ESTEP 2025 Annual Event
28-30 October 2025
Udine (ITALY)

How decarbonisation, digitisation and circular solutions forge the sustainable European steel future?

Jean BORLEE
CRM
Unit Manager ELIMIN

UPSCALING AT CRM
to support EU Iron-&Steelmaking de-carbonization & Circular Economy Roadmaps

Pre-processing tools

...

. ...

SinByOSe
TRANSinter

COACH

ZincVal
Zhyron

Application in
Iron-&Steelmaking
processes

Ironmaking pilots

EAF/SAF/Plasma
furnace
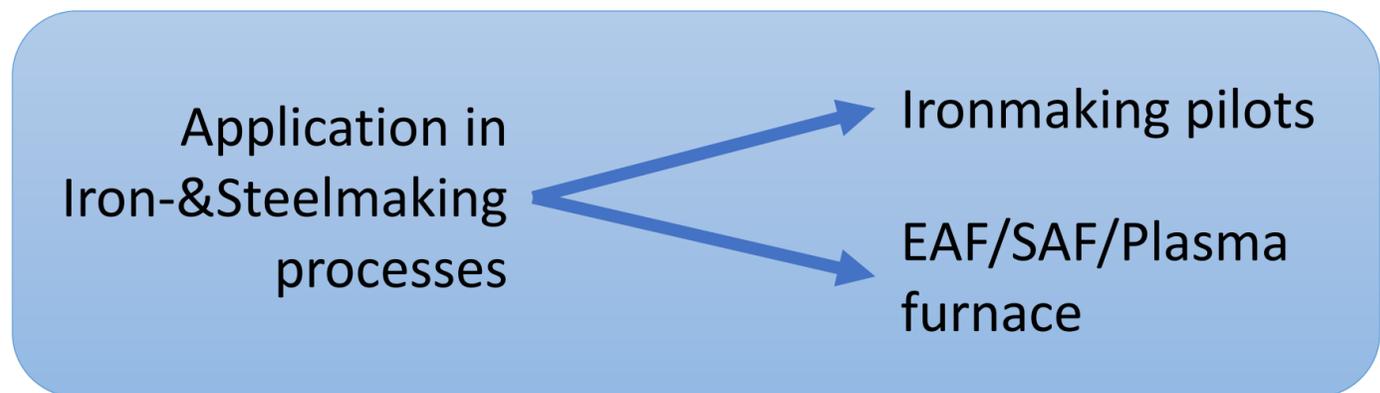
Ironmaking pilots BF & DR

Lab reduction furnace

500 g samples
Ambient pressure
Max 1000°C
ISO 11258:2015 or R180/COREM

HUGE

Batch processing of a fixed bed of granular solids → **40kg DRI**
- Sample : ∅16 cm - height 115 cm
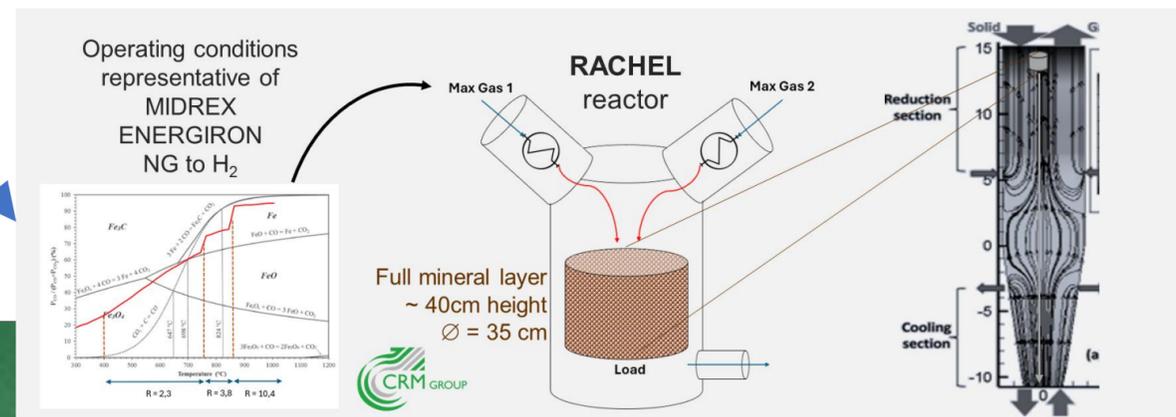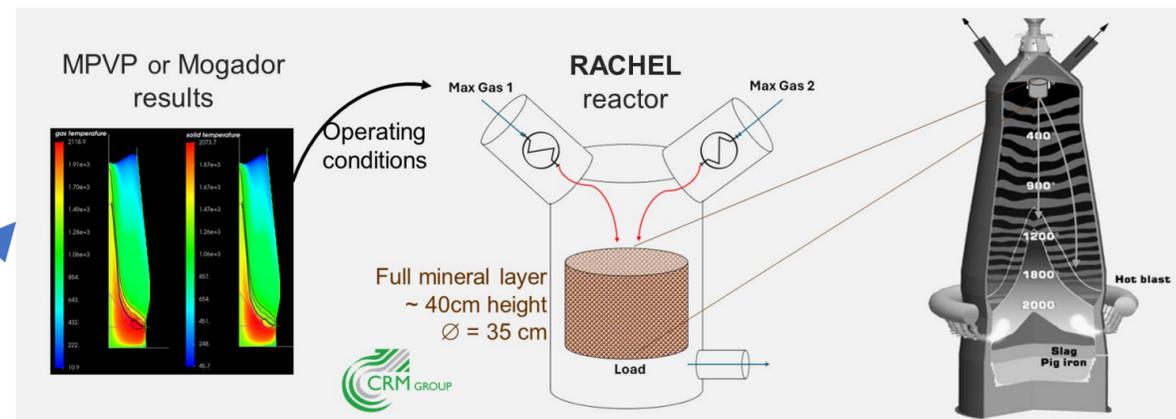- max 1000°C & 45 bar
- air, O_2, CO, CO_2, CH_4, **H_2O**, N_2, **H_2**

RACHEL 2025

55kg DRI – 10 bar

Full grain size distribution

Sinter, pellets, CBA
Mixed charges

N_2, CO_2, H_2, CH_4 & CO

100 NM³/h

1000°C

10 bar

H₂transBF 2030

Safe H-DRI

HBI C-Flex

MPVP or Mogador results

Operating conditions

RACHEL reactor

Max Gas 1   Max Gas 2

Full mineral layer ~ 40cm height
∅ = 35 cm

Load

400
900
1200
1800
2000
Hot blast
Slag
Pig iron

Operating conditions representative of MIDREX ENERGIRON NG to H_2

RACHEL reactor

Max Gas 1   Max Gas 2

Full mineral layer ~ 40cm height
∅ = 35 cm

Load

Solid   G
Reduction section
Cooling section

R = 2,3   R = 3,8   R = 10,4

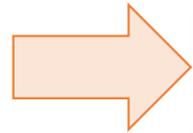# Pilot EAF/SAF/Plasma furnace

...

InSGeP

· ...

