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ACCELERATING INDUSTRIAL ELECTRIFICATION

KEY INSIGHT #4

A PATHWAY TOWARDS SUSTAINABLE FUELS

Comparing CCS and CCU for aviation fuel production

KEY TAKE AWAYS

Carbon-based e-fuels like e-methanol and e-kerosene are expected to play a key role in making heavy duty transport (long haul truck transport, aviation and sea shipping) more sustainable. These fuels can be produced from CO_2 that is captured from fossil point sources or from the atmosphere.

However, in situations where CO_2 storage is an option, the question arises whether the production of e-fuels adds value compared to using fossil fuels and underground storage of the captured CO_2. A comparative analysis of different e-fuel production configurations, based on a set of Key Performance Indicators, provides answers to this question. The results are summarized in Figure 1.

In the short term, the preferred configuration in terms of costs and energy efficiency is to apply carbon capture and storage (CCS) to fossil CO_2 point sources (e.g. at coal-fired power plants or blast furnaces), while continuing the use of fossil-based fuels for transport. This approach substantially contributes to avoiding CO_2 emissions. Combined with the storage of atmospheric CO_2 from direct air capture (DAC), it can even provide a net zero carbon emissions route at relatively low cost.

However, since this configuration still relies on fossil resources, it will not be a long-term sustainable solution. A sensible alternative is to use the CO_2 from fossil point sources to produce e-fuels. This requires considerable amounts of renewable electricity and is more costly, but it can stimulate the development of e-fuels production until sufficient renewable electricity and sustainable CO_2 are available.

For the long term, the only sustainable solution considered in this study is to produce e-fuels using CO_2 from DAC. It is the only configuration in the analysis that is net zero and does not rely on fossil fuels and storage of CO_2.

INTRODUCTION

To mitigate climate change, a transition to sustainable ways of transport is needed. Battery electric vehicles already offer a solution, but mainly for lighter vehicles, smaller loads and shorter distances. For heavy-duty and long haul transport, especially aviation and maritime shipping, sustainable fuels will be key. Carbon-based e-fuels like e-methanol, e-diesel and e-kerosene can make these transport modalities more sustainable. Upon combustion of these e-fuels, the carbon is emitted into the atmosphere as CO_2. When this atmospheric CO_2 is used as a feedstock for new e-fuels, a circular system can be

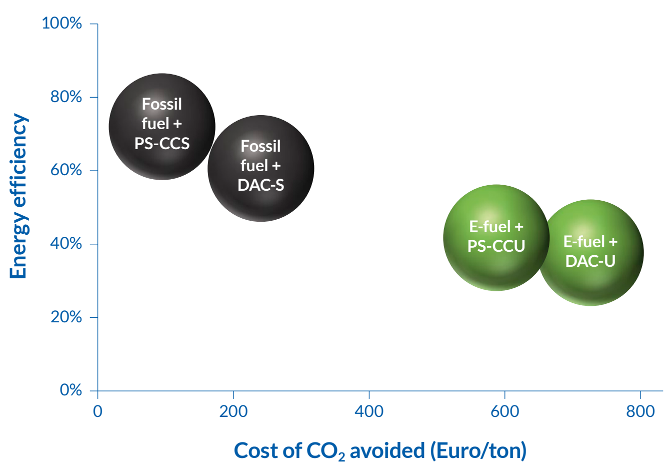


Figure 1: CO_2 abatement costs versus energy efficiency (projected costs towards 2030). PS-CCS = Point Source Carbon Capture and Storage; DAC-S = Direct Air Capture and Storage; PS-CCU = Point Source Carbon Capture and Utilization; DAC-U = Direct Air Capture and Utilization

created, resulting in net CO_2-neutrality. This can be achieved by using biogenic CO_2 available from biomass and its derivatives (which is outside the scope of this study), or by capturing CO_2 from the atmosphere through direct air capture (DAC).

