ESTEP SPRING DISSEMINATION EVENT

5-6 JUNE 2025 KRAKOW (POLAND)

MAXIMISE H_2 ENRICHMENT IN DIRECT REDUCTION SHAFT FURNACES - SUMMARY OF CURRENT PROJECT STATE

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ESTEP

MaxH2DR

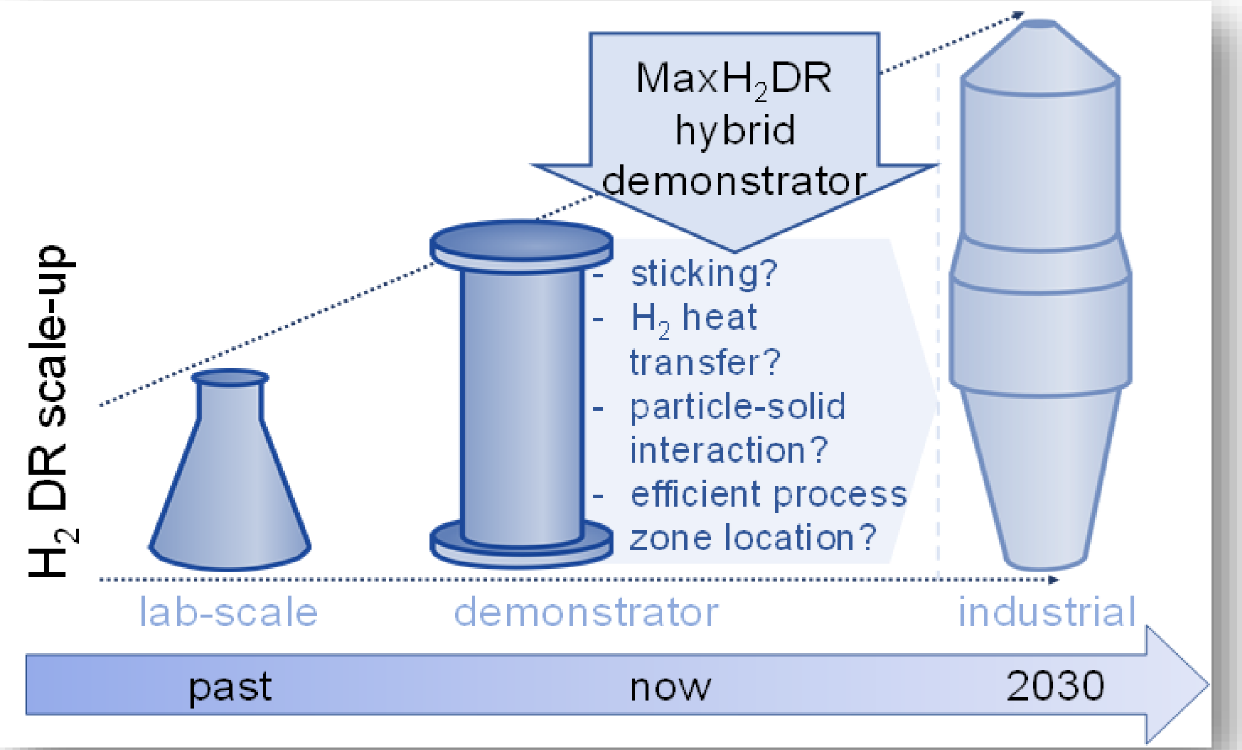
This project has received funding from the European Union under grant agreement NUMBER — 101058429 — MaxH2DR

HOTEL ★★★★ GALAXY JORDAN GROUP

Łukasiewicz GIT

MAXH2DR OVERVIEW: WHAT AND WHY ?

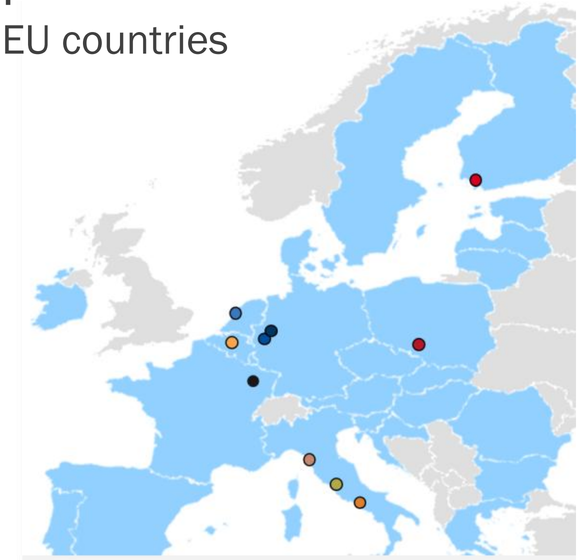
- Key facts:
  - HORIZON-IA: 4 years from June 2022 to Nov. 2026, 4.5 million Euro
  - Financial & formal coordinator: SSSA , Technical coordinator: BFI
- Background:
  - Natural gas based direct reduction fully established, but …
    … no industrial experience with >80% H2
    … operational problems and needed process optimisations unknown yet
- Objectives:
  - Knowledge: Kinetics, gas & burden flow
  - Exploit new knowledge+data into comprehensive models
  - Process analysis and optimisation



CONSORTIUM, AWARD AND GRANT

Consortium:

