth of 2.2%, and a 1.1% yearly fuel efficiency improvement, following T&E's roadmap modelling assumptions. Impacts of the additional costs from FF55 adopted policies (ETS carbon price and costs of SAF penetration resulting from RefuelEU mandates) on demand are taken into account to calculate final fuel burnt. At the time of writing this report, the European Taxation Directive (ETD) was not adopted.

- [**Directive RED II (EU) 2018/2001**]() **(2021)** gives a definition of RFNBOs.
    - Article 2(36): *'**renewable liquid and gaseous transport fuels of non-biological origin**' means liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, **the energy content of which is derived from renewable sources other than biomass**;*
- **The** [**Delegated Acts on RFNBOs**]() **(2023)** set criteria for the production of RFNBOs.
    - Regarding **electrolysers**:
        - RFNBO producers are required to have **power-purchase agreements (PPAs)** with renewable power generators (except if the grid-average electricity for the region is greater than 90% renewable electricity).
        - **Temporal correlation:** until December 31, 2029, the renewable electricity must be produced within the same calendar month as the hydrogen; starting January 1, 2030, they must demonstrate that the renewable energy was produced within the same hour as the hydrogen.
        - **Geographical correlation:** the hydrogen must be produced in the same bidding zone or a nearby bidding zone as the renewable electricity installation.
        - **Additionality**: If the average GHG intensity of grid electricity in the local bidding zone is higher than 18 g CO2e/MJ, then the producer must also demonstrate that the renewable energy production is additional.[5] RFNBO producers that begin operations before Jan. 1, 2028 are exempted from this requirement, and this exemption expires on Jan. 1, 2038.
    - Regarding the **CO_2 sources**, fossil CO_2 captured from power stations counts as zero emissions until 2036, and until 2041 for all other fossil industrial sources. After 2041 e-kerosene producers will need to source CO_2 from DAC or biomass combustion.

2. Mapping e-kerosene production in Europe

2.1. A good dynamic driven by ReFuelEU

A total of **45 e-kerosene projects** spread across the EEA have been referenced in this study, out of which 25 are commercial industrial projects, and 20 are demonstration projects[6]. The full list of projects can be found in the Annex of this briefing. In comparison, we listed 28 companies planning for e-kerosene production in the last version of the tracker. The growth in the number of projects referenced is largely due to new announcements, alongside older projects that we had not identified (e.g. France KerEAUzen, BioÖstrand, Jangada).

[5] In order to be additional, a renewable electricity facility must not receive subsidies (operational and/or investment aid) and must not be operational earlier than 36 months prior to the start of RFNBO production.

[6] The distinction between industrial projects and demonstrators is arbitrary, based on public announcements and project capacities.

In detail, **eight new major projects** (with a production capacity of more than 10,000 tons per year) have been announced since November 2022, as well as **seven new demonstration projects**. The largest of these new announcements was made during the German Aviation Conference in Hamburg in September 2023, by a consortium formed by the DHL Group, HH2E, and Sasol, for an annual production of 200,000 tons of e-fuels in eastern Germany from 2030 onwards, enough to fulfil the entirety of the 2% quota set by the German national PtL roadmap[7].

Many new projects have emerged in France during the past year, including the agreement signed by the SAF + Consortium and H2V to produce 80,000 tons of e-kerosene in Marseille Fos, starting in 2028[8]. During the Paris Air Show in Le Bourget, Emmanuel Macron announced a plant would be built by start-up company Elyse Energy with partners Avril, Axens, Bionext and IFP Investissements in the industrial Lacq area in the southwest of France. The plant, called BioTJet, aims to produce 75,000 tonnes/year of e-biokerosene by 2027[9]. Finally, EDF, Holcim, IFPEN and Axens have signed a Memorandum of Understanding to set up an industrial pilot project called "Take Kair", in Pays de la Loire[10].

This progress is tarnished by the abandonment of two projects in Germany. Two other projects previously listed were also removed from the tracker because their end products won't go to aviation, or won't qualify as RFNBO under the new regulatory framework.

In spite of this, the overall picture looks largely positive, which is mostly due to the signals sent out through ReFuelEU. **The EU's SAF mandate may have set a path in motion beyond its borders**, as some countries are now considering policies to mandate e-fuels too (like the UK), or financially supporting e-fuels (like the United States (US) and Canada). E-kerosene projects are also emerging in these countries (see Info Box below).

INFO BOX: E-kerosene projects outside the EEA

In the UK, the government has allocated over £135 million for the development of SAF production plants in the Kingdom through the Advanced Fuels Fund (AFF), out of which £27 million (20%) were awarded to e-kerosene projects. These include:

- **Arcadia e-Fuels (NABOO)**: Based in Teesside, the project is developing a commercial scale plant which is expected to be operational in 2028 and to produce 67.7 kt/y of SAF when at full operational capacity. Award: £12,341,000.

[7] DHL Group, HH2E, and Sasol Collaborate to Propel Germany as a Leader in Decarbonized Aviation. (2023, September 25). *Hh2e.de.*
[8] H2V et CONSORTIUM SAF+ signent un accord de collaboration industrielle en matière d'e-carburants. (2023, October 12). *Safplusconsortium.com.*
[9] Elyse Energy, Avril, Axens, Bionext et IFP Energies nouvelles annoncent l'implantation de l'usine BioTJet sur le bassin de Lacq, nouveau pôle d'excellence des carburants durables. (2023, June 16). *Avril.com.*
[10] EDF, Holcim, IFPEN and Axens join forces to participate together in the creation of the French e-fuels air transport industry, with the "Take Kair" project, supported by Air France-KLM. (2023, June 22). *Aifranceklm.com.*

- **Carbon Neutral Fuels (ASAP-DAC)**: This project is developing a demonstration plant using DAC CO_2, expected to be operational in 2027 and to scale up to 12 kt/y of SAF when at full operational capacity. Award: £1,376,000.
- **OXCCU Tech (OXEFUEL BIOGENIC)**: Based in Sheffield's Translational Energy Research Centre, the project is developing a demonstration plant expected to be operational in 2026 and to produce 7.4 kt/y of SAF when at full operational capacity. Award: £2,814,000.
- **Willis Sustainable Fuels (Carbonshift PtL)**: Based in Teesside, the project is developing a commercial-scale plant expected to be operational in 2026 and to produce 14 kt/y of SAF when at full operational capacity. Award: £4,721,000.
- **Zero Petroleum (PMZ.2):** This project is developing both a demonstration production module operating in Orkney and a commercial scale plant (using biogenic and DAC CO_2) expected to be operational in 2026 and to produce 6.1 kt/y of SAF when at full operational capacity. Award: £3,492,100.

In total, these five projects amount to a potential production capacity of **over 107 kt by 2030** in the UK, **enough to supply almost 1% of the country's total jet fuel needs in 2030**[11].

In the US, HIF Global plans to produce 11,000 barrels per day (~ 500,000 t per year) of e-SAF in Texas by 2030. In July 2023, Twelve started to build its first e-kerosene demonstration facility in Moses Lake, Washington. Scheduled to begin operations by mid-2024, the refinery aims to reach an output of 1 million gallons of SAF annually (~ 3,000 t). The start-up Dimensional Energy has already begun production at a pilot-scale plant in Tucson, Arizona, and is planning to scale up to over 44,000 tons of e-crude per year in 2027, with production facilities in California and beyond. Finally, Infinium's Project Roadrunner, located in West Texas, aims to be "the largest in the world" when it begins producing fuel in 2026. It has received $75 million in equity commitment from Breakthrough Energy Catalyst, and signed an offtake agreement with American Airlines.

