Update on the development of POSCO's hydrogen-based Ironmaking process, HyREX®

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POSCO
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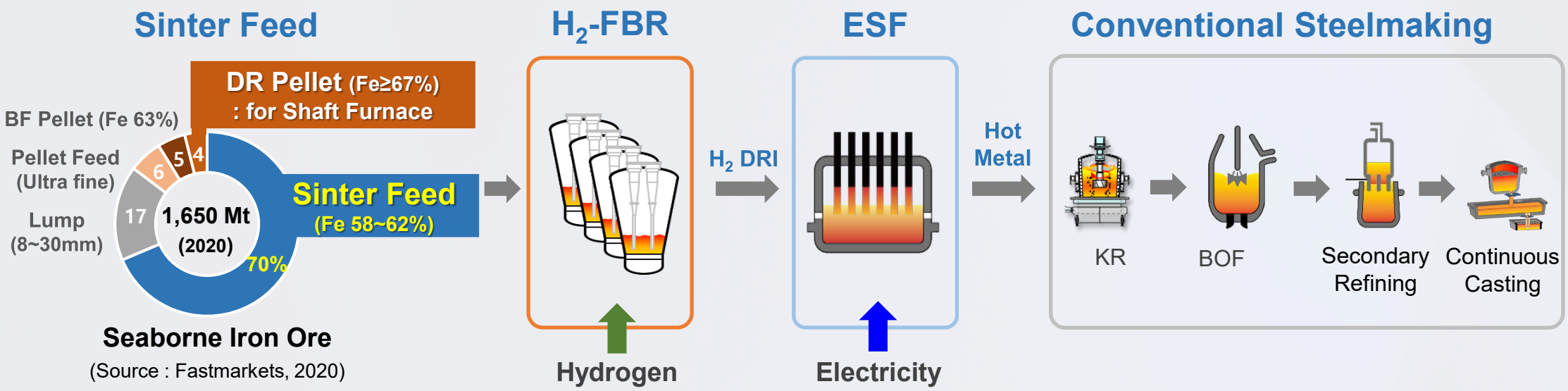
POSCO's Integrated Hydrogen Steelmaking



Direct Use of Sinter Feed

- Low-cost & abundant raw materials
- Holding proprietary steel technologies

※ Established expertise in large-scale FINEX fluidized bed operation

Hot metal and Slag similar to BF

- High Fe yield(>99%)
- Slag recyclable (C-free cement feed)
- Extensive experience in large-scale facility operations

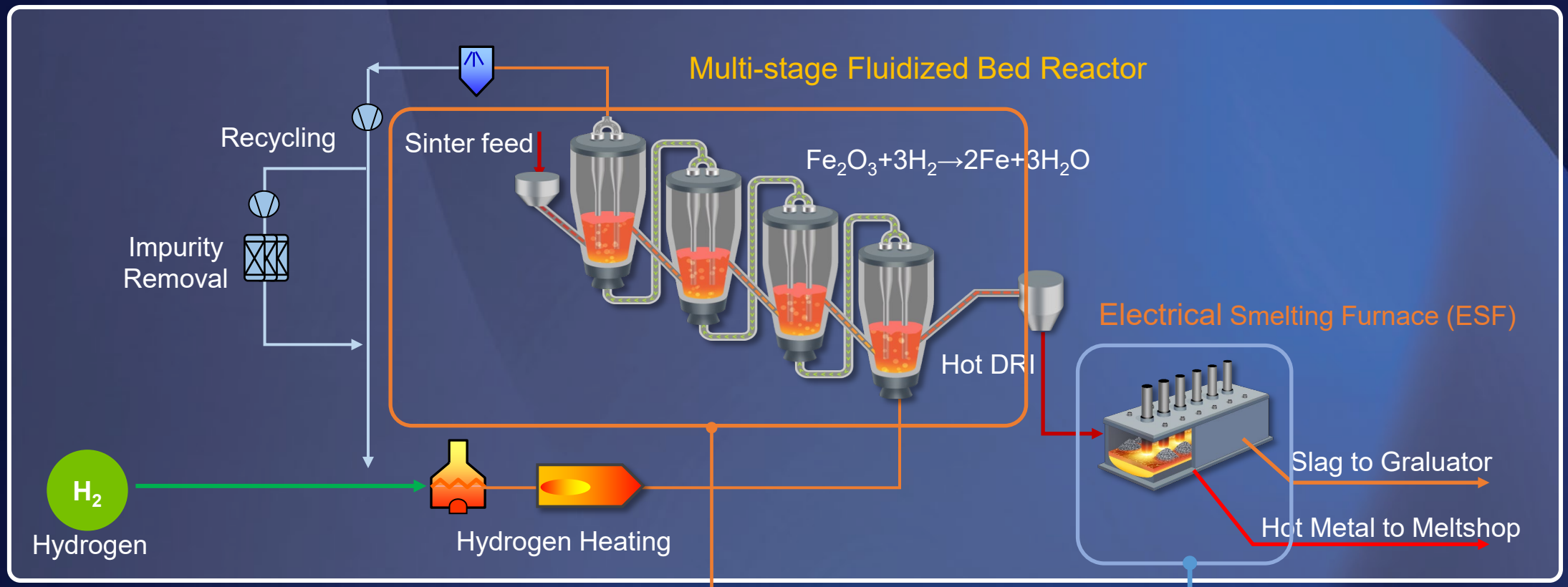
※ World's largest furnace at affiliate of POSCO, SNNC

Use of existing steelmaking facilities

- No restriction on high grade steel manufacturing
- Sunk costs savings in existing ISPs

HyREX® Process using 100% Hydrogen

* HyREX: **Hy**drogen **Re**duc**t**ion



FINEX Fluidized bed Technology

✓ FINEX fluidized bed core technology secured (scale-up from 30,000 to 2,500,000 tons/year)

Large ESF technology of POSCO affiliate (SNNC)

✓ World's largest ESF operation & management know-how (135MVA 40x14m to > 1.2Mt/y Melting Capacity of DRI)

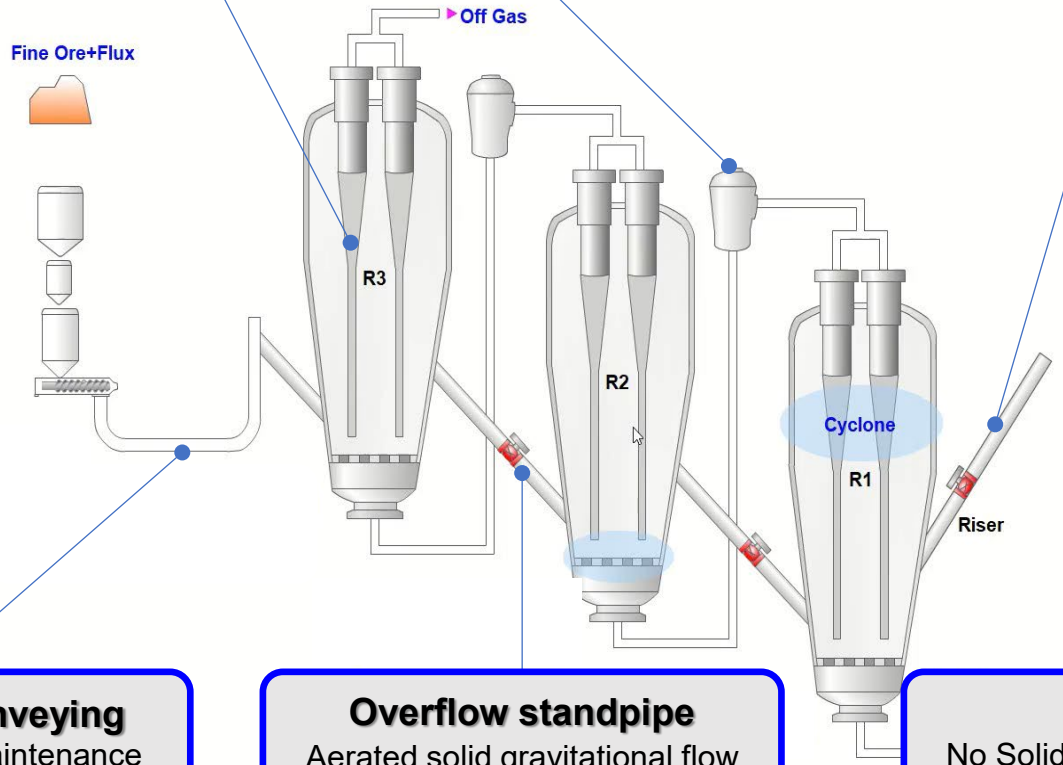
FINEX® Fluidized Bed Technology

Fine ore is reduced passing through the multi-stage turbulent fluidized beds in series

Tapered shape reactor
Homogeneous mixing

Oxygen Injection
Heat compensation

Riser
Easy discharge rate control

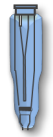
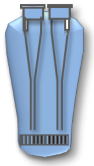
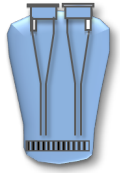
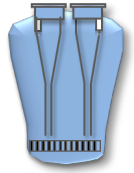


Pneumatic Conveying
Easy handling & maintenance

Overflow standpipe
Aerated solid gravitational flow

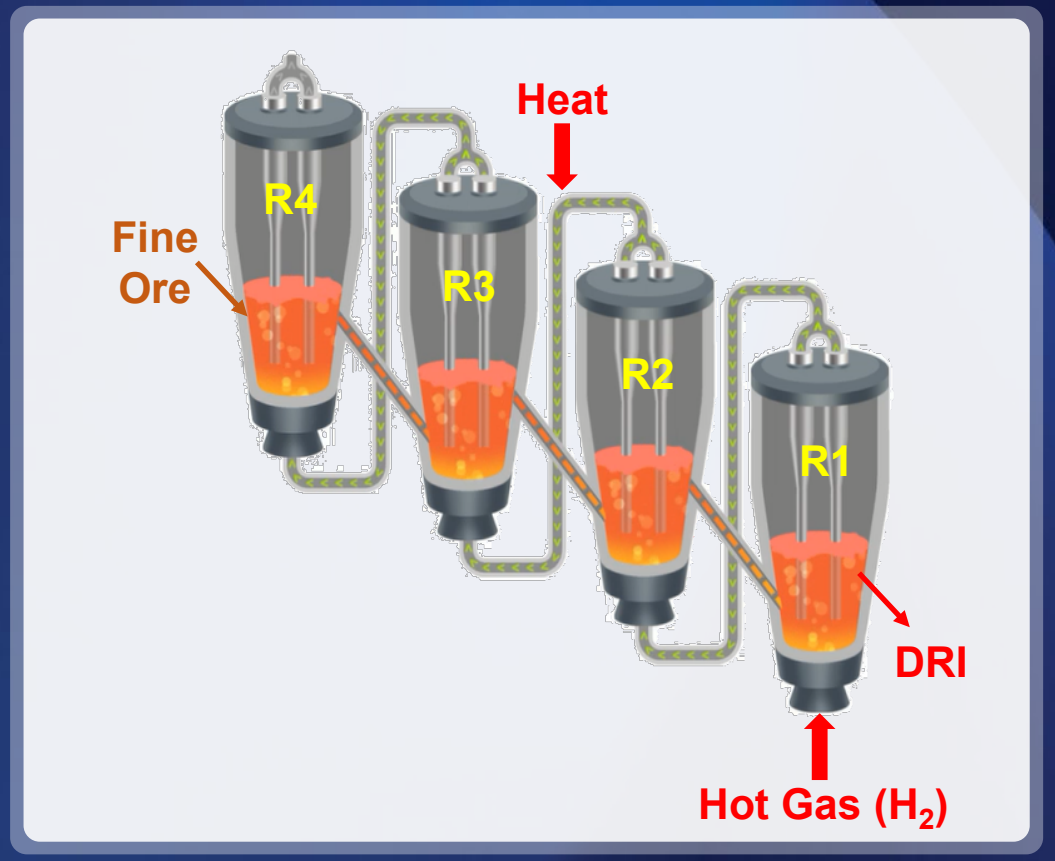
Distributor
No Solid stagnant near the wall

