Affordable Carbon Neutral Synthetic Kerosene Enabled by Electrochemistry

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Climate Neutral Strategies

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For the energy transition in aviation, synthetic fuels seem the only solution to deliver significant emission reduction on the medium term

Artistic impression of the transition from black airplanes on petroleum to green(er) planes on steel off gases, direct air capture units and hydrogen from off-shore windmills

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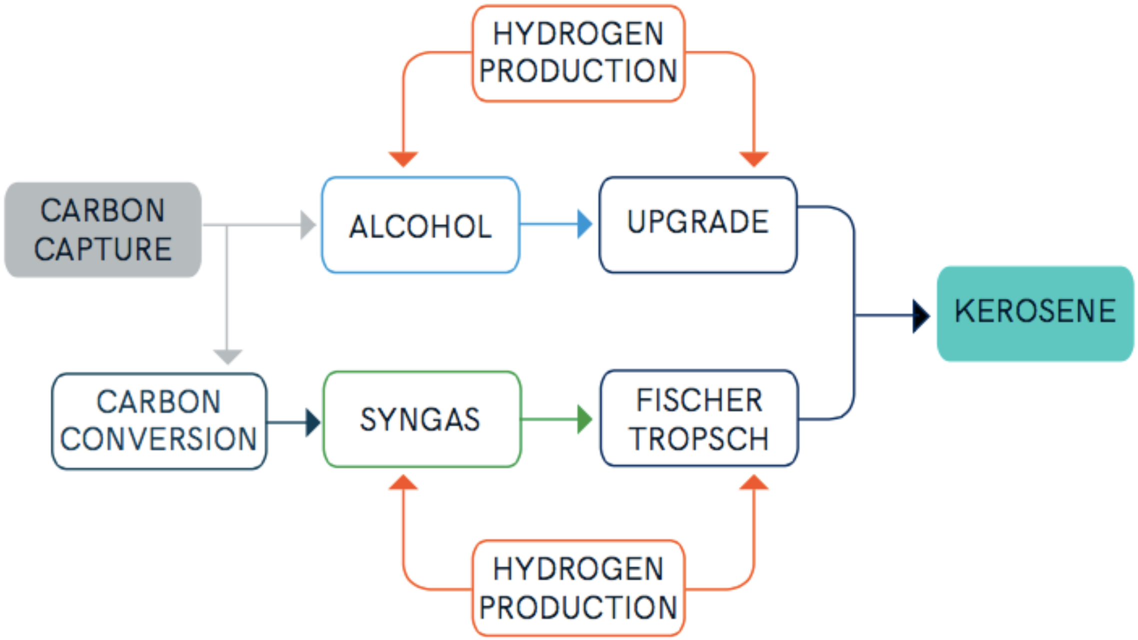
For the energy transition in aviation, synthetic fuels seem the only solution to deliver significant emission reduction on the medium term

- Aviation has grown historically with 4-5% a year, and this growth is expected to continue
- Currently planes use fossil kerosene as a fuel and they emit CO_2 (2-3% of worldwide anthropogenic CO_2 emissions)
- If nothing changes, the CO_2 emissions of aviation will strongly increase
- In the transition to a climate neutral society aviation deserves our attention, and should be looked in low carbon or zero carbon options
- Electric planes are expected to enter the market after 2030, with limited capacities (50-100 people) and range (1,000 km)
- Although kerosene from biomass is available, it is not CO_2 neutral and often difficult to scale up or competing with other land use
- Alternatively one can make synthetic kerosene from upcycled or re-cycled CO_2 and renewable H_2, to enable a medium term CO_2 reduction
- We looked into this last route in detail with Tata Steel, Shell, KLM, Port of Amsterdam, TenneT, Koole Terminals, Oiltanking, TKI E&I and Sanegeest

By capturing CO_2 from a carbon source, converting it to CO and adding renewable H_2, one obtains kerosene after synthesis & upgrading



- The syngas pathway has been demonstrated, the alcohol pathway only for gasoline
- The carbon source can be an industrial point source onto which carbon capture is applied, or the air via Direct Air Capture (DAC)
- With carbon capture from a point source CO_2 chain emissions are reduced by 55%, while DAC results in 100% CO_2 reduction

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We use a custom-built techno-economic model, validated by experts, to determine the most promising production pathways and costs

