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KERMIT STUDY E-KEROSENE: IMPORTING OR PRODUCING IN FRANCE?

A joint study performed with



For more information:



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EXECUTIVE SUMMARY ■

Sustainable Aviation Fuels (SAF) are proactively promoted as a lever for decarbonation of the European aviation sector. At the European level they are strongly supported by ReFuelEU Aviation Regulation. To achieve the objectives, the massive deployment of biomass-based SAF (bio-SAF) needs to be complemented by the development of electricity-based SAF (e-kerosene in this study). Identifying the most relevant e-kerosene supply chains is thus a key stake for the aviation industry.



KERMIT STUDY

Synthetic **KER**osene :
importing or producing in France?
A **MultIcriT**eria assessment

KERMIT study analyses three scenarios for sourcing e-kerosene for the French market, focusing on 2035 horizon: domestic production in France based on low-carbon grid electricity, or renewable-based e-kerosene imports either from a representative European country with good renewable energy production potential (Iberian Peninsula – e.g. Spain), or from a representative Middle East country (e.g. Saudi Arabia).

Our multicriteria analysis approach leads us to the following high-level conclusions:

- **Confirmation of the e-kerosene potential as a contributor to Greenhouse Gas (GHG) emissions reduction** for the sector: all three supply chains lead to reductions over 70% of GHG emissions;
- **E-kerosene production costs are expected to be significantly higher than fossil kerosene** (3000-4000€/t in our reference scenario with optimistic yet plausible assumptions vs. 600-1000€/t for fossil kerosene), leading to a significant competitiveness issue;

- To achieve such cost levels, **underlying technological bricks need to reach maturity** (e.g. for Direct Air Capture – DAC) **and be significantly deployed in the market** (e.g. electrolysis). This challenge needs to be tackled both technically and economically which requires significant investments and continuous R&D efforts;
- Producing large volumes of e-kerosene in Europe requires **to access massive amounts of low-carbon electricity and CO₂**, which raises question **on actual availability and long-term costs**;
- **Middle East countries could provide large volumes of e-kerosene** – provided DAC technology actually emerges – and thus set the international e-kerosene price;
- Given higher costs of DAC technologies, **European scenarios could be economically competitive** thanks to their access to cheaper concentrated biogenic CO₂.

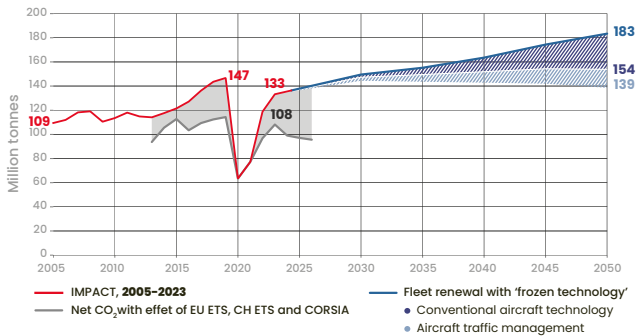
Some European e-kerosene production scenarios appear competitive as of today, and in the long-run, compared to DAC-based alternatives (notably Middle East imports). This is certainly the case for the Iberian Peninsula, and possibly for France granted baseload grid electricity price at a level around 60€/MWh.

This could be achieved provided EU regulatory explicitly allows to use all forms of low carbon electricity, including nuclear, and permits the use of dedicated long term contracts.

Strong additional benefits can also be expected from developing European e-kerosene production: sustainable fuel availability, increased technology leadership and energy sovereignty.

THE AVIATION SECTOR AIMS AT CONTRIBUTING TO THE EUROPEAN GREENHOUSE GAS EMISSIONS REDUCTION OBJECTIVES

Net CO₂ emissions of all departures from EU27+EFTA (base traffic scenario)



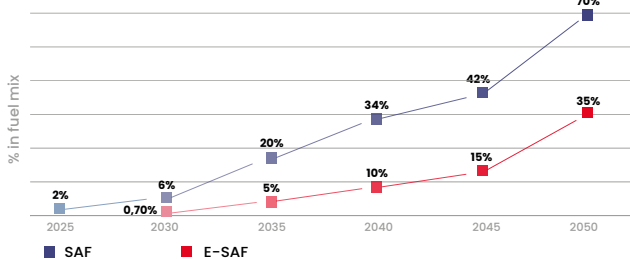
Source: Adapted from European Aviation Environmental Report 2025 – Executive Summary & Recommendations (EASA)

COVID-19 crisis left aside, air traffic has increased on average since decades, an overall trend which is likely to continue in the future.

Besides efficiency gains in aircraft design and operation, additional technical and demand-side solutions are required to meet the aviation decarbonation targets. Shifting towards Sustainable Aviation Fuels (SAF) is part of them.