Scaling-Up

	Pilot Plant (1999)	Demo Plant (2002)	1.5M Plant (2005)	2.0M FINEX (2010)
Reactor Profile				
No. of Stage	3	4	4	3
Diameter at Grid (m)	1.2	5.9	7.7	9.8
Height above Grid (m)	12.0	16.5	14.0	14.0
Capacity (ton-ore/day)	100 (base)	3,600 (x 36)	7,200 (x 72)	9,600 (x 96)
Specific Rate* (ton-ore /day/m^3)	0.92	0.99	1.65	2.14

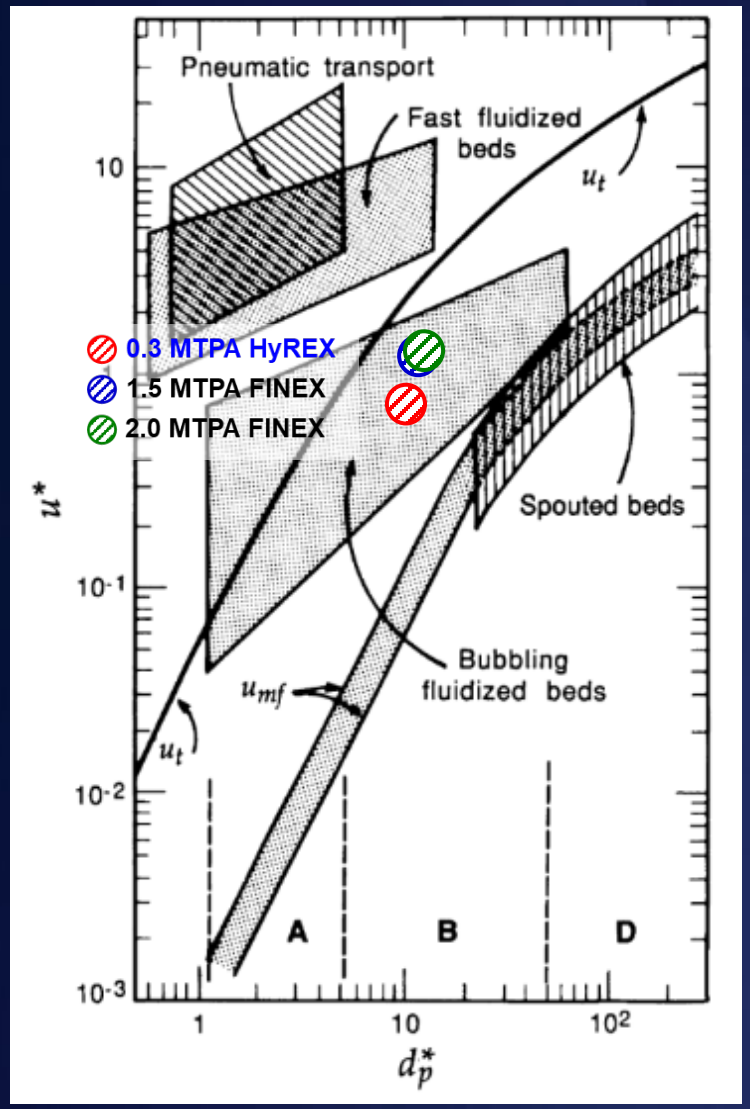
Development of HyREX® Process – FBR Redesign

- **Modifying reactor design criteria**
  - ✓ Adjustment on fluidizing condition
- **Re-design of multi-staged fluidized beds**
  - ✓ Target reduction degree
  - ✓ Specific gas consumption
  - ✓ Temperature profile
  - ✓ Residence time
- **Countermeasures for high reduction degree**
  - ✓ Raw material control
  - ✓ Anti-sticking & plating measure
- **Process and plant engineering**
  - ✓ Heating up of hydrogen
  - ✓ Material selection under hydrogen condition
  - ✓ Explosion-proof design



FBR Redesign for Hydrogen Use : Fluidization & Reduction

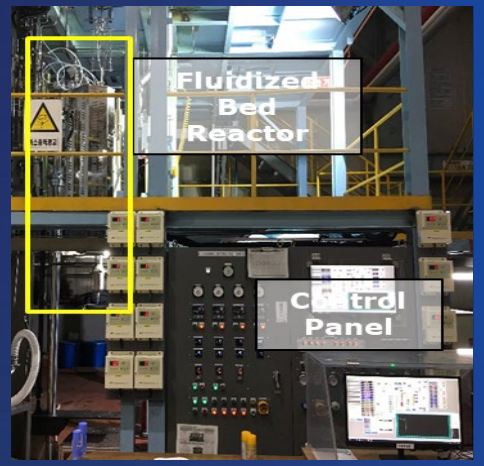
Fluidization cconditions under hydrogen use

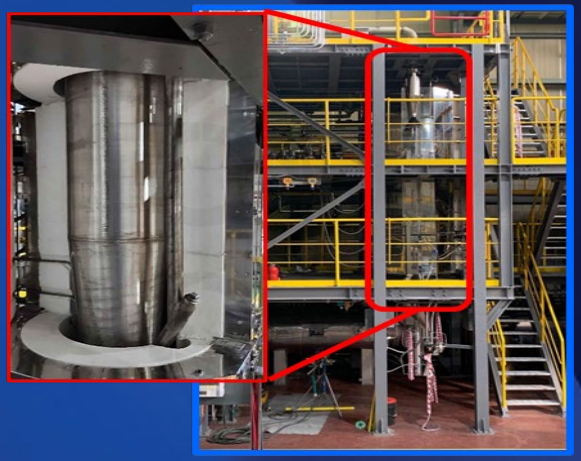


HyREX
(U_0 : 1.4m/s)

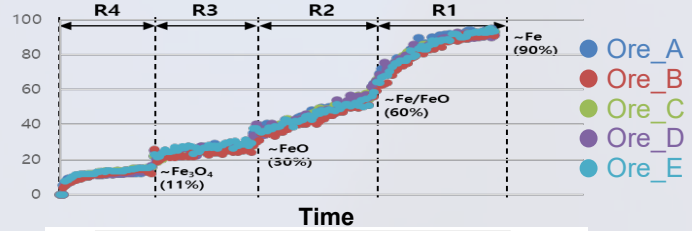
FINEX
(U_0 : 1.0m/s)

Fluidized bed reduction test

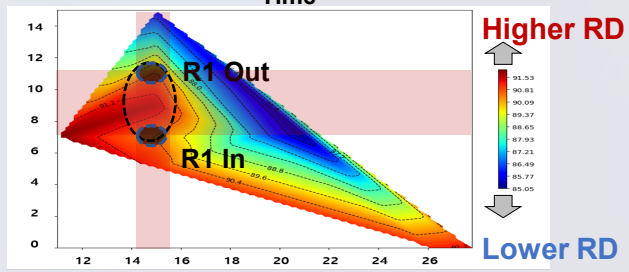




Effect of ore blend



Effect of Gas composition (N_2/GOD*)

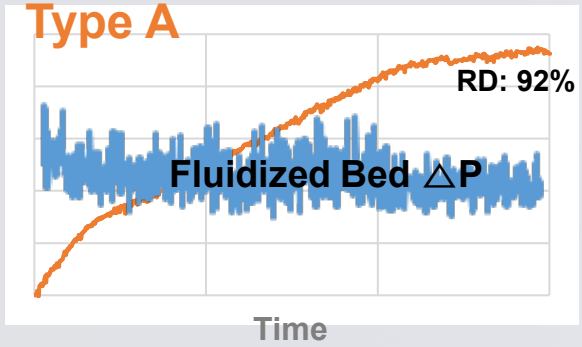


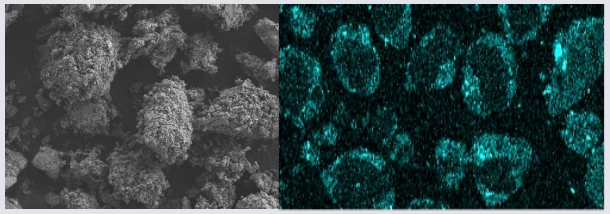
* GOD : Gas oxidation degree

FBR Redesign for Hydrogen Use : Raw Material Control

Sticking behavior according to ore type

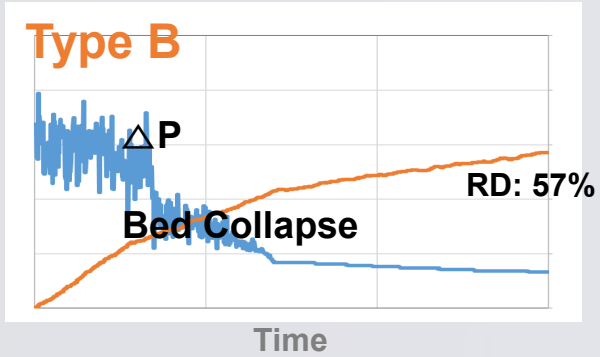
Type A

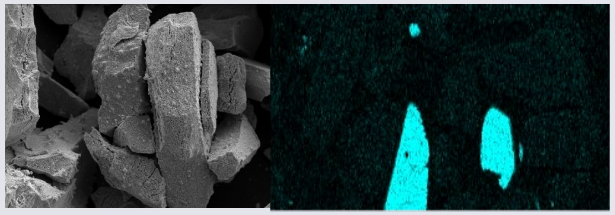




- Gangue exposed **superficially**
- No whisker formation

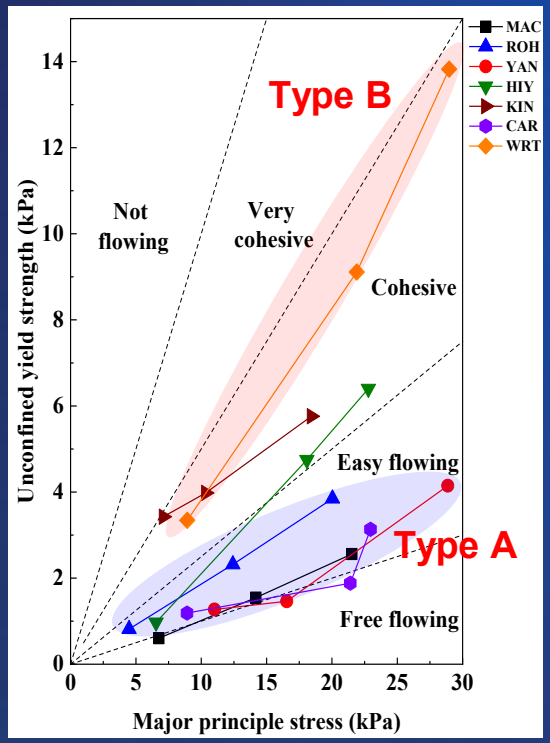
Type B



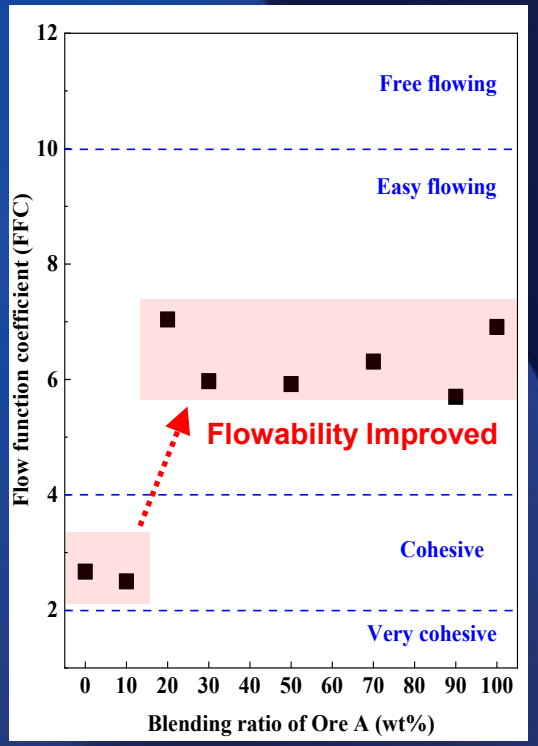


- Gangue embedded **internally**
- Fe bumps on surface

Flowability test of H_2-DRI*



[Flowability by ore type]