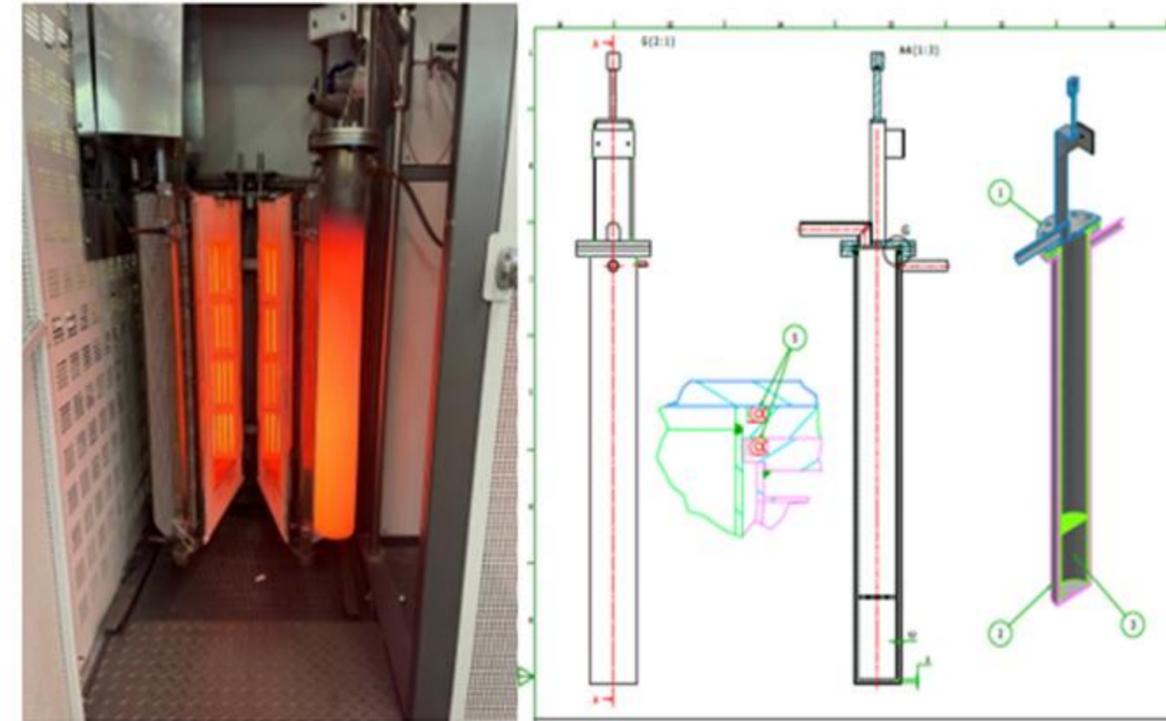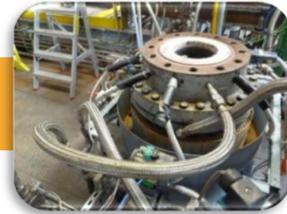# Direct Reduction reactors

Lab reduction furnace

500 g samples
Ambient pressure
Max 1000°C (1100°C ?)
ISO 11258:2015 or R180/COREM

HUGE

Batch processing of a fixed bed of granular solids → **40kg DRI**
- Sample : ∅16 cm - height 115 cm
- max 1000°C (1050°C?) & 45 bar
- air, O_2, CO, CO_2, CH_4, **H_2O**, N_2, **H_2**

RACHEL

Upcoming

55kg DRI – 10 bar
2 trials / day

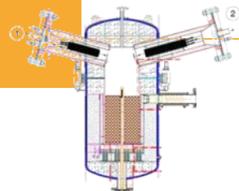**MIDREX
ENERGIRON
NG vs H_2**

Lab reduction furnace
- 2 coaxial tubes (sample on grate in inner one)
- Upward gas flow (inner tube)
- Gas is heated as it flows between both tubes
- Preheating to reduction temperature under a nitrogen flow

Input gas : N_2 - CO - CO_2 - H_2 – CH_4
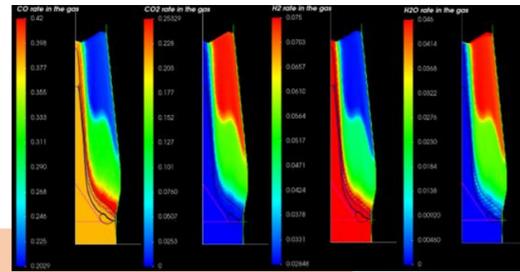
For a better future

Blast Furnace

Ways and means

On-line Dust counting/sizing
- Pilot + industrial scale

MOGADOR
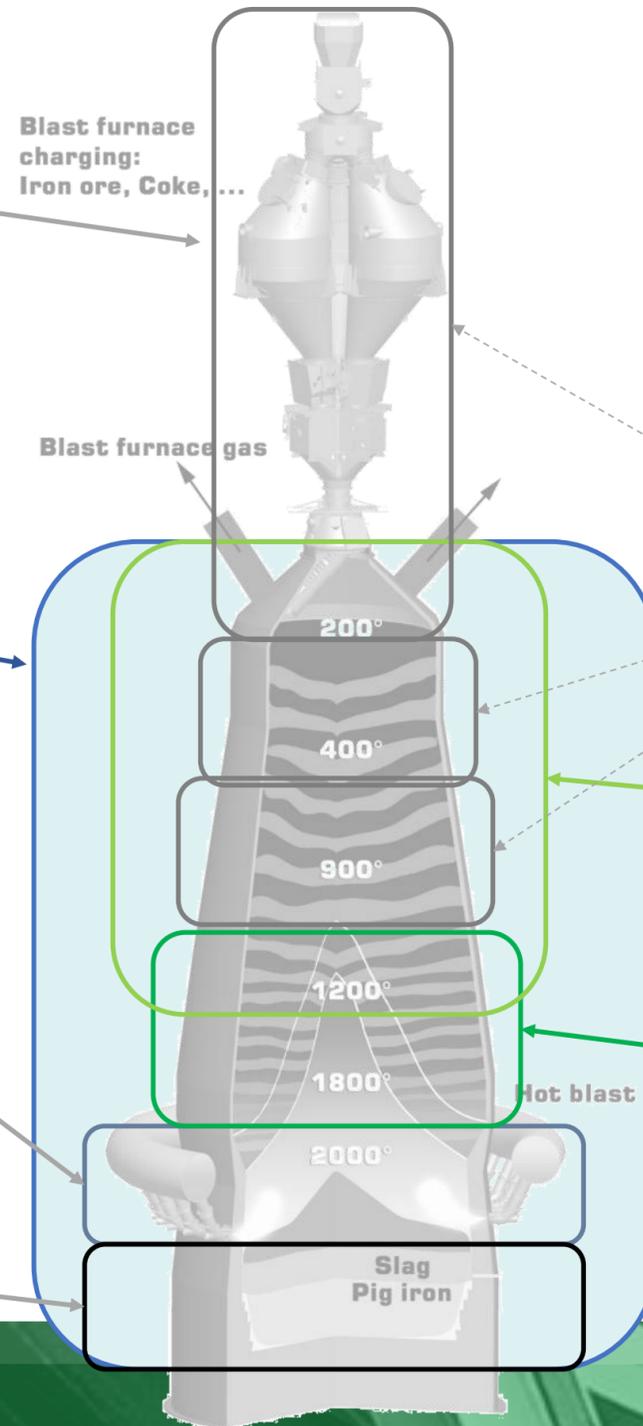2-D mathematical model of the blast furnace at steady state (symmetry of revolution)

+ FactSage

Design of instrumented tuyere
- Char movement
- Raceway depth
- Gas chemical analysis
- Raceway Temperature

Liquid levels model
Based on strain gauges measurements

Blast furnace charging: Iron ore, Coke, …

Blast furnace gas

200°
400°
900°
1200°
1800°
2000°

Hot blast

Slag
Pig iron

Burden characterisations

Carboneous burden

Cokarac
Coke degradation in the …
Thermal + mechanical + chemical

Ferrous burden

Standard Tests
- ISO T (2015)
- RDI (2017)
- Reducibility (2017)

HUGE/RACHEL reactors
New shaft simulation trial
Full grain size distribution

Softening trials
Shrinkage under load → Start of softening and start of melting trial.

