Aviation fuel composition changes: European refinery impacts

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Outline

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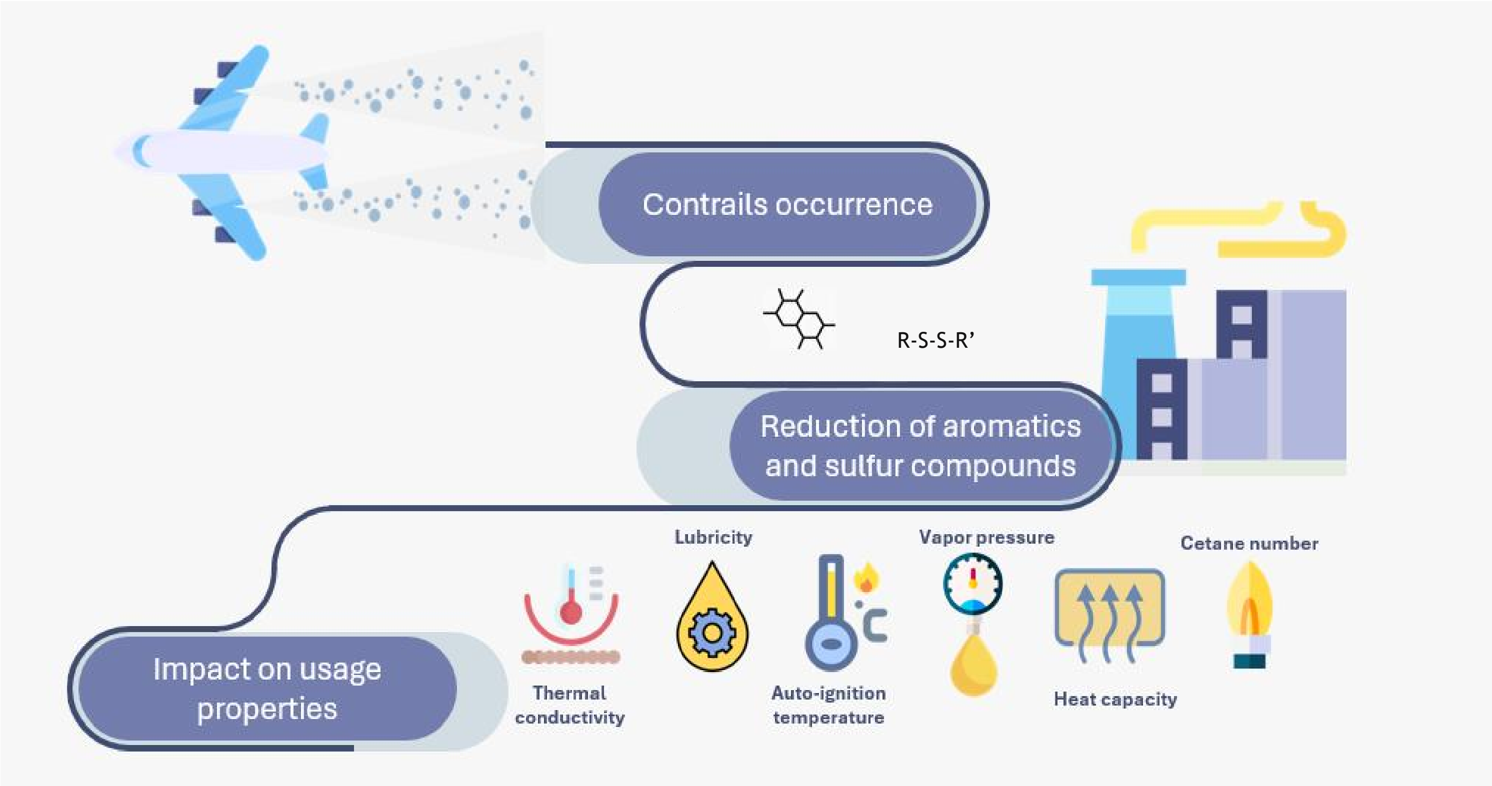
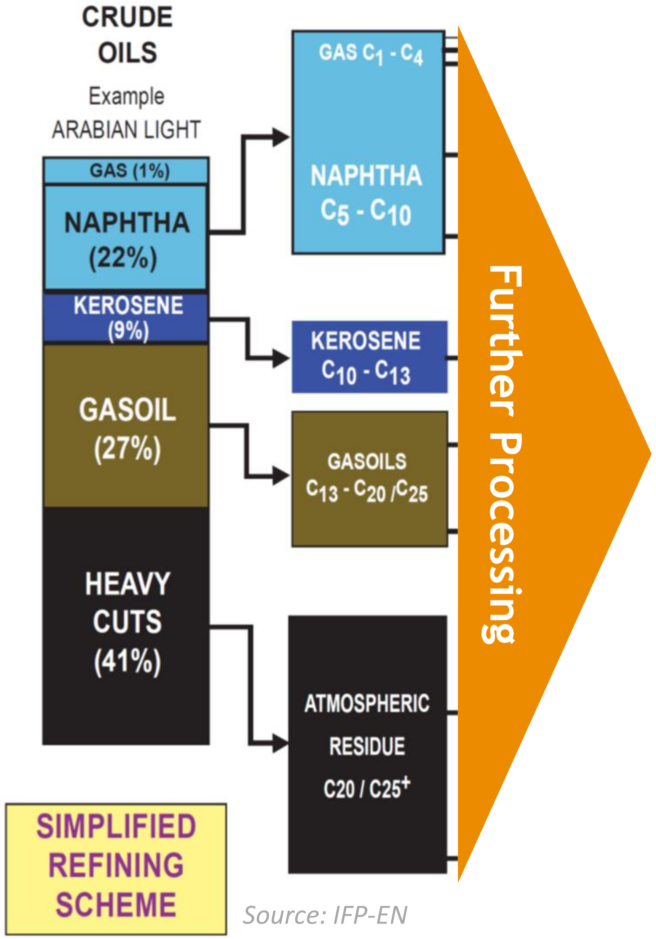
Study on European refinery impacts & fuel quality

