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KEROGREEN

"Production of Sustainable aircraft grade Kerosene from water and air powered by Renewable Electricity, through the splitting of CO_2, syngas formation and Fischer-Tropsch synthesis"

Project No: 763909

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Report for publication on the most feasible business concepts

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1 Introduction

The EU-funded project KEROGREEN aims at developing a new process to produce Sustainable Aviation Fuel (SAF) from water and air powered by renewable electricity, through the splitting of CO_2, syngas formation and Fischer-Tropsch synthesis. KEROGREEN's innovative approach focuses on reducing overall CO_2 emission by creating a closed carbon fuel cycle and at the same time creates long-term large-scale energy storage capacity which will strengthen the EU energy security and allow creation of a sustainable transportation sector.

The concept has been developed over the last years and shows interesting benefits for the aviation industry. The present report describes possible business models that arise from the technological concept of the project and suggests feasible value chains towards a successful commercialisation of the CO_2 neutral kerosene.

2 Technological background

KEROGREEN offers an innovative conversion route to sustainable aviation fuel synthesized from water and air powered by renewable electricity. The conversion is based on plasma driven dissociation of air captured CO_2, solid oxide membrane separation of oxygen and Fischer Tropsch (FT) synthesis of kerosene. Synergy between plasma activated species and novel perovskite electrodes of the oxygen separator raise CO productivity and energy efficiency.

Innovation also comes in with the experimental validation of the process chain and in coping with challenges in system integration of dissimilar technologies into one compact assembly by a multi-disciplinary team. Innovative heat integration raises overall energy efficiency. System integration into a container sized plant is set to produce 0.1 kg/hr kerosene. The technology is modular, scalable and relies on inexpensive existing infrastructure for storage, transport, and distribution. Innovative size reduction of KEROGREEN equipment yields a compact container-sized kerosene production plant. Close-coupled to an offshore wind turbine or a remote solar power array, this offers the prospect for decentralised, onsite production of high energy density Carbon Neutral Liquid Fuel, with no need for an expensive upgrade of the electricity grid.

By dynamically converting surplus renewable electricity in Carbon Neutral Liquid Fuel, vast energy storage capacity opens up for the electricity system, providing flexibility and allowing increased penetration of renewable electricity in sectors of the economy hitherto impervious to electrification. This Power-to-Fuel (P2F) technology is generic as it couples the electricity system to the existing oil, gas, and chemical infrastructure with the powerful potential to reduce overall CO_2 emission, strengthen EU energy security and create a sustainable transportation Sector.

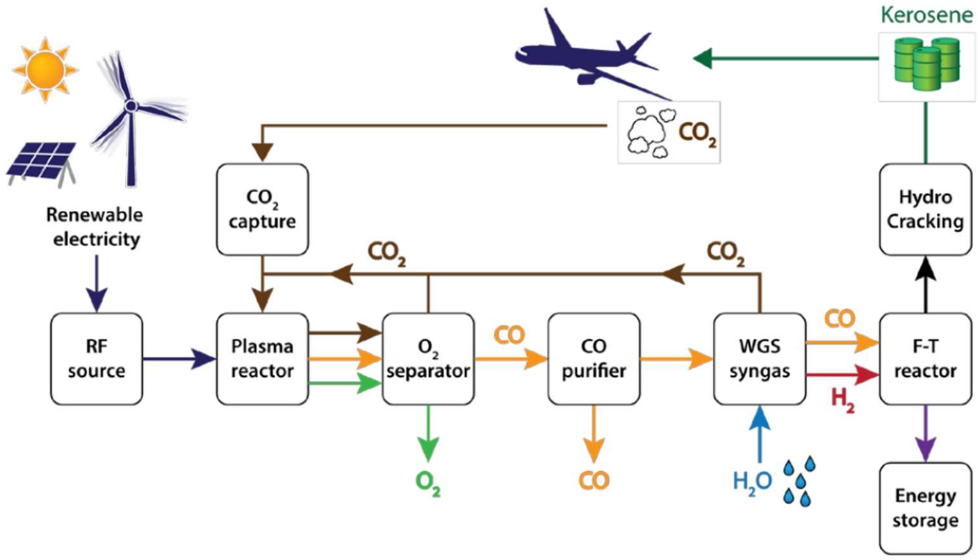

Figure 1 Industrial application concept of the KEROGREEN process

3 Feasible business concepts

Relying on a **Build-Own-Operate (BOO) model** by which a public entity allows a private company to finance, build, and operate infrastructure over a specified period, and the private company retains ownership of the infrastructure in perpetuity. The BOO model is well-suited for high-dollar projects with operations that require specialized expertise. It is currently popular in the power and transport sectors. The public partner grants the public company to design, construct, and finance the project.

