Used cooking oil:
one feedstock, different technologies
A comparative study

Preliminary results

Presentation to FUELS OF THE FUTURE

Study commissioned by EWABA and MVaK

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Which UCO pathway delivers the highest environmental benefits?

- Used cooking oil, UCO can be used to produce several types of renewable and sustainable fuel, via different pathways
- The four fuel types that are currently often considered are:

UCOME "Biodiesel"	UCO-HVO "Renewable diesel"	Co-processed UCO "Co-processed renewable diesel"	UCO-HEFA "Sustainable Aviation Fuel"
Through a relative simple process, vegetable oils are converted into biodiesel which can be used in blends with diesel or pure as B100 in road transport	Through a complex process, vegetable oils are converted into drop-in type diesel which can be used up to high fractions in road transport	Vegetable oils can be co-processed in existing oil refineries up to a fraction of about 5-10% simultaneous with the otherwise fossil feedstock	Via a complex process, vegetable oils are converted to sustainable aviation fuel that can be used in 50% blends with fossil jet fuel

- Each of these fuels falls in the Annex IX B category of the Renewable Energy Directive (RED II)
- The contribution of Annex IX B fuels to the RED II target of renewable energy in transport is limited to 1.7%
- This is actually a soft cap and Member States can implement higher national caps or targets

- Waste streams like UCO are eventually limited in available volumes
- So: how can UCO best be deployed?

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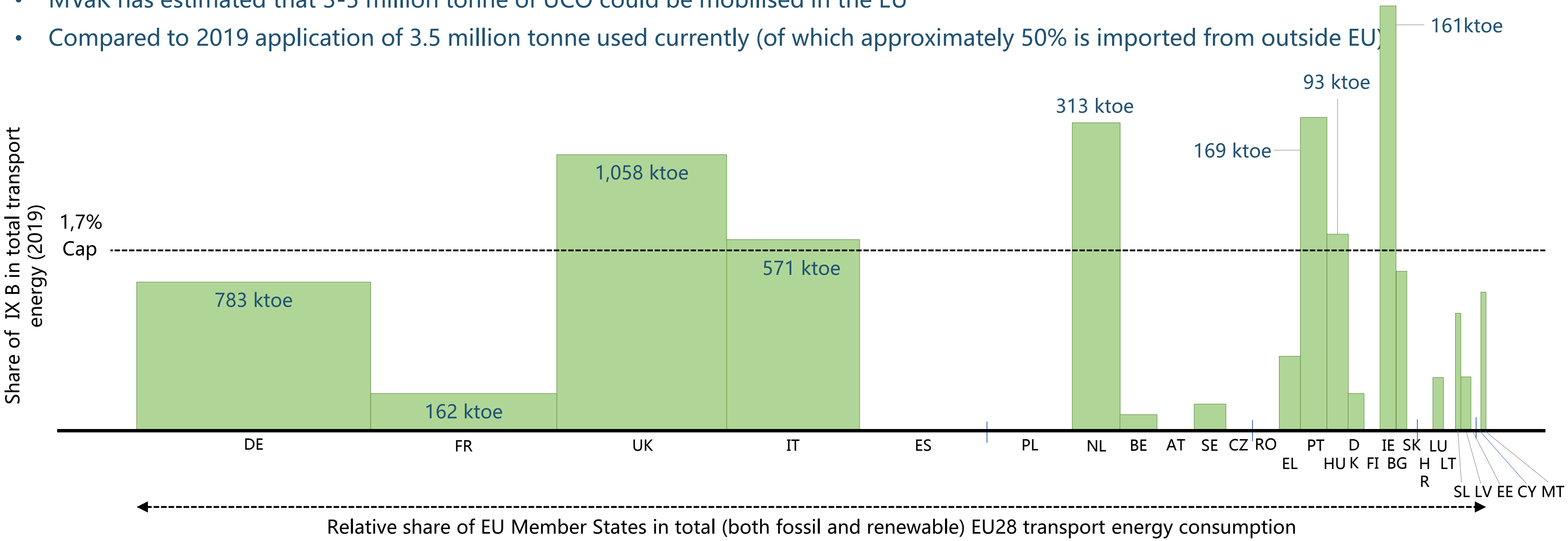
Market context

