Comparative assessment of power-to-methane technologies for sustainable synthetic natural gas production

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Significance and Relevance

In this study, 20 Power-to-Methane (PtM) plant concepts which integrate Solid Oxide Electrolysis Cells (SOECs) and various carbon capture technologies are optimized. The high efficiencies of the PtM systems achieved in this study highlight the significant efficiency gains from thermal integration of carbon capture processes by up to 8.4%. Additionally, the study demonstrated that exothermic SOEC operation can reduce capital expenditures with minimal plant efficiency loss, providing a new perspective on optimizing PtM systems for renewable fuel production.

Preferred and 2nd choice for the topic: CO_2 utilization and recycling, catalysis to electrify the chemical production
Preferred presentation: Oral preferred or Short Oral

Introduction and Motivations

The Power-to-Methane (PtM) technology offers a promising pathway to decarbonize the automotive industry by converting renewable electricity into methane, a sustainable fuel alternative when it is produced from captured CO_2[1]. When it integrates the carbon capture process, the technology not only provides a means to store excess renewable energy but also negates the overall greenhouse gas emissions of the downstream processes. The efficiency and viability of the technology can be enhanced by utilizing SOECs, supporting the transition to cleaner transportation solutions[2].

Materials and Methods

20 different PtM plant concepts are created by combining different methanation, SOEC and carbon capture technologies. Fixed-bed methanation reactors and three-phase methanation reactors are considered as methanation technologies, while electrolyte-supported and cathode-supported SOEC are studied as possible electrolysis technologies. The PtM plant concepts include a CO/CO_2 supply from either biomass gasification, amine gas treatment or direct air capture. A flexible simulation tool developed in Matlab simulates the plant concepts under different operating conditions, which are simultaneously optimized for maximum efficiency while considering constraints like temperature gradients in the electrolyzer and suitable Synthetic Natural Gas (SNG) output.

Results and Discussion

The optimization of the PtM process chains shows that the selected processes with integrated carbon capture technologies can reach high power to methane efficiencies of up to 84.6% with ideal thermal integration. Even when CO_2 is separated through the energy intensive direct air capture technology, plant high heating value efficiency can reach up to 74.8%. Specifically, it is the thermal integration of the carbon capture process with the methanation and electrolysis processes which allows to raise the efficiency of the combined plant by 8.4% compared to separated direct air capture and PtM facilities. The magnitude of this increase in efficiency makes the use of direct air capture a more realistic perspective.

Through a sensitivity analysis, the gas temperature at the inlet of the electrolyzer was identified as the operating parameter with the highest impact on the total plant efficiency by a large margin, owing to the increased electrical efficiency of SOEC at high temperatures and the possibility of using resistive heating to circumvent the losses incurred by the power rectifiers needed to operate SOEC with direct current.

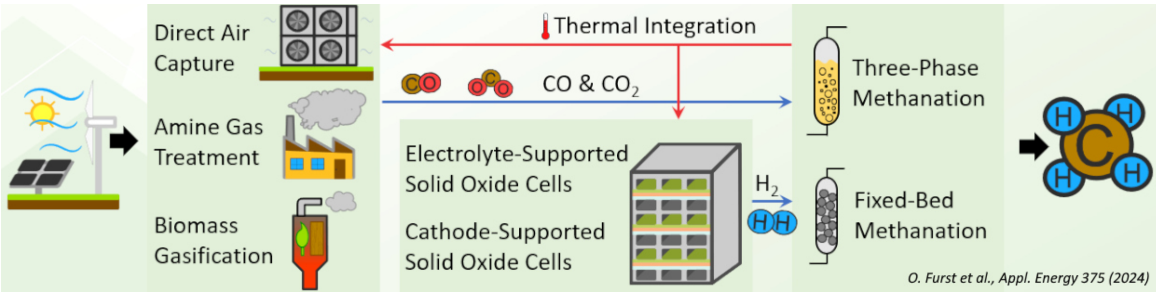

Figure 1: Visualization of the possible permutations of technologies selected to assemble 20 thermally integrated PtM plant concepts[3].

In addition, sweep gas recirculation in the SOEC was shown to lead to a substantial increase in PtM efficiency of up to 6.8% by reducing the amount of sweep gas heating required and by allowing the electrolyzers to be operated under pressure without the need to compress the sweep gas.

Finally, drawing the pareto front of a bi-objective optimization of the plant efficiency and number of electrolysis stacks required in the plant reveals that exothermic operation of the electrolyzers can allow to substantially reduce the amount of electrolyzers required without significantly impacting the plant efficiency, potentially allowing a large reduction of investment costs.

Through the comparison of a large number of PtM process chains, this study provides valuable insights into process optimizations which may greatly bolster the viability of sustainable SNG production.

References

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