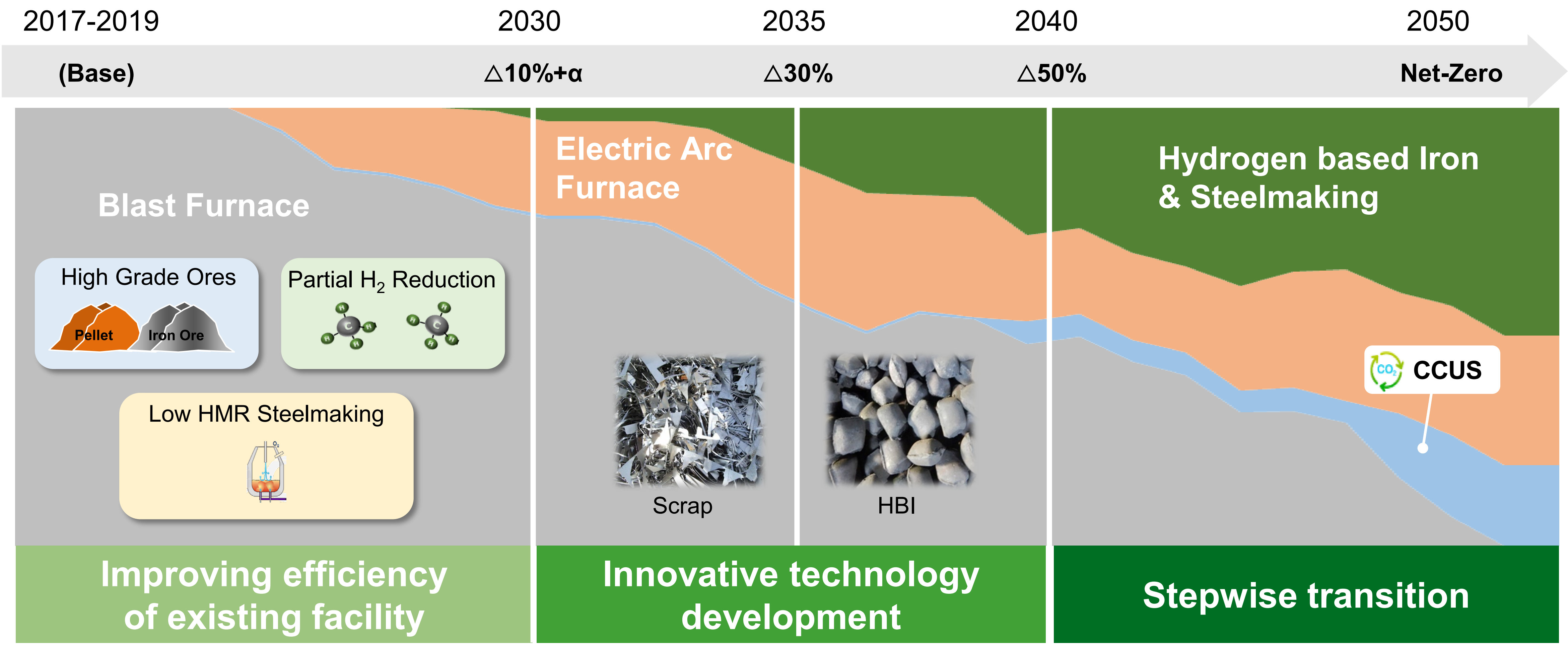
Update on the development of POSCO's hydrogen-based ironmaking process, HyREX

Low-Carbon Iron and Steel Making R&D Center

PosLAB, POSCO

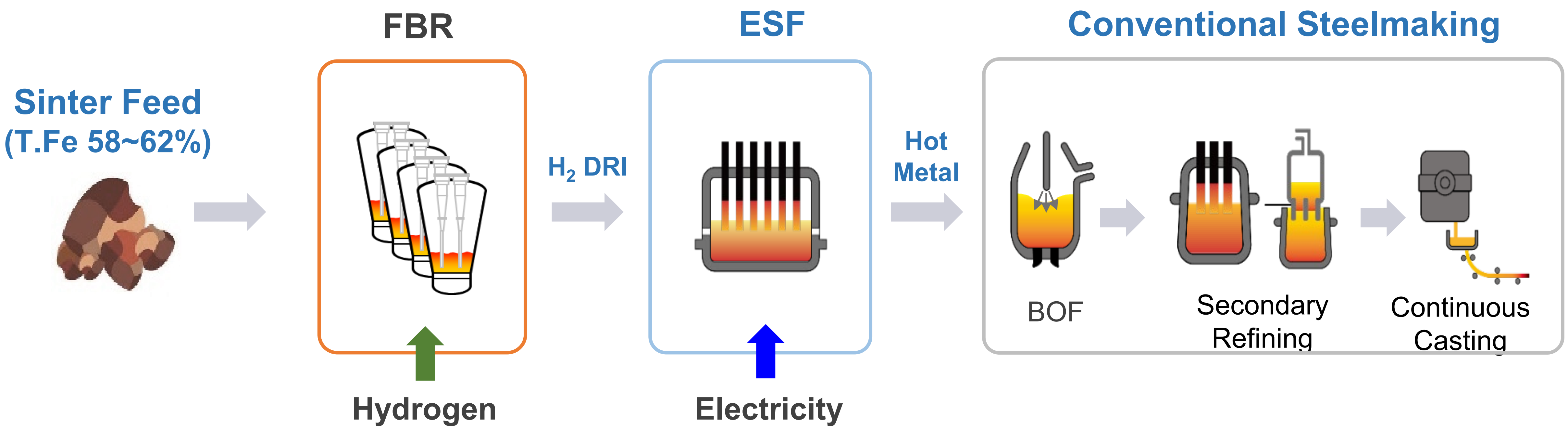
Shin, Myoung Gyun

Transition to Carbon Neutrality by 2050



POSCO established the target of CO_2 reduction 30% by 2035, 100% by 2050

POSCO Hydrogen Ironmaking - HyREX



Direct Use of Sinter Feed

Hot metal and Slag similar to BF

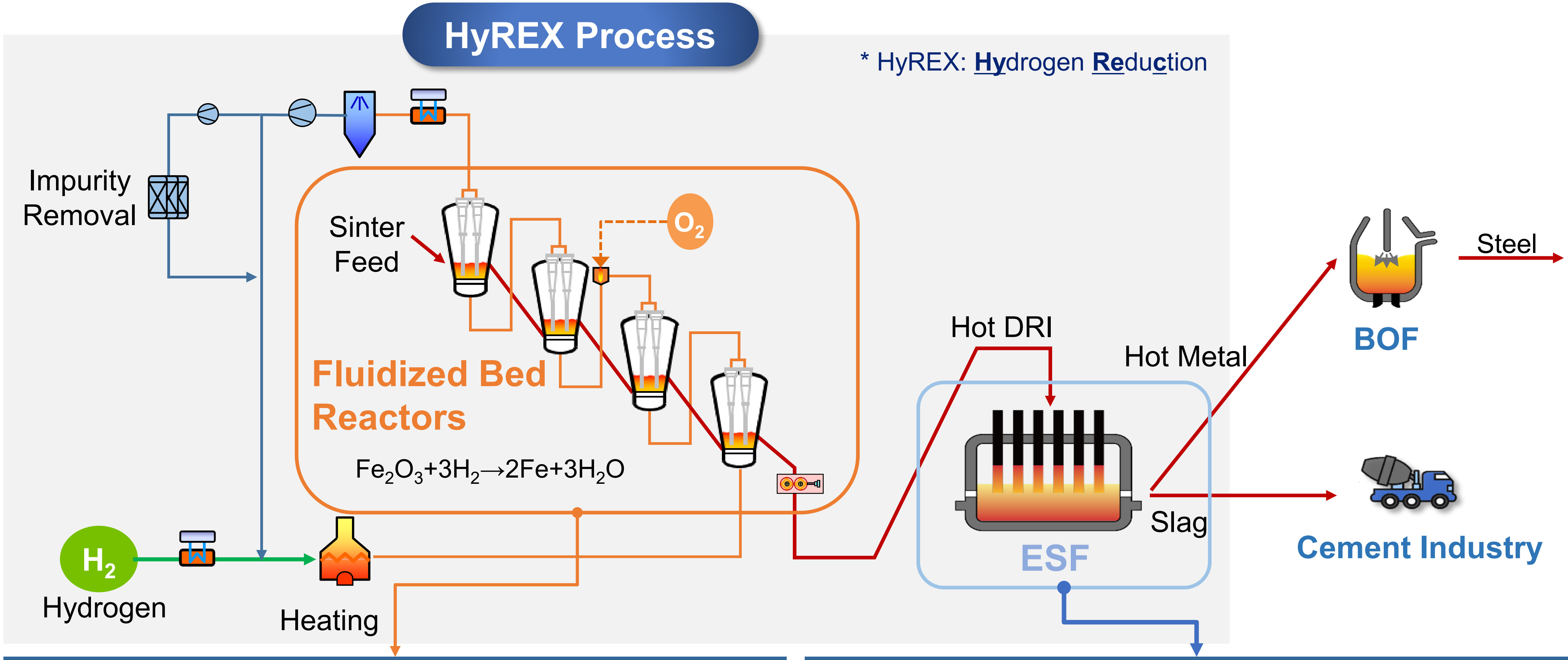
Use of existing steelmaking facilities

- Low-cost raw materials
- Abundant availability

- High Fe yield
- Slag recyclable (alternative to BF slag)