In the transition phase, awaiting the development of large scale DAC, fossil CO_2 can be used, captured from point sources. This Carbon Capture and Utilization (CCU) could facilitate the ramp up of the e-fuels industry. Meanwhile, the operators of these point sources are also looking at concepts in which captured CO_2 is stored underground (Carbon Capture and Storage, CCS). They are looking for ways to reduce the amount of emission allowances required under the European Emission Trading Scheme (EU-ETS) to eventually zero in 2040. There are concrete plans for this in the Netherlands with the Porthos and Aramis CCS projects.
In situations where CO_2 storage is an available option, the question arises what the added value is of using captured CO_2 (be it from fossil point sources or from the atmosphere) to produce and use e-fuels, compared to using fossil fuels and storing the captured CO_2 underground. Net CO_2 emissions are about the same in all cases. At the same time, the production of carbon e-fuels is expensive and requires a substantial amount of renewable electricity.

To be able to evaluate these different options on the pathway to sustainable mobility, this study provides a comparative quantitative analysis based on a set of dedicated Key Performance Indicators (KPIs). These are calculated for relevant configurations combining CO_2 capture, storage, and e-fuels production in different ways.

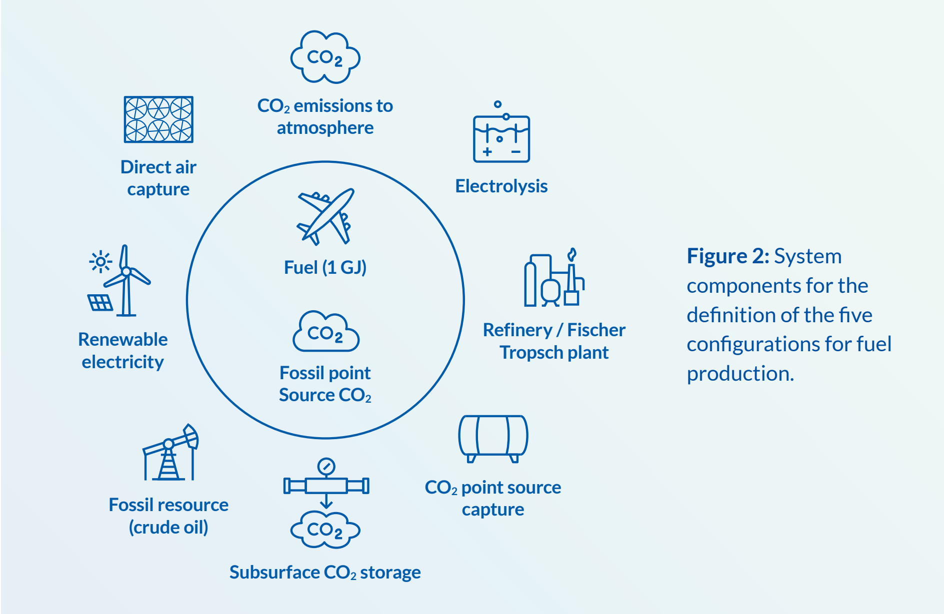


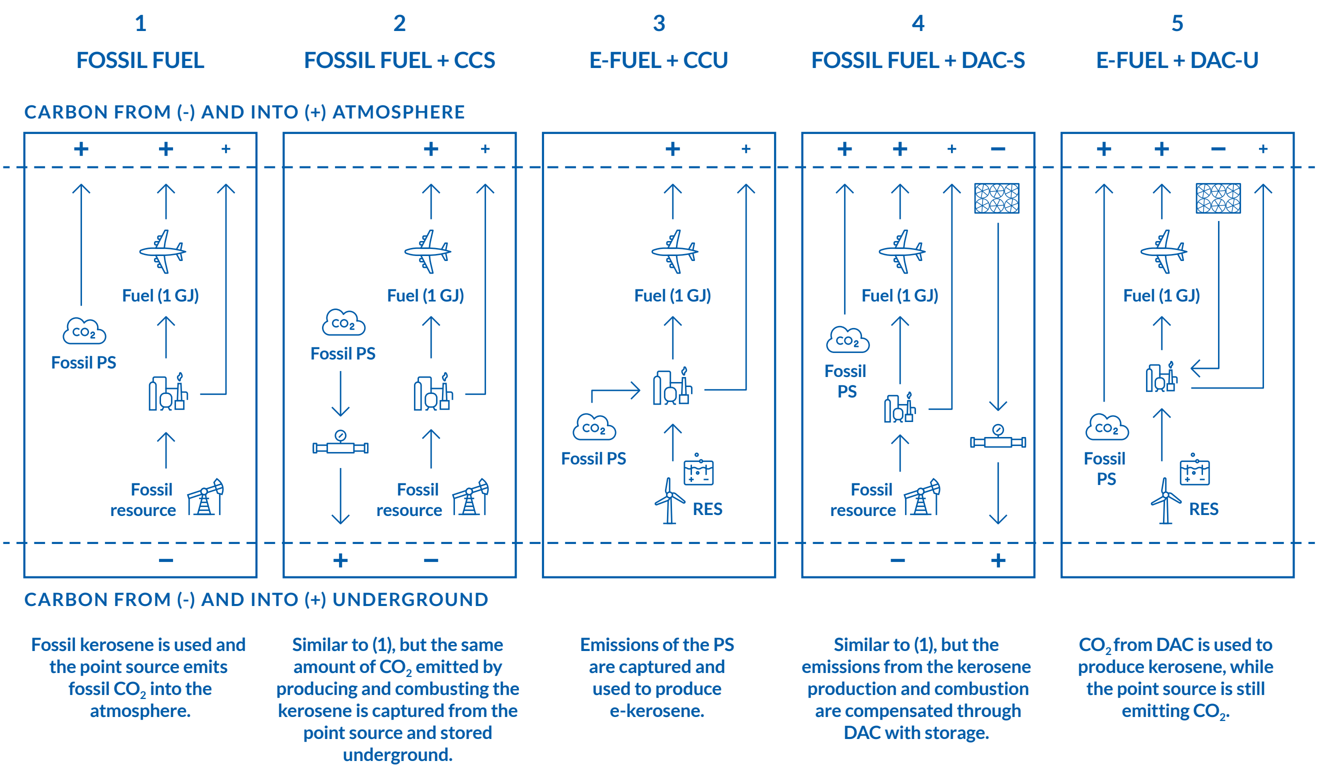
Figure 2: System components for the definition of the five configurations for fuel production.

APPROACH

The analysis focuses on the production of e-kerosene for air travel as an exemplary case study. A system is defined in which, on one hand, an airplane combusts 1 GJ of kerosene and, on the other hand, a fossil CO_2 point source emits 0.09 tCO_2. The latter value is chosen such that it equals the