Use of Annex IX-B in EU28 Member States in 2019

- Member States can only *report* up to 1.7% of these fuels in the frame of the RED transport target
- Member States can set higher targets for these fuels to obligated parties within their own markets
- Contribution of Annex IX B fuels is above 1.7% in some Member States, and below in other
- Overall, there is still room to increase the deployment of Annex IX B biofuels, until 1.7% is reached on an EU level

- UCO collection rates in the EU are increasing
- MVaK has estimated that 3-5 million tonne of UCO could be mobilised in the EU
- Compared to 2019 application of 3.5 million tonne used currently (of which approximately 50% is imported from outside EU)



Source: Eurostat, SHARES data set, Eurobserver - Biofuels Barometer 2020

Results

Carbon footprint

Main results

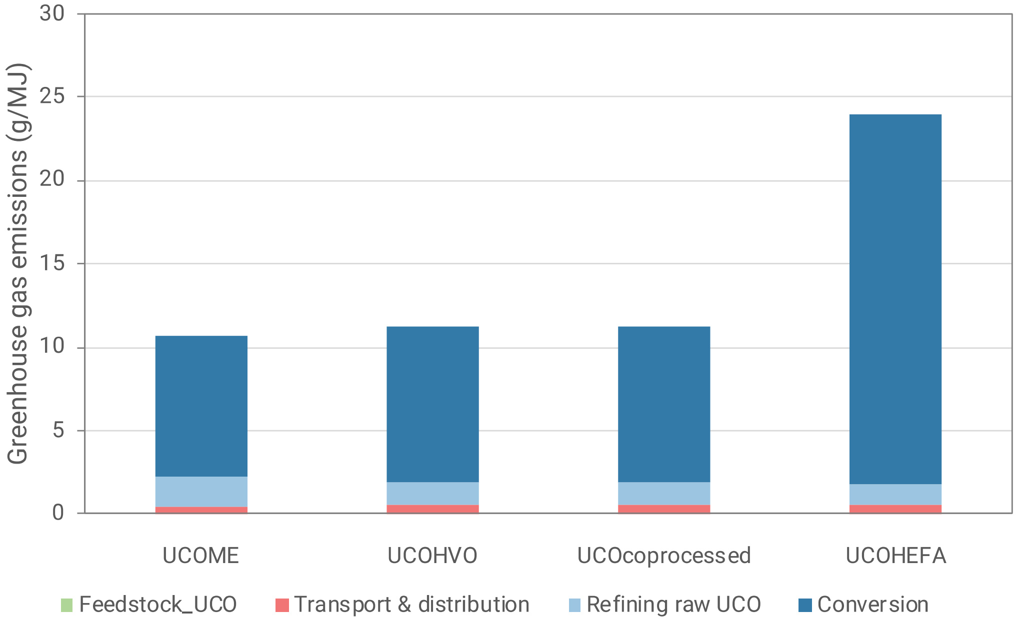
- All pathways achieve good savings compared to fossil fuels
- UCOME and HVO and co-processing achieve about 11-12 g/MJ
- This implies about 90% greenhouse gas savings
- In line with the typical value reported in the Renewable Energy Directive and other literature

- HEFA has a higher greenhouse gas impact, of about 24 g/MJ, which still means about 70% emission reduction
- In literature, ranges are found from about 14 – 28 g/MJ

Details

- Conversion step always contributes most to the carbon footprint
- In HEFA the hydrogen and steam use increase the footprint
- Co-products carry part of the carbon emissions
- The conversion efficiency does not play a role, because feedstock emissions are assumed to be zero
- Sourcing feedstock over longer distances would incur transport emissions which would be most visible in less

