DESIGN AND EVALUATION OF A HIGH-DENSITY ENERGY STORAGE ROUTE WITH CO_2 RE-USE, WATER ELECTROLYSIS AND METHANOL SYNTHESIS

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Abstract

In the context of the Energy Transition, **electricity storage** ranging from seconds to seasons is needed to increase the integration of variable renewables sources. The **power-to-fuel** process uses a liquid energy vector with high energy density for long-term energy storage. In the present work, we simulate the power-to-methanol process in Aspen Plus. Then, we use heat integration to increase the conversion efficiency from 40.1 to 53.0 %, evidencing large improvement potential thanks to **process integration**. Further work includes experimental design and development of control strategies.

Context

The power-to-fuel technology re-uses CO_2 and converts it into a sustainable energy carrier with the help of renewable electricity. Figure 1 evidences its three main steps: (1) CO_2 capture, (2) Water/CO_2 dissociation and (3) fuel synthesis.

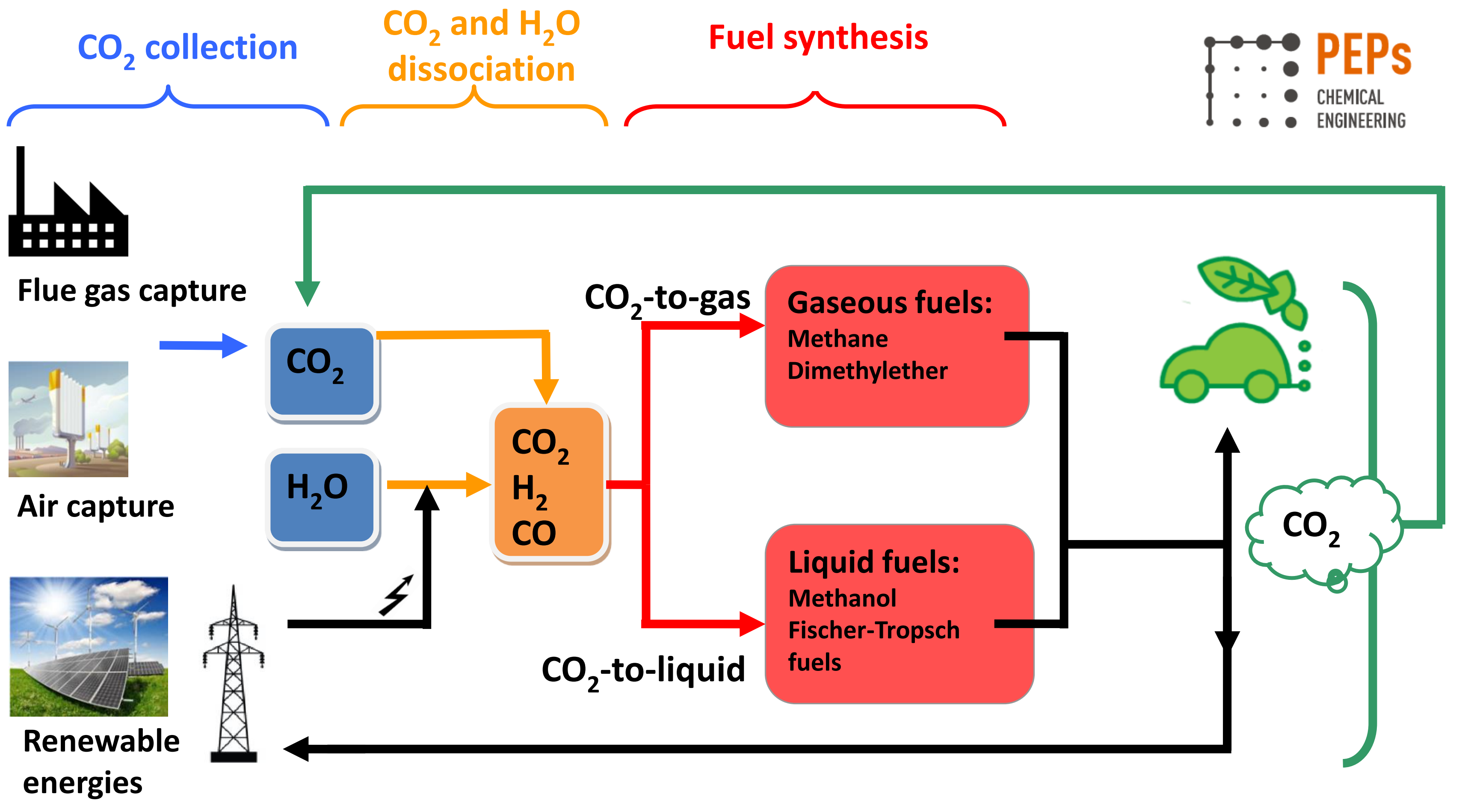

Figure 1: the power-to-methanol processes and the carbon loop

Methanol is selected as an energy carrier for its advantages:

- High energy density:
    - 22.4 vs. <1 MJ/kg for batteries or pumped hydro storage
    - 17.8 vs. 6-9 MJ/L for H_2-CH_4 at 250 and 700 bar resp.
- Straightforward synthesis and stability at ambiance.
- Interesting properties as transportation fuel: high octane rate, safe and clean combustion (no particulate matter).
- When produced with renewable energy and captured CO_2, methanol is a CO_2-neutral energy vector.

First power-to-fuel units have started operation in Iceland and Germany, and a conversion efficiency of 70% has been reported[1]. In the present work, we model the power-to-fuel process and perform a heat integration to improve its efficiency.

Model description

The water/CO_2 electrolysis and the fuel synthesis are modelled in Aspen Plus using Redlich-Kwong-Aspen EOS and NRTL methods. The model simulates the production of 1.12 t/day of methanol, corresponding to a mid-size unit.

References

[1] Sunfire, 2016. DOI:10.1016/S1464-2859(16)30063-3
[2] Sun X. et al.,, 2012. DOI:10.1016/j.ijhydene.2012.08.125
[3] Bos M. & Brilman W., 2015. DOI:10.1016/j.cej.2014.10.059