10 partners
from 7 EU countries



Formal coordinator: Prof. Valentina Colla, Pisa

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Net-zero industries Award 2024:

net-zero-industries-mission.net/netzero-industries-awards/

MAXH2DR WORK PLAN AND STATUS => ~70%

Horizon Europe Project MaxH2DR	
WP 1	**New fundamental knowledge and sub-models**
T 1.1	Experimental investigations of reduction kinetics in different scales
T 1.2	Experimental investigations of physical properties of raw materials, intermediates and products
T 1.3	Development of kinetic sub-models for H_2-enriched DR
T 1.4	Implementation of new kinetic sub-models into DR shaft process
WP 2	**Enabling Industrial Demonstration of Hydrogen-enriched Direct Reduction**
T 2.1	Physical demonstration of linked solid and gas flow in DR shaft furnace
T 2.2	Coupled DEM/CFD simulation of particle movement and permeability in DR shaft furnaces
T 2.3	Development of validated hybrid demonstrator by synergetic combination of models with physical demonstration
T 2.4	Scale-up towards digital demonstration of industrial DR shaft furnace reactors
T 2.5	Process optimisation for industrial scale DR shaft reactors
WP 3	**Efficient and flexible steelmaking process chains based on H2-enriched DR**
T 3.1	Adaptation and extension of available models and interconnection development
T 3.2	Stationary scenario analyses for transitional pathways
T 3.3	Dynamic investigations for flexible operation of new integrated steelworks with H2-enriched DR for high RES integration
T 3.4	Life Cycle Assessment and Cost
T 3.5	Social impact assessments
WP 4	**Dissemination, Exploitation and Communication**
T 4.1	Website and Project Branding Toolkit
T 4.2	Dissemination and Communication Strategy
T 4.3	Stakeholder consultations
T 4.4	Compliance / IPR Checks and concepts
T 4.5	Exploitation and transfer of results to recommendations
T 4.6	Exploitation to the market
WP 5	**Project Management**
T 5.1	Contractual Management
T 5.2	Technical and administrative project management
T 5.3	Reporting to the EC
T 5.4	Quality and Risk Management

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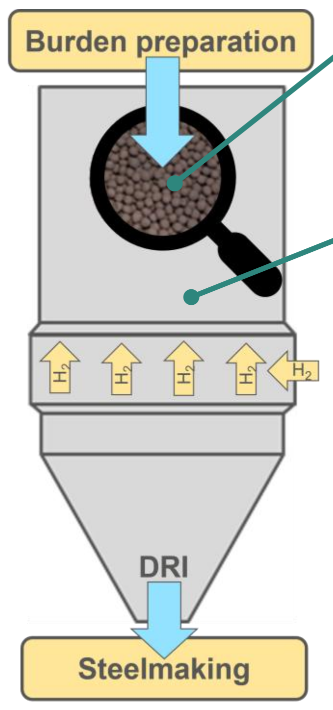
Now

MAXH2DR - OVERALL CONCEPT

1) Hybrid demonstration: Validating and fusing models with physical demonstration

2) Three perspectives of investigation:



WP1: "Particle scale"

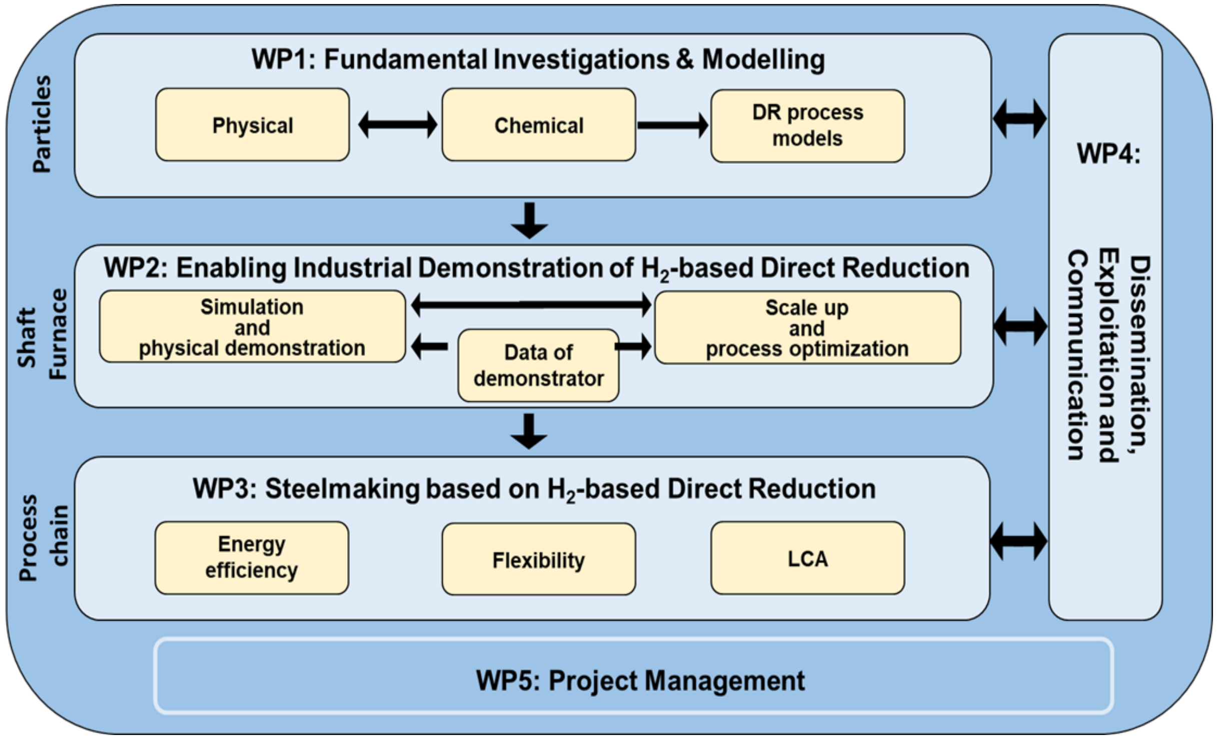
- Laboratory experiments
  - Kinetic sub-models