- No restrictions on high grade steel manufacturing

POSCO Hydrogen Ironmaking - HyREX



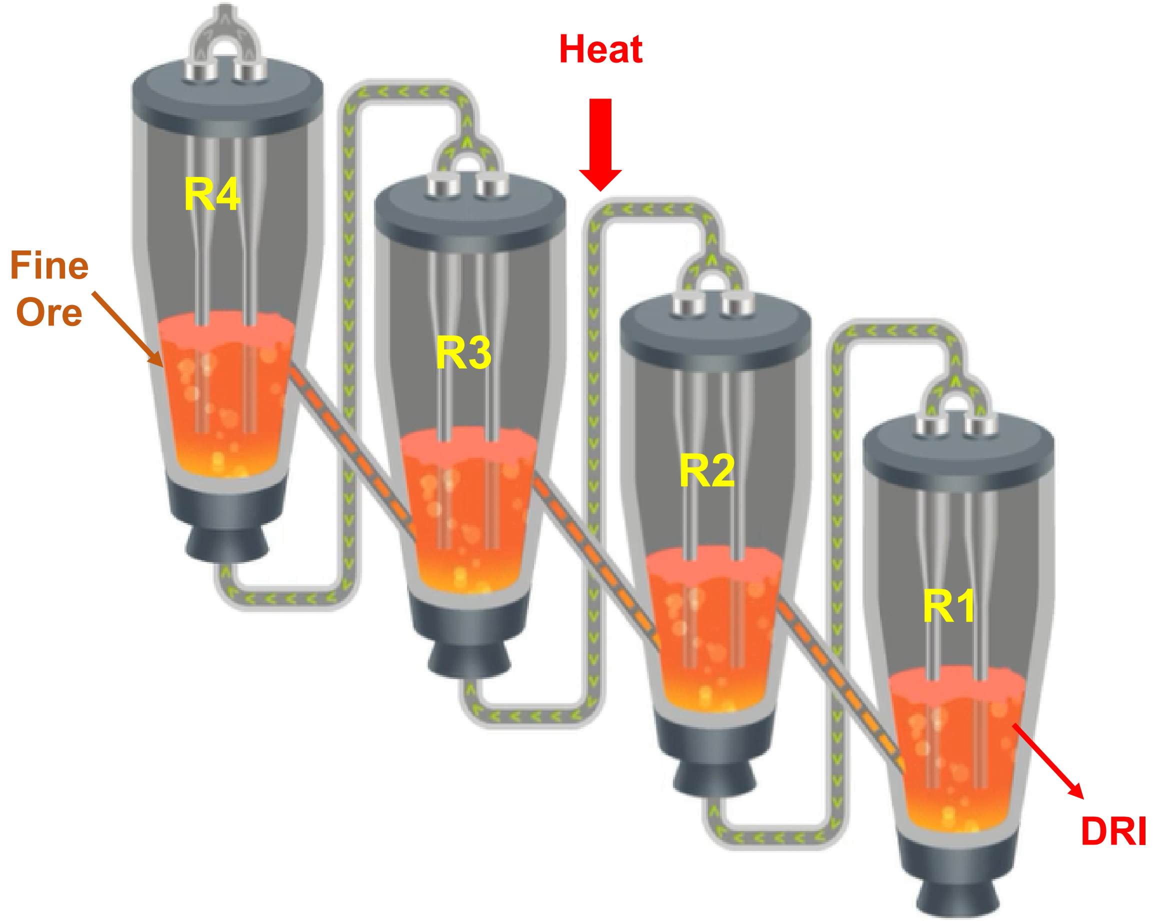
FINEX Fluidized Bed Technology

Operational technology in large-scale ESF (SNNC)

Fast development with own technologies

FBR Redesign for Hydrogen Use : Overall

- **Revision of 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

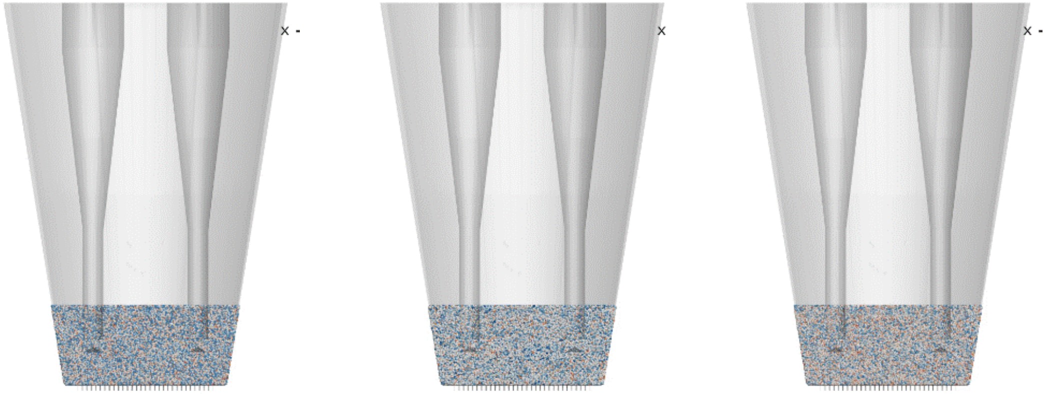


FBR Redesign for Hydrogen Use : Fluidization

Characteristics of H_2 as fluidizing gas

○ **Lower density and viscosity under hydrogen condition**

	FINEX gas	HyREX gas
H_2 [%]	15~20	70~80
Density [kg/m^3]	1.55	0.62 (40%)
Viscosity [Pa-s]	4.22x10^{-5}	3.51x10^{-5} (83%)

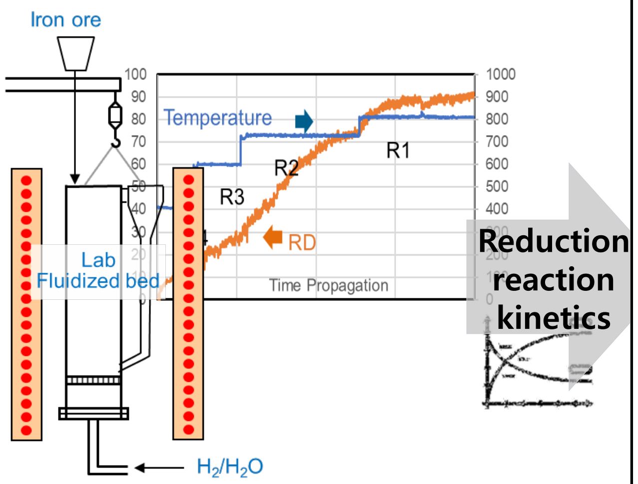


FINEX (U_0 : 1.0m/s) | HyREX (U_0 : 1.0m/s) | HyREX (U_0 : 1.4m/s)

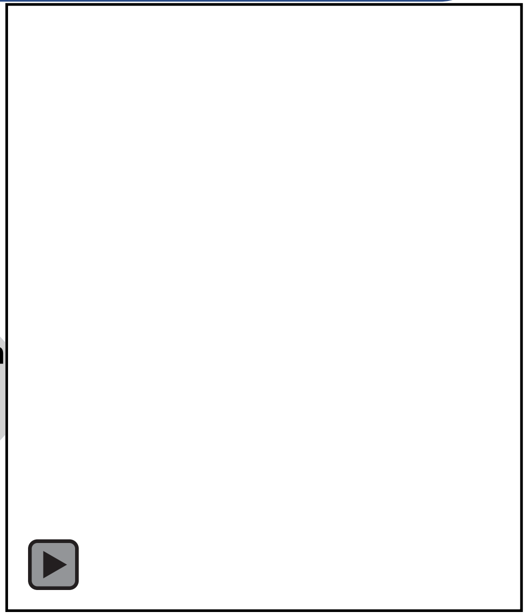
○ **Requires 40% higher velocity compared to that of FINEX**

- ✓ Good fluidization quality confirmed in Sim. & Exp.

Reduction kinetics of H_2 in fluidized bed



[Experimental result]



[CFD result based on exp. result]

○ **Using lab-scale fluidized bed, kinetics of hydrogen reduction analyzed**

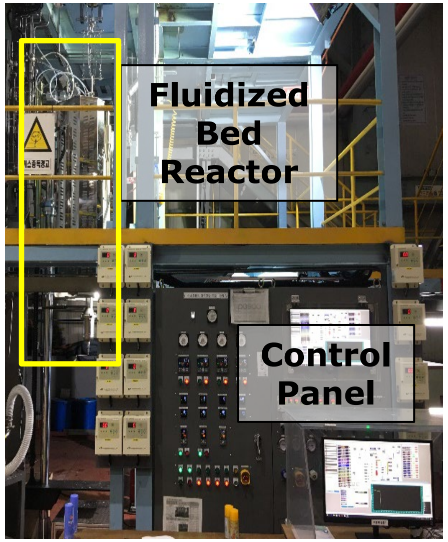
○ **Visualization of fluidized bed using CFD simulation**

- ✓ Enables to determine reactor size & residence time
- ✓ Prediction of reduction behavior under various operation conditions
- ✓ Demo plant CFD visualization under progress