efficient pathways



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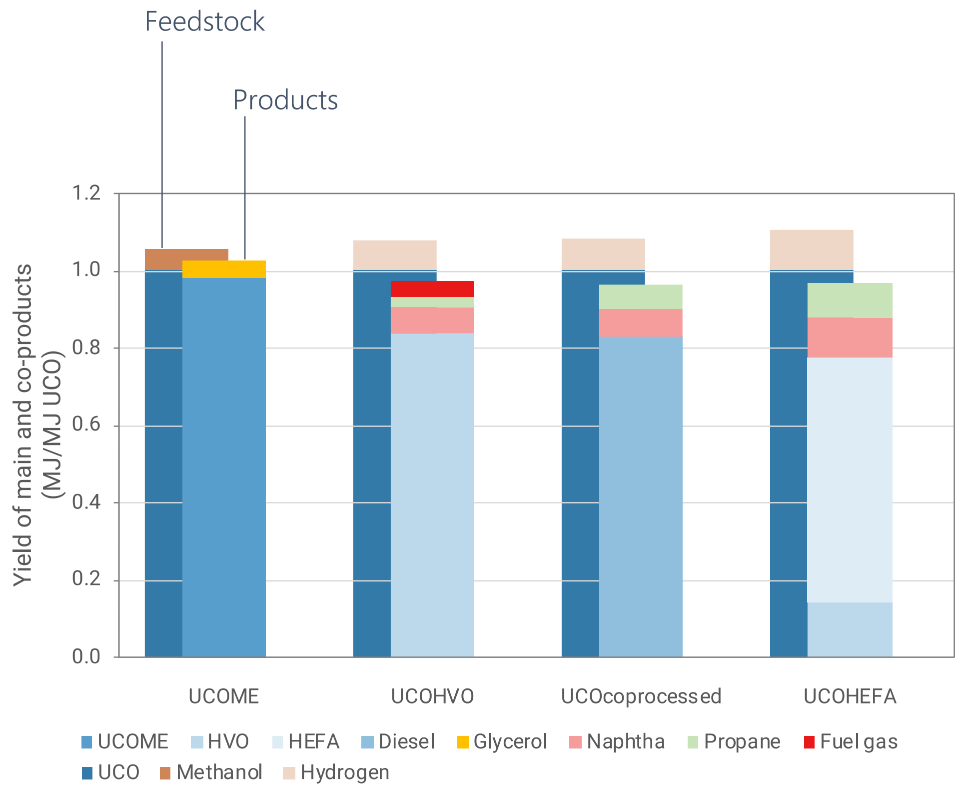
Feedstock conversion efficiency

Comparison on energy basis

- Conversion efficiency to main fuel is highest via UCOME pathway
- Cracking of the fatty acid chains produces more co-products: naphtha, propane and fuel gas
- Overall conversion efficiency from UCO to sum of products, is comparable for all pathways
- When including the input of methanol or hydrogen the HEFA pathway has lowest overall conversion efficiency
- Compared to HVO, some additional hydrogen is required for isomerisation in case of HEFA

Co-products cost energy

- Fuel gas and propane are not always co-produced
- Often used for internal energy supply
- When co-produced, this energy needs to be sourced externally



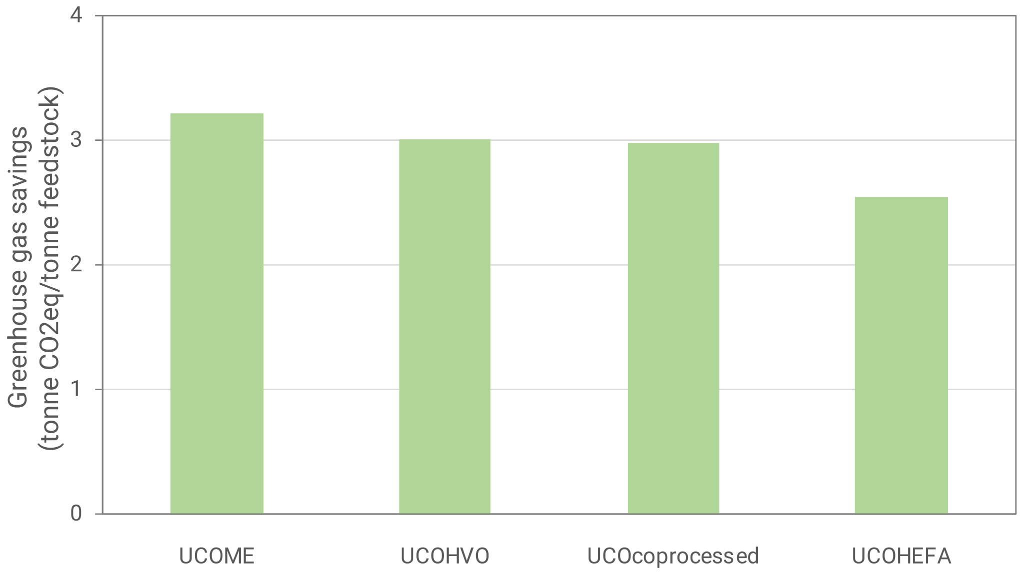
Carbon efficiency

Main results

- Savings achieved by fuels, combined with fuel yield per feedstock
  (all products considered)
- UCOME has best overall carbon savings per tonne of feedstock
- Lower yields of the main product in the other pathways lead to lower carbon efficiencies

