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System-Level Modelling of Methanol Production through Solar-Driven Supercritical Water Gasification of Algal Biomass

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The cost and competitiveness of solar-driven synthesis fuel production systems will be critical for their success in the market. Therefore, it is necessary to investigate the techno-economic performance of these systems through annual transient simulations. Supercritical water gasification (SCWG) with steam methane reforming (SMR) is considered as a promising thermochemical technology for the efficient conversion of wet biomass into syngas. This technology can be adaptable and attractive for different wet biomass feedstocks. The syngas from the SCWG process can be converted into useful liquid fuels such as petrol, diesel and methanol. Numerous recent studies have coupled syngas product with a downstream Fischer–Tropsch (FT) synthesis system, but it requires a long ramp time for the chemical chain reactions to stabilise (also due to its heat and mass transfer limitations).

Methanol synthesis, as a more mature technology, offers a relatively fast steady-state operation with cheaper capital/variable costs and a smaller size of the downstream route per unit of inlet syngas. However, more insight into the system-level dynamic behaviour of this technology is needed to evaluate its potential to penetrate the market due to the dynamic solar energy resource. This research aims at investigating the feasibility of methanol production via solar-SCWG-SMR of algae. The steady-state models of the SCWG and methanol synthesis plants are modelled in ASPEN Plus software. A fixed-sized 50 MW_{th} solar energy input drives the endothermic reaction in SCWG and SMR reactors. In order to condition the syngas before entering the storage, a fraction of carbon is discarded in the form of CO2 after the SMR process. Syngas storage is acting as a buffer in-between the intermittent SCWG and continuous methanol synthesis processes.

The annual behaviour of the system depends on the storage hours and solar multiple. Dynamic modelling is performed by extracting the off-design performance curves from the steady-state models, leading to an energy-based system-level model in OpenModelica. The case study developed here is based on one year of hourly weather data for Geraldton, Australia. The feasibility of the process has been assessed through a comprehensive techno-economic analysis (TEA). The total capital investment (TCI) of the incorporated units is calculated using the n^{th} plant scenario with 30 years plant life. The system capital, operating and maintenance costs are calculated to obtain the levelised cost of fuel (LCOF). The minimum LCOF of the plant achieved from a detailed parametric study was found to be 1.5 AUD/L. The sensitivity analysis reveals that the operating cost of algae is the main dominant components of the LCOF. Further reduction is possible at a larger scale of the solar field and more involvement of the algae market in producing cheaper algae feedstock.