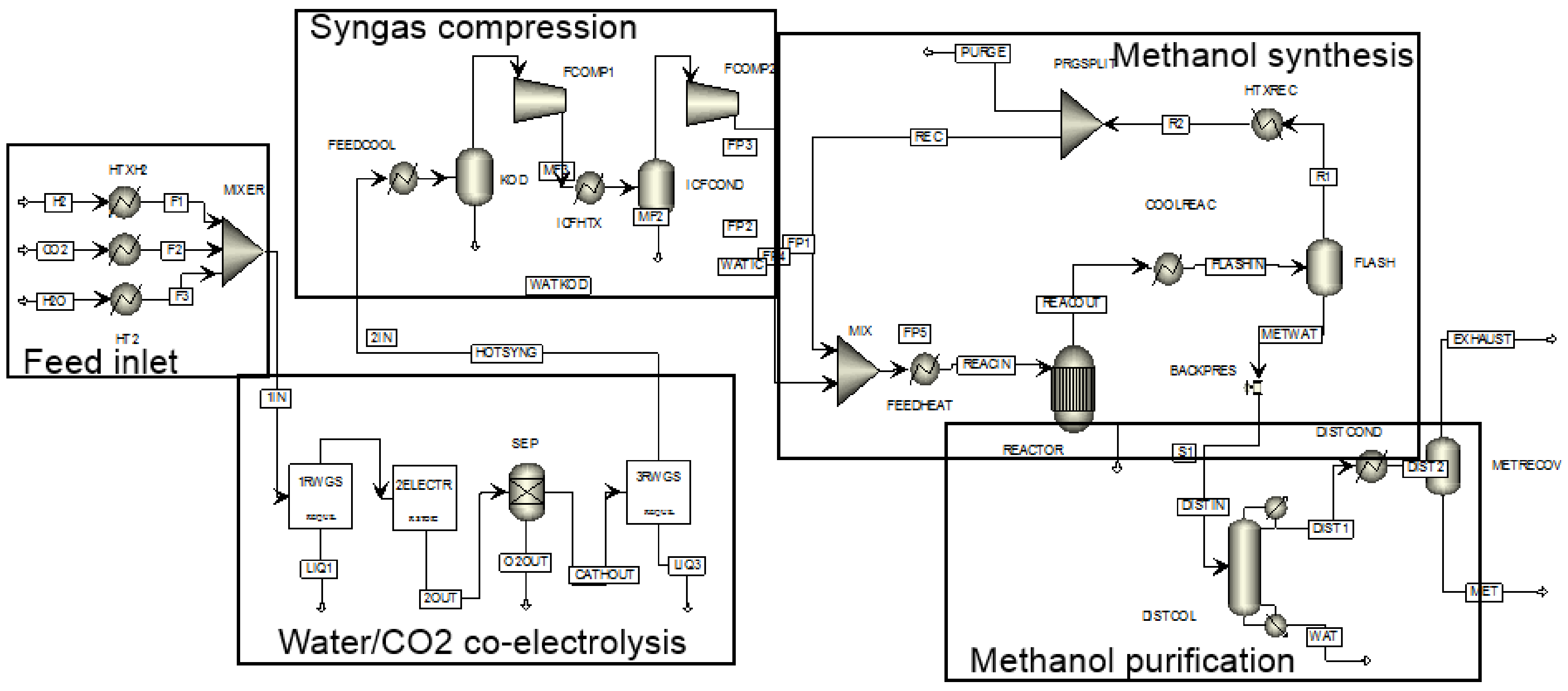

Figure 2: flowsheet of the power-to-methanol process

Following assumptions were made to build the model:

- The water/CO_2 electrolysis occurs at 850°C and 1 atm, representing solid oxide electrolysis operation
- Electrolysis conversion for H_2O and CO_2 are set to 70%, based on experimental results[2].
- Methanol synthesis assumes an internal condensation reactor[3] working at 50 bar with temperature ranging from 250°C (reaction zone) to 25°C (condensation zone).

Results

Heat integration was performed using pinch analysis. The pinch point was identified at 245.2 °C and the maximum heat recovery amounts for 3362 kW. The main contributions listed below represent 77 % of the maximum heat recovery achievable in a perfect network with 12 heat exchangers :

- 1116 kW heat from the hot syngas at the electrolyser outlet to the water feed heating (before the electrolyser),
- 962 kW heat generated by the methanol synthesis to the reboiler of the methanol distillation column
- 506 kW recovered inside the internal condensation reactor, coupling the off-gas cooling with the heating of the recycle loop.

The conversion efficiency can be defined as:

$$\varepsilon = \frac{\dot{M}_{Met,out} . LHV_{Met} - \dot{M}_{H2,in} . LHV_{H2}}{P_{in} + Q_{in}}$$

It was improved from 40.1 to 53.0% thanks to the heat integration as evidenced below. Moreover, if a heat source is available (Q_{in}=0), then the efficiency can rise up to 70%, confirming the experimental values reported in the literature[1].

Parameter	$M_{Met,out}.LHV_{met}$ MW	$M_{H2,in}.LHV_{H2}$ MW	P_{in} MW	Q_{in} MW	ε %
No heat integration	6.192	0.672	7.873	5.904	40.1
With heat integration	6.192	0.672	7.873	2.542	53.0

Conclusions and perspectives

The power-to-methanol process is a promising technology for long-term storage of energy from variable renewable sources. Heat integration was performed, evidencing the high improvement potential through process integration. Further work may also include control strategies to adapt the process to the variable availability of renewable electricity sources as well as experimental demonstration of the power-to-fuel process.