Viscometer (rheometer)
- Working temperature range: 600 - 1650 °C
- Liquid slag volume : 20 ml

Cold bonded agglomerates

Briquetting	Extrusion
B-220B roll press by Komarek	De-airing extruder by Handle (100 l/h)

ELIMIN pyrolysis facilities
Alternative reductants

DR reactor configuration

Variable gas inlet : H_2, N_2

Variable gas inlet :
CO, CO_2, H_2O, O_2

Pre-heater

Pre-heater : max 350-400°C but high flow (10-20Nm³/h)

600-1000°C max

Pre-heating Balls ~55 cm

H = 1.7m, inner diameter= 16 cm

Max 950-1000°C
Heating cycle freely adapted

Pellets
~115 cm
45 kg

HBI C-Flex

MIDREX

ENERGIRON

NG vs H_2

Gas output + analysis :
CO, CO_2, H_2, O_2, CH_4, C_2

- 40 kg DRI
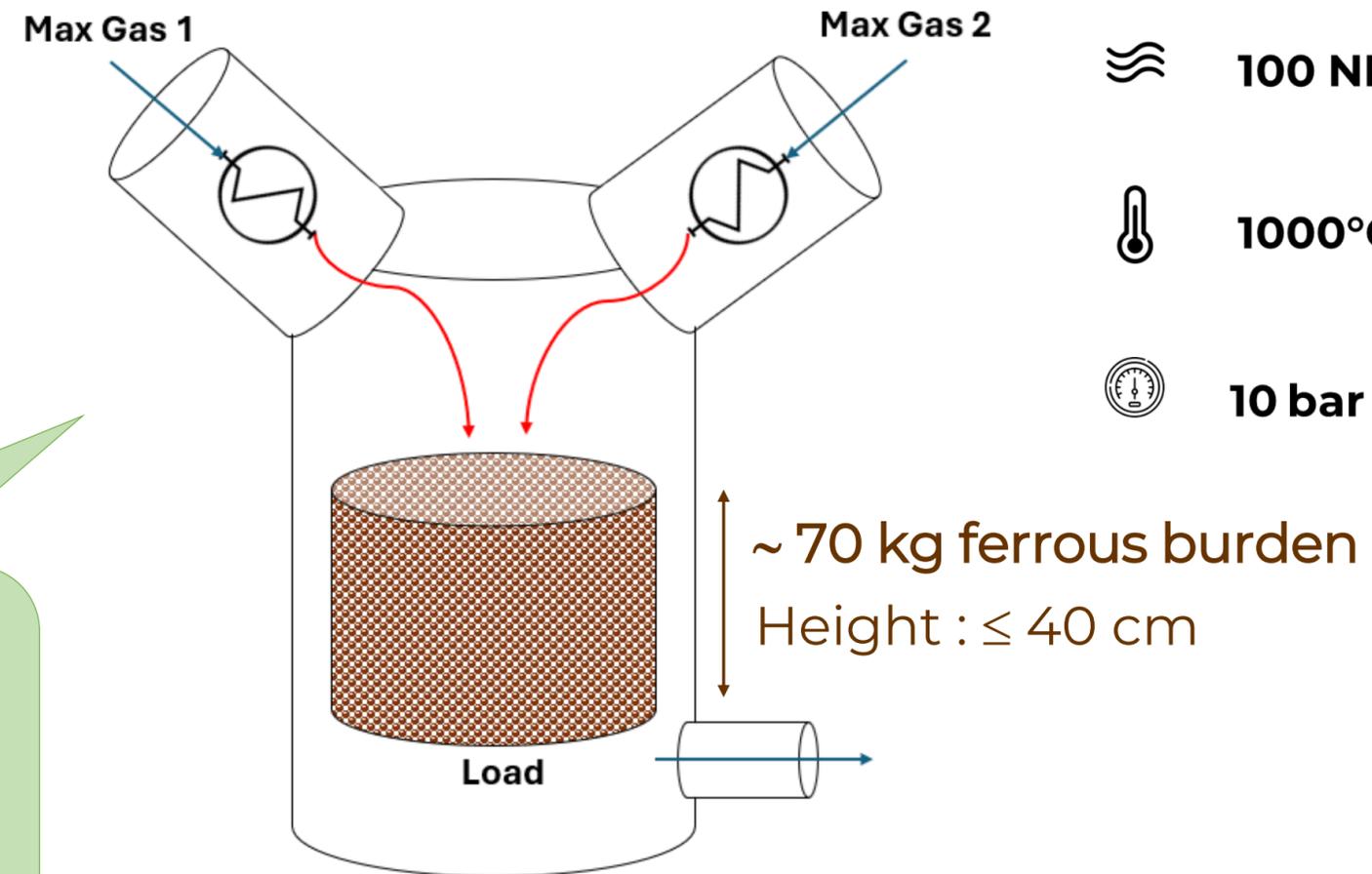- Weakness = time consuming
  → RACHEL

For a better future

New reduction pilot reactor
RACHEL

- Max 10 bars = 'easier' to operate
    ⇔ 2trials/day
- Homogeneous **55 kg** DRI

- Integration in existing HUGE infrastructure

- Commissioning S2 2025

N$_2$, CO$_2$, H$_2$, CH$_4$ & CO

100 NM³/h

1000°C

10 bar

Max Gas 1

Max Gas 2

~ 70 kg ferrous burden

Height : ≤ 40 cm

Load

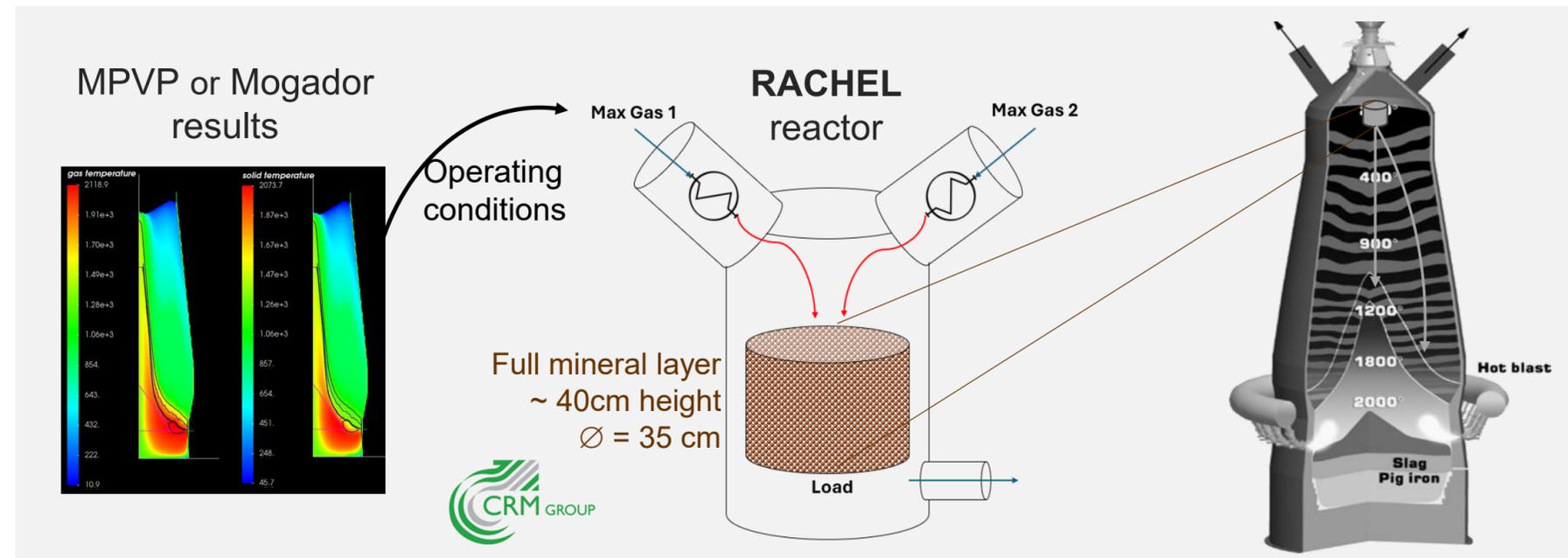**BF or DR shafts**

Classical & high%H$_2$ working points

BF shaft simulation
based on RACHEL reactor

Main features:

- Testing a full mineral layer
  - Height up to 45 cm
  - full grain size distribution and large size particles vs. very narrow grain size and small particles tested in classical lab tests
- Possibility to include mixes of [sinter & pellets + Cold bonded agglomerates]
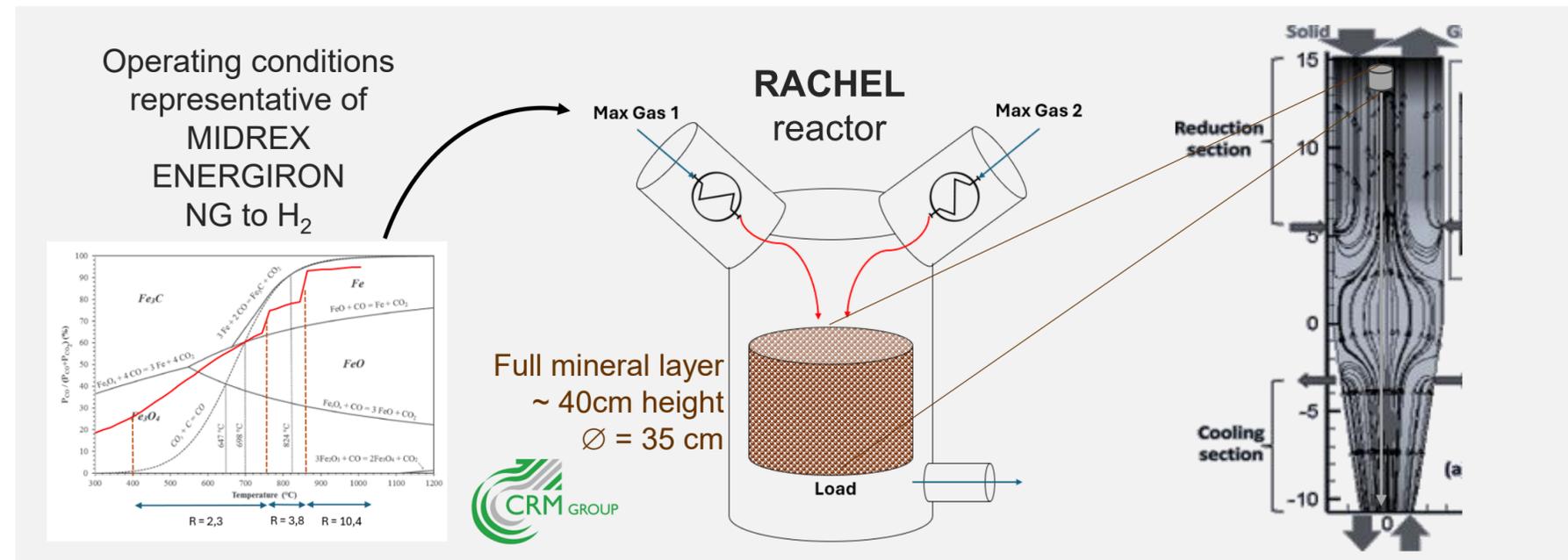- Possibility to simulate specific descent path with actual gas composition and flow

Gas injection and reactor temperature regulated to simulate a specific descent path, according to on-site probing or modelling (CRM's Mogador model) → variables in time

DR shaft simulation
based on RACHEL reactor

Main features:

- Testing a full mineral layer
  - Height up to 45 cm
  - full grain size distribution and large size particles vs. very narrow grain size and small particles tested in classical lab tests
- Possibility to include mixes [pellets + Cold bonded agglomerates]
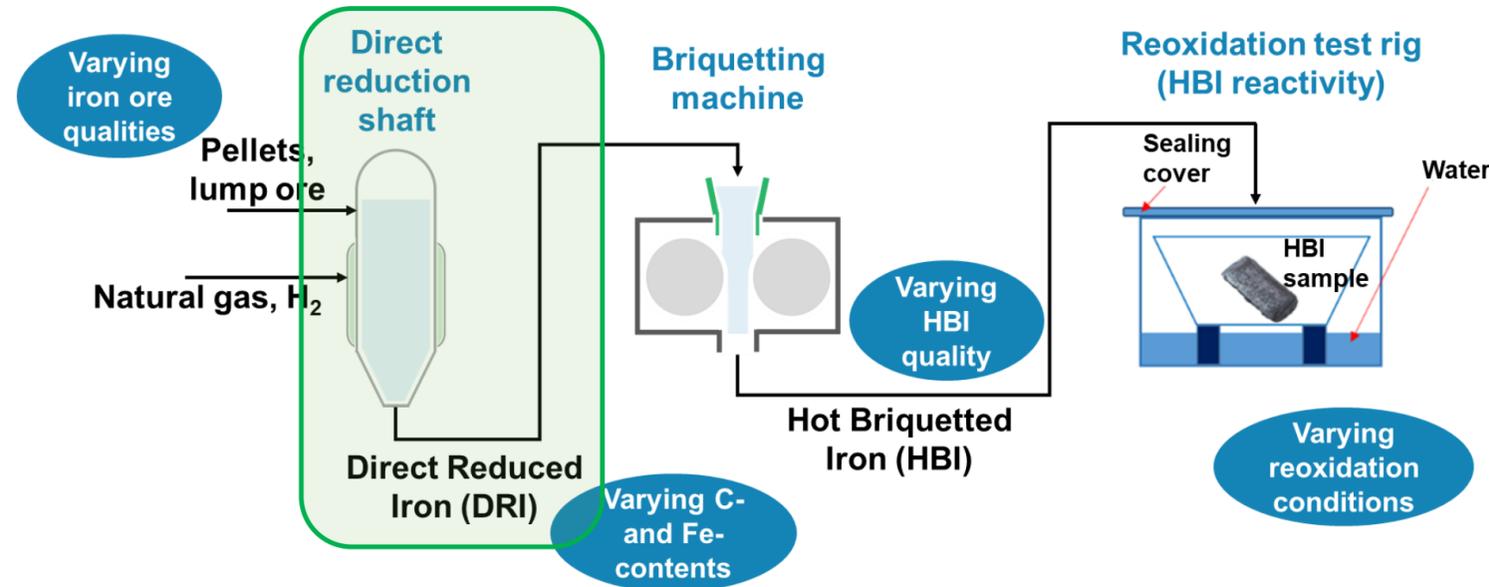- Possibility to simulate specific descent path with actual gas composition and flow

Gas injection and reactor temperature regulated to simulate a specific descent path, according to on-site probing or modelling (CRM's Mogador model) → variables in time

HBI C-Flex Project: Reoxidation behaviour and stability of direct reduced and hot briquetted iron with variable iron and carbon content

HBI C-Flex

CRM GROUP

- **Start date:** 01.07.2023
- **Duration:** 42 months
- **Budget:** 2.4 Mio. €
- **Coordinator:** K1-MET GmbH
- **Contact:** info@hbi-c-flex.eu
- **Website:** www.hbi-c-flex.eu

TATA STEEL · voestalpine ONE STEP AHEAD.