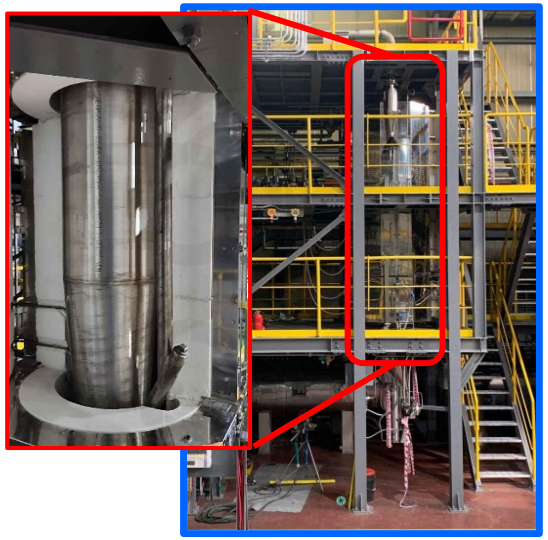
FBR Redesign for Hydrogen Use : Reduction

Experimental Facilities

○ **Experimental fluidized bed in various scale**



[Lab. Scale Facility]



[Bench Scale Facility]

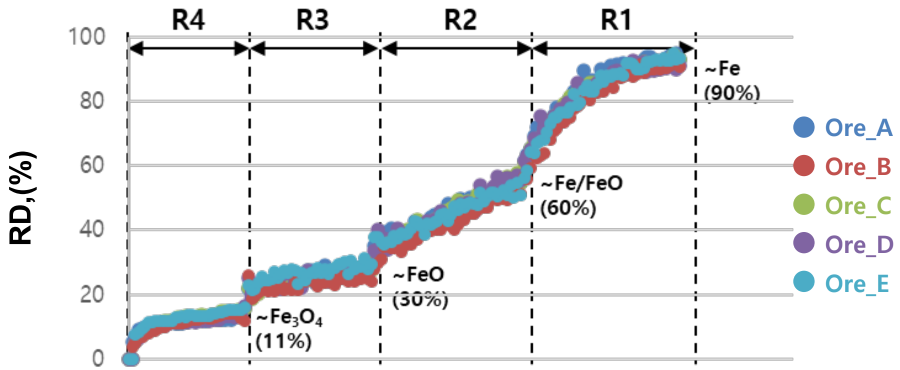
	Lab-scale	Bench scale
Bed dia.[mm]	50	300
Solid charge [kg]	1 (PSD 1~2mm)	50 (PSD <8mm)
Gas species	H_2, H_2O, CO, CO_2, N_2	H_2, CO, CO_2, N_2
Temperature [℃]	< 1,000	< 950
Pressure [bar.g]	~ 4	1.8

Fluidized bed reduction test

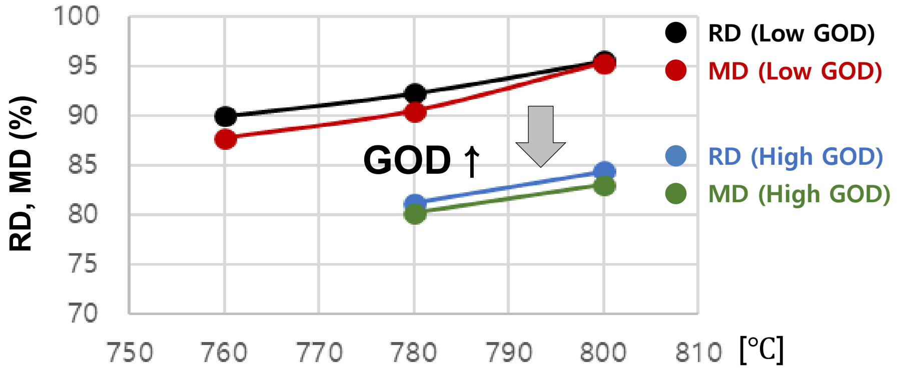
○ **Investigation on H_2 reduction behavior under various fluidized bed conditions**

✓ Ore blend, gas temperature and Gas Oxidation Degree (GOD)

Effect of ore blend



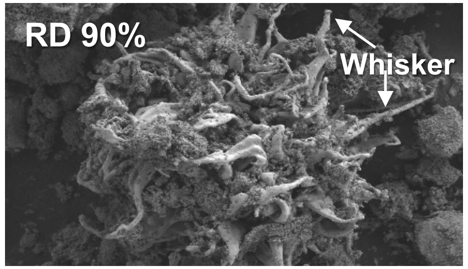
Effect of bed Temp. and GOD



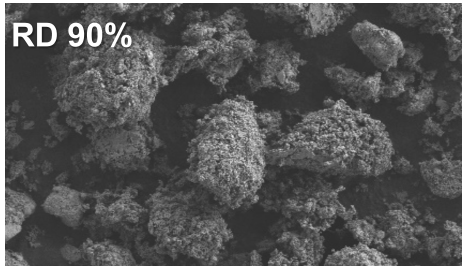
FBR Redesign for Hydrogen Use : Sticking

Sticking behavior and de-fluidization

○ **No whisker formation and less sticking**

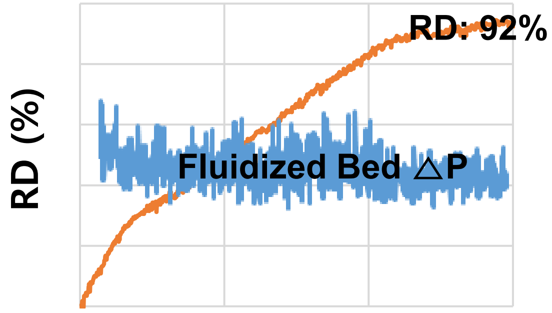


[DRI CO reduction]

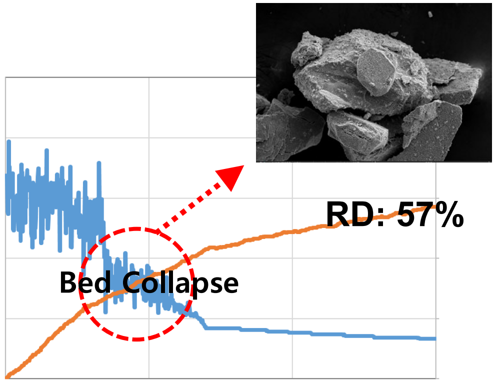


[H_2 reduced DRI]

○ **Effect of ore type on the sticking & fluidization behavior**



[Stable fluidization Case]

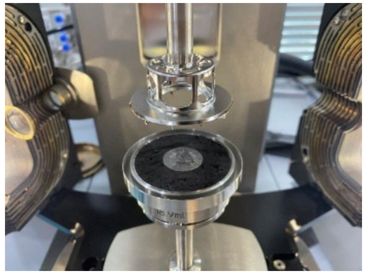


[De-fluidization Case]

Evaluation of flowability of H2-DRI

○ **Investigation on flowability of DRI with high RD**

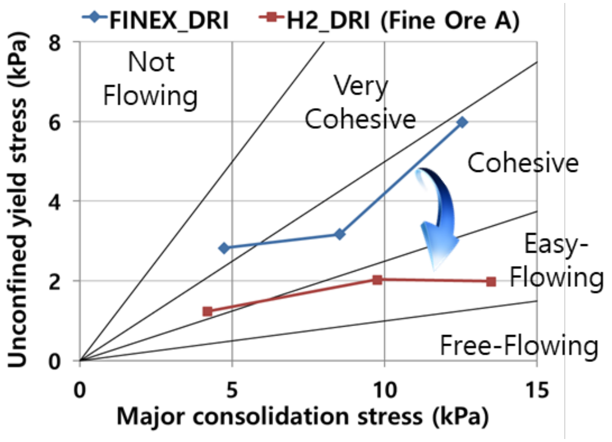
✓ Evaluation of flowability using standard apparatus



Small scale rheometer that can measure flowability in high temp.

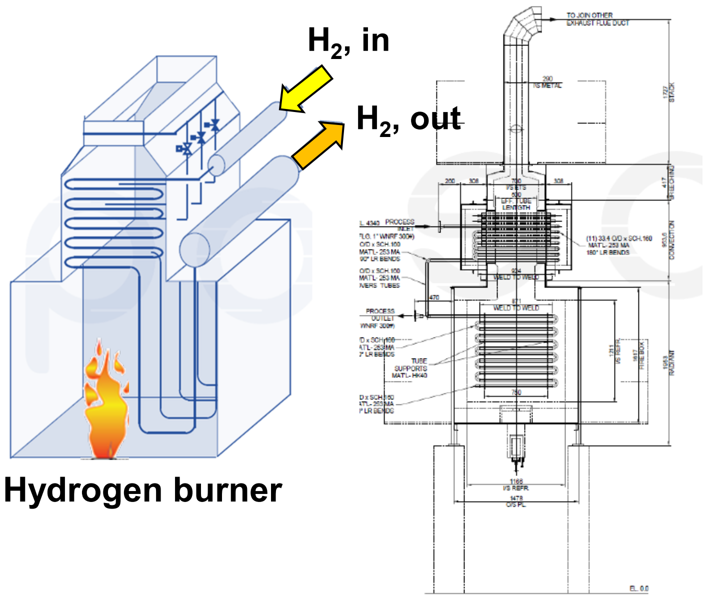
- DRI : < 50g
- Temp. : ~ 600℃ (DRI storage temp.)