EUROPEAN ReFUElEU AVIATION REGULATION IMPOSES A COMPULSORY INCORPORATION OF 5% OF E-SAF IN THE AVIATION FUEL MIX BY 2035

ReFuelEU Aviation: SAF and e-SAF mandates on fuel suppliers



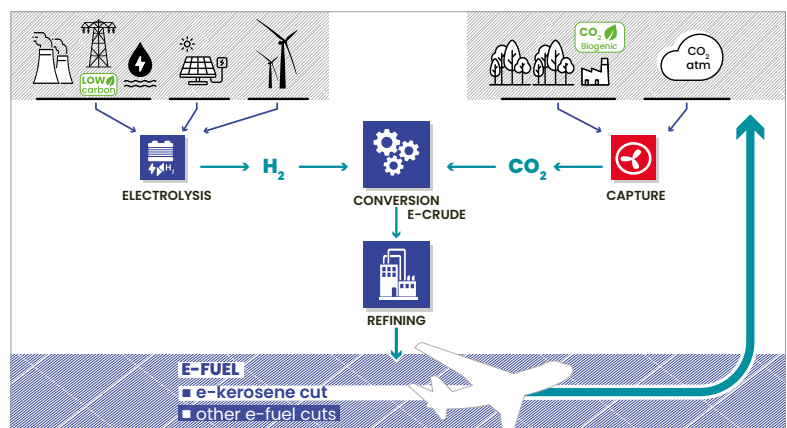
The ReFuelEU Aviation Regulation (2023/2405) aims at meeting the European GHG emissions objectives for 2030 in the aviation sector. Its major ambition is the deployment of Sustainable Aviation Fuels (SAF) as substitute to fossil jet-fuel, with a target of 20% of SAF within the fuel mix by 2035.

The e-SAF (synthetic SAF – produced based on electricity) have specific incorporation targets of 5% by 2035, and 35% by 2050.

E-kerosene is an e-SAF produced from low-carbon electrolytic hydrogen and CO₂, either captured from a point-source emitter or the atmosphere.

By 2035, it is assumed that SAF will consist only in drop-in fuels compatible with existing aircraft technologies. Therefore, e-SAF are assimilated to e-kerosene in this study.

Production and use of e-kerosene



Numerous questions however remain open regarding the supply chains for such e-kerosene: costs, quantification of environmental gains, and also other aspects (societal impacts, risks...).



THE KERMIT STUDY

A  &  SAFRAN study

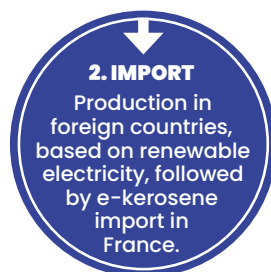
A MULTICRITERIA STUDY ASSESSING IN A FRENCH CONTEXT THE CHARACTERISTICS OF LOCAL PRODUCTION VS. DIFFERENTIATED IMPORT SCENARIOS FOR E-KEROSENE

■ CONTEXT

Fulfill the French e-kerosene need arising from ReFuelEU Aviation at 2035 horizon.

■ OBJECTIVES

Analyse the pros and cons of different geographic supply chains for sourcing e-kerosene:



A FOUR-STAGES APPROACH

1. SETTING SCENARIOS & HYPOTHESIS

Technical maturity of DAC, and significant cost-reduction of key technologies (e.g. electrolysis) are assumed, following performance improvement and mass industrialisation.

..... « **OPTIMISTIC YET PLAUSIBLE** » HYPOTHESIS

2. COMPUTING E-KEROSENE PRODUCTION COSTS

Performances and cost parameters for the different technical bricks are inputted in a techno-economic optimisation tool, to identify the optimum system sizing for each scenario, minimising the production costs of e-kerosene.

3. ENVIRONMENTAL ASSESSMENT

Regulatory-based assessment method and Life Cycle Assessment (LCA) are used to evaluate GHG emissions reduction and 15 other impact categories.