In South Africa, Sasol and its partners Linde, Enertrag and HydRegen, are making plans to build an e-kerosene plant in Secunda (HyShift), with a production capacity of 50,000 tons of e-kerosene per year.

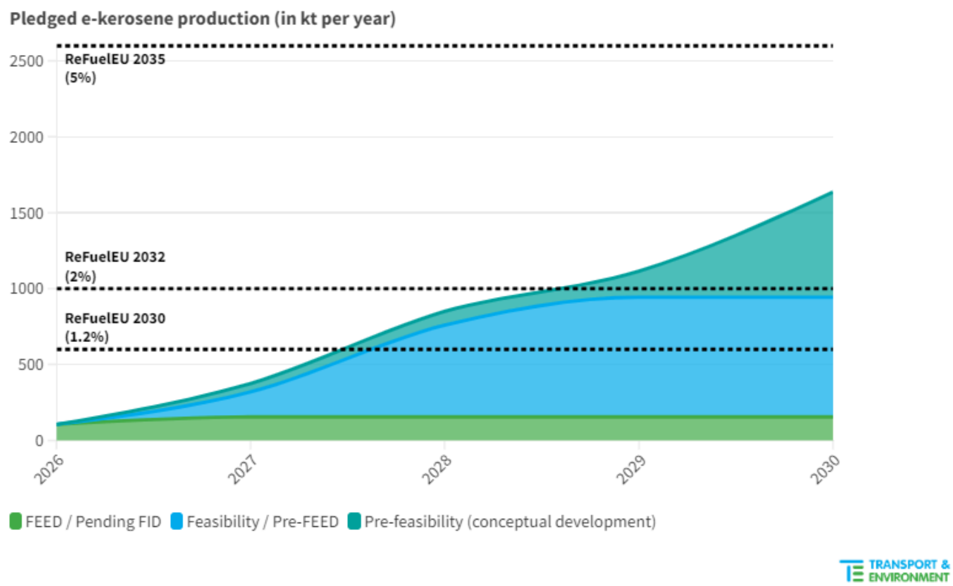
In Canada, the SAF + Consortium has been running a pilot plant in Montreal since 2021. The start-up is also planning to build a full-scale plant in Quebec by 2028 (CADAQ-100), in collaboration with Airbus Canada and Pratt & Whitney Canada, with a production capacity of ~75,000 tons of e-SAF per year.

2.2. Commitments to produce e-kerosene exceed the ReFuelEU mandates, but most projects are still at an early stage

[11] We estimate a jet fuel demand of 12.0 Mt in the UK in 2030 based on the UK Jet Zero Business-as-usual scenario including demand reduction through carbon pricing and technology efficiency improvements.

The total production capacity of the 45 projects analysed adds up to **1.7 Mt in 2030**, with the first drops of e-kerosene expected to arrive on the market in 2026. As shown on Figure 2, **this is theoretically enough to fulfil the ReFuelEU synthetic fuel blending requirements of 1.2% in 2030 (~0.6 Mt) and 2% in 2032 (~1 Mt)**. The 5% mandate in 2035 (2.6 Mt) still seems a bit far from reach, but if production scales up linearly it is safe to say the EU is on the right track to achieve its objectives.

Figure 2: Forecasted e-kerosene production capacity in the EEA per advancement stage compared with ReFuelEU blending mandates



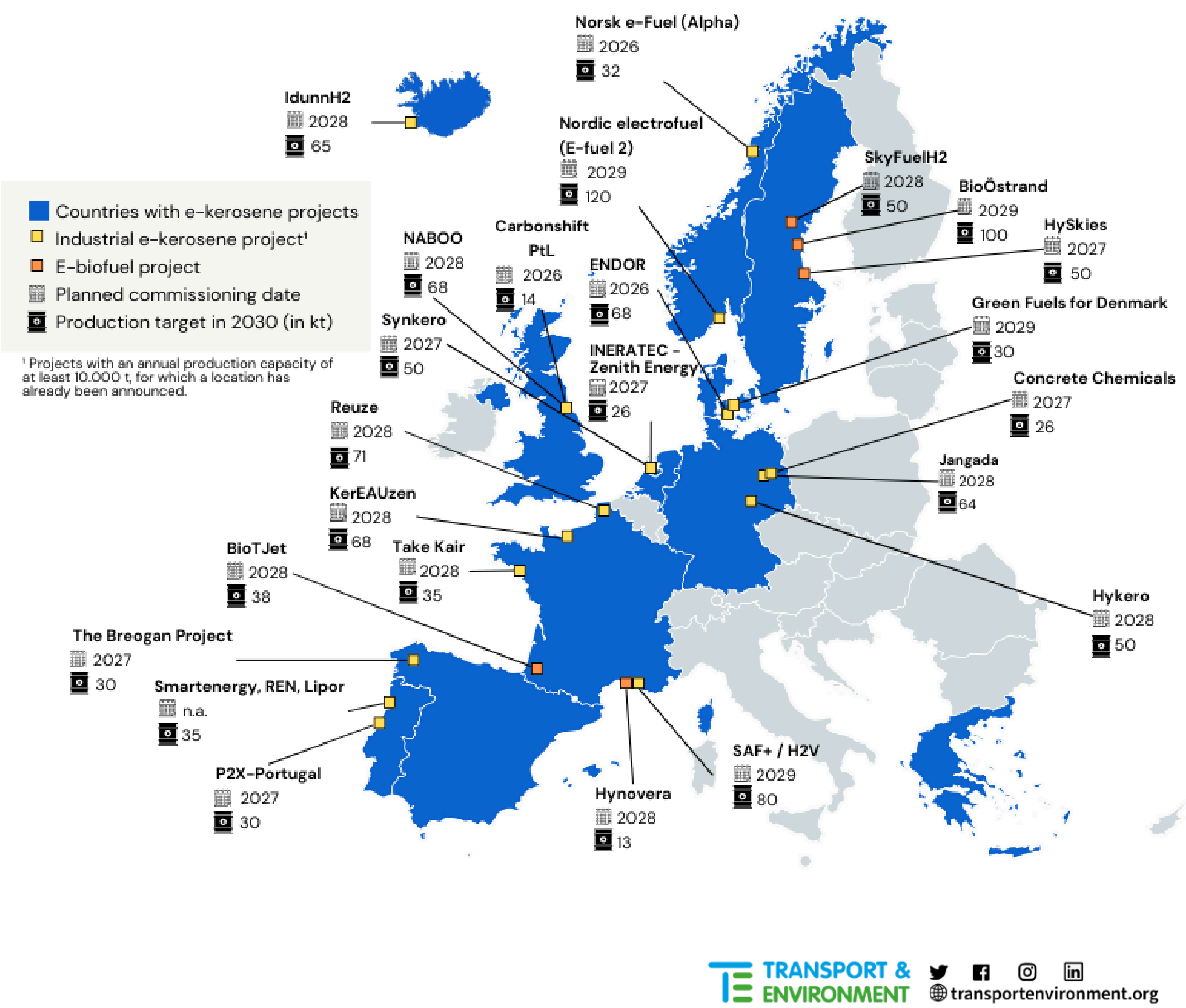
That being said, most of the projects analysed are still at an early stage of development, and it is assumed that all projects will reach their maximum production capacity. Therefore, this estimation should be taken with caution. **No major industrial e-kerosene project has reached a final investment decision (FID) yet**. Three projects stand out for being more advanced than others, namely Arcadia eFuels' plant in Vordingborg (Denmark), Norsk e-Fuel's Alpha plant in Mosjøen (Norway), and Nordic Electrofuel's pilot plant (E-fuel 1), in Herøya (Norway). These three plants are in the engineering phase and are hoping to reach FID by the end of 2024 and start production by 2026-2027. Together, they represent a combined production capacity of **105,000 tons of e-kerosene** (before scaling up), which is way below the objective of 600,000 tons in 2030. The rest of the projects referenced in this study were at various stages of maturity: one is in the Front End Engineering and Design (FEED) phase, 13 are still running feasibility studies or have completed them but haven't moved to FEED yet (pre-engineering phase), while eight are still at pre-feasibility stage, determining whether it is worthwhile to invest further resources and efforts into a detailed feasibility study.[12]

[12] The stages of major energy projects typically include feasibility study (to determine whether the project is viable and worth pursuing), pre-engineering, Front-End Engineering Design (FEED) (defining the technical requirements as well as rough investment cost for the project), Final Investment Decision (critical decision point where project sponsors evaluate all relevant information, including the results of the feasibility study, engineering design, and cost estimates, to make the final determination on whether to proceed with the project), detailed engineering and procurement, construction, commissioning, startup of operations.