✓ DRI reduced by H_2 is found to have **better flowability** compared to that of DRI reduced by CO



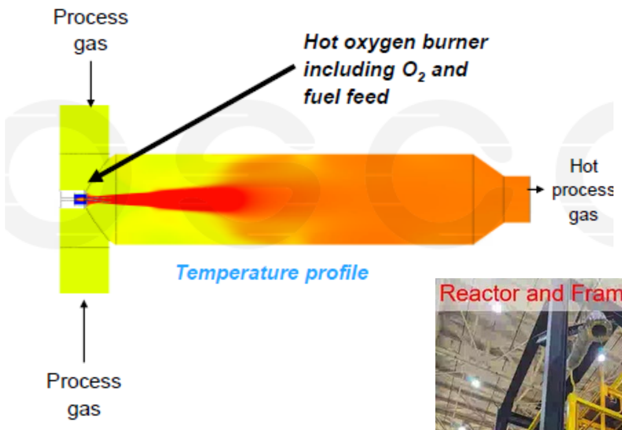
FBR Redesign for Hydrogen Use : Hydrogen Heating

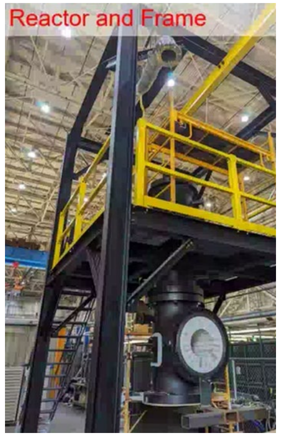
Indirect Gas Heating



- Industrial-scale readily available
- Good for low T application
- Complicated structure

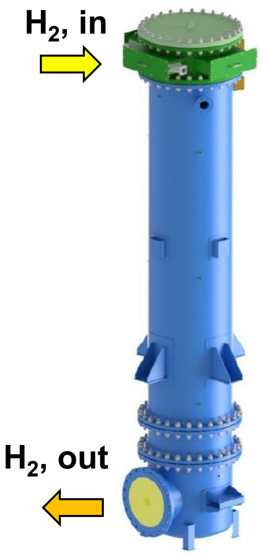
Direct Gas Heating





- High efficiency
- Simple structure
- Good for high T application
- H_2O in the heated gas

Electrical Heating



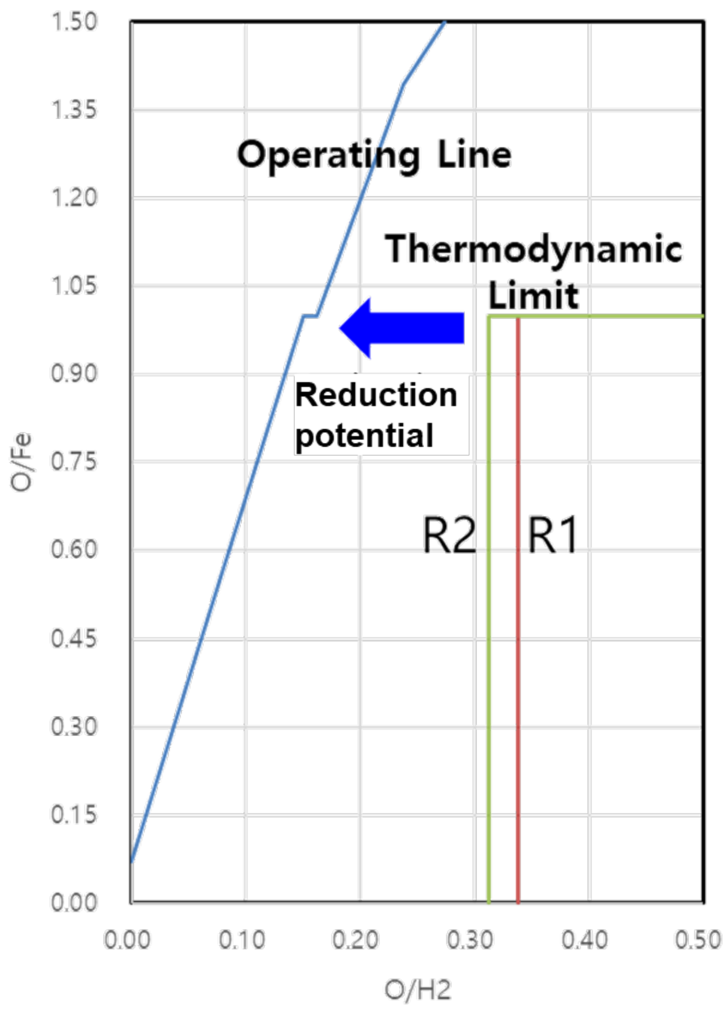
- Easy temperature control by adjusting power consumption
- No available industrial-scale

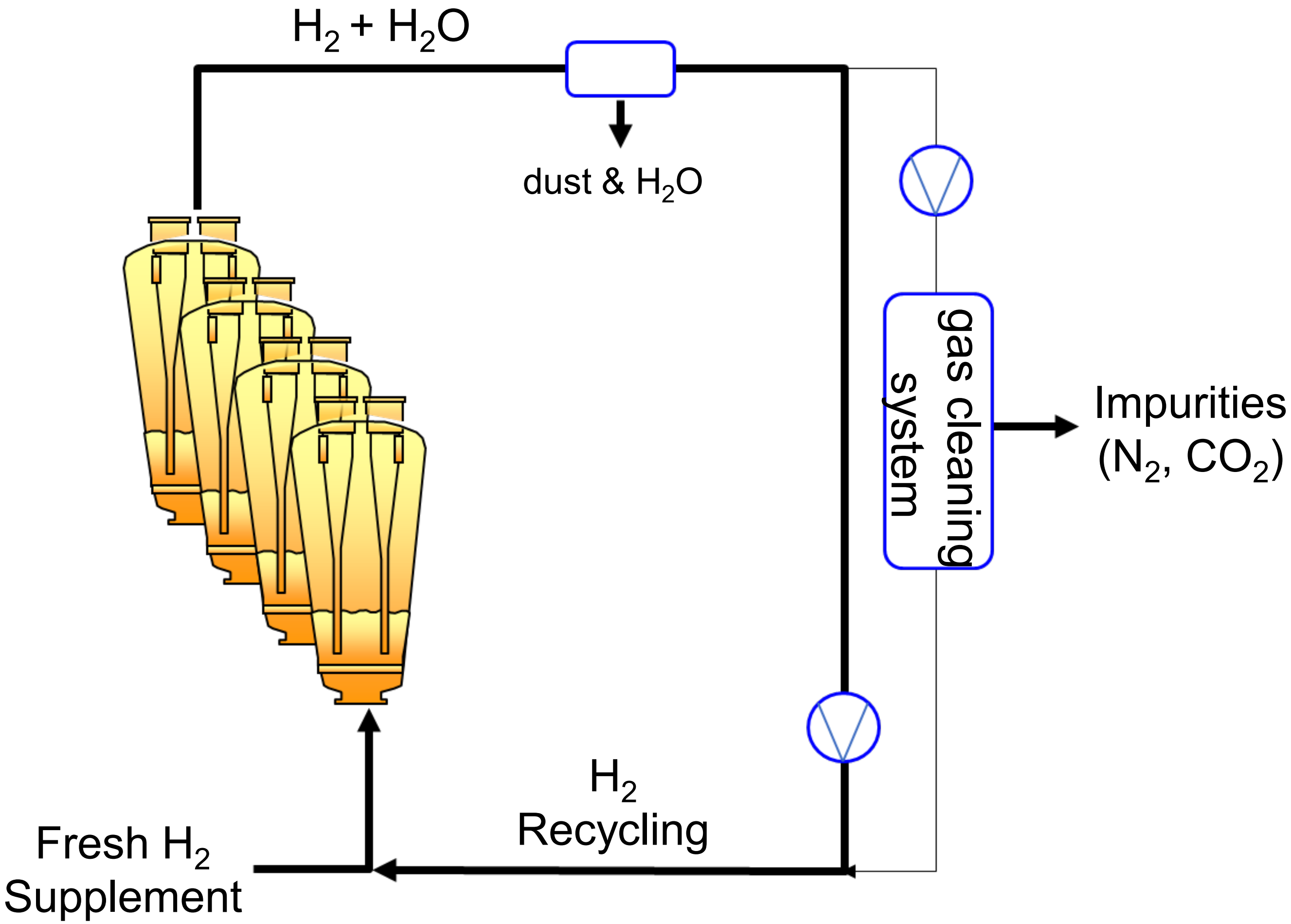
✓ International R&D collaboration project funded by Korean government

✓ Construction completed for direct & electrical heating facility (50~100 Nm^3/h, 50~100 kW), Experiments underway

✓ Hybrid heating method may be applied considering investment cost and thermal efficiency