Köppern · TUBAF Die Ressourcenuniversität. Seit 1765. · PRIMETALS TECHNOLOGIES

CRM GROUP

ArcelorMittal · MONTAN UNIVERSITÄT LEOBEN · voestalpine ONE STEP AHEAD. · K1 MET metallurgical competence center

Varying iron ore qualities — Direct reduction shaft — Pellets, lump ore — Natural gas, H$_2$ — Direct Reduced Iron (DRI) — Varying C- and Fe-contents — Briquetting machine — Varying HBI quality — Hot Briquetted Iron (HBI) — Reoxidation test rig (HBI reactivity) — Sealing cover — Water — HBI sample — Varying reoxidation conditions

Supportive Advisory Board

Mitsubishi Corporation · ROGESA · RioTinto

FMG Fortescue · NUCOR · MIDREX

H$_2$ green steel · BHP · iima International Iron Metallics Association

ENERGIRON DRI TECHNOLOGY BY TENOVA AND DANIELI · MITSUI & CO. · POSCO

NIPPON STEEL · VALE

Goals and expected results of HBI C-Flex

- Contribution to the decarbonisation of the steel industry
- Support the use of hydrogen-based direct reduction
- Examine the influences on HBI production
- Determination of **HBI reoxidation and reactivity** and strategies to avoid reoxidation
- Definition of strategies for safe handling and onsite storage
- Scientific basis for extending IMSBC Code to cover zero-carbon HBI
- Contribution to new, sustainable and low-carbon steelmaking materials
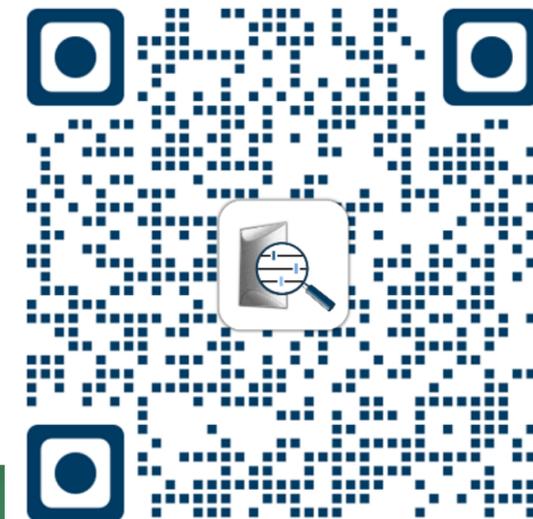
Follow HBI C-Flex on LinkedIn

For a better future
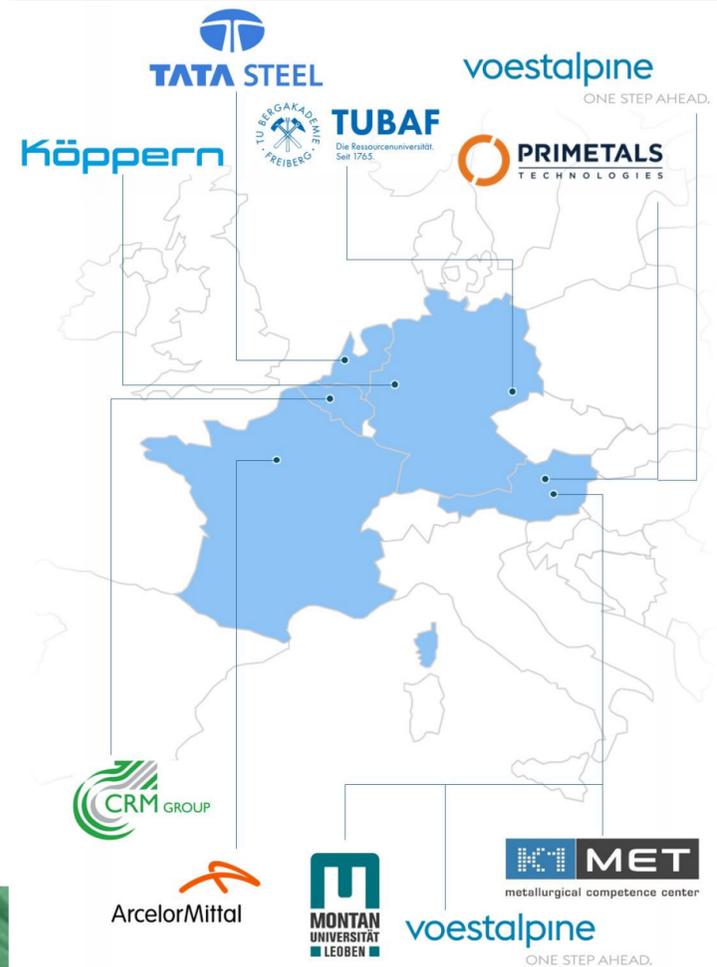
Safe-HDRI

✓ *CRM Contact persons =*
   Frederic.vanloo@crmgroup.be
   Damien.garot@crmgroup.be

Topic : Safe transport of DRI from H2-based direct reduction considering quality-related H-DRI reactivity, stability, the efficiency of passivation methods and health and recycling aspects

- H2-based direct reduction : ≠ iron ore qualities and conditions (pure H_2 and mixed with NH_3).
- H-DRI reoxidation : external and internal transport/storage + efficiency of passivation methods → to design a safe H-DRI transport system.
- Reuse of H-DRI fines produced during handling
- → updated transport system standardization and extend existing or new transport guidelines.

❖ **Project Start : Oct'24** – Kick-off meeting in Leoben 8-9 Oct'24

CRM contributions :
- **WP2** - Production of H-DRI with different qualities
  - Lab furnace   - 500 g
  - HUGE/RACHEL reactor   ~ 50kg
- **WP3** - Characterisations of input / output materials

+ Supported by letters of interest a.o.
ESTEP, Worldsteel, Eurofer, IIMA. ASMET, Erdemir, VDEh, Federacciai

| Partner	RTO / industrial	Country
K1-Met	RTO	Austria
ADI	Industrial	Italy
AM III	RTO	Spain
AM Mz	RTO	France
BFI	RTO	Germany
CRM	RTO	Belgium
Danieli	Industrial	Italy
DB cargo Aktiengesellschaft	Industrial	Germany
Dillinger	Industrial	Germany
HKM	Industrial	Germany
Innofreight Solution	Industrial	Austria
Innofreight Germany	Industrial	Germany
Univ Leoben	University	Austria
RINA	RTO	Italy
Tata Steel NL tech.	RTO	Netherlands
Univ. Salento	University	Italy
Voestalpine Stahl	Industrial	Austria
Voestalpine Stahl Donawitz	Industrial	Austria

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Optical microscopy : application for Ironmaking