The fact that there are **barely any demonstration plants running in the EU** at the moment should also prompt caution. [Atmosfair's pilot plant in Werlte](), Germany, was inaugurated in October 2021, but production is temporarily on hold. In the context of the second phase of the [Kopernikus P2X research project]() (funded by the German Federal Ministry of Education and Research (BMBF)), Ineratec is running a small integrated production unit together with its partners Sunfire, Climeworks and KIT in Karlsruhe. A few other pilot plants are under construction in Germany, like Synhelion's [DAWN]() plant in Jülich, Ineratec's semi-industrial demonstration facility in [Frankfurt](), or Caphenia [EnZaH2]() plant in Steyerberg.

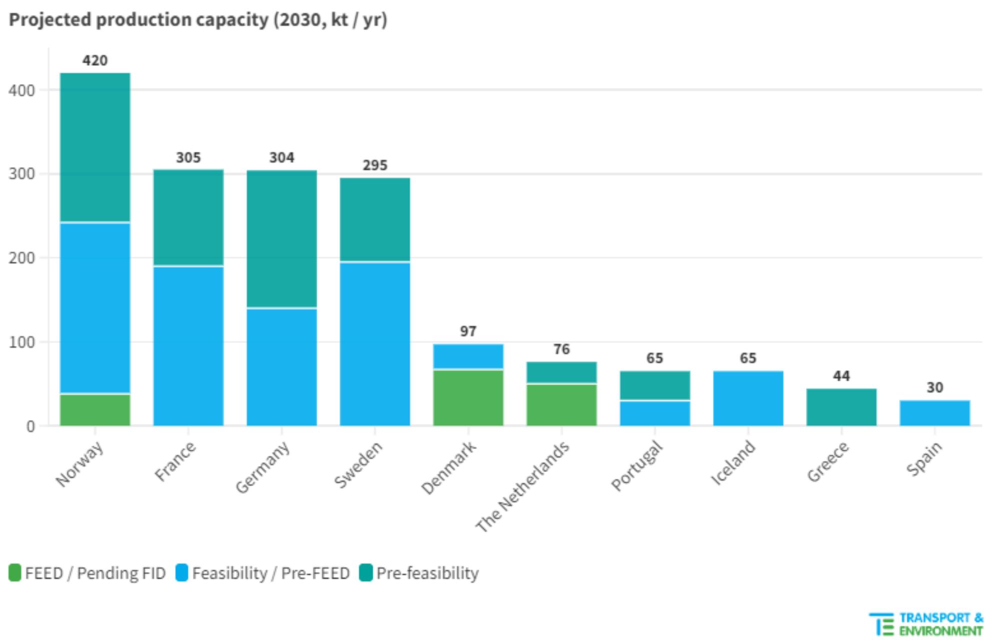
2.3. Norway, France and Germany stand out as future leaders of e-kerosene production in Europe

Figure 3: Major e-kerosene projects announced in Europe as of 2023



As shown on the map (Figure 3), as of 2023, the **25 industrial e-kerosene projects identified in this study are spread over ten EEA countries**. **Norway** stands out with a total production capacity amounting to 420,000 tons of e-kerosene in 2030, about a quarter of total projections. Two companies, Nordic Electrofuel and Norsk e-Fuel, have come up with ambitious plans to capture a significant share of the European market. Despite having adopted a SAF mandate (prior to ReFuelEU) that does not specifically incentivize e-kerosene, Norway benefits from a stable access to renewable energy from hydropower at a relatively low cost which can explain why it is currently leading the e-kerosene race, as electricity constitutes a significant cost element in the production of e-fuels.

Figure 4: Projected e-kerosene production capacity in 2030 by country



While it was lagging behind in our last study, **France** has been catching up during the past year, thanks to a number of new projects like Take Kair, BioTJet (e-biofuel), or the SAF + Consortium and H2V partnership, which come on top of two previously announced projects led by Engie (KerEAUzen and ReUze). The total production capacity of all six full-scale industrial projects identified in France amounts to around 300,000 tons of e-kerosene by 2030. In the context of the 4th Investment for Future Programme (PIA4) and of the national roadmap for the deployment of SAF, France has budgeted €200 million to support the deployment of innovative SAF projects[13]. Interestingly, the five winners of the first call for projects run by ADEME were all e-kerosene projects (including some e-biofuels projects), despite the tender not specifying synthetic fuels as a priority. The possibility for low-carbon (nuclear) synthetic aviation fuels to count towards the ReFuelEU synthetic aviation fuels blending mandate certainly plays in favour of France's electricity mix, at least in the short term. However, from a cost perspective, it is unlikely nuclear hydrogen can compete with hydrogen derived from renewable electricity in the long run[14].

With a projected production capacity of roughly 300,000 tons in 2030 and three major projects, **Germany** is reaping the rewards of its proactive approach to incentivizing e-kerosene production. Its PtL-roadmap was adopted in 2021 and aims at the use of at least 0.5% of e-kerosene in German airports by 2026, rising

[13] France's Macron vows to boost sustainable aviation fuel production. (2023, June 16). *Reuters*.
[14] IDDRI. (2022). *Hydrogen for climate neutrality: conditions for deployment in France and Europe*. p.17.

to 1% in 2028 and 2% in 2030. Although the future of the roadmap is still uncertain at the moment of writing (due to legal compatibility issues with ReFuelEU), it has certainly played a role in the eruption of e-fuels projects in Germany in 2021-2022 (more than 19 according to the PtX Lab Lausitz map). However, it should be noted that a lot of projects announced in Germany are of small scale. Two full-scale industrial projects have already been dropped, and only four remain under study. If it was not for Sasol, DHL, and HH2E's big announcement at the German Aviation Conference in September 2023, the total production capacity of the projects analysed in Germany would drop to 200,000 tonnes by 2030.

France and Germany are flanked by **Sweden**, where all four projects referenced are actually e-biofuels projects making use of the availability of local forestry biomass. The rest of the projects are spread across **Denmark** (97 kt), **the Netherlands** (76 kt), **Portugal** (65 kt)**, Iceland** (65 kt), **Greece** (44 kt), and **Spain** (30 kt). With a significant share of the EU's green hydrogen production (20% of the world's green energy projects in 2021[15]), it is particularly surprising to see that only 2% of e-kerosene production is forecast to take place in Spain. The country seems to be betting instead on other hydrogen products, such as pure hydrogen or e-methanol[16]. Belgium and Italy are also conspicuous by their absence from the map, and so are all Eastern European countries.

