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How to avoid 3.5 billion tons of carbon dioxide per year

The team of the Max-Planck-Institut für Eisenforschung investigates a new route to produce green steel through hydrogen plasma

Germany, Europe and almost all countries in the world are heading towards climate neutral economies in the future. This aspect means to minimize as much CO_2 emissions as possible plus compensating for the remaining emissions. However, this target is not yet met by current technology. One of the biggest industrial CO_2 emitters, the iron- and steelmaking industry, still lacks the possibility of producing green steel and is till now, responsible for about 7% of all CO_2 emissions worldwide. Facing these challenges, a team of the Max-Planck-Institut für Eisenforschung (MPIE) explores the possibility to use hydrogen plasma for the reduction of iron ore instead of using coke or reformed natural gas. The scientists published their latest findings in the journal Acta Materialia.

"Using pure hydrogen instead of coke or reformed natural gas to reduce iron ore can be one way to save CO_2 emissions. However, the chemical reaction using pure hydrogen requires an external supply of energy to proceed. The use of hydrogen plasma instead, allows us to conduct the reduction reaction with less energy. Inside the plasma arc domain, H_2 molecules collide among themselves and also with electrons, leading to the formation of high energy species (for example, ionized and atomized hydrogen). These species are accelerated towards the iron ore to be processed and partially release their energy at the reaction interface between oxide and plasma arc. This released energy serves as the energy needed for the reduction reaction. And that's why using hydrogen plasma is favourable here.", explains Dr. Isnaldi Souza, postdoctoral researcher at the MPIE and first author of the publication.

Using hydrogen plasma also allows the production of liquid iron ore in one single step melting and reducing the ores simultaneously with a less need for agglomeration or refining processes. "We investigated the nano-chemistry, interface structure and composition and phase transformation kinetics. Our results show that the hydrogen plasma reduction could take place in the established industrial electric furnaces without major modifications. Nevertheless, the effects of the hydrogen plasma on the electrode and refractory materials will be further evaluated.", states Dr. Yan Ma, postdoctoral researcher in the same team with Souza and co-author of the publication.

The latest MPIE investigations show the thermodynamics and kinetics of the hydrogen plasma reduction of iron ores thus providing an alternative route for the production of green steel. In general, the MPIE established several groups dealing with the different aspects of sustainable metals. Souza and Ma are both working in the interdepartmental group "Physical Metallurgy of Sustainable Alloys". Related groups are "Hydrogen in Materials", "Hydrogen Mechanics and Interfaces", "Computational Sustainable Metallurgy" and in cooperation with the RWTH Aachen University the group "Sustainable Materials Science and Technology".

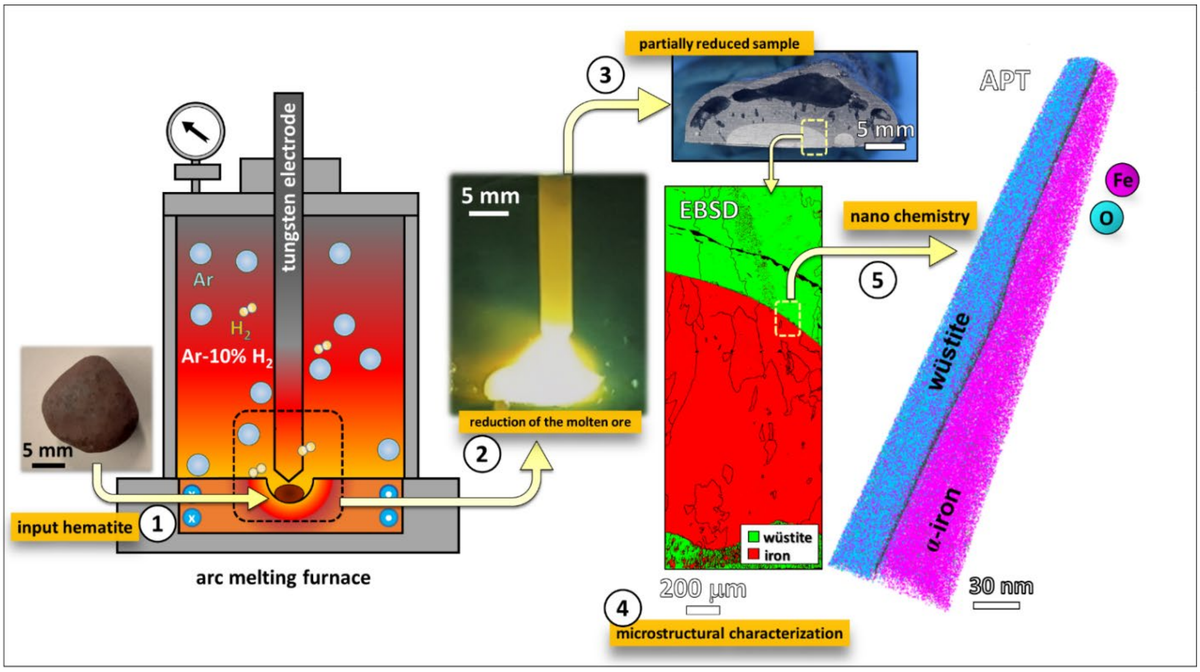

Fig. 1: Hydrogen plasma reduction of iron ores: **(1)** input hematite placed inside the arc melting furnace where the process is conducted. The furnace is equipped with a tungsten electrode and charged with a gas mixture of Ar-10% H_2. **(2)** Picture of the reduction process, where a hydrogen plasma is ignited between the tip of the electrode and the input material. The process melts and reduces the ore simultaneously. **(3)** Photograph of a sample partially reduced after 5 min of exposure to the plasma. Iron is observed in the bottom of the sample (light grey domains). The upper portion (dark grey) of the sample consists of remaining unreduced iron oxide (mostly wüstite, Fe_xO). **(4)** Microstructural characterization of the sample, conducted via Electron Backscatter Diffraction (EBSD). The EBSD map shows the spatial phase distribution acquired from the region highlighted by the yellow frame in (4). In this map, remaining wüstite and iron are represented in green and red, respectively. **(5)** Nano chemistry analysis conducted via Atom Probe Tomography (APT) at the phase interface between wüstite and iron. Fe and O atoms are shown in pink and blue, respectively. © Isnaldi Souza, Max-Planck-Institut für Eisenforschung GmbH

Original publication:

I. R. Souza Filho, Y. Ma, M. Kulse, D. Ponge, B. Gault, H. Springer, D. Raabe: Sustainable steel through hydrogen plasma reduction of iron ore: Process, kinetics, microstructure, chemistry. In: Acta Mater 213 (2021) 116971

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