WP2: "Furnace scale"

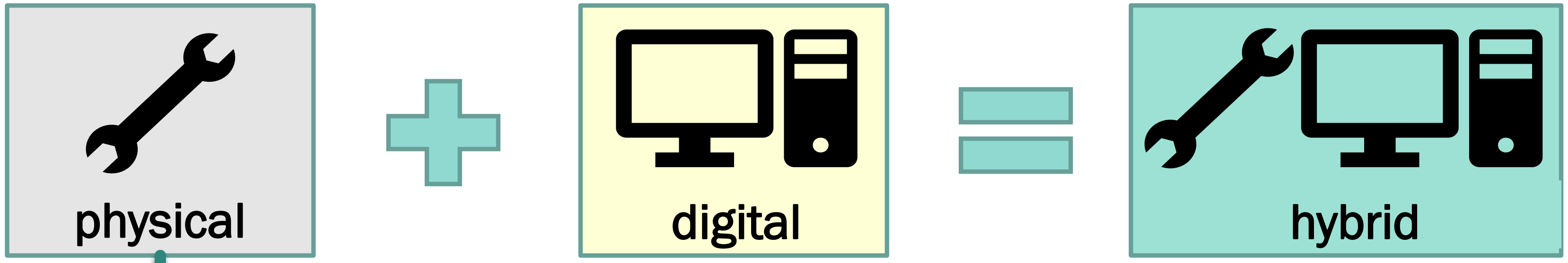
- Bulkflow demo experiments
- Fusion of 3 shaft furnace models
- Validation & process optimisation

WP3: "Process chain scale"

- Scenario analyses
- LCA, LCC, social impacts



MAXH2DR HYBRID DEMONSTRATION APPROACH

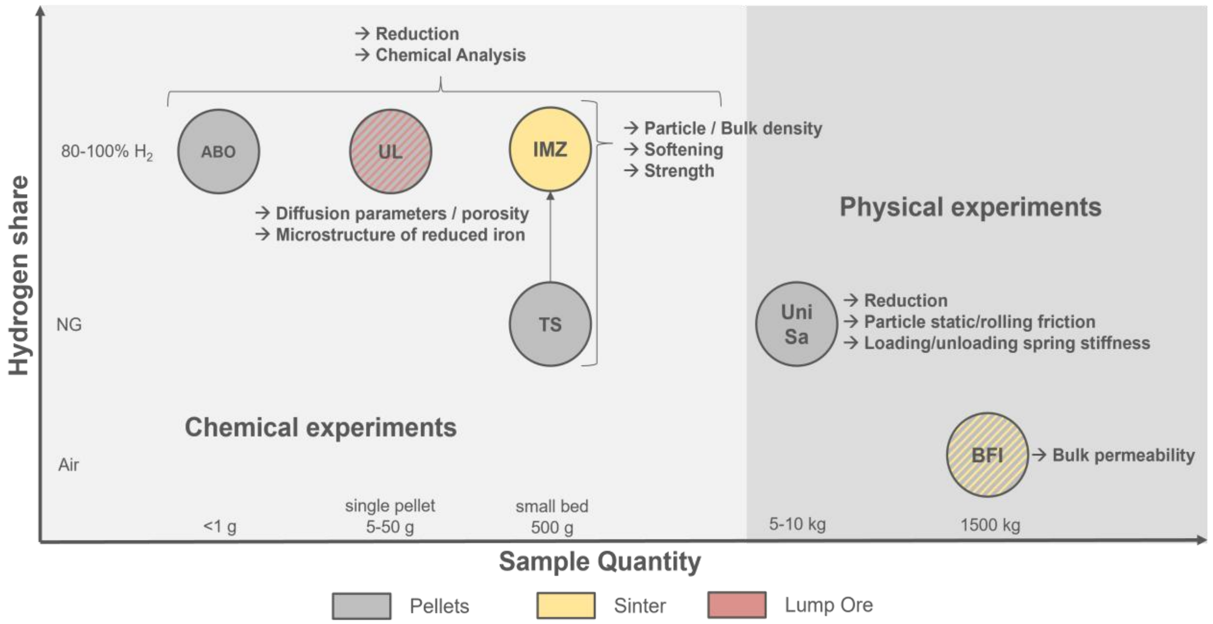


Physical components:

- Chemical laboratory experiments on kinetics
- Physical experiments (DRI properties & forces)
- Bulk & gas flow in demo scale