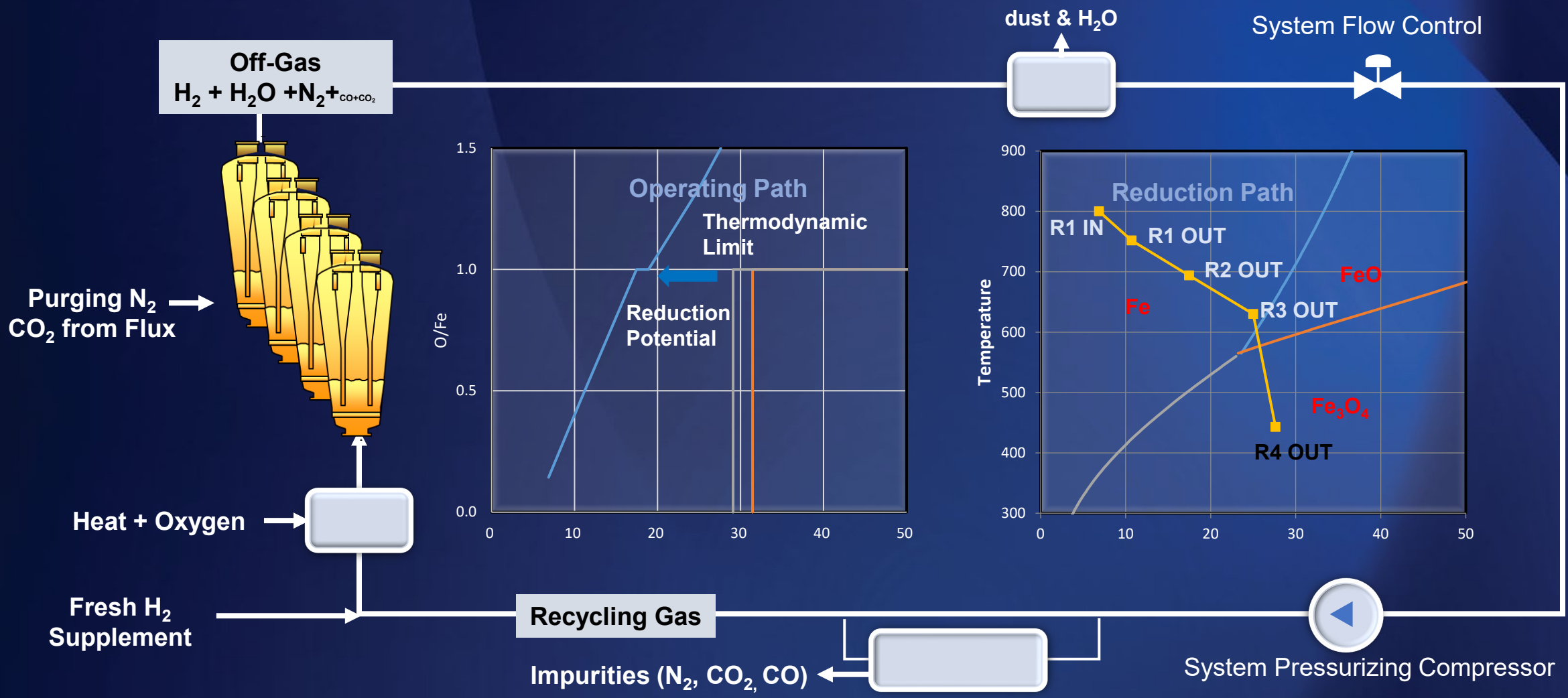


[Flowability by blending ratio]

- ✓ Spatial distribution of gangue phase within ore can cause sticking and hinder fluidization.
- ✓ Optimized ore blending enables the attainment of favorable sticking and flowability characteristics.

* H_2-DRI : DRI fines reduced by Hydrogen

FBR Redesign for Hydrogen Use : Gas System

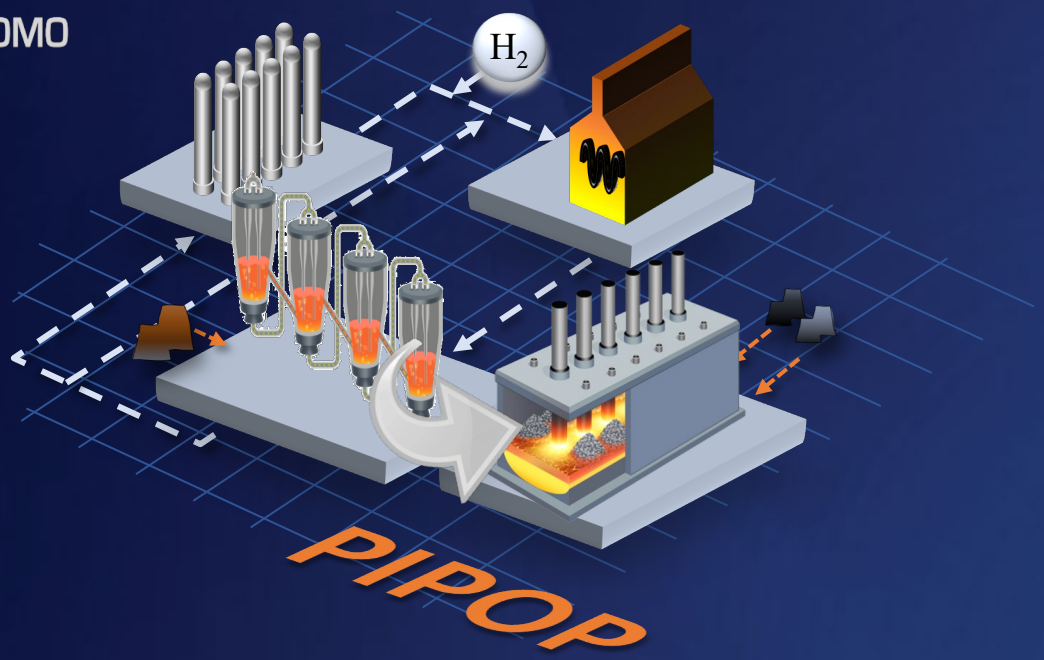


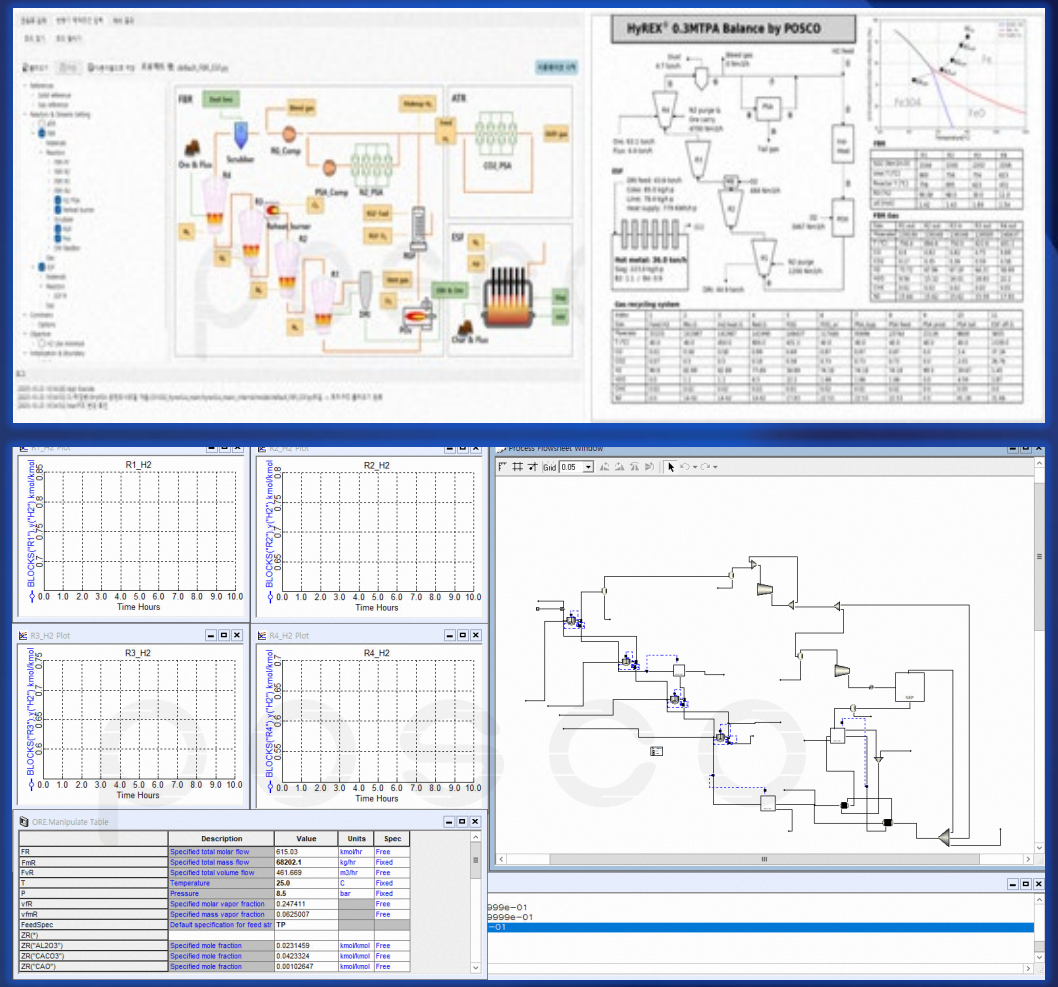
✓ The operating line is designed considering the heat balance and attaining a high reduction