4. MULTICRITERIA ANALYSIS

Going Beyond Costs and Environmental Impacts





KERMIT METHODOLOGY

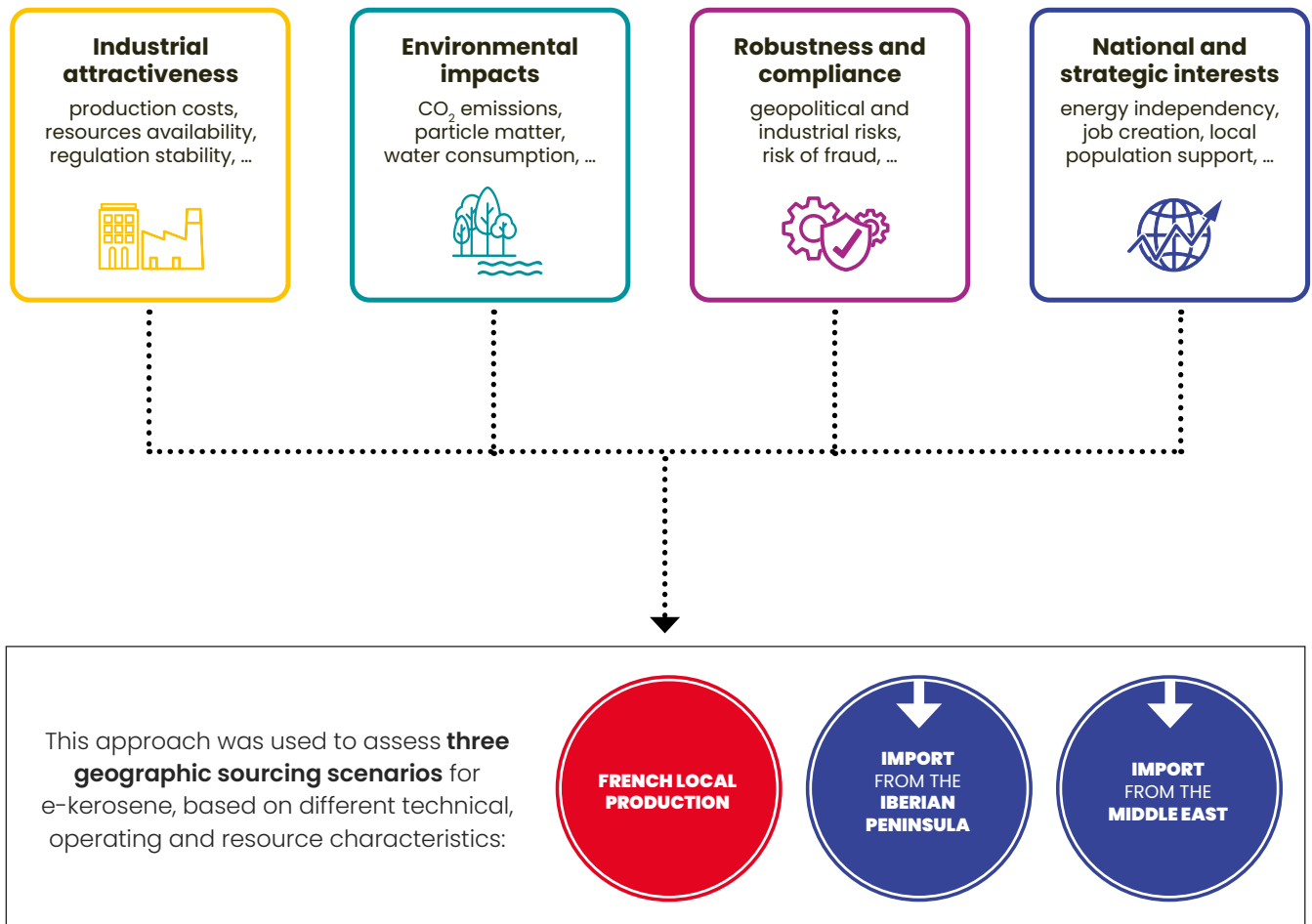
MULTICRITERIA DECISION-MAKING APPROACH

Choosing whether to import e-kerosene or to develop a domestic value chain should not only rely on economic or industrial considerations, but should encompass a wide array of criteria to reflect the numerous stakes that surround such choice. This includes for example national sovereignty, indirect economic gains, supply-chain robustness...

Decision-tree-based multicriteria decision-making methods enable to capture this variety of aspects of the decision and to put them in perspective with

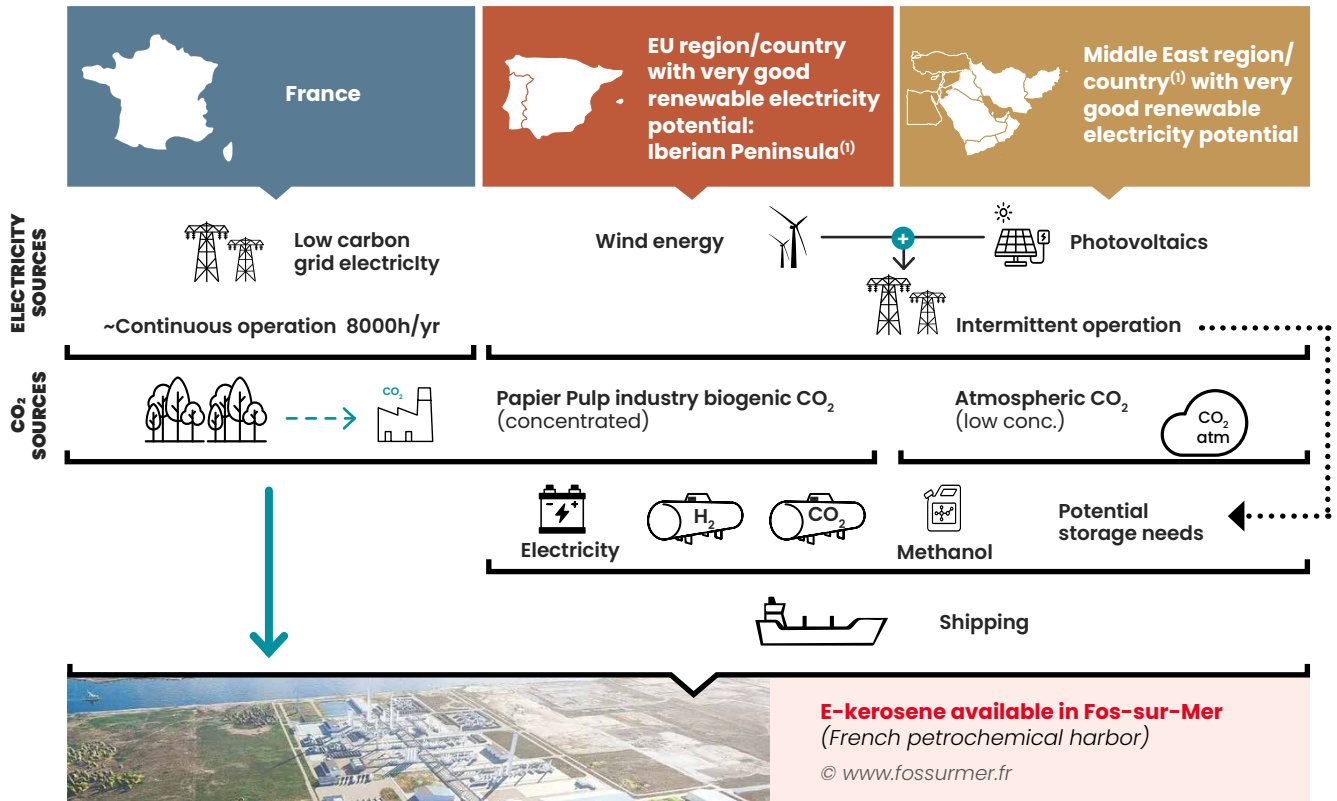
a decision-maker's own set of values and priorities. Such approach has been applied throughout this study.