FBR Redesign for Hydrogen Use : H_2 Recycling



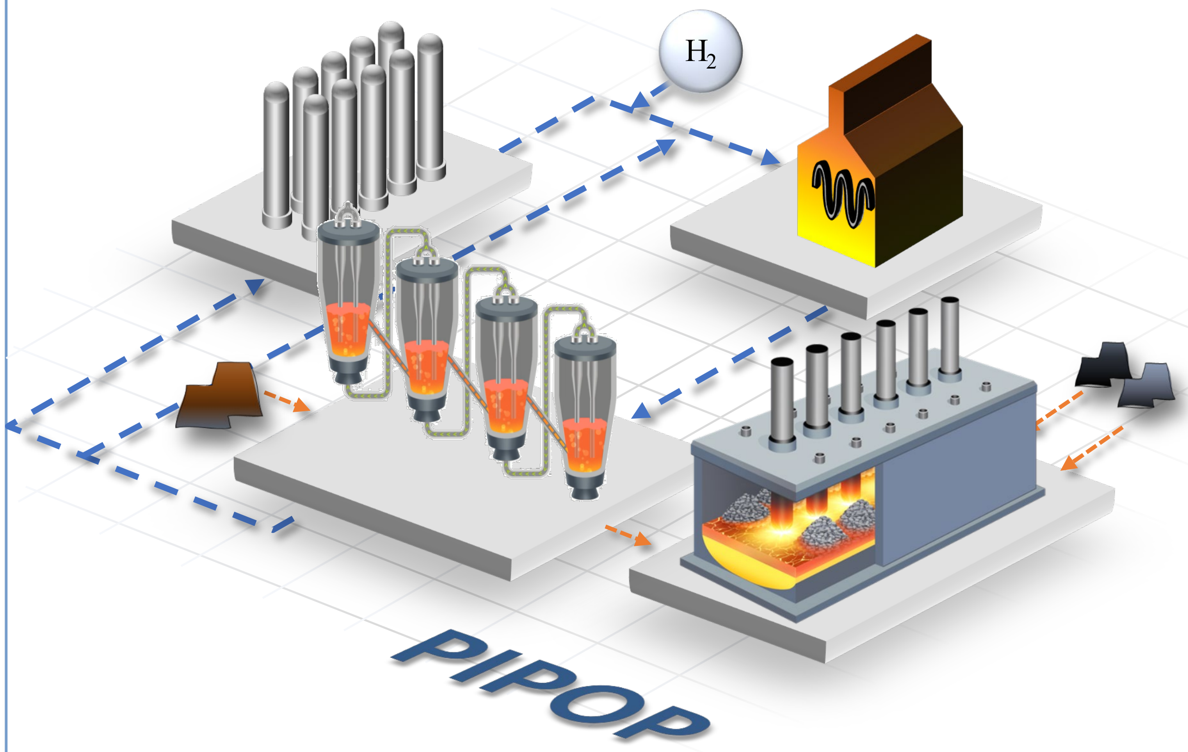


- ✓ Gas utilization is limited by temperature, moreover H_2 reduction is endothermic reaction
- ✓ In order to maximize H_2 gas utilization, off-gas recycling is mandatory with gas cleaning system

FBR Redesign for Hydrogen Use : Process Design

PIPOP*

*Python-based Ironmaking Process design & Optimization Program



- Heat & mass balance for every reactor units and streams
- Gas heating condition for target gas temperature and quality
- Gas mixing and cleaning condition for target purity
- Flux and carbon usage for target product quality

✓ Python and Pyomo based ironmaking process modeling and optimization program developed by POSCO for **HyREX & FINEX process**

✓ Convenient for iterative calculations for complex processes

✓ Can solve large-scale nonlinear optimization problem within a few seconds

✓ Various application available!

Optimization of **H_2 & Energy** consumption	Simulation of various **raw material** usage	Evaluation of **different process configurations**

ESF for H_2 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

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

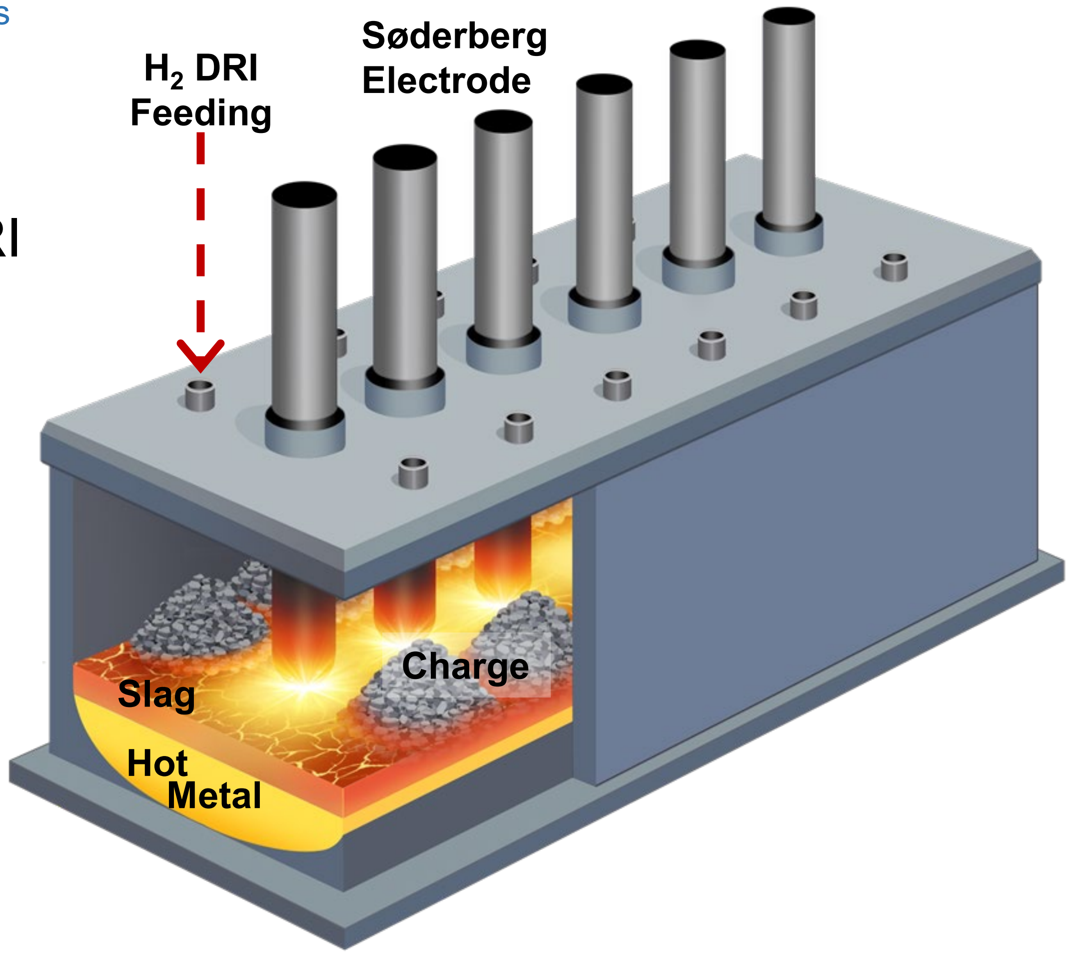
ESF operational design

✓ Brush arc operation for rapid melting

✓ Stable control of temperature and composition

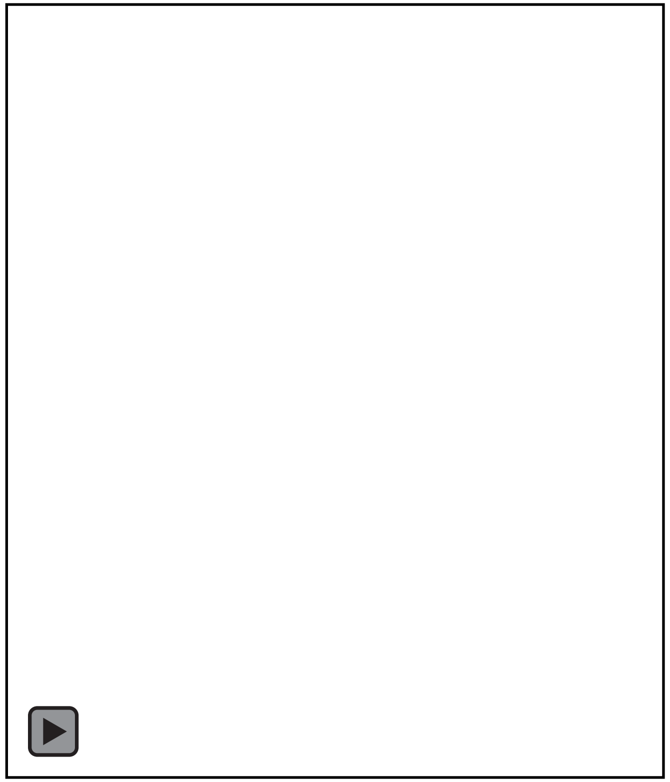
✓ Monitoring systems for automatic operation

✓ Slag chemistry control for recycling



ESF for H_2 DRI Melting : Large Lab-scale Test

DC Arc Furnace



- Batch Type Operation
- 280 kVA (70V, 4000A)
- Electrode: 150mmΦ

Experimental Results

○ 1st Trial: Low Reduced DRI(RD: 65%) + Cokes + Additive

(Raw Materials) (After Melting)

○ 2nd Trial: HBI(Crushed, RD 90%) + Carbonizing Material + Additive

(Raw Materials) (After Melting)

○ 3rd Trial: H_2-DRI(RD 90%) + Carbonizing Material + Additive

(Raw Materials) (After Melting)

Fe-4.2%C-0.02%P-0.015%S

ESF for H_2 DRI Melting : ESF Simulator

Phase 1: Fe-Ni Process(Completed)

○ The actual operation data of SNNC

- Inputs/Outputs material and energy balance etc.

