Institute of Mechanical and Electrical Engineering

PhD Defence

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presents her thesis

Title:	***Techno-Economic Assessment of Integrated Power-to-Methanol Plants:*** *Flexibility, Market Participation, and Sector Coupling"*
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POPULAR SCIENTIFIC ABSTRACT

Melika Taslimi

Techno-Economic Assessment of Integrated Power-to-Methanol Systems: Flexibility, Market Participation, and Sector Coupling

The decarbonization of hard-to-electrify sectors such as shipping, aviation, and chemical production requires scalable renewable fuel solutions. Power-to-X plants are considered a key pathway, but their feasibility is challenged by high capital costs, electricity price volatility, and interactions across power and heat markets, which require further investigation. This thesis develops a comprehensive techno-economic assessment framework to evaluate integrated Power-to-X systems under real market conditions. The framework combines optimization-based operational scheduling, sector coupling analysis, and market participation strategies. The framework is applied to the world's first large-scale Power-to-Methanol plant in Kassø, Denmark, integrating a 302 MW photovoltaic park, a 52 MW PEM electrolyzer, and a methanol synthesis unit with an annual production capacity of around 44 ktMeOH.

The results show that electricity price is the main driver of system operation and production costs, as it represents the largest cost share. Under high electricity price conditions similar to those observed in 2022, optimal annual methanol production decreases significantly—by 58% in this case study—and strict production commitments can lead to considerable financial losses. The methanol selling price is another key driver. Sensitivity analyses indicate that premium pricing for green methanol is necessary to achieve economically viable production levels. In this study, a premium of 4,800 DKK/t (€0.64/kg) is considered, corresponding to a total selling price of 8,400 DKK/t. On-site solar PV generation supplies around 30% of the plant's electricity demand and contributes approximately 20% of total revenues through electricity trading. These findings highlight the importance of aligning plant design and operation with both market conditions and climate variability.

The analysis further demonstrates that operational flexibility significantly improves economic performance. Hydrogen storage maintains feedstock supply to the methanol unit during electricity price fluctuations, decoupling methanol production from electrolyzer operation and supporting production during 8–11% of the year. Battery storage balances short-term electricity variations and supplies about 4% of the plant's annual electricity demand, thereby reducing the impact of market price fluctuations on production costs. It also enables electricity arbitrage, directly increasing profitability. In addition, participation in the manual frequency restoration reserve market creates additional revenue streams and contributes to up to a 5% reduction in the levelized cost of methanol.

The integration of available waste heat into the district heating network further enhances system profitability. At the Kassø site, 7.5 MW of excess heat from methanol distillation is available at around 73 °C for this purpose. In addition, low-grade waste heat from the electrolysis system is upgraded using a heat pump to make it suitable for district heating. The integration of an electric boiler for additional heat production is also considered. The profitability of this connection is evaluated through different heat purchase agreement structures. The assessment shows that electricity prices are the main driver of heat pricing across all scenarios. Among the contractual structures, the firm-capacity scheme provides high revenue stability and supply reliability but requires longer contract durations, with a payback period of around 11 years. Time-of-day pricing performs well across several performance indicators. Furthermore, the combination of dynamic pricing and Contracts for Difference proves to be a suitable approach, increasing annual income by approximately 2.5 mDKK.

Overall, the thesis shows that although green methanol production remains economically challenging under current market conditions, strategic flexibility investments, market participation, renewable integration, and well-designed heat contracts can significantly improve system performance and profitability. The developed optimization-based framework provides a transferable tool for evaluating integrated Power-to-X systems under evolving technical and market conditions.