- This means that if UCO is a limited feedstock,
  it is best used to replace fossil fuels via the UCOME pathway
- Results for HVO and coprocessing are also good
- HEFA achieves least carbon savings per tonne of UCO feedstock

- HEFA and HVO results represent maximal co-products
- If naphtha and propane are used for process energy,
  then savings per amount of product improve, but similar net result



Production costs

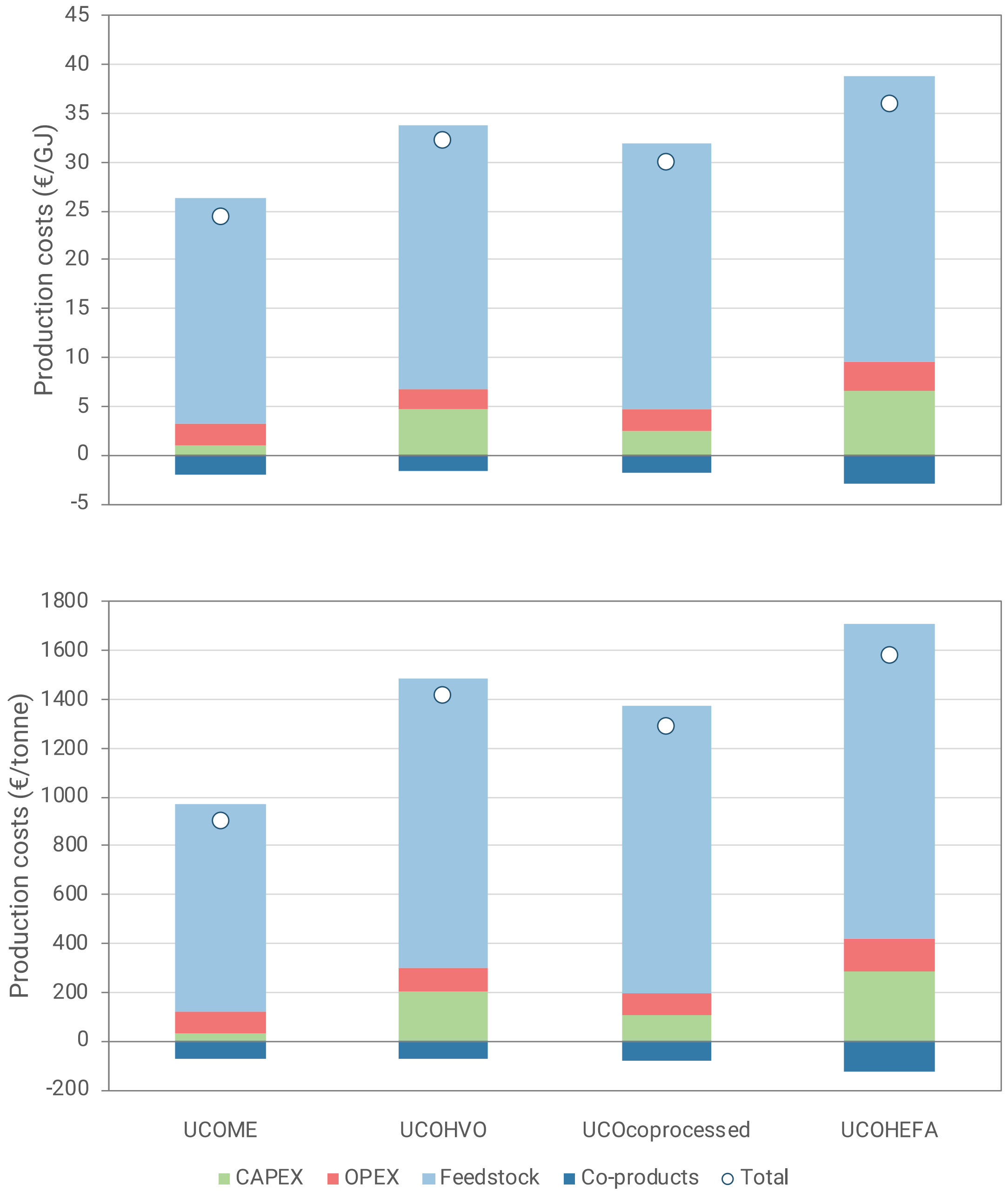
Main results

- UCOME has the lowest production costs and UCO HEFA the highest
- UCOME is the most attractive because
  (1) High feedstock efficiency towards final product
  (2) Simple tech with low investment costs
- Costs of HVO appear slightly higher than via coprocessing
- Still, co-processing is less attractive: it requires 90% fossil operation