amount of CO_2 that is required to produce 1 GJ of e-kerosene (including process losses). For the production of the kerosene, different elements in the system can be used like fossil resources (oil/natural gas), renewable electricity, electrolysis and DAC (see Figure 2). The CO_2 of the fossil point source can be emitted, captured and stored; or it can be captured and used as a feedstock for e-kerosene production.

Based on this system, five configurations are defined for the production of the kerosene as depicted in Figure 3. The five different configurations are evaluated using four classes of KPIs (see Figure 4).

Figure 3: Five configurations for fuel production.



1 Fossil fuel

2 Fossil fuel + CCS

3 E-fuel + CCU

4 Fossil fuel + DAC-S

5 E-fuel + DAC-U

ENERGY USE

This includes the use of fossil energy, of renewable electricity (for e-fuel production, point source capture and DAC; emission factor is accounted as 0 gCO_2/kWh), and the energy efficiency. The energy use of the point source is not included and is considered the same in all configurations.

CO_2 EMISSIONS

This refers to the net CO_2 emissions of the system, and relative avoided CO_2 emissions compared to configuration 1. For configurations 4 and 5 also relative avoided CO_2 emissions are taken into account in case the fossil point source is left out of the system.

COST (CAPEX / OPEX)

CAPEX and OPEX, including CO_2 abatement costs. CAPEX for existing assets, e.g. refineries, are assumed to be sunk and thus not accounted for.

REGULATIONS

Does the configuration contribute to CO_2 emission reduction targets in EU policies? Is the fuel considered as RFNBO (Renewable Fuels of Non-Biological Origin) under the Renewable Energy Directive (RED 3)?

Figure 4: Five different configurations are evaluated on four classes of KPIs.

RESULTS

The KPI scores for the different configurations are presented in Figure 5.