FBR Digital Twins – Flowsheet-based

Various process configurations evaluated, and gas system optimized
Abnormal operation case analysis and counter-measures reviews

python
PYOMO

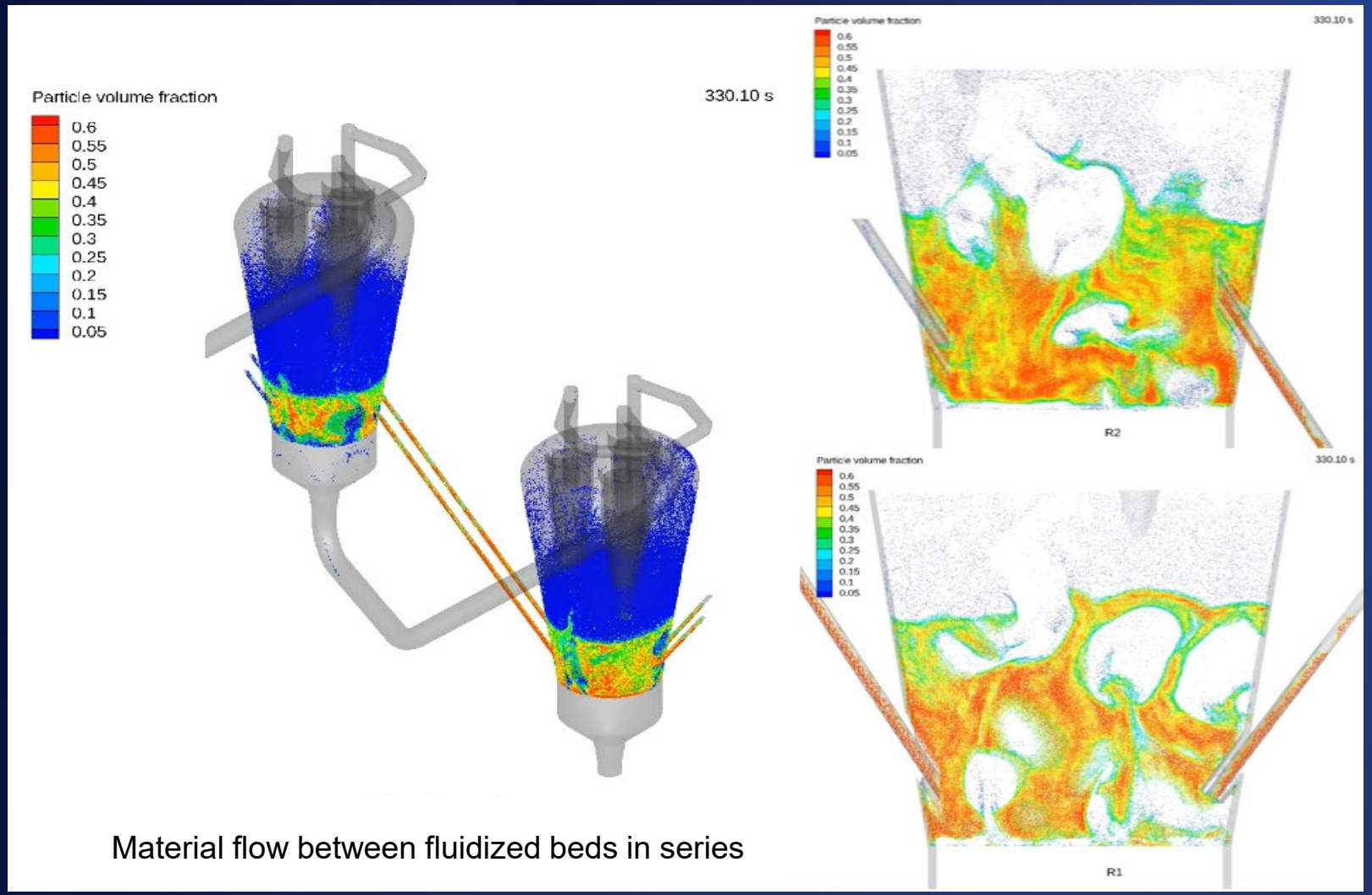




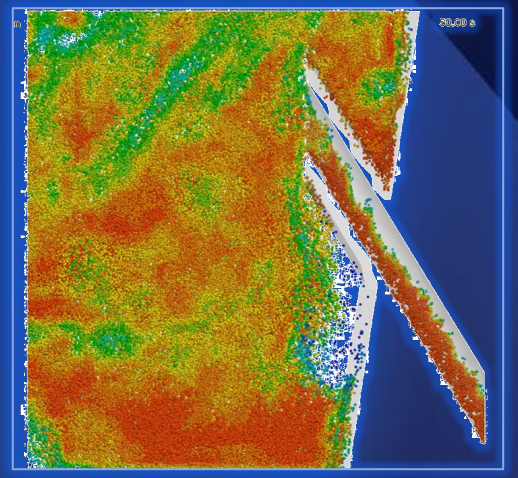
- ✓ Simulation of various **raw material** usage
- ✓ Optimization of Consumption Figures
- ✓ Dynamic Analysis of Abnormal Cases

FBR Digital Twins – Physics -based

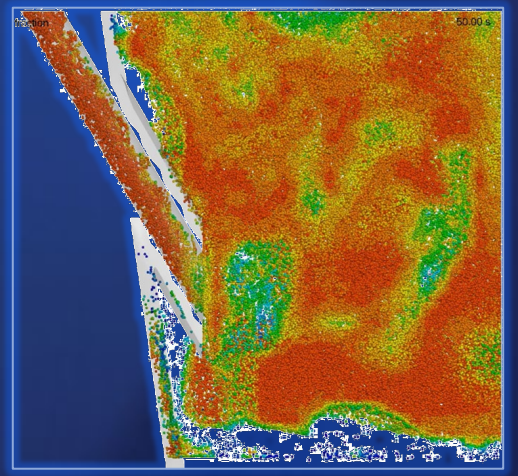
Visualization & analysis of fluidized bed reactor by CPFD (Computational Particle Fluid Dynamics)



Material flow between fluidized beds in series



Upper Reactor



Lower Reactor

ESF for Hydrogen reduced DRI Melting : Major Features

Design concept for H_2 DRI melting in ESF

- ✓ Based on SNNC* ESF, similar but different design for H_2 DRI smelting

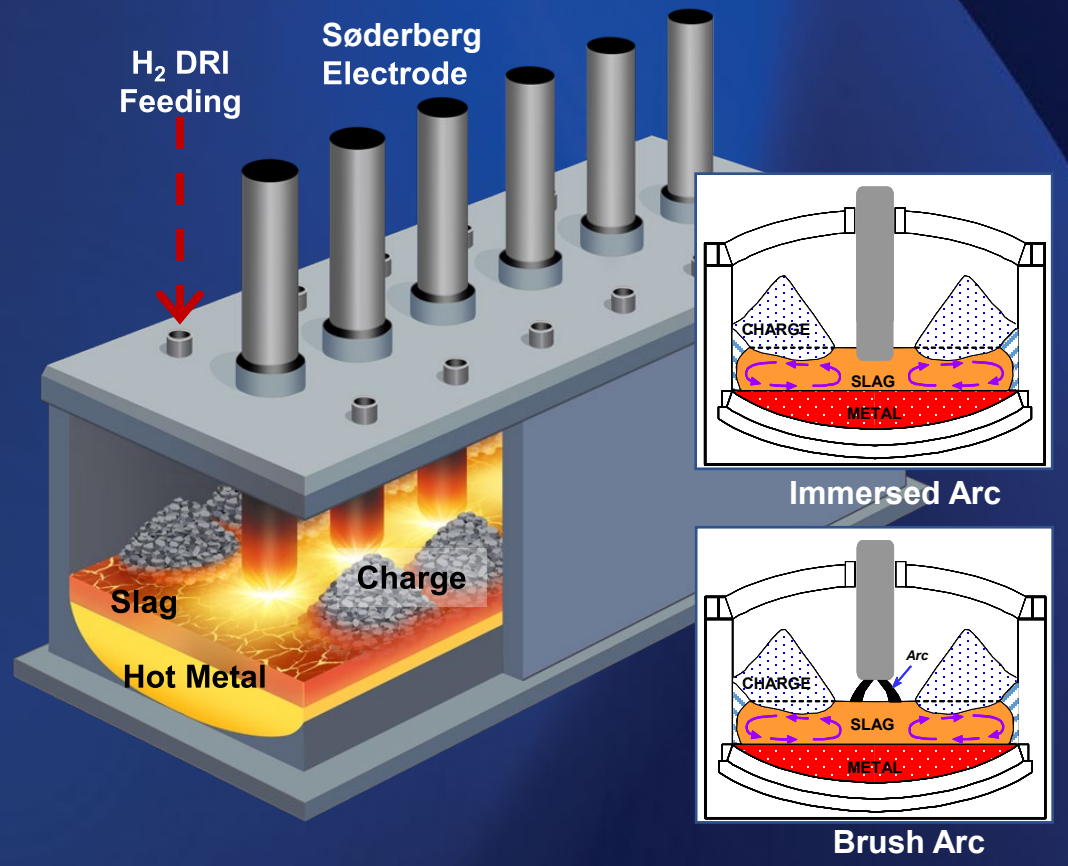
  * SNNC: Fe-Ni plant @ Gwangyang Works (135MVA 12.6x39m, 6 electrodes in series)

ESF structural design

- ✓ Robust structure for long-term operation
- ✓ Feeding equipment for briquette or powder of H_2 DRI
- ✓ Cooling panels and erosion resistant refractories
- ✓ Optimal electrode control system
- ✓ Off-gas system for gas recycle

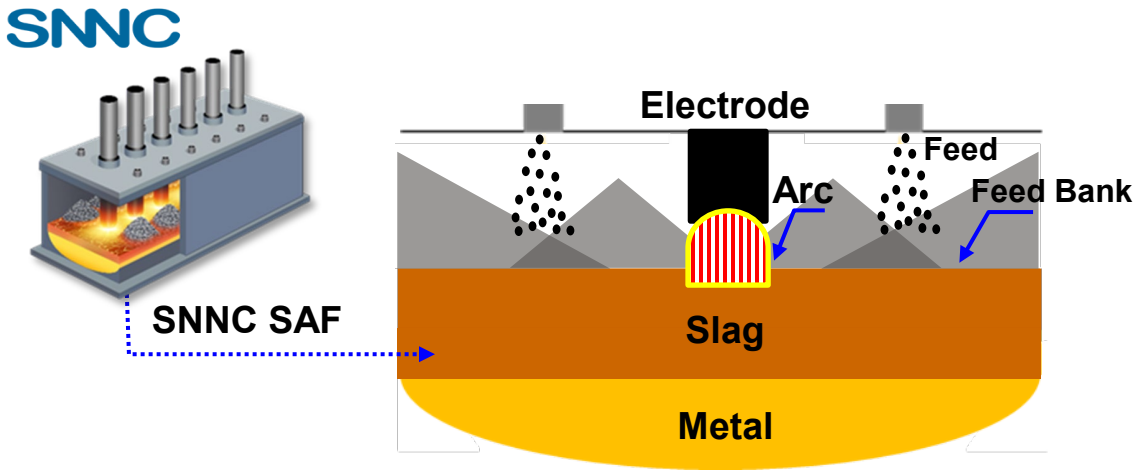
ESF operational design

- ✓ Immersed/Brush arc operation for H_2 DRI melting
- ✓ Stable control of temperature and composition
- ✓ Monitoring systems for automatic operation
- ✓ Slag chemistry control for recycling



ESF for Hydrogen reduced DRI Melting : ESF Redesign

SNNC: Ni Ore (High Gangue)