Four major aspects underpinning the set-up of an e-kerosene supply chain for France have been described and assessed on the basis of quantified indicators: industrial attractiveness, environmental impacts, robustness and compliance, and national strategic interests.



KERMIT E-KEROSENE SCENARIOS

Three geographical scenarios also differentiated by electricity and CO₂ sourcing, implying different technical system designs and operations.

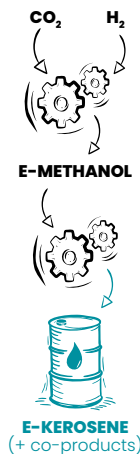


1. Evaluations based on local implementation hypothesis (e.g. CO₂ & H₂ transport/storage, renewable energy production) in Spain and Saudi Arabia, possible examples for these regions.

PRODUCING E-KEROSENE VIA E-METHANOL

From the possible chemical pathways to produce e-kerosene from hydrogen, the study chose to first produce e-methanol, due to the interest of relying on an existing chemical commodity as an intermediate product.

E-kerosene from the e-methanol pathway is currently under qualification process, with a target ASTM qualification in 2026/2027 for up to 50% mix in any aircraft.

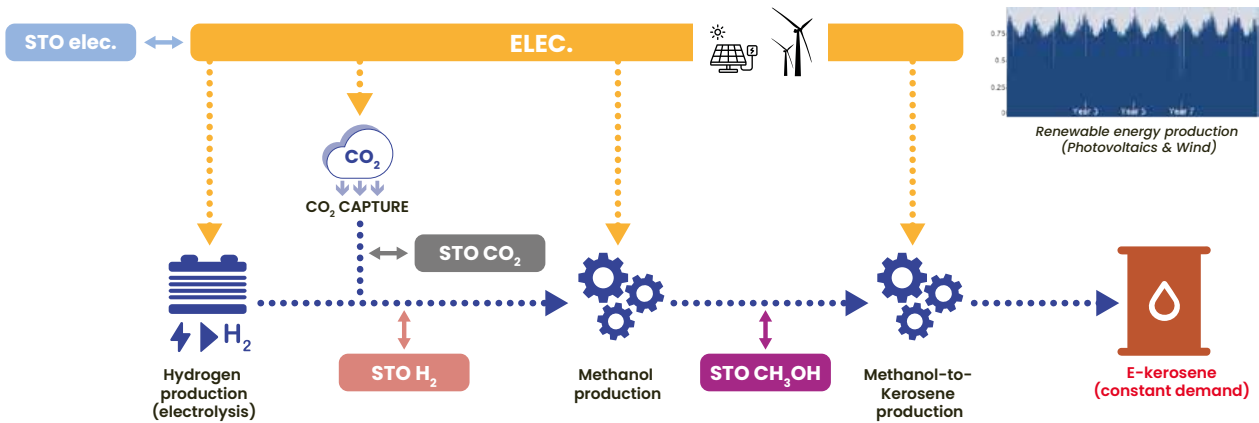


Detailed quantifications feeding the multicriteria assessment results are now presented for two of its major aspects:

- Industrial attractiveness:**
 How much does it cost to produce e-kerosene for each studied option?
- Environmental impact:**
 To what extent each option improves or degrades GHG emissions and other environmental impacts of the aviation fuel?