[Inputs/Outputs Material Balance]

○ Nickel Ore

Consumption	Ni	Fe	SiO_2	MgO	CaO	Al_2O_3	H_2O
-	-	-	-	-	-	-	-

○ Coal

Consumption	F.C	VM	Ash	S	P	Moisture
-	-	-	-	-	-	-

○ Calcine

Production	Temperature	NiO	Ni	Fe_2O_3	FeO	C
-	-	-	-	-	-	-

○ Ferro-Nickel Slag

Production	Temperature	Fe	SiO_2	MgO	CaO	Al_2O_3
-	-	-	-	-	-	-

○ Ferro-Nickel Metal

Production	Temperature	Ni	Fe	C	Si	S	Cr
-	-	-	-	-	-	-	-

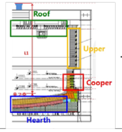
[Inputs/Outputs Energy Balance]

○ Inputs

unit	Electric Power	Preheated Calcine	Post Combustion of CO
kWh/cal_t	-	-	-

○ Outputs

unit	Metal	Slag	Off-gas	Reducing Reaction	Heat Loss
kWh/cal_t	-	-	-	-	Measurement Value

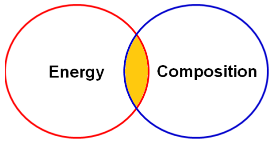


· $Q_{Heat\ Loss} = Q_{copper} + Q_{hearth} + Q_{upper\ Side} + Q_{Roof}$

○ Thermodynamics Analysis

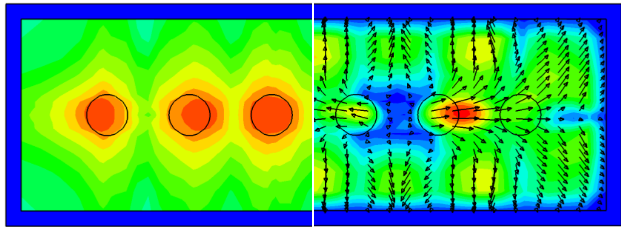
- Chemical reaction, mass and energy balance etc.

FactSage™

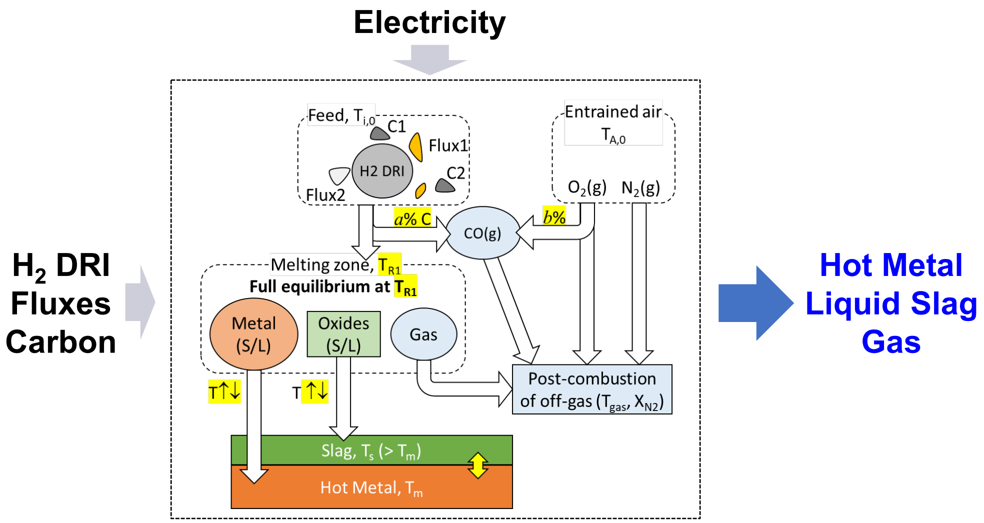


○ Computational Fluid Dynamics Analysis

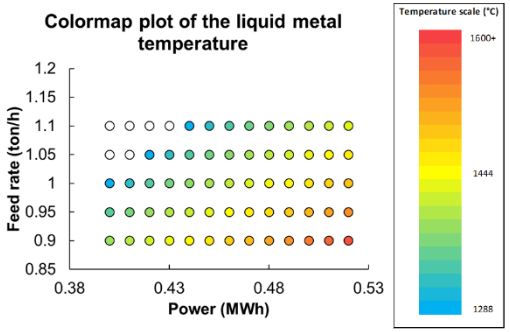
- Temperature, Flowage etc.

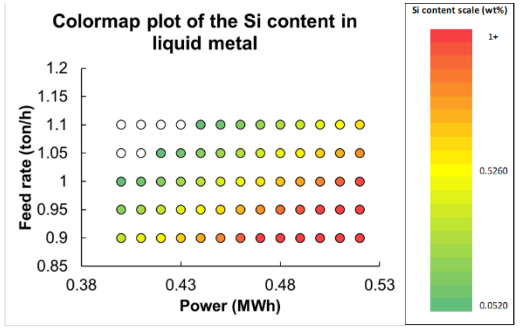


Phase 2: HyREX Process(Ongoing)



○ ESF Simulator predicts the temperature, mass and composition of hot metal, slag, and gas

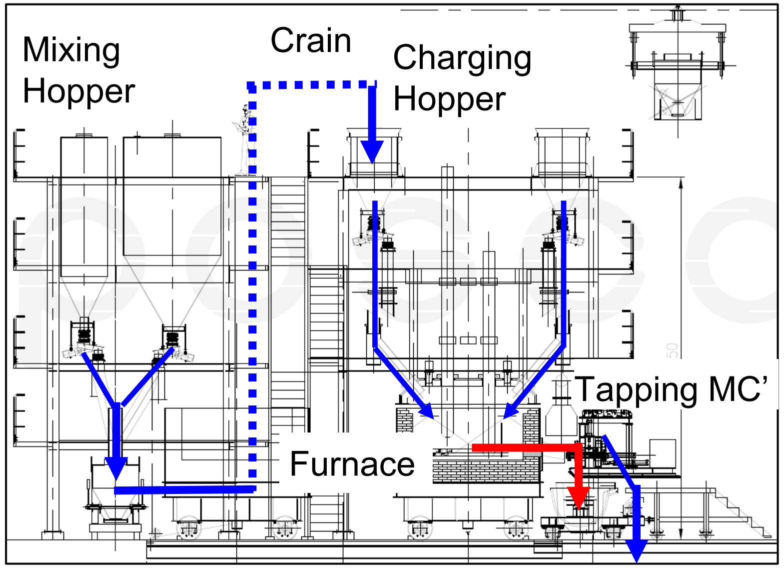




ESF for H_2 DRI Melting : Bench-scale Facility

■ Specification

- ○ Capacity : 1 ton/hr
- ○ Furnace : Round Type, 2.8m ID, Air tight, Moving furnace car
- ○ Transformer : 2.5 MVA, 3Phase AC Type, Brush & Immersed arc mode
- ○ Electrode : 12 inch (305mm), PCD 1.2 m
- ○ Tapping machine & mud gun, 1 hot metal & 1 Slag holes, 4~6 Taps/day

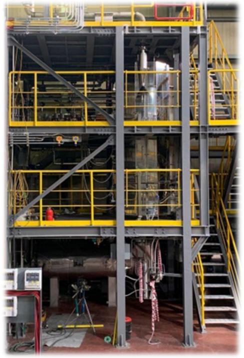


■ Schedule

- ○ Conceptual and basic design (~'23.1)
- ○ Detailed design: Mechanical and electrical parts (~'23.7)
- ○ Civil works and concrete foundation ('23.7~'23.8)
- ○ Manufacturing and installation ('23.9~12)
- ○ Hot test (~'24.1)

HyREX Demo Plant Engineering

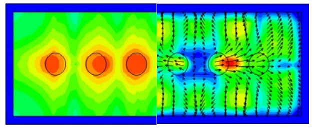
Bench Scale Test

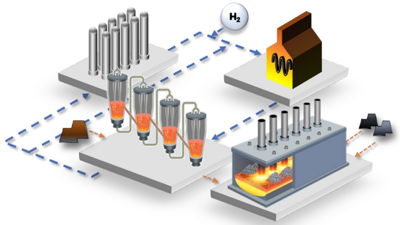


FBR 50 kg/batch

ESF 1.0 ton/hr

Simulator

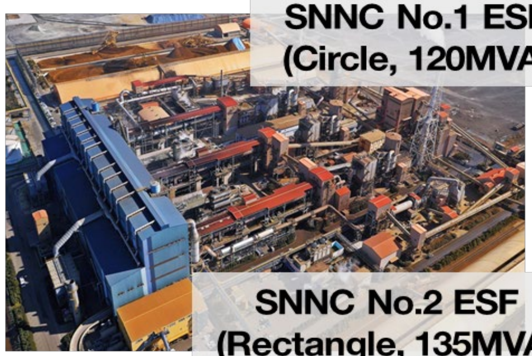




Know-How

No.2 FINEX®
(1.5 MTPA)

No.3 FINEX®
(2.0 MTPA)