Considering various fuel compositional change scenarios to mitigate non-CO_2 emissions:



Aromatics mostly Mono-Aromatics (Single Ring) in Jet Fuel
But also some Naphthalenes = Naphthalenic Aromatics = Di-Aromatics = Double Ring Aromatics

Introduction to Kerosene production



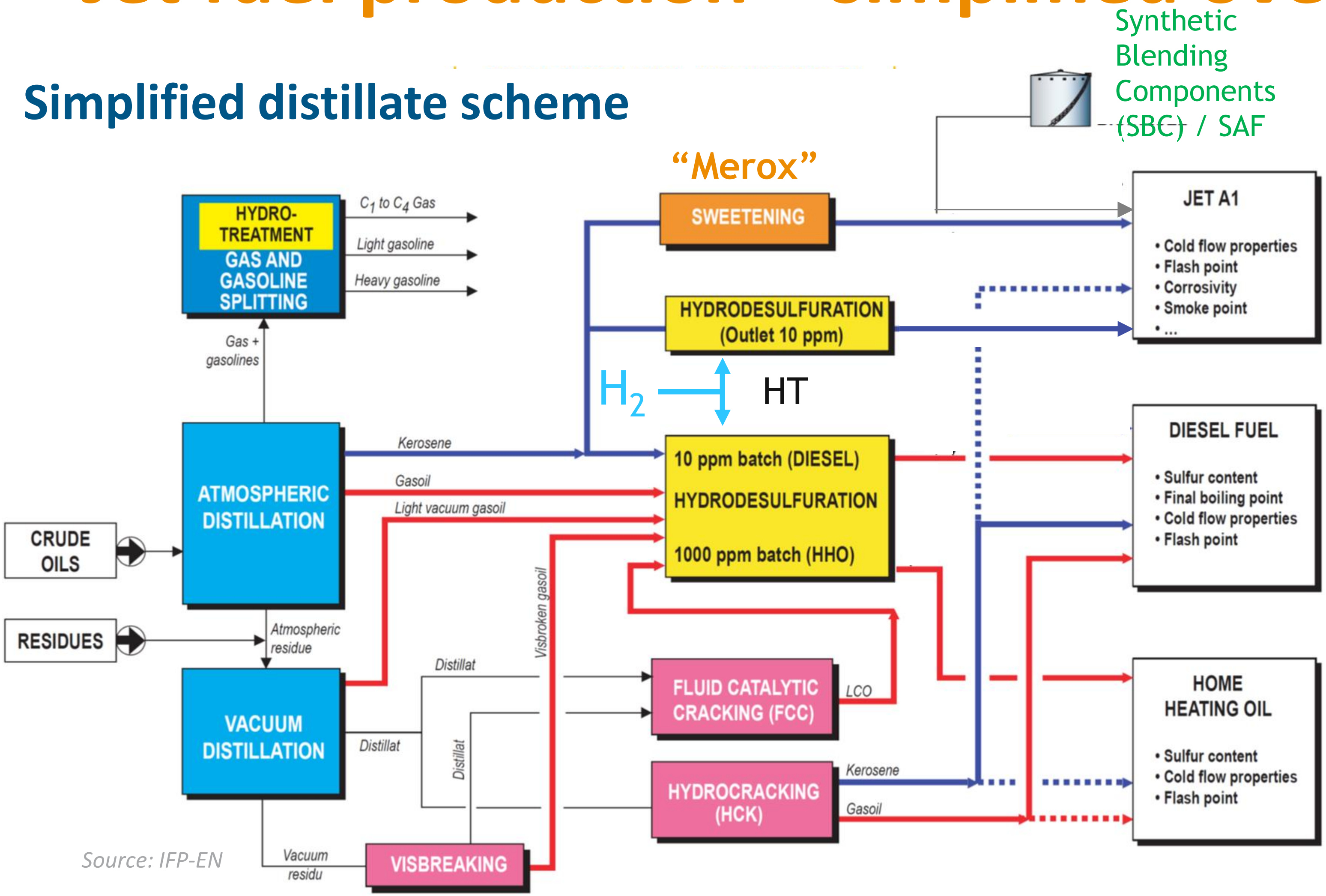
Source: IFP-EN

- Jet A / Jet A-1 is produced by an oil refinery from the kerosene cuts of crude oil atmospheric distillation unit and, in minor extent, of other secondary units

- Approximately 10% of the barrel becomes Jet fuel…

Jet fuel production – simplified overview

Simplified distillate scheme



Source: IFP-EN

The majority of kerosene used in jet fuel production comes from atmospheric distillation however refineries do not blend it directly and may have different configurations for Jet fuel:

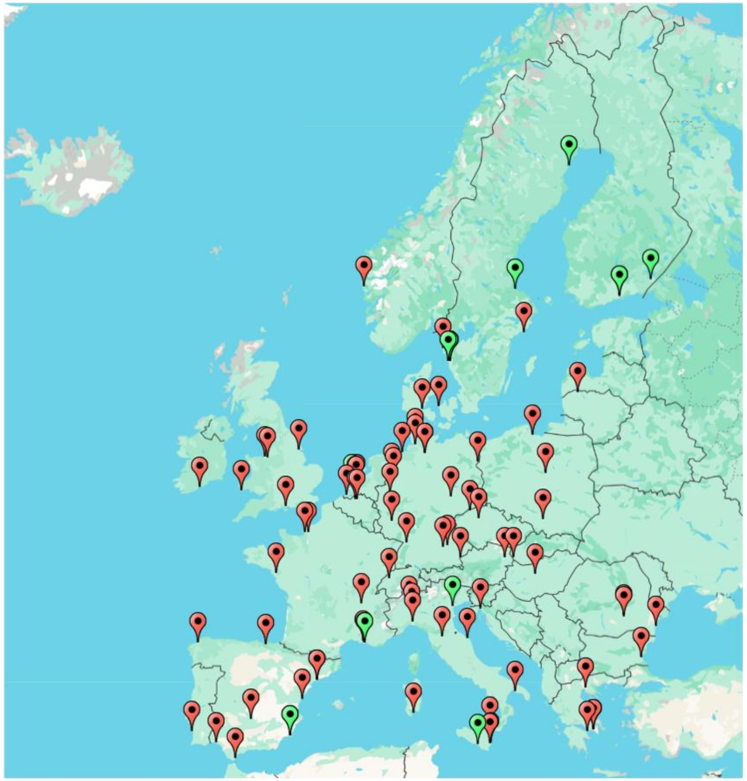
Some may only have a "**Merox**" or "Sweetening" unit which reduces mercaptans (converted into di-sulphides) but not affecting any other properties including total sulphur content, aromatics and naphthalenes

Some may also have "**Hydrotreatment**" units (HT) of various designs and capacities. Depending on design they can reduce sulphur, napthalenes and, to some extent, aromatics

Some may also have a "**Hydrocracker**" (HCK) which can produce low aromatic kerosene from heavier cuts and feedstock

Scope of the study

Understanding the impact of jet fuel composition changes on European refineries



Refineries (red) and biorefineries (green) active in 2025

Source: Refineries map - Concawe.eu

3 part study:

1. A survey was conducted to collect information on the configuration, unit availability/capacity, blending recipes & current fuel quality to asses how many refineries would be capable of meeting specification changes.

2. All refineries in Europe were modelled as 1 system using the Concawe refinery LP model. This was used to asses various Jet fuel specification scenarios and to quantify:
   - Cost (CAPEX & OPEX);
   - Additional refining CO_2 emissions resulting from the change.

3. Using actual blends of various levels of hydrotreated Jet fuel, critical fuel properties were measured to identify any safety or operational risks to consider for specification changes.

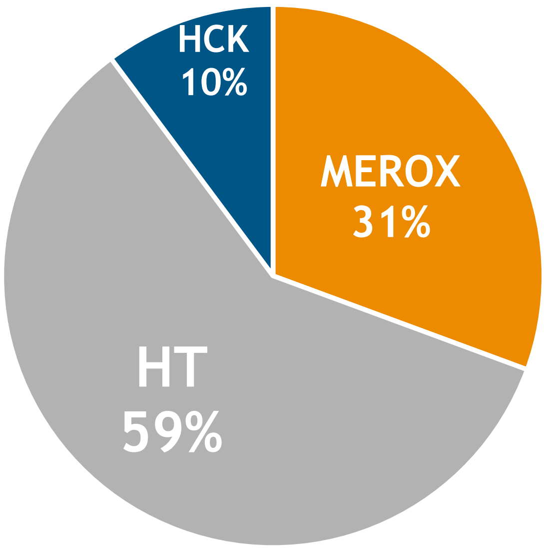
Part 1: Refinery Survey

INFORMATION REQUESTED TO CONCAWE MEMBERS ABOUT THEIR REFINERIES IN EU27+3 COUNTRIES

- Main units used in jet fuel production and pressure level when relevant
- Blending recipe (vol% from: Merox, KHT, other HT, HCK, other conversion unit, other components)
- Average fuel qualities (Aromatics, Naphthalenes, Sulphur) in 2024