KERMIT ECONOMIC MODELING & OPTIMISATION

**A TECHNO-ECONOMIC MODEL FED BY DIFFERENT SOURCES
TO OPTIMISE E-KEROSENE PRODUCTION COSTS**



KERMIT key assumptions

	Type	Flexibility	Performance	Economics		
				FR	IP	ME
Electricity input (France / Imports)	Grid mix / PV-wind through grid	8000h/yr Intermittent		65€/MWh ref. + sensitivity	Equiv. 42€/MWh	Equiv. 41€/MWh
Electrolysis	Alcaline	Partial + Stand-By	66% LHV yield	600€/kW	600€/kW	600€/kW
CO ₂ capture (FR and IP / ME)	Amine Capture Solid-DAC	Partial*		2 M€/tCO ₂ /h	2 M€/tCO ₂ /h	11 M€/tCO ₂ /h
Synthesis (Methanol / Kerosene)	Standard*	Partial Continuous	64% purity 56% selectivity		1.7 M€/t-methanol/h 3.9 M€/t-crude/h	
Storage (Elec. / CO ₂ / H ₂)	Batteries Compressed sto. Saline cavities			Infrastructure-based costs (incl. in system costs)*		
H ₂ and CO ₂ Transport	Pipes					
Co-products (Gas / Liquids)	Local markets valorisation*			Basic valorisation Valorisation with premium		

* Multiple cases

Process modeling including heat integration was used to characterise methanol synthesis and methanol-to-kerosene (Mtk) processes.

Localised geographic hypothesis for plants and storages provided infrastructure-based costs, including hydrogen and CO₂ transport costs.

Techno-economic optimisation was performed using the CAIRN tool to ensure minimisation of the levelised cost of e-kerosene.



CAIRN: AN OPEN TOOL TO MODEL AND OPTIMISE MULTI-ENERGY SYSTEMS

Intuitive graphical interface usable by both non-specialists and specialists

- Manage LCA, technical, and economic indicators
- Multi-energy and parametrizable components
- Modular connections

CAIRN GitHub: <https://github.com/CEA-Liten/CairnOpen>

What is the optimal size to install for each component?



What combination of technologies to use for each need?



What is the optimal way to control the components?



How to find the good balance between short and long-term decisions?

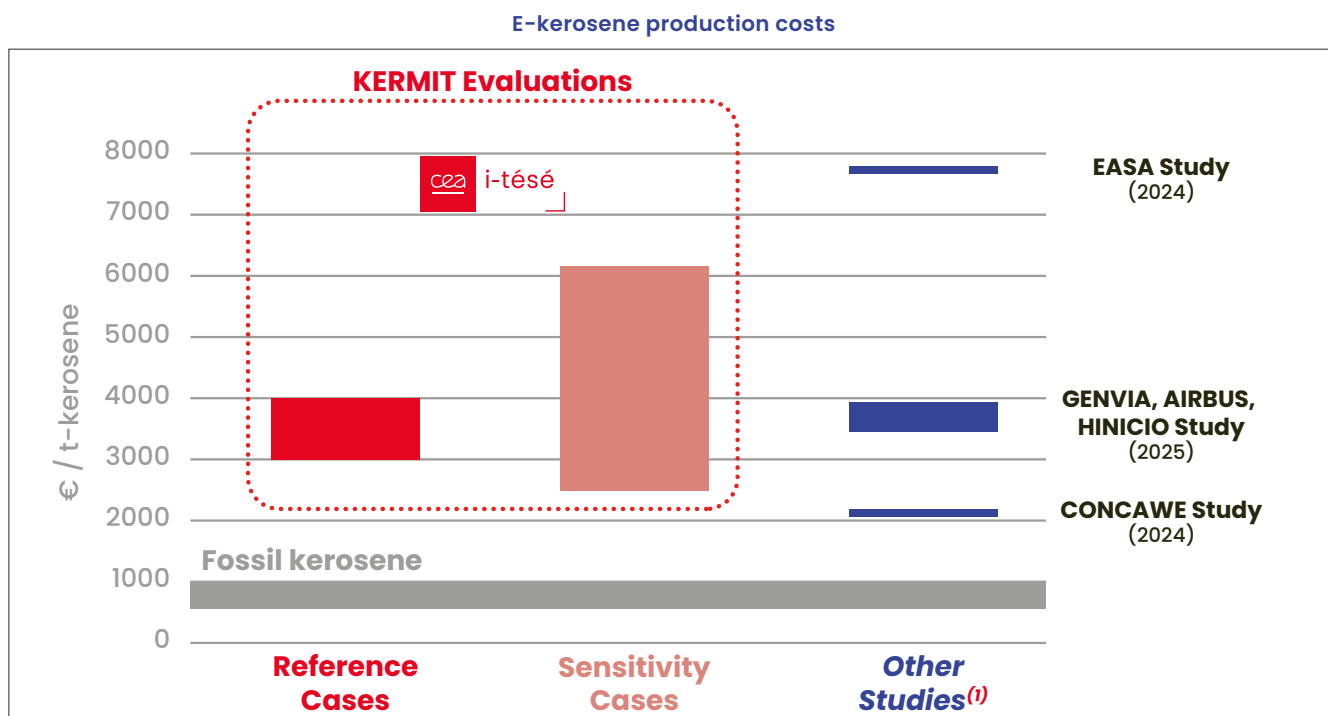
What impacts do uncertainties have on the results?