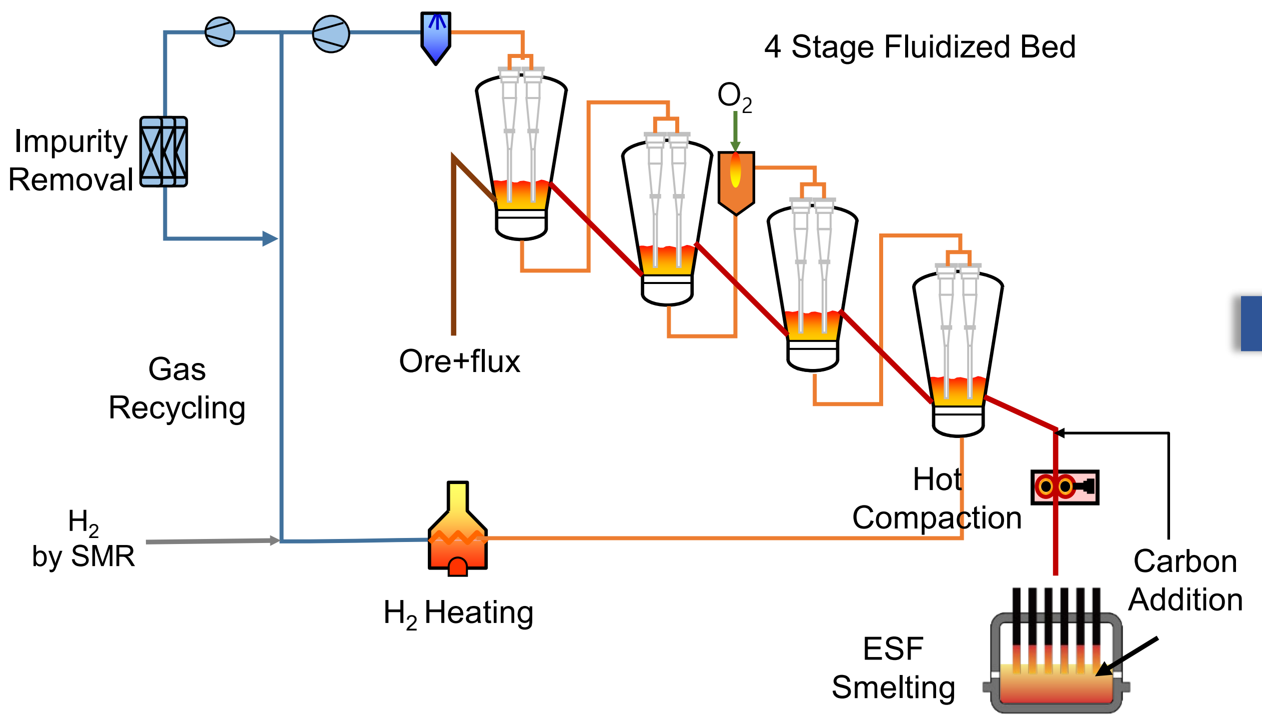
SNNC No.1 ESF
(Circle, 120MVA)

SNNC No.2 ESF
(Rectangle, 135MVA)