=> DATA RECEIVED FROM 49 REFINERIES

MAIN CONTRIBUTING UNIT TO JET BLENDING



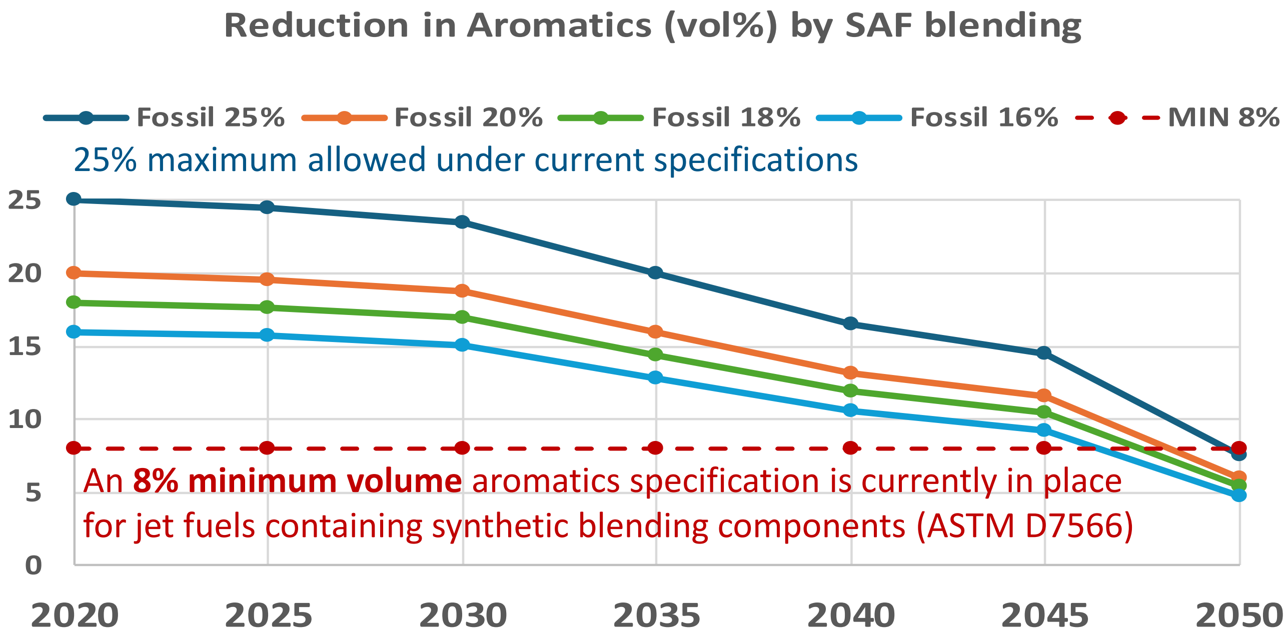
- **31% of refineries surveyed would not be able to achieve any reduction in Sulphur, Aromatics and Naphthalenes without major investments or major de-optimisation as they rely mainly or only on Merox units.**

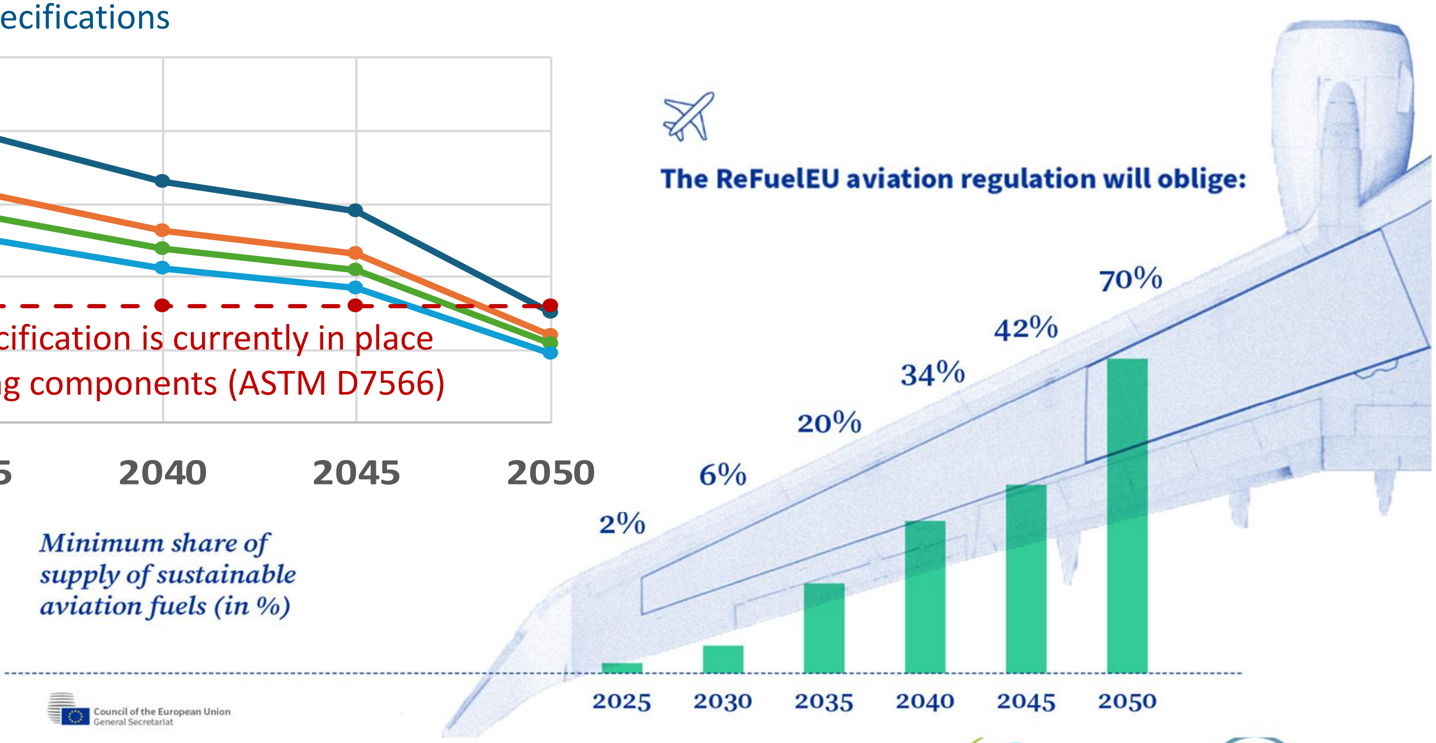
- A decision to invest in new hydrotreaters is questionable in the context of Refuel EU Aviation & fossil demand decline – Reduction of Jet fuel production may be the alternative.