KERMIT RESULTS

E-KEROSENE PRODUCTION COSTS

REFERENCE CASES FOR THE THREE SCENARIOS LEAD TO 3000-4000€/T FOR E-KEROSENE IN 2035



According to our study, reference cases for the three scenarios lead to 3000-4000 €/t discounted e-kerosene production costs by 2035. Bottom range can be achieved by an Iberic scenario or a French scenario with a 50 €/MWh⁽²⁾ baseload grid electricity. The high range corresponds to a French scenario with a 70 €/MWh baseload grid electricity.

Sensitivity analysis leads to widen the range to ~2500-6000 €/t of e-kerosene, main driving hypothesis being electrolysis yield, CAPEX, kerosene selectivity, and potential combinaison of these.

1. State of the EU SAF market in 2023 (EASA, 2024; Spanish case) E-Fuels: A techno-economic assessment of European domestic production and imports towards 2050 -Update (CONCAWE, 2024; Spanish case) Competitive eSAF with SOEC technology (GENVIA, AIRBUS, Hinicio, 2025; Methanol pathway)

Main sensitivity analysis conducted:

- Electricity cost,
- Electrolyser capital investment,
- Process yield in e-kerosene.

Differences with other studies⁽¹⁾ can be explained through respective hypothesis:

- EASA study: higher price of electricity,
- CONCAWE study: higher material yield.

2. In our calculations we added to the baseload price for electricity 5€/MWh as network costs for an electricity-intensive industrial customer. An identical figure was taken for the Iberian Peninsula and the Middle East.

E-kerosene is not projected to be competitive against fossil kerosene by 2035, whose prices are foreseen in the 600-1000 €/t range.



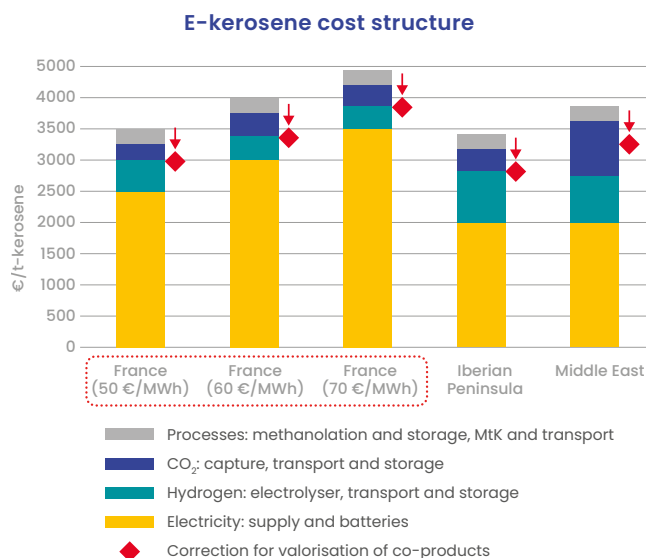
ELECTRICITY HAS A MAJOR INFLUENCE ON THE COST STRUCTURE

All scenarios show a strong dependency on electricity cost. The French scenario in particular requires long-term competitive baseload pricing for its grid-based electricity.

Evolution of EU regulatory status for established low-carbon non-renewable electricity sources (e.g. nuclear) would facilitate the development of long-term contractual supply frameworks.

The French scenario with electricity at 60€/MWh⁽³⁾ is competitive with Middle East production.

Atmospheric CO₂ capture from DAC comes at a significant cost disadvantage compared to capture from concentrated biogenic CO₂ sources, like in the Iberic and French scenarios.



3. For reference, cost of French historic nuclear energy production has been evaluated at 60,3-63,4€/MWh for 2026-2031 by the French Energy Regulatory Commission (CRE, 2025).

Guaranteed access on the long-term to competitive electricity and CO₂ prices is a key enabler for a competitive European e-kerosene production.



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At I-Tésé, our mission is to provide new insights into the possible paths toward Net Zero by advancing our understanding of the economics and sustainability of energy systems in transition.

Energy systems are by nature complex. We develop a systemic approach for our research, leveraging the CEA's historic expertise, creating numerical models, and utilizing the latest multicriteria

analysis and system dynamics software to run complex scenarios.

In addition to studying low-carbon energy production and storage technologies, we also evaluate the resources required to deploy these technologies, analyze existing and proposed regulations, and investigate the related market design principles.

And, because energy demand is a vital part of the equation, the social sciences and humanities are adding valuable perspectives to our research.

KERMIT RESULTS

ENVIRONMENTAL IMPACTS

OF E-KEROSENE

ALL SCENARIOS CONFIRM THEY ARE COMPATIBLE WITH ReFUElEU AVIATION OBJECTIVE OF REDUCING GREENHOUSE GAS (GHG) EMISSIONS BY 70%