- **BUILD:** Thus, the private company undertakes responsibility for constructing the asset and is expected to build the project on time, within budget and according to a clear specification and to warrant that the asset will perform its design function.
- **OWN:** The concession from the public entity allows the private company to own, or at least possess, the assets that are to be built and to operate them for the period of the concession. The concession agreement between the public entity and the private company will define the extent to which ownership, and its associated attributes of possession and control, of the assets lies with the private company.
- **OPERATE**: The private company assumes the responsibility for maintaining the facility's assets and operating them on the basis that maximizes the profit or minimizes the cost on behalf of the public entity.

For the KEROGREEN concept of e-kerosene production two main commercial concepts have been developed. Those concepts differ mainly in the responsibilities of individual partners and the resulting ways of benefit for those. The central building blocks for the expected value chain contain:

- The provision and supply of feedstock
- The conversion into FT-crude – the synthesis of the feedstock into FT-hydrocarbons
- The upgrading of the FT-crude & FT-Wax
- The trading of the final products to end-customers.

In case of KEROGREEN, the feedstock supply contains the CO_2 separation and the generation of syngas, and a subsequent Fischer-Tropsch-synthesis with an internal included upgrading. Due to the current regulatory background of alternative kerosene production, further upgrading of the fuels in a refinery is necessary so this step needs to follow the production within the KEROGREEN process. The final chain link is then the trading of the various products to the individual end customers.

A **trading model** and a **handling model** are both conceivable. These models differ from one another in who is operating the individual building blocks of the value chain and accordingly carries the economic risks and opportunities. However, in both models, the partner in charge of the synthesis steps of turning the gaseous inputs into synthetic hydrocarbons (FT-Crude & FT-Wax) will be investing in the synthesis unit in alignment with the BOO model. The two models will be explained in detail in the following.

3.1 Trading model

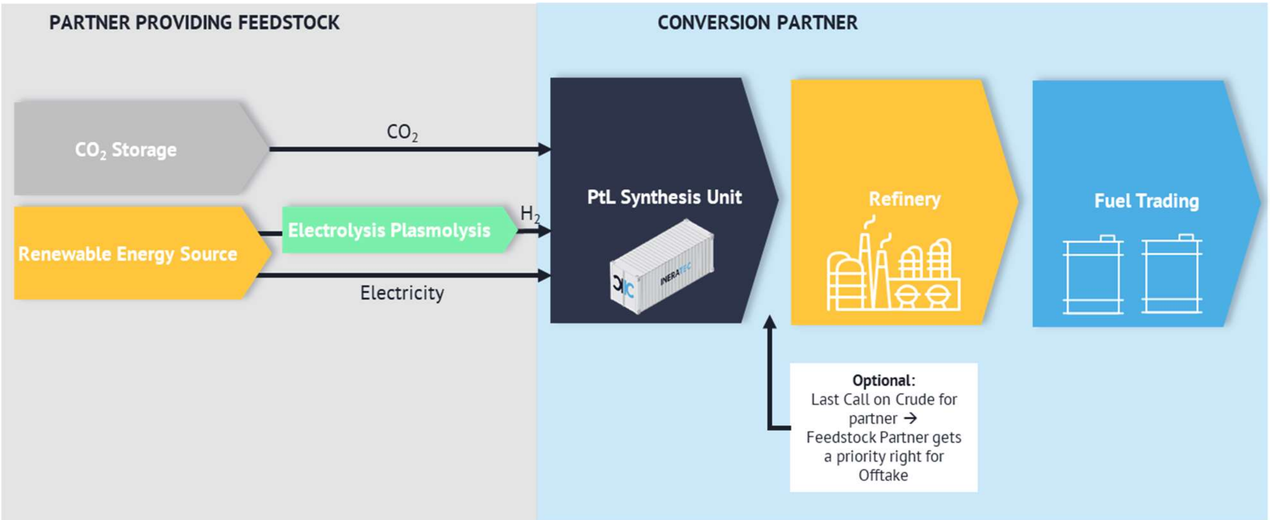

Figure 2 Trading model overview for the KEROGREEN concept

The **trading model** assumes that the partner operating the fuel production also takes responsibility of the subsequent steps downstream in the value chain. Consequently, the partner providing the feedstock is getting paid for his supply and steps out of the later commercialization of the synthetic kerosene. The price they receive for their products already contains their margin. The converting partner then turns the gaseous feedstock into liquid fuels, collaborates with a refinery to generate norm-conform fuels and brings those into market at his own prices, which generates the value and margin for the producing partner. To reduce the significant risk that goes along with the trading model for the converting and trading partner, long term contracts with customers will be preferred. Those offer the opportunity to adequate pre-planning of the production and sales.