- Since the potential to improve jet fuel quality depends on refinery process technology, **importers may encounter the same obstacles if equipped only with Merox units. This puts security of supply at risk as there is no guarantee that imports could offset a decrease in EU production.**

SAF Blending

Fossil jet needs to maintain an aromatic blending window to allow safe SAF blending





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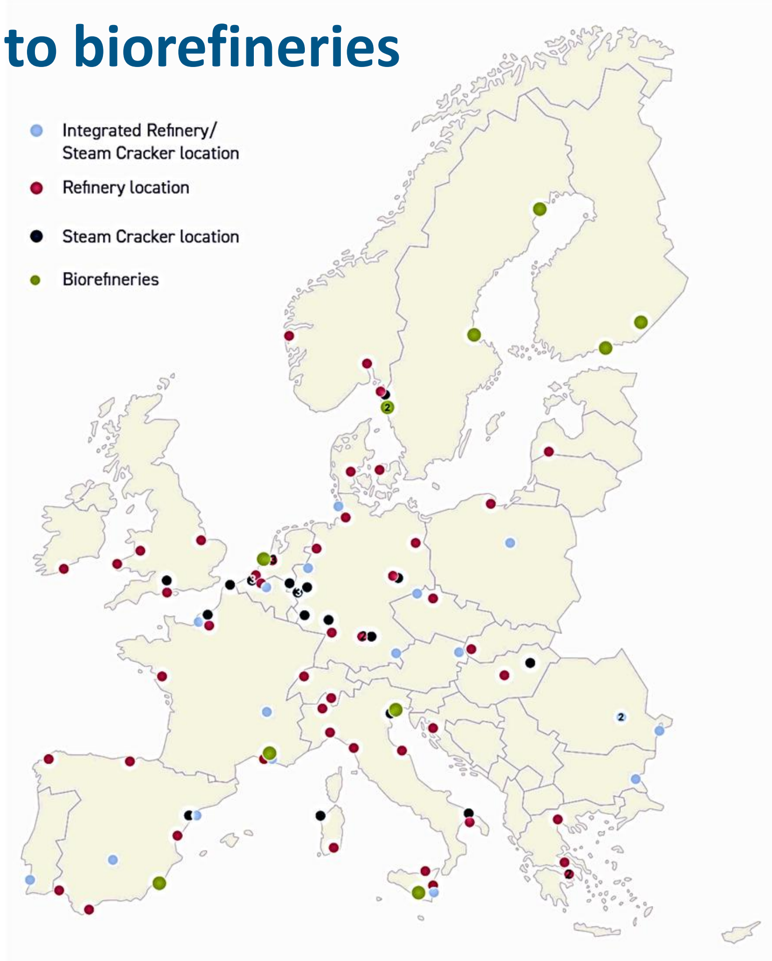
Trend of refinery closure

Consider security of supply – investment directed to biorefineries

MAINSTREAM REFINERIES IN OPERATION	NUMBER OF REFINERIES + BIOREFINERIES
73	94
SPECIALISED BITUMEN, LUBE OR CONDENSATE REFINERIES	BIOREFINERIES IN OPERATION
10	11

35 refineries have closed **since 2009**



Part 2 – EU refining study

Scope: Techno-Economic Assessment (TEA) of the reduction of sulphur, aromatics and naphthalenes in the production of fossil jet fuels in the EU27+3* refining system

Approach:

*EU27+3=EU27+UK+CH+NOR

- *Compliance to evolving jet fuel specification is evaluated through modification of operations of and/or investment in **hydrotreatment units***
- ***No other technological adaptation** were considered (i.e. hydrocracking and aromatic extraction)*
- ***Only fossil streams considered**: not taken into account SAF blending nor bio-feedstocks co-processing to lower aromatics and naphthalenes*
- ***Concawe Linear Programming (LP) model** used to assess the impact in a current single refinery configuration, in which the capacities of all EU27+3 refineries have been included.*
  - »Amalgamating all units of the EU refining system in one single refinery results in an "ideal" case which cannot be representative of the sum of the real costs which will have to borne by individual refineries and significantly understate the difficulty the industry would face in meeting specification changes.

Driver for optimization:

- *Calculate cases that **achieve expected specifications for aromatics, naphthalenes and sulphur***
- ***No properties connected to use** (i.e. lubricity) **were assessed***