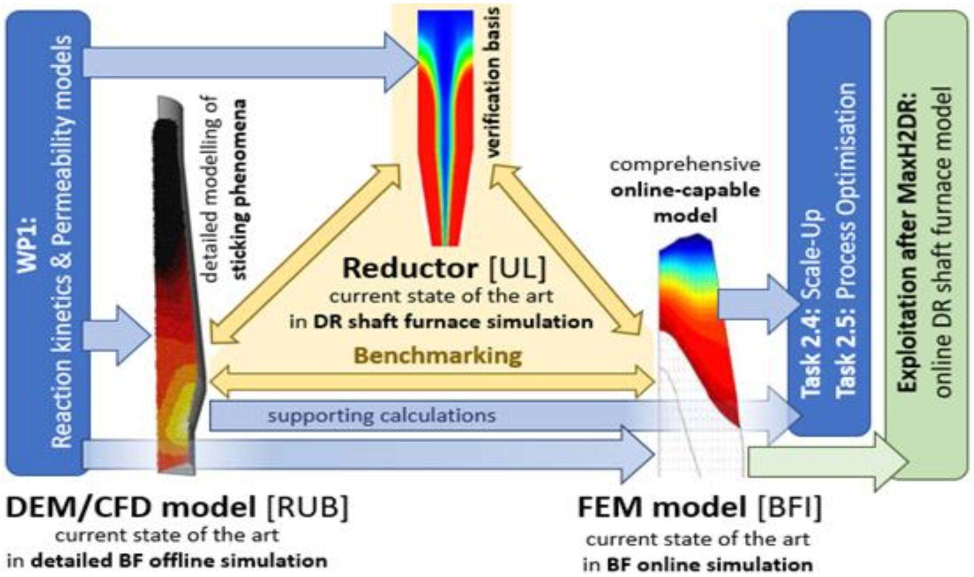
Digital components:

- Kinetic model
- DR shaft furnace models (FVM, FEM, CFD-DEM)
- Process chain model kit

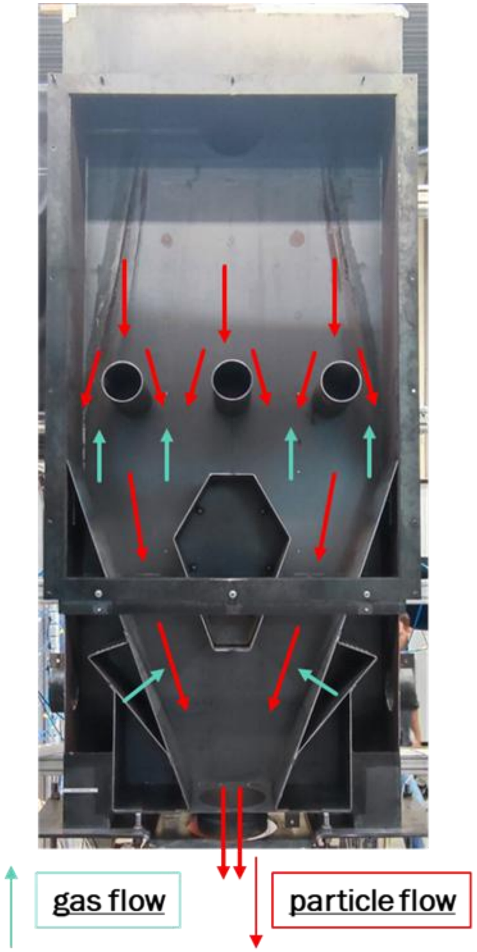


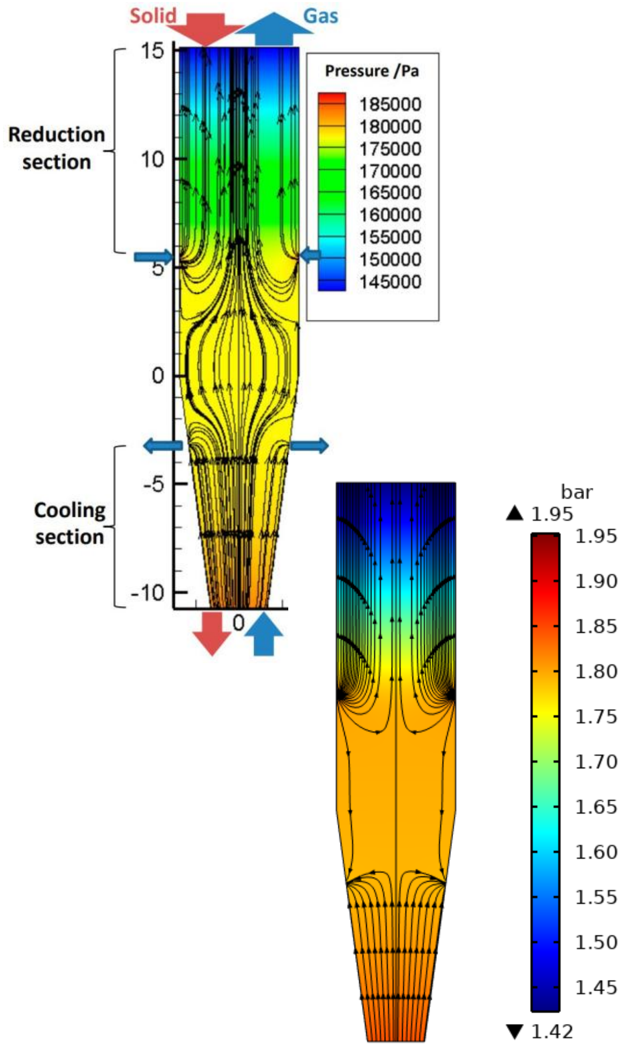
WP2: SELECTED OBJECTIVES AND PRELIMINARY RESULTS

- Key-Objectives:
  - Demonstration scale test rig for solid+gas flow
  - Synergistic combination of DR shaft models



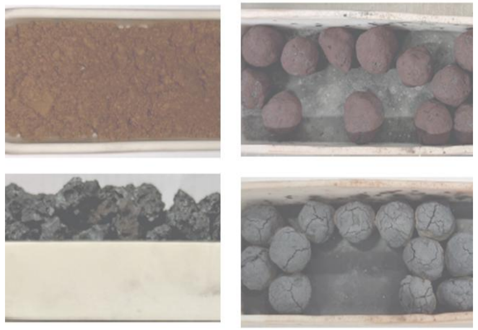
- State of work:
  - Experiments with DR-Pellets completed, experiments with smaller particles ongoing
  - First model versions ready and benchmarking started