Burden characterisation – Quantitative + Qualitative analysis

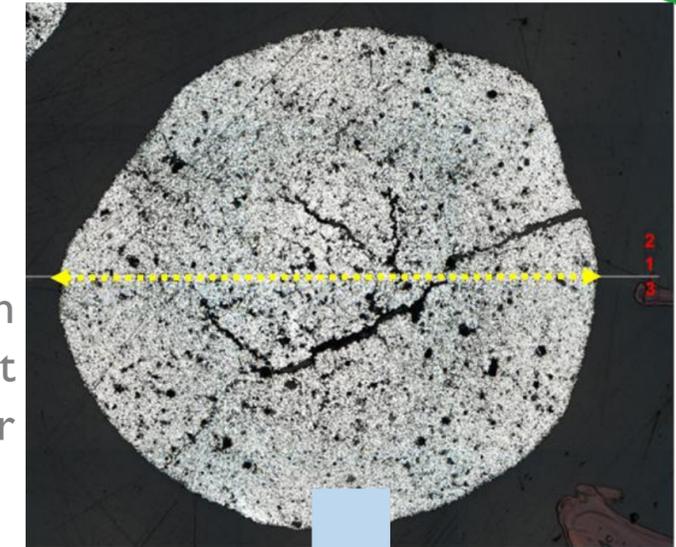- Metallization degree determination by Optical Image Analysis (OIA)
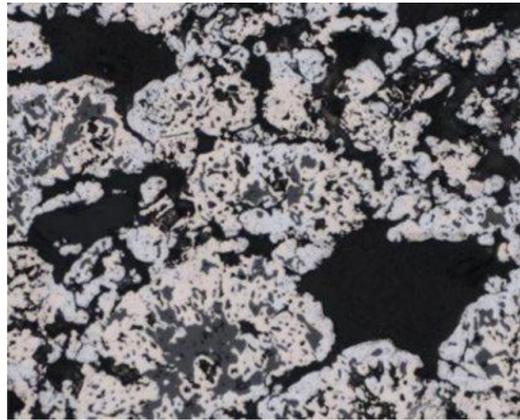
- Optical images
- 500x magnification
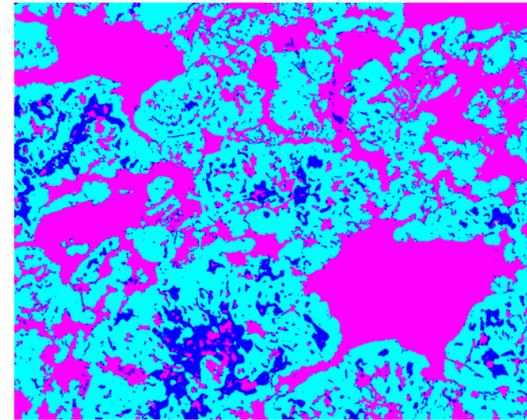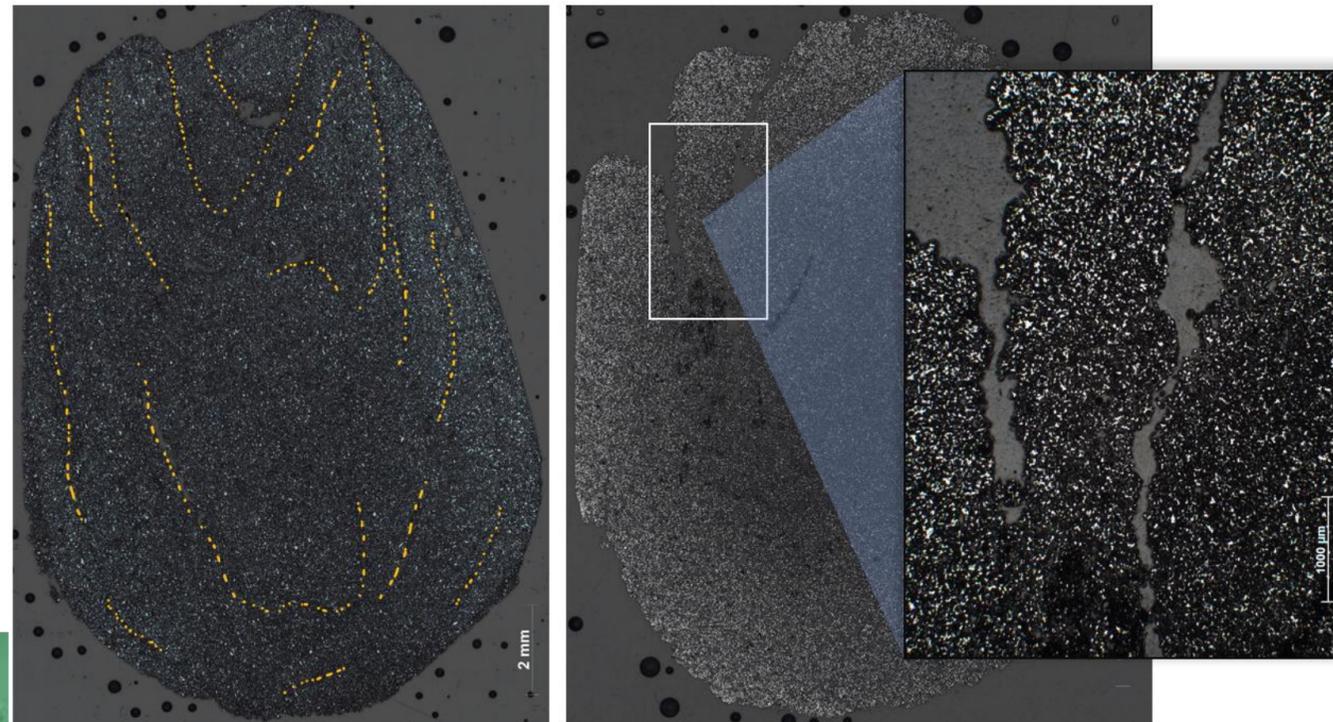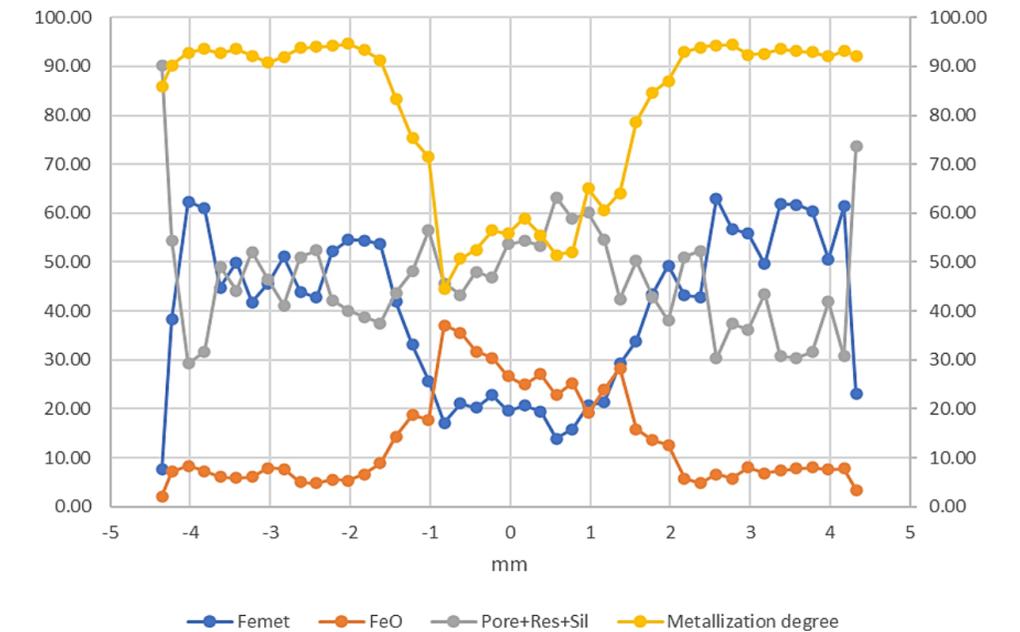
- RGB images
- Image segmentation

■ Fe metal
■ Fe oxide
■ Silicates + resin **+ pores**

Quantification
of phases pellet
diameter

Analyse pellet

Briquette's before
reduction with
"pathways" highlighted
and
reduced briquette with
cracks generated.