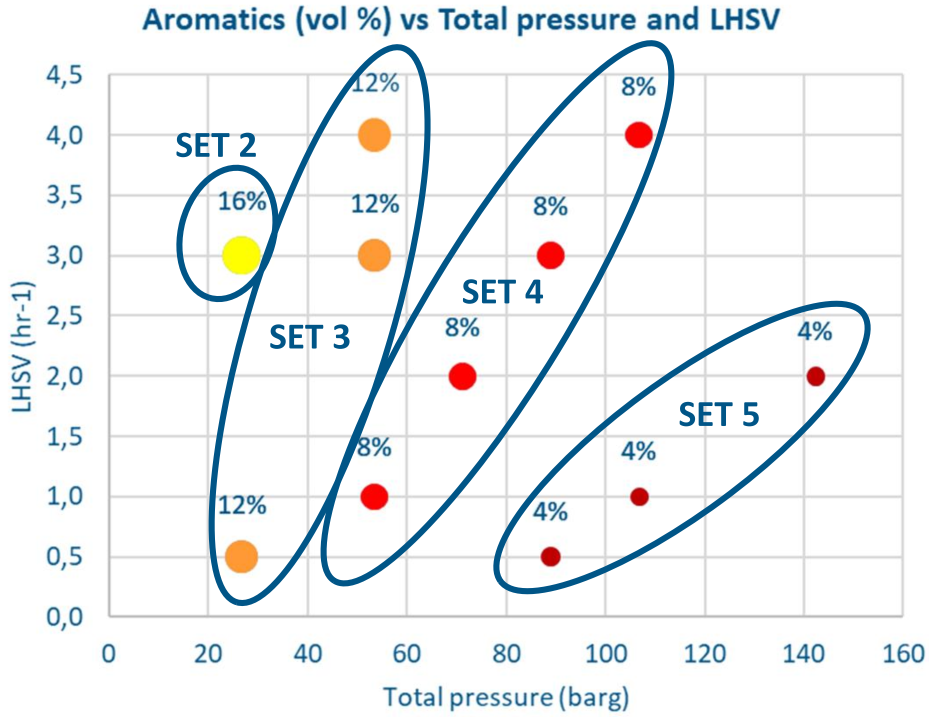
Result evaluation: Account for OPEX (from LP model) and CAPEX (provided by IFP-EN) to reach a unified economic impact assessment

Methodology

Main cases' definition (Specification Scenarios)

Case	Aromatics	Naphthalenes	Sulphur
ASTM D1655	ARO ≤ 25 vol%	NAP ≤ 3.0 vol%	S ≤ 3000 ppm wt
Set 1	ARO ≤ 20 vol%	NAP ≤ 0.5 vol%	S ≤ 1000 ppm wt
Set 2	ARO ≤ 16 vol%	NAP ≤ 0.4 vol%	S ≤ 1000 ppm wt
Set 3	ARO ≤ 12 vol%	NAP ≤ 0.3 vol%	S ≤ 1000 ppm wt
Set 4	ARO ≤ 8 vol%	NAP ≤ 0.2 vol%	S ≤ 500 ppm wt
Set 5	ARO ≤ 4 vol%*	NAP ≤ 0.1 vol%	S ≤ 100 ppm wt

*This level of aromatics does not meet the 8% minimum vol specification to be met in line with ASTM D-7566 and it should be considered purely to theoretically represent a very low aromatic / high paraffinic jet



Note: The two technical parameters (LHSV and Pressure) refer to the new HT units necessary to achieve those set of specifications. "ASTM D1655" and "Set 1" cases are not included as they do not require new hydrotreater units.

Input parameters

- ***Four variables used to model possible modes of operations of HT units*** *and generate input data: Crude, Pressure (barg), Liquid Hourly Space Velocity (hr-1) and Catalyst activity*
- *From all these data Concawe developed correlations fit for the LP model requirements, allowing to predict performances (mainly yields, dearomatisation and desulphurisation)*

Sub-cases (used to build alternative quality correlations)

- *Exclusion of all combinations that do not achieve the required specifications*
- *Exclusion of all combinations with unnecessary high pressure (extra CAPEX cost with no benefit)*
- *Consider, when relevant, combinations for both medium and high catalyst activity (different blending solutions)*

Main Results of "What if" scenarios

IMPORTANT DISCLAIMER: The model used for this calculation represents all EU refineries as if they were joined together as a single refinery. This simplification is useful to assess impacts on the whole system and estimate an "optimistic order of magnitude" for their economic effects but it does not represent the sum of the economical impact of each individual refinery in reality.

Set 1 & 2
Kerosene streams reallocation

- Specifications are achievable by existing HT and HCK units but Merox units' jet production is out of specification and minimised*
- **MAIN ASSUMPTION: What if production could be fully reallocated to refineries with HT and HCK units?**
  - **OPEX: +0,5 – 0,9 billions EUR/y (excluding logistics and CO_2 cost)**
  - **Extra CO_2 refinery emissions: +1,3 – 2,1 Mt/y (26-45 kg CO_2/ T jet)**

* In reality those refineries with only merox should consider whether to invest into a new HT unit as stream reallocation between separate sites has limited feasibility

Set 3 & 4 & 5
Investments in high pressure KHT

- No refinery can achieve the new set of specifications
- **MAIN ASSUMPTION: What if all jet production would come from investing in new high-pressure kero hydrotreaters?**
  - **CAPEX for new units: +5,0 – 11,8 billions EUR (excluding additional H2 production plant)**
  - **OPEX: +0,6 – 0,9 billions EUR/y (excluding logistics and CO_2 cost)**
  - **Extra CO_2 refinery emissions: +1,4 – 4,5 Mt/y (30-93 kg CO_2 / T jet)**

Conclusions from EU refinery study

- **Any reduction in specifications, *requiring reduction in average aromatics content*, would not be achievable by those refineries relying on Merox as the main jet production unit (~31% of the EU total)**

- A minor reduction in Aromatics of may be achievable without major investments by around 70% of EU refineries but with an increase in OPEX and CO_2 emissions and possibly lower jet fuel yields.

