Techno-economic analysis of bio-CLC: assessing the Nordic policy framework

Tomi Thomasson[1] Janne Kärki[1] Toni Pikkarainen[1]

[1]VTT Technical Research Centre of Finland Ltd.

In order to achieve the temperature targets set in the Paris Agreement, most climate scenarios rely on the assumption of negative CO_2 emissions to stay within the carbon budget. Bioenergy combined with carbon capture and storage (BECCS) offers an attractive way to generate these negative emissions while simultaneously providing energy. One of such technologies is chemical-looping combustion of biomass (bio-CLC), which has been considered to outperform its alternatives such as oxy-fuel combustion by allowing CO_2 capture and negative emissions at smaller unit sizes, lower capital cost and energy penalty.

Despite of being relatively inexpensive, the increased investment costs combined with insufficient income formation mechanisms make investments to bio-CLC economically infeasible at the present. As the negative emissions are not recognized by the European Union Emissions Trading System (EU ETS) and therefore have no market value, the lack of incentive limits the utilization of the technology in the day-ahead electricity market. On the other hand, the technical challenges of bio-CLC have an effect on its applicability. Capturing and storing the CO_2 emitted by bio-CLC plant leads to increased operating costs and energy penalty, which decrease the position of the system in the merit order. Furthermore, the flexibility of the process is constrained due to the sensitivity to operational temperature, limiting the possibility to provide ancillary services.

In the local scale, when bio-CLC is used in a combined heat and power (CHP) system, the barriers related to the energy penalty can be potentially overcome and the economics improved. This is due to the possibility to recover heat from the CO_2 capture processes, decreasing the fuel consumption of the system especially in the case of moist biomass fuel. However, in the global scale, the integrated targets such as the EU ETS do not constrain emission reductions to take place in a certain area; the solution may be locally optimal, but it may be better applied in other regions or sectors of the energy system.

By techno-economic modelling, the work assesses the feasibility of bio-CLC in both process and system level; in local (city) scale as well as global (Nordic) scale, focusing on near-term future and its expected changes with respect to market and regulatory environment. The local scale model is a partially dynamic representation of bio-CLC in a CHP plant. The modelled plant is able to operate based on market signals in multiple different modes, varying the amount of heat and electricity generated as well as the CO_2 captured. Realistic plant operation is enabled by linear optimization, which allows flexibility parameters to be elaborated from pilot bio-CLC plant operation. The global scale model is a multi-region partial equilibrium model based on linear optimization that aims to find the cost-optimal energy system fulfilling the given emission reduction target. Consequently, the future investments to bio-CLC are simulated.

The work has three key objectives which are addressed from both local and global perspective: a) to discuss the current policy framework in selected Nordic countries, showing that the existing support mechanisms are ineffective for bio-CLC particularly when coal is phased out; b) to compare the feasibility of bio-CLC to reference air-fired and oxy-fuel combustion systems in near-term expected policy framework, clarifying that economic feasibility may be achieved with relatively low price of CO_2 if negative emissions are acknowledged in the EU ETS; c) to discuss, propose and evaluate additional policy mechanisms to further boost the development of bio-CLC, such as subsidizing heat that is generated while simultaneously providing negative emissions. Combining the outcome of the two models allows the analysis to be expanded from power and heat to other sectors such as industry and transportation. Simultaneously, the techno-economic feasibility can be thoroughly assessed and the effect of changes in the policy framework evaluated from multiple perspectives.