2.4. Carbon sources: an exclusive reliance on biogenic CO_2

All industrial e-kerosene projects plan on using a biogenic carbon source (i.e. CO_2 derived from biomass combustion processes). Only a small share of projects (six out of 23) are still considering using industrial point source carbon captured from cement or steel plants, in combination with the biogenic share of the CO_2 sourced from these installations. The latter comes from the combustion of the biomass used in the plants' kilns (wood, compost, tires).

That shift from industrial point sources to biogenic sources is the direct consequence of the Delegated Act (DA) establishing a methodology for assessing GHG emissions savings from transport RFNBOs, which was published in February 2023. That DA allows the use of RED compliant biogenic CO_2 indefinitely, while **fossil industrial CO_2 sources can only be used until 2041.** For projects entering into service in 2027-28, that means a lifespan of less than 15 years, which some claim isn't long enough to amortise investments. DAC does not seem to be a viable alternative for producers due to its cost as well as potential lack of policy incentives to use it. As a result, all projects are turning to biogenic CO_2, and no project is counting on DAC until at least 2030. According to e-kerosene project developers, **the availability of biogenic CO_2 is turning into a key factor to determine the location and potential size of e-kerosene projects, and is likely to be a bottleneck for the further scale up of e-kerosene production.**

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[15] Spain bets on green hydrogen in clean energy push. (2022, June 22). *Euractiv.com.*

[16] Cepsa and C2X set up joint project to develop the largest green methanol plant in Europe. (2023, December 1). *Cepsa.com.*

3. Beyond ReFuelEU, many challenges ahead

ReFuelEU was a crucial first step to scale up e-kerosene production in Europe. By securing a minimum level of demand for e-kerosene, it has inspired many ambitious announcements, but there is still a lot to be done to ensure existing projects reach FID.

3.1. Some regulatory loopholes

3.1.1. A lack of incentives to supply e-kerosene before 2030

ReFuelEU only sets sub-targets for synthetic aviation fuels from 2030 onwards. The European Parliament's proposal to start incentivising e-kerosene as early as 2025 with a symbolic 0.04% subtarget was not retained by EU negotiators. The Council's proposal to explicitly allow Member States to go further than EU-wide targets was also dropped. As a result, there is a lack of incentives for fuel suppliers to supply e-kerosene before 2030, whereas the majority of projects are aiming to start producing before that date. There is still some legal uncertainty around the possibility for Member States to deploy higher national sub-targets (especially before 2030), but countries should be encouraged to set their own ambitious national targets to spur production, as was the case in Germany. Indeed, ReFuelEU states only a minimum harmonisation measure and therefore the regulation itself gives Member States the opportunity to go beyond the required minimum obligation set out by EU legislation.

3.1.2. Looming e-fuels in the road sector

In 2022, a historic agreement was reached on ending sales of new combustion engine cars by 2035 in the EU. In March 2023, however, the German government declared last-minute opposition and demanded that sales of new cars with combustion engines be allowed after 2035, if they run on e-fuels. The Commission eventually agreed to make a proposal that would allow cars running only on climate neutral fuels to be registered under vehicle type approval rules. Furthermore, in November 2023, the EU Parliament voted to allow trucks running on synthetic fuels to be counted as climate neutral.

Using synthetic e-fuels in cars has been proven to be an enormous waste of renewable energy, as running a car on synthetic petrol is close to five times less efficient than powering a battery electric vehicle through direct electrification[17]. Moreover, promoting even a limited use of synthetic hydrocarbons in road transport risks diverting the manufacturing and supply chains from being targeted at hard-to-abate sectors such as aviation and shipping[18].

3.1.3. Other regulatory loopholes: NZIA, taxonomy

In March 2023, the Commission released its proposal for a **Net Zero Industrial Act (NZIA)**, which aims to simplify the regulatory framework and scale up the manufacturing of green technologies in the EU, particularly through faster permitting procedures. Considered as a net-zero technology under the

[17] Transport & Environment. (2023). How to prevent an e-fuels loophole undermining the EU CO_2 law.

[18] Transport & Environment. (2023). Biofuels and e-fuels in trucks will make it harder for aviation and shipping to go green.

proposed act, e-kerosene plants would benefit from faster-permitting procedures[19], and easier access to funding, through relaxed State aid rules for instance. They would also indirectly benefit from the support granted to electrolyzers, which are included in the list of NZIA *strategic* technologies. As such, electrolyzers' manufacturing can be labelled as "Net Zero Strategic Projects" (NZSP) and would benefit from even faster permitting procedures[20] and favourable access to EU financing instruments. However, as e-kerosene plants are not included in the list of NZIA *strategic* technologies, they wouldn't be able to benefit directly from NZSP accelerated permitting procedures, and are unlikely to be prioritised in funding distribution under the Strategic Technologies for Europe Platform (STEP), the future investment scheme for strategic technologies across the EU.

Another relevant piece of legislation for the European e-kerosene industry is **the EU Taxonomy Regulation**, which establishes a classification system for environmentally sustainable activities. The Delegated Act adopted in November 2023 designates the operation of aircraft as a transitional activity if the aircraft is operated with 15% SAF from 1 January 2030, increasing by 2% annually thereafter. However, no distinction is made between biofuels and e-kerosene usage.

3.2. Feedstock availability

The availability of renewable electricity required to produce green hydrogen is a significant challenge for the scale-up of the production of e-kerosene. If aviation demand is not managed, producing enough e-kerosene to supply 35% of the EU's jet fuel demand in 2050 (as mandated by ReFuelEU) will require 534 TWh (assuming a mix of point source and DAC CO_2)[21], which represents 19% of the total electricity demand of the EU in 2022[22], and **around 11% of all projected renewable electricity generated in the EU in 2050**[23]. In a scenario where demand is managed[24], electricity requirements could drop to 290 TWh in 2050, which represents 10% of the total electricity demand of the EU in 2022, and around 6% of all projected renewable electricity generated in the EU in 2050.

Dependence on the roll-out of the green hydrogen ecosystem is also proving to be a challenge. Many e-kerosene projects are not fully integrated (i.e. they don't control every step of their production process). In particular, many projects don't plan on deploying their own electrolyser on-site to produce green hydrogen. Because they don't own the full supply chain, they depend on the realisation of green hydrogen projects, many of which are suffering delays at the moment.[25]

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[19] Net-zero technologies will have mandatory permitting timelines of 12 months for projects of less than 1GW annually and 18 months for larger projects and those not measured in GW.
[20] For NZSPs the permitting time is shorter: 9 months for projects under 1GW, 12 months for projects larger or not measured in GW.
[21] Efficiencies are based on Concawe. (2022). E-Fuels: A technoeconomic assessment of European domestic production and imports towards 2050.
[22] Ember. (2023). Yearly electricity data.
[23] Impact assessment EU Green Deal (2022).
[24] Leisure travel capped at 100% of 2019 levels, business travel capped at 50% of 2019 levels.
[25] IEA. (2023, September 22). Lagging policy support and rising cost pressures put investment plans for low-emissions hydrogen at risk.