- Feedstock costs are the most dominant factor in all four pathways
- Therefore, conversion efficiency has major impact on differentiation between the pathways

Important when considering literature

- Literature reports broad range of production costs for UCOME
  - UCOME : 17 – 29 €/GJ, as research took place over long time
- Narrower ranges for new fuels, based on less feedstock variations
- Every year will see different production costs
- Relative position to each other and to replaced fossil is important



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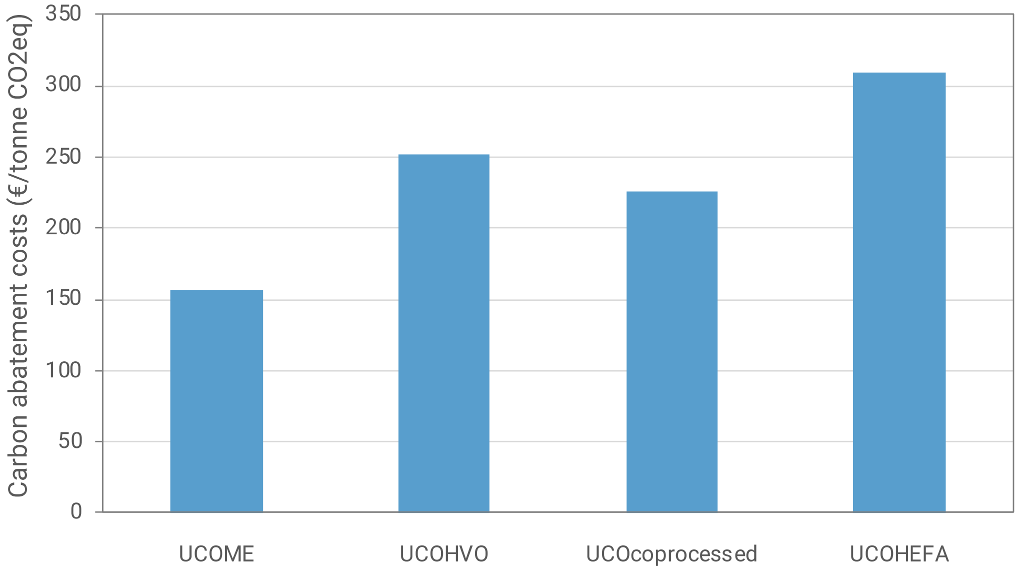
Results

Carbon abatement costs

- Combination of marginal fuel costs with carbon savings gives abatement costs
- UCOME has lowest carbon abatement costs of the four pathways

- Absolute results are sensitive to reference fuel prices!
- 0.20 €/l cheaper fossil diesel increases abatement costs with 70 €/tonne
- Results should be regarded in relative sense

- UCO HEFA has highest abatement costs, despite replacing a pricier fossil fuel



Air quality

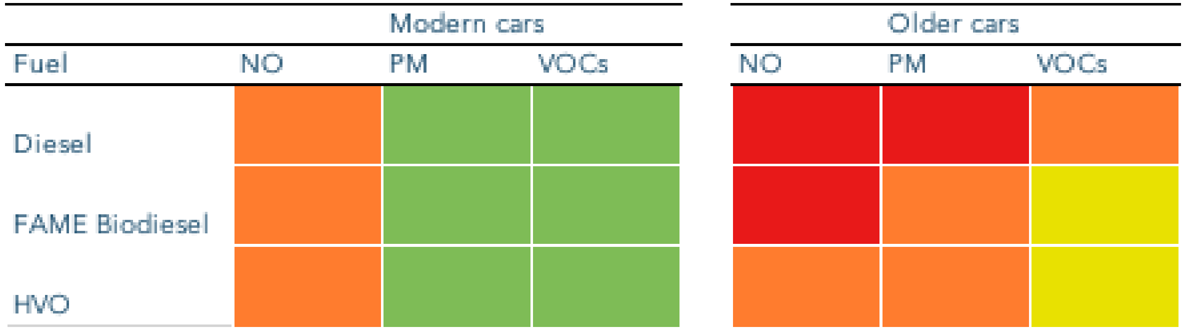
Literature does not allow for full & just comparison