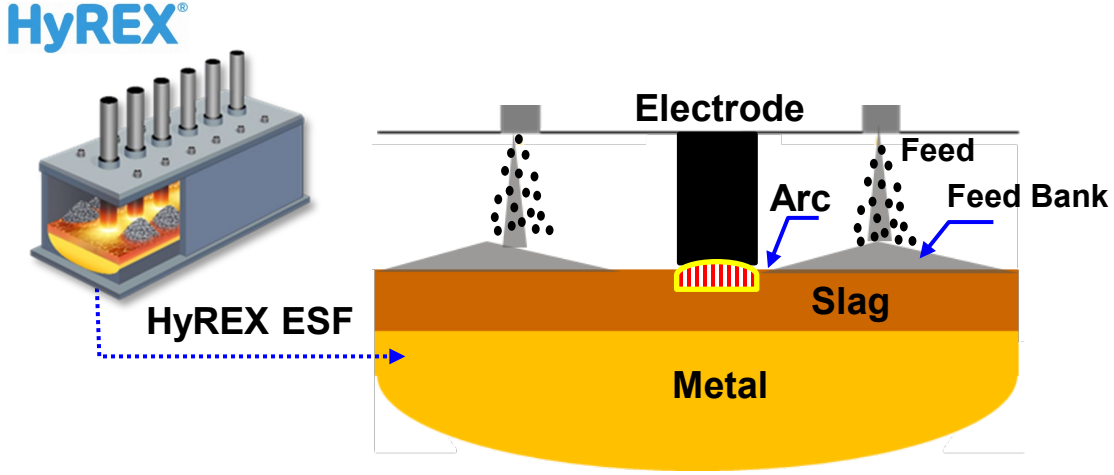
High Volumetric Feeding of Non-Conductive Calcines

- Wide coverage with high feed bank
- Combination of long arc heating and resistance heating
- High Slag Volume & Low Melt Volume

Large and multiple slag tapholes

- Intensive cooling in the slag zone
- Precise level control for molten metal

HyREX: DRI Fines (Low Gangue)



High Volumetric Feeding of Conductive DRI Fines

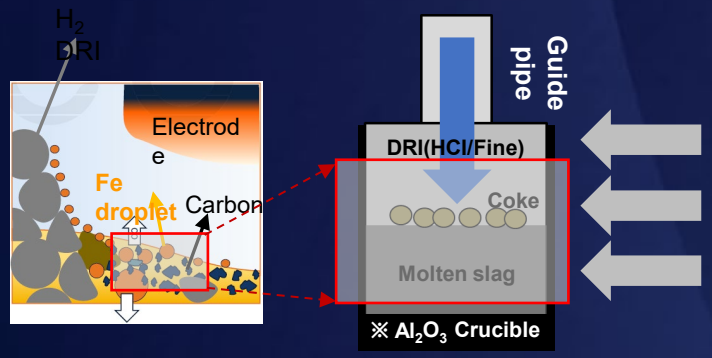
- Semi-open bath operation with low feed bank
- Combination of mainly resistance heating and brush/immersed arc heating
- High Melt Volume & Low Slag Volume

Robust metal taphole

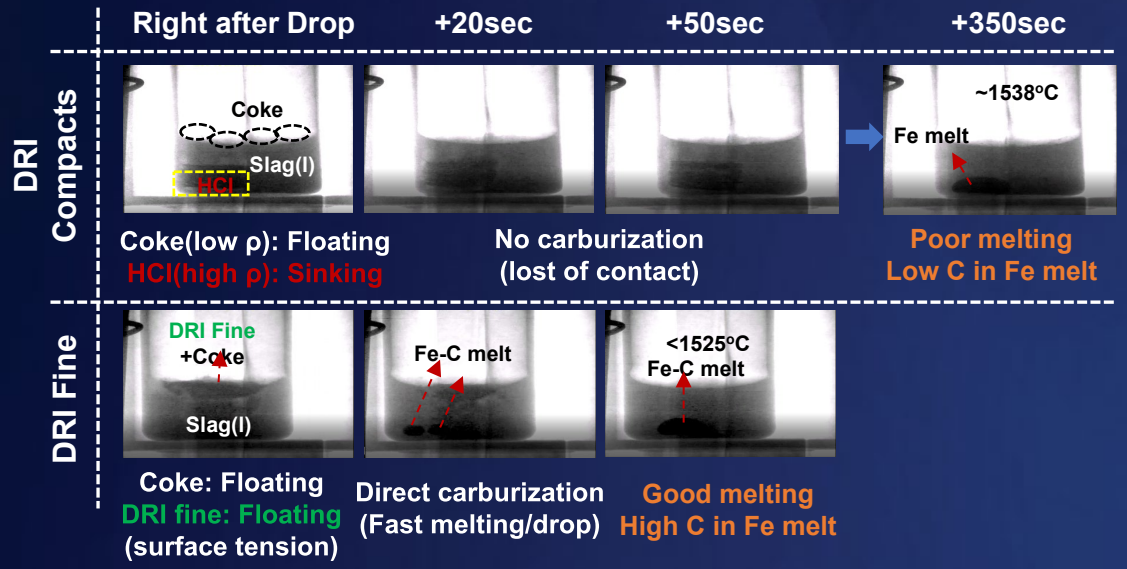
- Intensive cooling for slag zone and hot metal tapping zone
- Sufficient bath level for hot metal

ESF for Hydrogen reduced DRI Melting : Lab Scale Melting Test

In-situ X-ray Observation



X-ray
transmission



Experiments in Small Arc Furnace

- DC ARC Furnace (Batch Type)
- 280 kVA (70V, 4000A)
- Electrode: 150mmΦ
- Bruch Arc Condition Simulated

● **HBI(Crushed, RD 90%) + Carbonizing Material + Additive**

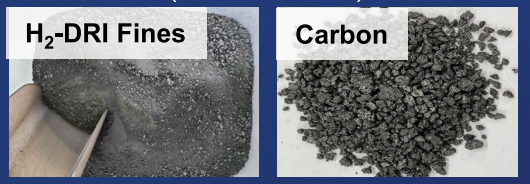
(Raw Materials)

(After Melting)

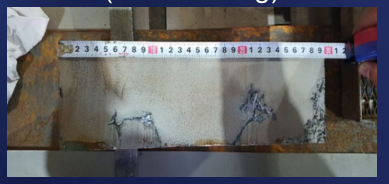
2.2~3.0%[C]

● **H_2-DRI Fines (RD 90%) + Carbonizing Material + Additive**

(Raw Materials)



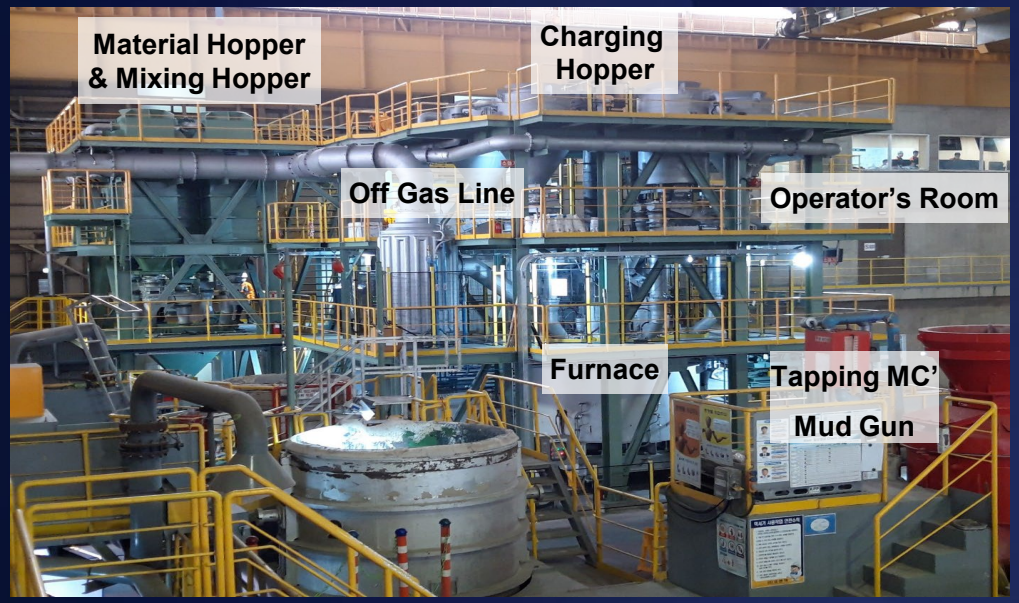
(After Melting)

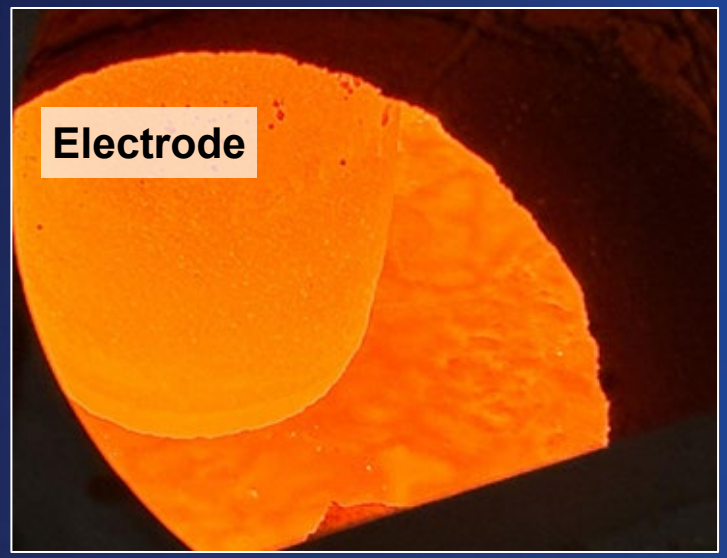


3.5~4.2%[C]

✓ DRI fines show improved carburizing and melting characteristics compared to compacts.

ESF for Hydrogen reduced DRI Melting : Bench-scale Facility





Capacity	1ton/hr
Furnace	Round Type, OD 3.6m, H 1.9m Moving Furnace Car 1 Metal & 1 Slag Tapping Holes
Transformer	2.5MVA, 3 Phase AC Type, 13 Taps OLTC Brush & Immersed Arc Mode
Electrode	12inch (305mm), PCD 1.2m
Auxiliary Devices	Hoppers & 7 Chutes on the Roof Sub Lance for Temperature & Sample Tapping Machine , Mud Gun , 9 Ladles, Pre-Heater 50tons Over Head Crane

ESF for Hydrogen reduced DRI Melting : DRI Fines Testing Works

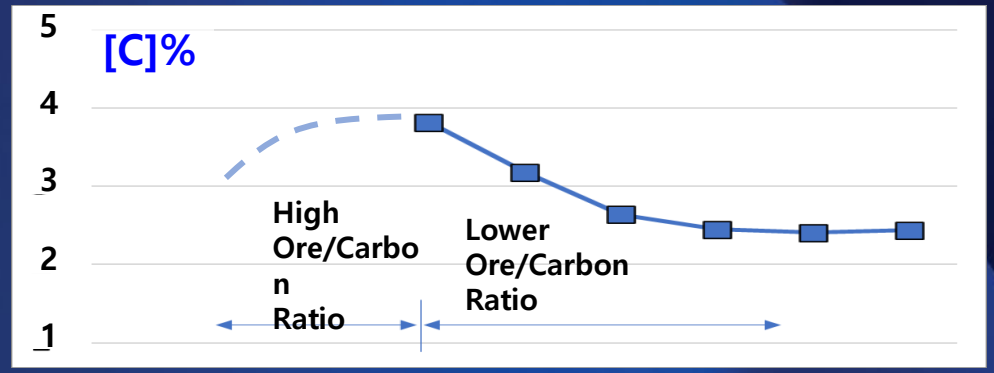
Operation

- ✓ 8 days Continuous Operation (3 days Ramp-Up)
- ✓ Charging Material : DRI Fines + Coke Breeze
- ✓ 6 Metal Tapping, 2 Slag Tapping
- ✓ Current & Impedance Mode Power Control (Automation)
- ✓ Continuous Charging Control (Automation)
- ✓ Materials Level Monitoring by Radar System