As outlined in section 2.4. of this briefing, the **availability of biogenic CO_2 sources** is also turning into a major challenge for e-kerosene producers. Due to the industrial point source deadline set by the DA on RFNBOs, all e-kerosene producers have their eyes set on biogenic CO_2 sources, but they will have to compete with other sectors (e.g. shipping, chemicals and plastics, construction materials, horticulture) which also need access to sustainable CO_2 sources to decarbonize. Additional competition could come from bioenergy with carbon capture and storage (BECCS), especially if it is incentivized through national negative emission targets. A study commissioned by T&E has shown that from 2030 onwards, existing fossil CO_2 and biogenic CO_2 supply won't be enough to meet the demands of the growing CO_2 market, requiring the development of DAC to fulfil the deficit.[26]

As DAC remains highly expensive, none of the e-kerosene projects analysed is planning to source carbon directly from the atmosphere (at least for the moment). **DAC companies themselves are reluctant to become active in the DAC and Carbon Utilisation (DACCU) market, and are focusing on DAC and Carbon Storage (DACCS) instead**. As of 2023, the portfolios of projects of Climeworks and Carbon Engineering, two leading DAC firms, did not include any e-kerosene plants (although Climeworks is part of the consortium led by Norsk e-Fuel). DAC companies argue that their technology will mature better via storage than utilisation because CCS projects imply shorter, easier to control value chains than DACCU for e-fuels. Moreover, due to the higher cost of avoiding one ton of CO_2 through carbon storage than e-kerosene[27], corporate customers and industry players (including from the aviation sector) are starting to show a higher willingness to pay for carbon storage than for e-fuels, despite many uncertainties as to the guaranteed permanence of capture and final usage of carbon storage technologies. For example, Airbus has an agreement in place with US-based 1PointFive (a partner of Carbon Engineering) for the pre-purchase of 400,000 tonnes of carbon-removal credits over four years[28], and will be selling these to airlines (including Lufthansa[29] and easyJet[30]) through its Carbon Capture Offer. There are many risks associated with the purchase of these carbon-removal credits, including the unintended effect of encouraging airlines to continue to rely on fossil fuels, and the possibility to use some of the captured carbon to dredge up more oil (through a technique known as enhanced oil recovery [EOR]), instead of permanent underground storage. The latter concern is justified by the recent acquisition of Carbon Engineering by Occidental Petroleum, whose president has not hidden the company's intentions of using captured CO_2 to produce more oil[31].

More importantly, apart from the deadline on industrial CO_2 included in the DAs on RFNBOs (which is in fact turning into an incentive for biogenic CO_2), **meaningful policy incentives are lacking to boost e-fuels from DAC specifically**. Future policy incentives in favour of DACCS, like national negative emissions targets, could also turn permanent CO_2 storage into a major competitor for CO_2 available for

[26] Ricardo. (2022). European CO2 availability from point-sources and direct air capture.
[27] Öko-Institut. (2021). E-fuels versus DACCS.
[28] Shepardson, D. (2022, July 18). Airbus, airlines to explore carbon capture technology. *Reuters*.
[29] Lufthansa Group joins Airbus' carbon-removal initiative. (2023, December 5). *Lufthansagroup.com.*
[30] easyJet signs up to Airbus' pioneering carbon removal solution. (2023, October 9). *Airbus.com.*
[31] White, N., Rathi, A. , & Crowley, K. (2023, October 23). An Oil Giant Quietly Ditched the World's Biggest Carbon Capture Plant. *Bloomberg*.

e-kerosene production, depending on how fast legislation and incentives are developed to support each of the applications.

3.3. High production costs are a significant barrier to securing offtake agreements with airlines

High production costs are an obstacle to the scale-up of e-kerosene production in Europe. Estimations vary a lot, due to different assumptions regarding electricity and CO_2 sources and prices. For example, the ICCT estimates that the production cost of e-kerosene in the EU was ten times higher than fossil kerosene in 2020, but that price gap is set to decrease substantially to 3.5 times in 2030 and 2.5 times in 2050, as the market matures, technology improves, and the cost of renewable electricity continues to decline.[32] Renewable electricity generation and electrolysers make up more than 60% of the total costs of production of e-kerosene.[33] Even with the expected hydrogen cost decrease, e-kerosene will remain more expensive than Jet A or biofuels in 2050.

Some e-kerosene producers report they are struggling to secure offtake agreements with airlines, who are reluctant to pay the green premium. Without offtake deals, it seems harder for some banks to lend producers the money to build the electrolysis and synthesis plants. Offtake deals are also an important criteria to be awarded public grants, like in the case of the Innovation Fund. A few exceptions are worth noting:

- Air France-KLM has signed MoUs with Engie (KerEauzen project), and EDF (Take Kair project);
- Lufthansa Cargo has signed an offtake agreement with Atmosfair;
- Norwegian has signed a partnership agreement with Norsk e-Fuel;
- Sunclass Airlines is collaborating with Nordic Electrofuel and Arcadia eFuels;
- SAS supports the Green Fuels for Denmark partnership and the HySkies project;
- The DHL group has announced its participation in a joint project led by Sasol and HH2E.

The fines planned in ReFuelEU should provide a sufficient incentive to change that situation, as fuel suppliers not fulfilling their quotas will have to pay at least twice the multiplication of the difference between the yearly average price of conventional aviation fuel and e-kerosene per tonne and of the quantity of aviation fuels not complying with the minimum shares of e-kerosene. If airlines want to avoid paying these dissuasive fines (which non-compliant fuel suppliers will pass on to them), they have two options: either trusting traditional fuel suppliers to fulfil their obligations, or engaging directly with new players on the market to secure their e-kerosene supply. That shift towards new ways of procuring jet fuel may take some time to be comprehended, but it needs to be understood by all players involved, starting with airlines.

[32] Zhou, Y., Searle, S., & Pavlenko, N. (2022). Current and future cost of e-kerosene in the United States and Europe.
[33] Yugo, M., & Soler, A. (2019). A look into the role of e-fuels in the transport system in Europe (2030–2050). *Concawe Review, 28*(1), 4-22.

Furthermore, financial incentives should help drive the cost of e-kerosene down and bridge the price gap with fossil kerosene. The 20 million **"SAF allowances"** that EU negotiators agreed to set aside under the European Trading System (ETS) reform are a first step in the right direction. All fuels defined in the scope of RefuelEU will be eligible for the ~ €2 billion support mechanism, which will be in place until 2030. However the coverage of the price differential will be modulated according to the type of fuel (95% for RFNBOs, 70% for advanced biofuels and 50% for other eligible fuels).

Contracts for Difference (CfDs) are another avenue to explore. CfDs are funding mechanisms through which public support is awarded to producers who can produce green hydrogen or e-fuel at the lowest cost, to cover part of their operational costs. Through a Contract for Difference (CfD), a public entity pays the price difference between the auction winning price (the strike price) and the renewable hydrogen market price (the reference price). CfDs have been used successfully in the UK to bring about cost reductions in offshore wind. With the Hydrogen Bank, the European Commission is implementing such a competitive bidding scheme for the production of renewable hydrogen through the Innovation Fund using fixed premiums and has launched a first auction with a budget of €800 million in November 2023.

Part of the solution could also come from alternative offtakers. Beyond commercial airlines, **private jet companies and corporate buyers also have a role to play in driving the demand for e-kerosene**. More and more companies are looking to purchase SAF to reduce their Scope 3 emissions. At the moment, they are only purchasing biofuels often supplied through an airline or fuel supplier corporate SAF programme, but in the future more European companies should follow initiatives like Microsoft, who recently signed an MoU with Twelve[34], a U.S. based e-kerosene start-up, and Alaska Air Group, to advance production and use of e-kerosene. The agreement includes plans to work toward the first demonstration flight in the U.S. using e-kerosene, as well as a commitment from Microsoft to use e-kerosene produced by Twelve to power its business travel flights on Alaska.

Finally, the lack of effective jet fuel tax or proper accounting of jet fuel emissions from European aviation under EU rules is also a barrier to addressing the cost gap between fossil fuel and cleaner alternatives like e-kerosene. More effective pricing of aviation emissions and therefore jet fuel usage would be the first step in discouraging the use of fossil fuels in the sector and play an important role in reducing the current price gap with cleaner fuels like e-kerosene. The more expensive it is to pollute, the more incentives airlines have to use technologies that reduce their emissions costs, therefore a better business case and larger market to serve for e-kerosene providers.