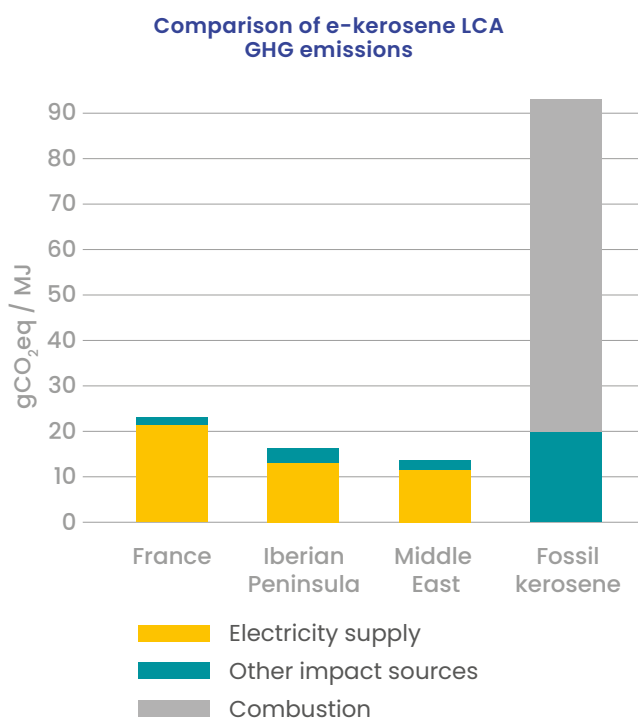
The assessment method promoted in ReFUElEU Aviation and related delegated acts, which considers renewable electricity as non-emissive, leads to an almost complete reduction in GHG emissions for e-kerosene produced in the Iberian Peninsula and the Middle East.

Thanks to its low carbon electricity mix, France also meets the EU target with a -77% reduction of GHG emissions.

A MORE DETAILED LIFE CYCLE ASSESSMENT CONFIRMS SIGNIFICANT GHG EMISSIONS GAINS FOR ALL SCENARIOS (REDUCTION BY ALMOST 4-7 FOLD)

Considering all GHG emissions in a cradle-to-grave perspective, including those related to renewable electricity production, a detailed LCA approach confirms very important GHG emissions reductions (despite higher than in the regulated approach).

Electricity feeds represent the highest GHG contributions in all scenarios. A more flexible operation in the French scenario to avoid fossil-based electricity (62% of electricity impacts, for only 3% of the energy used) could further reduce this impact (and possibly costs, in case of peak-hours electricity).



GHG emissions gains are confirmed for all sourcing scenarios, whether based on detailed LCA or on a regulatory-based assessment method.



LCA ALSO PROVIDES INSIGHTS ON OTHER ENVIRONMENTAL IMPACT CATEGORIES

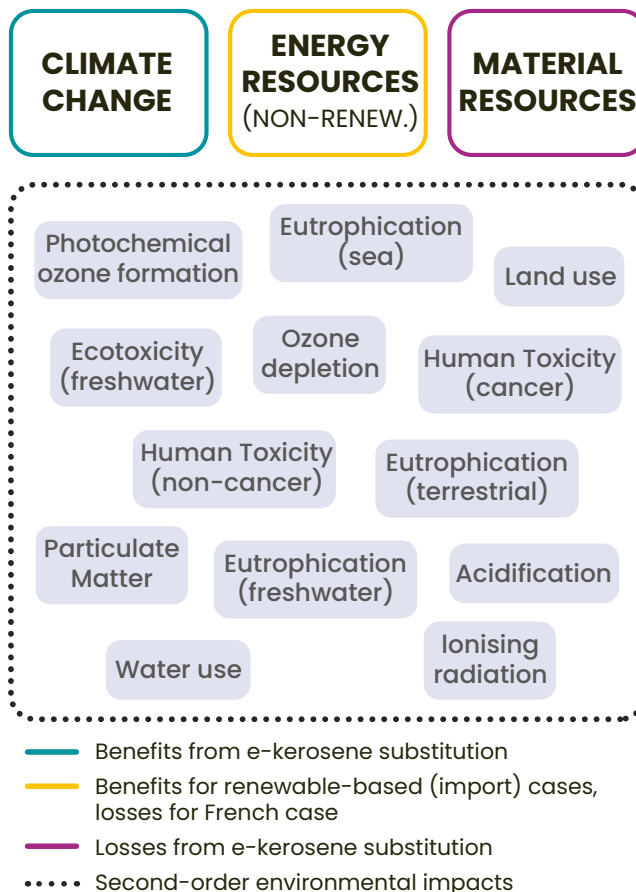
In addition to GHG emissions, LCA enables to quantify 15 other environmental impacts⁽⁴⁾ of e-kerosene substitution.

Among these, LCA-related methods⁽⁵⁾ identify three prevalent e-kerosene substitution effects as shown in the illustration.

This confirms GHG emissions reduction as a major benefit of e-kerosene substitution, while showing an increase in material resources (minerals and metals) use.

In the French case, non-renewable energy resources use is also impacted, due mostly to the uranium consumption related to the French electricity production mix.

Water desalination was assumed for the Iberian Peninsula and Middle East cases; water scarcity however remaining a potential subject of attention.



4. Environmental Footprint (EF) v3.1 assessment method.

5. LCA normalisation (comparing with a reference like the average annual impacts of an individual), combined with sustainability thresholds factors (e.g. planetary boundaries, health).

CEA-LITEN: INNOVATING FOR THE ENERGY TRANSITION

Founded in 2004, CEA-Liten has grown into a leading center for energy and environmental research.

With a focus on the pillars of the energy transition – solar, batteries, hydrogen, sustainable chemicals and fuels – CEA-Liten is innovating to improve energy efficiency and lay the foundations for a circular economy.