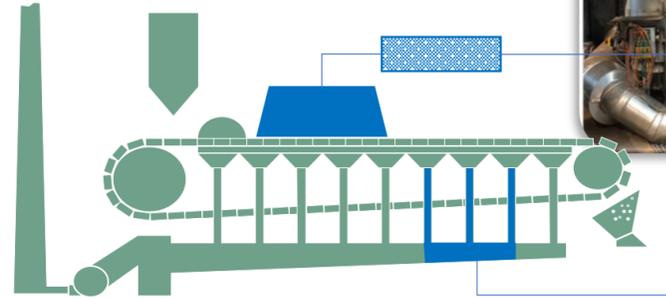Femet   FeO   Pore+Res+Sil   Metallization degree

Low CO_2 BF route

Sintering

- Waste Gas Recirculation
  - Support to plants
  - VeLoSint process

TACOS
RFCS

- Fuel gas injection
- Alternative Solid Fuels
- (New) By-products management

SinByOSe
RFCS

New 2023 :
- Sinter for DR process
- DR on sinter strands

TRANSiner
RFCS

Blast furnace

- **Cold-bonded agglomerates**
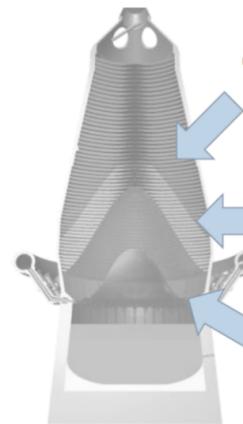 (By-products & fine ores)
  → No sintering/pelletizing step
  necessary anymore

COACH
RFCS

- **Alternative Reductants**

- **H_2-rich gas injection** at tuyere
  / lower shaft level and DRI (HBI)
  charging at BF

H2TRANSBF
RFCS

- Shaft gas injection to optimise gas utilisation and temperature zones
  - DRI/HBI to reduce energy demand and coke layer height
  - DRI/HBI + hydrogen to increase permeability
    (DRI/HBI: material stability, hydrogen: gas viscosity/density)
  - Coke oven gas, Syngas, fossil free methanol to reduce share of carbon based reduction

Alternative Reductants

Characterisation and pyrolysis tests of various mixed waste materials for assessment of their suitability for torrefaction, for gasification and for cokemaking

Rotary Kiln

Scrap

Scrap pre-treatment: Thermal pre-conditioning furnace

CAESAR (CirculArity Enhancements by Low quality Scrap Analysis and Refinement) HEU project:
Industrial demonstration of scrap sorting/cleaning based on innovative combination of best available technologies.

CAESAR
HEU

For a better future

H$_2$transBF 2030

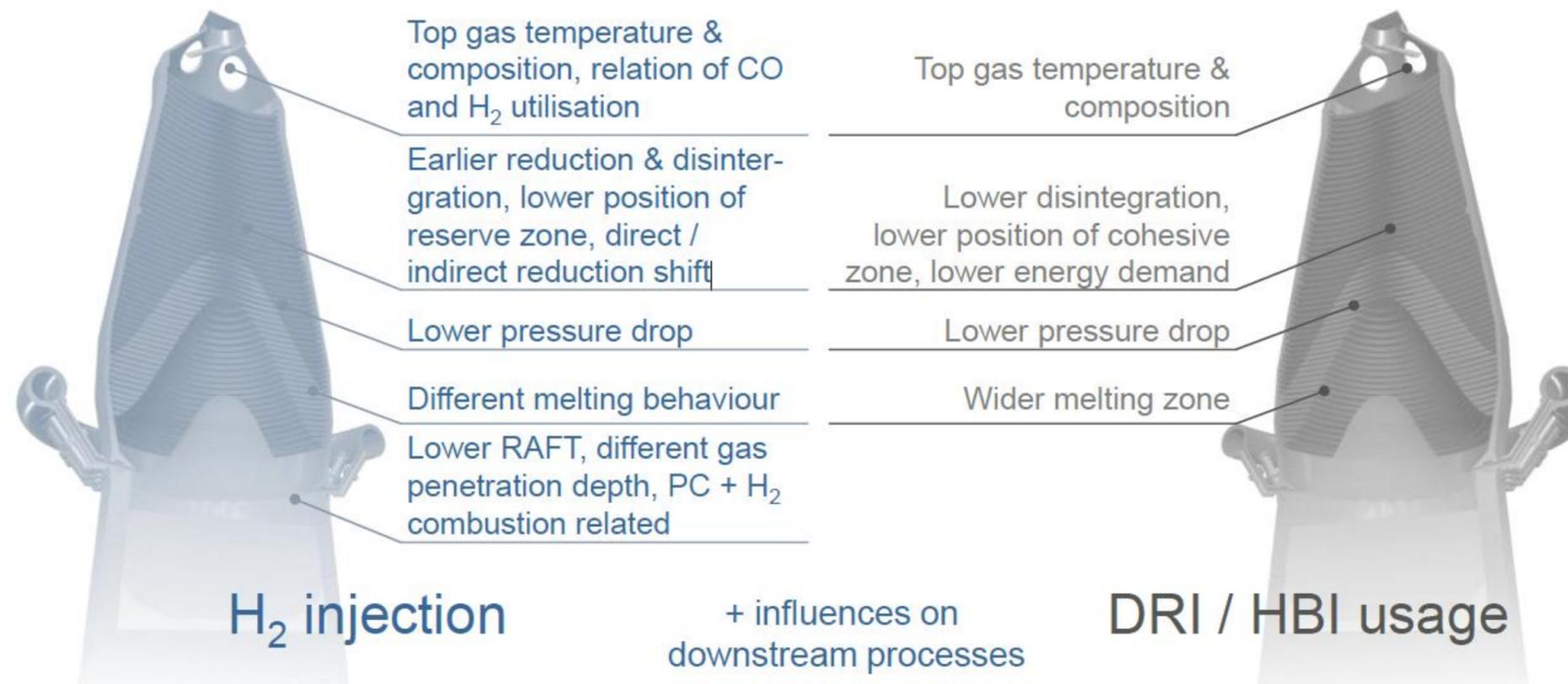RFCS funded project

Consortium
BFI (De) - Coordinator
CRM (Be)
AMMR (Fe)
Tata Steel (NL)
Dillinger (De)
HKM (De)
ABO (FI)
Oulu (FI)
PW (Lu)
Swerim (Se)

Duration
42 months

CRM Contact
R .Rabani

Proposal overview :

Title : Minimisation of CO$_2$ Emissions from the BF by hydrogen containing injectants and use of DRI/HBI during transition to new Ironmaking processes until 2030

Objectives :
The target = 25-35% CO$_2$ reduction,
using synergies from the increasing availability of H$_2$, H$_2$-rich injectants and DRI/HBI.

Top gas temperature & composition, relation of CO and H$_2$ utilisation

Earlier reduction & disinter-gration, lower position of reserve zone, direct / indirect reduction shift

Lower pressure drop

Different melting behaviour

Lower RAFT, different gas penetration depth, PC + H$_2$ combustion related

Top gas temperature & composition

Lower disintegration, lower position of cohesive zone, lower energy demand

Lower pressure drop

Wider melting zone

H$_2$ injection

+ influences on downstream processes

DRI / HBI usage

For a better future

Mogador

Mogador = good compromise : all aspects of the BF simulated (some in a simplified way) with a low calculation time (~ 20 min for high resolution on a 'classical laptop').