3.4. Insufficiently targeted public funding and cautious banks and private investors

A mix of public and private investments are required to support the build-up of e-kerosene industrial production capacity. On the private investment side, despite the regulatory certainty provided by ReFuelEU, e-kerosene start-ups report that venture capital funds are still reluctant to invest in their

[34] Twelve and Alaska Airlines to collaborate with Microsoft to advance sustainable aviation fuel derived from recaptured CO2 and renewable energy. (2022, July 14). *Alaskaair.com.*

projects, especially at early stages, when it comes to funding feasibility studies, for example. Banks are also reportedly hard to convince, even when potential offtakers have expressed their interest. Therefore, public financing or guarantees is particularly important at these early stages, yet only France has set up specific funding programmes for SAF/PtL projects.

EU public funds like the EU Innovation Fund (EUIF) can also provide financial support at later stages, although only a couple of e-kerosene projects have been awarded a grant. Out of the 41 projects selected for a grant in July 2023, only two were e-kerosene projects: BioOstrand, and Nordic Electrofuel, which was awarded €40 million to fund its Engineering, Procurement, Construction and Installation (EPCI) phase[35]. Previously, the HySkies project (Shell, Vattenfall, LanzaTech) had received a €80 million grant in the context of the EUIF second call, in July 2022.

As underlined in the previous section, the deployment of e-kerosene production will largely rely on the accessibility of affordable renewable electricity and the scaling of cost-competitive green hydrogen, which is used as a feedstock. The EU has set up many funding instruments to support the roll-out of a green hydrogen ecosystem, including the newly deployed Hydrogen Bank. However, EU grants and subsidies are not sufficiently focused on low infrastructure hydrogen applications for sectors without alternatives, like e-ammonia fertiliser and refining, e-kerosene for aviation, or e-methanol and e-ammonia for shipping. For instance, rather than spending €80-140bn on "a hydrogen backbone" that will carry mostly fossil gas for the foreseeable future, EU public money would be better spent on supporting e-fuels for aviation and shipping.

3.5. The control oil majors retain over the downstream e-kerosene supply chain creates barriers to entry

Conventional fossil kerosene producers are likely to remain in control of the downstream SAF supply chain. The e-crude produced by many projects analysed in this study could be co-processed with fossil kerosene in hydrocrackers located in conventional refineries, not in a separate refining process, as new players on the jet fuel market will not always be in a financial situation to invest in their own hydrocracker to separate the different slates of e-crude. In other words, **Big Oil and its downstream refining operations could remain a gatekeeper for e-kerosene production**, as it is very difficult for independent e-kerosene producers to get their product to the jet fuel market without passing by conventional refineries.

Even if an e-kerosene producer was to own a hydrocracker and refine its e-crude on-site, the e-kerosene produced without co-processing would still eventually need to be blended with fossil kerosene at fuel terminals (at least until 100% SAF flights are approved and certified). If fuel terminals are only developed and controlled by oil majors (and they have no obligation to make the facilities available to other small producers), or if there is a restricted access agreement between the fuel terminal operator and the oil major for exclusivity, independent e-kerosene providers will face additional challenges to enter the

[35] Projects selected for grant preparation. (2023). *Climate.ec.europa.eu.*

market. More transparency is needed about the ownership and operation of fuel farms in the EU in order to better assess the scale of this potential challenge.

3.6. Public acceptance, an emerging challenge

Social acceptability could be an emerging challenge as more and more e-fuels projects will have to run local consultations to secure environmental permits. Biomass, water and electricity requirements to produce e-fuels could increase local communities' scepticism towards the technology. Moreover, some e-kerosene production pathways like the e-methanol-to-jet route pose environmental risks (as methanol is a highly flammable substance). As a result, some e-kerosene production facilities could be classified as Seveso sites, which means they will have to comply with additional safety requirements[36].

The case of Hy2Gen's Hynovera project in Meyreuil Gardanne, France, is a good example. Hynovera's ambition was to produce e-biofuels from green hydrogen and wood chips for the shipping and aviation sectors. During the public consultation held in November 2022, local residents voiced their opposition to the low-threshold Seveso plant and their concerns regarding water and electricity needs. To take into account these criticisms, the project was scaled down, and Hy2Gen announced that its plant would no longer manufacture or store methanol, so as to avoid the Seveso label.[37] It will focus solely on the production of SAF for aviation instead. With total production capacity set to be halved, a number of avenues are being explored to ensure that the business model remains profitable. Rather than the Fischer-Tropsch route, Hy2Gen could opt for an alcohol-to-jet process involving fermentation of biomass, followed by distillation, in which case the final product would no longer qualify as an RFNBO.

4. Policy recommendations

1. **At national level:**
    a. **Member States should follow Germany's lead and boost early supply of e-kerosene by setting pre-2030 targets.**
    b. **Member States should earmark a percentage of the ETS revenues and/or additional ticket taxes, to support e-kerosene production (through grants, low-interest loans, state guarantees, subsidies)**. We recommend earmarking 25% of revenues generated by the ETS for shipping and aviation for Member States to support the production of green hydrogen and derived e-fuels on the condition of direct offtake of the produced fuels by the aviation and shipping sectors. For the aviation sector, the proposed 25% national earmarking would channel €10.25 bn from the national ETS revenues between 2024 and 2030. If the ETS is extended to all departing flights as of 2027, the total revenues would reach €72bn by 2030, of which €18bn would fund green hydrogen and e-fuels production.

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[36] Seveso sites are industrial sites that are regulated by the EU Seveso directive because of the presence of dangerous substances in large quantities.
[37] Barla, Jean-Christophe. (2023, March 1). Hy2Gen révise son projet Hynovera de production de carburants renouvelables à Meyreuil. *L'Usine Nouvelle*.

2. **EU funding should prioritise hydrogen use in hard-to-electrify sectors like aviation and shipping.** For funding schemes like the Innovation Fund, this can be done by requiring projects supported to have strategic partnerships or offtake agreements with these sectors for at least a substantial share of the production.

3. **E-kerosene projects should be included in the list of strategic net-zero technologies of the NZIA,** in order to benefit from even faster accelerated permitting procedures, and to be prioritised in funding distribution under the upcoming Strategic Technologies for Europe Platform (STEP).

4. **The Innovation Fund should offer Contracts for Difference for e-kerosene to bring costs down.** For example, the UK recently announced it will set up a "SAF revenue certainty mechanism" in 2026. The EU should follow the lead of its neighbour, but make sure to set up different pots depending on the type of SAF covered (with higher coverage for e-kerosene), and to use ETS revenues channelled through the Innovation Fund to fund the mechanism (in order to ensure polluters pay for their own decarbonisation).

5. **An effective jet fuel tax and proper accounting of jet fuel emissions from European aviation under EU rules would help address the cost gap between fossil fuel and e-kerosene.** This includes imposing jet fuel taxation as well as integrating all airlines departing emissions from the EU within the EU's carbon trading scheme.

6. **EU policies should not reduce available e-kerosene volumes by incentivizing the use of e-fuels in the road sector.** If e-fuels were to be credited in the CO_2 standards for heavy-duty vehicles (HDVs), for example, or if cars running on synthetic fuel were to be allowed to be sold after 2035, fuel suppliers would have an incentive to only provide the minimum volumes to the aviation and shipping sector that are needed to fulfil regulatory targets under ReFuelEU and FuelEUMaritime. They would tool their refineries to the detriment of e-kerosene output and try to maximise the fuel volume going into road transport, thus reducing available volumes for hard-to-decarbonise sectors and defeating any chance of meeting the aviation and shipping energy demand.

