ASSESSING THE COST-COMPETITIVENESS OF GREEN HYDROGEN PRODUCTION FOR OIL REFINERY DECARBONIZATION

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ABSTRACT

Refineries currently stand as the primary hydrogen consumers comprising over 43% of the global demand in 2022. Specifically, less than 700 refining plants worldwide utilize 41 Mt of hydrogen for hydrocracking and hydrotreating processes, which are crucial for producing lighter fuels and removing sulfur compounds. At present, refineries largely rely on fossil-based hydrogen, which is produced onsite through steam methane reforming (SMR) or naphtha cracking. These production routes ensure low-cost hydrogen, but they lead to substantial CO_2 emissions (up to 380 Mt per year). The adoption of green hydrogen in the refinery industry thus emerges as a promising decarbonization strategy since it can effectively curb CO_2 emissions without requiring plant retrofit or affecting the refining processes. In this context, an existing oil refinery located in Sicily (Italy) is considered as a case study. The annual hydrogen demand amounts to 3679 tonnes and it is currently met by importing grey hydrogen from a nearby SMR unit at a price of 1.67 €/kg [1]. This work thus aims at assessing the cost-competitiveness of low-carbon hydrogen produced by water electrolysis in a power-to-hydrogen (PtH) system. Further expanding the methodology proposed in [2], an optimization framework based on a meta-heuristic approach is developed for the cost-optimal sizing of the hydrogen production system. A grid-connected configuration is investigated and a sensitivity analysis on the electricity purchase price (50-200 €/MWh) is conducted. Both alkaline (ALK) and proton exchange membrane (PEM) technologies are examined by adopting detailed techno-economic models based on investment costs [3], [4] and real efficiency curves of MW-range electrolyzers [5], [6].

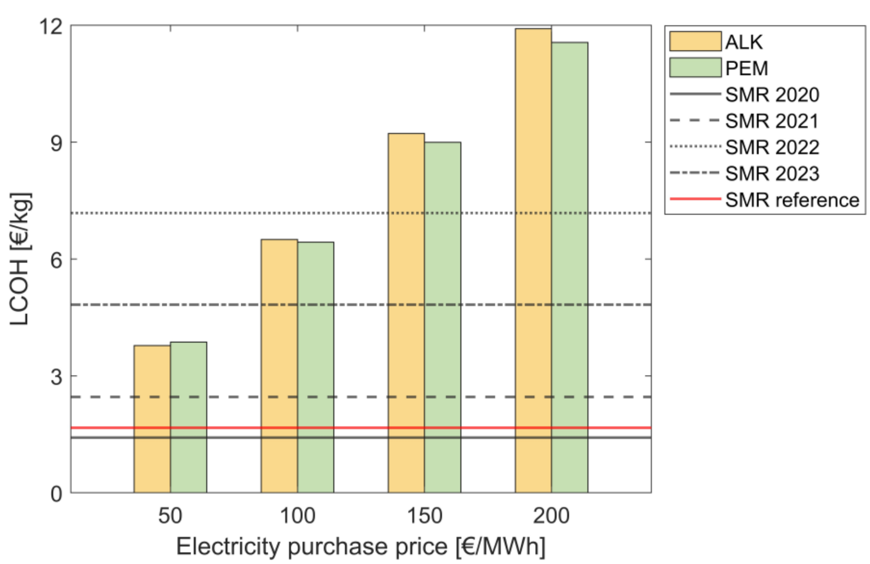

Figure 1. Cost-comparison between PtH and SMR.

The results of the cost assessment are shown in Figure 1. The levelized cost of hydrogen (LCOH) of the PtH system (yellow and green bars) lies within the range of 3.8-11.9 €/kg and the cost-effectiveness of the PEM technology (which is more capital intensive but exhibits higher efficiency) increases compared to alkaline as the purchase electricity price rises. The lower performance of ALK electrolyzer clearly affects the operating costs, but the long-lasting lifetime limits the number of stack replacements (in contrast to what occurs for PEM). A cost-comparison analysis with the SMR scenario is then carried out. The hydrogen production costs for SMR in the 2020-2023 period (horizontal lines in Figure 1) are estimated as a function of natural gas (NG) and carbon prices [7] . Annual average NG prices for large industrial users in Italy and values from the European Emission Trading System (EU ETS) market are utilized. PtH systems result far from being competitive with the reference scenario (red line corresponding to 1.67 €/kg) since even with low-cost electricity (i.e., 50 €/MWh) the LCOH turns out to be more than double. However, when considering higher NG and carbon prices (e.g., 2022 and 2023 values), the cost gap tends to reduce and the PtH solution can reach the cost-parity. More in detail, in 2022 grey hydrogen production cost exceeded 7 €/kg, thus resulting more expensive than a grid-connected PtH system importing electricity at 100 €/MWh. A sensitivity analysis finally explores a wide range of NG and EU ETS prices (20-200 €/MWh and 0-160 €/t_{CO2}) to identify the conditions for the economic feasibility of adopting PtH systems. The LCOH heatmap reported in Figure 2 highlights that for NG prices ≤ 40 €/MWh, a carbon price ≥ 160 €/t_{CO2} (i.e., 2.3 times higher than the current market value) is required to obtain a grey hydrogen production cost ≥ 3.8 €/kg (i.e., the minimum LCOH of PtH system).

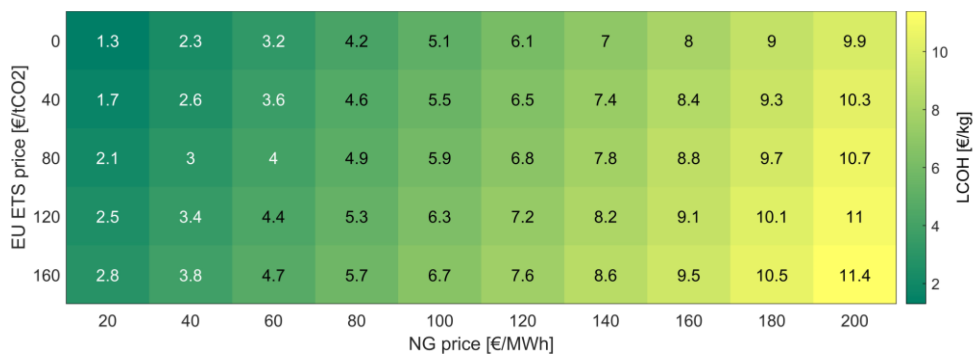

Figure 2. LCOH heatmap for variable natural gas and EU ETS prices.

Lastly, to assess the environmental performance of the grid-based PtH system, the hydrogen carbon footprint for different grid emissions factors is evaluated and compared with the SMR carbon intensity and the green hydrogen requirement set by the Delegated Act. In conclusion, a grid-based PtH system can limit the CO_2 emissions of the oil refinery plant but with higher LCOH than SMR. However, low-cost electricity and higher EU ETS prices can boost its competitiveness towards a cost-parity.

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