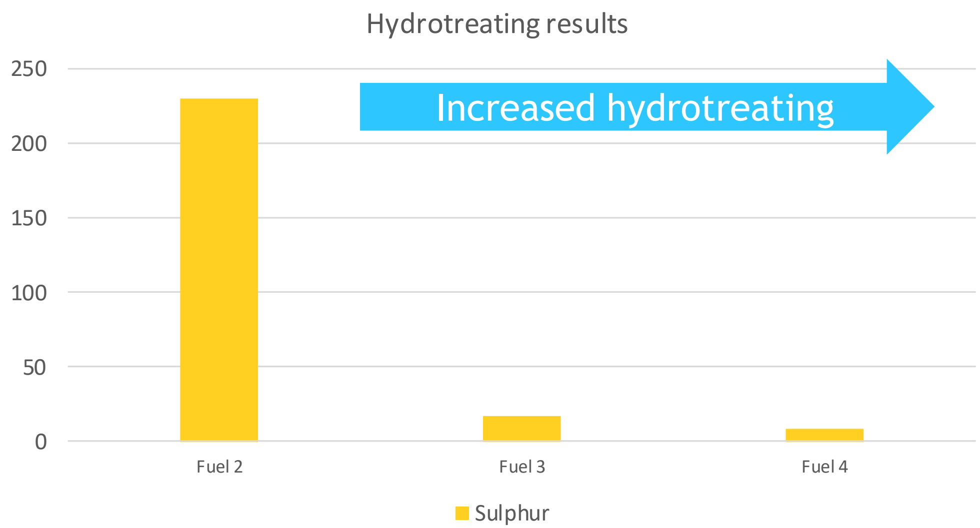
- A further reduction of Aromatics will need substantial capital investment (and significantly increased OPEX and CO_2 refinery emissions) for all EU refineries. 16% would be the minimum limit to allow 50% SAF blending.

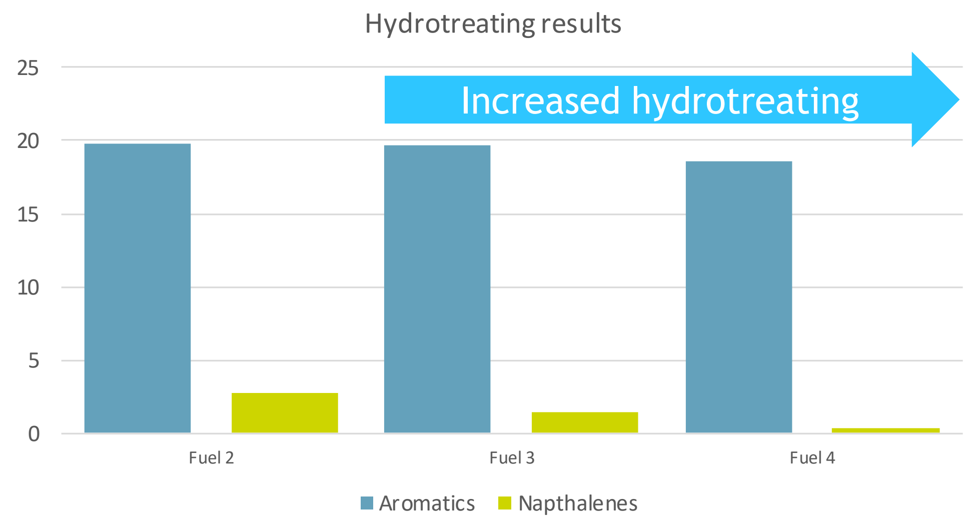
- Such investment requirements may accelerate refinery closure and risk security of supply.

Part 3 – Effect of hydrotreating on fuel quality

~20 blends were produced with varying levels of aromatics, napthalenes and sulphur

- Blends were produced using base fuels of various qualities, mixed with aromatic solvents
- Blends were designed to independently measure the trend of one variable whilst holding constant the other two
- Fuel property results show distinct trends for aromatics, naphthalenes and sulphur
- A typical base Jet A-1 fuel was hydrotreated in a pilot plant to represent a typical refinery hydrotreating process





The results above are typical for a HT unit: Sulphur & naphthalenes reduced effectively with mild hydrotreating
Aromatics require more intensive conditions & equipment to reduce

Fuel property results

Concern | Directional change | No impact

What are the directional property effects as we reduce ?

	Lubricity	*Permittivity	CN	VP
	Low lubricity (High wear scar) can cause fuel pumps and injectors to wear	Change in permittivity can result in fuel gauge inaccuracy *Not measured – Trends from literature	Cetane number indicates ignition quality. High cetane can overheat parts and low cetane can risk lean blow out	If the vapour pressure is too high the fuel could cause bubbles and thus cavitation or vapor lock in the fuel system
Aromatics	↑ Linear	↓ Linear	↑ Linear	↓ Non-linear
Naphthalenes	↑ Linear	✖ No Impact	✖ No Impact	✖ No Impact
Sulphur	↑ Linear	No info.	↑ Linear	No info.