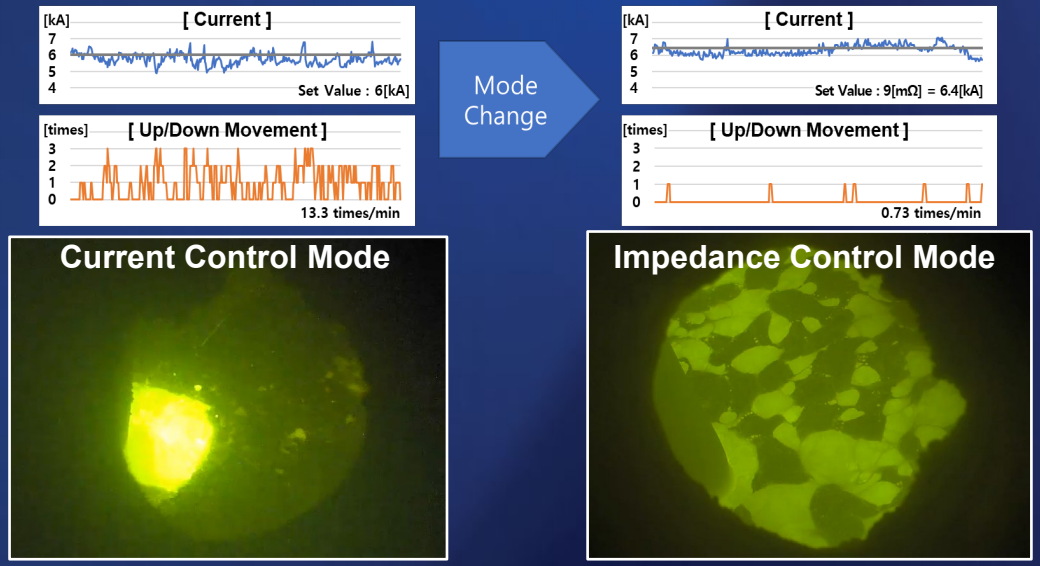
Results

- ✓ Tapping Weight of Hot Metal : 21tons, $[C]_{max}$ = 3.8%
- ✓ Tapping Weight of Slag : 5tons, Basicity(C/S) = 0.9
- ✓ Dust Loss from DRI Fines Charging = 2.3%
- ✓ Impedance mode achieved lower deviation with fewer up/down movements compared to current mode.

Carburization control by Ore/Carbon Mixing Ratio

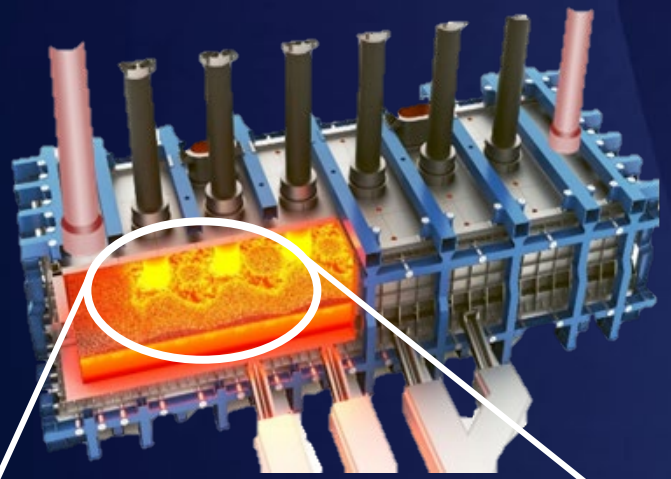


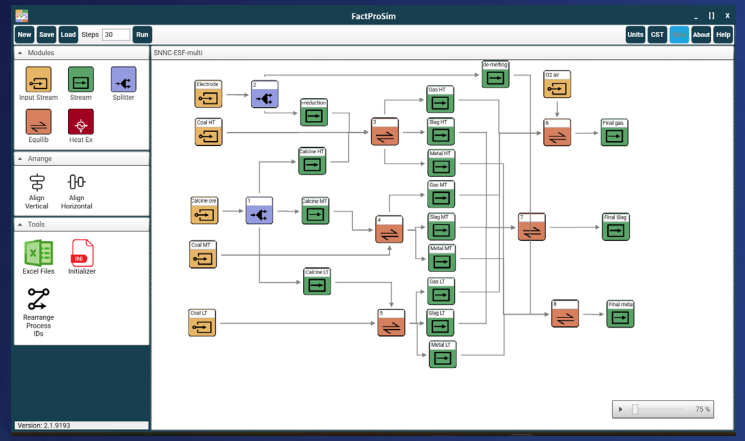
Effects of Power Control Mode on Smelting Operation



ESF Digital Twin – Thermodynamic-based

ESF process simulation model based on FactSage thermodynamic software





FactSage Simulator

Calcine

Composition (wt%)

Amount (kg)	Temperature (°C)	NiO	Ni	Fe2O3	FeO	Fe	Fe3C	C	SiO2
100	500	0	0	0	5	50	28	1	8
101	Norm.:	0.00	0.00	0.00	4.95	49.50	27.72	0.99	7.92
		0	1	2	3	4	5	6	7

Flux

Composition (wt%)

C from electrode

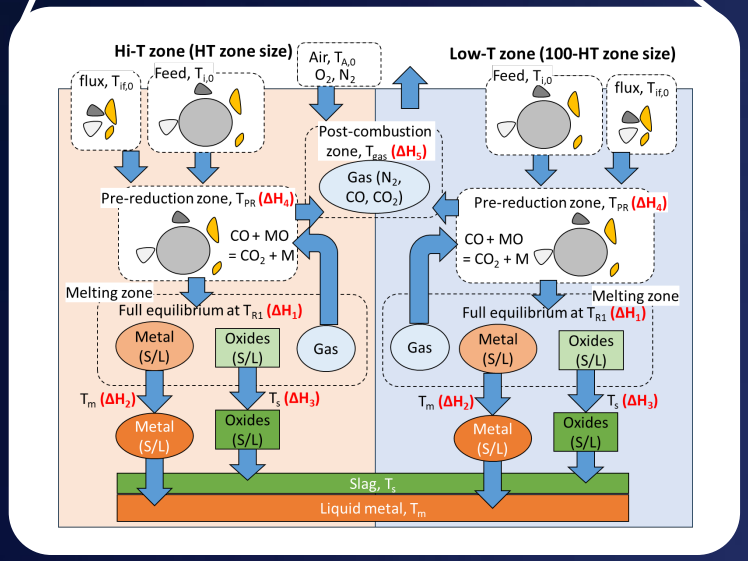
Amount (kg)	Temperature (°C)	CaO	MgO	Al2O3	SiO2	Total	Temperature (°C)
10	25	70	30	0	0	100	1500

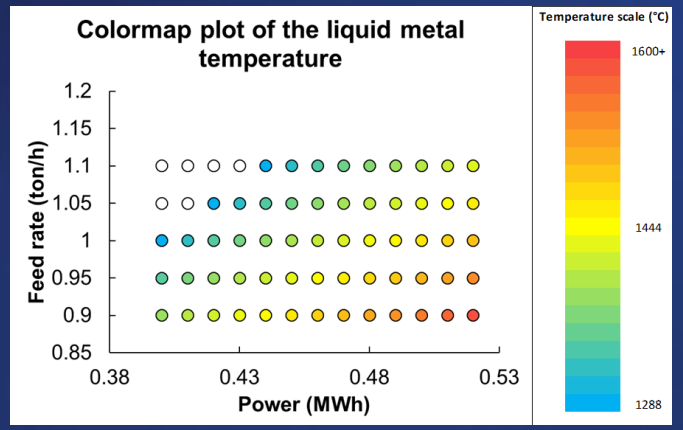
Calculation conditions

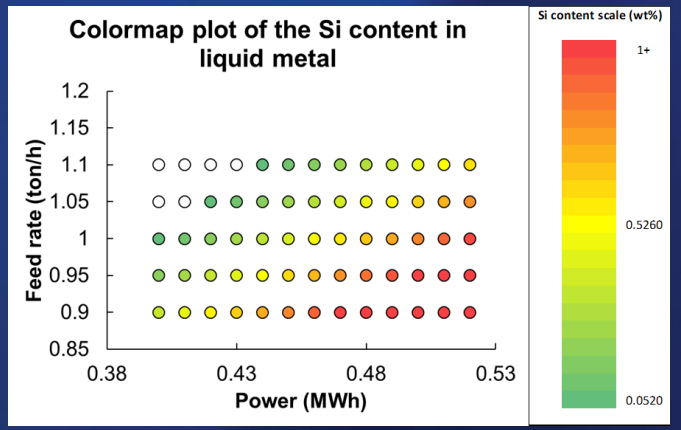
Number of scenarios: 6

calc #	Heat requirements: Electrical energy (kWh)	Heat requirements: Total heat loss (kWh)	Electrode consumption: Mass C (kg)	Electrode consumption: % to reduction	Furnace output: T metal (°C)	Furnace output: T slag (°C)	Furnace output: T gas (°C)	CO/CO2 ratio	Zone dimension: Size HT (%)	Zone dimension: PR-HT zone T (°C)
	45.5	10.36	0.25	25	1500	1550	1000	0.1	30	1000
	45.5	10.36	0.25	25	1500	1550	1000	0.1	40	1000
	45.5	10.36	0.25	25	1500	1550	1000	0.1	50	1000
	45.5	10.36	0.25	25	1500	1550	1000	0.1	60	1000
	45.5	10.36	0.25	25	1500	1550	1000	0.1	70	1000
	45.5	10.36	0.25	25	1500	1550	1000	0.1	80	1000