- Limited literature about HEFA, none about coprocessed
- Most literature focuses on air quality from renewable fuels compared to fossil fuels
- Barely literature that allows for comparison between renewable fuels
- Older literature relates to older engines, not representative
- Impossible to compare gains in road transport to gains in aviation

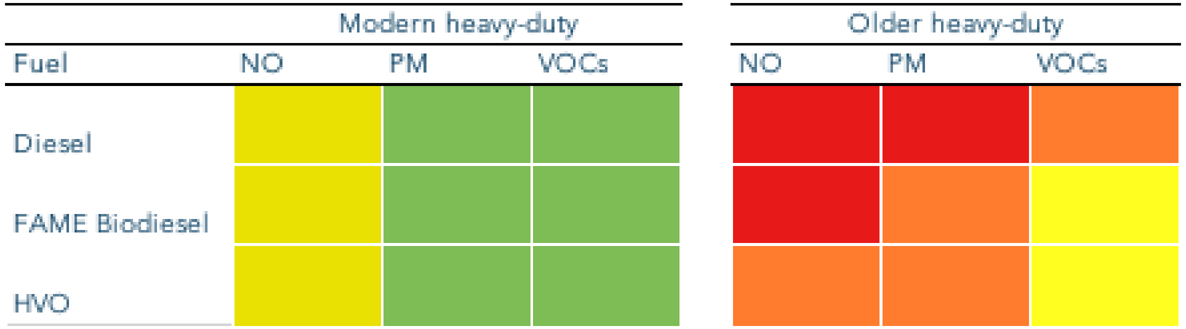
Main findings

- Air quality mostly determined by type of engine and combustion characteristics
- Difference found in air quality impact between fuel types in older engines
- In modern engines this difference becomes negligible, both in passenger cars and heavy duty vehicles
- Euro engine standards have decreased air pollution emissions considerably over the past 30 years, both for passenger vehicles and heavy duty vehicles
- For instance, Euro VI engines (heavy duty) have 60x less PM emissions and 20x less NOx emissions than Euro I engines

Air pollutant emissions by fuel from modern and older cars



Air pollutant emissions by fuel from modern and older heavy-duty vehicles



Older = Euro 3 or equivalent (e.g. model year 2000 in Europe)
Modern = Vehicles that meet Euro 6 emissions standards or equivalent.

Sources:
* IEA-AMF, 2017. Air Quality Implications of Transport Biofuel Consumption.
* Emission standards: https://dieselnet.com/standards/eu/hd.php

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Summary findings per indicator

Carbon footprint

- Both UCOME and HVO have low GHG impact per MJ
- HEFA production has highest GHG impact per MJ
- Material efficiency does not impact footprint as UCO starts at zero
- UCOME allows for highest savings per tonne of feedstock

Production costs

- UCOME has lowest production costs while HEFA has highest
- Feedstock costs represent largest share of costs in each pathway
- Therefore, feedstock conversion efficiency is determining factor
- UCOME combines high feedstock efficiency with low capital costs

Carbon abatement costs

- Carbon abatement costs of UCOME are significantly lower than of other pathways

Air quality

- This study found no significant differences between pathways in air quality performance
- Engine and operation determine emissions more than fuel does
- Literature claims that some fuels perform better than others could not be substantiated

Regional added value

- Most employment occurs in UCO collection – same for all pathways
- UCOME offers slightly more employment per product output
- HVO, HEFA and co-processing often concentrated in port cities
- Difference in regional added value between fuel pathways small

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Summary

- Application of UCOME plays a major role in decreasing the greenhouse gas emissions of existing car fleet
- In view of the urgency of climate action, renewable fuels should focus on minimising greenhouse gas impact
- We find that UCOME has highest carbon efficiency of all UCO pathways, and HEFA the lowest

- When the deployment of UCO is limited, and carbon emission reduction is main goal, then UCO is best deployed as UCOME in road transport
- Once the passenger car segment will become dominated by electric vehicles, then UCO might best be deployed as UCOME in heavy road transport and shipping, from a climate mitigation perspective
- UCOME contribution can be increased by introducing higher blends (B10, B20 or B30) or pure (B100)

- UCO can also be used to produce other fuels
- Such fuels are not additional, but compete with UCOME
- A focus on HVO and HEFA will reduce the contribution of UCO to carbon abatement, and increase the costs
- Also, it would cause a loss of capital invested in current UCOME conversion capacity

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