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Opportunities and Challenges of Disruptive Processes for Future Production of Zero-CO_2 Mn Alloys

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Extended Abstract

High-throughput primary production of Mn alloys will remain vital to the industry for the next decades to meet the demand for steel and non-ferrous alloys. The associated processes must shift towards sustainability, including the urgent need to cut their net CO_2 emissions. Upgrading existing plants is possible and necessary (e.g. use of biogenic carbon, carbon capture), and the development of new processes holds great potential for best compromises between performance (productivity and quality) and sustainability.

Direct H_2-reduction is one attractive method to enable zero-CO_2 iron production, however, ferroalloys of less noble metals such as manganese, silicon, and chromium require more disruptive approaches to fully reduce their oxides (e.g. high-throughput electrolysis, plasma). A wide-scale assessment of those disruptive zero-CO_2 metal reduction processes is needed, to ultimately guide the research and investments toward the understanding and overcoming of the fundamental challenges related to the most promising approaches. Most studies of this nature have been confined to iron production, and this work aims to tackle the case of manganese, one of the main alloying elements of steel. A comparative assessment of the possible technologies for zero-CO_2 production of Mn alloys is thus performed, identifying the key indicators of opportunities and challenges related to process performance and sustainability.

The methodology involves first the description and clustering of the processes according to fundamental aspects such as the reduction driver (carbon, electron, reductive gas and plasma, reductive metals) and temperature, with high temperatures allowing faster kinetics and melting of alloy but require high-performance reactor materials and management of large heat flows. Criteria of process performance, feasibility, and sustainability are selected to perform an MCDA (Multiple Criteria Decision Analysis). To quantify sustainability, the potential level of pollutants, consumption of resources, as well as land use are estimated. For assessing the potential for long-term business success, process performance criteria are defined based on cost aspects (related to energy and feedstock consumptions, and to the specific productivity) and generated value (depending on the grade of the alloy and its market). Two key factors are estimated, the specific energy consumption (MWh/t) and productivity ($t/h/m^2$), using preliminary theoretical calculations and existing data from past trials and similar processes. The level of technological maturity (TRL) and business viability are judged with review of the past and existing academic and industry actors and studies. The most critical technical elements specific to each process are presented to highlight the major opportunities and fundamental obstacles to be overcome through collaborative research, with a focus on material challenges such as high-temperature inert electrodes and durable catalysis.