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Project Title	Maximise H2 Enrichment in Direct Reduction Shaft Furnaces (MaxH2DR)
Industry Partner	Tata Steel
Industry Sector	Iron & Steel
Technology Pathway (Primary)	Low-carbon hydrogen
NIM Pillar	Technology Demonstration
Source	NIM Awards 2024
Description	H2-enriched direct reduction (DR) is the key decarbonisation technology for integrated steelworks mentioned in pathways of all major steel producers. Natural gas driven DR is established in industry mostly outside Europe but there are no experiences with high H2 enrichment > 80%. H2 based reduction is no principal issue but endothermic, and the influences on morphology, diffusion and effective kinetics are not known. Also properties and movement of particles in the reactor are not known and issues like sticking cannot be excluded. Probably, temperature distribution and flow of solids and gas will be clearly different. No reliable prognosis is possible yet, in particular with regard to local permeability, process stability and product quality of industrial size furnaces with higher loads on the particles and larger local differences. Many activities are initiated for first industrial demonstration of H2-enriched DR but they will not close many of these knowledge gaps. MaxH2DR provides missing knowledge and data of reduction processes. A world-first test rig determines pellet properties at conditions of industrial H2 enriched DR furnaces and a physical demonstrator shows the linked solid and gas flow in shaft furnaces. This is combined with digitals models including the key technology DEM-CFD to provide a hybrid demonstrator able to investigate scale-up and to optimise DR furnace design and operating point. This sound basis is exploited to optimise the DR process integration into existing process chains. Simulation tools are combined to a toolkit that covers impacts of product properties on downstream processes as well as impacts on gas and energy cycles. Thus, promising process chains, sustainable and flexible, will be achieved for different steps along the road to decarbonisation. The digital toolkits will support industrial demonstration and implementation and strengthen digitisation and competitiveness of the European steel industry.
Innovations Employed	• combined reduction trials at high H2-enrichment with different scales (powder, pellet, bulk) and materials (DR/BF pellets, sinter) • closing knowledge gaps on reduction regimes in H2-enriched DR, considering interaction of reactions and resistances by diffusion and restrained flow in industrial scale • providing a world-first test rig to quantify pellets behaviour and physical properties (e.g. movement, sticking) at realistic temperatures, loads and metallisation degrees • demonstrating coupled solid and gas flow in DR shaft furnaces in demo scale,

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	• providing the first DEM/CFD model and reliable and fast FVM/FEM models of H2-enriched DR shaft furnaces • deeply validating models by fusion with experimental results to a hybrid demonstrator • synergistically combining digital tools into a multipurpose simulation toolkit for integration of H2-enriched DR in steel production chains • exploit new tools to supply guidelines for process analysis, integration and optimisation
Dimension of Novelty	It was new to the International Market
Innovation Collaboration	Cooperation with scientific institutions: VDEh-Betriebsforschungsinstitut GmbH (BFI, Germany), Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna (SSSA) (Pisa, IT), Ruhr-University Bochum (Bochum, GE), Universite de Lorraine (Nancy, FR), Åbo Akademi University (Abo, FI), University of Salerno (Fisciano, IT), GIT (Gliwice, PL) **External partners:** Tata Steel (Velsen, NL), European Steel Technology Platform (Brussels, BE), CIOATECH/PNO (Rome, IT)
Intellectual Properties	Currently all planned project results are made available through public deliverables and documents. The elaboration of a suitable exploitation path for the developed tools is part of the project work and is currently under development.
IP Links	ESTEP Projects MaxH2DR
Timetable & Progress	The project is on mid-term and consists of several tasks which have different progress according to the project Gantt chart. The development started 2022.
Financing (Public/ Private)	Funded by the European Union as "HORIZON Innovation Action" according to topic: HORIZON-CL4-2021-TWIN-TRANSITION-01-18.
Finance Links	https://cordis.europa.eu/project/id/101058429
Project Phase TRL	TRL 6
Problems to be Solved and Risks to be Managed	Problems to be solved: • DR with H2-enrichment > 80% is a ground-breaking technology for climate neutral steelmaking and headed for by most steel producers but not validated on industrial scale • Knowledge on internal DR processes is still limited • Validated models for H2-enriched DR shaft furnaces are not available • H2-enrichment changes reactions, temperatures, particle and gas flows and material properties but these changes cannot be prognosed in a consistent way • Operational problems with H2-enriched DR (e.g. sticking) and necessary process optimisation measures cannot be foreseen

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	• Due to economical reasons European DR plants should be operated with maximum productivity and low quality raw materials Risks: • Experiments may produce conflicting results • New test rigs and/or trials may suffer from defects or technical issues • Models may suffer from excessive computational burden or low accuracy • Model and experimental results may conflict
Preliminary or Final Results Achieved	Available preliminary results of the project having reached mid-term (published on Clean Steel Partnership-MAXH2DR-Outcomes) • Benchmarking of developed steelmaking chain models (TRL 4->5) • A new kinetic model for the reduction of a single iron ore pellet in H2-rich atmosphere (TRL 4->6) • Procedures for the determination of physical properties of DR raw materials, intermediate and products (TRL4->5) • Modelling of iron oxide reduction with hydrogen in a small fixed bed (TRL4->5) • Benchmarking of FVM and FEM models and first coupled DEM/CFD simulations (TRL4->5) Six further publications are planned for ECIC 10/2024 in Bardolino.
CO2 Emissions Reduction Potential - Implementation and Future Market	The knowledge and the digital toolkits of MaxH2DR will significantly support DR process monitoring, control and optimisation as well as investment planning. This enables a sooner and more intensive H2-enrichment, a decrease of costs and operational risks, and a support of investment decisions. Reliable digital optimisation, monitoring and control will improve efficiency, safety and sustainability in the steel industry and its competitiveness and innovation potential. The CO2 emissions from ironmaking in Europe 2030 may decrease by 9 Mt/a (assuming 20 Mt/a production via DR, mitigation of 1,1 t CO2/t by use of green H2 instead of NG, and 10% more H2 enrichment 4 years earlier). This corresponds to an economic impact of ~2 Bn. €/a in 2030 just by saving emission certificate costs. The project results will furthermore support using cheaper raw materials and achieving higher productivity and quality so that the project impact is further significantly increased.
Market Positioning	The MaxH2DR commercialisation strategy ensures that all knowledge and all tools are available for commercialisation and are intensively disseminated for full awareness of the main target groups steel producers and plant suppliers but also of researchers. The data and results will be fully published, the new test rigs will be available as service and the digital toolkits and models will be made available as service and/or by licensing or even be fully published (DEM/CFD simulation framework). Different service packages will be proposed to customers with different extent and duration also including ad-hoc personalised services at an extra charge.

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	After project end the tools will be further improved to raise their benefits according to the customers' needs, like e.g. online connectivity of models to industrial plants in order to improve operational monitoring and control.
Project Location	Germany, Italy
Project & Technology Links	https://www.estep.eu/clean-steel-partnership/maxh2dr