- We built a techno-economic model which evaluates the synthetic kerosene production costs for various production pathways in 2030
- The model includes the Reverse Water Gas Shift and CO_2 electrolysis as carbon conversion options in the syngas pathway
- For the alcohol pathway it considers methanol (ethanol is discussed in the report)
- For DAC both amine and hydroxide solution systems are considered
- Data have been obtained from academic papers, technology developers and industry
- The model and its data have been validated by various parties, including the Shell New Energies research team in Amsterdam

The most promising production pathway includes water and CO2 electrolysis and FT synthesis and upgrading and offers flexibility features

- Using the model to explore the sensitivities of the various pathways, we found the following to be the most promising
  - CO_2 and CO are captured from Tata Steel's Blast Furnace or Basic Oxygen Furnace and/or CO_2 is captured from the air
  - CO_2 is electrochemically reduced to CO by a PEM electrolyser with proprietary catalyst (developed by Opus 12 and Haldor Topsoe)
  - Renewable H_2 is produced through water electrolysis (PEM system) with renewable electricity
  - Resulting syngas is fed into FT reactor and upgraded to kerosene
- It is operated as follows:
  - CO_2 capture and FT synthesis & upgrading are operated continuously
  - Electrolysis is operated flexibly; to match its volatile output with the continuous input for FT, H_2 is stored in a salt cavern
- This pathway offers electricity balance features and can work with both electricity shortage and excess!

Synthetic kerosene from off gases is more expensive than fossil kerosene in a 2030 reference scenario, but could reach price parity

- In a reference scenario synthetic kerosene (from Tata Steel's waste gases) costs are higher than fossil kerosene costs, with parameters
  - An average electricity price of €0.04/kWh
  - An average oil price of $80/bbl
  - A CO_2 ETS price of €0/t CO_2
- With this kerosene costs flight ticket prices would increase by 25-50% and CO_2 abatement costs would amount to €110/t CO_2
- The synthetic kerosene cost is mainly dependent on the electricity price, and the fossil kerosene cost on the crude oil price
- With relatively minor (<25%) changes price parity between these options can be reached, which happens at (for instance)
  - An average electricity price of €0.03/kWh instead of €0.04/kWh
  - An average oil price of $100/bbl instead of $80/bbl
  - A CO_2 ETS price of €20/t CO_2
- Then tickets cost the same and CO_2 abatement costs are €0/t CO_2
- In a reference scenario but with an electricity price of €0.015/kWh (lowest tender in ME), synthetic kerosene would be cheaper

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In North-Holland virtually everything is present for kerosene production: CO_2, water, electricity landing, transport infrastructure and demand

- With Tata Steel there is a large carbon source in North Holland: 9.1 Mton CO_2-eq
  - With this quantity of CO_2, 50% of planes which fueled at Schiphol in 2016 could be supplied with synthetic kerosene
  - With 5,000 FLH for electrolysers and 20% overcapacity for wind peaks, this would call for 10 GW of electrolysers for H_2 production and 2 GW for CO_2 conversion
- With ’t IJ and the North Sea there is plenty of water for electrolysis
- Electricity produced at ’new’ offshore wind farms near the North Holland coast lands in North Holland
- In the Port of Amsterdam the infrastructure and facilities for kerosene storage and transport are already in transport
- With a direct pipeline Schiphol Airport (consuming some 160 PJ or 3.5 Mton of kerosene) is supplied with kerosene
- In short, North Holland seems an excellent location for synthetic kerosene production if this is deemed economically viable

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Synthetic kerosene offers significant emission reduction and flex-ibility at reasonable to competitive cost; next steps are being taken

- Synthetic kerosene is a (possibly final) solution to significantly reduce aviation's CO_2 emissions that has already been demonstrated
- Its production process is part flexible, allowing electricity balancing
- Its cost depend mainly on the electricity price, and in a 2030 reference scenario it is more expensive than fossil kerosene, but not very much
- With renewables costs coming down worldwide (SA & MX bids of < $0.02/kWh), so would synthetic kerosene costs

- A follow-up project is being started up to look in more detail at the synthetic kerosene market, technologies and plant requirements
- This solution is included in the draft proposal for the NZKG table in the Dutch Climate Agreement

The model and report are available on kalavasta.com/pages/projects/aviation.html

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