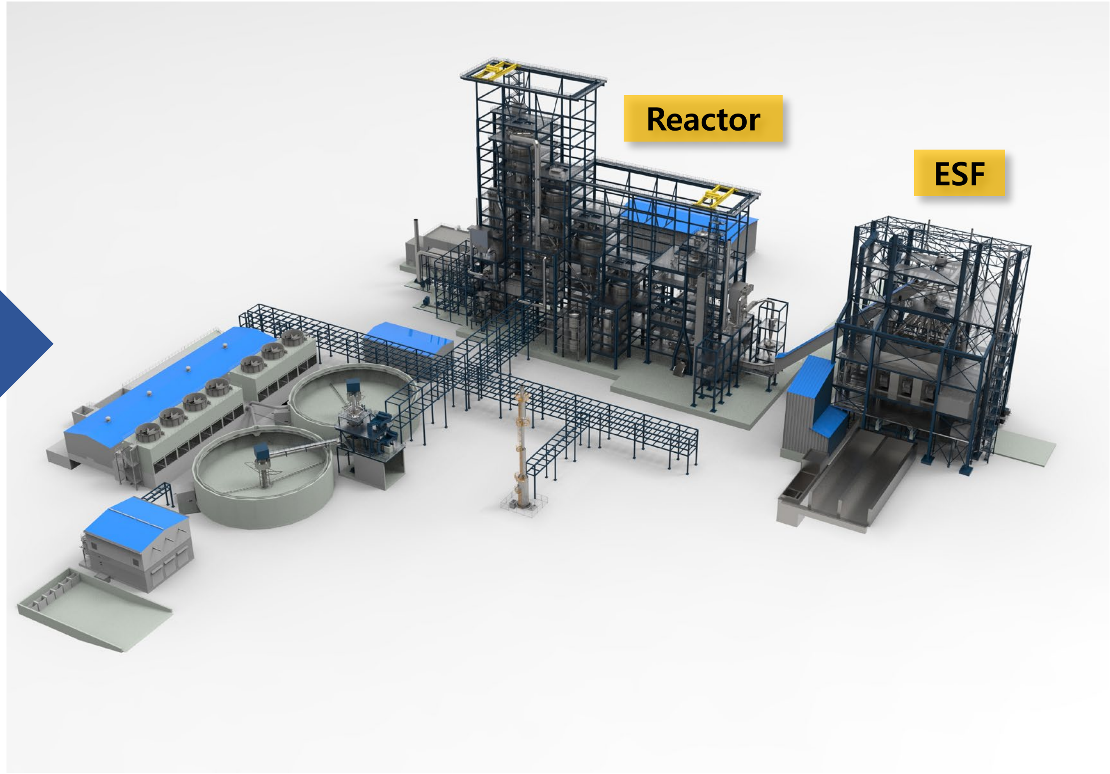
Demonstration Plant

HyREX Demo Plant Engineering

Process Engineering

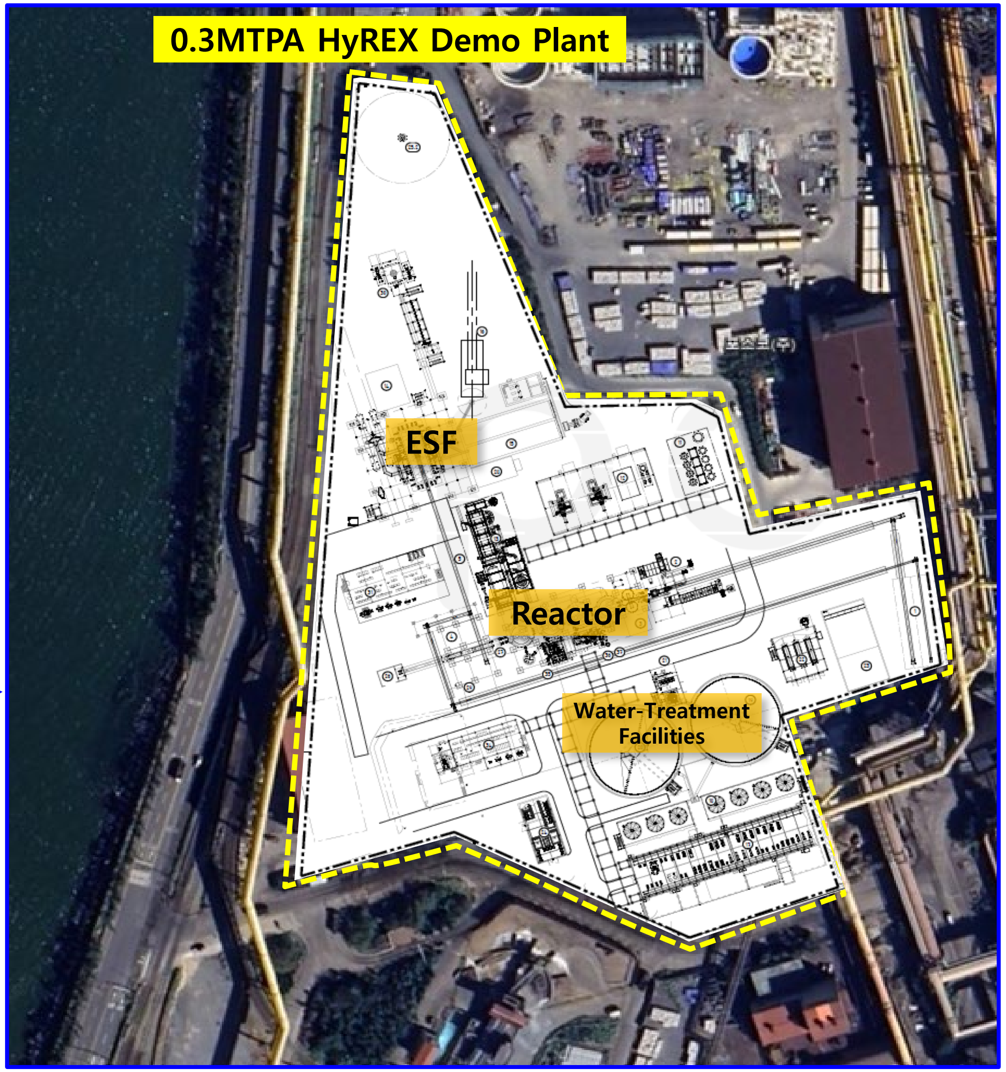


Plant Engineering



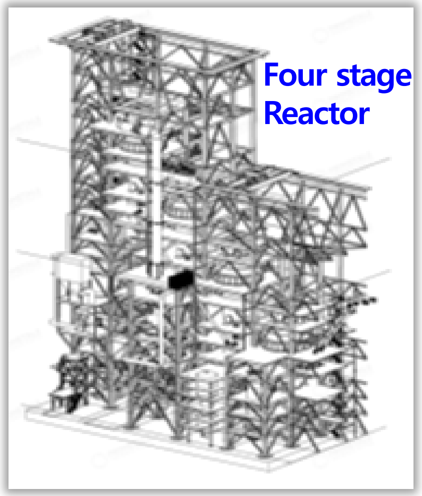
HyREX Demo Plant Engineering

Layout

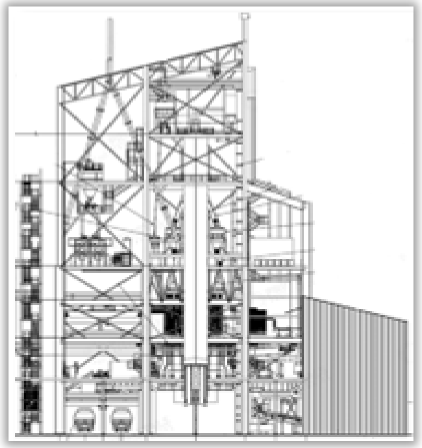


Towers

Reactor Tower



ESF Tower



Roadmap of HyREX Development

Demonstration by 2030, hereafter Stepwise Replacement of BF with HyREX

2022	2024	2026	2028	2030

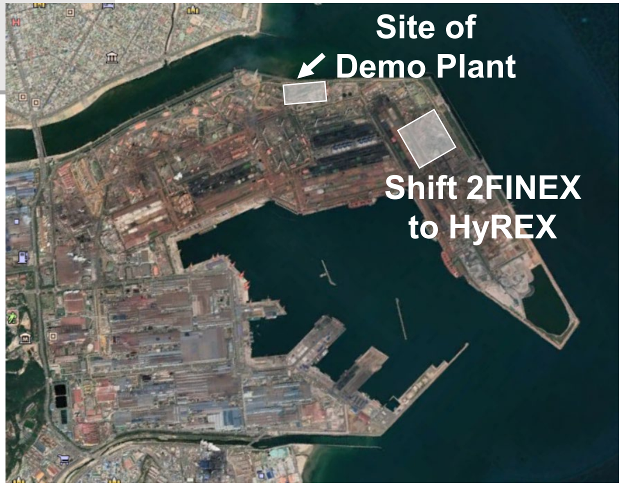
Lab Scale & Design for Demo Plant

Demo Plant Engineering Commenced

0.3 MTPY Demonstration Scale Verification & Optimization

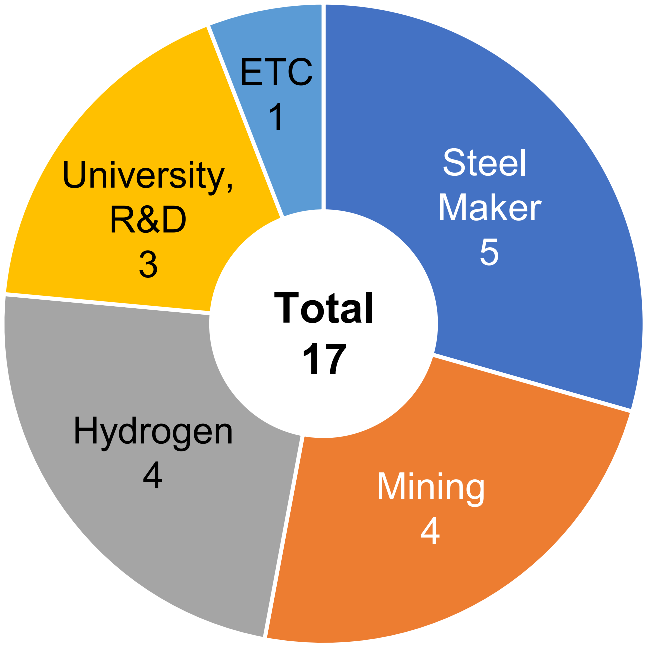
1.0 MTPY Commercial Plant Construction

Transition of FINEX to HyREX

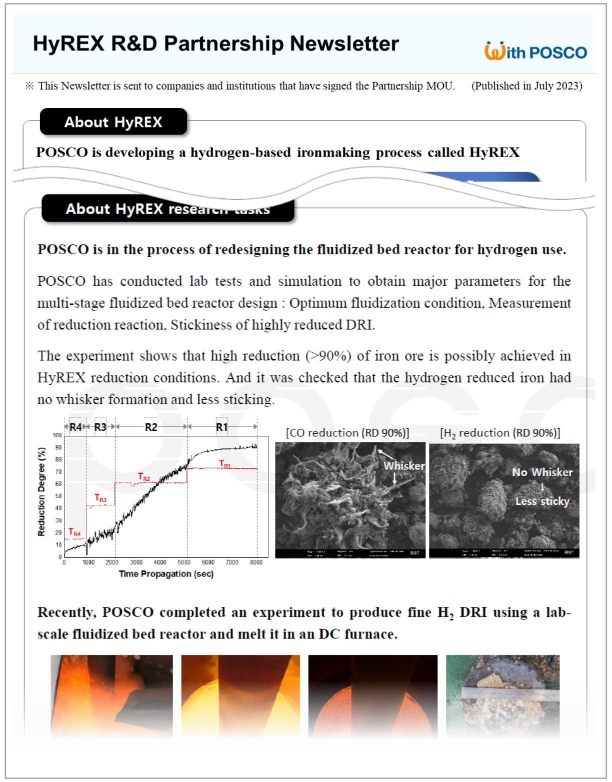


HyREX R&D Partnership

Global Cooperation Hub for the HyREX development and commercialization



[Partnership Status]



HyREX R&D Partnership Newsletter

With POSCO

※ This Newsletter is sent to companies and institutions that have signed the Partnership MOU. (Published in July 2023)

About HyREX

POSCO is developing a hydrogen-based ironmaking process called HyREX

About HyREX research tasks

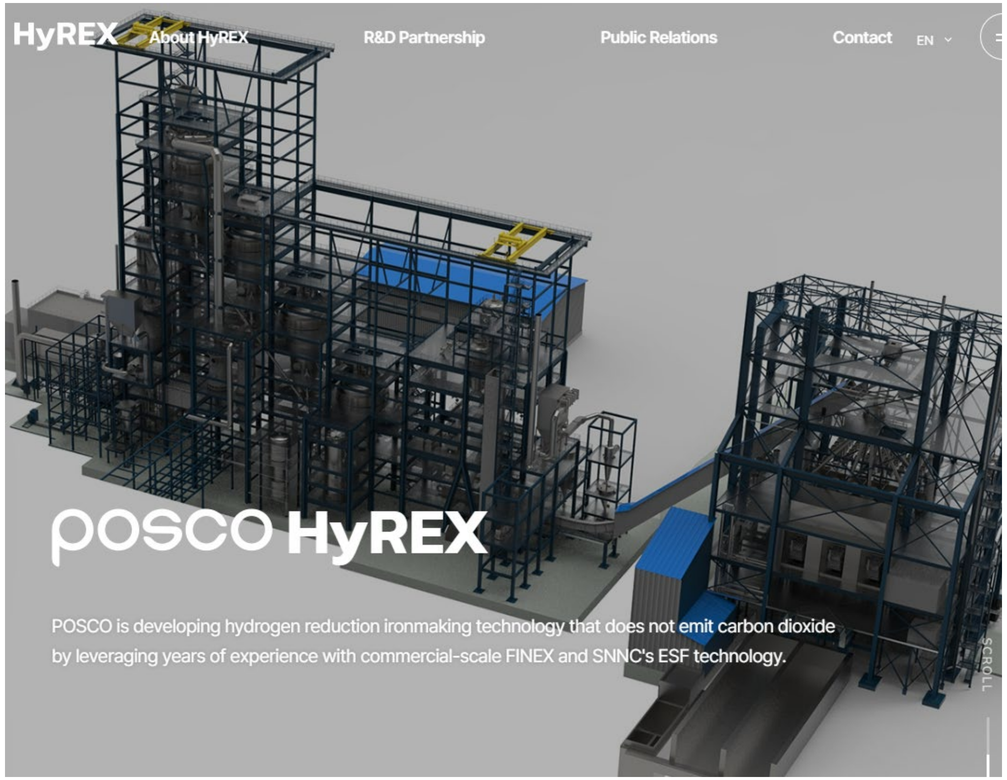
POSCO is in the process of redesigning the fluidized bed reactor for hydrogen use.

POSCO has conducted lab tests and simulation to obtain major parameters for the multi-stage fluidized bed reactor design : Optimum fluidization condition, Measurement of reduction reaction, Stickiness of highly reduced DRI.

The experiment shows that high reduction (>90%) of iron ore is possibly achieved in HyREX reduction conditions. And it was checked that the hydrogen reduced iron had no whisker formation and less sticking.

Recently, POSCO completed an experiment to produce fine H_2 DRI using a lab-scale fluidized bed reactor and melt it in an DC furnace.

[First Newsletter ('23.7)]



[Website (https://www.hyrex.co.kr)]

Concluding Remarks

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.

The pre-engineering of HyREX demonstration plant has been performed, and the basic data for EPC have been secured. The engineering work was initiated in earnest for plant building.

POSCO intends to develop the HyREX process as a reliable, universal, and globally available decarbonization solution for the steel industry. In this respect, POSCO is operating “HyREX R&D Partnership” as the technology exchange channels, information sharing of HyREX development status, and future cooperation.

posco HyREX®
Fluidized Bed Reactors
Iron Ore Fine
H_2 Recovery
Hot DRI
H_2
H_2O
Hydrogen Heater
Electric Smelting Furnace
Steelmaking
Molten Steel
Downstream
O_2
Hydrogen
H_2
Slag
Hot Metal
Cement Industry
Green Tomorrow, With POSCO