7. **Meaningful DAC policy incentives need to be developed,** including future mandates for DAC use within fuels policies (e.g. a DAC sub-target within ReFuelEU), and supply-side policy support, like funding for research, development and demonstration (RD&D) and project development. Future legislation and incentives in favour of negative emissions through carbon capture and storage should take into account competing demand for captured CO_2 to produce e-fuels for hard-to-electrify sectors like aviation and shipping.

8. **Airports and regulators should guarantee fair and unrestricted access to existing and future jet fuel infrastructure,** in order to promote a competitive e-kerosene market and avoid extending current fossil fuel monopolies into the SAF sector (which would result in higher prices).

Annex I: E-kerosene projects

E-kerosene production potential in Europe in 2030

Project name	Project partners[1]	Location	Commissioning date	Production capacity in 2030 (t/y)[2]	CO_2 source[3]
Projects at industrial scale					
E-fuel 1 **Accelerator** **E-fuel 2** **E-fuel 3**	Nordic Electrofuel, BPT, Aker solutions, P2X-Europe, Sunclass airlines	Herøya, Norway	2026 2027 2029 2030	6,000 20,000 120,000 114,000	PS, Bio
	Sasol, DHL, HH2E	Eastern Germany	2030	164,000	Bio
Alpha **Beta** **Gamma**	Norsk e-Fuel, Sunfire, Climeworks, Paul Wurth, Axens, Norwegian, Gen2 Energy	Mosjoen, Norway	2026 2028 2030	32,000 64,000 64,000	Bio ... DAC
BioÖstrand	Biorefinery Östrand AB, St1, SCA	Östrand, Sweden	2029	100,000*	Bio
Hy X	Vattenfall, St1	West Coast, Sweden	2030	100,000*	Bio
	SAF + Consortium, H2V	Marseille Fos, France	2029	80,000	PS, Bio
ReUze	Engie, Infinium, ArcelorMittal	Dunkirk, France	2028	71,000	PS, Bio
France KerEAUzen	Engie, Air France[38]	Le Havre, France	2028	68,000	PS, Bio
Endor	Arcadia e-fuels, Technip Energies, Haldor Topsoe S/A, Sasol Ltd, DCC/Shell Aviation Denmark A/S, Sunclass Airlines, BNP Paribas…	Vordingborg, Denmark	2026	68,000	Bio
Jangada	Hy2Gen, energy4future	Brandenburg, Germany	2028	64,000	Bio

[38] Corrected on 24 January 2024.

Synkero	Sky NRG, KLM, Schiphol Group	Amsterdam, The Netherlands	2027	50,000	Bio
Hykero	XFuels, EDL, Airport Leipzig-Halle, Johnson Mattey, BP	Leipzig, Germany	2028	50,000	Bio
HySkies	Shell, Vattenfall, LanzaTech, SAS	Forsmark, Sweden	2027	50,000*	Bio
SkyFuelH2	Sasol ecoFT, Uniper	Solleftea, Sweden	2028	45,000*	Bio
	IdunnH2, Icelandair	Helguvik Harbour, Iceland	2028	65,000	Bio
	Dimensional Energy	Greece	n.a.	44,000	n.a.
BioTJet	Elyse Energy, Avril, Axens, Bionext, IFPEN	Bassin de Lacq, France	2027	38,000*	Bio
Take Kair	EDF, Holcim, IFPEN, Axens, Air France-KLM	Saint-Nazaire, France	2028	35,000	Bio
	Smartenergy, REN, Lipor	Porto, Portugal	n.a.	35,000	Bio
Green Fuels for Denmark	Ørsted, Copenhagen Airports, DSV, DFDS, SAS, Topsoe, A.P. Moller - Maersk, Neste Shipping Oy, HOFOR , BIOFOS, CTR, VEKS	Copenhagen, Denmark	2029**	30,000**	Bio
Breogán Project	Greenalia - P2X Europe	Curtis-Teixeiro, Spain	2027	30,000	Bio
P2X-Portugal	P2X Europe - The Navigator, H&R Group, Mabanaft	Figueira da Foz, Portugal	2027	30,000	Bio
Concrete Chemicals	Sasol ecoFT, CEMEX, ENERTRAG	Berlin, Germany	2027	26,000	PS, Bio
	INERATEC, Zenith Energy Terminals	Port of Amsterdam, The Netherlands	2027	26,000	PS, Bio
Hynovera	Hy2Gen, Technip Energies, Bionext, Axens, Airbus Helicopters	Meyreuil-Gardanne, France	2028	13,000*	Bio
Total				**1,702,000**	
Demonstration Projects					
Technology Platform PtL (TPP)	DLR	Leuna, Germany	2027	7,500	n.a.

	PtX Lab Lausitz	Lausitz, Germany	n.a.	7,500	Bio
	Metafuels, European Energy	Denmark	2027-28	2,700	Bio
	Ineratec, Infraserv Höchst	Frankfurt Höchst, Germany	2024	2,500	Bio
	Repsol, Petronor, Saudi Aramco, Johnson Mattey, BP	Bilbao, Spain	2024	2,100	PS
EnZaH2	Caphenia, Avacon Natur, Oxxynova, Lühmann	Steyerberg, Germany	n.a.	1,500*	Bio
Reallabor Westküste 100 / KeroSyn100	Universität Bremen, CAC, DLR, IKEM, Raffinerie Heide, TU Bergakademie Freiberg	Demonstrationsanlage Raffinerie Heide, Germany	2023/2024	600	PS
Kopernikus P2X (3)	KIT, Ineratec, Sunfire, Climeworks	Karlsruhe, Germany	n.a.	500	DAC
Solarbelt Fairfuel	Solarbelt, Atmosfair, Siemens, Ineratec, EWE, EnergyLink, Lufthansa Cargo & Kühne+Nagel	Werlte, Germany	2021 (on hold)	360	Bio, DAC
DAWN	Synhelion, DLR, SWISS	Jülich, Germany Spain	2024 2026	3.5 350	Bio
Zenid	Zenid, Sky NRG, Climeworks, Rotterdam The Hague Airport, Rotterdam The Hague Innovation Airport (RHIA), Uniper	Rotterdam, The Netherlands	n.a.	280	DAC
	Spark e-fuels	Schönhagen, Germany	2025	< 300	Bio
Veturi e-fuel	VTT, NESTE, Kleener Power Solutions, Carbon Reuse Finland, Convion, Elcogen	Espoo, Finland	2023	0.3	PS
	Caphenia	Frankfurt Höchst, Germany	2024	n.a.	Bio
M2SAF	BASF, Thyssenkrupp, OMV, DLR, ASG	Burghausen, Germany	2027	n.a.	n.a.
SAFari	ASG Analytik-Service AG, BP Europa SE, Clariant	Freiburg, Germany	2028	n.a.	n.a.

	AG, German Aerospace Center (DLR), Südzucker AG, BDL				
PlasmaFly	University of Stuttgart IPV	Stuttgart, Germany	n.a.	n.a.	n.a.
FrontFuel	Topsoe, Sasol, Aarhus University	Aarhus, Denmark	n.a.	n.a.	n.a.
Avebio	Elyse Energy, Khimod	Tartas, France	n.a	n.a.	Bio
TAKE OFF	TNO, CNRS, RWE, Mitsubishi Power, Asahi Kasei, FEV, Sky NRG, RWTH Aachen University, University of Southern Denmark, CO2 Value Europe	Bergheim, Germany	n.a.	n.a.	Bio, PS, DAC

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Notes

The information combined in this table was obtained by mixing public information available online (see sources below) with personal communications.

