**Techno-economic and life cycle assessment for the industrial implementation of hydrothermal liquefaction coupling with aqueous phase reforming**

Edoardo Tito1, Giulia Zoppi1, Giuseppe Pipitone1\*, Edoardo Miliotti2, Arturo Di Fraia2, Andrea Maria Rizzo2, Samir Bensaid1, Raffaele Pirone1, David Chiaramonti2,3

*1 Department of Applied Science and Technology, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy*

*2 Renewable Energy Consortium for R&D (RE-CORD), Viale Kennedy 182, 50038, Scarperia e S. Piero, Florence, Italy*

*3 Energy Department DENERG, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy*

*\*Corresponding author E-Mail: giuseppe.pipitone@polito.it*

**1.Introduction**

Hydrothermal liquefaction (HTL) has shown to be an interesting technology for producing renewable advanced biofuels. HTL works in aqueous environment close to critical water conditions (374 °C, 22.1 MPa) and allows the conversion of waste biomass into an oil-like phase called biocrude. This phase is highly oxygenated and requires upgrading to produce a drop-in biofuel. Moreover, in addition to the biocrude, char, a gas phase and an aqueous phase are also produced as by-products, reducing the overall carbon recovery of the process. Thus, for an effective industrial application of HTL, it is critical to address the significant carbon loss in the aqueous phase (AP) and the need for biocrude upgrading [1]. In this work, we evaluated coupling hydrothermal liquefaction (HTL) with aqueous phase reforming (APR). APR is a catalytic process capable of converting the oxygenates contained in the aqueous stream into a hydrogen-rich gas, without requiring the energy-intensive vaporization of the feed. The gas thus produced can be used as an internal hydrogen source for the biocrude upgrading. In this work, a techno-economic assessment was performed for an HTL-APR integrated plant to produce biofuel. This allows to assess the feasibility of this novel integration and identify weaknesses that must be overcome in order to move to commercial-scale implementation. Finally, a life cycle assessment (LCA) was performed to assess the environmental impact of this technology as well.

**2. Methods**

Two cases were proposed, based on different lignocellulosic feedstocks: corn stover (CS), representative of several agricultural wastes that can be exploited, and lignin-rich stream (LRS), as by-product from cellulosic ethanol production. HTL-APR integrated plants were sized to work with a mass flow rate of 3.6 t/h and 10 wt.% of solid loading (input nameplate capacity of 20 MW for LRS and 16.5 MW for CS). Starting from mass and energy balances, the design of the main unit was performed; the calculations were based both on experimental data and the literature. The economic evaluation was carried out by calculating economic indicators: minimum selling prices (MSPs) and hydrogen production costs. The environmental analysis was carried out with LCA methodology (ISO 14040 and ISO 14044) [2]. The software GABI was used, and the impacts were evaluated by ILCD v1.09 method through to the global warning potential (GWP).

**3. Results and discussion**

With the LRS case, APR was able to supply 21% of the H2 required for the biocrude upgrading. On the other hand, with the CS case this value increased up to 165%. The improved coupling in the latter was due to the coexistence of some factors: higher hydrogen productivity from the organics dissolved in HTL-derived wastewater, lower biocrude production, and lower oxygenation of the biocrude. The minimum selling prices, (internal rate of return 0%), for the two biofuels were 1.27 €/kg for LRS and 1.23 €/kg for CS. Despite, the higher biofuel production rate of the former, the lower value of the latter was justified by the much lower H2 production cost through APR: 1.7 €/kg (CS) against 7.6 €/kg (LRS). The economic advantage deriving from the HTL-APR coupling was further assessed by evaluating the variation on the MSPs removing the APR section and using instead two established hydrogen production technologies: methane steam reforming (SR) and electrolysis (Figure 1). Unlike the LRS, with the CS the use of APR as hydrogen source showed lower MSP than both SR and electrolysis. These results reveal that the HTL-APR integrated plant is a valid technology to internally produce the hydrogen required for biofuel upgrading, being the hydrogen production cost lower than that of electricity-intensive electrolysis and comparable to that of fossil-based SR.

Regarding the LCA, the two cases had similar impacts (Figure 2). Despite the lower thermal and electrical demand of the LRS case compared to the CS case, its impact was highly dependent on the supply of the hydrogen missing share. To allow a comparison with other biofuels the GWP was based on 1 MJ of biofuel; for this purpose the LHV was assumed as diesel (43 MJ/kg). The resulting CO2eq/MJ was comparable with values for other biofuels.



**Figure 1**. Plant configurations for hydrogen supply. A) APR+electrolysis, B) APR alone, C) APR+SR, D) SR alone, E) Electrolysis alone, F) No upgrading. The percentage values refer to the variation of the MSP of the considered configuration compared to the respective base case (A for LRS and B for CS).

**Figure 2.** GWP for the CS and the LRS case based on 1 kg of biofuel. Subdivision among the different impact items.

**4. Conclusions**

HTL-APR coupling has been proven to be a valuable technology for biofuel production from an economic standpoint. In particular, this work has shown that the coupling is strongly dependent on the HTL carbon distribution and on the nature of the molecules dissolved in the HTL aqueous phase. H2 production cost through APR was particularly interesting with corn stover, being it equal to 1.7 €/kg, which is lower than production cost through electrolysis. The GWPs for these two biofuels resulted in line with other biofuels.

**References**

[1] J. Watson, T. Wang, B. Si, W. T. Chen, A. Aierzhati, and Y. Zhang, Prog. Energy Combust. Sci. 77 (2020) 1-45

[2] European Commission-Joint Research Center, ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance (2010)