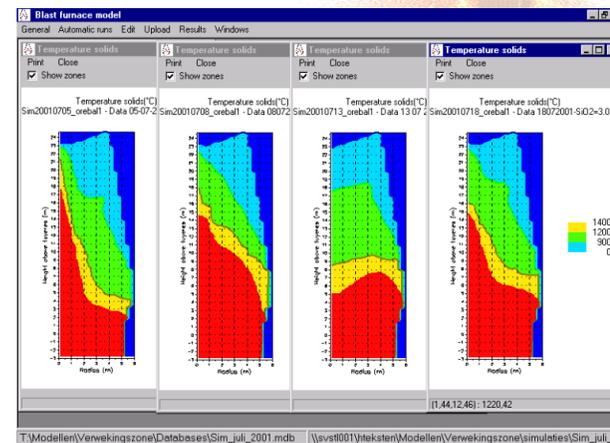MOGADOR – State-of-the-art numerical 'MOdel for GAs Distribution and Ore Reduction'

In 1995, CRM started the development of a 2-D mathematical model of the blast furnace at steady state (symmetry of revolution)

❑ Industrial validation at Arcelor Mittal Gent (2001)
❑ Industrial use of Mogador :
  • to help BF operators choosing the proper burden distribution pattern vs desired effect on BF results
  • to follow up evolution of cohesive zone (soft sensing)
  • Support to BF relining : optimal inner shape for maximized productivity
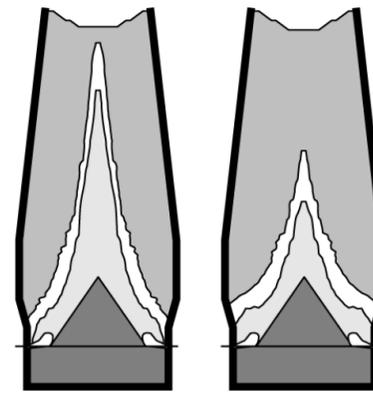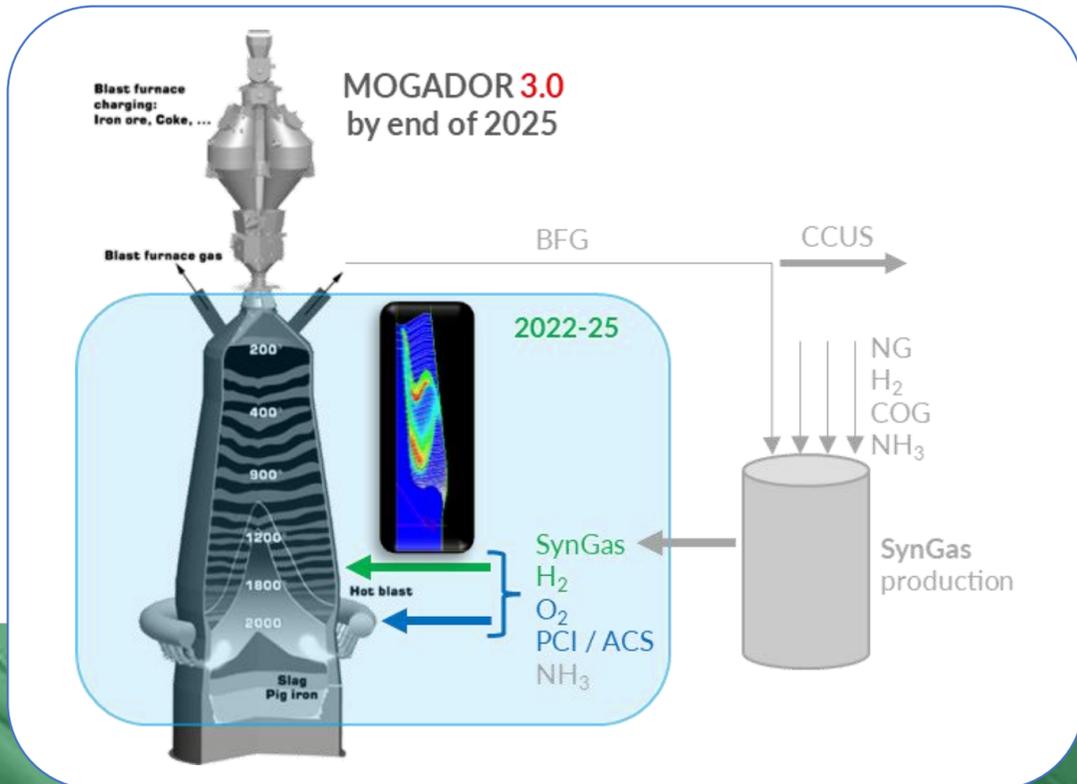
- Modification of the cohesive zone resulting of a slight charging pattern modification.
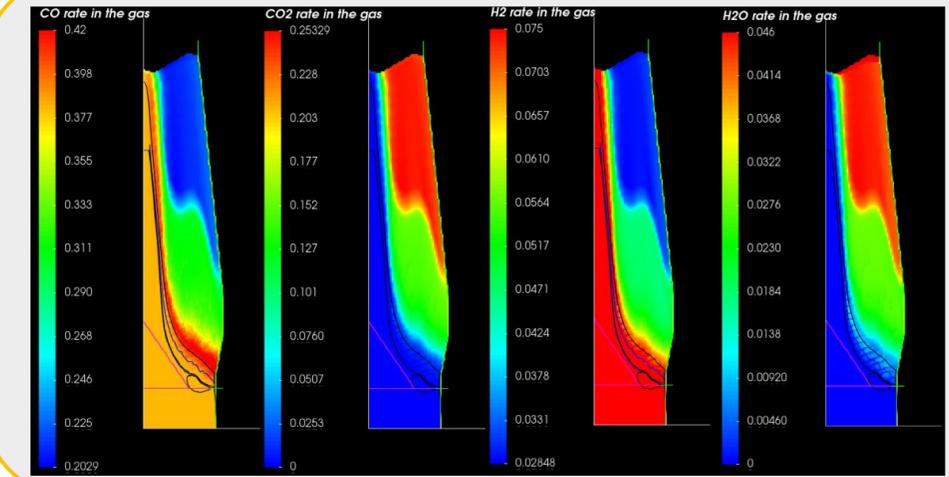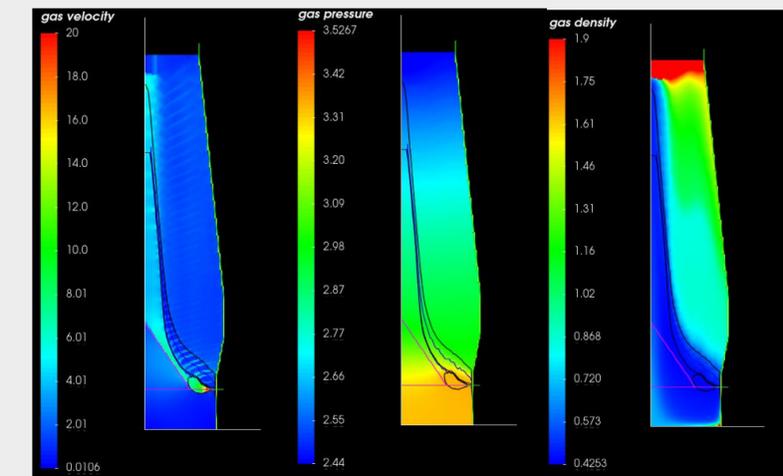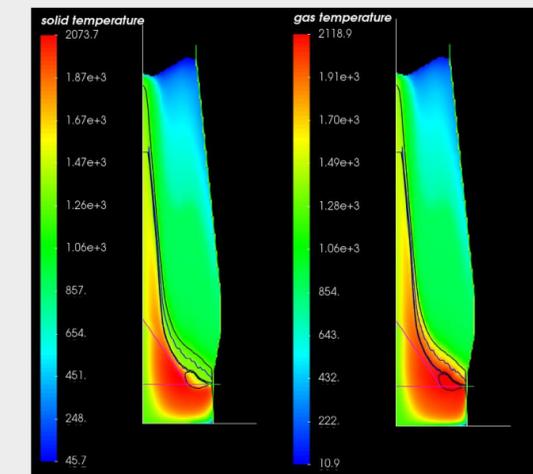
Evolution of the cohesive zone

Blast furnace charging: Iron ore, Coke, ...

MOGADOR **3.0** by end of 2025

BFG   CCUS

Blast furnace gas

2022-25

NG
H₂
COG
NH₃

Hot blast

SynGas
H₂
O₂
PCI / ACS
NH₃

SynGas production

Slag
Pig iron

Components of gas phase

Gas flow field

Gas-solid temperature field