Optionally the feedstock supplying partner can be offered a **last call**, meaning that they get a priority on the offtake of the crude product before final upgrading. The price would presumably be derived from prevailing market prices with the priority advantage for the buying partner.

Last Call:

Agreement between collaborating partners, to offer one partner, who is not originally involved in steps downstream in the value chain to buy product with a priority. The price for the product might originally not be fixed.

3.2 Handling Model

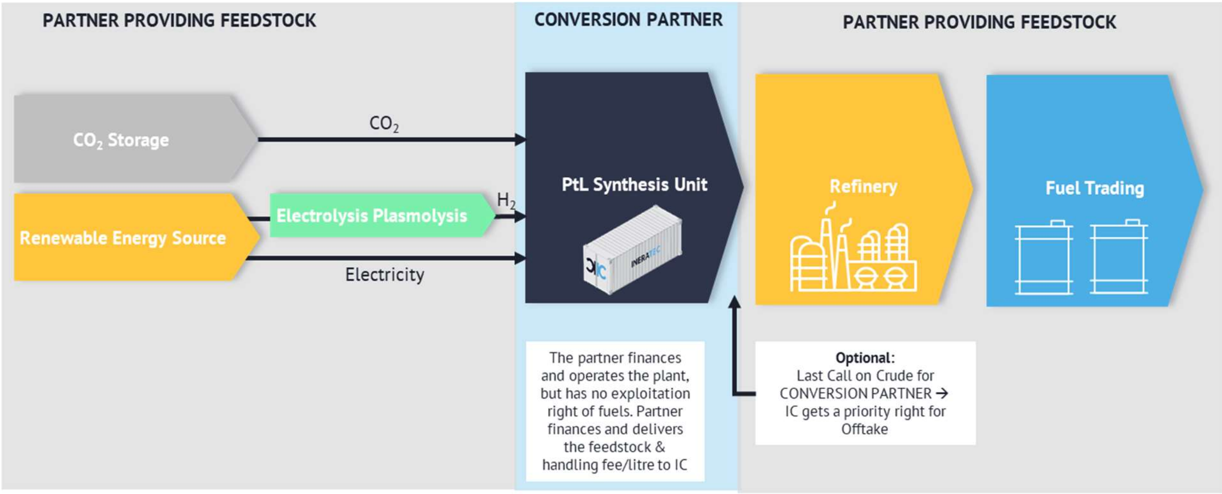

Figure 3 Handling model overview for the KEROGREEN concept

Contrary to the trading model described above, in the **handling model**, the feedstock supplying partner remains part of the exploitation of the produced e-fuel. The supplying partner provides the feedstock to the converting partner, who operates the Power-to-Liquid (PtL) synthesis unit. The produced FT- Crude is subsequently re-transferred to the feedstock providing partner who organises and handles the further upgrading and trade of the final products (e.g., e-kerosene). The plants are owned by the individual partners, hence the feedstock supplying partners own the CO_2 and the H_2 generating units and the converting partner owns the PtL synthesis unit. In this model, the partner producing the FT-Crude receives a handling fee from the other partner, which contains his margin and generates the profit. Simultaneously, the feedstock supplying partners generates its profit from the sales of the refined e-fuel.

This model also might contain a **last call option**, just like the trading model. In this case the partner operating the PtL-plant obtains the opportunity to buy the FT-crude at market prices and subsequently refine and trade this product.

The main risks for this model again lay with those partners refining and trading partners. The partner operating the PtL-module is working at lower risk as the margin is generated already within its own building block of the value chain.

3.3 Other possible models

As with every business opportunity, various nuances of the two models described above might be possible. One exemplary other model, which might also be possible for those partners providing technology would be the **pure plant sales or leasing model**, in which a third party would become owner/operator of the respective plant taking the risks of investment but also owing the possible profits.

Pure plant sales:

- The conversion partner in charge of the synthesis unit sells plants to owners / refineries who will then own and operate the devices like any other equipment
- The owners / refineries will be fully responsible for the procurement of certified green feedstock and product sales

- The conversion partner is awarded long-term maintenance and service contracts
- The conversion partner earns an ongoing license fee, potentially tied to production volumes.

