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CO_2-REDUCED STEELMAKING VIA ELECTROLYSIS-BASED DIRECT REDUCTION

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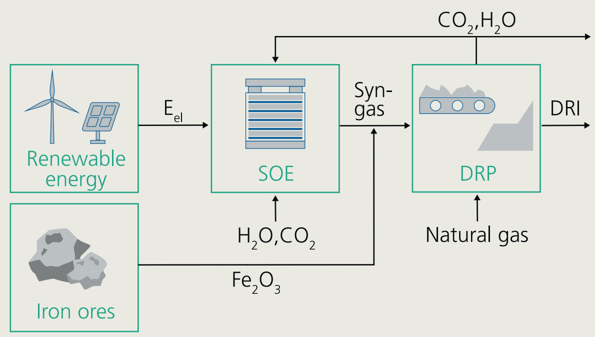
In order to achieve a sustainable resource and energy system, the reduction of carbon dioxide (CO_2) emissions is essential in all branches of industry. Currently 5 % of all greenhouse gas emissions in the European Union are caused by the steel industry, which ranks amongst the largest overall emitters. In the production of steel – one of the most important raw materials of the 21st century – substantial amounts of CO_2 are emitted as by-product of the conventional iron ore reduction using the established blast furnace route. Therefore, at Fraunhofer IKTS a current area of research focuses on the reduction of CO_2 emissions associated with the production of raw iron, through electrolysis-based direct reduction using renewable energy sources.

Roughly 95 % of global raw iron is currently produced via the blast furnace route. In this process, coke is used as a reducing agent. During the reduction process, the oxygen content in the iron ore is bound to the carbon. The reaction produces raw iron and CO_2.

A commercially available alternative is the direct reduction process. Its product is direct reduced iron (DRI), which is characterized by its carbon content and a small amount of residual iron oxides. Existing commercial plants are predominantly fueled by natural gas. In a so-called reforming step, this feedstock is converted into hydrogen and carbon monoxide, which are both available as reducing agents for the reduction of iron ore. As a by-product besides CO_2, water is formed. The partial reduction with hydrogen results in a significant decrease in CO_2 emissions compared to the blast furnace route, because the oxygen is partially bound and emitted in the form of water. A potential pathway for a further reduction of emissions, and perhaps in future for the complete abandonment of fossil fuel sources, is the generation of the relevant reducing agents hydrogen and carbon monoxide via electrolysis from water and CO_2 – a process called solid oxide electrolysis (SOE). This makes the electrolyzer the link between renewable energy sources and steel production.

Renewable energy in raw iron production



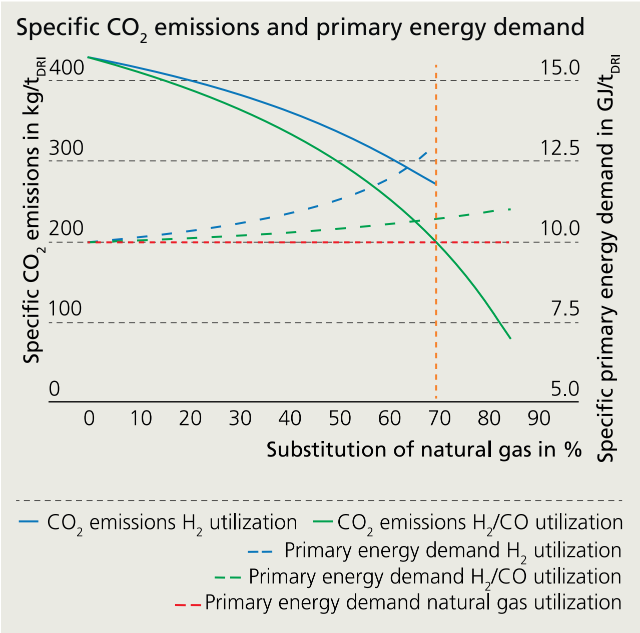
The simplest way to implement renewable energy into raw iron production would be a co-feed of sustainably produced hydrogen and natural gas, which would result in a significant decrease in CO_2 emissions without the need for any changes in the applied direct reduction shaft furnace. As the amount of hydrogen is increased, the CO_2 emissions decrease. However, beyond a certain threshold of hydrogen fraction reduction, the carbon content of the DRI also decreases. Such a decrease in carbon content within the DRI has an adverse effect on the subsequent process steps. Therefore the substitution of natural gas must be kept below 70 vol % to remain technically feasible.

This limitation is circumvented by a process concept proposed by IKTS, for which a patent is pending. The concept is based on the fact that SOEC stacks, also developed at IKTS, cannot only convert water, but also CO_2. During the direct reduction process, CO_2 that is already being separated can be recycled into the electrolysis together with water. This produces the reducing agents carbon monoxide and hydrogen. At the same level of substitution, the CO_2 recycle results in an even more significant decrease in emissions compared with simple hydrogen utilization. Additionally, the overall electricity demand required for the reduction of emissions decreases as well.

The boundary up to which the carbon content of the DRI is held stable is thus pushed from 70 vol % to 85 vol %, which means a significantly larger proportion of natural gas can be substituted – without negatively affecting the properties of the DRI. In the case of a 70 vol % substitution of natural gas with a syngas with a hydrogen-to-carbon monoxide ratio of 2:1, the CO_2 demand of the electrolysis is equal to the amount of CO_2 that is separated internally within the direct reduction process. Residual emissions are then caused only by the preheating of process gas through the combustion of a part of the H_2/CO mixture. The remaining carbon fed in via natural gas is bound in the produced raw iron. If renewable energy is also used for preheating, CO_2 emissions can be reduced to almost zero.

By further increasing the substitution beyond the 70 vol % threshold, the system of SOEC coupled with a direct reduction plant can even be operated as a CO_2 sink. This could allow for the sustainable production of raw iron and steel, without the demand for fossil carbon sources. Therefore, the proposed process concept offers enormous potential regarding the future goals of emission reduction.

We gratefully acknowledge the project funding of the Federal Ministry of Education and Research BMBF (funding reference 03EK3044A).



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1 *Tapping of a blast furnace (Shutterstock, Oleksiy Mark).*

2 *Iron ores prior to reduction within the direct reduction process.*

3 *Quality assessment of the final product.*

4 *Raw iron bars (Shutterstock, Kaband).*

5 *Direct reduction plant (Shutterstock, M.Khebra).*

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