Input Values for the ESF Model



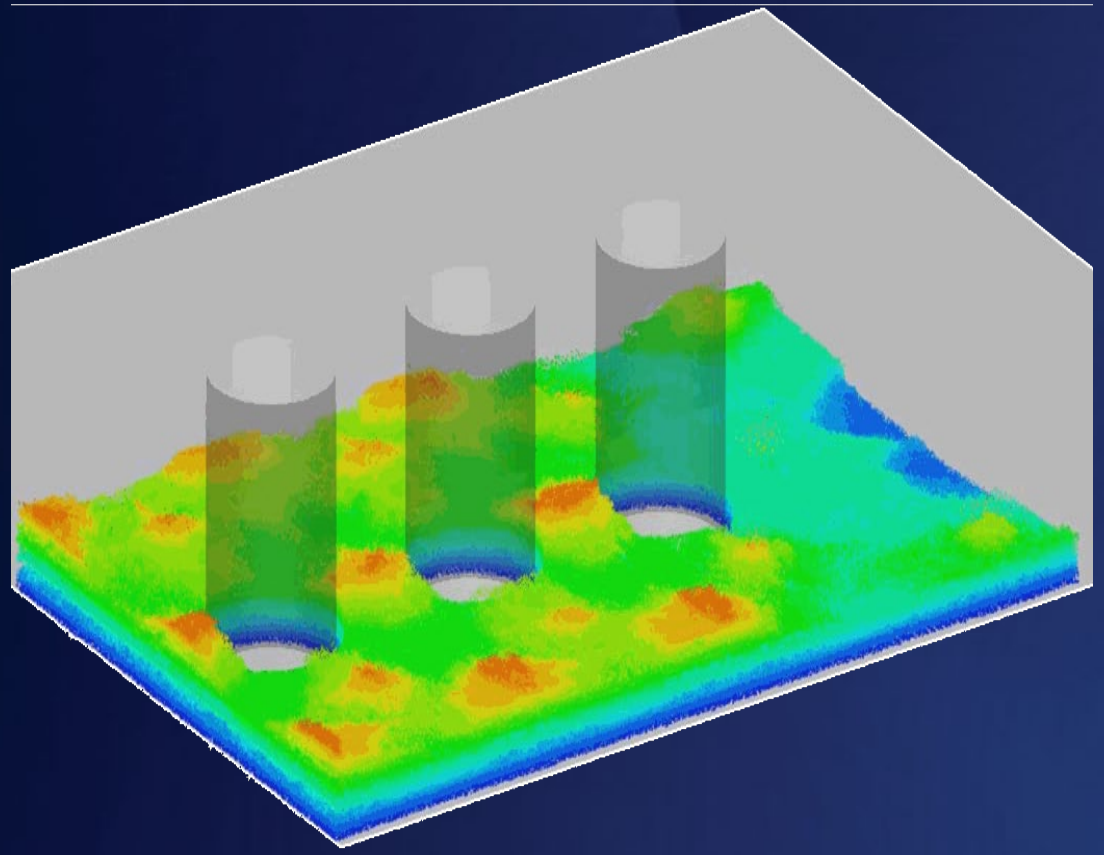




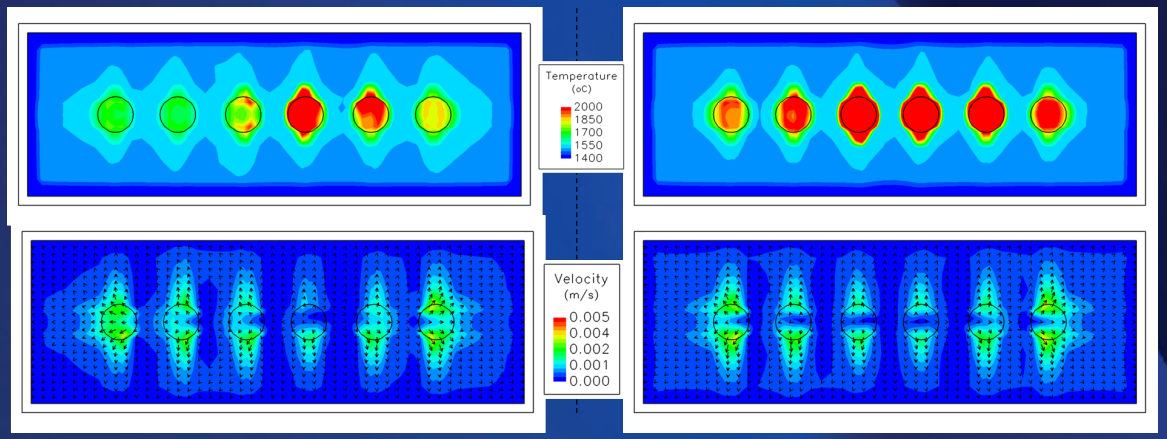
Temperature, Mass and Composition of Metal, Slag and Gas depending on Input Values

ESF Digital Twin – Physics-based

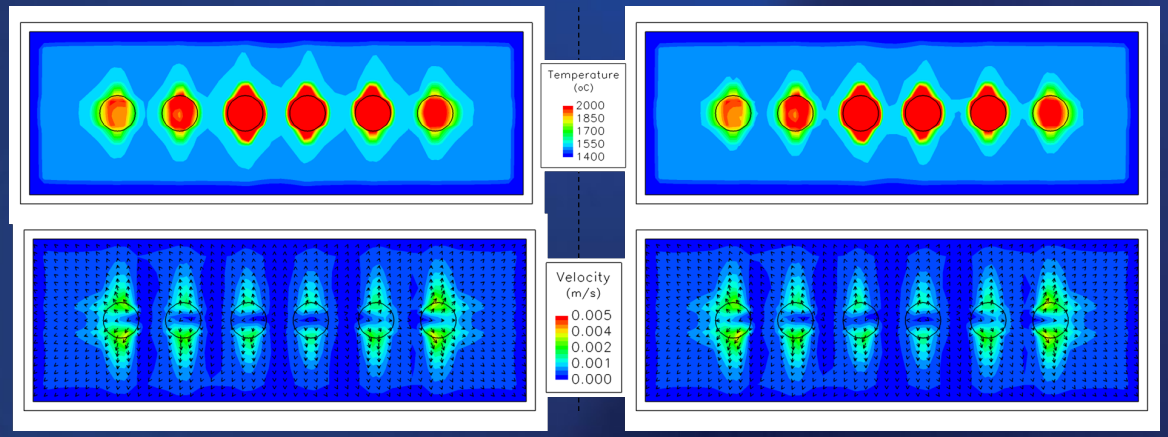
Visualization & analysis of feeding, melting, Arc heat transfer by CFD (Computational Fluid Dynamics)



Feeding and piling behavior



Slag Temperature & Flows according to Arc Length



Slag Temperature & Flows according to Feeding Rate

HyREX® Commercial Development : Action Plan

Know-How

2 FINEX® (1.5MPTY)

SNNC No.1 ESF
(Circle, 120MVA)

SNNC No2. ESF
(Rectangle, 135MVA)

3 FINEX® (2.0MPTY)

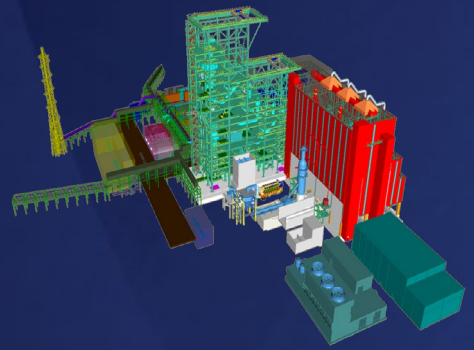
+

Bench/Pilot Scale Test

FBR 50 kg/batch

ESF 1.0 ton/hr

Demo Plant (0.3Mtpy)



- Performance Assessment
  - ✓ Operational stability & reliability
  - ✓ Various Ore usability
  - ✓ Engineering viability and effectiveness
- O&M skills & experience buildup

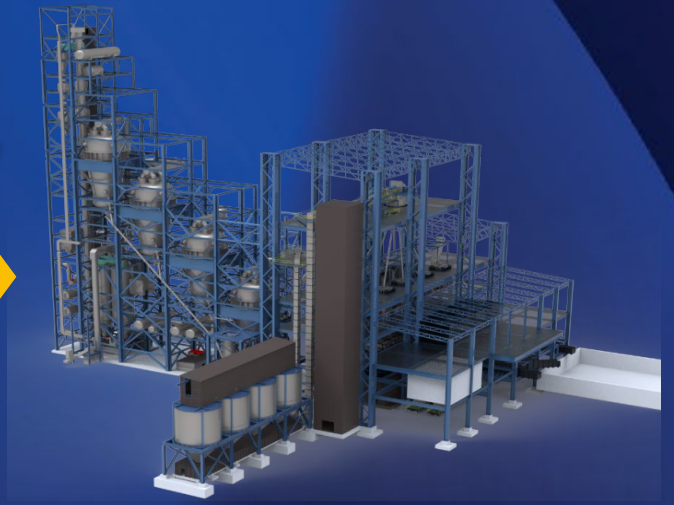
✓ Design adjustment & scale-up data generation

✓ Improvement & optimization engineering

✓ Equipment durability & reliability enhancement

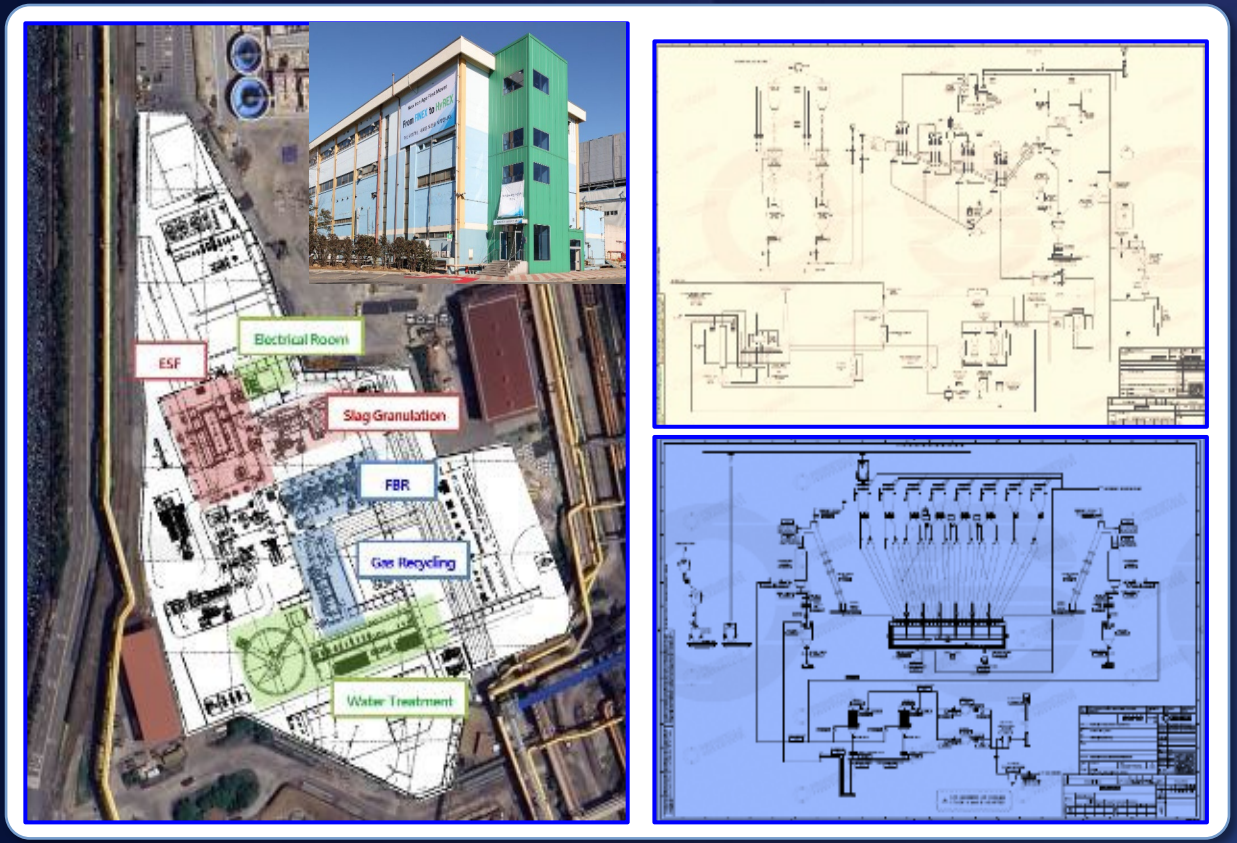
Scale-up

Commercial Plant (2.5Mtpy)

