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Techno-Economic Assessment of H_2-DRI and NG-DRI-CCS Processes for Low-Emission Iron Production

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The decarbonization of the iron and steel industry, responsible for approximately 7% of global energy-related CO2 emissions, represents a critical challenge due to its high energy demand and the intrinsic characteristics of the processes, making it strongly dependent on fossil fuels. Hydrogen-based direct reduced iron (H2-DRI) has gained increasing attention and is currently considered one of the most promising options for zero-emission iron production. Natural gas-based DRI plants equipped with carbon capture and storage (NG-DRI-CCS) also represent a competitive option, especially in areas with nascent CO2 infrastructure or limited access to renewable energy sources. The parallel development of CCS clusters and the continuous decline in renewable energy costs suggest that both pathways could play a complementary role in ironmaking decarbonization. This work provides a techno-economic assessment of low-emission DRI configurations based on CCS, electrification, and hydrogen.

The analysis is based on Aspen Plus® process simulations for a plant capacity of 2 MtDRI/y to derive mass, energy, and CO2 balances. The reference case is the Energiron Zero Reformer (ZR) process. In addition to the conventional configuration employing a combustion-based process gas heater, electrification of the gas heater is considered. Three CO2 capture options: (i) selective capture of the CO2 stream from the reducing gas recycle, (ii) full capture, which also includes post-combustion capture from the gas heater flue gas, and (iii) pre-combustion capture via water-gas shift reactor and CO2 removal. Two hydrogen-based cases are considered, which rely either on high-temperature electrolysis (HTE), with a Solid Oxide Electrolysis Cell (SOEC) system thermally integrated within the plant, or low-temperature electrolysis (LTE).
Techno-economic assumptions include a 25-year lifetime, an 8% discount rate, and cost assumptions consistent with the recent literature. A sensitivity analysis explores how variations in energy costs may impact the optimal configuration.

Results indicate a cost of CO2 avoidance of 70-150 €/tCO2 for CCS configurations, largely dependent on the cost of natural gas and of CO2 transport and storage. The cost of CO2 avoidance for H2-DRI ranges from 270 to 560 €/tCO2 in the HTE case and from 470 to 890 €/tCO2 in the LTE case, for electricity prices between 60 and 100 €/MWh. An analysis of the economically optimal configuration as a function of energy prices shows that NG-based solutions equipped with CCS remain preferable across a wide range of conditions, while hydrogen-based options become competitive only when the electricity-to-natural-gas price ratio falls below approximately 0.75, or for premium markets.

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