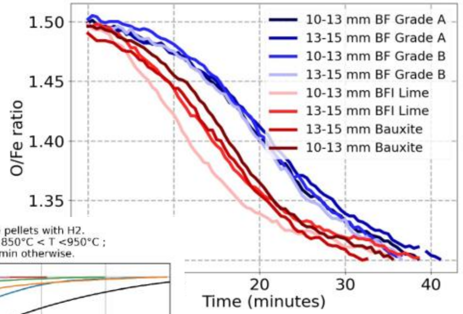


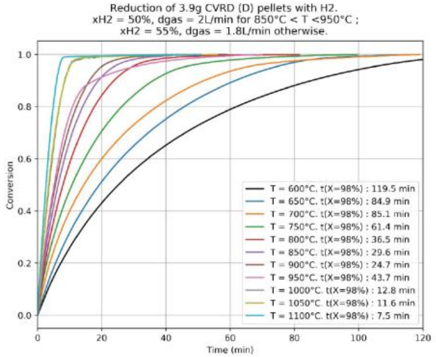


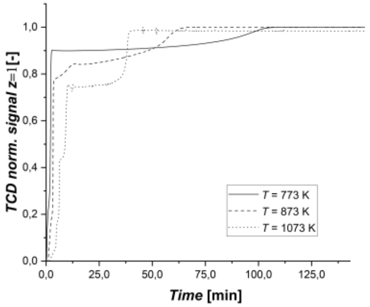
WP1: PRELIMINARY RESULTS ON KINETICS

- **Approach and results:**
  - tests with powder (AAU), single pellets (UL) and bulk material (TS, IMZ)
  - Reduction experiments for H_2-enriched DR and new sophisticated kinetic model
  - World-first test rig for adhesive forces of pellet bulks at industrial conditions

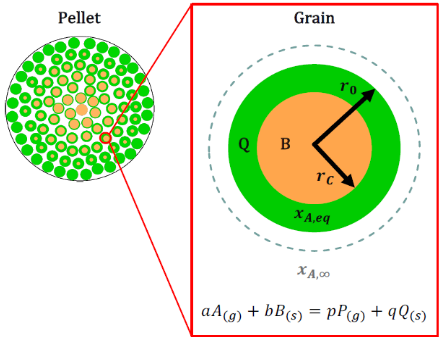


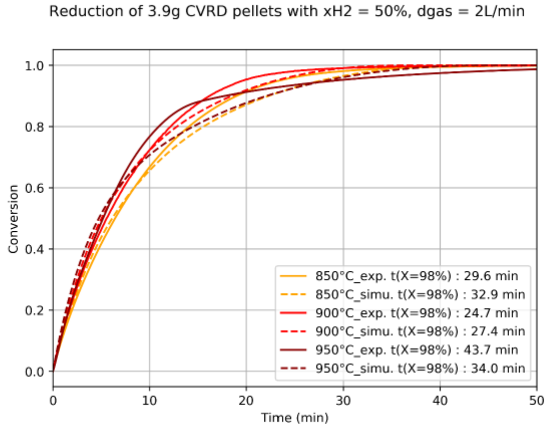






- **Exploitation into kinetic model:**
  - Grain model considers changes in microstructure
  - Implementation in FEM, FVM and CFD-DEM simulations





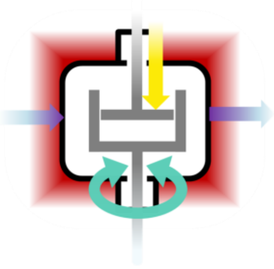
[1]

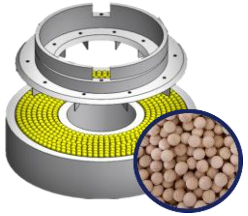
Figure 14 : Comparison of simulated and experimental results for the reduction of CVRD (D) pellets at 850, 900 and 950°C.

[1] HEU Project 101058429, MaxH2DR Deliverable 1.3. New kinetic models for the reduction of iron ore in H2-rich atmosphere, A. Marsigny, H. Saxen, F. Patisson

WP1: INVESTIGATION OF SOLID BEHAVIOUR

- World-first test rig for adhesive forces of moving bulk materials





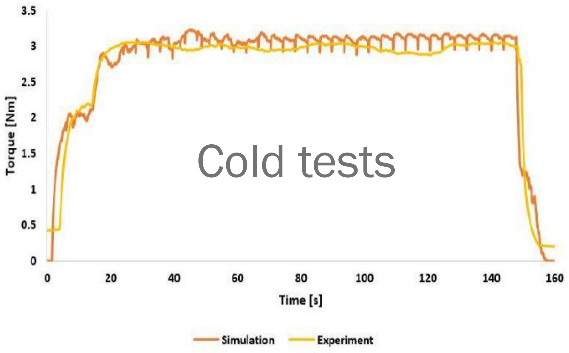
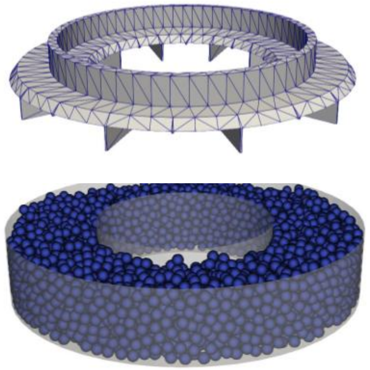