CEA-Liten’s mission is to develop technologically-competitive and environmentally-friendly solutions and transfer them to companies operating on the energy production and distribution, transportation, industrial process, and environmental markets.

As member of France’s Carnot Network and the Carnot *Énergies du Futur* institute, CEA-Liten operates from campuses in Grenoble and Chambéry, France.

KERMIT RESULTS

MULTICRITERIA DECISION-MAKING

Besides costs and environmental impacts, a multicriteria decision-making approach enables to capture a wide array of aspects that are relevant for decision-makers to decide whether or not supporting a domestic supply chain

MOST NOTABLE RESULTS

	France	Iberian Peninsula	Middle East
E-kerosene production costs	€€€ (6)	€€	€€€
CO ₂ emissions reduction ⁽⁷⁾	Important (> 70% both regulatory and LCA perspective)		
Availability and cost of CO ₂ supply	Limited availability (biomass-based CO ₂) Lower capture costs		Abundant (CO ₂ in air) Expensive

6. Baseload, grid-based power supply at 60 €/MWh. 7. Compared to fossil counterpart.

Focus: biogenic CO₂ supply

- Biogenic concentrated sources of CO₂ in the EU are cheaper and less energy-intensive to leverage than DAC-based CO₂ capture.
- By 2035, paper mill-based CO₂ could be sufficient in France to cover its domestic needs in e-kerosene;
- Biogenic CO₂ supply to cover increasing e-kerosene needs for 2040 and later could be at risk (limited biomass, competition for using CO₂...);
- DAC could become the default e-kerosene production scenario in case of insufficient concentrated biogenic CO₂ sources.

Which producer will set the future market-price of e-kerosene?

→ The one with access to biogenic CO₂ and cheap power.



DECISION-MAKERS POSSIBLE CHOICES

"I am a decision-maker, valuing equally environmental impacts, robustness and French domestic interests"



Enhanced robustness and domestic strategic interests outweigh the relative environmental benefits of Middle East imports.

"I am a decision-maker relying on e-kerosene. While compliant with EU environmental regulations, economical attractiveness is the most important aspect"



Advantageous implementation perspective of Middle East imports is balanced by the increased robustness of the EU scenarios.

► **REMINDER:** These constitute mostly illustrative results that depend on how each criteria is defined and weighted by the decision-makers.

CONCLUSIONS

MAIN TAKE-AWAYS

OF THE KERMIT STUDY

■ The reduction of aviation environmental footprint will require a massive deployment of SAF. As a complement to bio-SAF pathways, e-SAF have a critical role to play.

■ Three e-kerosene sourcing scenarios were assessed, very different from their geography of production (French local production vs. imports), but also on technological, operating and input sourcing choices.

■ E-kerosene confirms its GHG emissions reduction potential...

... but at significantly higher costs than its fossil alternative.

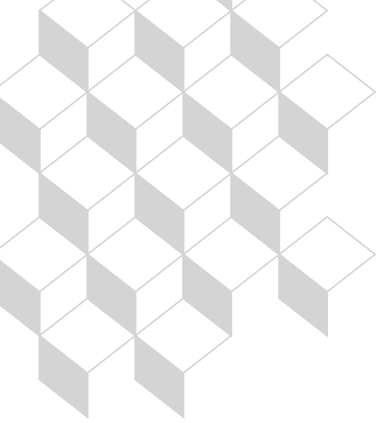
■ Key technologies need to achieve maturity, and significant cost reduction, which is a technical and economic challenge.

■ Large volumes of low-carbon electricity and CO₂ will be required for e-kerosene.

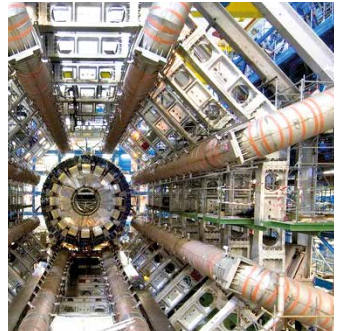
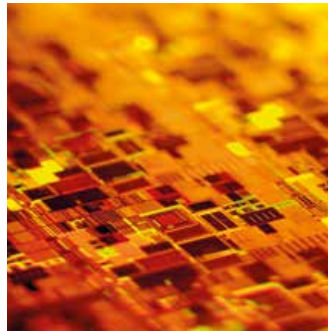
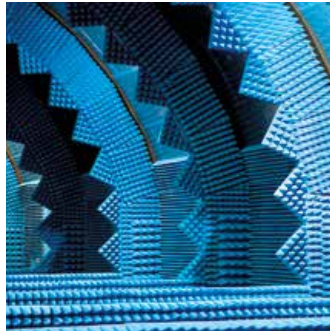
■ Provided DAC technology emerges, regions like the Middle East could become price-makers in case of concentrated biogenic CO₂ constrains.

■ E-kerosene produced in Europe appears competitive compared to imports, and should remain so on the longer-term.

■ This is in particular the case for France, provided access to competitive long term prices for baseload electricity.



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For more information, see www.cea.fr



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