A comparison of the configurations with respect to energy efficiency and emission savings (see Figure 6) reveals that the production of e-fuels (configurations 3 and 5) is less energy efficient than the fossil fuel options. This is caused by substantial energy need of renewable electricity to convert water and CO_2 into e-kerosene– in particular in the production of hydrogen from water is energy intensive. In all configurations, an equal amount of CO_2 emitted (from fuel production and combustion) is captured and stored (or used) from the point source or from the atmosphere. The reduction in CO_2 emission of the total system (including the fossil point source) remains below 50%, also for the e-fuels, because the point source in the system still emits CO_2. In case the fossil point source is removed from the system in scope, an emission reduction of 100% can be realized in the configurations with DAC (4 and 5).

The results of a global analysis of the levelized cost for the different configurations (in €/GJ of fuel, for 2030) are presented in Figure 7. It is obvious that the fossil-based configurations, even with DAC and storage, are less costly than the e-fuel routes, both in €/GJ and in € per ton of avoided CO_2. The relatively high costs for e-fuels are mainly caused by costs of electricity and electrolyser CAPEX.
It should be noted that in many projections future costs both of renewable electricity and electrolyser plants reduce substantially, which will dramatically impact the relative competitiveness of the e-fuel configurations. Also prices of fossil resources severely vary over time.
In addition, these costs do not take into account any pricing of carbon emissions. According to the assessment presented here, configuration 5 can only become competitive compared to configuration 1 if a CO_2 emission price of at least €725/ton (the CO_2 abatement costs of configuration 5) is levied.

	1: FOSSIL FUEL + PS	2: FOSSIL FUEL + PS-CCS	3: E-FUEL + PS-CCU	4: FOSSIL FUEL + DAC-S	5: E-FUEL + DAC-U
Energy use fossil (GJ)	1,14	1,14	0,00	1,14	0,00
Energy use RES (GJ)	0,00	0,24	2,40	0,58	2,66
Energy efficiency	88%	73%	42%	58%	38%
Net emissions (tCO_2)	0,17	0,09	0,09	0,09	0,09
Avoided CO_2 emissions	0%	49%	49%	49%	49%
Avoided CO_2 emissions (no PS)	0%	n.a.	n.a.	100%	100%
Costs (€/GJ)	14	22	63	34	74
CO_2 abatement cost (€/tCO_2)	n.a.	94	588	240	725
Regulations	No RFNBO	No RFNBO	RFNBO till 2040, but requires ETS allowances	No RFNBO	RFNBO

Figure 5: Quantification of KPIs for different system configurations for the production of 1 GJ of kerosene.

CONCLUSIONS

To mitigate climate change, configuration 2 (Fossil fuel + CCS) can provide a short term solution to reduce cumulative CO_2 emissions towards 2050. It is however not a long-term sustainable solution: it is not net-zero, and requires fossil energy.

In the medium term configuration 3 (E-fuels + CCU), though more costly than configuration 2 (Fossil fuel + CCS), can facilitate the ramp-up of the e-fuels industry. CO_2 from a point source is in general less costly than CO_2 from DAC, but is affected by EU-ETS allowances and is only accountable as RFNBO till 2035/2040.

Configuration 4 (Fossil fuel + DAC-S) can provide a low carbon emissions route that is significantly less costly than the e-fuels routes. These fuels are, however, highly dependent on fossil resources and not accountable as RFNBO under RED 3. Given that e-fuels are most likely necessary for the decarbonization of aviation and (maritime) shipping, the question is if this route will not frustrate the development of e-fuel production routes. Balancing between the different configurations may probably only be achieved through regulation (see EU Delegated Act C/2023/1086 final).

Configuration 5 (E-fuels + DAC-U) is the only route in this analysis that can provide a sustainable solution (no CO_2 storage and no fossil resources as primary input) for fueling aviation and shipping in the long term. To deploy sustainable e-fuel production on a large scale, development and scale-up of DAC and green hydrogen production are essential, combined with an increased deployment of renewable electricity supply. This technology deployment is also likely resulting in further cost reductions thanks to learning effects.