Figure 15: Torque evolution during one shear cycle at 50 N normal load, comparing experiments and simulations with cohesion

[1]



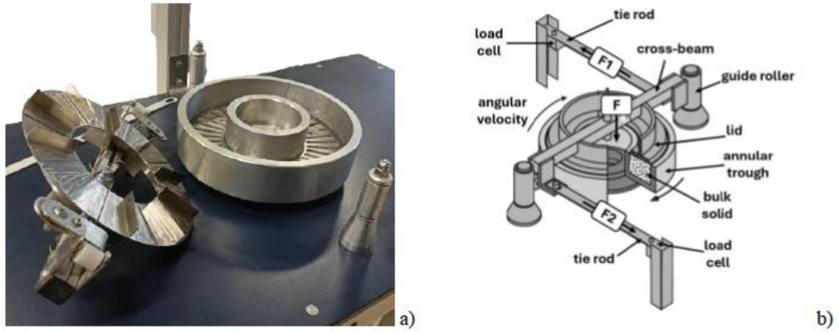


Figure 1: Rotational Shulze Shear Tester used in the experiments: a) the lid and the annular trough; b) the setup and the involved forces.

Force measurements under realistic DR-conditions

- Normal load of 800 kPa
- High temperature up to 1000 °C

Investigation of DRI properties

- strength
- swelling
- softening

➢ Exploitation into DEM code

Detailed modeling of particle movement and forces

Digital twin of shear cell enables calibration of DEM code with test results

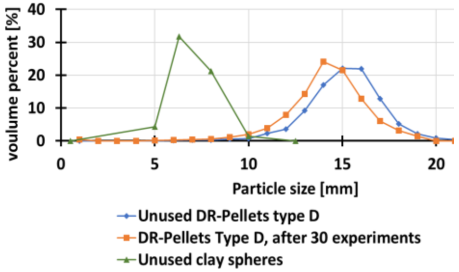
[1] Discrete Element Modeling of Shear Cell Experiments with Cohesive Wooden Spheres, K. Qyteti, S. la Manna, et. Al.

WP2: PHYSICAL DEMONSTRATION OF LINKED SOLID AND GAS FLOW

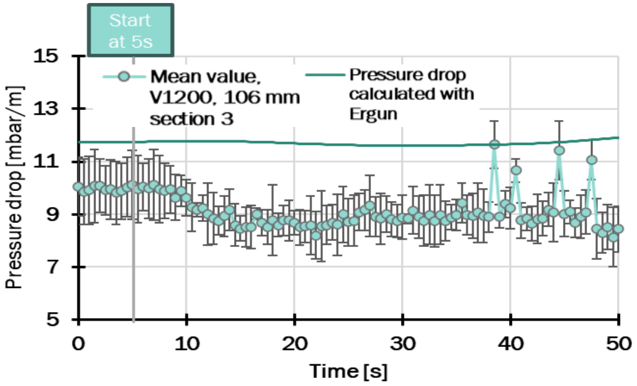
- Demonstration of linked solid and gas flow by experiments at BFI
- Output: Local pellet movement and permeability

➢ Calibration of furnace models

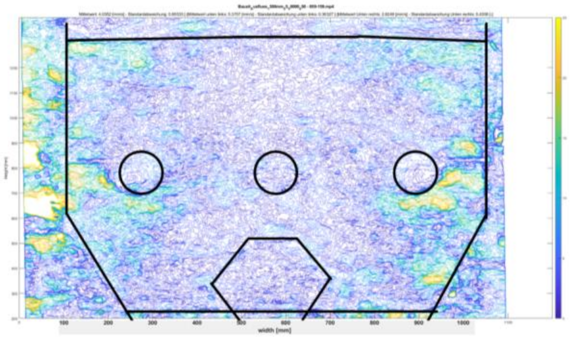
- Different materials are used
  - Wooden spheres (d=12/15 mm)
  - DR-Pellets ($\bar{d}$=14.5 mm)
  - Clay spheres ($\bar{d}$=5.9 mm)

