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Integration of direct air capture and biological processes for sustainable production of Methane

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Motivation

Carbon capture and utilization (CCU) is one of the strategies proposed for mitigating dependency on fossil resources. Direct air capture (DAC) technologies are able to capture CO_2 directly from ambient air [1]. The captured CO_2 can be used as commodity for multiple purposes or as a carbon feedstock for chemical production. A particularly interesting product is methane. With CO2 and H2 as feedstock, biomethanation reactors are able to produce grid-quality (>95%) methane [2].

Biological CO_2 methanation take place in anaerobic, mild conditions [3], with pH range between 6.2-8.5 and temperature between 35-40°C (mesophilic) or 55-65°C (thermophilic), according to the following reaction,

$$4H_2 + CO_2 \rightarrow CH_4 + H_2O$$
$$\Delta G^0 = -165 \text{ KJ/mol}$$

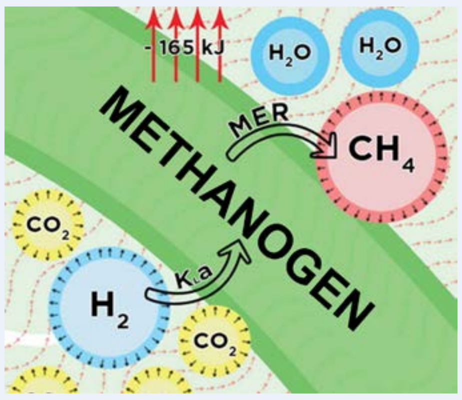

Fig.1 Biological CO_2 methanation [2]

This research seeks to develop an energy-efficient process to produce renewable and biomass-independent methane with CO_2 from atmosphere, by integrating an previously described electrochemically-assisted DAC (Fig. 2) [4] and biological CO_2 methanation step (Fig. 3).

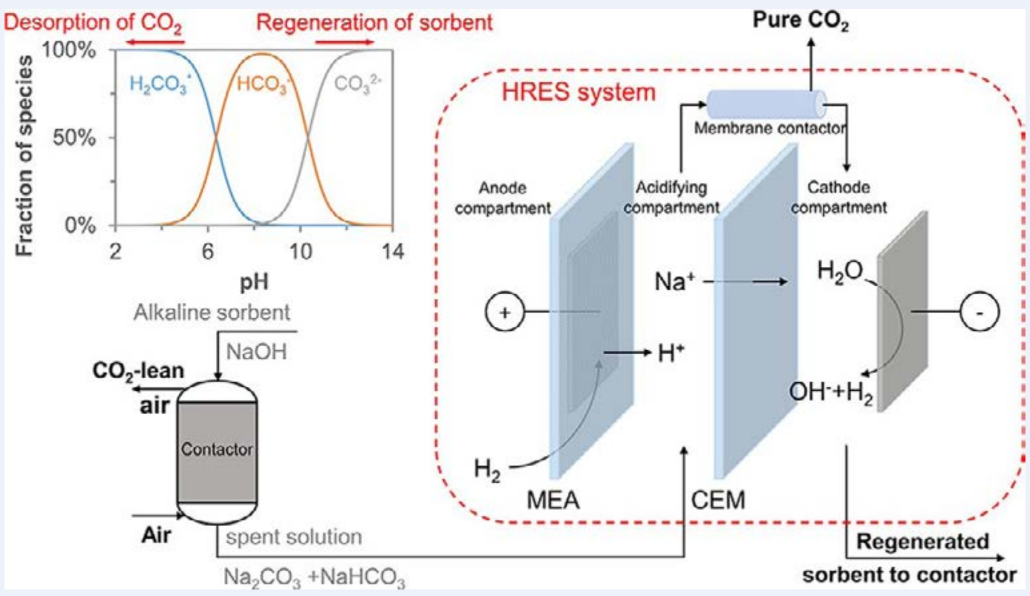

Fig.2 Principle of DAC process using a Hydrogen recycling electrochemical system (HRES) for CO_2 desorption.[3]

Technological challenge

Typically the electrochemical system can be characterized as fast-responding with extreme conditions, whereas the bioreactor operates best at mild and stable conditions. To integrate the electrochemical unit with the bioreactor unit, the balance betweenthese two systems is crucial.

