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Dynamic Modelling of a Solar-Driven Fuel System through Gasification-Fischer-Tropsch Synthesis

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Conversion of micro algae into liquid fuels via solar-driven supercritical water gasification (SCWG) with steam methane reforming (SMR) and Fischer--Tropsch (FT) synthesis offers a promising approach for production of clean fuels. While many research has been dedicated to the analysis of biomass gasification, methane reforming and FT synthesis separately, little emphasis has been placed on fully integrated systems based on these components especially when a variable heat source -- i.e. concentrating solar thermal (CST) -- is involved. This paper investigates the dynamic performance -- through storage dispatch dynamics and component-based operating control states -- and techno-economic feasibility of this technology at a system level.

The main components of the plant are a heliostat field, a dual thermo-chemical receiver (consisting of separate SCWG and SMR reactors), a syngas storage tank, an FT reactor and a control system. The concentrating solar energy collected from the solar field is used to drive the SCWG and SMR reactors, converting microalgae as feedstock into syngas. The solar-derived syngas is stored in a storage tank and supplied to the FT reactor to produce synthesis liquid fuels -- i.e. petrol and diesel.

A detailed steady-state physical model of the plant has been developed in AspenPlus®. Through (design and off-design) simulations of the physical model, polynomial curves have been obtained to model key component quantities, which are then combined to form an energy-based dynamic model of the plant in OpenModelica -- an open-source implementation of the object-oriented Modelica language used for modular modelling and simulation of dynamic systems. The development of the dynamic model is necessary to evaluate the performance of this technology under variable solar-derived thermal source. In order to simulate some technical constraints in a real-world plant, a number of control logics have been implemented in the main components, including operational cut-off points and startup/shutdown times. Little emphasis has been placed on the latter in the current literature. The annual optical efficiencies of the heliostat field as a function of solar position have been calculated externally by the SolarPILOT optical analysis tool, and provided to the solar field model as a lookup table. A typical meteorological year data set (in TMY3 format) provides the input weather data to a weather component in which a sub-component is defined to calculate the Sun position. The dispatch of syngas to the FT reactor is controlled by a dispatch control component. The economic analysis of the plant (including the capital, fixed and variable operational costs) are performed outside the OpenModelica platform using a Python script, resulting in a calculated levelised cost of fuel (LCOF) -- a key economic indicator used for system optimisation. Through a detailed parametric study, the optimal design of the plant is achieved from a techno-economic standpoint.