LABORATORY FOR CHEMICAL TECHNOLOGY
Technologiepark 125, 9052 Gent, Belgium

Coach	**Supervisor(s)**	**Funding**
Lukas Hiel Dr. Parviz Yazdani	Prof. Mark Saeys	CATCO$_2$RE

Development of novel CO_2 Sorbents for Integrated Capture and Methanation

Aim

- Investigate important material properties of sorbents for CO_2 capture and low-temperature regeneration.
- Synthesize, characterize and screen the performance of novel Mg- and LDH-based CO_2 sorbents for an integrated capture and methanation (CCU) process.

Justification

The European Green Deal outlines steps to reach climate neutrality in the EU by 2050, and the number of net zero-pledges increases persistently. In the wake of this climate crisis, Belgium faces a challenging transition to a sustainable, affordable and secure energy system. The large injection of intermittent renewable energy sources (RES) raises concerns about the security of energy supply and grid stability. In the future energy system, energy molecules take on an important role to eliminate these concerns. Energy molecules such as green hydrogen can be derived from power-to-X (P2X) technologies. This green hydrogen can be utilized as is, or can be converted into synthetic methane (syn-methane) via the Sabatier reaction (methanation). In Belgium, syn-methane can become a crucial strategic reserve to alleviate their dependency on natural gas geopolitics. While carbon capture technologies are becoming increasingly important, its implementation is hampered by the high energy costs to capture and separate CO_2 from dilute point sources (<2 mol% CO_2). The energy requirement for CO_2 capture is typically 100-200 kJ/mol [1, 2]. Interestingly, methanation of captured CO_2 releases a similar amount of energy (~165 kJ/mol) [3], suggesting potential process integration to compensate the energy costs (see Figure 1).

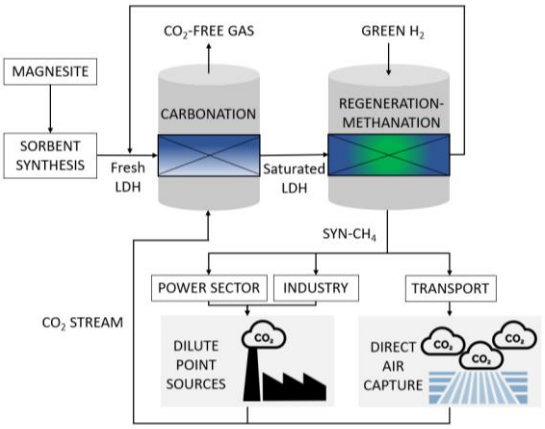

Figure 1: Potential system implementation of sorbent regeneration coupled to methanation.

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O \quad \Delta H = -165 \text{ kJ/mol}$$

By coupling the endothermic regeneration of the CO_2 sorbent to an exothermic reaction which consumes CO_2, both the **reaction energy** and the **thermodynamic driving force** to regenerate the sorbent are provided. Thereby, it is possible to catch two birds with one stone: the carbon footprint of the energy mix decreases by producing climate-neutral syn-methane, and the costs associated with capture, storage and transport of CO_2 are reduced. While a qualitative proof of concept for coupled CO_2 sorbent regeneration-methanation exists [4], the process performance is weak and the **materials** (i.e. CO_2 sorbents) need to be improved to allow coupling to a suitable methanation catalyst.

Mg-based (solid oxide) adsorbents emerge as a promising candidate for integrated capture and methanation, due to their low heat of decarbonation (~100 kJ/mol CO_2) and thermal heat capacity. Mg-based sorbents will slowly decompose at 300°C. At this temperature, novel Ni-based methanation catalysts display an excellent activity, selectivity and stability. Unfortunately, Mg-based sorbents suffer from poor (de)sorption kinetics. Hydrotalcites, known as naturally occurring Layered Double Hydroxides (LDHs), are a potential alternative to Mg-based sorbents due to their high sorption capacity and regenerability at 250-450°C. By upgrading the structural and textural properties of Mg- and LDH-based sorbents [5, 6], we will improve the sorption kinetics and low-temperature regenerability. The design parameters for these LDHs are more versatile that Mg-based sorbents and can be tailored to create the optimal material properties for integrated capture and methanation.

Program

1. Literature review: Sorption and decomposition of Mg- and LDH-based CO_2 sorbents.
2. Sorption: (a) Synthesis and characterization of commercial/new Mg- and LDH-based sorbents (b) Screening Mg- and LDH-based sorbents for sorption and decomposition.
3. Parameter estimation: Construct thermodynamic and kinetic model for selected Mg- and/or LDH-based sorbents, to be used for process simulations.

References

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