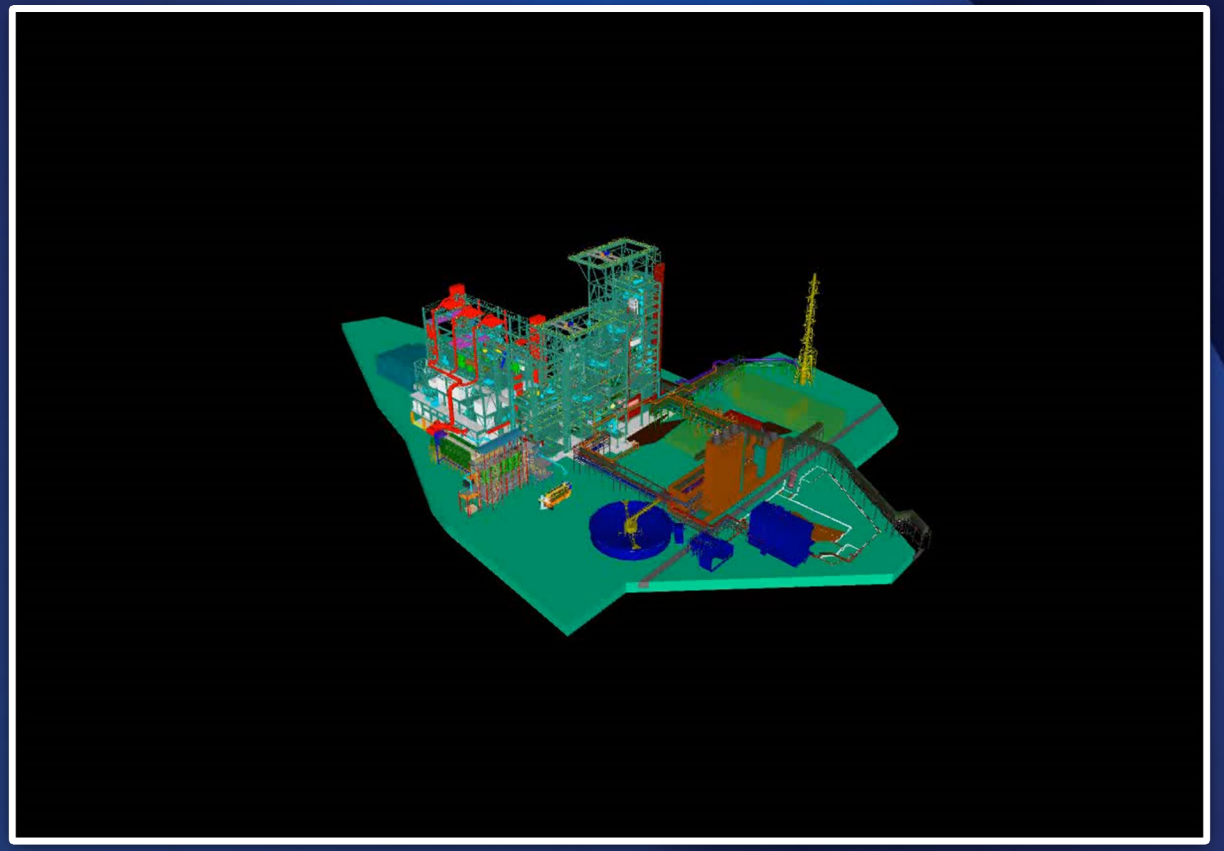


HyREX® Demo Plant Engineering

Layout & Process Engineering



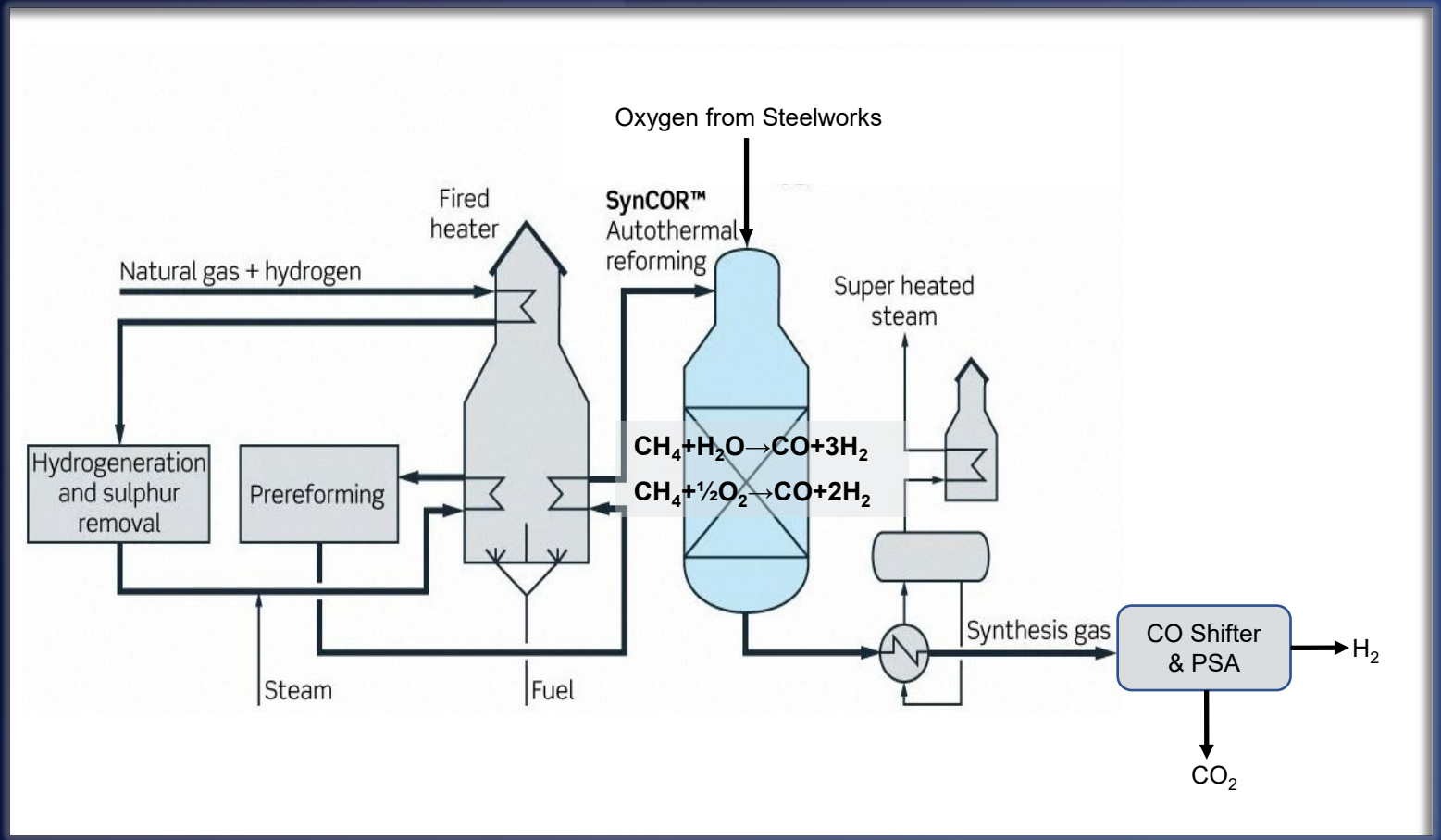
Plant Engineering

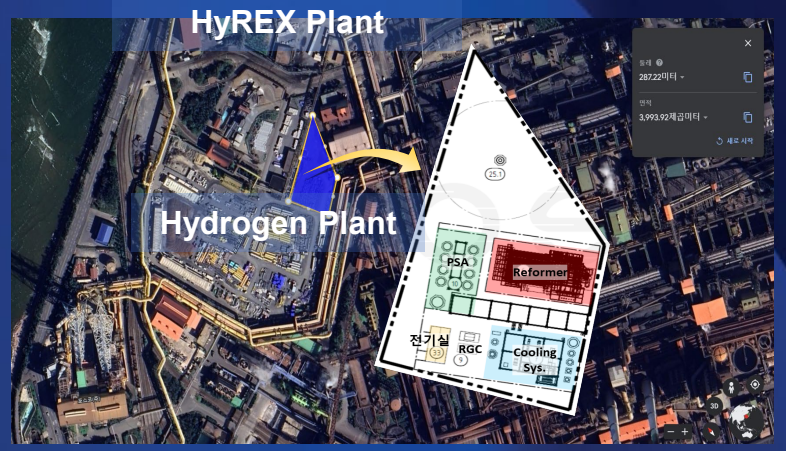


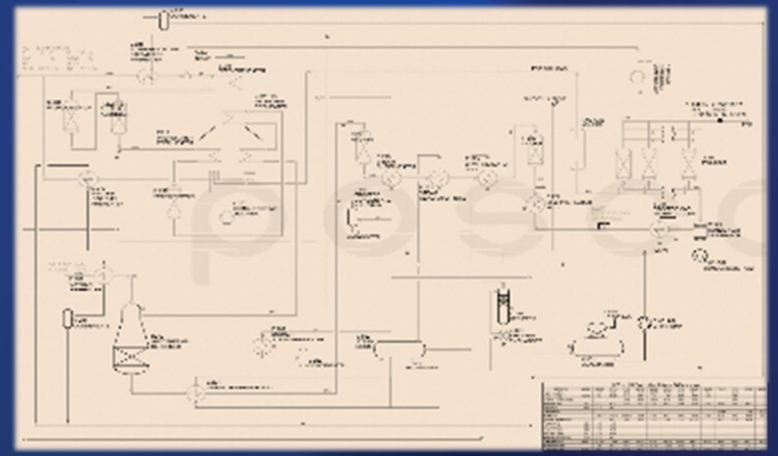
3-D Model of Demo-Plant

HyREX® Demo Plant Engineering : ATR Hydrogen Plant

Lower CO_2 emission and easy to convert to blue hydrogen







- ✓ Hydrogen with 99.9% purity is produced (2.63 Nm^3-H_2 per Nm^3-LNG)
- ✓ CO_2 capture facility is incorporated as a provision in the design

Collaboration to Develop and Globally Expand HyREX® Technology

HyREX R&D Partnership

HyREX R&D Partnership Conference 2024

Joint Cooperation

MOU with BHP for JC in HyREX R&D 2025

Exhibition & Promotion

World Climate Industry Expo 2025

- ✓ Collaborate with domestic and international companies, universities, and research institutes
- ✓ A total of 17 companies, including global steel companies, raw material suppliers, and hydrogen-energy supplier, join the HyREX RnD partnership
- ✓ Engineering project has been supported by the Korea Planning & Evaluation Institute of Industrial Technology(KEIT) and the Ministry of Trade, Industry & Energy(MOTIE, Korea) of the Republic of Korea
- ✓ National R&D project has been confirmed with government funding (June, 2025)

Demo Plant Construction

- Commenced on October 13, 2025
- On track for construction, mechanical erection and commissioning by mid-2028.

Concluding Remarks

1. The R&D of HyREX® is under progress with the physical experiments and numerical modeling combined with the actual operational experience from FINEX and SNNC Fe-Ni smelting plant. Several achievements are acquired in the respects of how to optimize the HyREX® process parameters and integrate into the process engineering.

2. The basic engineering for the HyREX® demonstration plant has been completed, and the essential data required for EPC have already been secured. Construction of the demonstration-scale HyREX® test facility commenced on October 13, 2025, to complete all necessary technological developments for future commercial use.

3. POSCO operates the “HyREX R&D Partnership” as a platform for technology exchange, sharing information on HyREX® development progress, and fostering future cooperation. This partnership serves as a foundation for advancing the HyREX® process into a reliable, sustainable, and globally scalable decarbonization solution for the steel industry.

Thank you for your kind attention

Pohang Youngil bay『SPACE WALK』