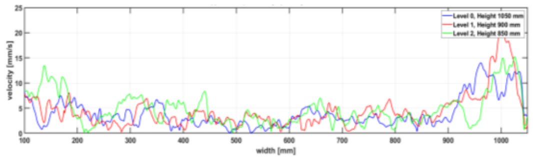


Local pressure drop

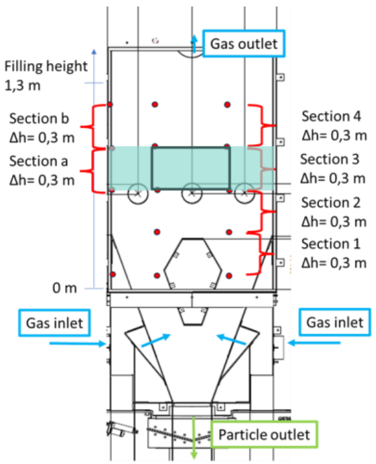


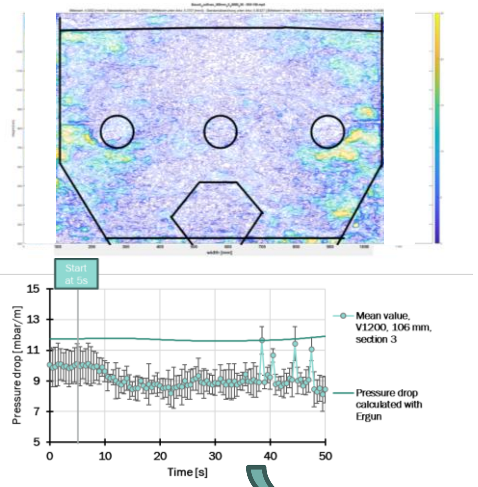
Local solid flow

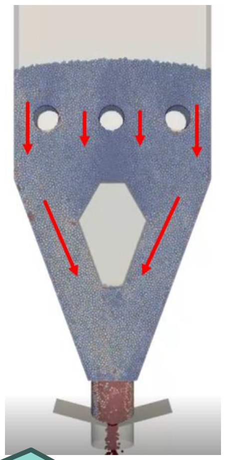


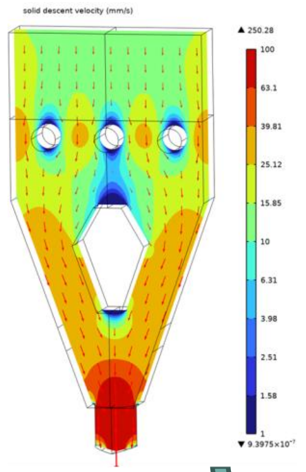


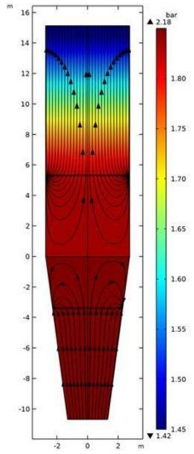
WP2: HYBRID-DEMONSTRATION TO CREATE VALID DIGITAL TWINS

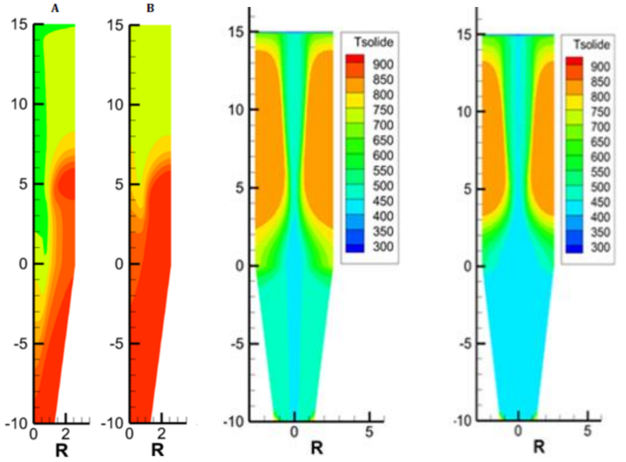












Variation of Bustle/Cooling Gas / solid flow

Physical bulk investigations (shear cell, demo plant)

- solid forces
- solid movement
- bulk permeability

Interaction of Gas-/solid flow

Lab experiments with different materials

CFD-DEM and FEM simulation of shear cell and demo plant

Calibration of permeability profile

Calibration of solid movement:

- Detailed for single particles (DEM)
- Simplified by rheology model (FEM)
- Benchmarking of DEM/FEM model

Next step: Investigation of installations

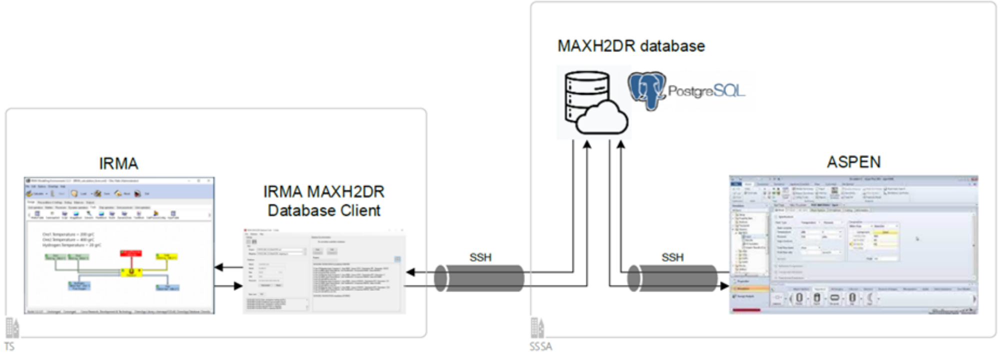
Upscaling to DR-shaft dimensions

- Benchmarking of models
- Parameter analyses
- Determine local conditions within industrial plants from validated digital twins

Next step:
Process optimization and recommendations for different H2 content

WP3: SELECTED OBJECTIVES AND PRELIMINARY RESULTS

- **Key-Objectives:**
  - Process chain simulation toolkit combining AML, IRMA and ASPEN
  - Promising future plant states including H_2-enriched DR
  - Assessment of optimal energy and material usage and costs including LCA
- **State of work:**
  - Simplified prognosis of transition routes using AML
  - Database and IT architecture available and interconnection demonstrated
  - Models of process units developed



System overview (left TS and right SSSA parts)