Fuel property results

Concern | Directional change | No impact

What are the directional property effects as we reduce ?	AIT	Surface Tension	Heat Capacity	Thermal Conductivity
	Low auto-ignition temperature can risk ignition in fuel tanks or premature autoignition in the engine, risking engine damage	A low surface tension will lead to better fuel atomisation, but a higher risk of cavitation in fuel pumps	A higher heat capacity means the fuel can absorb more heat, improving the efficiency of the cooling system	low thermal conductivity can lead to overheating of engine parts or promote the formation of fuel crystals
Aromatics	↓ Requires further study	✗ No Impact	✗ No Impact	✗ No Impact
Napthalenes	✗ No Impact	✗ No Impact	✗ No Impact	✗ No Impact
Sulphur	Not sufficient data on sulphur blends to generate conclusions on these properties			

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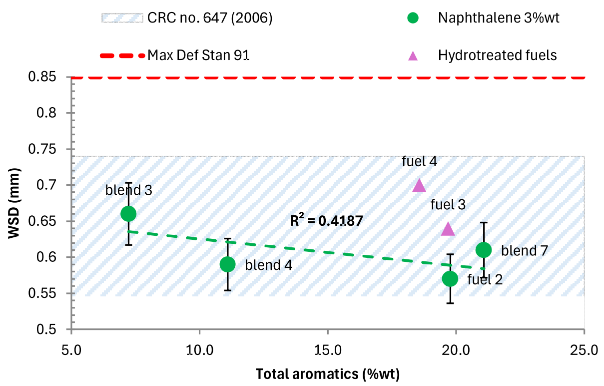
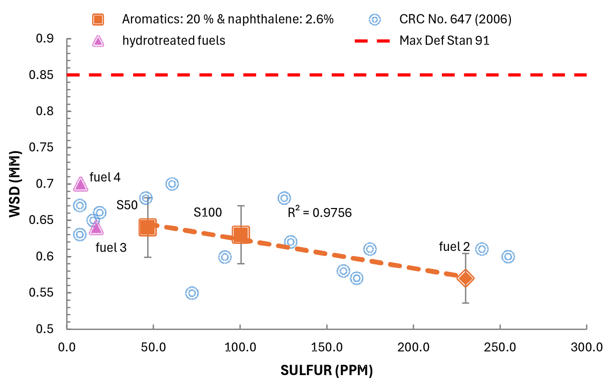
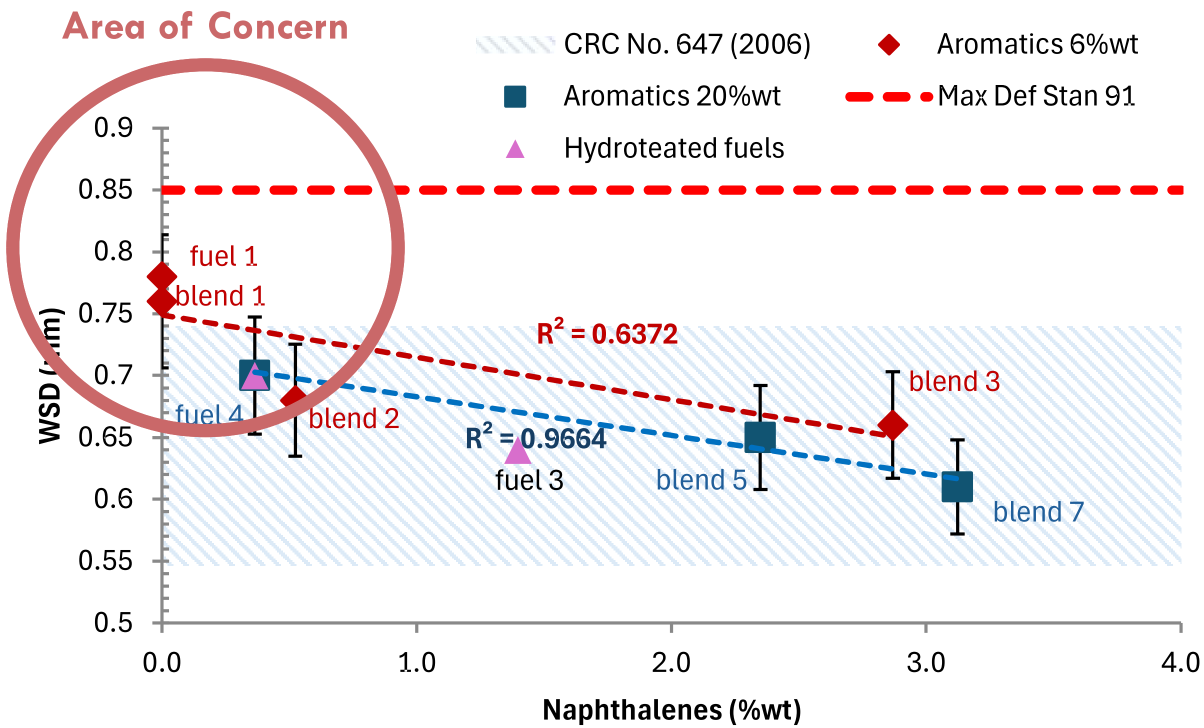
Lubricity approaches limits with hydrotreating

Blends with very low naphthalene's especially approach a BOCLE wear scar max limit of 0,85 mm (Def Stan 91-091)







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Conclusions from fuel property analysis

- Some key aviation fuel properties vary significantly with changing aromatic, naphthalene and sulphur content.
- There is no evidence in this study that the formulated fuels with lower aromatic, naphthalene and sulphur content would lead to values outside of the current aviation fuel specifications for the tested properties
- **The lubricity results in this study are close to the limit even with mild hydro-processing and this needs to be treated with caution.**
- Further detailed studies on fuel compatibility will be required should changes in fuel specification be considered.
- **Fuel dielectric constant (permittivity)** should also be featured in such studies as literature data indicates a significant influence of aromatics on this property, an attribute important for aircraft fuel gauging systems.

Concawe
Environmental Science for European Fuel Manufacturing

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Thank you for your attention

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