Leasing model:

- The conversion partner leases plants to owners / refineries who will concentrate on operating the devices like other equipment
- The owners / refineries will be fully responsible for the procurement of certified green feedstock and product sales
- The conversion partner will guarantee for the capacity and availability, but also remains responsible for maintenance and service

3.4 Pricing factors

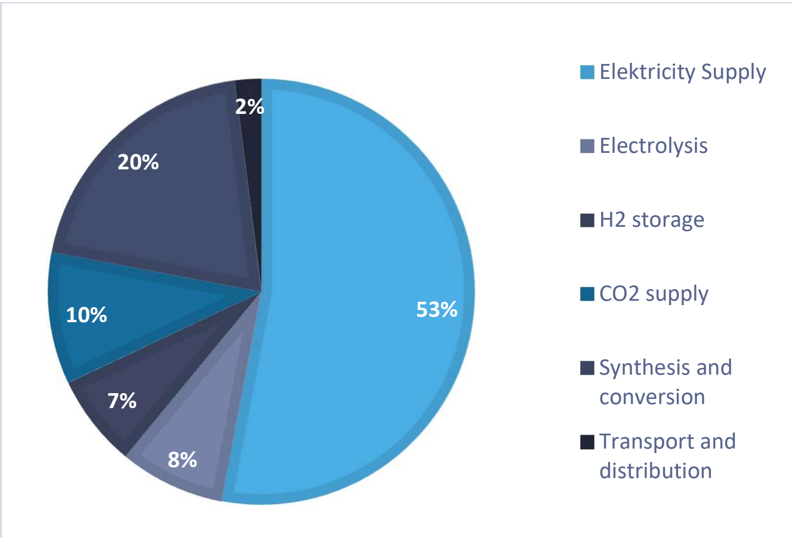

Figure 4 Price fractions for PtL SAF

As shown by the German Environmental Agency[1], the main cost driver for PtL products in general and SAF in particular, is the price for the electricity employed – accounting for 53% of the price (Fig. 4). Together with electrolysis (8%) and storage of H_2 (7%) this adds up to 68% of the overall costs for the supply of H_2 of sustainable fuels. The supply for the required CO_2 is only 10% and might even decrease with rising costs for the exhaustion of fossil CO_2 into the atmosphere through increasingly costly certificates. Though these numbers were derived for classic electrolysis technology pathways, the overall conclusions – especially regarding the cost share of the employed electricity – can be assumed to be valid also for alternative concepts like KEROGREEN[2]. In particular, because the KEROGREEN process also employs electricity as energy source for the reduction during the syngas generation from CO_2 and H_2O. The conversion technologies themselves account for about 20% of the product price, which is still an important factor, but due to the modular approach of the

[1] *Power-to-Liquids - A scalable and sustainable fuel supply perspective for aviation, Umweltbundesamt, 2022*
[2] *CO_2 Neutral Aviation by Adelbert Goede, KEROGREEN Workshop 15 Nov 2019*

KEROGREEN concept these plants could be realised in various locations and therefore other pricing factors can presumably be more in focus for price reduction. This highlights the importance of well-equipped locations with affordable renewable power available, whereas it shall not undermine the importance of CO_2 as mandatory source for the PtX-technology. At locations without CO_2 available the KEROGREEN process or similar concepts are less attractive.

Furthermore, this underlines the importance of qualifying strategic locations where specific requirements are met like the availability of renewable power at affordable price to guaranty a low price for green hydrogen (ideally less than 5€/kg), the near proximity to a CO_2 source (e.g., biogenic from a biogas plant, and Direct Air Capture plant) and a low CO_2 price (ideally less than 100 $/t), the proximity of offtakers (e.g. airports, aviation companies, etc.) to avoid long-distance transports. Considering such economic criteria and the current geopolitical situation in Europe (War in Ukraine), only few locations in Europe are being considered, because of the low availability and high price of green power from renewables. Although some regions in Scandinavia and others in Spain and Portugal as well as offshore locations in the North Sea could be considered as sweets spots, there is a considerable interest in sites outside Europa like Chile, Australia, MENA countries, USA, etc. where the green power price is kept low.

4 Conclusion

The KEROGREEN process provides a novel approach towards the production of SAF and similar sustainable fuels. Direct sales of the products, as they are produced in the KEROGREEN process, seem not relevant as it is currently required to include refining processes to get final drop-in products. Consequently, an upgrading step at such a site appears mandatory before fuel trade can be conducted.

Like other PtL processes, the economic validity of the concept is highly dependent on the energy supply and the attributed costs. Possible partners along the value chain have different possibilities to generate profit with the hydrocarbons. Two highly probable business concepts have been identified and described. The models distinguish mostly in the assignment of the risks and the resulting profit possibilities along the value chain.

The trading model transfers most risks to the FT-Crude producing partner while the feedstock supplying partners are not involved in later steps. In the handling model this risk is shifted to the feedstock supplying partners while the converting partner merely receives a handling fee. Taking these risks might be of interest for the individual partners as the trading of the fuels to end-customers offers the highest margins – especially in a market with increasing needs for sustainable aviation fuels.