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Flexible operation of DRI plants integrated with high-temperature electrolysis for cost-effective decarbonization of iron production

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Hydrogen-based direct reduced iron (H_2-DRI) represents a promising pathway for significantly reducing CO_2 emissions in iron production. Achieving economic competitiveness for H_2-DRI depends on lowering hydrogen production costs, which can be addressed through: (i) high-efficiency Solid Oxide Electrolyzer Cells (SOECs) and (ii) the flexible operation of both SOEC and DRI plants.
First, this study presents a process analysis of a SOEC-based H_2-DRI plant, evaluating different integration options between the SOEC and the DRI production system: top-gas from the DRI shaft furnace can be cooled down to generate steam for the SOEC feed, or can be directly fed to the SOEC system. All proposed configurations achieve reductions of direct CO_2 emissions of over 90% compared to a conventional natural gas-fed process, with the highest integration achieving a net energy consumption below 8 GJ/tDRI (Scaccabarozzi et al. 2025). The analysis is then extended to assess the off-design operation of the plant, considering both the flexible operation of the DRI reactor and the introduction of natural gas into the reducing loop.
Second, a mixed-integer linear programming model is developed to optimize integration with photovoltaic and wind power generation, as well as storage units. The analysis is conducted for two locations—Cleveland, Ohio (United States) and Pilbara (Australia)—under both short-term and long-term cost scenarios for renewables and storage technologies. Results indicate that a flexible SOEC integrated with an optimized photovoltaic and wind power plant can lower DRI production costs by more than 35%, with respect to an inflexible electrolyzer. Additional flexibility options, such as flexible DRI operation and natural gas injection, contribute to further reducing the required capacity of storage and renewable plants but result in more modest cost reductions (<10%).

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