All in all, at this point in time it seems unlikely that e-fuel routes will soon compete in terms of costs and energy efficiency with incumbent fossil fuel routes. However, upcoming EU regulation will require the ramp-up of e-fuels production in the near future. In this context, e-fuels production combined with CCU or DAC, as well as applying CCS on fossil CO_2 point sources, will serve their purpose in the transition to a CO_2 neutral society. Both approaches will likely be necessary to keep cumulative CO_2 emissions below the level required to meet the goals of the Paris Agreement on limiting global warming by 2050.

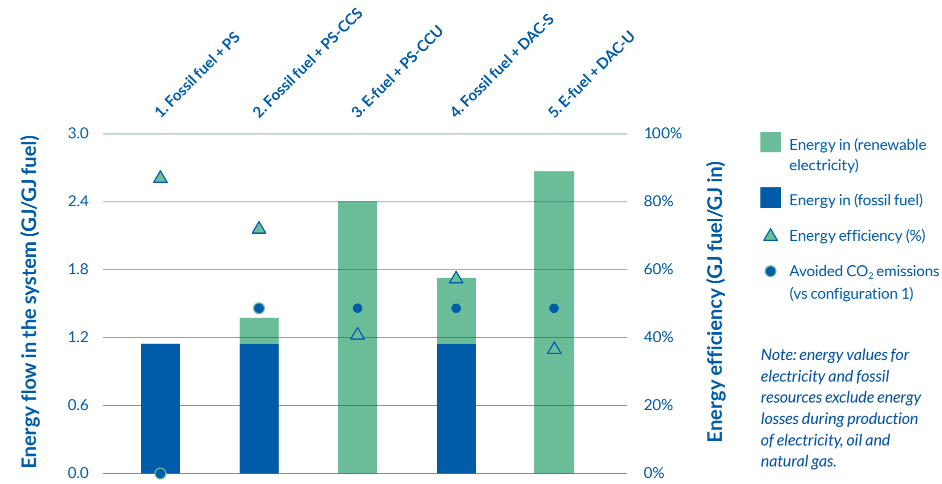
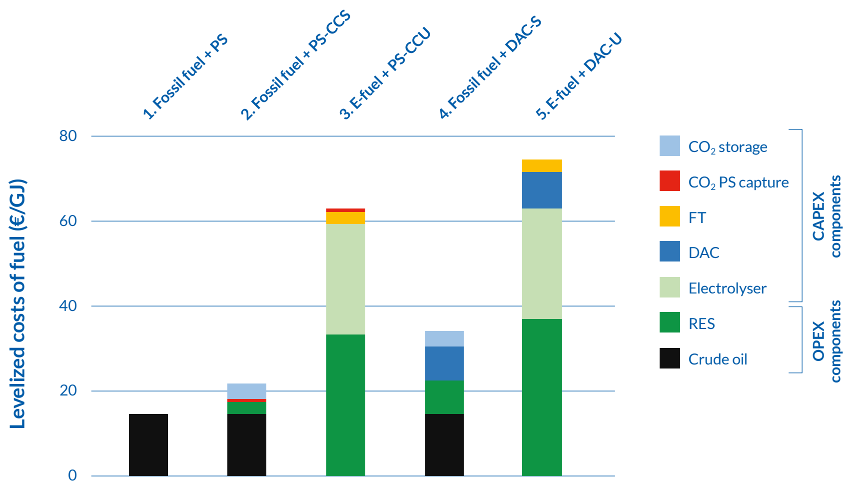


Figure 6: Energy use, energy efficiency and avoided CO_2 emissions compared to configuration 1.



- *High level cost calculation; no in depth analysis*
- *Calculations done based on levelised cost and scaled to 1 GJ configuration.*
- *Capital Recovery Factor (CRF) = 0.12*
- *Crude oil $80/boe*
- *Levelized cost of electricity of €0.05/kWh*
- *Electrolyser CAPEX €975/kW (2030)*
- *Point source capture CAPEX: €53/tCO_2 ; energy use 2.83 GJ/tCO_2*
- *Direct air capture CAPEX: 72 €/tCO_2 ; energy use 7.0 GJ/tCO_2*

Figure 7: Levelized costs in €/GJ of fuel for the five configurations.

WANT TO KNOW MORE?

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