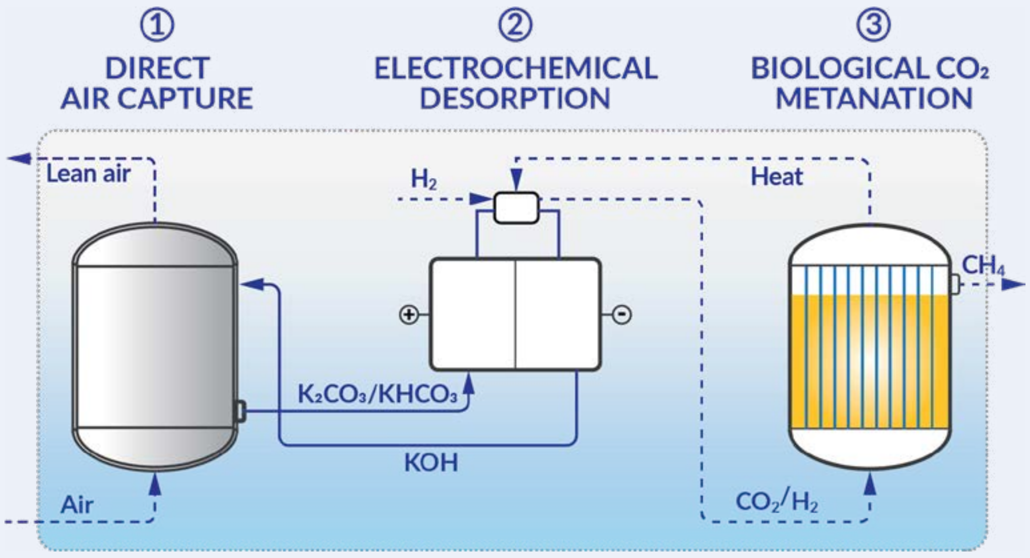

Fig.3 Scematic drawing of the integrated DAC-Biomethanation system.

Mass flows need be explicitly tuned to sustain a stable substrate/product balance for biomethanation. Heat and pH need to be managed to keep methanogens at optimal metabolic activity. Finally, in order to reach an efficient methane production, individual mass and energy flow need to be optimised in terms of energy requirements (kJ/mol CO_2), and product yield (mol CH_4/m^3 air).

Research goals

The research will be organized into three main objectives:

- Reach stable and tunable performance for integrated DAC with electrochemical desorption
- Optimize operating conditions and gas feeding strategy for biological CO_2 methanation
- System integration and overall process optimization. Concerning CO_2 and H_2 conversion efficiency, heat integration, electrical energy input, water production and losses in the system.

[1] Sanz-Pérez, E.S., et al., *Direct Capture of CO_2 from Ambient Air.* Chemical Reviews, 2016. **116**(19): p. 11840-11876.
[2] Rusmanis, D., et al., *Biological hydrogen methanation systems – an overview of design and efficiency.* Bioengineered, 2019. **10**(1): p. 604-634.
[3] Lecker, B., et al., *Biological hydrogen methanation – A review.* Bioresource Technology, 2017. **245**: p. 1220-1228.
[4] Shu, Q., et al., *Electrochemical Regeneration of Spent Alkaline Absorbent from Direct Air Capture.* Environmental Science & Technology, 2020. **54**(14): p. 8990-8998.

NWO

This research received funding from Dutch Research Council (NWO) in the framework of NWO Wetsus Partnership Programme on Sustainable Water Technology, under project number ENWWS.2020.004.

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