1 : Companies displayed include project operators, technology partners, investors and offtakers (not exhaustive)

2 : When only the overall e-fuels production capacity was known (without any distinction between e-kerosene and its co-products like e-naphtha), an average 75% e-kerosene yield was assumed, as the Fischer-Tropsch process and the post-treatment steps can be optimised to produce mainly e-kerosene[39].

3 : *Bio* stand for biogenic CO_2 ; *PS* stands for industrial point source ; *DAC* stands for Direct Air Capture

***** : For "e-biofuels" projects (combining e-fuels synthesis with biofuel production), a 50-50 split was assumed, unless a different split was specified by project designers. In practice, the split could potentially be a little higher in favour of e-fuels, depending on the engineering and economic details of the specific process as well as how strong the policy incentive is to produce more e-fuels[40].

****** : Green Fuels for Denmark is a combined e-methanol / e-kerosene project; joint production capacity

[39] Concawe. (2023). Aviation: technologies and fuels to support climate ambitions towards 2050.
[40] Ostadi, M., Rytter, E., & Hillestad, M. (2019, June 25). Boosting carbon efficiency of the biomass to liquid process with hydrogen from power: The effect of H2/CO ratio to the Fischer-Tropsch reactors on the production and power consumption. *Biomass & Bioenergy*. https://doi.org/10.1016/j.biombioe.2019.105282

is estimated to reach 60,000 kt in 2030 (phase 2b of the project); it is assumed that e-kerosene will represent 50% of the total production (i.e. 30,000 kt).

Project	**Public data source**
Nordic Electrofuels	Nordic Electrofuel. (n.d.) *Nordic Electrofuel will make it Green to Fly!*
Sasol / DHL / HH2E	DHL Group, HH2E, and Sasol Collaborate to Propel Germany as a Leader in Decarbonized Aviation. (2023, September 25). *Hh2e.de*.
Norsk e-fuels	Projects. Scaling production to make aviation sustainable. *Norsk-e-fuel.com*.
Hy X	Vattenfall and St1 form a new partnership to produce a large volume of fossil-free aviation electro fuel on the Swedish west coast. (2022, June 30).
Consortium SAF + / H2V	H2V et Consortium SAF+ signent un accord de collaboration industrielle en matière d'e-carburants. (2023, October 13). *Safplusconsortium.com.*
ReUze	ENGIE and Infinium unveil a partnership to develop an industrial hub on an European scale to produce synthetic fuel in Dunkirk. (2022, February 7). *Newsroom.engie.com.* France 2030 : Annonce des lauréats de l'appel à projets « développement d'une filière de production française de carburants aéronautiques durables ». (2023, February 15). *gouvernement.fr*.
France KerEAUzen	ENGIE joins forces with CMA CGM and Air France-KLM to accelerate the decarbonization of sea and air transport by launching the first industrial-scale renewable and low-carbon fuel platform in Le Havre. (2023, July 25). *Newsroom.engie.com.*
Arcadia eFuels	Arcadia eFuels news. *Arcadiaefuels.com.*
Jangada	Jangada. *Hy2gen.com.*
Synkero	Synkero: Futureproof Aviation. *Synkero.com*
Hykero	Project Hykero. *xfuels.de*.
HySkies	European Commission. (2023). *HySkies - A partnership to develop Sustainable Aviation Fuel.*
SkyFuelH2	Uniper and Sasol ecoFT continue to develop SkyFuelH2. (2023, July 4). *Uniper.energy.*
Dimensional Energy Greece	Bettenhausen, C. (2022, December 22). *Dimensional Energy cuts ribbon on CO_2 utilization plant.*

BioTJet	Elyse Energy, Avril, Axens, Bionext et IFP Energies nouvelles annoncent l'implantation de l'usine BioTJet sur le bassin de Lacq, nouveau pôle d'excellence des carburants durables. (2023, June 16). *Presse.avril.com*.
Take Kair	EDF, Holcim, IFPEN and Axens join forces to participate together in the creation of the French e-fuels air transport industry, with the "Take Kair" project, supported by Air France-KLM. (2023, June 22). *Airfranceklm.com*. Cabanas, E. (2023, July 14). *Take Kair : vers une production d'e-carburant en 2028*.
Smartenergy - REN - Lipor	Sustainable aviation fuel projects announced in Portugal. (2023, December 3). *The Portugal News*.
Green Fuels for Denmark	Green Fuels for Denmark. *Orsted.com*. Personal communications.
Breogán Project	Greenalia and P2X-Europe join forces to develop eFuel production project in Galicia. (2023, May 22). *p2X-Europe.com*.
P2X Europe - The Navigator	The Navigator Company and P2X-Europe announce a unique Joint Venture in Portugal to produce green, non-fossil synthetic eFuels and scale-up Power-to-Liquid business. (2022, July 22). *p2X-Europe.com*.
Concrete Chemicals	Concrete Chemicals: Project consortium in new composition. *Concrete-chemicals.eu*. (2022, April 12).
Ineratec - Zenith Energy Terminals	INERATEC und Zenith Energy Terminals arbeiten an einer kommerziellen PtL-Anlage im Hafen von Amsterdam. (2023, May 4). *Ineratec.de.*
Hynovera	Le projet Hynovera. *concertation.hynovera.fr.*
TPP	PtL technology platform – DLR research addresses the industrial production of electricity-based fuels. (2023, March 15). *dlr.de.*
PtX Lab Lausitz	PtX Lab Lausitz. *z-u-g.org.* Retrieved from https://www.z-u-g.org/en/strategic-tasks/ptx-lab-lausitz/ Personal communications.
Metafuels - European Energy	Metafuels, European Energy sign MoU to develop a methanol-to-jet sustainable aviation fuel project. (2023, June 29). *Metafuels.ch*.
Ineratec Frankfurt	E-Fuel Pionieranlage Frankfurt. (2023, April 18). *Ineratec.de.*
Respol, Aramco	Repsol, Aramco develop e-fuels plant in Spain. (2022, May 26). *Argusmedia.com.*
EnZaH2	CAPHENIA produces E-fuels in Lower Saxony. *caphenia.tech.*

Kopernikus P2X	Carbon-neutral Fuels from Air and Green Power. (2019, August 19).
Atmosfair Fairfuel	Erste industrielle Power-to-Liquid PIlotanlage. *Ineratec.de.*
Zenid	Consortium launches Zenid – sustainable aviation fuel from air. (2021, February 8). *Skynrg.com.*
DAWN	Synhelion starts construction of DAWN – the first industrial demonstration plant to produce solar fuels. (2022, September 6). *Synhelion.com*.
Veturi e-fuel	VTT and Neste agreed on building an integrated Power-to-liquids demonstration for CO2 capture, green hydrogen and e-fuels production. (2022, June 14). *Vttresearch.com.*
M2SAF	Consortium formed for developing new process technology to produce Sustainable Aviation Fuel. (2022, November 16). *omv.com*.
SAFari	Development of a pilot plant for the production of sustainable synthetic aviation fuels based on methanol. (2023, February 28). *ise.fraunhofer.de*.
PlasmaFly	Projektlandschaft. Projekte in Baden-Württemberg. *ptl-roadmap.de.*
FrontFuel	Sustainable aviation fuel from CO2 and renewable electricity - Topsoe receives funding from EUDP for Frontfuel-project. (2023, June 27). *Topsoe.com.*
Avebio	KHIMOD et Elyse Energy s'associent pour produire des carburants durables pour le transport aérien grâce au projet collaboratif AVEBIO. (2023, March 28). *elyse.energy/.*
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Further information

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