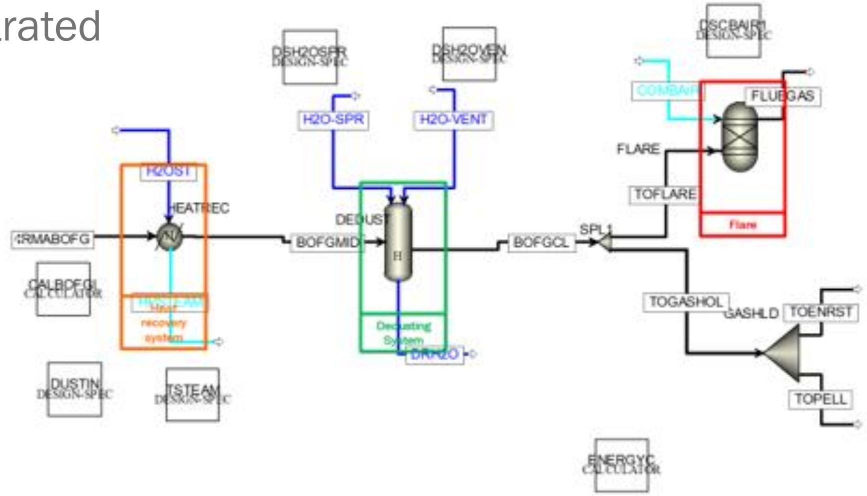
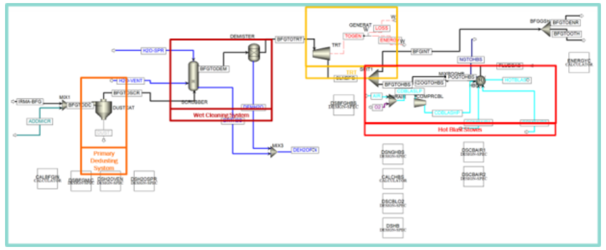


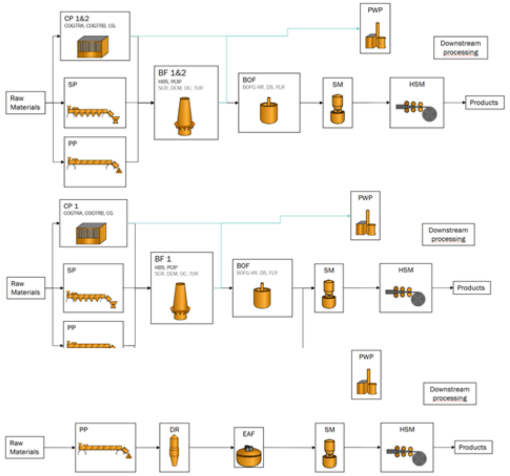
Figure 5. BOFG area model flowsheet.

[1] Guiding the transition towards H2-DRI based steelworks through a related simulation toolkit, Scuola Superiore Sant'Anna , I. Matino, V. Colla, A. Vignali

WP3: PROCESS INTEGRATION INTO INTEGRATED STEELPLANTS

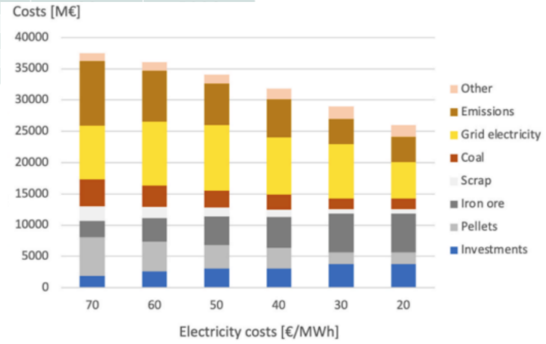
Section	Sub - process	Modelling tool
Raw Materials	Sinter plant	IRMA
	Pellet plant	IRMA
	Cokes plant 1 & 2	IRMA
	Coal grinding line	IRMA
Iron and steel making	Blast furnaces 1 & 2	TS HMB integrated in IRMA
	Basic oxygen steel plant	TS TCM integrated in IRMA
	Casters	Black box[1] in IRMA
	Hot strip mill	Black box in IRMA
Gas – energy	BFG Treatment area	Aspen Plus
	BOFG Treatment area	Aspen Plus
	COG Treatment area	Aspen Plus
	Mixing and Enrichment Station	Aspen Plus
	Auxiliary Boilers	Aspen Plus
	Power plant	Aspen Plus
	Air Separation Unit	Aspen Plus





MIDREX MODEL RESULTS

Variable	Unit of Measurement	Simulation	Reference
Iron Input Material	t/t_{DRI}	1.35	1.36-1.45
NG consumption	Nm^3/t_{DRI}	294.3	257-300
O_2 consumption	Nm^3/t_{DRI}	38.3	12-30
DRI metallic Fe	%wt	85	81-90
DRI Metallization	%	94	92-96
DRI C Content	%wt	2(50% as Fe_3C)	1-4
HDRI Temperature	°C	657	650-730
Bustle Gas CO Content	%vol.	33.2	29.8-36.0
Bustle Gas H_2 Content	%vol.	52.6	49.7-55.0
Bustle Gas CH_4 Content	%vol.		
Bustle Gas CO_2 Content	%vol.		
Bustle Gas H_2O Content	%vol.		
Bustle Gas Temperature	°C		
Top Gas Temperature	°C		



Coupling of different models and databases

Modeling of specific units in Aspen plus

- Definition of the possible process value ranges

Implementation of optimized DR-shaft model

Static and dynamic simulation of the process chain

- Including power plants and production of input material (coke, sinter, pellets)
- Different transformation steps of the process chain

Evaluation of different scenarios

Considering different developments of costs like electricity

Cost minimisation towards H_2 enrichment

SUMMARY

- MaxH2DR integrates …
  - … investigations on different scales from powder to steel plant
  - … different model approaches for maximum synergy
  - … digital with physical-chemical investigations for „hybrid-demonstration“
- MaxH2DR provides …
  - … a lot of new data and knowledge
  - … world-first test rigs and models

Project website via estep.eu

Follow us on Twitter and LinkedIn

➢ **Stay tuned for upcoming results !**

THANK YOU FOR YOUR ATTENTION!

THANKS TO THE COLLEAGUES FOR THE GREAT COOPERATION !